WATER RESOURCES GOVERNANCE IN THE UPPER SWAKOP BASIN OF NAMIBIA

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ABSTRACT

This dissertation examined and presented adaptive water governance analysis and tools for the Upper Swakop Basin (USB) in Namibia where integrated river basin management is still in its infancy. The water governance concerns in the basin include pollution monitoring and control challenges that are further threatening the security and adequacy of the developed drinking water sources. By applying and triangulating different methods (models, statistical analysis, quantitative and qualitative measures etc.), this study uniquely analysed the water governance issues in the Upper Swakop Basin.

The objectives of the study were to assess the water quality at potential pollution sources and at major receiving waters in the Upper Swakop Basin based on secondary data obtained from key stakeholders; to evaluate the adequacy and availability of drinking water sources in the USB; to assess the ethical, social and acceptability perceptions of water reuse for potable purposes based on primary data obtained from a purposive stakeholder survey; to qualitatively assess water governance structures and participation as well as to evaluate overall water governance processes and outcomes in the USB. Water quality parameters were assessed using descriptive statistics, extreme value analysis, spatial analysis and some of the parameters were compared to those given in the water quality regulations and standards of Namibia using ANOVA. The adequacy and availability of water was assessed using the simple water balance method, the Box-Jenkins ARIMA time series forecasting models, and the WEAP model. The ethical, social and health acceptability views and perceptions on water reuse for potable purposes were assessed using frequency tables, charts, and graphs. Stakeholder participation was analysed using scenario workshops, mediated

modelling and social multi-criteria evaluation methods and was based on the ADVISOR framework. The researcher developed the 7"I"s water governance tool which was used to map stakeholders and to assess the overall water governance performance of the USB.

The study found that water pollution parameters values were extremely high for agro-industries. Moreover it was found that the developed water resources supplying the USB are inadequate especially in Windhoek where additional drinking water sources outside the USB are required to augment its demand of 26.7 Mm^3 per annum in 2015 to a projected amount of 52.93 Mm^3 per annum in 2050. Acceptability levels of water reuse for potable purposes were found to be moderate. Stakeholder participation in water governance needs to be more inclusive. The existing legal and institutional framework for water governance was found to be inadequate due to lack of implementing technical capacity (in terms of personnel, technical skills, database management and information sharing). One of the unique contribution of the study to new knowledge is the development of the 7"I"s evaluation tool for overall water governance performance which can also be used in other similar basins. The *pollution extreme parameter values assessment* is proposed as a quick and initial evaluation of any problematic river catchment and to take remedial measures on would be polluters. Proper water pollution control and compliance strategies should be stepped up for agro-based industrial landuses. Landuse based water governance policy interventions may be required to prevent water pollution on the Swakoppoort Dam.

The study proposed a new concept of utilizing the smaller already polluted Goreangab Dam, which receives polluted water from Windhoek and is situated upstream of

Swakoppoort Dam, as a *pollution detention* and *check dam* as well as a *clean-up dam* for the downstream dam. A study on the feasibility of this new concept should be carried out. If the concept proves to be successful, it could be used to solve the problem of polluted dams downstream of "city river catchments" elsewhere.

The time series of the rainfall in Windhoek area was stationary. This could mean climate change might have had little effect on Windhoek rainfall for the past 121 years. Therefore the study recommended more adaptive water resource planning, multi-source optimization and water governance initiatives of exploring the available secondary sources for the sustainable development of the USB. Water security in the USB can be enhanced by optimizing the Windhoek Rechargeable Aquifer Storage capacity. Institutions that supply bulk water to Windhoek can be unified into a single water governance institution to optimize and integrate these multiple sources. Based on adaptive water governance resource planning and multi-source optimization, the study further proposed a basin management strategy to ensure suitable water quality and quantity and to build adequate technical capacity.

DEDICATION

To God! “*If any of you lacks wisdom, let him ask of God, who gives to all liberally and without reproach and it will be given to him”,* James 1 verse 5, New King James Version *(1982)*.

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DECLARATIONS

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ACRONYMS

ACF	AutoCorrelation Function
ADWF	Average Daily Water Flow
AIC	Akaike Information Criterion
AIWPS	Advanced Integrated Wastewater Ponding System
ANN	Artificial Neural Networks
ANOVA	Analysis of Variance
ARIMA	Auto Regression Integrated moving Average
ASOR	Adaptive and Solution Oriented Research
ASR	Aquifer Storage Recovery
BAC	Biologically Activated Carbon
BAT	Best Available Technology
BATNEEC	Best Available Technology Not Entailing Excessive Cost
BG	Blue Green
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources of Germany)
BMA	Basin Management Approach
BMC	Basin Management Committee
BMP	Best Management Practice
BOD_5	Biochemical Oxygen Demand
BPT	Best Practical Technology
BSO	Basin Support Officer
CAN	Central Area of Namibia

CAP	Central Arizona Project
CBD	Convention on Biological Diversity
COD	Chemical Oxygen Demand
CoW	City of Windhoek
CRBMC	Cuvelai River Basin Management Committee
DAF	Dissolved Air Floatation
DARD	Department of Agriculture, Water and Rural Development
DO	Dissolved Oxygen
DOC	Dissolved organic carbon
DRFN	Desert Research Foundation of Namibia
DSS	Decision Support System
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EDCs	Endocrine Disrupting Chemicals
EIA	Environment Impact Assessment
EMA	Environment Management Act
EMPs	Environmental Management Plans
ENWC	Eastern Natural Water Carrier
EC	European Commission
EWFD	European Water Framework Directive
GA	Green Algae
GAC	Granular Activated Carbon
GDP	Gross Domestic Product
GIS	Geographical Information Systems

GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GRN	Government of the Republic of Namibia
GWP	Global Water Partnership
HYCOS	Hydrological Cycle Observing Systems
ICRG	International Country Risk Guide
ICT	Information and Communications Technology
IFR	Instream Flow Requirement
IPJV	IWRM Plan Joint Venture
IWRM	Integrated Water Resources Management
IWRM-CEB	Integrated Water Resources Management Cuvelai Etosha Basin
IWSZC	Industrial Wastewater Stewardship Zones Committees
KMUB	Karst Water Management Body
MA	Moving Average
MAR	Managed Aquifer Recharge
MAWF	Ministry of Agriculture, Water and Forestry
MAWRD	Ministry of Agriculture, Water and Rural Development
MET	Ministry of Environment and Tourism
MTF	Management Transition Framework
NAU	Namibia Agricultural Union
NCRST	National Commission on Research, Science and Technology
NamWater	Namibia Water Corporation Ltd
NGWRP	New Goreangab Water Reclamation Plant
NMS	Namibia Meteorological Services
NPI	Namib Poultry Industries

NTU	Nephelometric Turbidity Units
O & M	Operation and Maintenance
OGWRP	Old Goreangab Water Reclamation Plant
PAC	Powdered Activated Carbon
pacf	partial autocorrelation function
PACN	Pan African Chemistry Network
PCWMU	Pollution Control and Waste Management Unit
PWWF	Peak Wet Weather Flow
RO	Reverse Osmosis
SADC	Southern African Development Community
SANS	South Africa National Standards
SARIMA	Seasonal Autoregressive Integrated Moving Average
SASSCAL	Southern African Science Service Centre for Climate Change Land management
SEA	Strategic Environmental Assessment
SMART	Specific, Measurable, Attainable, Realistic, Timely
SMC	Social Multi-Criteria
SMCE	Social Multi-Criteria Evaluation
SOE	State-Owned Enterprises
SPSS	Statistical Package for Social Sciences
SSR	Sum Squared Residuals
SUD	Suitable Drainage Systems
TDS	Total Dissolved Solids

TIPEEG	Targeted Intervention Programme for Employment and Economic Growth
TMDL	Total Maximum Daily Load
TOX	Toxic
TSS	Total Suspended Solids
UNAM	University of Namibia
UNDP	United Nations Development Programme
USA	United States of America
USB	Upper Swakop Basin
USBC	Upper Swakop Basin Committee
USEPA	United States Environmental Protection Agency
USR	Upper Swakop River
USRD	Upper Swakop River Day
WCPS	Water Control Pollution Strategy
WDM	Water Demand Management
WEAP	Water Evaluation And Planning (models)
WFD	Water Framework Directive
WGF	Water Governance Facility
WINGOC	Windhoek Goreangab Operating Company
WMARS	Windhoek Management Artificial Recharge System
wmo	water management organization
WMO	World Meteorological Organisation
WQ	Water Quality
WQM	Water Quality Management

WRA	Windhoek Rechargeable Aquifer
WRAS	Windhoek Rechargeable Aquifer Storage
WSQCCC	Water Supply and Quality Customer Care Centre
WWTP	Wastewater Treatment Plant

SI UNITS

ha	hectare
hl/l	hectolitre/litre
km^2	square kilometre
l/p/d	litres/person/day
m^3/h	cubic meter per hour
mg/L	milligram per litre
mm	millimetre
Mm^3/a	million cubic meter per annum
mS/m	milli-Siemens per metre

CHEMICAL SYMBOLS AND WATER QAULITY PARAMETERS

Cl	Chloride
N	Nitrogen
Na	Sodium
NO_2	Nitrite
NO_3	Nitrate
P	Phosphorous
pH	potential Hydrogen
SO_4	Sulphate
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorous

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Some of study findings were published in 1 refereed journal, 2 workshop proceedings, and 6 research conference presentations as follows:

Publications

Pazvakawambwa, **G. T**., Ogunmokun, A. A., and Tjipangandjara, K.F. (2017) Assessment of the Ethical, Social and Health Acceptability Perceptions of Water Reuse for Public Purposes in Windhoek, *Namibia Journal of Managerial Sciences* (NJMS) 3, 1-2. (In print).

Pazvakawambwa, **G. T**., Ogunmokun, A. A., and Tjipangandjara, K.F. A Time-series Forecasting Model for Windhoek Rainfall, Namibia, Proceedings of the Andrews Research Conference (ARC) in STEM Disciplines, May 17-21, 2017, Chan Shun, Andrews University, Michigan, USA. *https://digitalcommons.andrews.edu/arc/2017/may-18/8/.*

Pazvakawambwa, G. T., Tjipangandjara, K. F., and Chulu, E. Management of the Upper Swakop Basin: Key water security to the Central Area of Namibia, proceedings of the Workshop, 8-10 February 2012, Hotel Safari, Windhoek, Namibia

Workshop and Conference Presentations

1. **Pazvakawambwa, G. T.,** and Tjipangandjara, K. F. Water governance in Namibia Upper Swakop Basin: Water Quality and Security Challenges, poster presented at the International Conference on Fresh Water Governance for Sustainable Development, 5-7 November 2012, Champagne Sports Resort, Drakensburg, South Africa

2. **Pazvakawambwa, G. T.** Basic Stakeholder Mapping tool in Adaptive Governance in the Upper Swakop Basin, poster presented at the Workshop on the formation of the Upper Swakop Basin Management Committee, 20 February 2014, NamPower Convention Centre, Windhoek, Namibia

Other Presentations

3. **Pazvakawambwa, G. T.,** Ogunmokun, A. A., and Tjipangandjara, K.F. A Time-series Forecasting Model for Windhoek Rainfall, Namibia, Proceedings of the Andrews Research Conference (ARC) in STEM Disciplines, May 17-21, 2017, Chan Shun, Andrews University, Michigan, USA. *https://digitalcommons.andrews.edu/arc/2017/may-18/8/.*
4. **Pazvakawambwa, G. T.,** Ogunmokun, A.A., and Tjipangandjara, K. F. Using WEAP Model in the Upper Swakop Basin, paper presented at the 2nd Annual Science Research Conference, University of Namibia, 30 -31 October, 2014, Windhoek, Namibia.
5. **Pazvakawambwa, G. T.,** Tjipangandjara, K. F., Ogunmokun, A.A., and Ogedengbe, K. Water Reuse as a water governance strategy in Windhoek, paper presented at the 9th IWA International Conference on Water Reuse, 27-31 October 2013, Windhoek, Namibia.
6. **Pazvakawambwa, G. T.,** Tjipangandjara, K. F., Ogunmokun, A.A., and Ogedengbe, K. The ethical and social issues of water reuse, 9th IWA International Conference on Water Reuse, paper presented at the 9th IWA International Conference on Water Reuse, 27-31 October 2013, Windhoek, Namibia.

CHAPTER ONE

1 INTRODUCTION

1.1 Orientation of the Study

According to the United Nations, Department of Economic and Social Affairs, Population Division (2014) approximately 54% of the world's population resides in urban areas where water supply and sanitation services should be provided without fail to avoid health risks and social insecurity that could result from the high population density. The freshwater resources from aquifers, lakes and man-made dams, usually prone to high evaporation, should be supplied to the ever growing demands especially to the urbanized centres in adequate quantities and quality to achieve sustainability (Butler & Memon, 2006; Fontdecaba et al., 2012). The challenge, however, is the continuously intensifying scarcity of finite, rain-fed, freshwater resources because of: 1) climate-change driven droughts, costly undeveloped water resources and inadequate availability of water in the face of growing water demands especially where there are mushrooming unplanned informal settlements and townships and 2) the vulnerability of water sources to both point and non-point sources of pollution causing the deterioration of water quality and resulting in increased cost of treating potable water, before it becomes unusable (Kostas & Chrysostomos, 2006; Payment et al., 2003; Yang et al., 2013). The pollution from point and non-point sources results in eutrophication of lakes, reservoirs and rivers which is one challenge that has emerged as a risk to freshwater worldwide (Jones & Brett, 2014).

The absence of good water governance in a basin together with increased pollution of the basin, may result in water being unusable for drinking as is the case of Hartebeespoort Dam in South Africa where a replacement 50 km-long supply pipeline had to be constructed from Brakfontein to Hartebeespoort at a great cost to ensure that residents of the area had adequate water supply (Anonymous, 2007, 21 March; Department of Water Affairs [DWA], South Africa, 2015). The eutrophication of Lake Chivero in Zimbabwe has been reported to be due to poor water governance that includes the lack of pollution control and management in the upper catchment (Nhapi & Tirivarombo, 2004; Nhapi et al., 2004; Nhapi et al., 2005a). Pahl-Wostl et al. (2008a) observed that one of the challenges of pollution control is using historical solutions that relied primarily on wastewater treatment without focusing on the source control. Ensuring good water governance and stewardship of water sources in river basins should therefore be of high priority to ensure security of water supply, intergeneration, sustainable growth and development of human social, economic, cultural, and political systems. This study, therefore, looked at the complex challenges and issues regarding water governance in a river basin.

It is worthwhile then to first define *water governance* and differentiate it from the related concept of *integrated water resources management (IWRM) process* which is commonly applied to bring solutions to challenges in river basins.

IWRM is a process which promotes the coordinated development and management of water, land and related resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP, 2010). While van der Zaag and Savenije (2000), Savenije and van der Zaag (2008) and Gain et al., (2013) supported and stated definitions for IWRM similar to that of GWP (2010), Gain et al. (2013) however indicated that IWRM's global diffusion of practice has resulted in not only multiple interpretations of IWRM but also conceptual confusion. While IWRM is one approach or means to resolve the challenges arising from the "silos" that often characterize water management structures, mechanisms and processes (Mitchell, 2015), there is a thin line and interwoveness between it and water governance as per its contemporary definitions.

Though there is no universally agreed definition, broadly, **water governance** is the range of political, social, environmental, economic and administrative systems *(usually by the responsible state organisations)* that are in place to *regulate* and *implement* the development and management of water resources and provision of services *sustainably and optimally* (Rogers & Hall, 2003; Franks & Cleaver, 2007; Tropp, 2007, Serrno, 2012, Havekes et al., 2013). This definition is adopted in the study.

The key difference between IWRM and water governance approaches is that whilst IWRM emphasises on integrated, coordinated development and management of water resources, water governance places the emphasis on accountability of administrative systems, regulation and implementation of the developed and managed resources.

The nature of water pollution challenges affecting water security in river basins is dynamic and complex, especially at the interaction with urban centres, where adaptive water governance approaches are required. Without ignoring integrated water resources management (IWRM) concepts that have been implemented worldwide and with their intended results not fully realized, there is a need for good water governance framework and practice to be put in place and adopted in river basins (Biswas & Tortajada, 2010). Blaines et al. (2006) highlighted the potential water scarcity threat to New York City (NYC) in the USA due to source-water watershed deterioration caused by pollution that resulted in lawsuits and mistrust. However, by embracing good water governance approaches, the issue was eventually solved by the NYC watershed memorandum of agreement that enhanced source-water monitoring, involvement of stakeholders, and institution of a watershed management plan (*ibid*). This resulted in the improvement of the pollution target sites that were impairing the ecosystem and the water quality (*ibid*). Similar water governance challenges causing water insecurity are also prevalent in Namibia.

1.1.1 Namibia Hydrological Climate

Namibia is characterised with high aridity and water scarcity where annual rainfall decreases from north east to west and south (600 mm to less than 50 mm respectively (Namibia, I. P. J. V., 2010). According to Department of Water Affairs (DWA), Hydrology Division, (1988) the annual potential evapotranspiration (PET)) rates are as high as 3,700 mm per year and as much as 83% of precipitation is lost via evaporation. The prevailing climate is characterised by prolonged droughts, high variability and unpredictability of rainfall (Namibia, I. P. J. V., 2010). Due to the poor hydrological climate, Namibia's internal rivers are ephemeral which in essence require good water governance efforts to achieve water security.

1.1.2 Study Area Description, Issues and Challenges

The Upper Swakop Basin (USB), the study area located in Namibia, is the upstream portion of the Swakop River basin forming one of the eleven *management* river basins. The location of the USB in relationship with the Central Area of Namibia (CAN) is shown on Figure 1.1. The CAN is an integrated water supply system comprising of surface and groundwater sources from both within the USB as well as other developed water sources from other basins. Figure 1.2 shows the USB study area map depicting local drainage; type of water sources; landuse patterns for townlands and farmlands; dams' locations (Swakoppoort, Von Bach, Goreangab and Avis Dams); and regional political and administrative boundaries that traverse across the whole USB. The USB receives highly variable annual rainfall of between 300 mm to 500 mm (World Bank, 2007; Namibia Meteorological Services, 2015).

The USB was created by stakeholders to address mainly the water quality and related quantity challenges threatening the water security of Windhoek among other demand sites supplied from this basin. Windhoek, the capital city of Namibia, is situated upstream of the catchment of Swakoppoort and Goreangab freshwater dams from which the city is supplied with water. The veins of the ephemeral Upper Swakop River and its tributaries drain through Windhoek, Okahandja Town and a large number of scattered industries within the basin which contribute significant pollution loads to the water.

The landuse types in the USB are mainly urbanized areas, farmlands; tourism centres and very little of rural area. The farmlands use mainly groundwater within the basin as depicted by the distribution of boreholes for both the Otjozondjupa and Khomas political and administrative regions. Four dams namely Avis, Goreangab, Von Bach and Swakoppoort are built in the USB. Goreangab and Swakoppoort Dams are situated downstream of the semi-arid Upper Swakop Basin. It should be noted that in this study, the word 'dam' is interchangeably used to mean the 'dam reservoir' as this suits how the term is applied by the stakeholders who participated in this study. For instance, the three integrated storage reservoirs of Von Bach, Omatako, and Swakoppoort Dams are known by the stakeholders as the "three integrated dams".

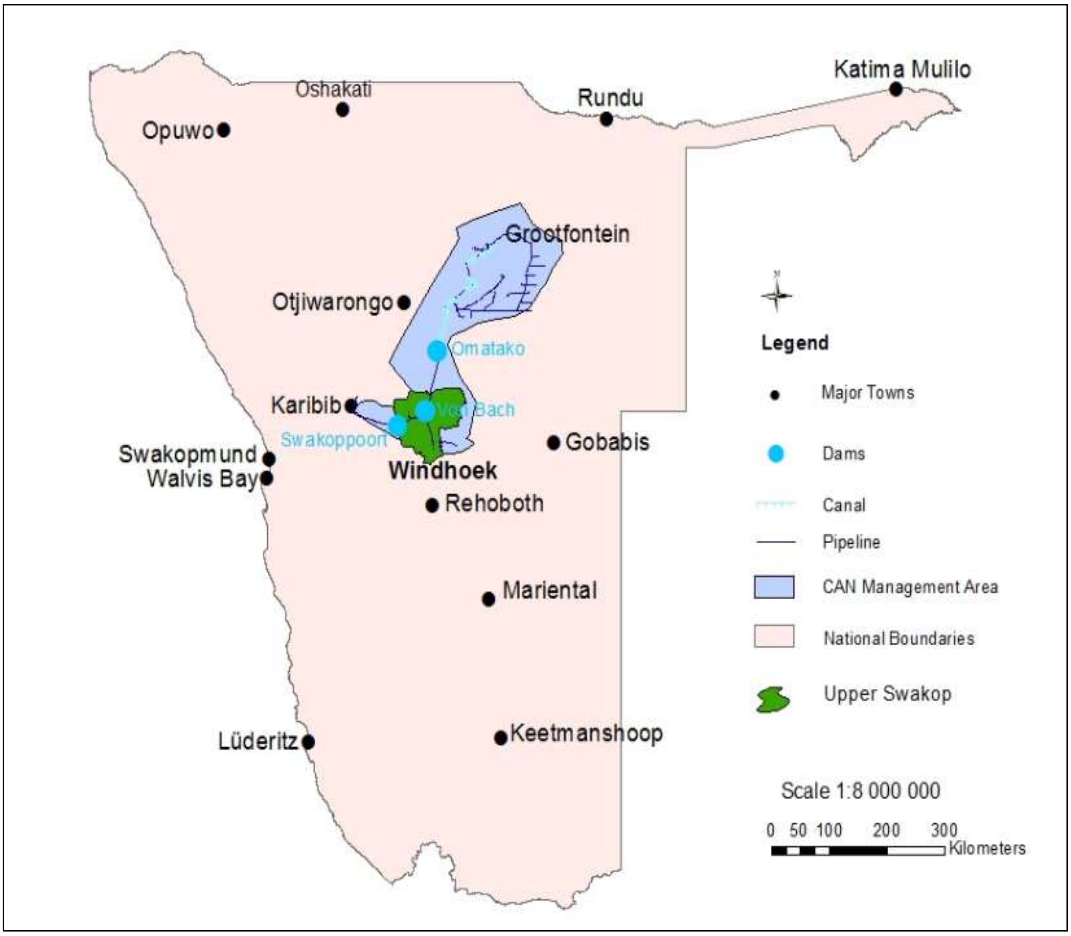

Figure 1.1 Namibia Map Indicating CAN and Upper Swakop Basin Study Area of Namibia

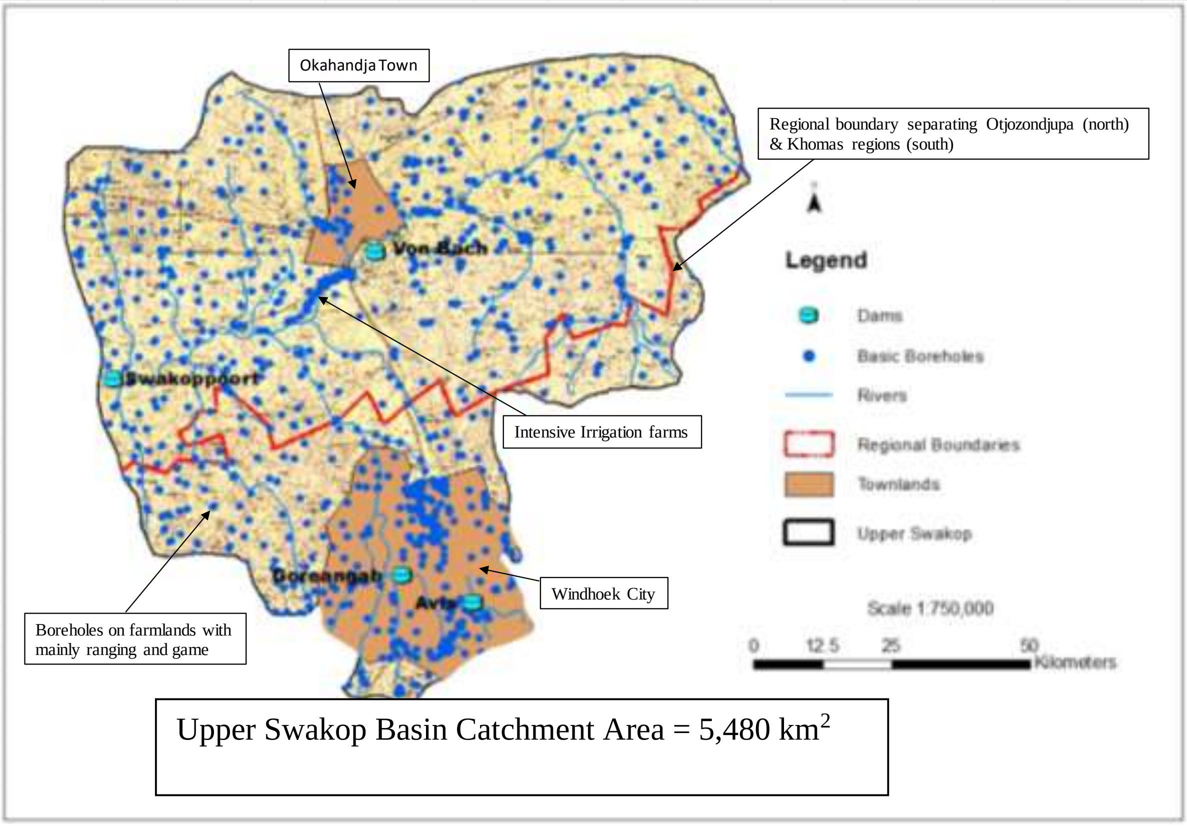

Figure 1.2 Upper Swakop Basin Showing Distribution of Boreholes, and Location of Towns and Administrative Regions

Challenges in the USB

The water pollution problem in the Upper Swakop Basin threatening the dams' water sources is very serious and endemic (Namibia Water Corporation [NamWater], 2011a). The pollution menace (especially the presence of algal blooms) could render Swakoppoort Dam water unfit as a drinking water source or make it expensively difficult to treat. The Swakoppoort Dam's water is hypertrophic and since 2009, the Goreangab Dam's water is no longer fit to be used as source water to the New Goreangab Water Reclamation Plant (NGWRP), which supplies drinking water to Windhoek. Instead, treated water effluent from the Gammams Wastewater Treatment Plant (also referred as Gammams Water Care Works) is being used at the reclamation plant. The risk of losing Swakoppoort Dam water to pollution, as part of the integrated three-dam system supplying the Central Area of Namibia (CAN) can create unprecedented insecurity of water supply to Windhoek as well as hurt the economy since Windhoek is Namibia's hub for commercial, industrial, government services, transport, business and tourism sectors. The deterioration and the pollution of surface water sources in the USB could be a clear indication of crisis of water governance resulting in water insecurity. The current water demands in the USB cannot be met from water sources within the basin and additional water is transferred from other basins (Omatako River sub-basin) and groundwater from the Karst aquifers located near Gootfontein to augment these water sources (NamWater, 2011a). However, it appears these developed sources may require further augmentation and optimization to meet future demands.

The study focused on the water resources management and governance design (Hooper, 2003) with regard to the sustainable socio-economic, ecological effects on the Swakoppoort and Goreangab Dams, water quantity and quality aspects that are of concern and negatively impacting the USB. The main focus was on the water governance of the Upper Swakop Basin (USB) in Namibia where integrated river basin management was in the evolution stages. Up until November 2014, the water resources in the Upper Swakop Basin were conventionally managed within administrative rather than along natural hydrological boundaries. The modern integrated water governance basin approach (Baril, Maranda, & Baudrand, 2006; Koehler & Koontz, 2008) is usually asymmetric to the existing political/administrative governance structures and physical boundaries, as was the case in the USB.

The USB comprises multiple-users, multiple-stakeholders (urban residents, farmers, industries, local authorities, water suppliers etc.) and multiple-value systems with what happens in one part of the basin affecting the environments and people in other parts. The greater the degree of water demand within the Upper Swakop sub-catchment, the greater the degree of interdependence among users and the possibility of potential tensions, thereby calling for collective governance of the basin with increasing developments. There is need to explore adaptive decision support models that incorporate the urban and industrial developments and associated water pollution control, reservoirs operation and abstraction regimes, water adequacy analyses and optimization to ensure sustainability of the available freshwater resources in the USB.

1.2 Statement of the Problem

In 2010, the Namibia Water Corporation Limited responsible for supplying potable bulk water to villages, towns and cities in Namibia, observed algae blooms from the eutrophic Swakoppoort Dam water source for urban centres of Windhoek, Okahandja and Karibib (NamWater, 2011a). The algae blooms and associated possible cyanobacteria rupture (Chorus & Batram, 1999) during pumping of the water to Von Bach Dam render the water poisonous and unusable, necessitating the retrofitting of other expensive treatment processes to render the water source usable. The pollution of the USB from urban sources affect water supply dams downstream and it is a threat to the security of water supply to Windhoek and Okahandja Town. The pollution also affects the ecosystem and human health.

Among the major concerns is whether the current pollution management and governance system in the Upper Swakop Basin is integrated, coordinated and working properly (Biswas, 2008). Anecdotal evidence indicates lack of key stakeholder participation in the management and governance of USB. Also lacking in the basin are coordinated pollution statistics that may be used in the proper management of the USB.

Biswas and Tortajada (2010) alluded to the lack of global informative research and case studies on good water governance. This lack of informative research on good water governance in Namibia makes the USB case study unique. As experienced in many African countries (United Nations Environmental Programme, 2010), this lack of effective water quality monitoring statistics and programmes in Namibia is probably due to underinvestment and poor or absence of accountable water governance structures (*ibid*). Furthermore, Gleick (2014) indicated that the water crisis that is affecting so many people is mainly a **crisis of water governance** - not of water scarcity. Water governance exists where state organizations responsible for water management establish an effective policy, along with an appropriate legal framework to regulate and manage water in ways that respond to environmental, economic, social and state policy needs, with the participation of all social stakeholders and application of adaptive approaches to water resources management.

In general, it is accepted that ethical issues such as responsibility, accountability, transparency, equity and fairness are fundamental requirements for good governance (Rogers & Hall, 2003; Totajarda, 2010; UNDP Water Governance Facility, 2014). Totajarda (2006) stated that unresolved discussions of non-functional or partially functional water institutions and laws, in most developing countries are complex. In Namibia, the slow implementation of enactments, like the Environmental Management Act, 2007 and the Water Resources Act, 2004 which were only finalized in 2011 and 2013 respectively, is a clear example of non-functional or partially functional laws which impact water governance structures. While IWRM is widely accepted as a pro-efficient and effective water management concept that is anchored on appropriate national and international policies, laws and institutions at river basin scale, the practical implementation of IWRM tend to raise questions of water governance.

How can we assess and measure these lagging elements such as regulation of water usage and pollution and how can the gaps created by these lags be mitigated? Since water governance is not only broad but has many sides that are complex, this study analysed the significance of various issues and related observations of water governance in the USB by adopting a multi-faceted approach. The states of water scarcity and aridity, the quality and the multi-source water supply systems in the USB are critical water governance issues that were to explored and investigated.

Questions and issues that need to be explained and addressed include: What are the types and patterns of major pollution sources among domestic- industrial and agro- industrial users or uses in the USB? To what extent can water supply sources, storages and their water quality and demands be optimised and improved? Another aspect is the evaluation of the effectiveness of contemporary reviews and strengthening of the legal and institutional frameworks in the USB. What are the ethical and social perceptions of water reuse for potable use in the USB? To what extent is the participation of relevant water use stakeholders in the creation of consensual water governance solutions? To what extent do the relevant water use stakeholder's access information? Is there transparency and accountability in the sharing of experiential knowledge? Could there be improved participatory water management as well as adaptive approaches to ensure water security? To what extent can policies be guided by the derived lessons?

1.3 Objectives of the Study

The aim of the study was to assess water governance issues for drinking water security with respect to issues of water quality, quantity and governance structures in the Upper Swakop Basin. To adequately articulate and address the challenges raised in the problem statement, specific objectives are formulated as follows:

1) Assess the water quality at potential pollution sources and at major receiving waters (discharge points, dams, rivers and aquifers) in the Upper Swakop Basin with respect to the prevailing water quality regulations and standards.
2) Evaluate the adequacy and availability of the drinking water sources in the USB; and also assess the adequacy of water in the USB (as well as CAN).
3) Assess the ethical, social and health perceptions of water reuse for potable purposes in Windhoek.
4) Qualitatively assess water governance structures, participation, and the overall assessment of water governance processes and outcomes in the USB based on institutional organograms, legal framework and participation.

The following hypotheses were tested.

1.4 Hypotheses

Hypothesis 1: There are no significant spatial variation in the mean concentration levels of water quality parameters of the 12 sampling points upstream of Swakoppoort Dam.

Hypothesis 2: The Windhoek rainfall time series is stationary i.e. there is no significant increase in the mean and variance of the series over the century (no significant climate change effects).

1.5 Significance of the Study

The unique contribution of this study is the way in which different research methods (models, statistical analysis, quantitative, qualitative etc.) were used to analyse the water governance issues at the USB which had, hitherto, not been attempted before.

The main significance is that the study provides valuable information about water governance and water security in the USB which may be used to provide solution to the water security issues in the USB. The models and water governance analysis tools, management structures and proposed strategies will contribute new knowledge not only for Namibia but can be used to expand water studies in similar countries and basins. The study will inform and contribute to knowledge on sustainable water governance practices and policy on maintenance of a healthy city river, ecosystem, and society. A healthy city river will ensure security of sustainable water from the available sources and deferment of major capital investments to develop new sources. The new knowledge created in this study, if applied, may be used to reduce the increasing pollution of the Swakoppoort and Goreangab Dams and improve the water security situation of the Windhoek, Okahandja and other consumers supplied from the deteriorating water sources (NamWater, 2011).

1.6 Limitation of the Study

River basin management initiatives involve moves towards governance within the basin's natural hydrological boundaries to manage water more holistically, equitably, efficiently and sustainably. For ease of implementation of the water governance concepts and IWRM principles, the most appropriate unit for analysis, planning, management and institutional arrangements is based on the river basin or watershed approach. However, the present USB water supply infrastructure and sources are already extended beyond the local USB coverage and communities. Hoekstra and Chapagain (2011) and Gleick (2014) stated that basin overlaps and transfers pose and result in challenges and difficulties in studying and understanding individual river basins. According to Namibia Water Corporation (2011a), significant amount of the water supplied to the USB is water transferred from the Omatako Dam basin as well as from the Berg Aukas, Kombat and Karst groundwater sources outside the USB. Moreover, to augment inadequate supplies within the USB, there are plans to transfer additional water from the Trans-boundary Okavango River. Considering the existing water transfer scheme from the Omatako Dam and the proposed transfer from the Okavango River, the water governance issues of the USB cannot be understood fully within its own single hydrological basin context without impacting on issues of national security, regional, trans-boundary, international trade, politics and development cooperation (Allan, 2001; Smakhtin et al., 2004; Mundial, 2004) of the other Okavango River riparian states namely: Angola and Botswana. In this present study, it is acknowledged that good water governance of the USB requires a regional trans-boundary complementary approach (Hoekstra, 2011). However, the adopted approach focused on the USB hydrological scale and perspective of water governance owing to the water quality deterioration issues of this basin and did not extend to the Okavango River or the whole Swakop Basin. Despite this limitation the study significantly showcased water governance issues in a basin context.

Due to limited financial resources, time and logistical challenges, the study was limited to Upper Swakop Basin as opposed to the whole Swakop River basin area. Moreover, seasonality and intermittent river flow regimes can make the water quality measurements in the USB none continuous. It was inevitable that there were limitations in the use of secondary data, however, appropriate data collection and data validation procedures were used to ensure representativeness of the data. Given that the literature on the study area and on water governance in Namibia was sparse and often unpublished, the research drew lots of information from grey literature which in itself should not be construed as a limitation but seen as a way of bringing these grey literature into the public domain.

1.7 Organization of the Study Document

The first chapter gives an orientation of the study, problem statement, objectives of the study and its significance and limitations. A review of related literature on water governance and related issues within and outside the basin is presented in Chapter 2. The third chapter outlines the generic methods used for the different study phases in terms of their research designs, study populations, samples, research instruments, ethical considerations and the data analyses procedures. Chapter 4 presents the results of the assessment of water quality within the Upper Swakop Basin while Chapter 5 presents the assessment of availability and adequacy of drinking water sources in the USB. The ethical, social perceptions and acceptability of water reuse for potable use by residents of Windhoek are also presented in Chapter 6. Chapter 7 presents the evaluation of water governance structures, participation, integration, processes and outcomes in the USB. Lastly the conclusions and recommendations of the study are presented in Chapter 8.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Introduction

This chapter reviewed literature on water governance in the USB and that of other basins around the world. The review first looked at the background population and estimated per capita water consumption, socio- economic situation and the rule of law and freedom of expression in the USB. This is followed by review of water quality and quantity situation; water reuse issues; water banking; water demand management, water evaluation and planning models; water security; administrative and hydrological regions. The review also looked at institutions responsible for management of water resources, water basin management experiences; legal and policy framework reforms; institutional water sector reforms and framework; water pollution control; effluent and wastewater discharge instruments; and water governance evaluation models.

2.2 Socio- Economic and Political Characteristics of the Upper Swakop Basin

2.2.1 Population of the Upper Swakop Basin

The population of the USB based on Namibia Statistics Agency (2011) is summarized in Table 1. The total population is estimated for year 2014 to be 360,000 people comprising of 348,500 people from both Okahandja Town and the metropolitan capital city of Windhoek while the rural areas contribute only about 11,500 people (3% of the total). As presented in Table 1, the annual growth rates of the urban areas are 3.4% for Windhoek and 4.9% for Okahandja while the rural areas show negative growth rates (-0.3%) that can be attributed to the rural – urban migration. According to Steytler (2014), the Namibia population is projected (2011-2041) to result in the number of people living in the rural areas to shrink gradually leading to the share of the national population living in urban areas increasing from 43% in 2011 to a projected 67% in 2041.

Table 1 Windhoek and Okahandja Population, population growth rates, consumption per capita and water demand growth rates in 2001 and 2011 (NSA, 2011)

Region	**Khomas**		**Otjozondupa**	
Census year	**2001**	**2011**	**2001**	**2011**
Area (km^2) of Region	36,948		105,295	
Rural population (Khomas)	16,733	16,283		
Area of Rural (Khomas) (km^2)	36,468			
Annual Growth Rate for Rural Khomas (%)	-0.27			
Population Density for Khomas Rural (person/km^2)		0.6		
Okahandja Constituency population			18,071	24,451
Area of Okahandja Constituency (km^2)				14,643
Population Density for Okahandja Constituency (person/km^2)				4.2
Okahandja Constituency Annual Growth Rate (%)			3.53	
Regional Population	250,262	342,141	135,384	143,903
Population Density for Region(person/km^2)		9.3		1.4
Annual Growth Rate for Region (%)		3.67		0.63
% with No Toilet Facility in 2011		20%		31%
Local Authority in USB	**Windhoek Municipality**		**Okahandja Town Council**	
Town Population	233,529	325,858	14,039	22,639
Area (km^2)		480	36,948	
Population density (person/km^2)		676		
Population Density Katutura Suburb in Windhoek (person/km^2)		12,148*		
Annual Growth Rate town (%)	3.39		4.9	
Water Demand m^3/annum	14,951,343	24,474,045	1,251,081	1,291,163
Average Consumption / capita (l/day)	175	206	244	156
Water Demand Growth Rate (%)	3.9		0.3	

* Katutura Suburb, where there is limited coverage of sanitation facilities, has the highest population density in Windhoek City of 12,148 persons/km^2.

It should be noted that the population of Windhoek is approximately 90% of the total population within the Upper Swakop Basin hosting a diversity of cultures and races that include the population cultural groups of: Oshiwambo, Herero, Damara, Kavango, Lozi, Nama, San, Coloureds, Asians, Europeans and other minority groups (Matengu, 2003). In the Khomas Region, the population is projected to increase from 340,000 in 2011 to 645,000 by 2030. The same predictions indicated that Namibia's population will be 3.4 million in 2041 (Steytler, 2014).

As shown in Table 1**,** 20% of the total population in the Khomas Region (where 90% reside in Windhoek) have no toilet facilities. In the Otjozondjupa Region, in which the Okahandja Town is situated, 31% of the population do not have toilet facilities (Namibia Statistics Agency, 2011). This implies that the environment, surrounding the public streams and rivers are prone to being contaminated with faecal waste. The unserviced peri urban informal settlements of Okahandja and Windhoek are contributors to the pollution. Failure to properly plan and avoid informal settlements is tantamount to failure to curb pollution of natural streams and the ecosystem of the basin.

Of concern is the higher than average population density around the informal settlement, for example, as shown in Table 1, Windhoek's Katutura Township on which the informal settlements grow, has a population density of 12,148 people/km^2 compared to 676 people/km^2 average for Windhoek. This high population density with no full sanitation coverage in the neighbourhood is the likely cause of sewer pipe burst due to overloading (Laryea-Adjei, 2007; Newaya, 2010). The challenges of these unplanned urban and un-sewered settlements in the USB include:

1. Construction of temporal structures in the informal settlements located in Katutura and Okahandja Townships.
2. Throwing of litter into gutters, drains and river channels.
3. Widespread dumping of refuse and littering in informal settlement backyards into streams and channels which flow through town during the rainy season i.e. refuse washed into Goreangab Dam (Figure 2.1).

Figure 2.1 “Refuse and litter” discharging into and polluting Goreangab Dam (approximately 100 m upstream of reservoir)

4. Indiscriminate defecation in public places due to inadequate toilet facilities and education can be high. Laryea-Adjei (2007) in Ghana, recommends 8 persons per flush toilet hole, whilst Brown et al. (2012) recommends a maximum of 20 people per dry toilet hole in emergency situations. These figures do not correlate well with Katutura’s 50 persons per shared toilet hole (Newaya, 2010). The “uncontrolled” expansion and informal settlements of Windhoek and Okahandja are deemed to make these urban areas unsustainable water sensitive areas giving rise to water pollution of the basin.

2.2.2 Population Growth Rates, Estimated Water Consumption per Capita and Water Demand Growth Rates between 2001 and 2011 (Windhoek & Okahandja)

From the 2001 Population Census figures, the gross per capita water consumptions were estimated to be 0.175 m^3/capita/day and 0.244 m^3/capita/day for Windhoek and Okahandja respectively. Based on the 2011 Population Census figures, the gross per capita water consumption were estimated to be 0.206 m^3/capita/day and

0.156 m^3/capita/day for Windhoek and Okahandja respectively. It is believed that increased industrialisation leading to increased industrial water consumption is responsible for the increased gross per capita water consumption in Windhoek in comparison with Okahandja which is reduced. Another contributing factor could be the higher proportion of affluent population residing in Windhoek compared to Okahandja. Worldwide, the affluent class of society uses more water than the rest of the society (Harlan et al., 2009). As shown in Table 1, the water sales growth rates between 2001 and 2011 for Windhoek and Okahandja urban centres were estimated at 3.9% and 0.3% respectively. These water sales are treated as proxy for water demand of customers taking cognisance of losses which may occur in the distribution system.

2.2.3 Rule of Law and Freedom of Expression in Namibia with Regard to Water Governance

Water governance is affected and influenced by the prevailing political stability and overall rule-of-law of a country (Kaufman et al., 2000; Kaufman et al., 2005; Kaufman et al., 2009; Zaaruka & Fedderke, 2011). Based on measurement criteria on political governance and stability prescribed by Banks (1976); key aspects of judicial independence prescribed by Feld and Voigt (2003); reflections on the Namibian Constitution and laws by Amoo and Skeffers (2008) as well as observations by Kangira (2012) and Parker (2009), there seems to be objective promotion of democracy, the rule of law and respect for human rights to attain efficient, transparent and fair public administration in Namibia. Given the foregoing it can be postulated that water governance in Namibia is founded on a country that strives to respect the rule of law.

2.2.4 Namibia Economic Situation and its Anticipated Impact on Water Governance in the USB.

Although huge disparities exist among income groups in the USB, Namibia's GINI-coefficient is quoted to have improved from 0.74 in 1992 to 0.68 in 2015 (World Bank, 2015). The GINI- coefficient is a measure of the level of inequality in a society i.e. the index measures the extent to which the distribution of income (or, in some cases, consumption expenditure) among individuals or households within an economy deviates from a perfectly equal distribution. These income disparities are likely to have an impact on low income earners in the USB that may find it difficult to pay their water bills (Newaya, 2010). However, according to Kavishe (2015), the overall Namibian economy shows an upward looking trend with a moderate GDP growth of approximately 5.5% in 2015 and a corresponding inflation average of 5.6% in 2015. The major constrains to GDP growth were reported to be inadequacy of bulk water resources and power supplies (Kavishe, 2015).

The USB areas are water stressed due to unavailability of developed water resources. Several water sources are being investigated to address the situation (Lund & Seleenbinder Consulting Engineers, 2014). It is feared the basin may be affected by the delays to implement the long-planned water pipeline to be supplied from the Okavango River or water supplied from the desalinated seawater at the Atlantic Coast due to limited financial resources. The Okavango River project, among other feasible options, may be considered as the long term sustainable water source that will ensure security of bulk water supply in the USB as well as boost economic confidence and drive.

2.3 Water Resources Situation Assessment of the Upper Swakop Basin

2.3.1 Groundwater Sources in the USB

The major aquifers that augment water supply from the Von Bach Dam in the USB are the Windhoek, Osona and the Okahandja aquifers which show high density zones of developed boreholes as indicated in Figure 1.3. The Osona aquifer is a riverbed alluvial aquifer in the vicinity of the confluences of the Swakop and Okahandja rivers. The Osona wellfield supplies water to the population of Okahandja and some nearby irrigation farmers.

The Windhoek aquifer is underlain by schist and quartzite rocks, and receives the bulk of its recharge from precipitation over the Auas Mountains. According to Biggs and Williams (2001) and Namibia, I.P.J.V. [IWRM Plan Joint Venture Namibia] (2010), any abstraction of water from Windhoek aquifer greater than 2 Mm^3/a is considered unsustainable. In the past, it is reported that the Windhoek aquifer used to flow freely at the surface as natural springs that originally attracted settlers in the late 1800s, but it has since ceased to flow as the aquifer has been abstracted beyond its sustainable recharge rates quoted as 1.7 Mm^3/a (du Pisani, 2006). Instead, the aquifer is now partly used as a reservoir into which water is pumped artificially to avoid evaporation. In times of plenty, treated surface water is banked into the Windhoek aquifer (du Pisani, 2006) to enhance its natural recharge. It is further indicated that the surface water to be artificially recharged should be treated to avoid excessive organic carbons that may cause bacterial contamination of the aquifer. During the drought periods, the banked water in the aquifer is abstracted to augment available dwindling surface water supplies (du Pisani, 2006). The aquifer is presently a major supply source, providing Windhoek with ±2.34 Mm^3/a.

2.3.2 Surface Water and Hydrological Parameters of Dam Reservoirs in the USB

The USB's annual rainfall ranges from 250 mm in the west to 450 mm in the east and forms runoff that fills the dams in the USB and recharges the aquifers. The Swakop River and tributaries that are highly ephemeral form the drainage arteries with only surface runoff flowing immediately after a series of heavy rainfall. The surface water sources in the USB include the Von Bach (with a volume capacity of 48 Mm^3) and Swakoppoort (with a volume capacity of 63 Mm^3) Dam reservoirs as well as the Omatako Dam reservoir (with a volume capacity of 45 Mm^3) outside the USB forming a system of three dams operated as a single integrated transfer scheme. Water from the larger surface area dam reservoirs is transferred into the deeper and smaller surface area Von Bach Dam reservoir thereby reducing the net surface area evaporation. The characteristics of the three-integrated dam system are given in Table 2. The dams have different capacity to surface area and storage ratio relationships as illustrated in Table 2. The dams were designed to hold 3-year mean annual rainfall, giving a long residence time. Dealing with water quality issues may be made difficult under these circumstances as the dams seldom spill as illustrated in Table 2. The Omatako Dam is prone to more evaporation, due to its lower volume to surface ratio, but it has a higher storage ratio resulting in it being filled up approximately once in 1.4 average rainy seasons. On the other hand, the Swakoppoort Dam requires 3.5 average rainy seasons to fill. As shown in Table 2, the combined 95% yield of the three dams is ±13 Mm^3/a. However, when the three dams are operated optimally as an integrated system to minimize evaporation; the 95% yield of the system is increased to 20 Mm^3/a.

Table 2 Combined and Individual yields of the Three-Integrated-Dam System of the USB (Adapted from Namibia Water Corporation [NamWater], 2000).

Dam / Reservoir		Omatako	Von Bach	Swakoppoort
Characteristic	**Unit**			
Catchment area	km^2	5, 320	2,920	5,480
Mean annual runoff	Mm^3/a	32.5	22	18
Full supply capacity	Mm^3	45.12	48.56	63.489
Storage ratio		1.39	2.21	3.53
Full surface area	km^2	15.545	4.884	7.808
Volume/surface area ratio	m	2.90	9.94	8.13
Dam separate 95% yield	Mm^3/a	4	6.5	2
3-dam integrated system 95% yield	Mm^3/a	20		

The main inter-basin transfer to the USB is via the Eastern National Water Carrier (ENWC), where water from the Omatako Dam and other ground water sources from the Karst areas near Grootfontein (approximately ±300 km to the north of Windhoek) is discharged via a combination of canal/pipeline system to Von Bach dam. Strategic extension of this water supply system is being considered to tap water from the trans-boundary Okavango River via a still to be constructed pipeline that will link to the ENWC conveyance system. Two other small dams water sources i.e. the Avis (for recreational) and Goreangab Dams are situated in Windhoek. The Goreangab Dam, with a full supply capacity of 3.6 Mm^3, is situated downstream of the city drainage and is heavily polluted. Due to the increased pollution of the water from this dam, its water has been abandoned as a source for drinking water.

2.3.3 Non-Conventional Sources - (New and Old Goreangab Water Reclamation Plants in Windhoek)

The progressive developments of water supply sources for potable water for Windhoek are described in du Pisani (2006): The Windhoek springs supplied water to settlers in 1840 after which the aquifer well-fields were developed in 1911. In 1933, the Avis Dam, with a capacity of 2.1 Mm^3 was developed and in 1954 water re-use was considered. By 1957, the aquifer was overused by 57% and in 1958 the Goreangab Dam with a capacity of 3.6 Mm^3 was completed. The Old Goreangab Water Reclamation Plant (OGWRP) with a capacity of 2.9 Mm^3 per annum, was later commissioned in 1968.

Based on Asano (2002), the water quality cycle for the USB starting with treatment of raw water from dam reservoirs; to use of the treated water; disposal of wastewater; treatment of the wastewater and water reuse processes are summarized and graphically presented in Figure 2.2. The figure shows different levels of water qualities expressed as turbidity in Nephelometric Turbidity Units (NTU) and total dissolved solids (TDS) for various sources, uses and after use. Domestic and industrial water use tends to degrade water quality through physical, chemical or biological contaminants. The quality changes necessary to upgrade water of low quality, or wastewater, then becomes the basis for the required treatment. As more advanced technologies are applied for water reclamation, the reclaimed water can exceed conventional drinking water quality on various measured parameters. The Old Goreangab Reclamation Plant (OGWRP) is presently used to treat polluted water from the Goreangab Dam but to a level unsuitable for human consumption after which is used for irrigation, mainly of sport fields and a golf course. The capacity of the OGWRP plant is 8,000 m^3/day. The treatment process consists of flocculation, dissolved air flotation, rapid sand filtration, granular activated carbon filtration and chlorine disinfection.

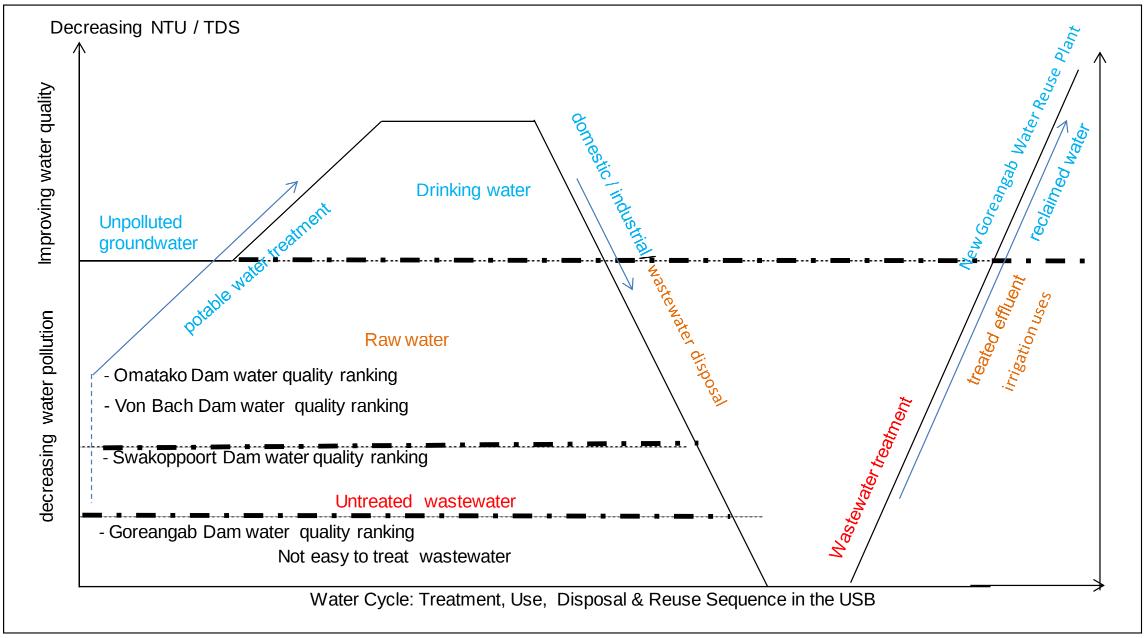

Figure 2.2 Water Quality Cycle through Raw Water Treatment, Use, Disposal and Reuse in the USB (Adapted from, Asano, 2002)

Due to limited developable freshwater sources around Windhoek and despite the city being supplied by the three integrated dams that were built in the 1970s, the Old Goreangab Water Reclamation Plant (OGWRP) was replaced with the New Goreangab Water Reclamation Plant (NGWRP), with a capacity of 7.5 Mm^3/annum which was commissioned in 2002. The new multi-barrier water purification processes in the plant include raw water blending coagulation; dissolved air flotation; rapid gravity sand filtration; biological activated carbon filtration; granular activated carbon filtration; ultra-filtration; disinfection; stabilization and finally blending with water supplied from Von Bach Dam in a ratio of 1:3. Blending the reclaimed water with treated surface water and/or groundwater provides additional safety. Almost a quarter of the Windhoek's total water demand is supplied by the New Goreangab Water Reclamation Plant (NGWRP) (du Pisani, 2006).

The maximum portion of reclaimed water fed into the distribution system is 50% in times of water scarcity and low water demand (winter season). Originally, it was decided that the maximum reclaimed water will be 35% of the total potable water released into the distribution network (du Pisani, 2006). This decision was based on achieving a dissolved organic carbon (DOC) value of approximately 5 mg/L in the final water produced in the distribution network after blending. Because the DOC values of water from NGWRP are rarely greater than 2.6 mg/L (du Pisani, 2006), the maximum ratio of reclaimed water to total potable water released into the distribution system was increased to 50%. The plant is managed and financed through a 20-year operation and maintenance (O&M) contract which was drawn between the Windhoek Municipality and the Windhoek Goreangab Operating Company Ltd (WINGOC). In order to include as much specialist process and operating know-how, WINGOC is made up of three major international water treatment contractors: Berlinwasser International, VA TECH WABAG and Veolia Water.

According to Cashman et al. (2014), the NGWRP source-water quality from the Gammams Wastewater Treatment Plant is occasionally diminishing making it unsuitable as input into the reclamation plant. This is due to the incapacity of the Gammams Wastewater Treatment Plant to treat and handle industrial wastewater from Prosperita and Southern Industrial areas. Apart from failure to comply with wastewater discharge regulations (discharging into public sewer without pre-treatment) of Windhoek Municipality, this industrial wastewater should not have been connected to the domestic wastewater treatment plant meant as source water for water reuse in the first instance. The measured bromide in the effluent is above the norms and is thereby affecting the treatment processes of both the Gammams Wastewater Treatment Plant and NGWRP. If pre-treatment is not retrofitted at NGWRP, then this industrial effluent should be treated separately or piped for treatment to the Ujams treatment plant to avoid jeopardizing the proper water treatment at NGWRP.

2.3.4 Social, Health and Ethical Issues of Water Reuse for Drinking Water in Windhoek

Water reuse is recycled water that is separated and highly treated so that it can be used again. Generally, water reuse for thermal cooling, industrial use, irrigation of recreational parks and other purposes has been popular worldwide, but water reuse for drinking has not been widely accepted as indicated by Environmental Protection Authority in Western Australia (Authority, Environmental Protection [EPA], 2005). Chen, Ngo, and Guo, (2013) stated that the observation is the same globally. Driven by the growing climatic-change-induced water stress and scarcity, as well as chronic imbalance between available fresh water resources and demand (Abdel-Dayem et al., 2011), many countries worldwide are looking into direct and indirect water reuse strategies that also have the benefits of controlling pollution to water reservoirs that are downstream.

Water reuse can be unplanned or planned. Indirect planned potable reuse (there is an intent to reuse the water for potable use) is where raw water withdrawals for drinking are made downstream of a wastewater outfall. Indirect unplanned potable reuse (incidental) is widespread, for example in the United Kingdom, United States of America and Australia (Williams, 1997). Planned potable reuse typical example is in Singapore's so called NEWater, meeting 30% of the country's needs (Biswas & Kirchherr, 2012). However, the first potable direct reuse plant in the world was established in Goreangab, Windhoek, as far back as 1968 (Murni et al., 2003; Law, 2005). Some countries like the United States and Australia experienced consumer resistance to water reuse for drinking. A survey carried out in 2010 indicated that only 36 % of respondents in Australia would consider drinking directly reclaimed water (Biswas & Kirchherr, 2012) while 15% would not even wash their cars with it. A survey carried out in the United States and Israel (Friedler & Lahav, 2006; Abdel-Dayem et al., 2011; Biswas & Kirchherr, 2012) showed that the respondents' resistance were based on health and social related concerns.

Fresh water resources are scarce in Namibia and water reuse for potable purpose was adopted as a sustainable way to enhance water security within the USB where demand, especially in and around Windhoek, has outgrown the available fresh water sources. The city relies on both surface water, groundwater and water from WINGOC water reuse plant. However, the raw water source for the water reuse plant is constrained by deteriorating water quality. WINGOC preferred to abstract raw water for its plant from the final filtrate coming from the Gammams Wastewater Treatment Plant that also has seasonal variations in water quality. Even though water reuse for drinking in Windhoek is long established, no study could be found as of the time this study was started on the public perceptions of this water reuse for potable purposes.

2.3.5 The Concept of Water Banking

Central Arizona Project Water Banking

Groundwater is a critical component of the water supply either for agriculture, urban areas, industry, and ecosystems, but managing it is a challenge because groundwater is invisible and difficult to quantify and evaluate. Megdal et al. (2014a) indicate that assessment of governance of the groundwater resources has been largely neglected. A survey in the USA by Megdal et al. (2014a) revealed that 1) States' legal frameworks for groundwater differ widely in recognizing the hydrologic connection between surface water and groundwater, the needs of groundwater-dependent ecosystems, and the protection of groundwater quality; 2) States reported a range in capacity to enforce groundwater responsibilities; and 3) States experienced substantial changes in groundwater governance in the past few decades. The overall conclusion indicated that groundwater governance across the United States was fragmented. The States nevertheless identified three common priorities for groundwater governance as: water quality and contamination, conflicts between users, and declining groundwater levels. Megdal et al. (2014b) further indicate that innovation born of necessity to secure water for the U.S. state of Arizona has yielded a model of water banking that serves as an international prototype for effective use of aquifers for drought and emergency supplies. If understood and adapted to local hydrogeological, water supply and demand conditions, this could provide a highly effective solution for water security, even in the USB.

Namibia, just like Arizona (a semi-arid state in the southwestern United States) has growing water demands, significant groundwater overdraft, and surface water supplies with diminishing reliability. Arizona has developed an institutional and regulatory framework that has allowed large-scale implementation of managed aquifer recharge (MAR) in the state's deep alluvial groundwater basins. The most ambitious recharge activities involve the storage of Colorado River water that is delivered through the Central Arizona Project (CAP). The CAP system delivers more than 1,850 Mm^3 per year to Arizona's two largest metropolitan areas, Phoenix and Tucson, along with agricultural users and sovereign Native American Nations, but the CAP supply has low priority and is subject to reduction during declared shortages on the Colorado

River. In the mid-1980s the State of Arizona established a framework for water storage and recovery; and in 1996 the Arizona Water Banking Authority was created to mitigate the impacts of Colorado River shortages; to create water management benefits; and to allow interstate storage. The Banking Authority has stored more than 4,718 Mm^3 of CAP water; including more than 740 Mm^3 for the neighboring state of Nevada. The Nevada storage was made possible through a series of interrelated agreements involving regional water agencies and the federal government. The stored water will be recovered within Arizona; allowing Nevada to divert an equal amount of Colorado River water from Lake Mead; which is upstream of CAP's point of diversion.

Windhoek Water Banking

The water bank water management input known as Windhoek Management Artificial Recharge System (WMARS) is used as pilot project to artificially recharge and manage the Windhoek Aquifer. The lessons of the Central Arizona Project may find application on the Windhoek aquifer that is being investigated. WMARS storage characteristics and the potential storage of the aquifer compartments are being established in and around the city to augment the limited water resources available. According to Namibia, I.P.J.V. (2010), water banking was identified as the "best next" supply option involving storing (artificially recharging) excess treated water from surface dams, as well as reclaimed water, in the Windhoek Aquifer for abstraction during periods of drought. Phase 1 of the water banking project was completed in 2004 and a further phase, including drilling of 10 deep boreholes, was completed in 2008. If completed in full (4 phases) it is estimated that the stored water will be enough to supply Windhoek for approximately three years (about 60 Mm^3).

However, according to Lund and Seleenbinder Consulting Engineers (2014) the Current Storage Abstraction Potential of the Windhoek Aquifer is estimated at 41 Mm^3 while the present abstraction capacity is projected to likely reach only 9 Mm^3/a by the end of 2016. The Best Estimate of the Future Storage Abstraction Potential of the Windhoek Aquifer is 89 Mm^3 while the Maximum Storage Abstraction Potential of the Windhoek Aquifer is estimated 112 Mm^3. Besides effort to increase the abstraction capacity from the aquifer, there are also concerted efforts to protect the Windhoek aquifer (Mapani 2005; Ministry of Agriculture, Water and Forestry [MAWF], 2015).

2.3.6 Water Demand Management

Biggs and Williams (2001) indicate that further supply augmentation for Windhoek is becoming increasingly expensive, depending on how far the water suppliers have to look further afield for water. The prevailing estimated unit cost of the various water sources suppling Windhoek are indicated in Table 3 (Desert Research Foundation of Namibia [DRFN], 2008). The cost of water transferred from the Okavango River and Tsumeb in 2008 for instance, are double the cost of the prevailing water sources supplying Windhoek, while the water transferred from Kunene would cost more than double. Water demand management (WDM), implemented to reduce demand rather than continue to augment supply, and non-conventional supply schemes have become important components in Namibia's integrated water resources management (IWRM) programme. At the beginning of the 1980s, average water consumption was 600-700 litres/person/day (l/p/d) in the affluent areas of Windhoek.

Table 3 Indicative and Comparative Cost of Prevailing and Potential Water Sources Supplying Windhoek in 2008 (DRFN, 2008)

Potential Water Supply Options for Windhoek	Potential Volume of Water assumed per Annum (million m^3)	Unit cost per m^3 at Windhoek
Existing supply (combined sources)	15	N$3.17
Okavango	17	N$6.25
Kunene (option 1)	30	N$7.85
Kunene(option 2)	190	N$10.85
Tsumeb Aquifers	21	N$6,40

IWRM was introduced in the early 1990s as a concerted effort to both reduce the level of consumption and increase the safe yield of Windhoek's water resources to meet increased demand. Considerable progress was made with the average water consumption having reduced to 180 l/p/d, although this was still above the average of African cities (Biggs & Willems, 2001). However, there was an increase in average water consumption to 206 l/p/d based on 2011 Census figures (see Section 2.2.2).

Since 1994, Windhoek Municipality introduced an integrated water demand management programme that included policy directives, legislation, education, technical and financial measures which during severe droughts are rigorously enforced (van der Merwe, 1999; Lahnsteiner & Lempert, 2007). See Tables 4 for more details. On the issue of water demand management, the bills and tariffs are banded for Windhoek and Okahandja according to basic water needs and amount of domestic use. However, Karuaihe et al. (2012) indicate difficulties in calculating marginal and average water price in Windhoek given the information provided in users' utility bills appear cryptic and one may resort to hedonic regression tools.

Table 4 Regulatory Water Demand Measures by Windhoek Municipality (van der Merwe, 1999; Lahnsteiner and Lempert 2007, MAWF, 2015)

Regulation Requirement	**Method of Implementation**
Water Initiatives in 1996	
water consumption - private properties	Wastage of water on a private property can be addressed immediately by a water control officer.
Water efficient equipment	As of 16 December 1996, the following are compulsory in new developments in the city: Metering taps must be used in hostels; Taps outside non-residential buildings must be self-closing or lockable. Only low flow showers are allowed. Toilet cisterns must be 6/3 litres dual flush units. Automatic flushing devices without activation by user are prohibited. Retrofitting of existing inefficient water devices is compulsory within 3 years
Groundwater	Groundwater abstraction from private boreholes and groundwater levels is controlled
Gardens	Gardens may not be watered during high evaporation times, i.e. between the hours of 10:00 and 16:00
Swimming Pools	Swimming pools must be covered when not in use
Water Pollution	Regular testing of groundwater fuel tanks is mandatory. All tanks were registered
Water Initiatives in 2015	
Draft Memorandum on Water Intensive Industries	A moratorium be placed on the establishment of water intensive industries (with a water consumption greater than 100 m^3 per day) in the CAN until the selected long-term water supply alternative has been established and supply has stabilised. Furthermore, that any such potential developments be encouraged to establish in other areas of the country where water resources are more plentiful.
Proposed Scarcity Levy	A "Scarcity Levy" on the use of water be approved for water application received during times of critical shortages in supply. Such a levy shall be subject to approval with the standard endorsement and announcement of annual tariffs in the applicable Local Authority or NamWater jurisdiction. The funds collected under this levy should be put aside and only used to fund investigations into and the design of measures to alleviate shortfalls in supply.
Draft Memorandum on Water Control Areas	The Water Control Area (in terms of the Water Act of 1956 and the Water Resources Management Act, Act No. 11 of 2013) to protect the Windhoek Aquifer be extended to cover the entire Windhoek Aquifer be promulgated by the Ministry of Agriculture, Water and Forestry in concurrence with the Windhoek Municipality. Ban installation of fuel tanks in the aquifer areas.

As highlighted in Table 4, the Windhoek Municipality is making efforts and initiatives to keep new big wet industries from being established in and around Windhoek given the limited water resources available and the aim to protect the Windhoek's aquifer (MAWF, 2015). Due to prevailing drought (2013 to 2016), the Windhoek Municipality is instituting and drafting various water demand measures that were not published at time of compilation of this study.

2.3.7 Water Security for Windhoek and Okahandja as Major Drinking Water Demand Centres

In 2014, it was stated that: "Windhoek faces escalating freshwater problems and will experience prolonged water deficits within the next 3 to 7 years if current patterns of water use continue unchanged" (Lund & Seleenbinder Consulting Engineers, 2014). The level of conventional and non-conventional water resources utilization in Windhoek is very high and new sources are necessary to stretch the limited water supplies available to meet projected demands for water. Feasibility studies are therefore required to investigate other options. Economic and technical analysis used in similar studies (Ghaffour et al., 2013a & b) could be carried out on the Windhoek aquifer storage and recovery (ASR) as an option to store the surplus treated water which could be used when water demand is high. In addition, increased reuse of treated wastewater could augment the existing developed sources.

2.4 Water Resources Modeling Concepts and Tools

2.4.1 Rainfall Forecasting Models

Times series analysis plays a significant role in modelling meteorological data such as humidity, temperature, rainfall and other environmental variables (Collischonn et al., 2005; Hung et al., 2009; Htike & Khalifa, 2010; Kanna et al., 2010; Mahsin et al., 2012; Ansari, 2013 Meher & Jha, 2013). Rainfall forecasting is crucial for making important decisions and performing strategic planning of water resources. The ability to predict and forecast rainfall quantitatively guides the management of water related problems such as extreme rainfall conditions like floods and droughts among other issues (Htike & Khalifa, 2010; Kanna et al., 2010; Ansari, 2013; Meher & Jha, 2013).

Therefore, predicting hydrological variables like rainfall, floodstream and run-off flow as probabilistic events is a key subject in water resources planning. These hydrological variables are usually measured longitudinally across time. This makes times series analysis of their occurrences in discrete time appropriate for monitoring and simulating their hydrological behaviours (Ansari, 2013). Rainfall is among the sophisticated and challenging components of the hydrological cycle to model and forecast because of various dynamic and environmental factors and random variations both spatially and temporally (Htike & Khalifa, 2010).

2.4.1.1 Time Series Analysis

A time series analysis often exhibits four main components such as trends, seasonality, cycles and irregular fluctuations. Trends are the long term underlying movements representing growth or decline in a time series over an extended period of time due to natural, human, economic and other processes. They are usually described by a smooth, continuous curve or a straight line. Trends can be captured using times series regression, double exponential smoothing and moving average methods. Seasonal variations are fluctuations in a time series that are repeated at regular short intervals usually within a year (e.g. daily, weekly, monthly, and quarterly). These variations are usually due to recurring environmental influences such as climatic conditions (seasons and climate change, Wegner, 2010). Seasonal patterns are usually measured using index numbers, which can be very useful in the estimation of short term forecasts. Cyclical variations are wavelike fluctuations around a trend which can vary substantially in duration and amplitude, suggesting possible existence of periodicity with longer intervals. To a limited extent, index numbers can also be used to measure cyclical fluctuations in terms of the phase of the cycle through which a particular time series is moving and this can be used to adjust forecasts and to account for the likely influence of cyclical forces. Irregular fluctuations are the residuals after other components of the time series have been removed. Causes of irregular components are generally unpredictable once-off events such as natural disasters (floods, droughts, fires) or man-made disasters (strikes, boycotts, accidents, and acts of violence, Wegner, 2010).

Time series decomposition facilitates the separation of the components either additively or multiplicatively. Additive time series decomposition is according to the model given in Equation 1, while multiplicative decomposition is according to the model given in Equation 2

$$\boldsymbol{Y_t = T_t + S_t + C_t + I_t} \qquad \textbf{Equation 1}$$

$$\boldsymbol{Y_t = T_t . S_t . C_t . I_t} \qquad \textbf{Equation 2}$$

where Y_t is the observed time series, T_t is the trend component, S_t is the seasonal component, C_t is the cyclical component, and I_t is the irregular component.

Popular statistical techniques used for rainfall forecasting are the Box-Jenkins Auto-regressive Moving Average (ARIMA) models and Artificial Neural Networks (ANN). ARIMA models possess many desirable features. They allow the analyst who has observations only on past years (e.g. historical data on rainfall) to forecast future events without having to search for other related time series data (e.g. temperature). ARIMA models have been widely applied in a variety of water and environmental management applications (Otok & Suhartono, 2009; Rabenja et al., 2009; Mauludiyanto et al., 2010; Abudu et al., 2010; Turalam & Ilahee, 2010; Chattopadhyay & Chattopadyay, 2010; Shamsnia et al., 2011; Babu et al., 2011; Mahsin et al., 2012).

2.4.1.2 Artificial Neural Networks (ANN) modelling

With advancements in Information and Communications Technology (ICT), ANN have also become popular and they are the most widely used forecasting models for forecasting purposes in many engineering and computer science domains. This is because ANN are data driven methods which have the ability to model both linear and non-linear systems without needing to make apriori assumptions which are implicit in most classical statistical approaches such as ARIMA models. Other models assume that the time series under consideration are generated from a linear process, which is usually not the case with real life scenarios. ANN are capable of generalizations since after learning the data that have been given to them during training, they can often correctly estimate the unseen part of a population which is not part of the training data. ANN has also proven to be universal functional approximators and can approximate any continuous function to any desired accuracy (Htike & Khalifa, 2010; Hung et al., 2009). However, ANN are criticised for their "black box" nature, computational burden, proneness to overfitting and their empirical nature of model development (Tu, 1996). The theoretical advantages of ANN come at the cost of reduced interpretability of the model output (Sargent, 2001).

2.4.1.3 *Autoregressive Integrated Moving Average Models*

If historical data on the dependent variable (e.g. water demand) is available, ARIMA models can be employed for analysis and forecasting as they account for autocorrelation in the water demand time series and use the previous period's value (day, week, month or year) as an independent variable.

An autoregressive model of order *p* is conventionally classified as AR (p) and a moving average model with *q* terms is known as an MA (q). A combined model that contains *p* autoregressive terms and *q* moving average terms is called ARMA (p,q). If the object series is differenced d times to achieve stationarity, the model is classified as ARIMA (p,d,q) where the letter "I" stands for "Integrated". This means that an ARIMA model is a combination of an autoregressive (AR) process and a moving average (MA) process applied to a non-stationary data series (Mahsin et al., 2012; Jakasa et al., 2011; Meher & Jha, 2013). Thus the general non-seasonal ARIMA (p,d,q) model as given in Equation 3 is composed of :

AR: *p*=order of the autoregressive part,

I: *d*=degree of differencing involved and,

MA: *q*=order of the moving average part.

$$\boldsymbol{Y_t = c + \emptyset_1 Y_{t-1} + \emptyset_2 Y_{t-2} + \cdots + \emptyset_p Y_{t-p} + e_t - \vartheta_1 e_{t-1} - \vartheta_2 e_{t-2} - \cdots - \vartheta_q e_{t-q}}$$

Equation 3

The same equation can also be presented using the backshift notation as given in Equation 4:

$$\boldsymbol{\left(1 - \emptyset_1 B - \emptyset_2 B^2 - \cdots - \emptyset_p B^p\right) Y_t = c + \left(1 - \vartheta_1 B - \vartheta_2 B^2 - \cdots - \vartheta_q B^q\right)}$$

Equation 4

Where for both equations, c= constant term, $\emptyset_i$ =i^{th} autoregressive parameter, ϑ_j =j^{th} moving average parameter, e_t is the error term at time *t*, and B^k is the k^{th} order backward shift operator.

Further to the non-seasonal ARIMA (p,d,q), one can identify Seasonal ARIMA(P,D,Q) parameters for the time series data known as SARIMA. These parameters are seasonal autoregressive (P), seasonal differencing (D) and seasonal moving average (Q). The general form of the SARIMA (p,d,q)(P,D,Q)$_s$ model using the backshift notation is given by equation 5.

$$\boldsymbol{\emptyset_{AR}(B_{sAR})(B^s)(1-B)^d(1-B^s)^D Y_t = \vartheta_{MA}(B)\vartheta_{sMA}(B^s)e_t} \qquad \textbf{Equation 5}$$

where s = number of periods per season;

$\emptyset_{AR}$ = non-seasonal autoregressive parameter

ϑ_{MA} = non-seasonal moving average parameter

ϑ_{sMA} = seasonal moving average parameter

The Box-Jenkins methodology applies ARMA, ARIMA or SARIMA to establish the best fit of a time series historical values to make forecasts. The methodology consists of four stages namely model identification, estimation of model parameters, diagnostic checking for the identified model appropriateness for modelling, and application of the model (i.e. forecasting). Model identification involves testing whether the time series is stationary and if there is significant seasonality to be modelled. The data can be examined to check for the most appropriate class of ARIMA processes by selecting the order of the successive seasonal differencing required to make the series stationary as well as the specification of the order or regular and Seasonal Autoregressive Integrated Moving Average (SARIMA) polynomial required to sufficiently represent the time series model. The autocorrelation function (ACF) and the partial autocorrelation function (PACF) are the most important tools for time series analysis and forecasting. The ACF quantifies the extent of linear dependence between time series observations separated by lag k. The PACF plot is used to determine how many auto regressive terms are necessary to reveal one or more of the following characteristics: time lags where high correlations appear; seasonality of the series; and the trends either in the means or variances of the series. Stationarity of data can be assessed by the Ljung-Box test with test statistic as given by Equation 6.

$$\boldsymbol{Q = n(n+2)\sum_{k=1}^{n} \frac{r_k^2}{n-k}} \quad \sim \quad \chi^2_{h-m} \qquad \textbf{Equation 6}$$

where

r_k is the autocorrelation at lag k
h is the maximum lag being considered
n is the sample size
m is the number of parameters in the model which has been fitted to the data.

The Akaike Information Criterion (AIC) is mostly used to choose the best model from among competing models and is given by Equation 7.

$$\boldsymbol{AIC = -2\log(L) + 2(p + q + P + Q + k)} \qquad \textbf{Equation 7}$$

The model which has the minimum AIC is considered the best model (Mahsin et al., 2012). When the most appropriate model has been chosen, the model parameters can be estimated using the least squares method. The values of the parameters can be chosen such that they minimize the Sum of Squared Residuals (SSR) between the actual data and the estimated values. Alternatively, non-linear estimation can be used to estimate the identified parameters using the generally preferred maximum likelihood estimation techniques. The next stage of the process is the diagnostic checking where the residuals from the fitted model are examined, usually by correlation analysis with the aid of ACF plots. If the residuals are correlated, the model will need to be revisited. Otherwise the correlations are Gaussian white noise (i.e. normal with zero mean and constant variance) and the model is adequate to represent the time series.

It is important to evaluate and understand the adequacy and the availability of water in the USB using time series forecasting models for Windhoek rainfall, water demand for Windhoek City and Okahandja Town and to assess adequacy of water in the USB to have an integrated decision support system for holistic water governance.

2.4.2 Water Demand Forecasting and Modelling

The most significant determinants for increases in water demand are population growth, climate change (including droughts sensitiveness), and the type of urban development that occurs (House-Peters et al., 2010). Fontdecaba et al. (2012) referred to econometric studies showing that residential water demand in cities is correlated with:

a) income (Renzetti, 2002; Arbues et al., 2003; Arbues & Villanua, 2006);
b) population density (Lavière & Lafrance, 1999);
c) age distribution of people in the household (Murdock et al., 1991);
d) religious and cultural characteristics (Smith & Ali, 2006);
e) the number of people living in a household (Nauges & Thomas, 2003; Zhang & Brown, 2005);

f) the optimized systems under water supply–demand imbalances caused by climatic changes (Liu et al., 2003; Hasse & Nuiss, 2007; Hellegers et al., 2010);
g) temperature and rainfall (Griffin & Chang, 1991); and
h) The presence of water-saving technology in the form of efficient appliances (United States Environmental Protection Agency [USEPA], 2005).

Depending on the availability of data, the water demand can be predicted and matched with supply into the foreseeable future.

Several methodologies for forecasting future water demand are summarized broadly by Bougadis et al. (2005) as follows: 1) short term forecasts used for operation and management; and 2) long term forecasts required for planning and infrastructure design. Predicting and managing urban water demands is complicated by the closely coupled relationship that exists between human and natural systems in urban areas. The general practice in long term forecasting is to assume stationarity of long term climate (Milly et al., 2007). However, Gober (2010) and House-Peters and Chang (2011) argue that climate change introduces uncertainties that may limit the accuracy of this approach that assumes that historical trends are reliable for predicting future climate-sensitive water demands. Based on coupled human and natural systems theoretical framework, methodologies have been developed to model complex urban water demand. Human and natural system dynamics in urban environment are coupled with human behaviours and resources that act as both drivers and constraints of natural ecosystem functions (Martin et al., 2004; Pickett et al., 2008). These systems are characterized by complex interactions between human and natural system variables at multiple spatial and temporal scales. The framework of coupled human and natural systems which can also be referred to as social-ecological systems has four themes as follows:

1. scale-influence of variables at multiple spatial resolutions (Anderies et al., 2006; Walker et al., 2006)
2. uncertainty; because measured water demand data exhibit random fluctuations based on variability across space and time
3. non-linearity; because water demand is sensitive to both human and natural stresses, and
4. dynamic processes (Walker et al., 2006; Pahl-Wostl, 2007).

House-Peters and Chang (2011) compared and assessed ten methods of urban water demand forecasting. The models employed various statistical tools namely:

a) Multiple regression (Wong et al., 2010);
b) Piece-wise linear regression (Chang et al., 2010);
c) Spatially explicit ordinary least squares (OLS) regression (Balling et al., 2008; Lee et al., 2010);
d) Geographically weighted regression (GWR) (Wentz & Gober, 2007);
e) Simultaneous equation demand model (Torregrosa et al., 2010);
f) Auto-Regressive Integrated Moving Average (ARIMA) (Bougadis et al., 2005)
g) State-space forecasting model (Billings & Agthe, 1998; Billings & Jones, 2008);
h) Bayesian Maximum Entropy (BME) (Lee & Wentz, 2008; Lee et al., 2010);
i) Artificial Neural Networks (ANN) (Bougadis et al., 2005; Adamowski & Karapataki, 2010; Herrera et al., 2010) and

j) System Dynamics Models (SDMs) and municipal water conservation policies (Rosenberg et al., 2007; Ahmad & Presha, 2010).

The assessment indicated that increased data richness, technological advances in spatial science and innovations in statistical methods has led to progress in identifying and quantifying relationships among numerous social, climate, and water consumption variables. House-Peters and Chang (2011) concluded that as a trade-off between the parsimony of traditional methodologies and the data-hungry, computationally intensive models currently being developed, there is need to settle for some middle ground forecasting methods that are not complicated but still are able to incorporate the now available spatially explicit land information into water demand modelling so that water planners can use these methods easily. Therefore, suitable methodologies still need to be developed that will have the ability to incorporate these numerous types of data.

According to Qi and Chang (2011), recently developed dynamic models are computationally intensive while multiple regression models may lack the highly aggregated temporal and spatial data. The ARIMA based models may demand household, community and spatial predictors for detailed analysis. The traditional forecasting models such as multivariate regression and time series analysis as well as advanced modelling techniques (ANNs) inadequately manage the dynamics of the water supply system. Lack of long and continuous historical records of water demand and the independent variables are still a challenge to water demand forecasting.

In Namibia, like in most developing countries, data on predictors of water demand are lacking or sporadically available. However, with the availability of historical data on the dependent variable (water demand), ARIMA models can be employed for analysis and forecasting as they account for autocorrelation in the water demand time series. These models make use of the previous period's value (day, week, month or year) as an independent variable. Therefore, the ARIMA models will be used to forecast water demand in the USB.

2.4.3 Water Evaluation and Planning (WEAP) Model (SEI, 2014)

The WEAP model was developed by the Stockholm Environment Institute [SEI] (2014) and various collaborators. WEAP, as a computer-based decision support system (DSS), allows the user to forecast and evaluate the impacts of different possible future trends and management strategies including the impact of various proposed water infrastructural developments, policy and regulation under various scenarios before implementing them. WEAP is a tool for integrating water resources management. It is capable of evaluating the water sources, infrastructure, water demands and assists skilled water resources planners, managers and brings awareness of water inadequacies and in-stream pollution challenges to stakeholders. It is capable of simulating both natural (for example evaporation, evapotranspiration, in-stream flow, runoff, base flow) and man-made components (for example in-stream water quality, reservoirs drawdowns, groundwater abstraction and artificial recharge) and other programmable factors of influence to the water resources. When applied, WEAP can be used to assist in the decision making by predicting future changes on the system and by comparing impacts of different management approaches such as tracking pollution and water quality levels and vulnerability and maintaining ecosystem sustainable balance.

2.4.3.1 Worldwide Usage of the WEAP Model

WEAP has been applied in water assessments in 170 countries of the world (SEI, 2014), including the United States, Mexico, Brazil, Germany, Ghana, Burkina Faso, Kenya, South Africa, Mozambique, Egypt, Israel, Oman, Central Asia, India, Sri Lanka, Nepal, China, South Korea, and Thailand. Mugatsia (2010) developed a WEAP model Decision Support System (DSS) that evaluated the current water management scenario and the effect of proposed water development projects in Perkerra catchment in Kenya. Jenkins et al. (2005) used WEAP as a participatory tool to comprehensively quantify the water supply and demand and allocate water among competing stakeholders on the stressed Njoro river basin in Kenya. WEAP was also applied to the almost fully allocated Olifants River basin in South Africa. In this case, WEAP was used to make stakeholders aware of the water inadequacies by analysing various water demand scenarios during drought periods while making sure that adequate allocation was made including the ecological reserves within the basin (Levite et al., 2003). Yates et al. (2009) used WEAP to assess the effects of climate change on water resources and hydropower generation on the Sacramento Basin, California, United States. Hellegers et al. (2013) used WEAP to assess the economic implications of water supply-demand imbalances in Iran, Morocco and Saudi Arabia. Thompson et al. (2011) used WEAP to draw up a management adaptive tool to prevent climatic-change induced loss of Spring-Run Chinook Salmon in California. Loukas et al. (2007) assessed the sustainability of water resources in the agricultural intensive Pinios River and the lake Karla basin in the Thessaly Region in Greece. Despite these examples of WEAP's use to model water, no literature could be found on its use in Namibia.

2.4.3.2 Why Use WEAP in the Upper Swakop Basin

Previously, a localised conventional supply-oriented simulation model, the Central Area of Namibia [*CAN] model* has been used by NamWater since 1995 to plan and evaluate scenarios especially on short term scenarios. However, the *CAN model*, written in the almost obsolete Visual Basic 6 language is not supported in the Microsoft Windows environment. MAWF (2012) indicated that the *CAN model* is neither user friendly or flexible to changing scenarios and of late has not always provided adequate planning and management options to implement sustainable water use strategy. Considering the antecedent of the WEAP model and its various usages by many researchers in many countries, it is hoped that the model can be used to achieve an overall integrated management plan for the USB. This will make information easily available for discussion and decision making on water resources use and sustainable development of the USB.

2.4.4 Basic Water Balance and Water Quantity Optimization

While considerable attention has been devoted to the optimization of the quantity of water from sources in the USB (Van Rensburg, 2006; Jac/van der Gun, 2012), little has been done with respect to the protection of the quality of the water sources in the basin. Regarding water quantity, the basic water balance for a given time interval can be expressed as the changing storage, equalling the sum of inputs minus the sum of outputs (Mitchell et al., 2003). Hydrologically, a water balance equation can be used to describe the flow of water in and out of a system. Simple water balance equation/s approaches can be used to solve the various possible multi-objective optimization problems of the yearly sources, demands and storages. This is done by conceptually analysing water supply systems and computing the balances (Lee &

Chang, 2005; Rothman & Mays, 2013; Nazari et al., 2014). Units need to be consistent for all terms in the equation and can be either volume based, such as Mm^3, or based on an areal depth, such as mm. On the water balance of water supplied from the reservoirs in the USB, the 95% yield of the reservoirs was used. The 95% yield is the estimated assured usable volume with a probability of 0.95 i.e. 95 years out of 100 years, the estimated volumetric yield will be assured and 5 years will be failure.

2.5 Institutions Responsible for Management and Governance of Water Resources in Namibia (USB)

Like many countries, Namibia's water provision and governance of water systems are of a complex nature, involving many different stakeholders and players at different levels and shaped by the political and institutional context of the country's policies, laws, adapted principles of IWRM as well as multilevel water governance and international best practices. The institutions responsible for water resources are divided into the several categories for ensuring efficient and effective management water resources in Namibia.

The overall water resource policy, inventory, monitoring, control, regulation and management fall under the Directorate of Resources Management within the Ministry of Agriculture, Water and Forestry (MAWF). The bulk water supply of both raw water and treated water is the responsibility of the NamWater that abstracts water from primary sources (e.g. rivers, aquifers or dams), treats and supplies to the bulk users and at times to end-users directly on a cost recovery basis. There are also self-providers that include commercial farmers, tour operators, mines and nature conservation parks, who supply their own water subject to appropriate agreements and licences. The rural areas are supplied water through the Directorate of Water Supply and Sanitation Coordination in the MAWF, while, in urban areas, the Local Authorities and Regional Councils buy bulk water from NamWater or supply water from their own boreholes or other sources for delivery to end users.

2.6 General Nature of River Basins and the Basin Experiences in Namibia

According to Hooper (2005), river basin organizations can take the form of an (1) advisory committee, (2) council or (3) commission. For example, River Catchment Councils exist in Sweden since 1950 (Gooch & Baggett, 2013) and in Zimbabwe since the enactment of the Water Act (Government of Zimbabwe (1998). These river basin councils provide platforms for the involvement of stakeholders in decision making. In Europe these river basins can vary in form and structures but all are based on IWRM. The EU WFD (Carter & Howe, 2006; Blomqvist, 2004; De Stefano, 2010) stated that the total involvement and participation of key stakeholders in decision making processes is key to good water governance. The river basins in Europe have processes with increasing intensity of participation which include informative, consultative and shared decision (Bressers & Kuks, 2004; Antunes et al., 2009; Gooch & Baggett, 2013; Mitchell, 2015). Antunes et al. (2009) evaluated the issue of participation for sustainable river basin governance in five water related projects in different European countries. The study concluded that, in most situations, the decision-making processes fell short of including the interests, perceptions and values of affected parties. Moss (2003), on a case study of the implementation of the EU Water Framework Directive in Germany, found interesting interactions of spatial landuse and water governance based on river basin management institutions. He used these relationships to predict the success of EU policy reform and the degree of fit with existing institutional structures and practices. The findings recognized that although there is a relative agreement regarding the need to develop new multi-dimensional, inclusive and plural approaches to water resource management, there is still a deficiency of related methodologies and tools among these river basin organisations. Similar studies in countries such as Australia (McKay, 2005); Brazil (Tortjada, 2006); New Zealand (Lennox et al., 2011); South Africa (Colvin et al., 2008; Herrfahrdt-Pähle, 2010a & b; Matiwane, 2012) and Zambia (Uhlendahla, 2011) further emphasised on the deficiency methodologies and tools for proper water resources management among these river basin organisations.

In Namibia, the concept of basin management was introduced to stakeholders during the water sector review process in the late 1990s (MAWF, 2005; MAWF, 2013) though the old Water Act (1956) made some provision for the establishment of groundwater control bodies. The concept was later incorporated into the Water Resources Management Act (2004) of the Republic of Namibia as a tool for implementing integrated water and land management at basin level. Although this Act was not operationalized, it appears the section on basin management was tested in a variety of river basins with differing approaches and outcomes (Amakali & Shixwameni, 2003). In 2004, the Ministry of Agriculture Water and Forestry (MAWF) resolved that the water resources of Namibia will be managed within 11 water basin management areas comprising of 4 perennial trans-boundary rivers and about 25 internal ephemeral rivers as shown in Figure 2.3 (Namibia, I. P. J. V., 2010). The following discussions will be limited to the internal river basins in Namibia and will not discuss further the transboundary river basins even though some of the internal rivers are both.

Namibia consists of 14 administrative regions and can also be divided into four geographic regions: the Namib Desert, the Namib escarpment, the Central Plateau and the Kalahari sandveld (Goudie & Viles 2015). The 14 administrative and 11 Hydrological Regions in Namibia differ and are unique as shown on Figure 2.3. The criteria for demarcating the water management basins at national level were mainly based on the surface and groundwater catchments of the larger river systems. In most cases (except the Kuiseb Basin), two or more rivers and their minor tributaries were combined into one larger management basin. Other criteria such as water supply, administrative regions, infrastructure or cultural and environmental units were also considered.

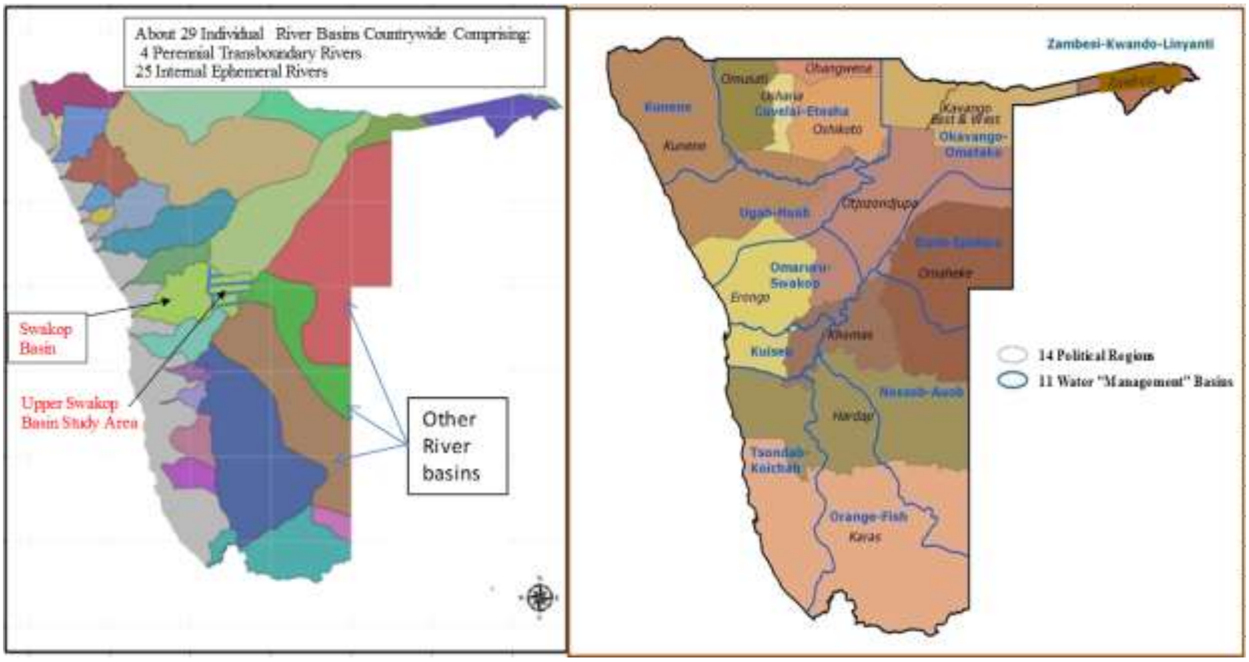

Figure 2.3 Eleven 'Management" River Basins of Namibia and Fourteen Political Regions (Namibia, I. P. J. V. 2010).

It can be assumed that this combination was to conveniently manage these ephemeral rivers and sparsely populated basins. The main objective was to establish equally sized basins throughout the country where relevant water matters of national and regional importance can be adequately addressed. However, it is stated in the Integrated Water Resources Plan for Namibia (Namibia, I. P. J. V., 2010) that these basins do not correspond with the current fourteen political regions and as such this may pose a major challenge in managing the water resources. Heyns (2005) postulated that these basins are formed on the basis of convenient water management areas or integrated water basins based on common water supply schemes, canals and pipelines.

The key purpose of basin management was to decentralise decision-making and the management of water resources in Namibia using the river basin as the unit of management. Basin management based on integrated water resources management principles brings stakeholders within a shared drainage area together, and creates a platform for information sharing on water resources issues such as water scarcity, floods, deteriorating water quality, competition for water and other water related challenges, joint planning and management of the basin's resources. The Water Resources Management Act (2013) provides for the establishment of advisory river basin committees and river basin commissions on trans-boundary rivers. The expected functions of the basin management committees include co-managing the basins with government by developing water strategic plans and research agenda; monitoring river basin's health; resolving conflicts and educating water users.

In the river basins where basin management is being applied in Namibia, membership at basin management committees was initially open to all interested basin stakeholders (Figure 2.4). From this forum, a basin management committee comprising of selected sector representatives of the basin stakeholders was recommended to be established. The responsibility of the basin management committee is to facilitate the functions and operations of the basin while the forum is a broad interactive, open and transparent structure that supports the basin management committee (Ministry of Agriculture, Water and Forestry [MAWF], 2005; Ministry of Agriculture, Water and Forestry [MAWF], 2013). So far, the existing river basin committees in Namibia have been initiated by basin residents and water users or the water authorities, donors and environmental non-governmental organisations like the Desert Research Foundation of Namibia that became the champion facilitator during the formation of these river basins. The basin committees were established for sharing knowledge and experience.

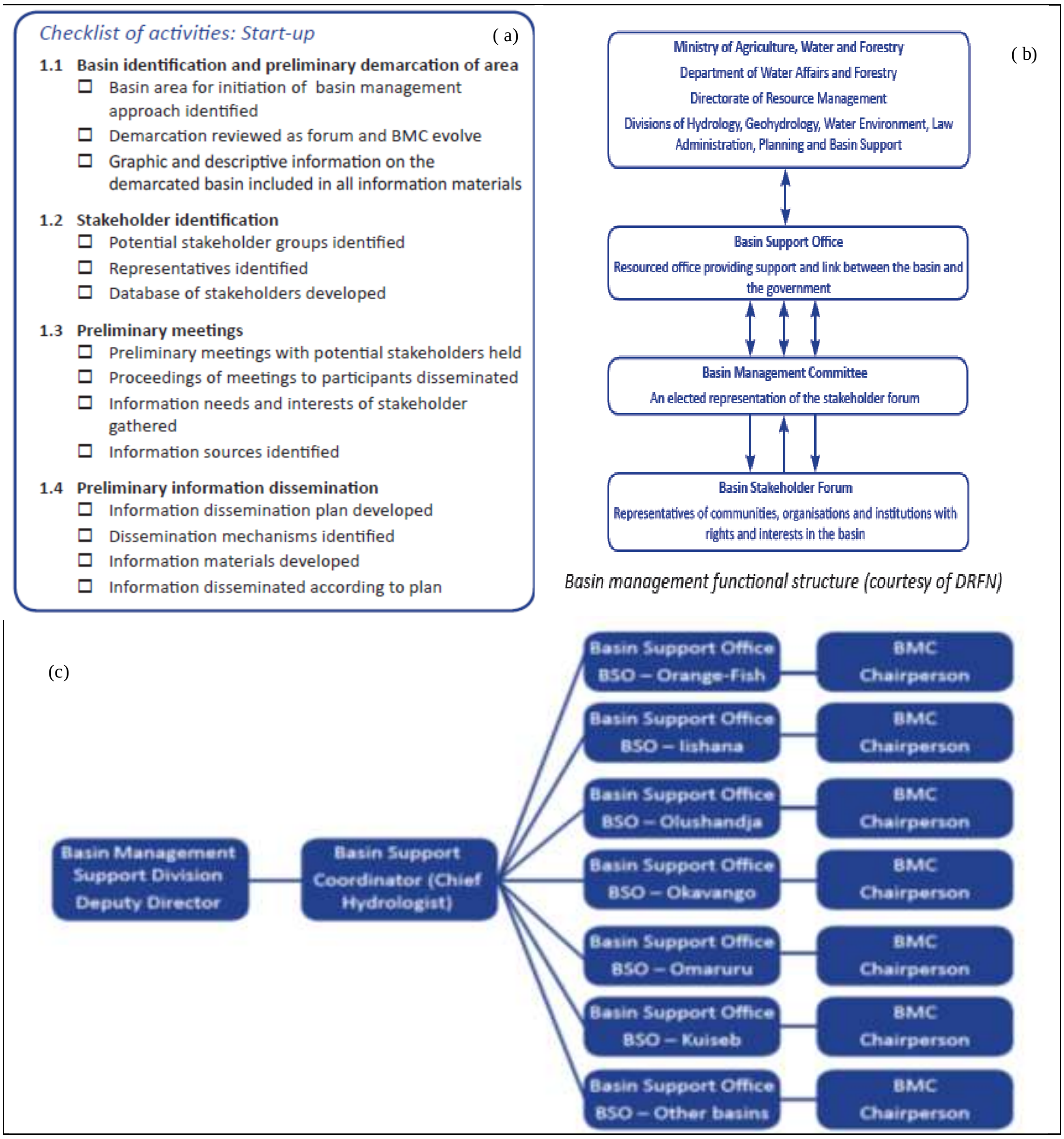

Figure 2.4 Basin Formation Steps and Proposed Basin Management Institutions in Namibia (MAWF, 2013)

Table 5 Drivers of, and challenges to, the Formation of the Basin Management Committees in Some Basins in Namibia (Namibia I.P.J.V., 2010)

Driven By	Some Key Reasons for Establishing	Challenges
Cuvelai-Etosha Basin (has 4 sub-basins formed at various times and reasons)		
a) Iishana Sub - Basin (formed in 2005)		
Government with the support of GIZ as the donor	Objectives include water management (institutional arrangements) and health (water quality and ground water monitoring aspects)	Security of water supply and brackish ground water
b) Niipele Sub -Basin (formed in 2010)		
	To conform to IWRM principles	Poor attendance of BMC meetings
c) Olushandja Sub - Basin (formed in 2010)		
	To conform to IWRM principles	
d) Tsumeb Sub -Basin as represented by Karst Water Management Board (KWMB) was formed in 2003		
A farmers' stakeholder group called Karst Water Management Body (KWMB)	Protection of groundwater sources in the Karst aquifers.	Bush encroachment; groundwater management and monitoring
Okavango - Omatako Basin		
Joint commisssion for the three riparian countries to the Okavango River Basin	Tourism and wildlife conservation: The Mangetti, Mahango, Khaudum, Popa and Caprivi Game parks are in the basin; the Karstveld area is the main maize-growing area in commercial irrigation projects (including the Green Scheme along the Okavango river) are the biggest waterNamibia and hence large-scale users in the basin. The major crops grown are mahangu, maize, cotton and wheat	Irrigation: establishing green schemes along the Okavango River
Omaruru - Swakop Basin (formed in 2003)		
Farmers and lodges owners' interest on the limited Omaruru aluvial aquifer	To conform to IWRM principles	The planned Windhoek aquifer development upgrading of the Von Bach system was behind schedule and security of supply was a major concern with the increased water demand
Kuiseb Basin (formed in 2003)		
Varied interest from commercial farmers, Walvis Bay Municipality; Khomas & Erongo Regional Councils; Gobabeb Training and Research; Government Departments and Environmental organisations	Focused was on water management and groundwater monitoring) aspects; environmental issues of the desert riverine; water planning and utilisation; geohydrology; socio-economic assessments; institutional capacity building and water education	Pollution concerns included seepage from tailing dams of an increased number of uranium mines; nitrate contamination from cattle feedlots; wastewater and effluent disposal of tourism operations; possible seawater intrution into the production area of the Lower Kuiseb Aquifer
Ugab Basin (there were efforts to establish this basin but not able)		
Not established due to starting problems	not applicable	not applicable
Orange -Fish Basin (formed in 2008/9)		
Desert Research Foundation of Namibia (DRFN) under the Ephemeral River Basins Project (2005 to 2010)	Focus on water management (institutional arrangements) and looking at the Issues of the Mariental Town flooding ; Neckartal Dam implementation	Completion of Neckartal Dam irrigation; Control of flooding of Mariental Town; Limited sanitation services coverage and inadequate information-sharing basin-wide

Each basin was formed based on the key principles of IWRM such as stakeholder participation, transparency and information sharing, and these were the main objectives during the formative stages. To date, various basin management committees have been established and according to Amakali and Shixwameni (2003) and Botes, et al. (2003), the basin committees piloted were according to the willingness and interest of the stakeholders. The drivers and challenges of the formation of the basin management committees in Namibia are summarized in Table 5 (Namibia, I.P.J.V., 2010). Besides a brief introduction by Namibia I.P.J.V. (2010), there is no adequate literature (only anecdotal) on how functional the basins are. However, it can be concluded that the following internal basins are functional and established: Cuvelai and its sub-basins namely (Iishana, Niipele, Olushandja and Tsumeb); Okavango - Omatako; Orange - Fish; Omaruru; and Kuiseb. There were problems with setting up of the Ugab Management Basin Committee during the mobilization of stakeholders. In almost every basin, the management of the water resources is still centralized among government-agents, while the basin management committees are only advisory. A brief overview of the some internal basins and their management committees now follows.

2.6.1 Kuiseb Basin and Management Committee

The Kuiseb River does not reach the sea very often, and ends in the sandy riverbed of a large delta serving as an “oasis”. Groundwater from the sandy riverbed delta supplies the Walvis Bay Town and other coastal areas with potable and industrial water supplies. The interest to protect the delta area could have prompted Kuiseb Basin formation. However, there are about 300 small farm dams and one large dam on the upper reaches of the river. The Friedenau Dam upstream has a storage capacity of 6.7 Mm^3 and has the largest volume in the basin.

The European Commission funded the Interactive Environmental Learning and Action (ELAK) project, (implemented by the Desert Research Foundation of Namibia) which facilitated the formation process of the Kuiseb Basin Committee (Travel News Namibia, 2012, 3 July). The composition of the Kuiseb Basin Committee included (NamWater, Directorate of Directorate of Rural Water Supply, Municipality of Walvis Bay, Ministry of Fisheries and Marine Resources, Municipality of Walvis Bay, Gobabeb Training and Research Centre, Coastal Environmental Trust of Namibia, Commercial and Communal farmers, Erongo and Khomas Regional Councils. The Kuiseb Basin Committee had only three meetings held between its inception in 2003 and 2012 (Travel News Namibia, 2012, 3 July). Nothing significant about the basin could be found beyond 2012.

2.6.2 Omaruru -Swakop Basin and Management Committee

The Omaruru - Swakop Basin is the formal larger basin that contains the Upper Swakop Basin. The Omaruru and Swakop Rivers, the major rivers in the basin, are ephemeral. The Okondeka and Khan Rivers are, respectively, their main tributaries. Both rivers flow westward towards the Atlantic Ocean. The Omaruru River recharges several underground river channels (alluvial aquifers) that form the Omaruru Delta towards the river mouth. Water from the Swakop River is stored in two major dams, the Von Bach and Swakoppoort Dams from where it is pumped to various large centres such as Windhoek, Okahandja and Karibib Town, the Otjihase Mine and the Windhoek Airport. The Von Bach Dam, which is part of the Eastern National Water Carrier (ENWC) system, also receives transferred water from the Swakoppoort Dam, the

Omatako Dam and groundwater sources near Grootfontein in the north. The Omdel Dam built on the lower Omaruru River about 40 kilometres east of Henties Bay, is used artificially to recharge the groundwater sources in the Omaruru Delta.

Based on IWRM principles, the Omaruru-Swakop Basin Management Committee was established in 2003. The Committee focused on four aspects that are water management, institutional arrangements, water quality and groundwater monitoring. Typical basin operational issues presented by the basin committee indicated the need for MAWF to field adequate basin management officers (Haraseb & Müller, 2012). The issues highlighted ranged from the need to have a basin management plan, the absence and secondment of the basin management officer, who is key secretariat to the basin operations.

2.6.3 Orange Fish River and Basin Management Committee

The Orange Fish River Basin is the biggest basin south of Windhoek that drains into the trans-boundary Orange River. The DRFN, when carrying out some research in the basin in 2011, triggered the formation of the basin management committee. A major ongoing project, the Neckartal Dam Irrigation Scheme also aroused interest among stakeholders. The planned project envisages the irrigation of a total of 5,000 ha once completed. The overall basin management committee is in the formative stages with most activities handled by the Mariental Taskforce that is overseeing the challenge of flooding from the Hardap Dam on the Fish River. There are also new emerging issues (plans to build a transboundary dam across the Orange River) associated with the functions and formation of this basin committee on the transboundary Orange River.

2.6.4 Cuvelai -Etosha Basin Management Committee (BMC)

The Cuvelai -Etosha Basin in located on the central north of Namibia and consists of 4 sub- basins. DRFN (2011) reported that there was little participation or no interest in the affairs of the Cuvelai –Etosha among the sub-basin committees of the Cuvelai Basin. For example, in Niipele sub-basin only two internal stakeholder organizations attended all the five forum meetings; in the Olushandja sub-basin, none of the internal stakeholder organizations attended all the four forum meetings; and in the Tsumeb sub-basin only two internal stakeholder organizations attended all the six stakeholder forum meetings. However, the number of internal organizations represented at the various stakeholder forum meetings in all the three sub-basins is increasing over time, except that inconsistency in the individual representatives from some organizations is a concern (Namibia I.P.J.V., 2010; DRFN, 2011). Participation of external stakeholders in the Olushandja and Niipele sub-basins is low compared to the Tsumeb sub-basin. The IWRM Cuvelai Etosha Basin (IWRM-CEB) Project team attended all forum meetings as this could have been pushed by their facilitation role. The MAWF Division of Geohydrology in collaboration with Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), a donor agency, were the most supporting external stakeholders throughout the process, especially in the Olushandja and Tsumeb sub-basins.

However, there were remarkable positive information and knowledge sharing benefits by the Basin Management Committee (BMC), which helped dispel misconceptions about the smelter in Tsumeb that was suspected of polluting groundwater. In Olushandja sub-basin, the BMC discussions led to reduced water loss and lower energy bills in the Etunda irrigation scheme. The Niipele sub-basin committee influenced the improvement of the quality of water supplied from boreholes to communities after the basin committee initiated investigations into the source of the problem (MAWF, 2013).

2.6.5 The Upper Swakop Basin Committee Formation

It should be noted that the Upper Swakop Basin (USB) Committee, the focus of this case study, is unique and differs in its basin's nature (ephemeral and urbanised) and in the purpose of its formation (to abate water pollution challenges within the basin). The basin issues and management will be used to explore new methodologies and tools for its improved water governance.

2.7 Governance Theory, Themes and Issues

2.7.1 IWRM, Water Governance and Water Security

Water security, IWRM and water governance have been defined in Chapter 1, Sections 1.1 and 1.2. IWRM is one approach or concept being implemented worldwide to resolve the challenges arising from the silos that characterise water management structures, mechanisms and processes. However, Mitchell (2015) states that societies are vulnerable to water inadequacy due to their inability to deal with complex water risk and water governance issues. This is because individual water management organisations often emphasize "local" optimization rather than "system" optimization of the resources and demands leading to the growing concern of water security. Lankford et al. (2013) discussed many facets and definitions of water security. Water security goes beyond the realm of policy and good water governance to encompass the interconnectedness of climate variability; ecosystem and environmental security; pollution; water scarcity, variability and access; stakeholders and institutions. Since water security can only be contextually described, this study can be a lens through which the risks of a lack of water, poor water quality, salinization and drought mitigation in the USB can be understood (Galaz, 2007) by carrying out a holistic study considering many facets of water governance and security.

It also refers to actions that acknowledge that water insecurities exist and can be managed. Water security refers to more than the neutral term “IWRM” when practically managing water which in many cases is highly complex because of political, economic, environmental and social concerns involved in limited variable resource. However, Scott et al. (2013) were more specific in defining water security (as related to the arid Americas) as the sustainable availability of adequate quantities and qualities of water for resilient societies and ecosystems in the face of uncertain global change. They then related water security to adaptive water management to account for this uncertainty through flexible planning, knowledge sharing and enhanced capacity. In summary, water security simply entails adaptively ensuring water of suitable quality is available to meet water demands among all humans and their needs without any being vulnerable while seeking balance with the maintenance of sustainable ecosystems. Thus, water security in a basin can only be achieved through good water governance, which, may also be lacking in the basin. Serrano (2012) analysed the regional processes of water governance, IWRM and water security in the Americas. Three thematic issues emerged in Serrano’s study that ought to be strengthened: 1) decentralization, 2) coordination and 3) participation.

The three concepts of IWRM, water security and governance may be strongly interwoven as Biggs et al. (2013) indicated that the three pillars of water security as resource, *governance* and accessibility. Jiang (2009) noted that China’s water scarcity, especially in the northern part, is characterized by insufficient local resources as well as reduced water quality due to increasing pollution both of which results in negative impacts on the society and the environment. Three factors contribute to China's water insecurity: uneven distribution of water resources, rapid economic development and urbanization with a large and growing population, and poor water resource management. Jiang showed that improving water resources management represented a cost effective option that could alleviate China's vulnerability to water insecurity and that this could be achieved through capacity building and economic market incentives (Jiang, 2009).

As fresh waters become increasingly degraded and impacts of climate change begin to be felt on local hydrological systems, scholars and practitioners have increasingly recognised a *crisis of governance* as the major force behind this degradation. On a global scale, various conventions, protocols and rules are shaping water governance. The global UN Watercourses Convention Law of Non-navigational Uses of International Watercourses came into force in 2014 (McIntyre, 2015) which recognises the importance of water governance worldwide. This legal framework will not only assist countries resolve water related trans-boundary conflicts but it could also help every country prioritize the management of local water issues by utilizing, developing, managing and protecting freshwater resources and ecosystems sustainably through the entire river basin (*ibid*).

2.7.2 Stakeholder Participation in Water Governance

Tropp (2007) highlighted that formal and informal networks, partnerships and stakeholder participation are necessary to manage the complexity of water management. He also emphasised that water decision makers and managers are currently not prepared to fully realize the development potentials of new forms of governance, such as facilitating inclusive decision making processes and coordinated and negotiated outcomes. This exposes the need for what he termed additional *sociocratic* knowledge and capacity development that, for example, puts the emphasis on the management of people and processes, diversity of organization and knowledge sharing.

Pahl-Wostl et al. (2008a) observed that one of the challenges of pollution control in the past decades is the shift from technical end-of-pipe solutions that relied primarily on wastewater treatment without focusing on the source control. These technical approaches, in many places, resulted in the natural dynamics of the river environment being destroyed. Moreover the technical approaches cannot adequately deal with the growing uncertainties, increasing rates of change, different stakeholder perspectives, and growing inter-dependence that are characteristic of today's resource management issues (*ibid*). There is need for a new understanding of sustainable water resource management as societal search and learning process. Thus, participatory and adaptive approaches enrich water governance of river basins.

Lennox et al. (2011), using case studies of New Zealand's water resources, demonstrated the need for extensive, systematic, deliberative, participatory processes structured stakeholder engagement with clarity and transparency in modern water resource governance. They concluded that stakeholder participation with the use of evaluative criteria and weighting is beneficial and increasingly necessary to resolve the problems and tensions around water governance. In USA, Koontz and Johnson (2004) agreed with Lennox et al. (2011) that multiple stakeholder collaboration and involvement in water basin governance was necessary in that broad inclusion leads to better environmental solution while also establishing legitimacy, building social capital and overcoming conflicts. However, such broad inclusion may be costly in terms of time, energy, and resources and may not yield desired results. Koontz and Johnson (2004) concluded that: a) Groups with a narrow membership and groups primarily of non-governmental participants may focus on pressurizing government for policy change; b) relatively balanced mix of governmental and non-governmental participants prefer planning, research and group development and maintenance, and c) the groups with a broader array of participants tend to excel in the watershed plan creation, identifying/ prioritizing issues.

2.7.3 The Impact of Centralization and Decentralization on Stakeholder Participation in Water Governance

Although water governance is commonly believed to be complimentary to the widely accepted IWRM concept, IWRM has been criticised for not being adequately defined and for unrealistically assuming equitably distributed power among stakeholders and that the definition formulated by the Global Water Partnership is "unusable, or ineffective or un-implementable, in operational terms" (Biswas, 2008). While IWRM is not synonymous with good water governance, IWRM has gained increased acceptance among water policy makers and researchers as a way to create more effective institutions and better integrated water development solutions (Galaz, 2007).

Both water governance and IWRM are multi-disciplinary concepts, where there are external and internal relationships and interdependency among various components of a river basin system. Notwithstanding arguments put forth by Goldin (2010) that IWRM participatory approaches reach out to the needs and interest of the affected poor stakeholders who then are co-opted into decision making processes, the participation of the marginalized poor in these processes requires adequate financial and human capacitation which are often lacking. There are pros and cons in the decentralization and centralization of IWRM structures of governance. Review of IWRM implementation in Spain exposed problems that include the lack of institutional coordination, blind spots in technical information and path dependences (Bielsa & Cazcarro, 2014). Similarly, Demetropoulou et al. (2010) reported that the centralized structure of the Greek state has been an impediment to the implementation of IWRM in Greece especially the introduction of public participation in water governance. Tortajada (2006) reported on the water sectors decentralisation and inter-comparison of the practices in Mexico, Turkey and Brazil.

It has been suggested that Integrated River Basin Governance (IRBG) should be formulated to embrace equity, ethics, communicativeness, inclusiveness, decentralization, integration, coherence, transparency, sustainability, responsiveness and accountability (Rogers & Hall, 2003). However, decentralization and localization of power and authority in water governance seem to remain unaddressed and unelaborated (Uhlendahl et al., 2011; Gupta et al., 2013). Hill (2013) discussed the shift from state-centric notion of governance, where a contextualized shift from a communal and centred paradigm in water governance to a more decentralized integrated and flexible approach is proposed. In essence, this may allude to embracing the *adaptive water governance concepts.* From a definitional perspective, institutions and governance are interlinked and inseparable (Ostrom, 2015; Herrfahrdt-Pahle, 2010a & b). They further argued that centralization of power is required in water governance as it should be controlled by the state to ensure equity. However, this is at the expense of stakeholders' knowledge, interest, local needs and concerns that are usually not considered in centralized governance. A centralized governance regime usually result in the imposition of a top-down hierarchy which is technocratically instituted. Gupta et al. (2013) elaborated that decentralized mechanisms are difficult to be functional and tend to externalise impacts that affect communities downstream.

Schad (1998), Hooper (2003), Ballweber (2006) and Ashton et al. (2008) gave two major IWRM approaches as top-down and bottom–up management and institutional approaches depending on the national, political, cultural, social conditions and financial capacity of water institutions. Unless there is a proper water governance regime there can be market failure, governance failure, and system failure at the local, national or international scale of water management which might be characterized by gaps in the institutional structures that impede the use of politics (*ibid*). Hooper (2005 stated that the successful implementation of IWRM plans as well as effective governance strategies are crucial processes and more emphasis should be on co-ordinated activities rather than amalgamated programs. Action on basin management strategies should target critical issues first and prioritize the related work programmes (Hooper, 2005).

Considering the aforementioned discussions on the two major IWRM approaches (top-down and bottom–up management) and the centralized versus the decentralised institutional approaches, there seem to be considerable water governance gaps and challenges with even the implementation of IWRM concepts. Water governance tends to interrogate the successes, gaps and challenges of the practical implementation of IWRM.

2.7.4 Principles for Successful Water Governance

Water governance will not be a success if the following principles (Gooch & Baggett, 2013; Lubell & Edelenbos, 2013; Tortajada & Joshib, 2013; UNDP Water Governance Facility, 2014) are not satisfied:

a) *Transparency*, which comprises of all means to facilitate citizens' access to information and their understanding of water–related decision-making mechanisms.

b) *Accountability*, which is about being answerable for one's actions and requires the ability of citizens, civil organizations and the private sector entities to scrutinize the water sector's leaders, public institutions and governments and hold them accountable for their actions.

c) *Participation*, which entails the meaningful involvement of all stakeholders, including marginalized and resource-poor groups, in water management decisions. This requires governments to put legislation in place to grant communities and other stakeholders a right to become involved in the water management process, and to encourage statutory institutions to provide stakeholders with sufficient information and incentives to participate in a meaningful manner.

d) *Access to Justice*, which ensures that effective water governance promotes principles of IWRM and provides a framework where access to water for everybody can be realized. Practically, this means that legal frameworks need to provide solutions that enable all users to demand their rights from water duty bearers. This requires not only an effective legal framework, but also well-functioning legal institutions.

e) *Responsiveness*, which refers to how well leaders and public organizations take the needs of citizens into account and are able to uphold their rights. A water governance agenda addressing responsiveness could include the following components: human rights, gender equity, pro-poor policies, integrity and regulatory equality.

All the above principles are fundamental to the creation and maintenance of a peaceful and secure water governance structure.

2.7.5 Elementary Building Blocks of Water Governance

Governance of water supply systems is of a complex nature as many different stakeholders are involved at different levels. Thus, water governance is shaped around the hydrological boundaries, social, political context and reveals the national, regional, institutional and legal frameworks. The Water Governance Centre (Havekes et al., 2013) emphasizes the need for five elementary building blocks of water governance. The first block deals with *powerful administrative organisation* of water management. This building block ensures that there is absolute clarity on the responsibilities of the water management organisation. The Water Management Organisation (wmo) should have sufficient administrative knowledge, technical capacity, staff time and experience. The wmo should facilitate the necessary data sharing of information that is open to cooperation with other public organisations and interest groups. The wmo should be keen or willing to be innovative and be transparent about its activities (Havekes et al., 2013).

The second building block is a *legally embedded system of water management* based on the rule of law and a coherent legal framework which fosters public consultations and legal protection. Compliance and enforcement of laws are other important elements of this building block. This entails looking at policy gaps which include overlapping and unclear gaps on the allocation of roles (Havekes et al., 2013). This building block also looks at sectoral water related tasks across ministries and agencies. Most of the water governance guidelines and code developed in different parts of the world, espouse a model of stakeholder inclusivity and involvement that is based on the enlightened shareholder approach to corporate governance (King Committee on Corporate Governance, & Institute of Directors (South Africa) [King Report II], 2002). Good governance is not something that exists separately from the law and the enabling institutions. Rogers (2002) commented that what is needed is a new framework within which to examine the interaction between politics or hydro-politics as cited by Scarpa (2004); law; legal regulations; civil society; water service providers, and consumers.

The third building block is *adequate financing system of water management* and economic analysis of water measures with accountability for capital, operation and maintenance, as well as governance costs (planning, administrative permit awarding, levying of taxes, enforcement and supervision) (Havekes et al., 2013). The fourth building block emphasises on the *systematic planning approach* which entails strengthening of internal coherence in water resource management, making sure that other policy areas such as environmental policy and spatial planning are incorporated so as to arrive at a well- functioning water resources management and infrastructure in the future. The plans should incorporate strategic and operational issues on international, regional and local basin levels. Water resources plans should have sound financing, be implementable and integrated among multiple users; water quality and quantity; surface water and ground water (Havekes et al., 2013).

The fifth building block emphasises *the participatory approach* which aims to forge a balance across various interest and involve all the stakeholders for ownership and effective water governance to be strengthened. The participation processes may include preliminary problem identification, stakeholder analysis, developing, implementing, monitoring and reporting progress of a participation strategy to foster transparency and trust as well as equal opportunities for stakeholders. Even though they emphasise on five, Havekes et al., 2013 enlist the sixth building block of water governance as a framework for better communication. Without good framework for better communication it is difficult to achieve the desired results to control water pollution, the prevention of disastrous flooding and, the effective and well balanced dealing with periods of water shortage *(ibid).*

2.7.6 Adaptive approaches to Water Governance

Scott et al. (2013) indicated a paradigm shift in the development and implementation of integrated and adaptive water management approaches. According to Pahl-Wostl et al. (2008b), adaptive management is defined as a systematic process for improving management policies and practices by learning from the outcomes of implemented management strategies. They added that the development and implementation of adaptive management approaches requires structural changes in water management regimes. Such changes are slow due to the inertia inherent in prevailing regimes. Pahl-Wostl et al. (2010) emphasized that the concepts for understanding water regime properties and transition should be understood in the context of the processes of social learning in multi-level governance regimes.

Galaz (2007) analysed the participatory arrangements for the preparation of the management plan for Evrotas River Basin and affirmed the need for participatory processes to respect the context within which they are pursued and with specific alterations to the way public participation has been planned and implemented in Greece. Fritsch and Benson (2013) argued that IWRM is now a globally generic concept encompassing a multitude of environmental governance approaches in different national contexts. However, conspicuous gaps in the IWRM literature concerning the application of this concept in practice are still evident suggesting a need for further theoretically driven comparative research.

In line with IWRM definition, the European Water Framework Directive (WFD) (European Commission [EC], 2000) key aims were 1) expanding the scope of water protection to all waters, both surface waters and groundwater; 2) achieving "good status" for all waters by a set deadline; 3) establishing water management based on river basins; 4) establishing an integrated and coordinated "combined approach" of emission limit values and quality standards; 5) getting the prices right; 6) getting the participation of stakeholders and 7) streamlining legislation.

However, Rahaman et al. (2004) cited seven mismatches between the EU Water Framework Directive and key IWRM principles as follows: 1) Gender awareness is omitted as there is no guideline for the role of women in the provision, management and safeguarding of water; 2) there is no guideline to encourage and regulate the private sector; 3) there is no guideline to ensure co-ordination between different sectors. 4) there is no clear guidelines for the active participation of local people and water users in the management of water; 5) there is no focus on poverty; 6) while the EU WFD promotes technology-oriented management for drinking water and sanitation and ensuring good quality of water, better management would call for the integration of technology-oriented management with human-oriented management and 7) there is no standard guideline to develop responsibilities at the lowest appropriate level. Contextually, the WFD may have been aligned to *adaptive water governance* principles rather than merely satisfying the definition of IWRM. It can be argued that IWRM is but a tool box from which to "adapt' appropriate water governance principles pending on their relevance to national or basin context.

Water governance in the Arab Regions, classified according to El-Khoury (2014) as arid or semi-arid (desert) receiving fewer than 250 mm of rainfall annually, is a critical issue in the light of the effect of climate change and rapid population growth. The resulting escalating water demands have brought in adaptive governance measures to consider conjunctive use of both surface and ground water, and use of non-conventional water sources (desalinated water, treated wastewater reuse, water harvesting and cloud seeding (UNDP, 2013 and UNDP, 2007).

2.7.7 Water Governance Reforms and Institutions

According to Pahl-Wostl et al. (2012), water governance reform and institutions have relied on simplistic panaceas without testing of appropriateness in diverse contexts. Based on the study of 29 basins in developed and developing countries, Pahl-Wostl et al. (2012) used a generic contextual diagnostic analytical framework to distinguish among water governance regimes, regime performance and environmental and socio-economic context. They provided evidence that polycentric governance regimes characterized by distribution of power and effective coordination structures resulted in higher performance than state-centric governance regimes.

Economic and institutional developments often focus on, and lead to, fulfilling the needs of human population at the expense of the environment. Thus, fit-for-purpose governance is required in formulating water governance institutions. Watkins (2006) and Falkenmark et al. (2007) considered water scarcity as (1) a crisis arising from a lack of service that provides safe water and (2) a crisis caused by scarce water resources. These reports concluded that the world's water crisis is not related to the physical availability of water, but to the imbalanced power relations, poverty, and related inequalities in the water sector. Thus poor water governance worsens natural water scarcity and water crowding – an increasing pressure being placed on finite, erratically available and vulnerable water resources. On observing similar challenges, the Government of Namibia enacted laws and compiled the strategic Vision 2030 that would try to address the water resources management issues (Government of the Republic of Namibia [GRN], 2004a; Government of the Republic of Namibia [GRN], 2004b).

2.7.8 Contextualizing the Namibia Water Resources Legal and Policy Framework

According to Heyns (2005), Namibia's independence in 1990 brought about political and socio-economic reforms within the democratic framework including water sector reforms that incorporate IWRM principles. The reforms resulted in a new era of policies, legislations and institutions. However, it also resulted in substantial staff losses and reduced human capacity because many competent people returned to South Africa when Namibia became an independent sovereign nation. Prior to these reforms, the water resources of Namibia were managed through the Water Ordinance of 1932; Water Act No. 54 of 1956; Mountain Catchment Areas Act No. 63 of 1970 (GRN, 1970); Water Research Act No. 34 of 1971 (GRN, 1971) and their respective amendments. These laws were promulgated by the South African Government during the apartheid era. As much as these Acts provided for control and conservation principles, the sustainable IWRM approaches were absent, especially the decentralization and stakeholder participation. To belabour this point, although the Mountain Catchment Area Act No. 63 of 1970 made provision for mountain catchment areas, no published records could be found to indicate formation of such areas.

Despite being enacted, the Water Research Act was also not practically implemented in Namibia. This is reflective of the little or scanty water research activities in Namibia resulting from the relocation of water experts to South Africa. An abortive attempt was made to come up with a new water law in 1977. The Assignment of Powers Act No. 12 of 1990 (GRN, 1990) weaned the Namibian government from the apartheid regime of South Africa. The Regional Councils Act No. 22 of 1992 (GRN, 1992a) and the Local Authorities Act No. 23 of 1992 (GRN, 1992b) empowered regional councils and local authorities to supply water and sanitation within their jurisdictional areas. However, this brought about ambiguity, overlap, conflict, paralysis and inefficiency within the water management practices (Namibia, I. P .J. V. (2010). There was no clear hierarchical structure among the water supply and sanitation institutions. Subsequently, the Namibia Water Corporation Act No. 12 of 1997 (GRN, 1997) was enacted with the prime objective of establishing Namibia Water Corporation, a commercial bulk water supplies entity owned by government for efficient supply of both raw and potable water to consumers based on a cost recovery model.

Namibia has had various water resources acts and policies put in place since Independence: Namibia’s Environmental Assessment Policy, 1993, (Namibia, Tarr, 1993); Water Supply and Sanitation Sector Policy, 1993 (GRN, 1993); Namibia Water Corporation Act, 1997; National Water Policy, 2000 (GRN, 2000c); Decentralization Enabling Act, 2000 (GRN, 2000a); Traditional Authorities Act, 2000 (GRN, 2000b); Water Resources Management Act, 2004; Water Supply and Sanitation Policy, 2008 (GRN, 2008b) ; Revised Green Scheme Policy, 2008; Namibia, I.P .J. V., 2010; National Development Plans 1 to 5 and Water Resources Management Act, 2013; Vision 2030). These legal and policy frameworks were to enhance the smooth implementation of water supplies and sanitary facilities in communities. The acts were to enable the functional capabilities and capacitation of the required institutions based on IWRM model as enshrined in the four 1992 Dublin Principles.

Heyns (2005) and Namibia, I. P .J. V. (2010) elaborated on how these new national water policies, despite their good intention to invigorate and trigger water sector institutional reforms, suffered from lack of the required level of skills for implementation and supporting legislation. The Water Resources Management Act of 2004 was not enforced for nine years after which it was repealed, revised and re-enacted into the Water Resources Management Act of 2013, whose regulations are also not yet finalized. This legal gap has resulted in the related water sector institutional arrangement being inefficient.

Equally, the Environmental Management Act (EMA) No.7 of 2007 (GRN, 2007) only became effective four years after its adoption (Government Gazette of the

Republic of Namibia, 2012). The implementation of EMA was reportedly fast-tracked when allegations of pollution at a smelter in Tsumeb came to light (Goitom, 2012). The Environmental Management Act seeks to prevent or minimize the consequential qualitative or quantitative impact of a wide range of activities on the environment. The objectives of EMA include, inter alia:

- ensuring that the significant effects of activities on the environment are considered in time and carefully;
- ensuring that there are opportunities for timeous participation of interested and affected parties throughout the assessment process, and
- ensuring that findings of an assessment are taken into account before any decision is to be made in respect of activities.

The activities of any major development project require environmental clearance. The activities requiring environmental clearance among others include mining, establishing industries in gas refining, production of oil and petroleum products, timber harvesting, construction of resorts and other hospitality facilities, and construction of roads, dams, reservoirs *etc*.

Integration within a unitary river basin context is the key governance process to address fragmentation in managing water distribution inequalities and water pollution issues. Molle (2008), GWP (2010) and Cohen and Davidson (2011) argued for a more context-driven application of these integrated water resource management (IWRM) principles rather than making them the norm for good water governance because in most cases the basin institutions have low management capacity. Hirsch et al. (2006) highlighted that the main problems that basin management seeks to address is geographical, bureaucratic, social, scalar and political fragmentations. Using and managing water without reference to the basin results in fragmentation.

Even though the environmental legislation is provided for in Namibia, the challenge is on how the environmental assessments are coordinated with the water sector in particular with the Ministry of Agriculture, Water and Forestry's input. This challenge is complicated by the third Draft of the Pollution Control and Waste Management Bill (2003) that is to be enacted under the Ministry of Environment and Tourism (MET) (Government of the Republic of Namibia [GRN], 2003). The bill when it becomes enacted, will promote sustainable development; provide for the establishment of the Pollution Control and Waste Management Unit (PCWMU); prevent and regulate the discharge of pollutants to the air, water and land; make provision for the establishment of an appropriate framework for integrated pollution prevention and control; regulate noise, dust and odour pollution; establish a system of waste planning and management; and enable Namibia to comply with its obligations under international law in this regard. The PCWMU will, inter alia, be responsible for the designation of a water quality action area for the detailed plan of action to improve water quality within that area; issue pollution licences; and integrated pollution control licenses. Given the aforementioned "competitive'' and fragmented environment, there can be little coordination and integration among these ministries and institutions responsible for water use and management.

These territorial, institutional and administrative fragmentations of functions, especially from intergovernmental organs with limited capacity, tend to compromise sustainable transition to pluralistic, participatory, and accountable water governance practice. Inclusive policies that are multi-sectoral require nurturing for successful water sector reforms.

2.7.9 Contextualizing Namibia's Institutional Water Sector Reforms and Framework

Hooper (2003), Ballweber (2006) and Biggs et al. (2013) explained that implementation of IWRM is often hampered by inadequate or inefficient political and institutional environment. There are three major pillars to support IWRM namely: 1) political; 2) technical or operational co-operation and 3) institutional pillars (van der Zaag & Savenije, 2000). The political pillar constitutes a conducive and enabling political will and environment that ensures the upholding of the rule of law. The technical co-operation pillar includes vertical (national, regional and local) scales and the horizontal (public, non-public, academic etc.) scales which are the technical expertise and data that are integrated or shared to sustain IWRM. The institutional pillar, in conjunction with the political pillar and laws, constitutes the required institutional framework and capacity. With merits and demerits, ideally river basin institutions should be decentralized to the lowest level so as to have some autonomy to be able to set priorities and obtain funding independent of existing government agencies which are dependent on the national budget.

Livingston (2005) reflected that analysis of institutional change is challenging for a scholar in any discipline. The water institutions cannot be separated from the legislative framework, policies and political administration rules. In this sub-section, a summary of the institutional reforms and structures of the Namibia Water Sector based on the legal and policies framework and context is presented.

Table 6 is an attempt to chronologically present these water sector reforms and changes in the Namibian context. The post-independence water sector institutional arrangements are presented in Figure 2.5. It is noteworthy that the focus of the water sector reforms was to embrace river basin management as was initially enshrined in the Water Resources Management Act of 2004.

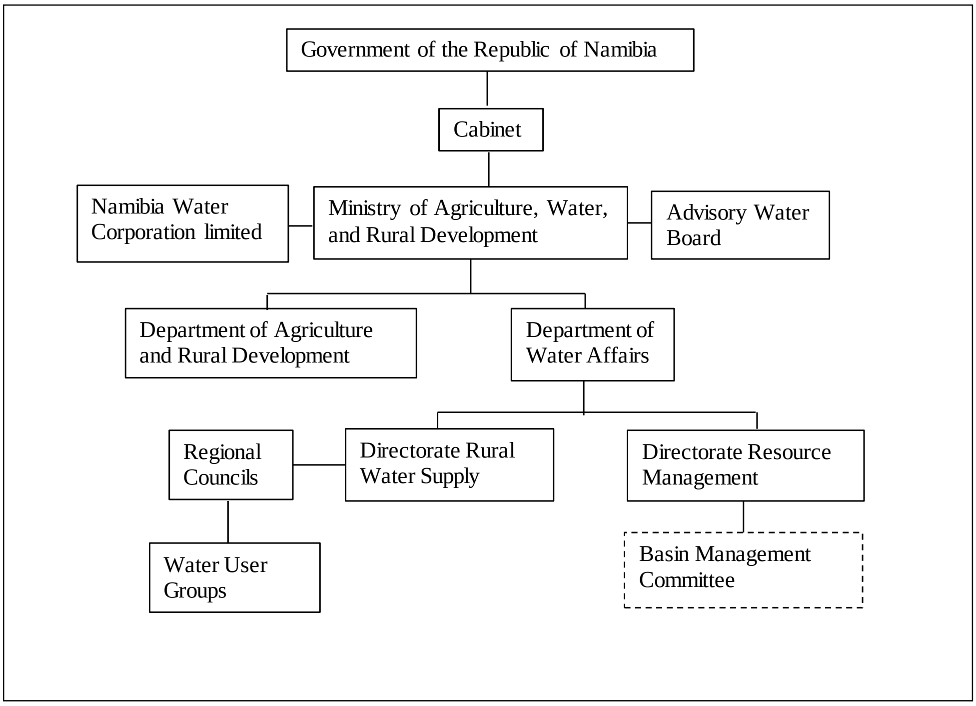

Figure 2.5 Namibia’s Post-Independence Water Sector Institutional Arrangement

Table 6 Summary of the Chronological Water Sector legal reforms and framework in Namibia (GRN 2000a; GRN, 2004a; Heyns, 2005; GRN, 2013)

Period	Water Institutional Nature, Reforms and Rationale
	Pre-independence Era
1884-1921	Two German Imperial Government drilling teams explored and develop ground water for railway systems, towns, mines, farms, etc.
1921-1932	Union of South Africa drilling team in Department of Works investigated large scale irrigations
1932-1956	Water Division in the Department of Works and Water Board advised the Secretary for South West Africa on diversion, storage and use of water. The enactment of the Water Act No. 54 of 1956 (GRN, 1956) took place during this period.
1956-1977	Department of Water Affairs of South Africa and Water Advisory Board improved capacity (human, technical and financial) during this period. Master Water Plan for South West Africa facilitated the construction of large scale water supply infrastructure that started in 1973 supporting water needs at least until 2000.
1977-1990	South African authorities started implementing “apartheid” homeland policy that tried to make provision for rural water services.
1980-1990	Department of Water Affairs South West Africa completely weaned from its mother department in South Africa leading to substantial staff losses and reduced capacity with many competent skilled labourers deciding to return to South Africa.
Period	**Independence Era**
1990	Department of Water Affairs (DWA) incorporated into the Ministry of Agriculture, Fisheries, Water, and Rural Development. -Water Advisory Board abolished- not politically representative enough -Apartheid homeland authorities centralized and assigned to the Department of Agriculture and Rural Development (DARD)
1992	Ministry of Agriculture, Water and Rural Development (MAWRD) established; Rural water supply function shifted from DARD to the DWA with a new directorate with two water supply divisions (bulk and rural) and a planning division.
Period	**Post-Independence Era**
1993	-DWA established a directorate responsible for key functions of regulation, planning, control and rural water services. -Water Supply and Sanitation inter-ministerial coordination unit was established as a new division that dealt with water, environmental and sustainability issues, -local authorities – water supply reticulation and wastewater treatment and disposal within their jurisdiction - Department of Works – water supply and maintenance of border posts, clinics etc. -Ministry of Health and Social Services- drinking water quality compliancy enforcements
1997	The bulk water supply function transferred to NamWater from DWA and this resulted in technically under-capacity of DWA to continue carrying out rural water supply functions that remained with DWA.
2000-2004	MAWRD reviewed the management of water resources that culminated into the Water Resources Management Act (2004), that was never enforced with only the National Water Policy (2000) implemented. The Water Resources Management

	Act (2004), intended to replace DWA institution with the envisaged Water Resource Agency. Among other issues, the Act was to introduce an independent water price regulation, water tribunal; enable the formation of river basin management committees; re-introduce the Ministerial Advisory Boards and Irrigation Boards.
2003	Pollution Control and Waste Management Bill, third Draft (2003), under the Ministry of Ministry of Environment and Tourism (MET) to include water pollution and still a draft to date.
2007-2010	IWRM Plan documents for Namibia were compiled
2010-2013	Water Resources Management Act (2013) was promulgated
2013 to date	Regulations being drafted for Water Resources Management Act (2013)

However, these river basin management structures were not fully operational and established. This gave way to the repealing of the Water Resources Management Act of 2004 and subsequent promulgation of the Water Resources Management Act of 2013 that relies less on river basin management. Before leaving the subject of water reforms in Namibia, it is worth emphasising that the old water pollution and discharge instruments in the Water Act of 1956, which are still in force, require being overhauled as most sections are now redundant to the current situation.

In conclusion, the implementation of IWRM principles, water reforms and centralisation/decentralisation are some typical issues of water governance indicative that water governance is multi-faced, still evolving and is worthy of being studied to enhance its understanding and application in Namibia.

2.8 Water Pollution Control and Water Governance

2.8.1 Water Pollution and Control

It is widely accepted that the deterioration of the quality of surface water and groundwater is mainly influenced by the geological structure and lithology of watershed, landuse and urbanization and other anthropogenic activities (Melidis et al., 2007; Alexakis, 2008; Tsakiris et al., 2009; Loukas, 2010; Naseem et al., 2010; Tsakiris & Alexakis, 2012). Water pollution is a major threat to fresh water in many rivers and basins (Nhapi & Tirivarombo, 2004; Jaji et al., 2007). Studies in Africa have shown that wastewater plays a major role in the pollution of lakes and river basins (Scheren et al., 2000; Jonnalagadda & Mhere, 2001 and Nhapi, 2004). In east Africa, Scheren et al. (2000) established that domestic pollution was far higher than industrial pollution and recommended that management policies should be directed toward reduction of domestic pollution. Juahir et al. (2011) showed that industrial wastewater in Malaysia was the major water pollution contributor. Bressers and Kuks (2004) applied comparative descriptive basin management and analytical statistics to assess the use of water resources from immersions or emissions perspective both theoretically and empirically in Netherlands. Brown and Clarke (2007) stated that in towns, it is imperative to transition stepwise from a just-sewered city to a drained city then to a water way city. The water way city is where management of point source and diffuse (storm water) pollution management is established. The water way city finally transitions to a water cycle city, that is, fit-for-purpose water use, managing the supply, energy and nutrient cycles, and providing highway urban protection leading to a water sensitive design city. Brown and Clarke (2007) further elaborated that environmentalism and growing social activism around waterways (river basins) are the seed for change.

Nutrient (phosphorous and nitrogen) loading is usually the main cause of eutrophication in water bodies with phosphorous generally being the main nutrient leading to accelerated growth of algae (Correll, 1998). According to Litke (1999), eutrophication became a water quality problem within the Great Lakes of United States of America with inputs of phosphorus to the environment being increased since 1950 due to the increased use of phosphate fertilizer, manure, and phosphate laundry detergent. Following basin and lakes studies, the manufacture of phosphate detergent for household laundry was ended in the USA voluntarily in about 1994 after many States had established phosphate detergent bans. Raw wastewater effluent in the USA contained about 3 mg/L of total phosphorus during the 1940's, which increased to about 11 mg/L at the height of phosphate detergent use (1970), and then declined to about 5 mg/L around 1996 following the bans and catchment control measures. However, in some cases, tertiary wastewater treatment is still needed to effectively improve water quality of streams (Litke, 1999). Despite these downward trends in phosphorus concentrations since 1970 in many streams, the median total phosphorus concentrations still exceed the recommended limit of 0.1 mg/L. A variety of phosphorus-control measures and strategies that included reduction of total maximum daily loads, limiting total phosphorous (TP) within range of 0.5 to 1.5 mg/L of the sewage wastewater effluent, may be used to evaluate the effects of various control strategies. Litke (1999) listed some water governance areas of concern in the United States at that time to include: evaluation of the effects of increased manure loadings of phosphorus on soil phosphorus and, subsequently, on ground water and subsurface runoff; determination of point-source and nonpoint-source components of phosphorus loads by geographic modeling and hydrologic separation techniques; and development of methods or indices to evaluate nutrient impairment in streams and rivers to serve as a basis for developing phosphorus criteria or standards (Litke, 1999). To control excessive algae growth, the United State Environmental Protection Agent (USEPA) recommended limits of 0.05 mg/L total phosphates in streams that enter lakes and 0.1 mg/L of total phosphates for flowing rivers.

Schoumans et al. (2015) looked at the management of total phosphates from manure in the European Union and suggested innovative ways of extracting the phosphorous from manure instead and thus avoid the phosphorous pollution of the underground and surface water environment. Blomqvist (2004) shared experiences in Sweden where the local water user groups controlled and managed the eutrophication of the Baltic Sea through increased stakeholder participation in the efforts to reduce nutrient losses from agricultural lands.

Many studies have indicated that pollution sources in basins were generally of anthropogenic sources (industrial, municipal waste and agricultural runoff) (Singh et al., 2005; Qadir et al., 2008). Savage et al. (2010) attributed urban land development to be positively associated with increase in water pollution. Magadza (2003) attributed the water quality challenges in the SADC region to being caused by inadequate institutional frameworks while Nare et al. (2006) questioned the stakeholders' participation and ownership of the processes to curb pollution sources.

2.8.2 Characteristics of the Polluted Goreangab and Swakoppoort Dams

Goreangab and Swakoppoort Dams are polluted, eutrophic, and consist of phytoplankton with numerous species of photosynthetic algae, protists, and chlorophyll-containing bacteria (Cyanobacteria, also referred to as blue-green algae) (NamWater, 2011a). The water is literally pea-soup green and the scum of phytoplankton is usually floating on the surface. The two dams have lost their previous oligotrophic body of water with its recreational qualities unappealing for swimming, boating and sport fishing. Nutrient enrichment seriously degrades aquatic ecosystems and impairs the use of water for drinking, industry, agriculture, recreation and other purposes. In aquatic ecosystems, these nutrients cause diverse problems such as toxic algal blooms, loss of oxygen, death of fish, loss of biodiversity (including species important for commerce and recreation), loss of aquatic plant beds and coral reefs, and other problems. Carpenter et al. (1998) established that eutrophication is a widespread problem in rivers and lakes caused by over-enrichment with P and N due to point and non-point sources of pollution such as industrial and domestic wastewater, overstocking of animals resulting in excessive manure; agricultural fertilizers and leaching.

From Figures 2.6 and 2.7, it can be seen that Swakoppoort Dam's value as a source of drinking water has been greatly impaired because phytoplankton rapidly clogs water filters and causes a foul smell. The growth and die-off of phytoplankton give rise to detritus, growth of bacteria and depletion of dissolved oxygen and the suffocation of higher organisms like fish. It is suspected that the dead fish noticed (Figure 2.7) in Swakoppoort Dam in February 2015 (NamWater, 2015) could have died due to thermal stratification and the resultant turning/mixing of the reservoir (Komatsu et al., 2006; Lindim, et al., 2011). With each turning, the DO levels on lake strata become depleted to a level that may not support survival of fish. According to Wright and Nebel (2005), dying phytoplanktons secrete various toxins into the water that are injurious to human health. This could have occurred in 2010 when NamWater halted the transfer of water to Von Bach Dam for treatment (NamWater, 2011a). However, the quality of Swakoppoort Dam water may be so bad that the effect of dilution by water from Omatako Dam may not improve the Von Bach water.

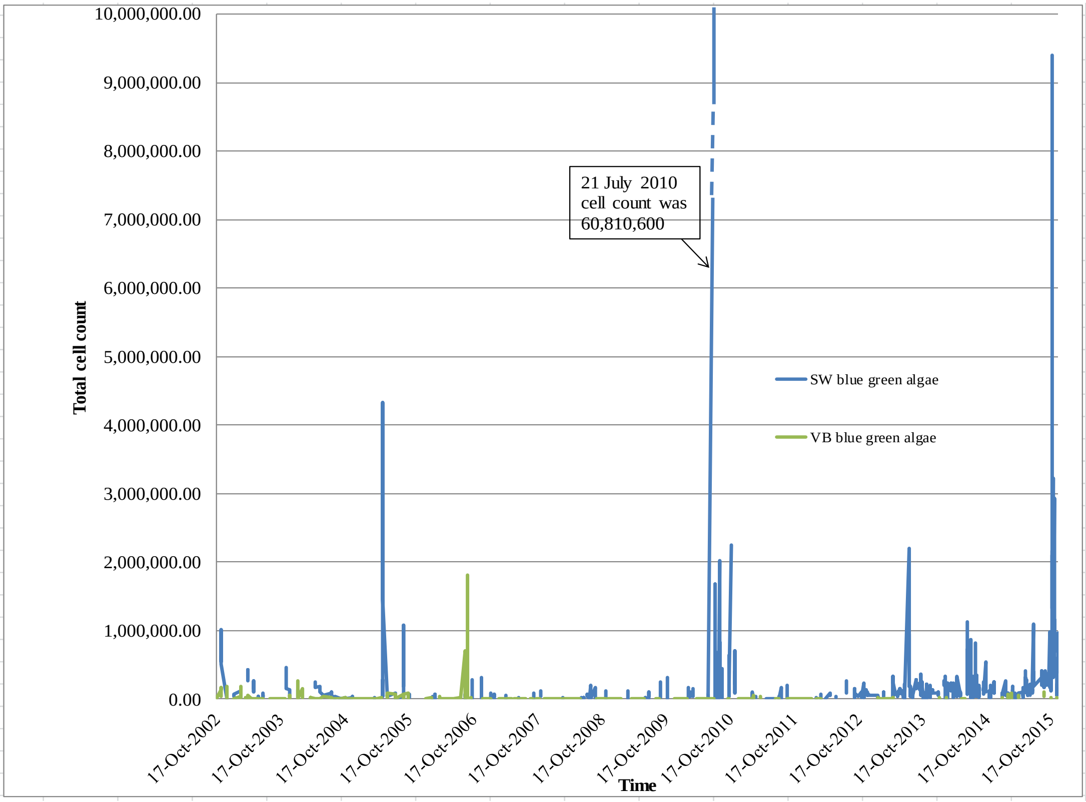

Figure 2.6 Blue Green algae counts (Total cells/ml) for Swakoppoort (SW) and Von Bach (VB) Dams (2002 to 2015) (Namibia Water Corporation, 2015)

Sirunda and Mazvimavi (2014) indicated that the transferred water from the polluted Swakoppoort Dam reservoir has a negative effect on Von Bach Dams' water. *Cultural eutrophication*, is the accelerated eutrophication caused by humans, resulting from sediments, excess nutrients and pathogens.

Photos of fish dying in Swakoppoort Dam Reservoir in February 2015. Causes were not established.
Photos taken by NamWater Khomas Region Manager.

Figure 2.7 Dead fish in Swakoppoort Reservoir likely due to water pollution

In the USB, this may be emanating from Windhoek and Okahandja sewage treatment plants, urban runoff, tanneries and the chicken farm. Two approaches are already being used to combat the unprecedented eutrophication of Swakoppoort Dam. According to Namibia Water Corporation [NamWater] (2015), phoslock (herbicides) were sprayed and Solar Bees' aeration was applied to get rid of the algae, which is just attacking the symptoms. Other studies, however, considered a method aimed at getting rid of the root causes by employing long term strategies (eco-regional nutrient criteria) for instance, reducing the reservoirs 'total phosphate to less than 8 µg/l; chlorophyll to less than 2.43µg/l and maintaining secchi depth of ±4.93 metres (Aneeshkumar & Sujatha, 2009). The secchi depth quoted is for oligotrophic-mesotrophic boundary (Numberg, 1996; Dodds et al., 2006).

2.8.3 Characteristics of the Potential Water Pollution Sources Discharging into Goreangab and Swakoppoort Dams

As was discussed earlier in Chapter 1 on the land use patterns of the USB, potentially there are both point sources and non-point sources of pollution discharging into the Goreangab and Swakoppoort Dams. In general, the activities generating pollution can be summarised as town domestic effluent and industrial effluent; sediments from mining sites; agriculture and wildlife; tree cutting and de-bushing. In detail, the sources of pollution generation can be listed as follows:

1. Nutrient oversupply –sewer burst; under capacity sewage treatment plants /wastewater treatment plants both effluent and capacity overflows e.g. Ujams, Gammams, Otjomuise, Okahandja industrial and domestic sewage treatment plants. Burst sewer pipes are mainly from Windhoek and Okahandja.
2. Fertilizer runoff from lawns, gardens and agriculture; animals watering points around a borehole and ground water source e.g. from farms and tourist resorts.
3. Pesticides/herbicides- leaching from lawns, gardens and agricultural fields from both urban areas and farms.
4. Toxic chemicals- direct discharges from certain industries e.g. Ramatex clothing factory even though the factory was closed in 2008. The water ponds on the Ramatex site are still heavily polluted with salt used as a dye fixative, and there

are several large containers of hydrocarbons that are still not disposed of. Windhoek Municipality officials estimated 120,000 cubic meters of salty wastewater and sludge on the site (Magadza, 2009).

5. Storm water drainage from streets; informal settlements, parking lots and lawns and atmospheric depositions from air pollutants washed to earth and deposited as dry particles (Vogel et al., 2005). Non-point highway litter; city streets; landfills; servicing of land / suburban developments e.g. from Windhoek and Okahandja.
6. Spills from trucks, tankers, power plants; leaching from disposal sites from Windhoek and Okahandja.
7. Tourist hunting farms and holiday resorts e.g. Daan Viljoen, Okapuka, Dusternbrook Guest farms etc. exhibit both point and non-point sources of pollution.
8. Pathogenic-disease causing bacteria, viruses and other parasitic organisms, emerging endocrine disrupters and estrogenic compounds produced in domestic effluent especially from Windhoek and Okahandja are likely to contaminate and pollute the wastewater. There are no detailed epidemiological studies that have been carried out in the USB to ascertain prevalence of these type of water pollutants (Faul et al., 2013).
9. Agro-industries sitting in the USB e.g. Meatco and Nakara Tanneries, Namib Poultry Industries and NamDairies etc. produce point sources of pollution.
10. Mining activities (e.g. Otjihase Mine) produce mainly point sources of pollution.

2.8.4 Water Pollution Monitoring, Applicable Regulations and Personnel in USB

The Windhoek Municipality, Okahandja Municipality and MAWF are the three organizations responsible for policing the public waters in the USB. This section highlights the laid down regulations operating in the areas of their jurisdiction as of 2015.

a) MAWF Regulations (According to Water Act of 1956)

Based on the provisions of the Water Act, 54 of 1956, and General Standard Quality restrictions as laid out in Government Gazette R553 (1962), MAWF sets each discharge permit in accordance with the information provided and verified on site by each potential permit holder as summarized in Annex 1. New regulations are still being worked out in accordance with the Water Resources Management Act of 2013. It should be noted that discharge permits issued under the Water Resources Management Acts (2013) should comply with the provisions of other laws that are still enforceable, for example, the Public Health Act (1919). Contravention of, or failure to comply with, any of the permit conditions shall constitute an offence and shall render the permit holder liable to prosecution under Section 21(8) of the Water Act, 1956 (Act 54 of 1956).

(b) Windhoek Municipality and Okahandja Municipality Regulations

According to the Local Authorities Act (no. 23 of 1992), Section 30(1) (u), the Municipalities of Windhoek and Okahandja are required to gazette the sewerage and drainage regulations as well as the related sewerage tariffs (GRN, 1992). The sewerage and discharge parameter threshold limits for Windhoek published in 2010 are given in Annex 2. Annex 3 gives the Okahandja effluent discharge tariffs and their approaches that were published in 2008. Although the Windhoek Municipality discharge permits regulations have penalties with respect to industrial effluents exceeding the threshold limits, these penalties are not punitive enough to discourage offending industries. The Okahandja regulations do not have incentives and disincentives for the quality of pollution discharged by industries. It should also be noted that the wastewater effluent discharge regulations from MAWF, Okahandja Municipality, and Windhoek Municipality are not harmonized, making it difficult to improve the quality of receiving waters in the USB.

(c) Monitoring

The MAWF officer responsible for monitoring the USB is also responsible for monitoring the whole of the Khomas Region. In 2014, there was only one pollution control officer responsible for inspecting and monitoring all the industries in the expanse of Windhoek. Okahandja Municipality does not also have a designated officer to monitor pollution and enforce compliance of effluent discharge from industries.

In summary, the wastewater discharge permit management in the USB as reported by MAWF, the Municipalities of Windhoek and Okahandja, is limited by personnel capacity and require strengthening for effective monitoring.

2.8.5 Approaches to Wastewater Discharges and Pollution

Two major approaches to the treatment of wastewater discharges have been in use world-wide. **The Best Available Technology (BAT)** approach (Bolong et al., 2009) ensures highest efficiency and highest quality of effluents discharged from premises and sewerage treatment plants. This approach does not consider the assimilative capacity of the receiving waters for the effluents neither does it consider the affordability of the technology. **Best Practical Technology (BPT)** approach (Fresner & Engelhardt, 2004; Zhang et al., 2006; Esplugas et al., 2007) is normally adopted where financial resources are limited, based on the delicate balance between cost and benefit as illustrated in the following paragraphs.

a) Ability of the industries and individuals to pay for pollution control facilities especially using cleaner production methods, an effective approach to analyse the productive processes that aid to reducing use of chemicals and generation of waste and emissions. It also helps to sensitize workforce and management for environmental problems caused by the enterprise including health and safety.
b) The need to maintain at least minimum standards of environmental quality in relation to the health requirements, considering the complication of treating wastewater sources especially those containing endocrine disrupting chemicals (EDCs). The emerging endocrine disrupting chemicals (EDCs) usually comprise of pharmaceuticals, personal care products, surfactants, various industrial additives and numerous chemicals purported to be endocrine disrupter. Cleaner production leads to the reduction of the use of unhealthy and hazardous chemicals in the production processes and limits the generation of waste and emissions.

Zhang et al. (2006), Esplugas et al. (2007), Bolong et al. (2009) and Ramalho (2012) highlighted the options of using activated carbon, oxidation, activated sludge, nano-filtration and reverse osmosis membranes, and their efficiencies in removal of these pollutants. In particular, the nano-filtration removal mechanism is emphasized because of its importance in eliminating micro pollutants. According to Mara (2013), the Advanced Integrated Wastewater Ponding Systems (AIWPS); Best Available Technology Not Entailing Excessive Cost (BATNEEC) and cheapest available technology approaches should be harnessed to give the most appropriate technologies of wastewater treatment for the continuous improvement of the USB.

Nhapi (2004), Nhapi et al., (2005a & b) and Nhapi (2008) gave the 3- Step Strategic Approach to wastewater treatment. The 3- Step Strategic Approach, based on water conservation, treatment, and reuse strategies as well as water demand management strategies that include water-saving devices, regulation, leak detection and repair, looked at the three levels where wastewater can be handled on site, decentralized, and centralized. The approach aimed at the sustainable use of water, nutrients, and other resources in the urban environment. This 3-Step Strategic Approach consists of pollution prevention and minimization (Step 1), reuse after treatment (Step 2), and discharge into the environment with stimulation of self-purification capacity of the receiving environment (Step 3). The 3-Step Strategic Approach was applied to the Lake Chivero catchment, where it was demonstrated that the approach could substantially and potentially reduce the water pollution and future water scarcity problems in Harare, Zimbabwe (*ibid*). This approach can also be employed in the USB. Pollution control facilities and management in the USB should be affordable and be aided by total environmental planning approach to development. Usually the urban poor are worst affected and suffer from improper planning and poor implementation of plans that breed slums and informal settlements.

The current approaches to wastewater treatment in the USB are reactive and this has led to the postponing of the proper planning of pollution control. Reactive planning of wastewater infrastructure in the poor urban settlements, in the hope that environmental management will improve when the economy and planning capacity is reasonably buoyant, are unsustainable. This reactive planning is called “in situ upgrading” in Windhoek i.e. installing additional services on plots that are already settled (World Bank, 2002). This was the case with increased informal settlement upstream of Goreangab Dam that resulted in further pollution of the Goreangab Dam water, which has since been abandoned as a source of water for direct water reuse plant because of pollution. Windhoek remains a major destination for people looking for a better life in an urban setting. In 2002, the suburbs of Katutura are growing at a rate of 9.5% per year (World Bank, 2002) and this is reflected in the 2011 census where it was shown that, of the 36% increase in the population of Windhoek between 2001 and 2011, 71% of these live around Katutura (NSA, 2011). Reality has shown that the focus on sanitation, pollution control planning as an aftermath, as done in Windhoek, is too complicated to solve due to political socio-economic and budgetary problems faced by urban authorities (Kayizzi-Mugerwa et al., 2014; Nhapi, 2015).

According to Brown and Clarke (2007), urban water design, also known as water sensitive urban design, has in recent years gained a considerable attention as a sensitive water pollution prevention strategy deployed to arrest water pollution before it is a menace. Cities like Johannesburg, Cape Town, Tshwane and eThekwini in South Africa have adopted water sensitive design framework and are implementing sustainable urban drainage (SUD) systems and sanitation safety plans (Armitage et al., 2013). Both Windhoek and Okahandja can adopt water sensitive urban design framework, which include pollution source controls like:

- Green roofs – a roof with a vegetated surface providing a degree of retention, attenuation and treatment of rainwater (Stahre, 2006; Wanielista et al., 2008).
- Soakaways – excavated pits packed with coarse aggregate and porous media to detain and infiltrate storm water runoff from a single source.
- Check dam – low weir or dam that lies across a drainage channel to retard or re-route flow from a channel ditch or canal for purposes of erosion or scour reduction.

- Permeable pavements; filter strips swales; bio-retention areas and sand filters (Mays, 2001; Parkinson & Mark, 2005).
- Detention ponds, retention ponds and constructed wetlands can also be strategically implemented at appropriate points along river channels as a way to retain stormwater runoff.

2.8.6 Water Quality Assessment Approaches

The assessment of water quality usually starts with exploratory descriptive statistics before delving into deeper analysis. Various statistical methods have been employed to model and map water pollution within a basin. Both seasonal and longitudinal data analyses (Girija et al., 2007; Pejman et al., 2009) and cross sectional data analyses (Jaji et al., 2007) have been employed to describe the spatial variations in water pollution. Multivariate statistical techniques for water quality assessment using cluster analysis, principal component analysis, factor analysis and discriminant analysis have been widely applied for data reduction and classification of homogenous pollution sites where many parameters were captured (Singh et al., 2005; Shrestha & Kamaza, 2007; Pejman et al., 2009). Other researchers have used analysis of variance (ANOVA) techniques (Jaji et al., 2007; Brauer et al., 2009) and Geographical Information Systems (GIS) (Wang & Yin, 1997; Girija et al., 2007) to map spatial variations in pollution.

2.8.7 Basin Water Quality Challenges and Issues in the USB

The principal objective of raw water treatment is to produce domestic water that is consistently safe and reliable at a reasonable cost to the consumer (Schutte, 2005). The main challenges facing water treatment facilities are the deterioration in the quality of many raw water sources with or without taking seasonal variations of in-streams of surface sources. The increasing difficulty in the removal of potentially harmful synthetic organic substances and resistant microorganisms in the water sources, and the demands for process integration and flexibility require improved water quality governance. Despite some interventions there has been deterioration in the quality of source waters i.e. Swakoppoort Dam in Namibia (NamWater, 2011) and Hartebeespoort Dam in Pretoria, South Africa (Department of Water Affairs [DWA], 2015). Chauret et al., (1995) indicated that source water management requires an understanding of the natural and human factors that impact on water quality and the means to control, reduce or eliminate those impacts where possible. Hroncich (1999) indicated that the biggest threats to water quality include urban development and agricultural activities. Nhapi and Tirivarombo (2004) investigated water pollution loading and characterized the Marimba River, one of the major inflow rivers into Lake Chivero, Harare City's main water supply source. Due to mainly sewage effluent sources of pollution and the overflowing Crowborough Sewage Treatment Works into Lake Chivero, the lake is eutrophic and the water has to be blended with source water from Lake Manyame to render it treatable and usable.

Emerging, and possibly persistent, water quality and quantity challenges suggest an assessment is needed to determine how the water governance efforts in the USB can be improved. Based on these challenges, a research problem was formulated that there is little or patchy water governance research in the USB (Sirunda, 2010; Ruppel & Ruppel-Schlichting, 2011; Shinana, 2011). At the same time there could be peculiarities in the Upper Swakop Basin studies especially with regard to water quantity and quality aspects and adaptive water governance tools and prescriptions (Huitema et al., 2009) for aiding decision making on sustainable water governance.

Even though legal and institutional frameworks exist, the capacity of the institutions to manage the USB system may be lacking (Cohen & Davison, 2011). On one hand, there could be historical disparities among stakeholders reminiscent of the apartheid system common to South Africa (Colvin et al., 2008) and Namibia. This study therefore, saw a need to assess water governance institutional framework.

While applauding the direct water reuse for drinking in Windhoek to augment surface and groundwater sources, the other challenge was that there is little or no antecedent research on the water governance fears on its health and ethical acceptability and approval by the stakeholders. This study therefore, investigated the social, health and ethical issues of water reuse for drink in Windhoek.

This study, seeks to check the governance interrelationships in the supra-system of the ephemeral USB. Thus the aim of this study is to comprehend, explore and discover the contemporary water governance challenges and issues.

2.9 Water Governance Evaluation Approaches Models

Videira et al. (2006) critically reviewed the water governance evaluation of related case study projects in five European countries (Portugal, Greece, the Netherlands, the United Kingdom and Spain), with respect to participatory criteria. The horizontal comparison of these cases accounted for criteria such as the political and institutional context, the design, the implementation and evaluation of outcomes of participation to formulate guidelines for adoption. One water governance evaluation approach is the integrated ADVISOR conceptual framework (Antunes et al., 2009), composed of the institutional, political and socio-economic context in which the river basin governance issue occurs. Antunes et al. (2009) research methodology comprised the development of a robust theoretical understanding of the barriers and opportunities for integrated evaluation processes in the USB context; and different methods to support implementation of integrated river basin evaluation processes to promote sustainability and improved governance of such processes. This conceptual framework consisted of three interrelated dimensions namely 1) Information (collecting and presenting the relevant scientific information to the evaluation, accounting for the quality of data, the complexity of the problem and the uncertainty of the future, and allowing for multiple description and explanatory frameworks); 2) Assessment: (applying an assessment module to the data, consisting of a comprehensive evaluation of the plausible alternative actions, accounting for different sustainability related criteria); and 3) Process: (actively involving the civil society and the stakeholders in the process of building-up the information base and performing the assessment) (*ibid*).

Rauschmayer et al. (2009) indicated that effective evaluation of the governance of natural resources involves evaluating both the outcomes of the governance processes or the governance process itself. It makes sense to combine the two approaches: a normative reason relating to standards of good governance; a substantive reason relating to the complexity of the system to be governed and a third instrumental reason relating to the task of policy evaluation and implementation itself. Hedelin (2007) constructed a set of usable normative criteria for analysis and evaluation of sustainable water management based on twin concepts of participation and integration for decision –making or planning process.

The most popular participatory approaches are based on some form of stakeholder group (Hedelin, 2007; Salgado et al., 2009). Methods to evaluate participation in water governance include Social-Multi-Criteria Evaluation, mediated modelling and scenario workshops. Social Multi-Criteria Evaluation (SMCE) is connected with participation as a necessary, but not sufficient condition, for reaching transparency and accountability. A good Social Multi-Criteria (SMC) framework defines evaluation as a mixture of representation, assessment and quality check connected with a given policy problem, in this case, the USB water pollution challenge. The SMCE fosters transparency, reflection and learning in decision making processes, simultaneously integrating political, socio-economic, as well as ecological, cultural and technological dimensions. Social multi-criteria evaluation is best for evaluating alternatives, revealing trade-offs' and aiding convergence between divergent stakeholder views, but relies more heavily on experts and allows less participation and deliberation in goal setting than the other two methods (Kallis et al., 2006).

In mediated modelling, analysts work together with members of the public to develop a model representing a particular natural resource management system of interest ranging from watersheds, or local ecosystems to huge regions or even the globe (Kaufman, 2006). Members of the public participate in all stages of the modelling process, from initial problem scoping to model development, implementation and use. The resulting model can be used for determining ecosystem services that are potentially important to the public and evaluating alternative scenarios of interest. Due to public involvement and inclusiveness in the modelling process, the model and any results derived from it are likely to enjoy ‘‘buy - in’’ and reflect group consensus (Kaufman, 2006).

“Scenario Workshops” create basis for local actions on topics such as water pollution. They are used to gather knowledge about barriers and participants’ experiences and vision of the topic as well as basis for these (Kallis et al., 2006). Participants usually consists of 25 -30 people with different roles in the local community such as politicians, government officials, civil servants, technical experts, investors, business people, citizens and local associations. Scenario workshops can create new knowledge surrounding a local community issue such as pollution in the USB. Scenario Workshops are well suited to the early stages of a planning process (problem-solving and identification of goals and alternatives) and are good at evaluating participants and supporting capacity building.

Schneider et al. (2014) have come up with a sustainability governance wheel to have a better understanding of the complexity of water governance. Knieper et al. (2010) gave insights into water governance regimes. They employed a multidisciplinary comparative analysis tool, the Management Transition Framework (MTF) on cases from different social and environmental contexts. Araral and Wang (2015) used 17 indicators of water laws, policies and administration to test and assess 10 Chinese provinces on water governance issues. They verified that water governance ranked as one of China’s most serious problems today and in the foreseeable future due to its rapid urbanization, industrialization, overconsumption, pollution and inefficient water use. This shows that improving water governance is the key to water security in developing communities including China, and Namibia is not an exception.

2.10 Conceptual Framework

Water governance is more than just analysing and managing the physical environment of the water resources to meet the needs and demands of various users. From literature, water governance can be summarized to include the following theoretical concepts:

a) Participation of *interested, impacting and affected parties* to ensure equity, fairness and trust building, ensuring no harm to fellow users and promoting eco- efficiency and eco- water principles of IWRM (Wang & 王雨, 2014).

b) *Political and legal influences* on administrative and basin-wide bounded regions to promote eco-democratic opportunities (Pahl-Wostl et al., 2007; Pahl-Wostl, 2009; Pahl-Wostl et al., 2012).

c) *Investing in the future* through the promotion of sustainable, inter-generational principles of good water governance by implementing appropriate primary and secondary school curriculum (Maude, 2012).

d) *Information sharing*, communicativeness and transparency pillars in empowering stakeholders in water governance. Various fora, databases and communication media are the means through which information is shared (Hirsch, 2012; Matiwane, 2012).

e) *Implementing agencies and institutions* ensure the efficient implementation of policies, governance structures as well as required water supply infrastructure. Their technical responsiveness, coordination, integration, accountability reflects the efficiency of the water governance. The capacity of these implementing agencies is usually found inadequate (Hooper, 2005; Turton et al., 2007; Tropp, 2007; Pahl-Wostl, et al., 2008b; Huitema et al., 2009; Tortajada, 2010; Uhlendahla, et al., 2011; Pahl-Wostl & Knieper, 2014.)

f) Water governance is dynamic and requires *innovative agencies* that are adaptive, geared towards water sensitive cities and employ results oriented research from renowned institutions of higher learning e.g. universities and research institutions (Cohen, 2011; Brunner & Lynch, 2013; Hill, 2013)

g) Water governance is also usually associated with how much inclusiveness and collaboration is practised with *independent bodies and institutions* (Huitema et al., 2009; Scholz & Stiftel, 2010).

The italicised phrases from (a) to (g), to a large extent, encapsulate the concepts and theory of water governance. Based on these concepts, the study derived and deployed a water governance tool, the 7 "I"s' for the overall evaluation, as outlined in Chapter 3 and 7, to assess water governance in the USB.

CHAPTER THREE

3 METHODOLOGY

As stated in Chapter 1, the objectives of this study are to:

1) Assess the water quality at potential pollution sources and at major receiving waters (discharge points, dams, rivers and aquifers) in the Upper Swakop Basin using descriptive statistics and spatial analysis of secondary data collected from several sources between 2008 and 2014, with respect to the prevailing water quality regulations and standards.
2) Evaluate the adequacy and availability of the drinking water sources in the USB using time series forecasting models for Windhoek rainfall, and water demands for Windhoek and Okahandja based on secondary data from 1891 to 2012, 1967 to 2014 and 1998 to 2014 respectively; and also complement these by assessing the adequacy of water in the USB (as well as CAN) using the WEAP model and simple audit water balance method.
3) Assess the ethical, social and health perceptions of water reuse for potable purposes in Windhoek using frequency tables and charts based on primary data obtained through a survey of a purposive sample of stakeholders.
4) Qualitatively assess water governance structures, participation, and the overall assessment of water governance processes and outcomes (integrated ADVISOR conceptual framework and 7 “I”s tool) in the USB based on institutional organograms (content analysis), legal framework (content analysis) and participation (socio-multi-criteria evaluation; mediated modelling and scenario workshops).

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This chapter presents the methodologies used to achieve each of these objectives. Due to the many facets and complexity of the study, this methodology chapter was divided into sub-sections accordingly.

3.1 Water Quality Assessment in the USB

3.1.1 Research Design

A descriptive and spatial analyses of secondary data collected between 2008 and 2014 from different institutions were used to assess the water quality of the USB. The physical, chemical and biological parameters of the water quality were obtained from the available secondary data. Water quality variables were selected based on desk study, literature review and the availability of data sets.

3.1.2 Population and Sample

The population in this study comprised of the potential pollution sources and the receiving waters from the Upper Swakop River catchment. A total of 222 water quality data sets collected from the potential pollution hot spots within the USB between 2008 and 2014 were used for water quality analysis.

3.1.3 Research Instruments

The secondary data used were collected by MAWF; Windhoek Municipality; Okahandja Municipality and NamWater. The data from MAWF were recorded in hard copy from various file folders due to lack of electronic data base. The water quality data from both NamWater and Windhoek Municipality were received in electronic Excel spreadsheets format. The procedures and instruments (such as water quality sampling bottles, sampling iron, sampling tubes, sticks, bailers and suction-lift pumps including appropriate data collection forms) used in collecting the primary data were confirmed to have conformed to standard procedures and requirements. Standard instruments such as GMH3430/3530 digital metres were used to measure and collect on site parameters such as pH, temperature, and conductivity. The samples were analysed at NamWater, Analytical Laboratory Services and Windhoek Municipality laboratories using standard procedures such as Inductively Coupled Plasma-Optical Emission Spectrometer (ICPEOS), Calorimetric, Electrode and Titration, and Spectrophotometric instruments and methods.

Based on the secondary data, the coordinates of water sampling points were plotted and mapped using GIS, ArcMap version10. Sampled sites with extreme values of water quality parameters were also plotted as thematic layers of the maps using GIS, ArcMap version10.

3.1.4 Procedure

A letter requesting consent for the use of the data sets was prepared and signed by researcher's supervisor. After permission was granted, appointments and collection of the secondary water pollution data were organised with the respective organisations that supplied the data. Before analysing the secondary data, these data were categorised as (1) whole set data and (2) subset data. The whole set of secondary water quality data collected from NamWater, Windhoek Municipality and MAWF were cleaned, rearranged and grouped according to the parameters. The subset water pollution data were for 12 sites where sampling had been replicated and obtained from NamWater (Shinana, 2011).

Twelve sampling points upstream of the Swakoppoort Dam (Goreangab Dam; Klein Windhoek River; Dan Viljoen Dam; Swakop River; Swakoppoort Dam; Monte Kristo farm borehole; Okapuka River; Dusternbrook Farm; Otjiseva farm; Ghoub River; Gammams River and Dobra River) were investigated. Samples were replicated at each point at least on three different periods.

3.1.5 Data Analysis

For the whole set of secondary data, a total of 32 parameters were analysed for each site subject to their availability in the data set. The data were summarised using descriptive statistics (measures of centrality and dispersions) and identifying the extreme pollution parameter values and their corresponding sites. Extreme value analysis was conducted through exploratory descriptive analysis using the 5 number summary (minimum, maximum, median, lower quartile, and upper quartile). Parameter observations which fell outside the arithmetic mean ± 1.5 x Interquartile Range were regarded as extreme (Larson, 2006). The extreme values were mapped using GIS and were used to establish the relationship between landuse /sites and the intensity of water pollution at the investigated sites. USB management intervention strategies would be focused on the identified hot spots. IBM SPSS version 22 and MS Excel were used for data entry, cleaning and analysis.

The data from the 12 sites with replicated sampling were used to check if there were significant differences in mean pollution levels of different water quality parameters within the 12 sites. Water quality parameters which included but were not limited to chlorine, alkalinity, hardness, iron, copper, zinc, manganese, cadmium, lead, total phosphate, dissolved oxygen, UV, Ammonia, and Total nitrogen were considered. A one-way analysis of variance (ANOVA) was carried out to establish whether there were significant differences in the mean levels of each pollutant among the twelve sampling points at 5% level of significance. The water quality variables were also compared against the proposed Namibian water quality standards. The results of the water quality assessment are presented in Chapter 4.

3.1.6 Validation and Reliability

Before using any data set, it was first established that the water sampling techniques used in collecting the data were based on the Namibian general standards for wastewater discharge into the environment in terms of Section 21(5) and 22(2), for compliance with the requirements of Section 21(1) and 21(2) of the Water Act (1956). It was also confirmed that the NamWater laboratory, Analytical Laboratory Services and Windhoek Municipality laboratory are all compliant of the Water Resources Management Act (2013) proposed quality standards. These laboratories are also regularly tested using the inter-laboratory proficiency quality testing according to the South African Bureau of Standards and they are all working towards complying with ISO 17025.

3.1.7 Research Ethics

Letters of introduction and permission to use secondary data were distributed to the respective organizations prior to data being given. The given data were not manipulated and the analyses were carried out on the collected raw data as they were given. These ethical considerations also apply to data used in Sections 3.2 and 3.3.

3.2 Assessment of the Availability and Adequacy of Drinking Water Sources in the USB

To assess the availability and adequacy of water within the USB, three approaches or methods were used as follows:

1) Time series forecasting: Time series forecasting method was used to assess and predict (a) rainfall for Windhoek; and water sales used as proxy for demand for (b) Windhoek and (c) Okahandja up to 2050.

2) WEAP Model: The WEAP model was used as "what – if" scenario technique to simulate natural hydrology, dams and borehole capacities, treatment plants capacities, water quality parameters, water demands, transfer capacities of pipelines and pump stations and other programmable factors that impact on water resources to predict future changes in water quantity and quality for management decision support in the USB and CAN.

3) Simple Water Balances: Based on content analysis, cross sectional simple water balance equations for CAN for financial year 2013 and a conceptual model for Windhoek were developed. Based on the components in the water balance for Windhoek, a qualitative assessment was carried out using adaptive approaches to optimise the available water resources.

The methodologies used for each approach are presented the next sections.

3.2.1 Time Series Forecasting for Windhoek Rainfall and Annual Water Demands (Windhoek and Okahandja)

3.2.1.1 Research Design, Population, Sample and Research Instruments

Time series ARIMA forecasting methods (Section 2.4) were used to assess and predict rainfall for Windhoek and water sales for Windhoek and Okahandja. In the case of Windhoek rainfall the population was the totality of all monthly rainfall from 1891 to 2012. With regards to annual water demand, the population is the totality of all annual water sales for Windhoek from 1967 to 2014 and for Okahandja from 1998 to 2014. The monthly rainfall data from 1891 to 2012 were sourced from NamWater whose primary source was the Namibia Meteorological Service (NMS)'s daily rainfall figures.

The daily rainfall data were measured and collected by the Namibia Meteorological Service, using standard rain gauges in millimetres according the World Meteorological Organization (WMO) standards (WMO, 2015). The data are stored in a data bank for access by authorized users (Namibia Meteorological Service, 2015). Water sales figures for the Windhoek and Okahandja were measured as sold water from installed water meters. These sales data were treated as proxy for water demand of customers taking cognisance of losses which may occur in the distribution system. For the purposes of this study, the distribution losses after the sales meters for Windhoek and Okahandja were assumed to be equal to the 'normal' loss allowance usually incorporated for calculating water demands for these towns.

3.2.1.2 Procedure -Rainfall (Windhoek) and Water Demand (Windhoek and Okahandja) Modelling

Descriptive summary statistics of rainfall and the respective water demands, in the form of measures of centrality and dispersion, time series plots, and autocorrelation functions were generated using R time series statistical software. The Box Jenkin's ARIMA modelling procedure (model identification, model estimation, model validation) was used. The commands for the time series analysis are given in Annex 4 and Annex 5.

3.2.1.3 Data Analysis

Time series and autocorrelation plots of the data using R, Statistical Package for Social Sciences (SPSS) and MS Excel packages were carried out. Various univariate ARIMA models were explored to determine the best model. The Trend and seasonality observed in the time series plot and ACF plots were removed by appropriate differencing methods prior to the development of the ARIMA model. The best model was chosen based on the AIC. Residual analysis was performed to assess the identified model for adequacy. This model was then used to forecast monthly rainfall for up to the year 2050 to assist decision makers and policy makers to prioritize water demand, storage distribution and disaster preparedness. Model diagnostics based on residual analysis were performed to assess the adequacy of the identified models.

3.2.1.4 Validation and Reliability

Reliability refers to the consistency of measures and how replicable they are. This means the instrument measures should be the same each time used under the same conditions with the same subjects (Dutra et al., 2013; Stampoulis et al., 2013). The NMS provide a level of service to standards set by the World Meteorological Organization (WMO) and the International Civil Aviation Organization (ICAO). The NMS ensures that data supplied to users are of acceptable quality using national and international proven quality control methods and adhering to climate data management standards as set by WMO. The Municipalities of Windhoek and Okahandja ensure that the installed water metres, from which the historical water demands are computed, are constantly monitored and replaced when necessary to avoid the risk of disputed bills from NamWater. At the terminal reservoir supplying Windhoek, two water meters in series are installed so that any malfunctioning meter is quickly detected.

NamWater, in collaboration with MAWF, ensures that the hydrometric instruments and equipment they use are regularly calibrated, serviced and maintained for validity and reliability of water flows and evaporation measurements according to the SADC Hydrological Cycle Observing Systems (HYCOS) (Rutashobya, & Wellens-Mensah, 2002).

3.2.2 Assessment of the Availability and Adequacy of Drinking Water Sources in the USB and CAN – WEAP Modelling

3.2.2.1 Research Design, Population. Sampling and Research Instruments

For the WEAP model the population of the study comprised the demand sites, transmission links, reservoirs, main rivers, water pollution point sources and their reaches in the USB and CAN. The WEAP model simulated natural hydrology, dams and borehole capacities, treatment plants capacities, water quality parameters, water demands, transfer capacities of pipelines and pump stations other programmable factors which generated data for the analysis. To model water quality with the WEAP model, the Klein Windhoek River (up to the discharge point into Swakoppoort Dam) and pollution sources within its confines were purposively selected as they closely met the WEAP model assumptions. Secondary data on river flows, reservoir inflows and net evaporation losses fed into the WEAP model were confirmed to have been measured using weirs, gauging plates, weirs flumes, water meters, evaporations pans and data loggers from standard installations operated by NamWater and MAWF. A free student WEAP software license was obtained over the period of the study.

3.2.2.2 Procedure –WEAP Modelling in the USB

A WEAP tutorial version was tested on-line and then a formal student licence (lasted for a year) was applied and obtained on-line. This was followed by setting up the time frame, spatial boundary, system components and configuration of the USB and CAN areas. The model was then calibrated by comparing the actual demands, resources and supply system generated by WEAP with the CAN model results.

Different parameter values were then input into the WEAP to simulate different scenarios to see the impact of alternative assumptions on the future water availability. Finally the results of the model were evaluated and used.

In detail, the WEAP model comprised of 4 main stages namely **analysis, scenario generation, evaluation** and **decision**. The analysis stage described the representative water situation of the basin and produced the basic inputs for the next phase. The analysis stage included the assigning of the topology of the water system (i.e. main rivers, reservoirs, transmission links, and demand sites), historical hydro-meteorological data, and the water quality parameters. At the scenario generation stage, reference scenarios were developed as 'developments which cannot be directly influenced by the decision makers' like population growth or hydro-meteorological variability. To see how the model would perform in terms of demand and supply, various scenarios were demonstrated. The scenarios included the baseline, emergency period cases, outcomes of alternative management practices, and estimation of future supply conditions. The evaluation stage involved the definition of possible alternatives along with their time frames of application and the simulation of comprehensive scenarios which combine reference scenarios with alternatives yielding the performance matrix which is the basic instrument for decision making (Yilmaz & Harmancioglu, 2010).

The initial stage of the WEAP modelling was to construct the schematic layout of the area to be modelled. To simplify this process, two areas were delineated and schematized as follows. The CAN area being the integrated water supply area supplying the USB (Figure 3.1), was first mapped then the secondly a schematic map of the USB constructed (Figure 3.2). The WEAP topology was constructed according to NamWater (2011a). The raw water from the Three–Integrated–Dam System is transferred to the Von Bach Water Treatment Plant. Raw water is also supplied from Swakoppoort Reservoir to Karibib Town and Navachab Mine and other small water customers.

The water pollution point sources and their reaches including Gammams wastewater treatment plant and Goreangab Dam water combined as a single point source of pollution in the WEAP model while, Meatco Tannery and the Chicken farm and Okahandja ponds effluent were included as three additional point sources of pollution. Since the Ujams industrial wastewater effluent was commissioned in 2014, the outflows scenarios, considered only at the Meatco tannery to enable modelling of mixing carriage or head flow waters at the tannery. The rivers shown in red on Figure 3.2 were the ones water quality modelling was attempted.

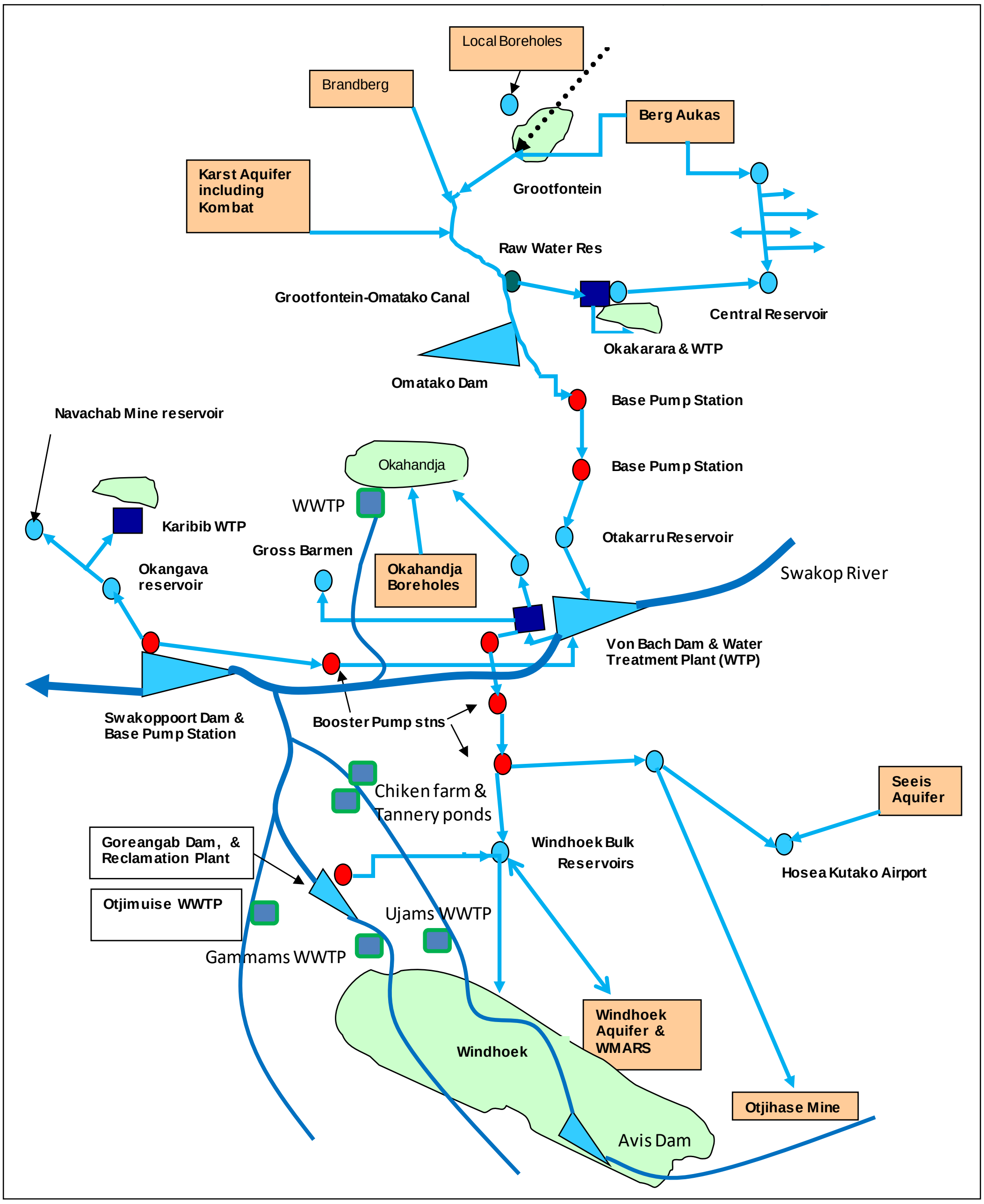


Figure 3.1 Layout of the Central Area Water Supply Network of Namibia (Including the USB)

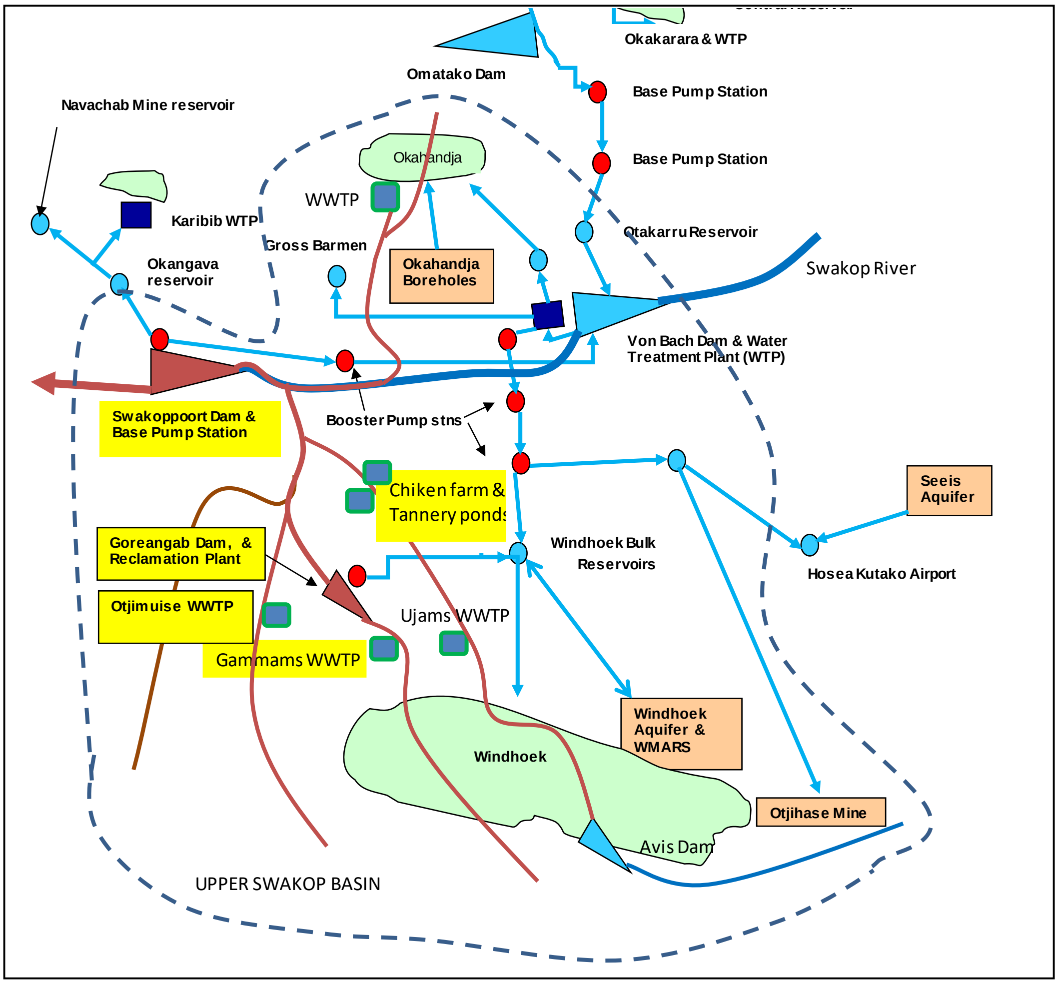


Figure 3.2 Layout of the Upper Swakop Basin Study Area

Groundwater, supplied from Kombat, Berg Aukas and Karst, is transferred from the north and discharged at Von Bach Dam reservoir where the water is treated and distributed to Windhoek, Okahandja and other customers. Groundwater from Windhoek Aquifer and the reclaimed water, is also supplied to the area as has been discussed in Section 2.3. Based on these operations, the WEAP model was developed to follow the schematic water flows as shown in Figures 3.1 and 3.2

Using the two schematic maps, input data for the study area was fed into the WEAP model during the training phase of the model. The data used in the WEAP model were collected from Namibia Water Corporation, Windhoek Municipality and Ministry of Agriculture Water and Forestry and they are comprised of the following:

- The simulated river flows (runoff), reservoir inflows and river head flows and flow requirements (data supplied from NamWater).
- Monthly net evaporation losses of reservoirs and other consumptive water demand sites (added to the model as demand nodes) (data supplied from NamWater).
- The water demand inputs for Windhoek and Okahandja were outputs from the time series forecasting (Section 3.1.2) and water demand models (Section 3.2.2). The rest of the inputs were based on historical sales (data supplied from NamWater) as well as Namibia National Census figures (2011). While the water demands of the Okahandja and Windhoek were projected using ARIMA model, the water demands for the rest of the CAN were adopted from Lund & Seleenbinder Consulting Engineers (2014), (See Annex 6).
- The surface water sources, including the Omatako, Von Bach, and Swakoppoort Dams- a system of three dams operated as a single integrated transfer scheme that is optimised to reduce evaporation. The dams have different capacity to surface area and storage ratio relationships as illustrated in Table 2 (Section 2.3.2). The discrete sum total 95% yields of these three dam reservoirs is 12.5 Mm^3 per annum while the optimized 3-dam integrated system 95% yield is 20 Mm^3 per annum as shown in Table 2.
- Omatako Dam water should be transferred to Von Bach Dam first then followed by transfer from Swakoppoort Dam. The water treatment plants input to the model included Von Bach and WINGOC

- Reservoirs' characteristics (locations; surface area capacity curves, operation rules) (data from NamWater).
- The direct water reclamation supply volumes in Windhoek (WINGOC)
- Reclamation plant capacities and characteristics (WINGOC).
- The characteristics of existing water infrastructure (pipelines, pumps, capacity and likely losses) (data from NamWater).
- Monthly net evaporation of reservoirs (data from NamWater).

Some of the key scenario assumptions of the WEAP model included the ground water sources that could be varied and abstracted during drought emergency periods. The drought scenario, in the model was triggered by the assumption that the storage of Von Bach Dam would be set at 0 m^3, then emergency groundwater were to be abstracted from Karst areas (1.48 Mm^3/a); Berg Aukas Mine shaft (5.2 Mm^3/a); Kombat Mine shaft (5.4 Mm^3/a); and Windhoek rechargeable boreholes (5.5 Mm^3/a).

The final simplified schematic map (skeletonization) for WEAP Model with basic data of supply and demand nodes is depicted in Annex 7.

3.2.2.3 Data Analysis

Simulations and scenarios run on the WEAP model included yearly inflows and outflows and their comparison with the CAN model for calibration and validation under the following conditions: a) normal and emergency water supply periods b) abstraction levels to artificially recharge the Windhoek aquifer and c) the 40% limit of the blending of reclamation plant water to the overall Windhoek water demand.

3.2.2.4 Validation and Reliability

The WEAP model is linked to a parameter estimation tool (PEST) that can help produce results that match historical data records by examining a range of parameter values and combinations thereof. Based on PEST, the WEAP output data on dams' yearly inflows and outflows were compared with results of the existing CAN model figures as a means of calibration and validation of the WEAP model and to enable the model results to approximate the observed data, since the CAN model has been used on the operation and management of the three integrated dams.

3.2.3 Assessment of the Availability and Adequacy of Drinking Water Sources in the USB - Water Balance Optimization of Windhoek Water Sources

The water balance optimisation scenarios included (a) enhancing the Windhoek Rechargeable Aquifer storage capacity; (b) the use of Goreangab Dam as a pollution detention and check dam and (c) consideration of a unified governance institution. The possible optimisation scenarios resulted in various initiatives being proposed to have a full understanding of the governance of water supply to Windhoek and utilization of the Windhoek Rechargeable Aquifer Storage (WRAS).

3.2.3.1 Research Design

A cross-sectional design incorporating CAN supply and demand data was adopted. Data for water supply sources and water demand for the CAN water supply areas were supplied by NamWater. The Windhoek data were conceptually analysed using the simple water balances of the various components. This was done as a general approach to see possible future optimization scenarios. To gain an understanding of proxy demand growth, the sample sales were analysed for Von Bach– Windhoek water supply system.

3.2.3.2 Population, Sample and Research Instruments

The population was all the yearly water sources amounts (95% yield) for Windhoek and CAN water supply areas and all the yearly water demands for the CAN and in particular the Windhoek.

The cross sectional sample water balance comprised the year 2013 water sources figures for the CAN water supply area and the 2013 yearly demands for the CAN water supply area. For the calculation of Windhoek's demand growth, the Von Bach -Windhoek historical water sales (proxy for demand) from 2009 to 2013 years were used.

3.2.3.3 Procedure

Using simple water balance equation/s approaches, the various possible optimization scenarios of the yearly sources, demands and storages were conceptually analysed and discussed based on key conceptual equations. Based on content analysis of possible optimization scenarios of the available water sources supplying Windhoek, the conceptual water balance was constructed and analysed. From the simple water balance components, water quality and quantity of these sources were optimised. The key conceptual equations used are given as follows:

a) Rainfall = evaporation +transpiration + seepage (groundwater) + runoff (turning into surface storages and flows);
b) Inflow $_{\text{Von Bach}}$ = Transfers from other dams into Von Bach reservoir + runoff – evaporation – demand abstractions- seepage = change in reservoir storage
c) Supply to Windhoek = yield of surface reservoirs + water reuse + aquifer (Windhoek rechargeable aquifer) + rainwater harvesting within the city.

To assess the water security situation (cross section), a simple water balance of yield of supply sources and the sales (proxy for demands) and based on the 2013 historical sales figures was carried out.

3.2.3.4 Data Analysis

The annual rate of increase in water sales from Von Bach dam reservoir in Windhoek from 2009 to 2013 was calculated as the difference in the annual sales of 2009 and 2013 divided by the number of years' difference expressed as a percentage of the base year sales (2009) i.e.

$$\frac{Annual\ Sales(2013) - Annual\ Sales(2009)}{(difference\ in\ years).(Annual\ Sales(2009)}\ x\ 100\% \qquad \text{Equation} \quad 8$$

Validation and Reliability

The combined yield of the three dam system, water levels, evaporation losses, storage changes and abstractions and transfers, from each of three dams' reservoirs (Omatako, Von Bach and Swakoppoort) supplying water to Windhoek and other demand centres (data obtained from NamWater) were checked and corrected for errors using weekly water balance model of NamWater.

3.3 Assessment of the ethical, social and health acceptability and perceptions of water reuse for potable purposes in Windhoek

3.3.1 Research Design

The study was based on a mixed design incorporating quantitative and qualitative cross-sectional studies of some Windhoek residents' perceptions on the social, ethical and health issues of water reuse.

3.3.2 Population and Sample

The population of this part of the study was all the residents of Windhoek involved in the water sector. From the informed public, a purposive sample of 100 residents were selected and investigated. The informed respondents were sampled based on either acquiring or having acquired tertiary education and having a water profession background (UNAM students, MAWF, NamWater, Municipality of Windhoek and WINGOC employees). Some general workers from Katutura Suburb, one of the low income suburbs of Windhoek were also included. Another 15 respondents considered to be key stakeholders were sampled from those involved in the processing, management and regulating of water reuse in Windhoek (MAWF, Municipality of Windhoek and WINGOC senior technical employees). For the survey carried out to the informed public, a set of 100 questionnaires on perceptions of water reuse were issued and 86 people (86% response rate) responded.

3.3.3 Research Instruments

Based on literature on previously conducted surveys elsewhere (Hurlimann, 2008; Ogilvie, Ogilvie & Company, 2010; Vedachalam & Mancl, 2010), the public's views and perceptions on water reuse for drinking were collected using a self-administered structured questionnaire. This questionnaire (Annex 8) captured the respondent's demographic information, water resources knowledge of the USB, familiarity with water reuse terminology, water reuse purposes and their acceptability and the degree of confidence in water treatment and reuse agencies in Windhoek. The questionnaire also inquired on water reuse quality assurance publicity and public participation and governance areas.

The second questionnaire (Annex 9) to key stakeholders involved in the production and water process quality assessment of the recycled water for drinking, captured the respondent's knowledge and perception on standards, the independence of water quality results, acceptance and ethical issues, quality of the raw water sources for the water reuse plant, confidentiality and public water governance issues. The questions in this questionnaire were mixed (open –ended and close ended).

3.3.4 Procedure

The two sets of questionnaires were pre-tested and pilot tested on colleagues. The questionnaires were administered face-to-face to willing/volunteering respondents. The permission of the respondent were first requested after the purpose of the spontaneous questionnaire process had been explained. Some respondents requested to hand in the questionnaire latter. Telephonic and email appointments were made with the key informants / stakeholders. From both set of questionnaires the returned surveys were reviewed by checking completeness and call backs were done where necessary to validate the responses. Upon completion of the survey the responses were transcribed into electronic coded format.

3.3.5 Data Analysis

Data entry, cleaning and analysis were carried out using SPSS and MS Excel. Qualitative responses were organised into emerging patterns and themes which were then summarised. The quantitative data were analysed using descriptive summary statistics in the form of frequency tables and charts. The results and findings were reviewed and triangulated and presented in Chapter 6.

3.3.6 Validation and Reliability

To improve the validity and reliability of this section of the study, the questionnaires were pre-tested and pilot tested on colleagues. The results of the pilot test survey were used to modify the research instruments as necessary. For the key informants the semi structured interview format was adopted to ensure that the same subject or scope was maintained at each questionnaire administered.

3.3.7 Research Ethics

Letters of introduction and requesting permission to collect data were developed for respondents where data were collected. For each questionnaire administered, the respondents were requested to participate freely. Anonymity and confidentiality were guaranteed since no name was attached to the recorded responses; the collected information was monitored and was not available for unauthorised access.

3.4 Assessment of water governance in the USB (legal and institutional framework, participation, integration and coordination)

This section focused on the objectives related to water governance assessment of various stakeholders and issues on the management of source water quality in the USB. To achieve these objectives, three sequential workshops were held based on integrating scenario workshops, mediated modelling and socio-multi-criteria evaluation techniques to assess participation of stakeholders in the water governance issues of the USB.

Background to Workshop 1: During the 2010 and 2011 annual CAN workshops (Namibia Water Corporation, 2010[1] and 2011[2]) it was highlighted that the hypertrophic Swakoppoort and trophic Von Bach Dams' water quality had deteriorated to deplorable levels. At the second CAN workshop, when discussing the undesirable

[1] Namibia Water Corporation, [NamWater] (2010b). Minutes on the Annual CAN Workshop.
[2] Namibia Water Corporation, [NamWater] (2011b). Minutes on the Annual CAN Workshop.

development around these drinking water source dams the researcher, supported by NamWater, proposed to engage other stakeholders and carry out basin-wide management to improve the quality of water abstracted for drinking from these dams. This was seconded by the Windhoek Municipality representatives. Consequently, a series of meetings were held especially between NamWater and MAWF to prepare for a stakeholder workshop. During the meeting held on 19 October 2011 the upper part of the Swakop Basin upstream of the Swakoppoort Dam was delineated as the relevant domain for the Upper Swakop Basin Committee to focus on addressing the water pollution threatening the security of water supply in the basin. Before Workshop 1 was held, the researcher, MAWF and NamWater identified potential and relevant representatives of stakeholders that form part of the USB. A three day workshop (Workshop 1) was conducted for a purposive sample of the key stakeholders and conducted between 8 and 10 February 2012. The objectives of Workshop 1 were to raise awareness among stakeholders and water users on the water quality and quantity management challenges of the USB; to exchange information on current development challenges and their impacts on the water resources; to discuss the importance of basin (health) protection towards sustainable development; and to initiate discussions towards establishing a USB Management Committee based on IWRM principles. Workshop 2 followed Workshop 1, and its objective was to facilitate the formation of the USB Management Committee.

Background to Workshop 2 Following Workshop 1, MAWF together with NamWater invited proposals for an independent consultant to facilitate the formation of the Upper Swakop Basin Management Committee. While this process should be driven by MAWF, NamWater with vested interest in the successful outcome of the work of such Committee, agreed to fund such facilitator. NamWater was then tasked to champion the process with the researcher being the leader. It is for this reason that NamWater procurement process was followed in selecting the facilitator. The initial bids advertised and evaluated in September 2012 were unsuccessful as the requested proposals were overpriced and fell short of the technical expectations. The request for proposal was re-advertised and evaluated between March 2013 and July 2013. The Desert Research Foundation of Namibia (DRFN) was awarded the consultancy to continue the process towards establishment of a functional basin management committee and the drafting of the constitution for the Upper Swakop River Basin Committee under the supervision of NamWater. The task of DRFN was to mobilize and engage stakeholders of the USB in the management of water resources; to reinforce the development of a stakeholders' forum structure through reviewing the stakeholders list; and to facilitate a workshop to establish a Basin Management Committee.

Background to Workshop 3: The objectives of a follow-up Workshop 3 were to nominate the USB Executive and formulate its constitution.

Given the nature of three workshops, the roles played by the researcher were mixed and heuristic. The researcher was part of the organisers of the workshops, presented (disseminated ideas, results, received feedback, gathered ideas) and participated (listening, summing up the emerging water governance themes and encouraged open discussion) in the workshops.

3.4.1 Research Design

The research design for the three workshops was based on the integrated ADVISOR conceptual framework outlined in Section 2.9 which consists of three interrelated dimensions namely 1] Information (collecting and presenting the relevant scientific information to the evaluation, accounting for the quality of data, the complexity of the problem and the uncertainty of the future, and allowing for multiple description and explanatory frameworks); 2] Assessment: (applying an assessment module to the data, consisting of a comprehensive evaluation of the plausible alternative actions, accounting for different sustainability related criteria); and 3] Process: (actively involving the civil society and the stakeholders in the process of building-up the information base and performing the assessment). Scenario workshops, mediated modelling and social multi- criteria evaluation methods were used in study. Stakeholder mapping, awareness and advocacy were some of the pillars of water governance that were employed during the course of the study. Focus group discussions and workshops were conducted among target groups, users and key players. A theme-related-excursion (to Ujams Wastewater Treatment Plant (WWTP), Goreangab and Swakoppoort Dams) was undertaken during Workshop 1 to have participants gain a visual understanding of the extent of pollution in the USB.

3.4.2 Population and Sample

Representatives from various key water-related stakeholder sectors were chosen to participate in the workshops and focus group discussions based on purposive sampling. Workshop 1 held between 8 and 10 February 2012 had 87 participants, Workshop 2 was held on 20 February 2014 with 60 participants while, Workshop 3 was held on 12 November 2014 with 23 participants. The workshops were attended by stakeholders who mainly included representatives of MAWF, NamWater, Municipalities of Windhoek and Okahandja and Farmers among other representatives. The workshop embraced the *process-oriented pollution investigative approach* in the selection of participants. The participants from key industries were given opportunities to present their water quality and quantity programs on and off their sites.

3.4.3 Research Instruments

The workshops were carried out in conducive and convenient places (Safari Hotel for Workshop 1 and NamPower Convention Centre for workshops 2 and 3). For Workshops 1 and 2, structured questionnaires, power-point presentation by stakeholders and focus group discussion guidelines were developed and used to collect quantitative and qualitative data from stakeholders of the Upper Swakop sub-catchment to capture their opinions on water governance issues (Annex 10). Workshop 1 proceedings were captured using tape recorders as well as workshop review questionnaire. Flip-charts were used for Workshops 2 and 3.

During the Workshop 2, the researcher developed and introduced the 7 "I"s tool (see Figure 3.3). The tool, as a water governance checklist, was constructed from the 7 key water governance concepts outlined in section 2.10. The tool (applied in section 7.2) encapsulates the 7 key water resources governance concepts namely: stakeholder participation; policies and legal framework; intergenerational and sustainability issues; information sharing; efficiency and accountability of implementing agencies and institutions; innovative, adaptive, and results oriented research; inclusiveness and collaboration of independent bodies. Key water related sectors' stakeholders who were invited to the forming of the USB Management Committee participated in using the tool. The implementation of the tool was assisted by DRFN who were the facilitating consultants. The 7 "I"s tool was used to place the stakeholders into seven segments. The 7 "I"s tool was presented as (form) in Table 7 and given to each stakeholder from the sector representatives to conduct a selfcategorization into the seven stakeholder segments through an exercise of scoring each of the seven stakeholder segment. The segment that was served highest was the segment to which the representative was categorized. These key sectors nominated representative organisations to represent them in the USB Management Committee.

Where there were ambiguities as to the sector to which a particular stakeholder belongs the whole workshop was consulted for consensus. Thereafter, all the stakeholders were mapped into the seven stakeholder segments depending on where they had the strongest score. The agreed required strength of each segment (number of nominees each segment would nominate to the Basin Management Committee) and the total number of nominees (organisations only) required to make up the Basin Management Committee was agreed upon by all the stakeholders through consensus.

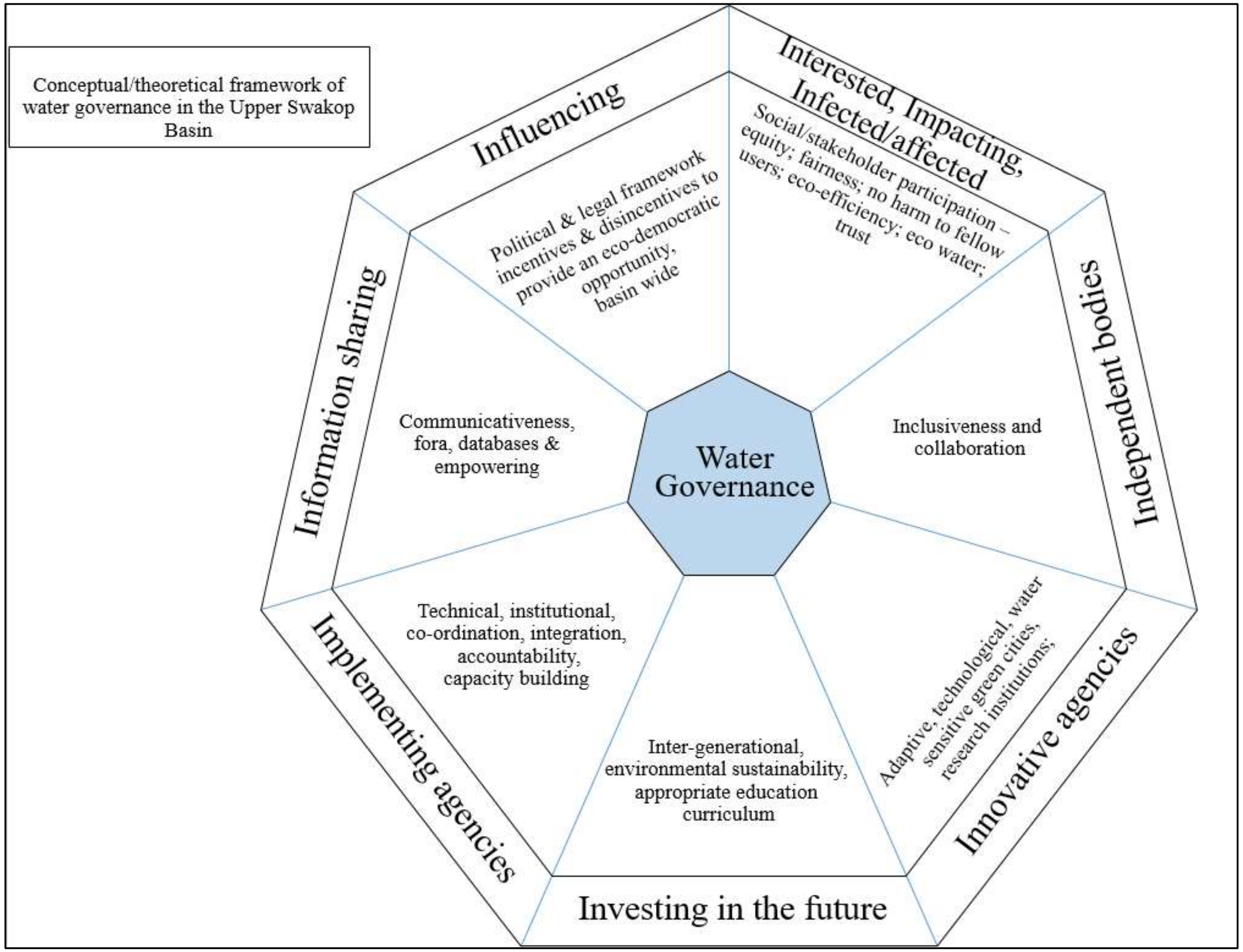


Figure 3.3 The 7 "I"s tool as the Conceptual Framework of Water Governance in the Upper Swakop Basin

Table 7 Adaptive Stakeholder Self-Mapping Tool

	Stakeholder Self-Mapping Tool		
Segment	**The 7"I"Segments**	**Characteristics and Roles**	**Rank your involvement in increasing order from 1 to 7 (your final segment is the one with your highest score)**
1	Influencing agent	wield political power and will at local level (in the basin)	
2	Information sharing agent	responsible for media reporting	
3	Interested /infected / affected / Impacting	suffer damages from a risk due to poor water quality; water user /discharging substantial effluent	
4	Implementing agents	Have mandatory roles due to statutory laws; Responsible for monitoring, policing and control of water pollution; developing and managing water resources	
5	Independent bodies	pressure groups, observers, collaborators	
6	Innovative bodies	Universities, Engineering Council and research bodies etc.	
7	Investing in the future agents	Primary and secondary schools – education and learning (activities to include role plays, drama, essay competitions e.g. " I want to clean water in my future", special events e.g. "Swakop River day"	

3.4.4 Procedure

Workshop 1 Procedure:

Workshop 1 was initiated by the researcher and the General Manager for Engineering and Scientific Services at NamWater. The researcher coordinated the whole process with input from key proponents that includes NamWater, MAWF, DRFN and other stakeholders. The issues pertaining to water pollution impairment of the USB were presented on power point and discussed. The representatives of Windhoek and Okahandja gave the situation assessment of the pollution status and their views on the water pollution challenges. The Namib Poultry, which was then a new wet industry establishing in the basin, highlighted their future pollution management programs. Government institutions, in turn, made presentations on their institutional and legal frameworks as well as challenges they faced. The workshop was chaired by the General Manager of Water Supplies at NamWater and the researcher summarized the salient points of the deliberations and the resolutions agreed upon at the end of the workshop. Views of participants with respect to workshop design, objectives, awareness of protecting water resources, missing links in protecting water resources, and overall views on water governance were evaluated based on Likert rating scales and open ended questions. The researcher was the main editor of the workshop proceedings.

Workshop 2 Procedure: Before Workshop 2 was held, the researcher, MAWF, NamWater and DRFN, as the facilitating consultant, formed a steering committee. The committee identified additional stakeholder organisations that were to be included beyond the stakeholders invited during Workshop 1 formed nucleus stakeholder forum from which the USB Management Committee would be formed. During Workshop 2 the 7 "I"s tool was introduced and utilised by DRFN to map stakeholders into their respective segments. The tool was also administered to reveal sectors that needed strong representation in USB management committee and to facilitate the fair representation of each sector. The USB management committee was nominated and thereafter tasked to take over the implementation of required basin activities, come up with the constitution and nominate the Executive Committee of the USB in-line with DWAF guidelines as contained in the Basin Management Approach Guidebook (2013).

Workshop 3 Procedure: A follow up Workshop 3 was held on 12 November 2014. At this workshop, the Upper Swakop Basin Executive was nominated from the wider basin management committee formed at Workshop 2. The Constitution for the Committee was formulated and the roles, responsibilities and functions thereof were endorsed. The draft constitution prepared by the DRFN was endorsed during Workshop 3 and recommended for final approval by the Minister of Agriculture, Water and Forestry as required by the Water Resources Management Act (2013).

Procedure for the assessment of (1) *participation, and the overall evaluation of water governance in USB:* The participatory Workshops 1, 2 and 3 were organised based on scenario workshops, mediated modelling and socio –multi criteria evaluation techniques. The data obtained during the workshops were analysed based on the ADVISOR analytical framework (Antunes et al., 2009). The tool assessed the level of participation, stakeholder groups involved, participatory platform, participant selection procedure and overall influence of participation on the final decision. The overall governance of water resources in the USB was assessed based on the developed 7 "I"s tool and content analysis.

For the assessment of participation and overall water governance, the study employed a systems' adaptive approach to analyse and contextualize the water governance in the USB based on the derived 7 "I"s tool. The tool integrates the seven domains of water governance contemporary to the USB study area. Using the tool, the overall water governance performance for each segment was evaluated on a rating scale of 0 (0= absence of the desired attribute); 0.5 (0.5=limited presence of the desired attribute) and 1 (1=presence of the desired attribute).

Procedure for the assessment of 2) *Legal and Institutional Frameworks* (*water governance structures):* Permission and appointments to the collect the data was sought and given. Content analyses of the existing legal policies and laws as well as institutional organograms were carried out respectively. The results were analysed and evaluated within the water governance themes.

3.4.5 Data analysis

Institutional Framework and Organograms: Analysis of the strengths and weaknesses of the Directorate of Water Resources Management personnel was based on the number of established posts, vacant posts, personnel strength (filled posts divided by total posts in the establishment). An assessment of water governance structures, pollution awareness, participation, integration, and coordination of main players was carried out. The existing bottom up reporting structures were analysed based on the length of the line of command in their decision making process, decentralization, empowerment and governance effectiveness. Qualitatively, the existing (e.g. MAWF) and forming (e.g. USB) basin management structures were analysed in terms of their empowerment (decentralization), technical capacity, accountability; responsiveness, perceived political relevance, and route length of the reporting structure of the basin management committee. For the assessment of the legal framework, content analyses of existing policies and legal frameworks as well as institutional and legal reforms were carried out.

3.4.6 Validation and Reliability

The research instruments (questionnaires for assessing the workshops) were pilot-tested to iron out oversights and omissions. Based on recommendations of various authors (Patton, 2002; Yin, 2003; Creswell, 2009), the theory /perspective triangulation method was employed to ensure consistency and validity of the analysis for the overall water governance. Triangulation involved the use of several methods or data that is from observation, documents, interviews, piloting and refinement of such data.

3.5 Summary

The methods used in achieving each of the four objectives have been discussed in this chapter. The next four chapters (chapters 4 to 7) will give the results and discussions of each of the objectives of the study.

CHAPTER FOUR

4 RESULTS OF THE ASSESSMENT OF WATER QUALITY WITHIN THE UPPER SWAKOP BASIN

4.1 Results and Discussion

This section presents the results and discussion on the assessment of water quality within the USB.

4.1.1 Descriptive Statistics for the Water Pollution Parameters

The minimum, maximum, mean, standard deviation, 95% confidence interval and median values of the water quality parameters and the proposed corresponding limiting values for each parameter MAWF (2012) standards are given in Table 8. Generally, the physical and nutrient parameters were heavily skewed rendering the arithmetic mean unsuitable for measuring central location thereby making the median the more appropriate measure. The sample sizes used in obtaining the descriptive statistics for each parameter ranged from 4 to 222 indicating many data gaps. This was because the samples were taken by various organizations for different objectives.

The medians of the water quality parameters were compared to MAWF (2012) standards. Results indicated that the median concentrations of Dissolved oxygen (DO) (1.8 mg/L); Conductivity (146 mS/m); Total dissolved solids (TDS) (878 mg/L); Total suspended solids (TSS) (160 mg/L), Chemical oxygen demand (COD) (123 mg/L); Chromium (3.20 mg/L); Colour (18.00 Pt- Co units) and Sodium (175 mg/L) were all outside the permissible limits.

Water pollution from the heavy metal chromium could emanate as a result of either natural leaches from top soil and rock or from industries that include electroplating, leather tanning and textiles. Health-wise, chromium is carcinogenic and causes asthmatic and allergic reactions.

Table 8 Descriptive Statistics of Key Parameters showing Extreme Values and MAWF (2012)

Parameter	Sample Size	Minimum	Maximum	Mean	Median	Standard Deviation	95% Confidence Interval		MAWF Permissible Limits (2012)
							Lower	Upper	
DO mg/L	115	0.1	14.20	2.79	1.80	3.67	2.23	3.36	>75% Saturation
Redox mV	111	1	579.00	156.78	103.00	127.36	132.83	180.74	
PH	222	5.9	12.30	7.98	7.85	0.83	7.87	8.09	6.5-9.5
Conductivity mS/m	222	1.8	23,500.00	653.97	146.00	2,635.29	305.40	1,002.54	<75ms/m
Turbidity NTU	221	0.02	4,109.00	133.57	9.40	472.60	70.91	196.23	>12ntu
Total dissolved solids TDS mg/L	105	1.23	160,905.00	3,382.18	878.00	16,013.00	283.26	6,481.10	<500
Total suspended solids TSS (mg/L)	151	1	134,714.00	3,762.16	587.00	16,770.20	1,065.56	6,458.75	<100
COD mg/L	111	10	26,967.00	1,365.05	123.00	3,982.32	615.97	2,114.12	<100
BOD mg/L	111	0.99	4,020.00	253.26	18.00	772.68	107.92	398.61	<30
Absorbed Oxygen mg/L	111	2	2,260.00	96.27	16.00	284.78	42.70	149.83	
Sulphate mg/L	215	0.99	4,706.00	324.76	139.00	659.63	236.09	413.43	<40
Total Phosphate mg/L	151	0.1	67.00	8.72	1.60	14.45	6.39	11.05	<3
Chlorine as Cl mg/L	215	2	75,650.00	1,778.91	160.00	8,669.48	613.48	2,944.33	<0.1
Nitrate as NO3 mg/L	217	0.1	68.00	3.80	1.00	8.49	2.66	4.93	<20
Nitrite as NO mg/L	148	0	55.00	0.77	0.10	4.55	0.03	1.51	<3
Ammonia as NH4 mg/L	128	0	1,057.00	35.82	1.00	134.20	12.34	59.29	<10
Total kjeldahl nitrogen (TKN) mg/L	128	0	1,057.00	59.21	5.20	155.72	31.97	86.44	<33
Sodium mg/L	214	6	64,570.00	1,499.68	175.00	7,219.50	526.88	2,472.48	<90
Copper mg/L	133	0	0.10	0.01	0.01	0.01	0.01	0.02	<2
Zinc mg/L	129	0	0.23	0.02	0.01	0.03	0.02	0.03	<5
Cadmium mg/L	135	0	0.20	0.11	0.01	0.02	0.01	0.01	<0.05
Pb mg/L	130	0	0.05	0.01	0.01	0.01	0.01	0.01	<0.1
Total Chromium mg/L	10	0	8.00	3.05	3.20	3.22	0.75	5.35	<1
Colour (Pt- Co units)	100	1	1,335.00	61.92	18.00	161.24	29.92	93.91	<15
Chlorine mg/L	103	0	5.00	0.47	0.40	0.53	0.36	0.57	<70
Silica mg/L	102	1	81.00	19.14	1.60	14.49	16.29	21.98	
P-Alkaline mg/L	67	0	2,300.00	43.05	-	280.94	25.48	111.58	
T-Alkaline mg/L	103	80	14,750.00	539.53	272.00	1,465.48	253.12	825.95	
T-Hardness mg/L	58	20	6,103.00	683.19	419.50	1,109.88	391.36	975.02	
Potassium mg/L	103	3	407.00	29.13	19.00	45.89	20.16	38.10	
Magnesium mg/L	102	8	869.00	90.22	50.00	136.57	63.39	117.04	
Calcium mg/L	101	19	1,011.00	137.00	105.00	134.69	110.42	163.59	
Mangenese mg/L	106	0	25.00	0.90	0.01	4.09	0.11	1.68	>0.4
Iron mg/L	90	0	8.00	0.29	0.04	1.23	0.04	0.55	>1.0
Langelier Index	30	0	1.00	0.58	0.50	0.29	0.47	0.69	
Ryznar Index	30	6	8.00	6.35	6.25	0.39	6.20	6.50	
Corrosivity	30	0	4.00	1.71	1.65	0.93	1.36	2.05	
Stability	30	7	8.00	6.92	6.85	0.22	6.83	7.00	
Sediment	27	0	27.00	2.68	0.20	5.91	0.34	5.02	
Chlorophyll	4	43	130.00	70.00	53.50	41.20	4.43	135.57	
UV-254	17	0	2.00	0.36	0.21	0.41	0.15	0.57	

NB: Median values coloured in red exceeded acceptable limits of Ministry of Agriculture, Water and Forstry (MAWF)

However, median concentrations of Turbidity (9.4 (Nephelometric Turbidity Units (NTU)); Total Phosphate (1.6 mg/L); Nitrate (1.0 mg/L); Nitrite (0.0990 mg/L); Ammonia (1.00 mg/L); Total Kjeldahl Nitrogen (5.2 mg/L); Manganese (0.01 mg/L) and Iron (0.04 mg/L) were within the permissible limits, even though some of the parameter values were extreme and beyond the permissible limits (see Table 8). On the other hand, the median concentrations of the metallic parameters like Copper (0.01 mg/L); Zinc (0.01 mg/L); Cadmium (0.0099 mg/L); Lead (Pb) (0.0099 mg/L); were within the permissible range and had no extreme values. Similarly Chlorine (0.40 mg/L) values were within permissible limit and had no extreme values.

The statistical definition of an extreme value does not always coincide with the technical water quality parameter permissible ranges and maximum limits but are a very useful tool for highlighting unusual behaviour in data sets. Statistically extreme values were isolated to identify critical potential pollution sites (top 5), where applicable, in the USB. All the sampled water pollution parameters data with highlighted extreme values, together with descriptions of their corresponding locations are tabulated (See Annex 11). The most extreme values for each parameter are shown in italics.

The discussion of water quality analysis results was guided by the MAWF (2012) standards, Windhoek effluent discharge regulations (GRN, 2010), and the general water quality assessment guidelines (Chapman, 1996; Stockner et al., 2000). From MAWF and Windhoek regulations, there were generally no specified ranges or limits for silica, potassium, magnesium and sediment load. It should be noted that the MAWF permissible limits are for effluent discharge standards. Freshwater river water standards are different from effluent discharge standards according to each national legal regulatory framework. The study focused on effluent discharge standards as these are more relevant to the USB. According to Part 13, Water Pollution Control section of Water Resources Management Act 2013, Namibia does not prescribe River Water Standards although transboundary monitoring reports are applicable (OkaCom, 2016). Instead, the Act provides for Effluent Discharge Standards. This could be because most of the internal rivers are ephemeral. However, for water pollution control of reservoirs and perennial rivers to be enhanced, there may be need to stipulate and regulate receiving water standards in Namibia as in South Africa. (Water Quality Guidelines for South Africa, 1996)

4.1.2 pH

From the results, the pH values were within permissible range (median pH=7.85) except at the following sites: Okapuka Meatco Tannery (pH=12.3); Namib Breweries (pH=11.0); Namib Poultry Industry (pH=10.2) and Nakara Tannery (pH=10.2). High pH values tend to facilitate the solubilisation of ammonia, heavy metals and salts. The precipitation of carbonate salts (marl) is encouraged when pH levels are high. Low pH levels tend to increase carbon dioxide and carbonic acid concentrations. Lethal effects of pH on aquatic life occur below pH 4.5 and above pH 9 (Nieto et al., 2013). The sampled points with extreme pH levels are shown on the GIS map on Figures 4.1.

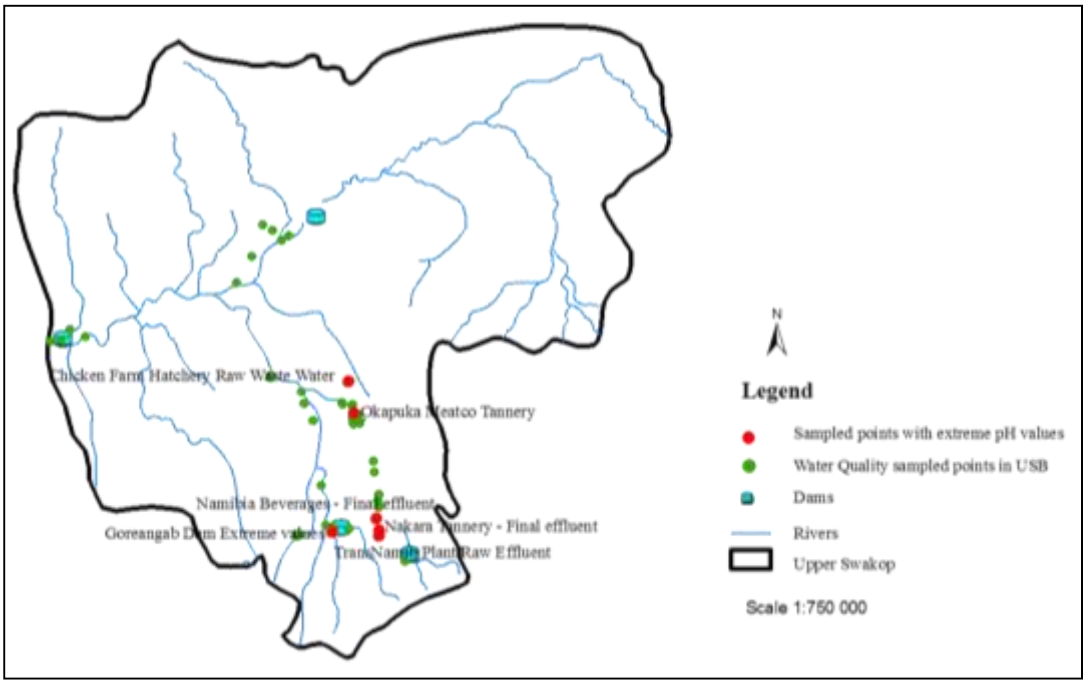


Figure 4.1 GIS map depicting points of extreme pH values and their spatial distribution.

4.1.3 Colour

Colour is a measure of the dissolved colouring compounds in water and is usually attributable to the presence of organic and inorganic materials absorbing different light frequencies. Typically, discoloration is measured in platinum–cobalt scale abbreviated as Pt-Co units. Colour is regarded as a pollution problem in terms of aesthetics, though not detrimental to aquatic life, but excessive levels could be indicative of serious pollutants in the water column. Anthropogenic sources of discoloration include industrial and sewerage effluents, pulp and tannery effluents, and agriculture. MAWF's permissible values are less than 15 Pt-Co units, yet in the USB, the median was 18, indicating serious pollution. The sampled points with extreme colour levels are shown in the GIS map on Figures 4.2. The analysis of extreme concentration values in Pt-Co units indicated that Okapuka Meatco Tannery (Borehole North (Colour= 491), Okapuka Meatco Tannery Evaporation pond E11 (Colour=

1,335), Okapuka Meatco Tannery Evaporation pond E1 (Colour=377), Swakoppoort Dam inflow Dam site water (Colour= 121), Klein Windhoek River (Colour range: 383-599), and Goreangab Dam S1 (Colour= 163) had extremely high colour values. The undesirable colour on the Klein Windhoek River could have been emanating from the Ujams industrial waste treatment plant that has since been upgraded in 2014. The effect of the upgrading was not pursued further in this study.

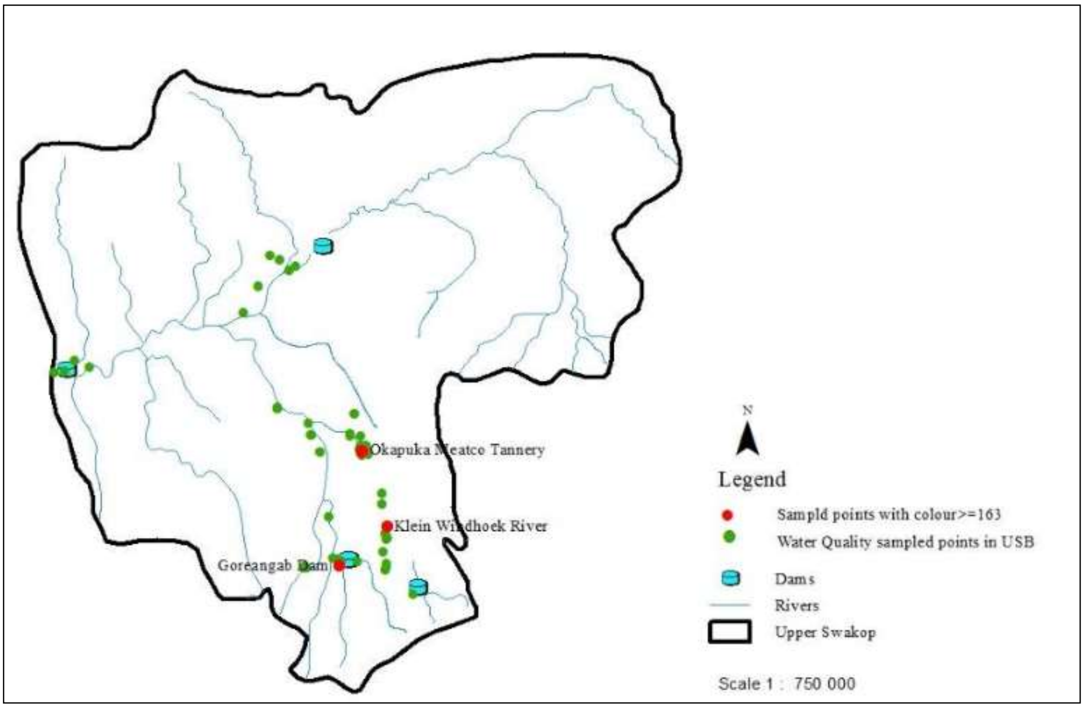


Figure 4.2 GIS map depicting points of extreme colour values and their spatial distribution.

4.1.4 Turbidity

The sampled points with extreme turbidity levels are shown in the GIS map on Figures 4.3. The results for turbidity revealed that final effluent from Okapuka Meatco Tannery (4,109) and Namib Dairies (3,782) had extremely high turbidity. Other pollution sampled points that included Nakara Tannery (2,172), Trans Namib Plant (1,923), Poultry (1,470) and Otjomuise Wastewater Treatment Plant (801) also had final effluent with turbidity values greater than the upper permissible limit of MAWF

(2012). Turbidity is the water clarity measurement to test the quality of water. The suspended materials may include soil particles (sand, silt and clay), algae, plankton, microbes and other substances. Turbidity then measures the relative clarity of the water based on the optical characteristics of water (Davies-Colley & Smith, 2001).

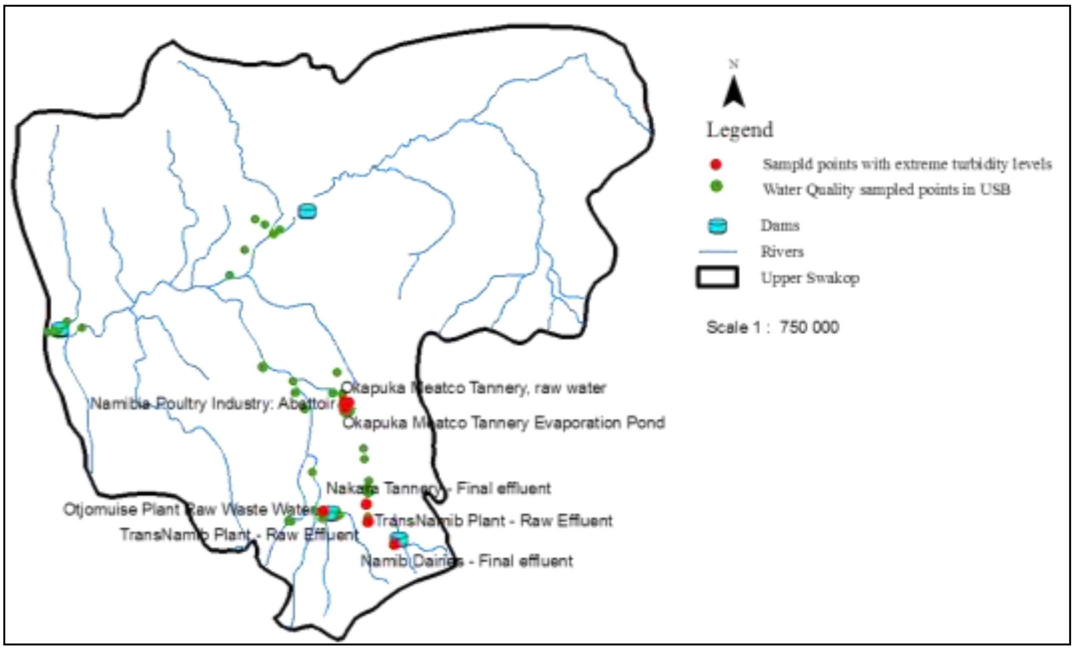


Figure 4.3 GIS map depicting points of extreme turbidity values and their spatial distribution.

4.1.5 Total Suspended Solids (TSS)

Total Suspended Solids (TSS) is a solid-phase measure made up of insoluble materials and chemicals in the water column. In the USB, the TSS concentrations with a median of 587 mg/L, were higher than the MAWF permissible maximum of 100 mg/L. The extreme TSS points are shown in the GIS map on Figure 4.4. Extreme TSS concentration values were observed at Okapuka Meatco Tannery (TSS Range 20,869-134,714 mg/L).

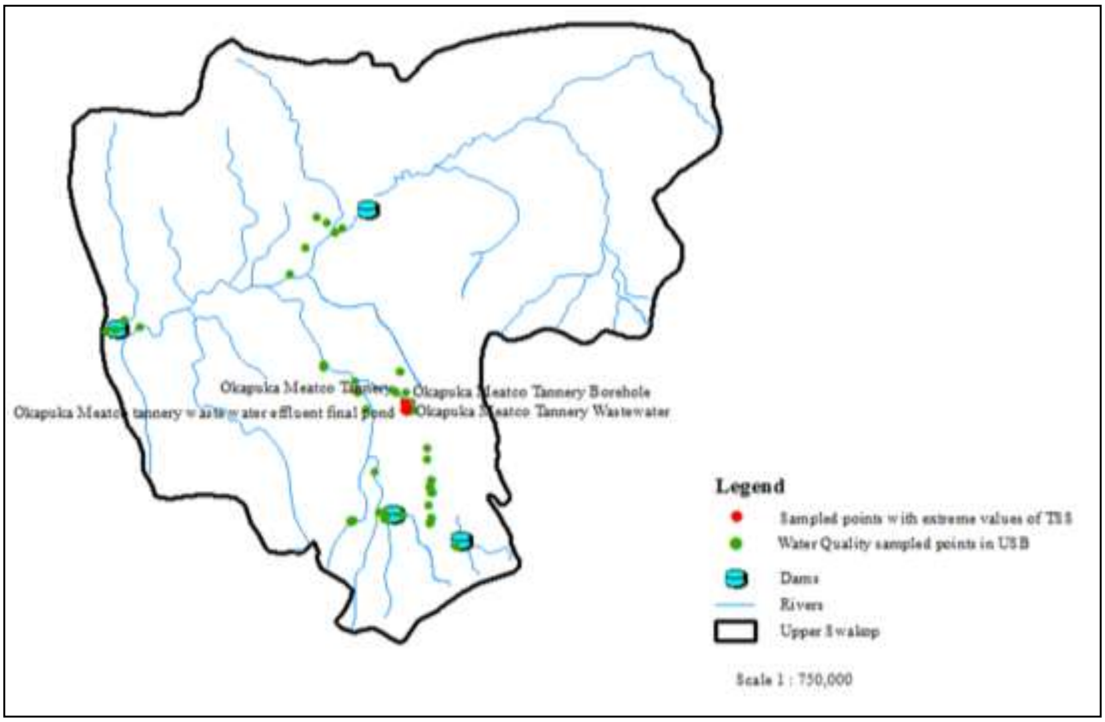


Figure 4.4 GIS map depicting points of extreme TSS values and their spatial distribution.

4.1.6 Conductivity

The median conductivity of water in the USB (Median=146 mS/m) was outside the MAWF and Windhoek permissible limits of 75 mS/m. The extreme conductivity sampled points are shown in the GIS map (Figure 4.5) with extremely high conductivity values observed at Okapuka Meatco Tannery and boreholes (Conductivity range: 4,030-23,500 mS/m). These high conductivity levels could be emanating from the chemicals and salts used at the tannery. Specific conductivity is a measure of the ability of water to conduct an electric current. The greater the content of ions in the water, the more current the water can carry. Ions can be dissolved metals or other dissolved materials. Specific conductivity may be used to estimate the total ion concentration of water and is often used as an alternative measure of dissolved solids when a correlation factor is applied.

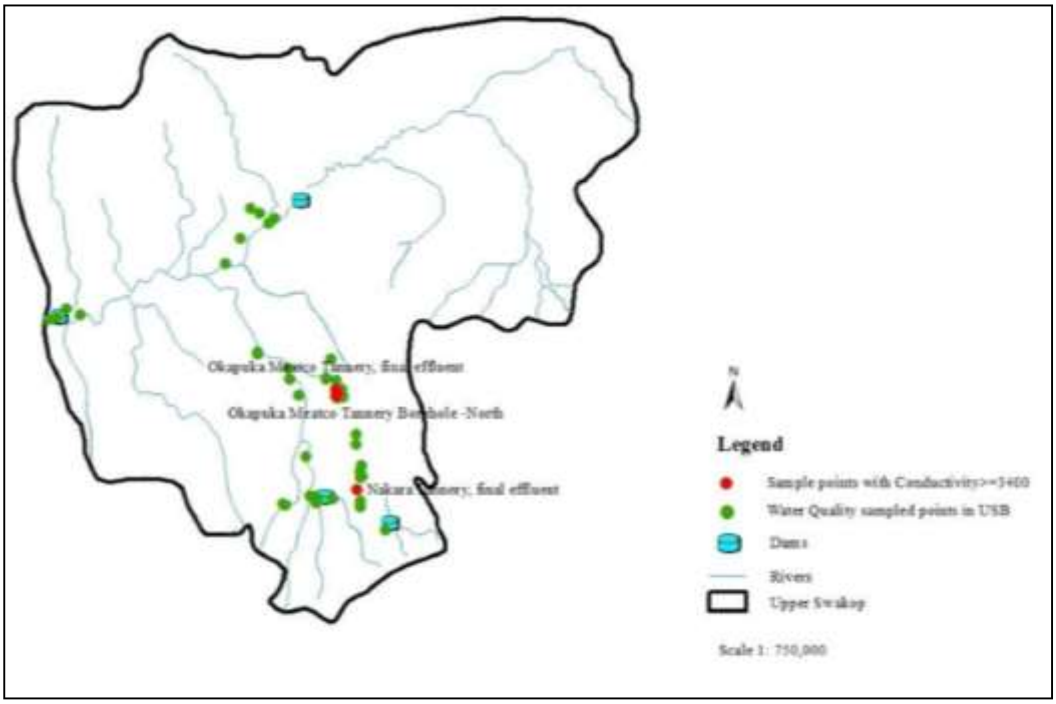


Figure 4.5 GIS map depicting points of extreme conductivity values and their spatial distribution.

4.1.7 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) is a measure of the amount of dissolved materials in the water columns. In natural fresh water, the TDS values range from 0 to 1,000 mg/L (Oram 2010; Oram, 2014). The anthropogenic sources include mining, industrial effluent, sewerage treatment plants, tanneries and road salts. Drinking water values have a maximum of 500 mg/L (Oram 2010; Oram, 2014) which is the same as the MAWF (2012) permissible limit for effluent discharge. However, the median value of TDS in the USB is 828 mg/L which is above the permissible limits and is a cause for concern for the receiving water quality. The extreme TDS sampled points are shown in the GIS map on Figure 4.6. Highly extreme TDS values were recorded at Nakara

Tannery (23,608 mg/L) and Okapuka Meatco Tannery (TDS range: 15,925-161,028 mg/L).

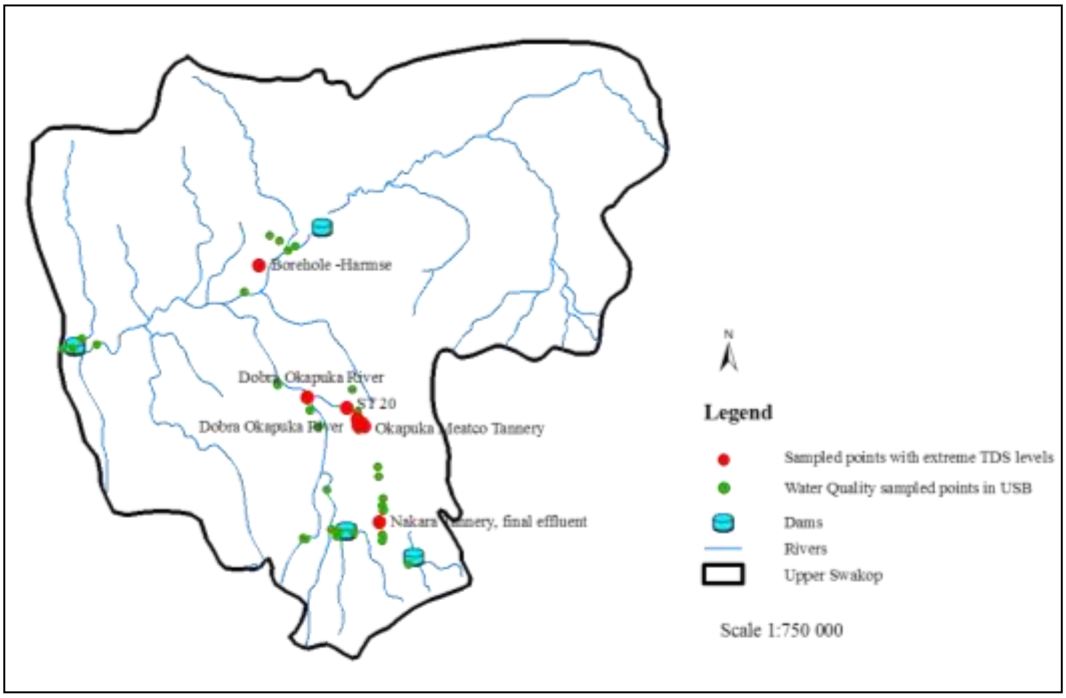


Figure 4.6 GIS map depicting points of extreme TDS values and their spatial distribution.

The results revealed that Okapuka Meatco Tannery, Nakara tannery, Namib Poultry, Namib Dairies, TransNamib, Gammams, and Otjomuise and Ujams wastewater treatment plants had extreme values of TDS. The results also showed that the Okapuka monitoring boreholes (borehole west, borehole south, and borehole north-west) were already polluted. The TDS levels of the Hamse borehole were high possibly because of chemical contamination by irrigation water discharges or because of the natural aquifer chemical properties.

4.1.8 Dissolved Oxygen (DO)

The maximum amount of dissolved oxygen that water can hold (saturation value) depends on the temperature and salinity of the water with cold water and fresh water holding more dissolved oxygen than salty and warm water. The dissolved oxygen data used in the research was measured in milligrams per litre (mg/L). However, the Ministry of Agriculture, Water and Forestry [MAWF]'s (2012) proposed acceptable standard was expressed in percentage saturation (%). According to the MAWF, the dissolved oxygen permissible limit in percentage saturation (%) should be greater than 75%. Assuming an average ambient temperature of 20^{o} C, this permissible range was estimated at between 6.6 mg/L and 8.6 mg/L (Kemker, 2013; Oram, 2014). Results indicated that the median DO concentration (1.8 mg/L) in the basin was below the MAWF permissible range. Based on the sampled population, the extreme values for dissolved oxygen at the USB were 0.1 to 0.5 mg/L. The results showed an environmental hypoxia within the USB with generally extremely low values of DO concentrations (< 0.1 mg/L) as shown on the GIS map (Figure 4.7).

According to Kemker (2013), low values of DO are an indication of excessive pollution depleting the oxygen in the water environment. According to Oram (2014), the dissolved oxygen in a stream may vary from 0 mg/L to 18 mg/L. The generally accepted minimum amount of DO that will support a large population of various fishes is from 4 mg/L to 5 mg/L. Extremely low DO levels may also be indicative of too many bacteria and excess amount of biological oxygen demand - BOD (untreated sewage, partially treated sewage, organic discharges, anoxic discharges and fertilizer runoff from farm fields and lawns) which use up DO.

The minimum DO to avoid acute mortality of aquatic life is 4 mg/L while values greater than 8 mg/L, depending on the water temperature, supports reasonable aquatic life. Usually 2 mg/L is adequate for recreational bathing and swimming. Eutrophic (high nutrient) lakes and dams like Swakoppoort and Goreangab, tend to have low concentrations of DO in the hypolimnion (deeper waters) relative to the epilimnion (shallow waters) while oligotrophic (low nutrient lakes) tend to have high concentrations of DO in the hypolimnion relative to the epilimnion (Nürnberg 1996; Stockner et al., 2000; Kemker, 2013; Jones & Brett, 2014). This implies that the receiving waters in the USB are much starved of DO thereby threatening the ecosystem. Caused by anthropogenic activities, DO is generally decreased by waste water from sewerage treatment plants (domestic and industrial), tannery industries, harvesting of thorn bushes and impoundments (dams).

In the USB, extremely low DO concentrations were observed at Namib Poultry; Okapuka Meatco Tannery; Ujams Wastewater Treatment Plant; TransNamib Plant Effluent; Gammams Wastewater Treatment Plant; Namib Dairies; Okahandja Oxidation Pond final effluent; Nakara Tannery final effluent, Otjomuise Wastewater Treatment Plant, and Goreangab Dam. All these potential pollution sources had DO concentrations of 0.1 mg/L except for Goreangab Dam which had a value of 0.5 mg/L.

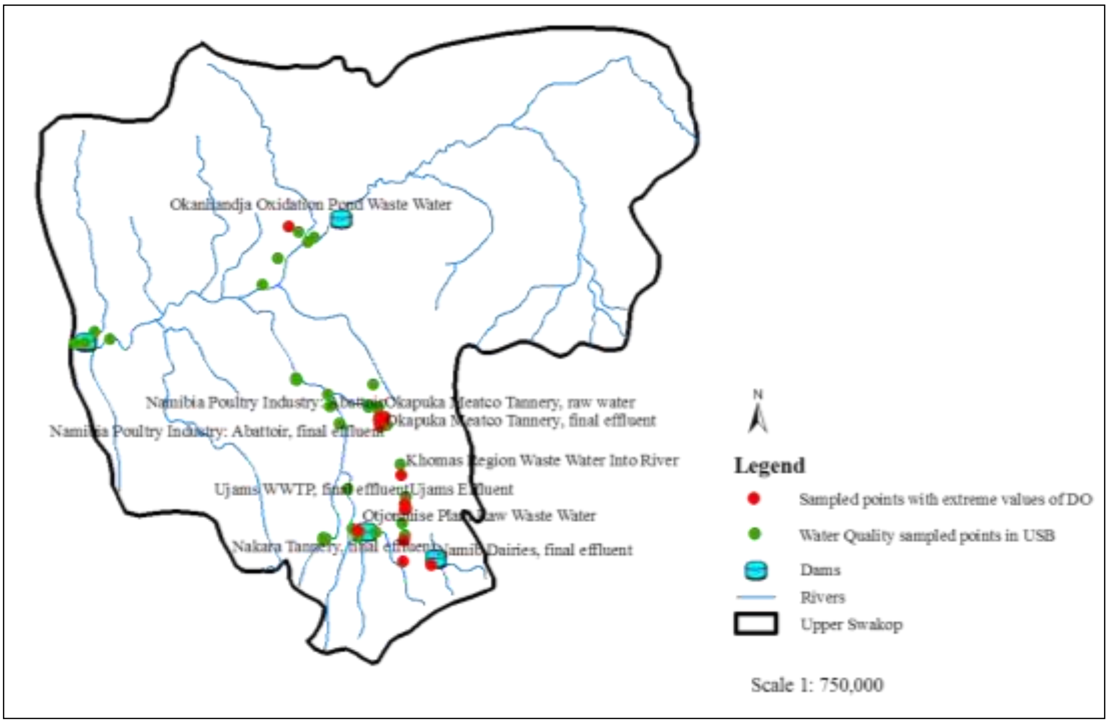


Figure 4.7 GIS map depicting points of extreme DO values and their spatial distribution.

4.1.9 Chemical Oxygen Demand (COD)

The Chemical Oxygen Demand (COD) value is an indirect measure of the amount of organic compounds in a water column by measuring the mass of oxygen consumed per litre of the solution. The COD is used to determine the extent of organic pollutants in water. Anthropogenic sources of COD in storm water are food industries, poultry industry, domestic and tanneries. In the USB, the COD median value was 123 mg/L which is above the MAWF (2012) permissible maximum limit of 100 mg/L. Of concern are the highly extreme values of COD at various effluent discharge sites of Okapuka Meatco Tannery with values ranging from 13,817 mg/L to 26,967 mg/L as well as the final effluent at Nakara Tannery with an extreme COD value of 1,620 mg/L.

These and other extreme COD sampled points are shown in the GIS map on Figure 4.8.

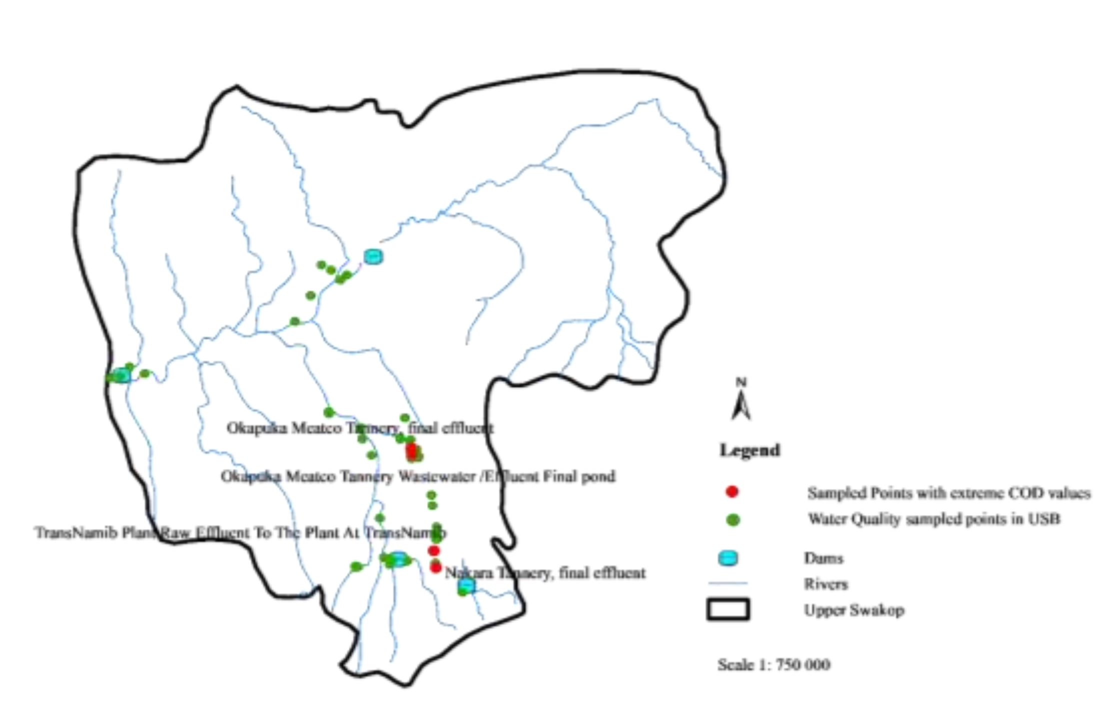


Figure 4.8 GIS map depicting points of extreme COD values and their spatial distribution.

4.1.10 Biological Oxygen Demand (BOD)

Biochemical oxygen demand (BOD) (also called biological oxygen demand) is the amount of dissolved oxygen needed (i.e., demanded) by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period. The BOD value is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20^{o} C and is often used as a surrogate of the degree of organic pollution of water. BOD_5 is often used as a robust surrogate of the degree of organic pollution of water (KrishnaKumari et al., 2016). Even though it is similar to COD which measures everything that can be chemically oxidized, BOD_5 gauges the biologically active organic matter. This measure is also used to check the effectiveness of biological processes of wastewater treatment plants. Anthropogenic sources of water pollution where BOD_5 can be prolific include domestic effluent, tanneries, agro industries effluent etc.

In the USB, median BOD_5 of 18 mg/L was reasonably less than of the MAWF (2012) permissible maximum limit of 30 mg/L. Of concern are the highly extreme values at some effluent discharge sites of Okapuka Meatco Tannery ranging from 2,520 mg/L to 4,020 mg/L as well as the final effluent at Nakara Tannery with an extreme value of 1,620 mg/L. The extreme BOD sampled points are shown in the GIS map on Figure 4.9.

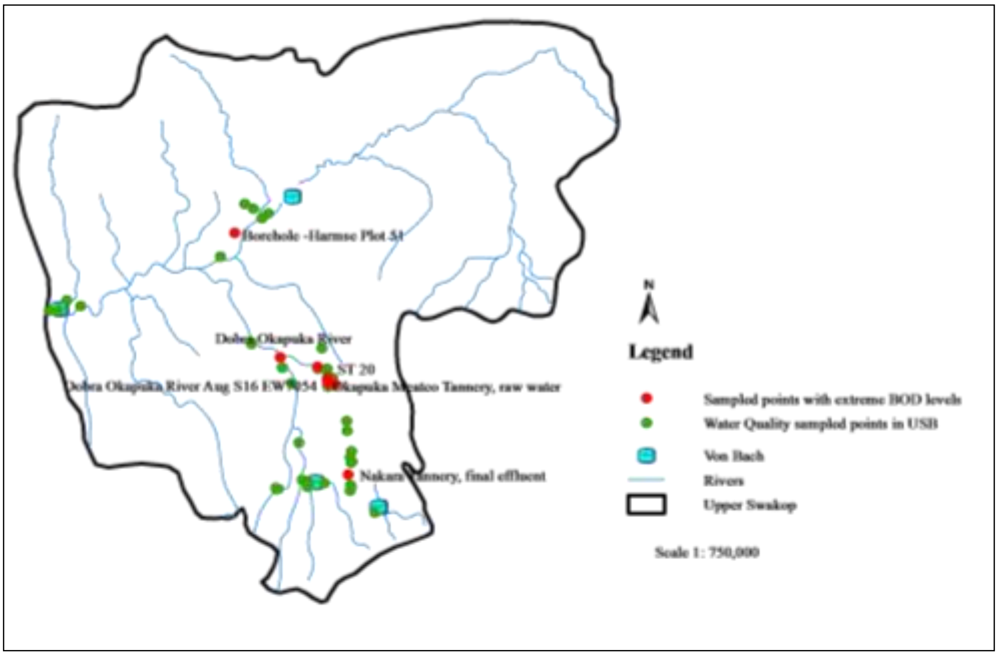


Figure 4.9 GIS map depicting points of extreme BOD_5 values and their spatial distribution.

4.1.11 Nitrates (NO_3)

Nitrate is the most oxidized and stable form of nitrogen in the water body. Without anthropogenic inputs, most surface waters would have less than 0.3 mg/L of nitrate (Gerber et al., 2007, Oram, 2014). Nitrate is the primary form of nitrogen used by plants as a nutrient to stimulate growth, and in water, excessive amounts of nitrogen may result in phytoplankton and macrophyte proliferation. It is a key nutrient for eutrophication. At high levels, it is toxic to infants. Anthropogenic sources include sewerage treatment plant effluents, agriculture effluents (manure and fertilizer), mining (blasting residuals), urban developments (non-point sources of pollution), tanneries, poultry farms, and forestry mills.

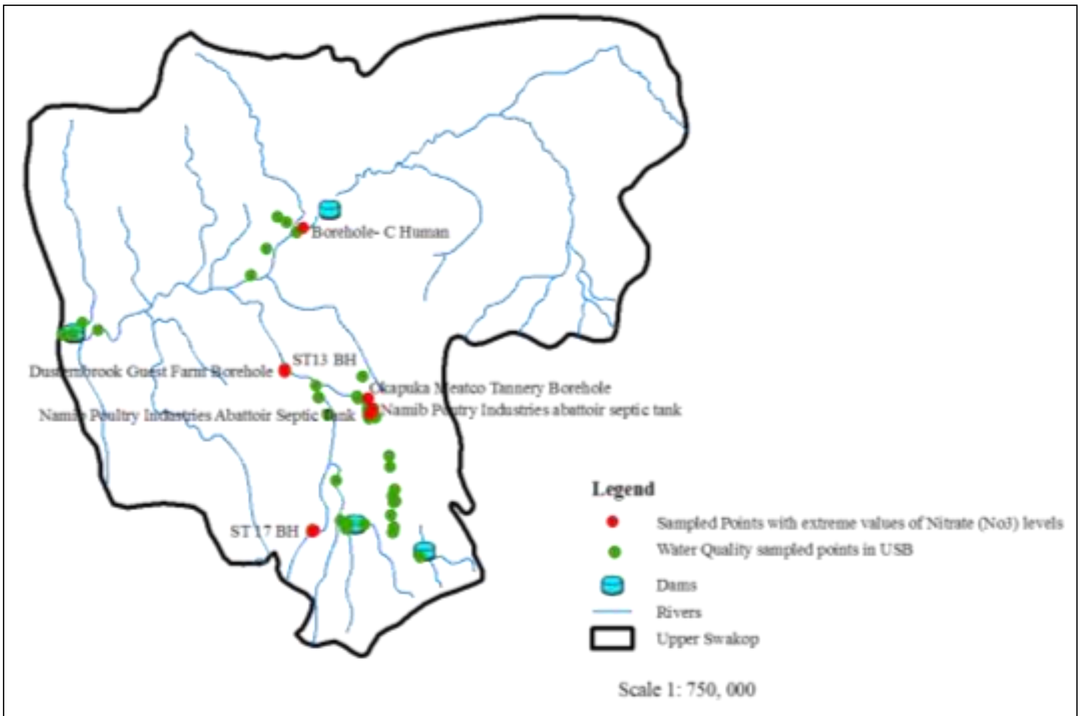


Figure 4.10 GIS map depicting points of extreme Nitrates values and their spatial distribution

In the USB, the median nitrate concentration was 1.0 mg/L. Generally accepted levels of nitrates for drinking water are less than 10 mg/L (Gerber et al., 2007, Oram, 2014) although the MAWF (2012) permissible limit is 20 mg/L. The MAWF acceptable limit is considered too conservative in the case of USB given the eutrophication levels of the water at Goreangab and Swakoppoort Dams. Therefore, a nitrate permissible level of 10mg/L was assumed for the USB. The extreme NO_3 sampled points are shown in the GIS map on Figure 4.10. Based on this, extreme values of nitrates were noted at Meatco Tannery borehole ST 17 borehole (NO_3 =16 mg/L), Meatco Tannery borehole ST 13 borehole (NO_3 =20 mg/L), Namib Poultry (NO_3 =37 mg/L), Human Farm borehole (NO_3 =18.7 mg/L), Dusternbrook Guest Farm borehole (NO_3 =20.7 mg/L), and Okapuka Meatco Tannery borehole North (NO_3 =27.0 mg/L).

4.1.12 Nitrite (NO_2)

Highly extreme nitrite concentrations were observed at Namib Poultry (55 mg/L). The other extreme values were found at Okapuka Meatco Tannery borehole, Swakoppoort Dam, and Goreangab Dam which might be attributed to high ammonia pollution sources. The extreme NO_2 sampled points are shown in the GIS map on Figure 4.11 as Namib Poultry and Meatco Tannery effluent discharge point and Meatco Tannery boreholes. According to Letterman (1999), while nitrate is one of the major anions in natural waters found in low concentrations (0.2 to 2 mg/L) and elevated due to leaching nitrogen from fertilizers, feedlots/tanneries, sewers and septic tanks, nitrite does not typically occur in natural waters at significant levels.

The high values of NO_2 that were observed may be caused if water with sufficient ammonia is treated with permanganate or where sodium nitrite is widely used for cured mats pickling and beer. Intensification of poultry production may cause water pollution due to leaching and runoff of nutrients such as nitrogen, phosphorus and other excreted substances such as hormones, antibiotics, pathogens and heavy metals. The conversion of dietary nitrogen to animal products is relatively inefficient (50% to 80%). It should be noted that nitrogen from manure (possibly from Meatco Tannery feedlot and Namib Poultry sites) takes four main forms: ammonia (NH_3), dinitrogen (N_2), nitrous oxide (N_2O) and nitrates (NO_3) (Gerber et al., 2007). The extreme generation of nitrites at Meatco Tannery feedlot and Namib Poultry sites could be seriously negatively impacting on the downstream water in Swakoppoort Dam.

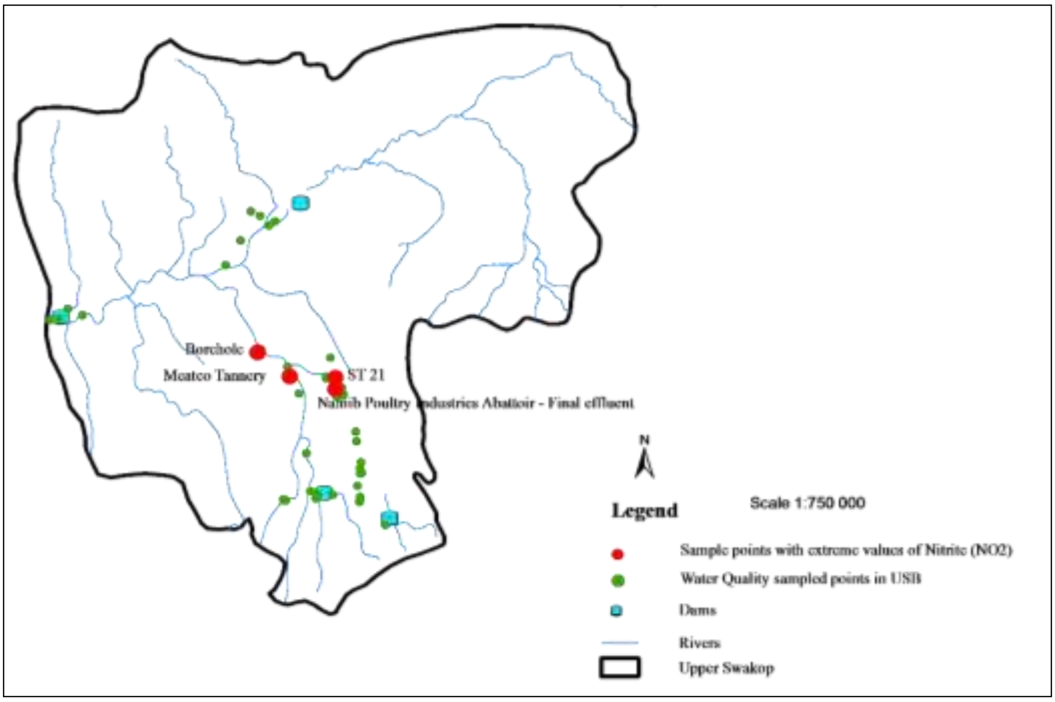


Figure 4.11 GIS map depicting points of extreme nitrite values and their spatial distribution.

4.1.13 Total Kjeldahl Nitrogen (TKN)

Total Kjeldahl Nitrogen is the sum of organic nitrogen, ammonia (NH_3) and ammonium (NH_4+). Total Kjeldahl Nitrogen also promotes the prolific algal growths that have deleterious impacts on other aquatic life, drinking water supplies and recreation as observed in Swakoppoort and Goreangab source water dams. Anthropogenic sources are similar to those of nitrates. MAWF (2012) maximum limit of TKN for discharge effluents is 33 mg/L, while the median TKN concentration at the USB was 5.2 mg/L. However, extreme concentrations were observed at Okapuka Meatco Tannery Waste Water Effluent primary pond (TKN range 409-1,057 mg/L), Otjomuise Sewerage treatment plant (TKN=153 mg/L), and Nakara Tannery (TKN=467 mg/L). The extreme TKN sampled points are shown in the GIS map on Figure 4.12.

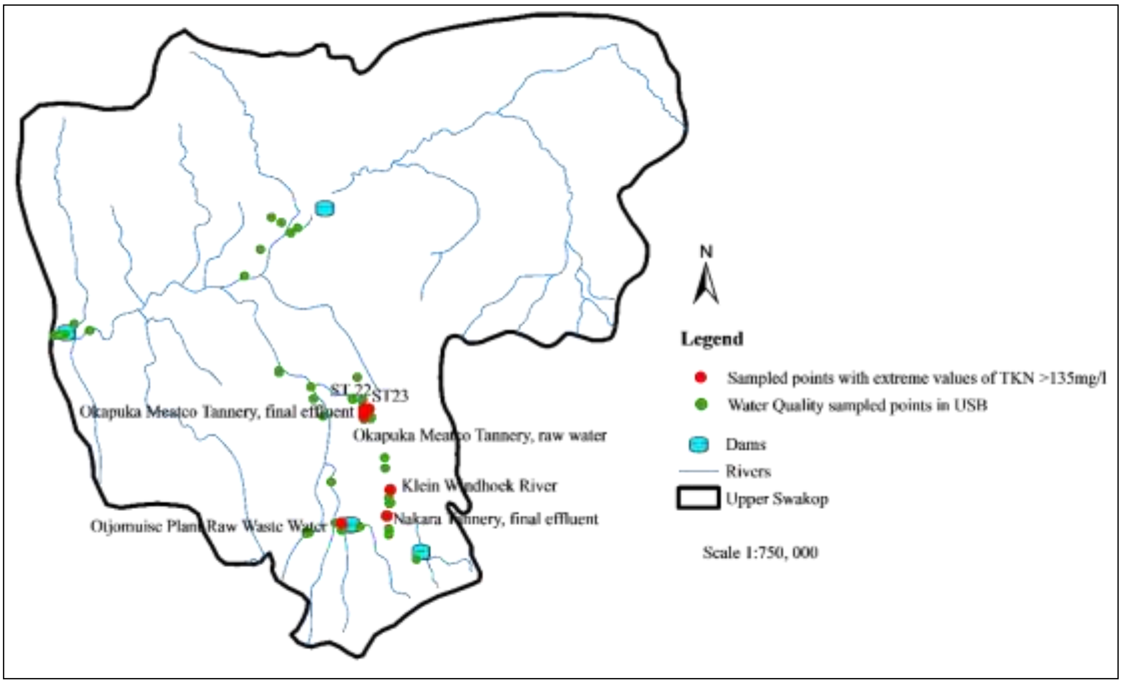


Figure 4.12 GIS map depicting points of extreme TKN values and their spatial distribution.

4.1.14 Total Phosphate (P)

The median TP concentration in the USB was 1.6 mg/L. Extreme TP concentrations were observed at Ujams effluent (TP =61 mg/L); Okahandja oxidation pond wastewater (TP =58 mg/L), Gammams Wastewater Treatment Plant (TP =28 mg/L), Okapuka Meatco Tannery (TP =46 mg/L), Namib Dairies (TP =19 mg/L), Namib Poultry Industry (TP =42 mg/L), and Klein Windhoek River S11 (TP =67 mg/L).

The extreme Total phosphate sampled points are shown in the GIS map on Figure 4.13.

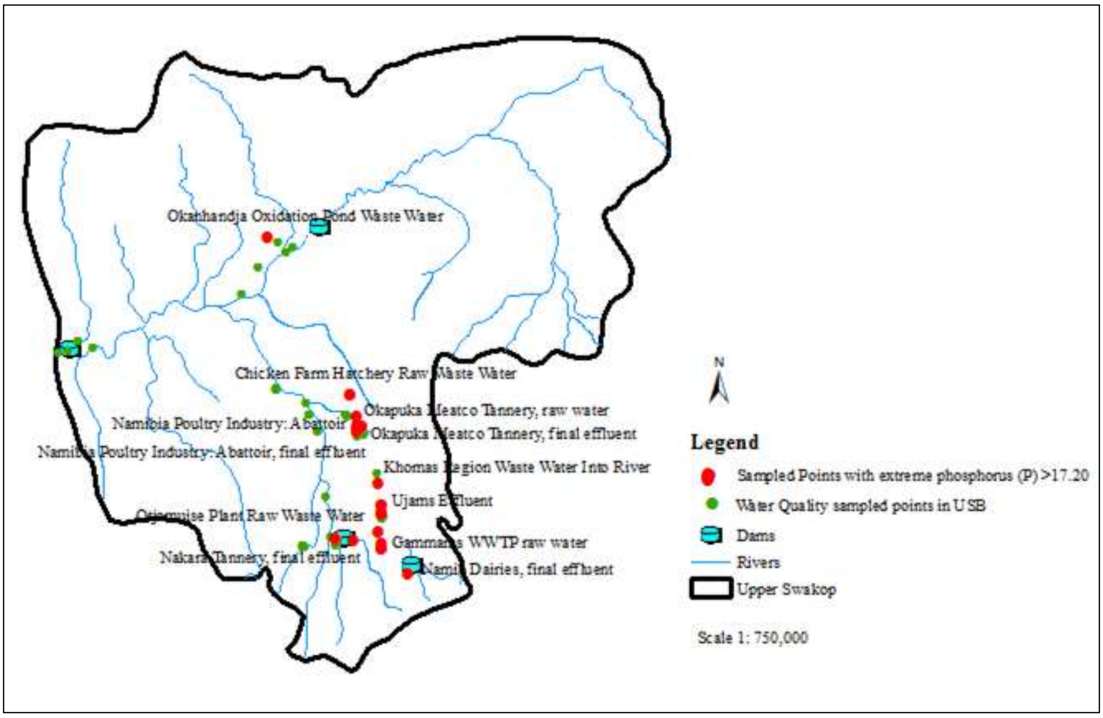


Figure 4.13 GIS map depicting points of extreme Total Phosphate values and their spatial distribution.

Total phosphate is a measure of both inorganic and organic form of phosphorus which may be present as dissolved particulate matter in the water column. It is an essential plant nutrient often the most limiting to plant growth in fresh water. Total phosphorus concentrations in fresh water basins that are not affected by anthropogenic inputs are generally less than 0.01 mg/L (Clark et al., 2000).

As a limiting nutrient, its input to fresh water systems can cause extreme proliferation of algal growth and eutrophication. Generally, lakes and dams are classified according to the level of phosphorus concentration. A lake or dam with less than 0.01 mg/L phosphorus is considered oligotrophic-mesotrophic; below 0.03 mg/L phosphorus concentration, mesotrophic-eutrophic; and >0.1 mg/L phosphorus concentration, eutrophic-hypereutrophic (Numberg, 1996; Dodds et al., 2006). Generally, anthropogenic sources include sewerage treatment plant effluent, agriculture, industrial effluents, and high phosphorus detergent industries. The MAWF (2012) permissible discharge effluent limit of Total Phosphate (TP) is 3 mg/L while for drinking water it is less than 0.01 mg/L of phosphorus (NB: measured phosphates (mg/L PO_4) concentrations can be converted into units of phosphorus (mg/L PO_4-P) by dividing by 3.06).

4.1.15 Sulphate (SO_4)

In the USB, the median sulphate level was 139 mg/L which is above the MAWF (2012) maximum limit of 40 mg/L. Extreme values were observed at Okapuka Meatco Tannery ranging from 3,329 mg/L to 4,706 mg/L as well as at the final effluent of Nakara Tannery with an extreme value of 2,985 mg/L. The extreme SO_4 sampled points are shown in the GIS map on Figure 4.14.

World Health Organization (WHO) Guidelines for Drinking-Water Quality (WHO, 2008) set the maximum level of sulphate in drinking water at 500 mg/L while the stricter European Commission [EC] (1998) Standards set a maximum of 250 mg/L. In general, the origin of most natural sulphate compounds in water bodies is the oxidation of sulphite ores and the presence of shales. Anthropogenic sources include industrial waste, domestic effluent, acid mine drainage environments and (agriculture) sulphate-rich fertilizers.

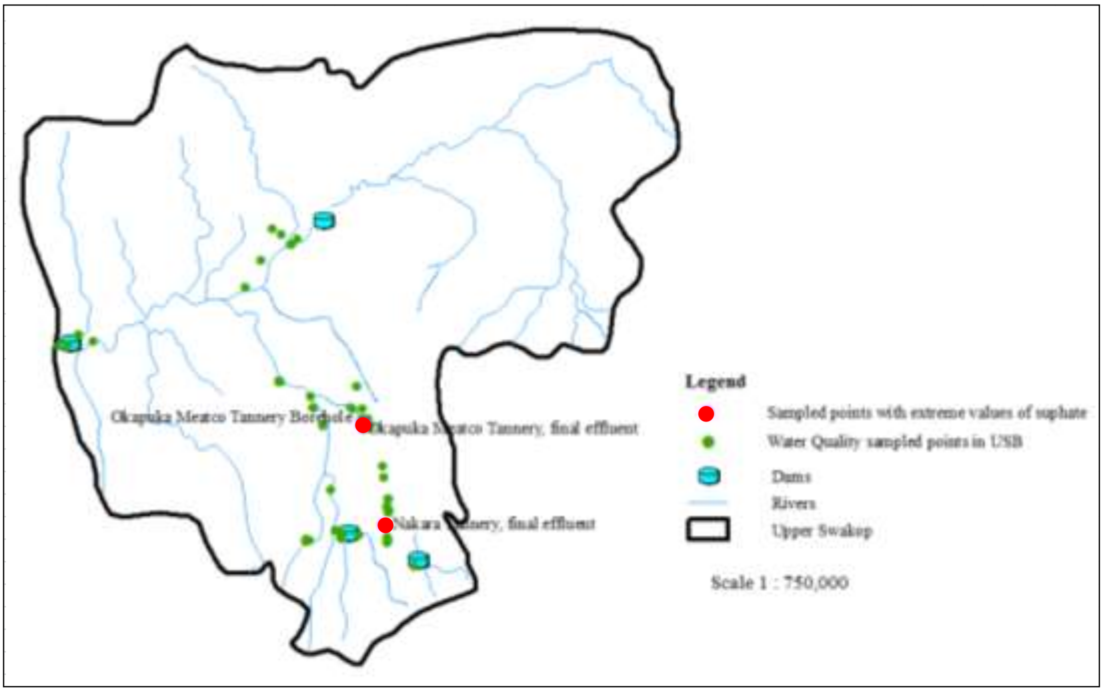


Figure 4.14 GIS map depicting points of extreme sulphate values and their spatial distribution.

High concentrations of sulphate in the drinking water can have a laxative effect on humans when combined with calcium and magnesium, the two most common constituents of water hardness. Apart from the salty taste, people or animals not used to drinking water with high levels of sulphate can experience dehydration and diarrhoea or even death. High sulphate levels may also be corrosive for water distribution pipelines, particularly copper piping. In areas with high sulphate levels, it is common to use corrosion resistant pipe materials, such as plastic pipe.

4.1.16 Chlorides (Cl)

Extreme values were observed at Okapuka Meatco Tannery ranging from 7,885 mg/L to 75,650 mg/L as well as the final effluent at Nakara Tannery with an extreme value of 9,628 mg/L. The sampled points in the USB median value for chloride is at 160 mg/L. MAWF (2012) has set acceptable threshold limit of chloride concentration exposure for freshwater at 40 mg/L and 70 mg/L for specific and general discharges.

Chlorides (Cl) are ions in the water sample that naturally occur as part of the dissolved salts. High chloride concentrations in freshwater can harm aquatic organisms by interfering with osmoregulation, the biological process by which the organisms maintain the proper concentration of salt and other solutes in their bodily fluids. Impaired osmoregulation can hinder survival, growth, and reproduction of these organisms. Anthropogenic sources of chlorides include agriculture (potash fertilizers), urban runoff, septic tanks, industrial waste, domestic and food industry effluent, tanneries, acid mine drainage environments and water ionic softeners. The extreme chloride sampled points are shown in the GIS map on Figure 4.15.

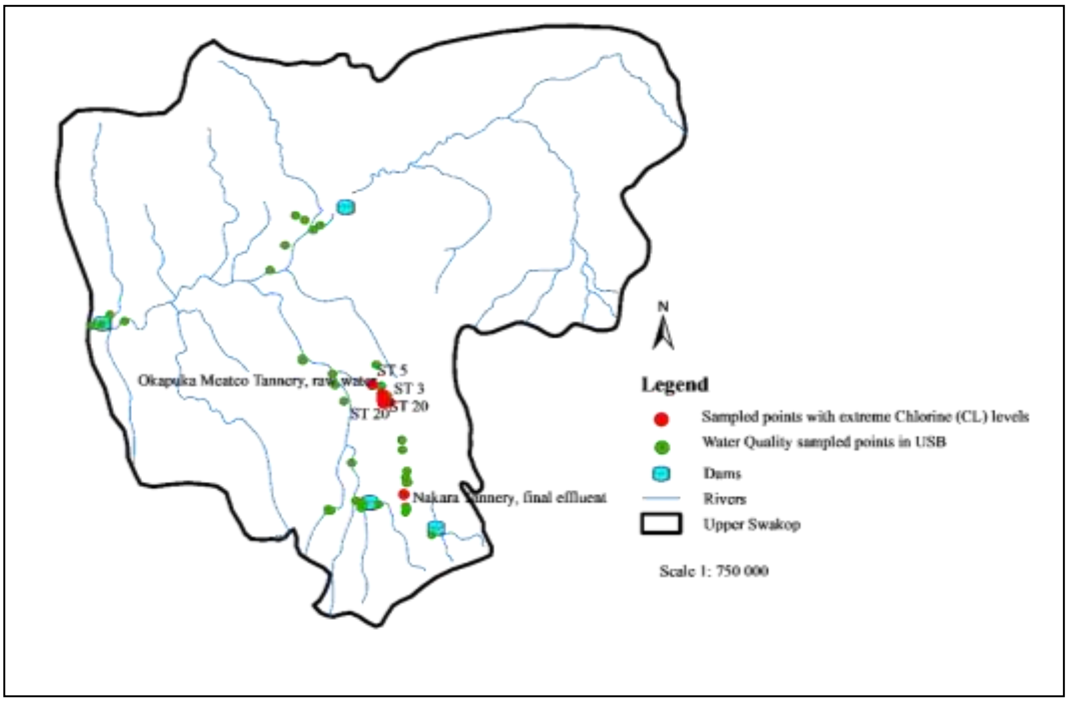


Figure 4.15 GIS map depicting points of extreme chloride values and their spatial distribution.

4.1.17 Sodium (Na)

Sodium (Na) is the measure of sodium ions in the water sample and naturally occurs as part of the dissolved salts. High sodium concentrations in freshwater can harm aquatic organisms by interfering with osmoregulation. Anthropogenic sources of sodium include agriculture fertilizers (sodium nitrates), urban runoff, septic tanks, industrial waste, domestic and food industry effluent and tanneries. The acceptable sodium concentration exposure limits for freshwater set by MAWF (2012) is 90 mg/L while the USB median value for sodium is 175 mg/L. The spatial distribution of extremely high sodium levels is shown in the GIS map on Figure 4.16. Extreme values were observed at Okapuka Meatco Tannery sites and boreholes ranging from 7,540 mg/L to 64,570 mg/L as well as the final effluent at Nakara Tannery with an extreme value of 8,710 mg/L.

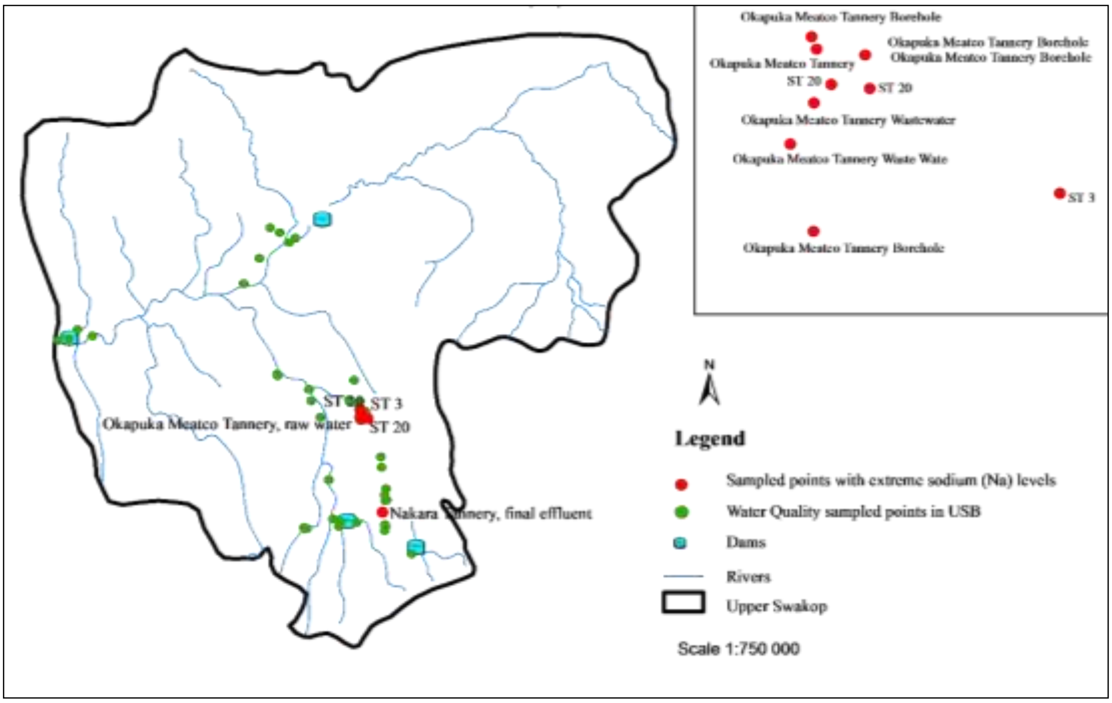


Figure 4.16 GIS map depicting points of extreme sodium values and their spatial distribution.

4.2 Overall Assessment of Sites with Extreme Pollution Levels in the USB

The sites that exhibit extreme values (in red) in one or more pollution parameter in the USB are shown in the GIS map on Figure 4.17. Agro-industries that include tanneries (Okapuka Meatco and Nakara) are the biggest sources of pollution in the USB followed by Namib Poutry. Wastewater treatment plants that include Ujams (although now upgraded in 2015), Gammams, Okahandja oxidation pond final effluent, Otjomuise are also shown to be secondary pollution generation sites (Figure 4.17 and Table 9). Goreangab Dam was revealed as a collector of pollution possibly from both non point and point sources of pollution from Windhoek.

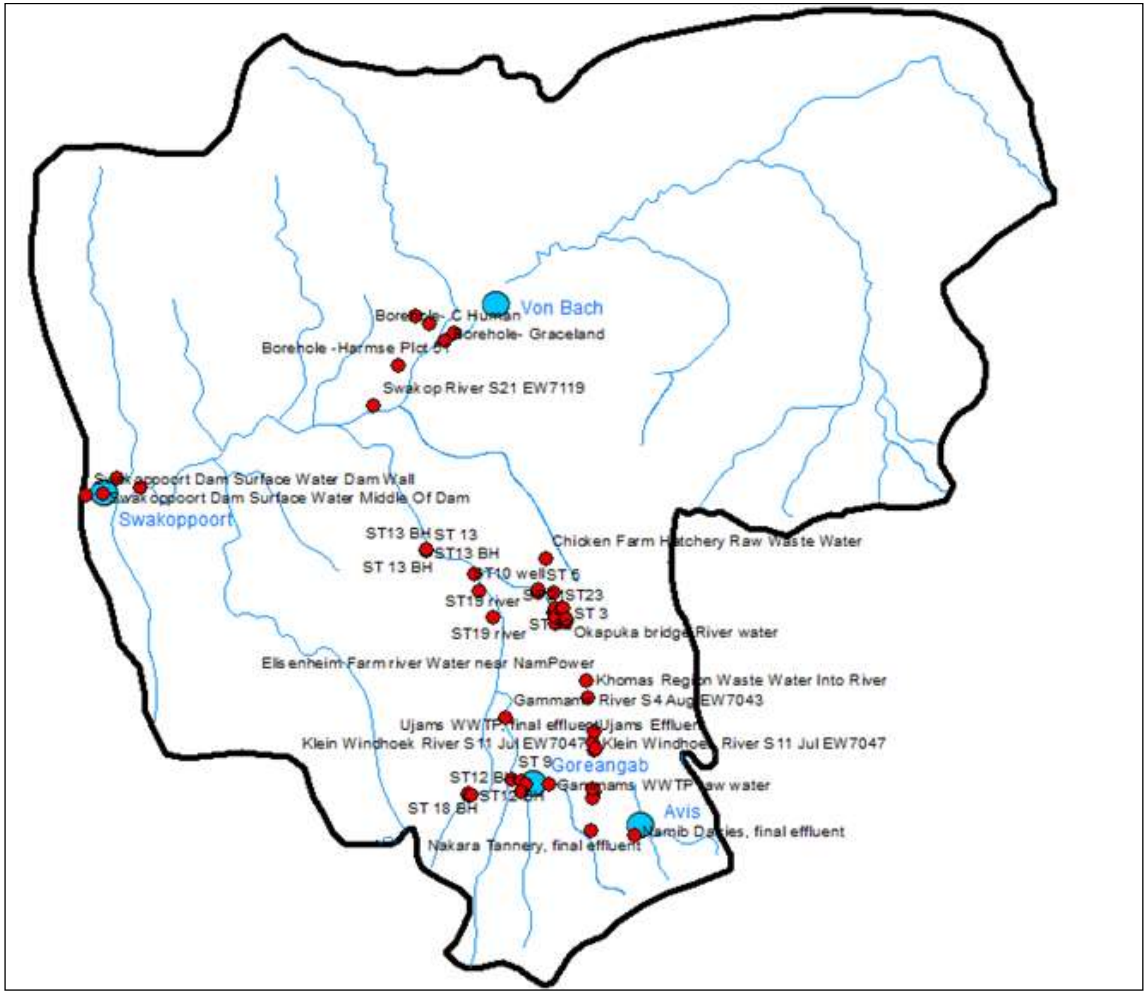


Figure 4.17 GIS map showing all sampled locations in the USB with at least one extreme pollution parameter

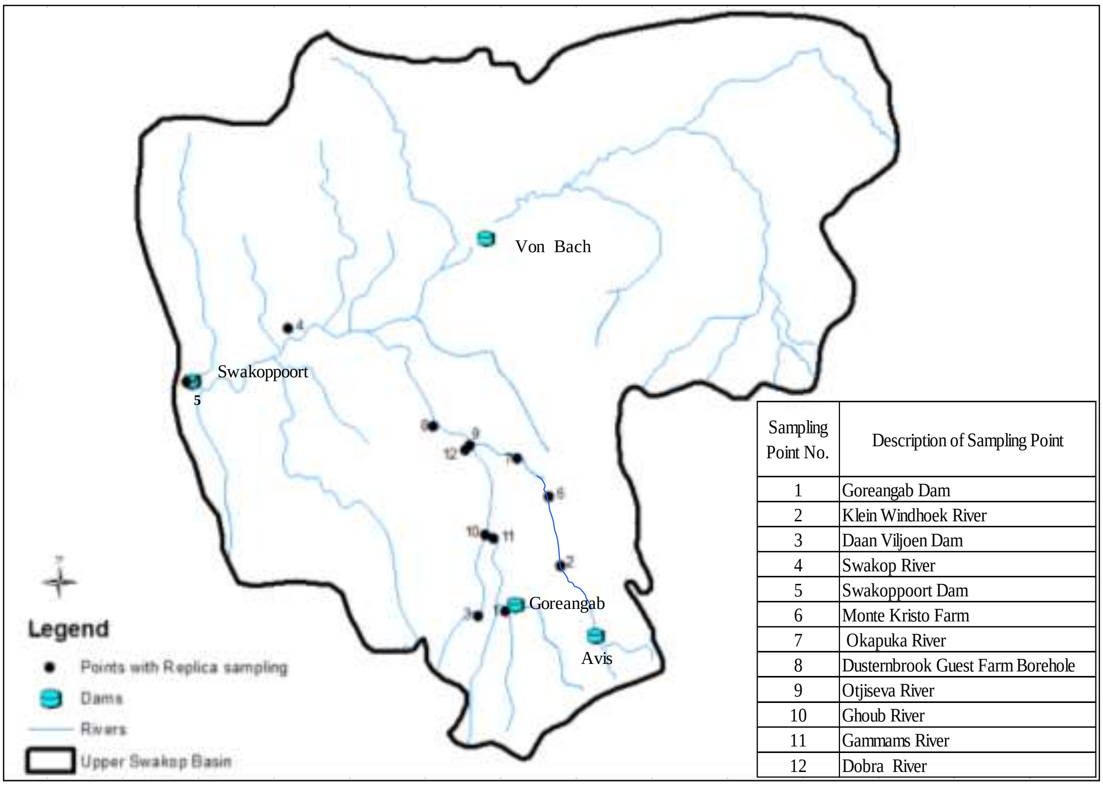
Key: The sites that exhibit extreme values in one or more pollution parameters in the USB are shown in red and shown in blue are potable water reservoirs (dams)

Table 9 Sites with extreme pollution parameter values.

Site	DO	Conductivity	TDS	TSS	NO_3	Kledahl Nitrogen	Colour	Phosphorus	COD	BOD	Sulphates	Chlorides	Sodium	Count
Okapuka Meatco Tannery, effluent	X	X	X	X		X	X		X	X	X	X	X	**11**
Okapuka ST 13 borehole					X									**1**
Okapuka ST 17 borehole					X									**1**
Okapuka ST 22 borehole						X								**1**
Okapuka ST 23 borehole						X								**1**
Okapuka Meatco Tannery Evaporation pond E1 and E 11							X							**1**
Okapuka Tannery borehole North					X		X							**2**
Nakara Tannery	X		X			X		X	X	X	X	X	X	**9**
Namib Poultry	X				X			X						**3**
Ujams water works,	X							X						**2**
Gammams Water Works,	X							X						**2**
Namib Dairies,	X							X						**2**
Okahandja Oxidation pond final effluent	X							X						**2**
Otjomuise Wastewater Treatment Plant	X					X								**2**
Goreangab Dam	X						X							**2**
Klein Windhoek River							X	X						**2**
Namib Beverages								X						**1**
TransNamib Plant,	X													**1**
Human Farm borehole					X									**1**
Dusternbrook Guest Farm borehole					X									**1**
Swakoppoort Dam Inflow site							X							**1**

4.3 Analysis of Spatial Variation for Water Quality Parameters at 12 Sites Upstream of Swakoppoort Dam that had Replicated Sampling

The spatial analysis results of the quality of water at the 12 sampling points upstream of the Swakoppoort Dam are presented in this section. Figure 4.18 shows the sampling points with replicated samples taken during March 2011 to April 2011.



Sampling Point No.	Description of Sampling Point
1	Goreangab Dam
2	Klein Windhoek River
3	Daan Viljoen Dam
4	Swakop River
5	Swakoppoort Dam
6	Monte Kristo Farm
7	Okapuka River
8	Dusternbrook Guest Farm Borehole
9	Otjiseva River
10	Ghoub River
11	Gammams River
12	Dobra River

Figure 4.18 Sampling Points with replicated samples taken during March 2011 to April 2011.

The analysis of variance (ANOVA) results of the 12 different sites for water quality parameters are presented on Table 10. The ANOVA results indicated that there were significant differences in the mean levels of chlorine ($p=0.007$), Iron ($p<0.001$), and copper ($p=0.041$) at the various sampling points.

Table 10 Analysis of variance results for the water quality parameters (* $p<0.05$, ** $p<0.01$, *** $p<0.001$)

Parameter	F- Statistic	P- Value
Chlorine (cl)	2.921**	0.007
Alkalinity	1.291	0.268
Phenolftalen	1.212	0.374
Iron (Fe)	10.494***	<0.001
Manganese (Mn)	1.921	0.069
Copper (Cu)	2.145*	0.041
Zinc (Zn)	0.95	0.507
Cadmium (Cd)	0	1
Lead (Pb)	0	1
Total Phosphate (P)	0.346	0.967
DOC	0.697	0.732
UV_{254}	1.499	0.175
Ammonia	1.175	0.339
Total Kjeldahl Nitrogen	1.137	0.363

The evaluation of the variables for the potential pollution sources against Namibian standards showed that Swakop River, Otjiseva River and Dobra River had unacceptably high levels of iron, copper and chlorine. This spatial variance, unless explained by the natural geo-physical characteristic of the river basin especially for metals, should be further investigated.

4.4 Discussion

Statistical analysis of water pollution in the USB showed that most of the metallic water pollution parameters (copper, zinc, Cadmium, Lead, Manganese, iron) were within the MAWF (2012) water quality permissible limits except Sodium with extreme values recorded at the Okapuka Meatco Tannery, and at the Nakara Tannery. The Okapuka Meatco Tannery and Nakara Tannery in Windhoek release high concentrations of sodium chloride into a tributary of the Swakop River, and increased concentrations have been detected in the groundwater. Over time and with floods, there is a risk that these pollutants enter not only the farm dams downstream but also the Swakoppoort Dam, one of the key water sources for Windhoek (Seely et al., 2003). DO, Conductivity, TSS, TDS, COD, and BOD_5 extreme values revealed potential pollution sites that need immediate attention chiefly Okapuka Tannery, and secondly Nakara Tannery. Namib Poultry was identified as another site with potential pollution issues. Not only are the threshold values of several water quality parameters exceeded at these sites, but some of the parameters' values were highly extreme. Point sources of untreated and poorly treated industrial and domestic effluents from Okahandja and Windhoek contributed to the pollutant loads in the Upper Swakop Basin. The high variability of runoff into the three integrated dams which seldom spill, make accumulation of pollution especially through salinization, even more difficult to treat and handle. The quantity-quality matrix of the three-dam system and the trends of the pollution threatening the Swakoppoort and Von Bach Dams may be a cause for concern with increasing TDS, sodium and sulphate concentration levels into Swakooppoort Dam (NamWater, 2015). Moreover, the contribution of non-point sources of pollution from informal settlements, littered environment, farmlands and construction sites to polluting dam reservoirs which are located downstream (Swakoppoort and Goreangab Dam reservoirs) in the USB cannot be discounted even though it was not analysed in this study.

4.5 Summary

The above discussion has answered the requirements of objective number 1 of assessing the water quality at potential pollution sources and at major receiving waters in the Upper Swakop Basin as given in Chapter 1. To address the water quality challenges, the following issues need to be addressed.

1) All wet industries in both Windhoek and Okahandja that have considerable wastewater discharges, should install onsite wastewater plants and pre-treatment plants. In particular, Namib Poultry and Okapuka Tannery should have combined or individual treatment plants on site to avoid pollutants from their industries being washed downstream and eventually reaching Swakoppoort Dam reservoir thereby threatening this water source and the security of water supply to the USB.

2) Gammams and Otjomuise domestic wastewater treatment plants should be upgraded and augmented in terms of their capacities and the quality of effluent. Effluent from the Southern Industrial area and Prosperita should not be combined with domestic effluent that goes into the Gammams and Otjomuise wastewater treatment plants.

3) The study was done based on the available patchy data from various sources and at varying times. A proper basin wide monitoring network and management program and management information system should be formulated through the USB Committee.

4) The results of this chapter dealing with the water quality of water supply sources in the USB reveal serious water pollution sources and concerns. The secondary data used and the results of extreme values of pollution parameters analysed indicate uncoordinated and the lack of a strong pollution control programme in the USB. The absence of a centralised and integrated data base for pollution monitoring, control and management by the key stakeholders in the USB (that include MAWF, Windhoek Municipality, Okahandja Municipality, NamWater, Industries etc.), indicates weak

water governance in the basin. This prevailing poor water quality governance has long term negative impacts on the drinking water supplied from Swakoppoort and Von Bach Dams. Besides, the security of water supply from these dams will increasingly be compromised unless there is an improved water governance system deployed to ensure water pollution is controlled and managed sustainably.

5) There is need to come up with both the receiving water and effluent water quality objectives and standards in order to reduce the mass of pollutants into the streams and rivers in the USB. However, one should bear in mind the limited self-purification capacity of the rivers and streams due to ephemeral flows.

As part of the solutions to the water quality challenges revealed in this chapter, the study proposed a strategic water quality monitoring and water quality governance system. To avoid duplication, the overall water quality strategy of the basin is given as recommendations in Chapter 8 and Annex 12. The next chapter looked at the water quantity issues in the USB.

CHAPTER FIVE

5 ASSESSMENT OF THE AVAILABILITY AND ADEQUACY OF DRINKING WATER SOURCES IN THE USB

In this chapter, the results of the forecasting models for Windhoek rainfall; water demand for Windhoek and Okahandja urban areas and thereof the WEAP model for the water evaluation and planning in the Upper Swakop Basin are presented.

5.1 Windhoek Rainfall Forecasting

The time series plot of the monthly rainfall is presented in Figure 5.1. Monthly rainfall was highly varied with a minimum of 0 mm and a maximum of 321 mm. The average monthly rainfall was 31.21 mm (95% confidence interval: 28.21 mm, 33.77 mm) with a standard deviation of 48.81 mm. There were notably high rainfall figures in February 1923 (303.00 mm), January 1893 (308.00 mm), March 1954 (312.20 mm), January 2011 (320.90 mm) and January 2006 (321.30 mm).

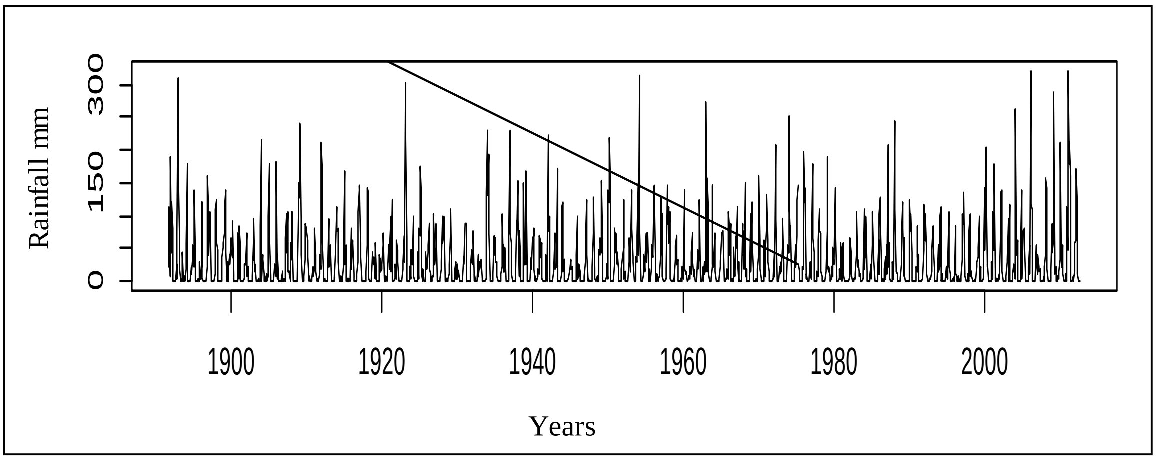


Figure 5.1 Time series plot of Windhoek monthly rainfall from 1891 to 2012

The time series plot suggests that the time series is stationary since the mean and the variance of the series do not seem to vary with the level of the series, making additive decomposition ideal for the separation of the time series components. The results of the additive time series decomposition are presented in Figure 5.2**.**

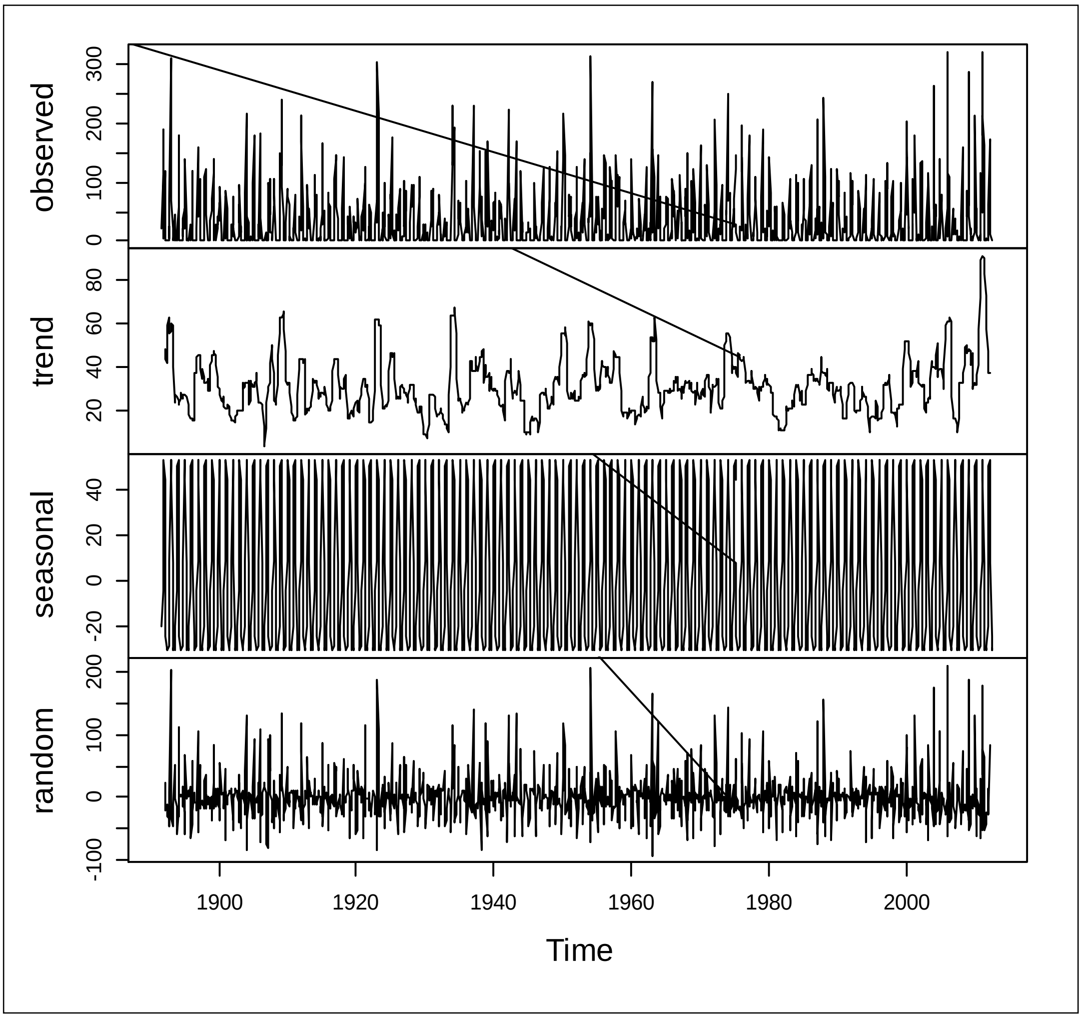


Figure 5.2 Decomposition of the Windhoek Rainfall Time Series

The ACF and the PACF of the rainfall series are presented in Figure 5.3 and they show seasonality in the data. Therefore, a general ARIMA $(p,0,q)(P,0,Q)_{12}$ was proposed for the rainfall data. After model identification, the p, q, P, and Q parameters were estimated.

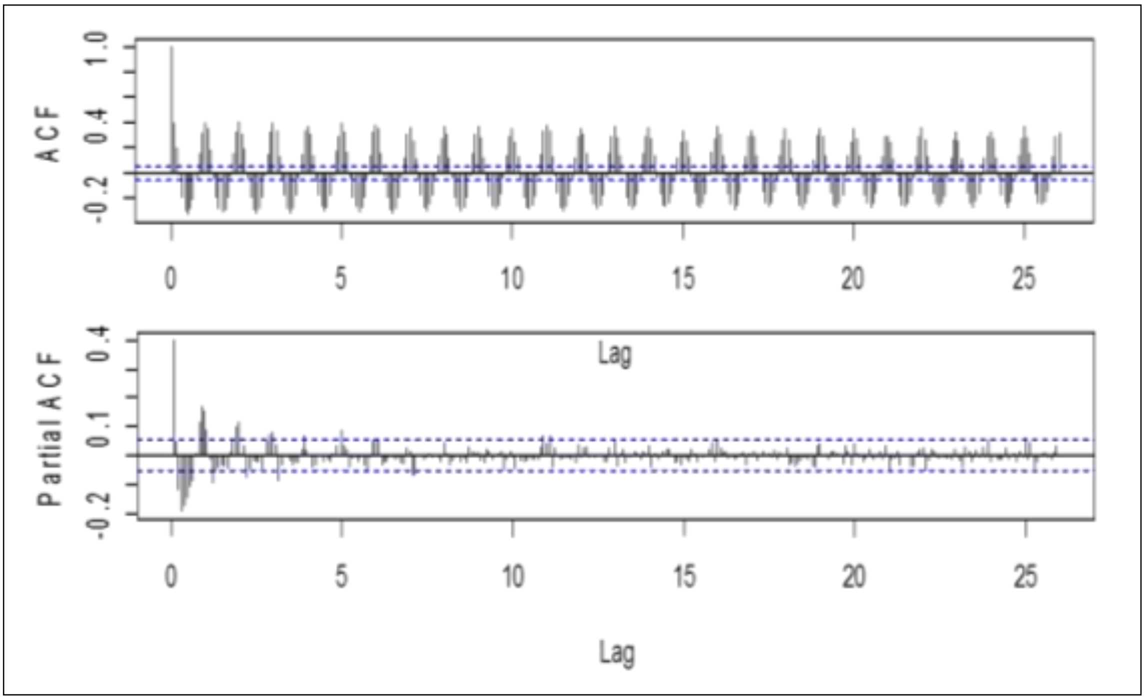


Figure 5.3 ACF and the PACF of the Windhoek rainfall series

On the basis of automatic ARIMA forecasting, the selected model was a seasonal ARIMA(1,0,1)(1,0,2)$_{12}$ i.e. SARIMA(1,0,1)(1,0,2)$_{12}$. This model was adequate to represent the data and could be used to forecast future rainfall. The maximum likelihood estimates of the SARIMA(1,0,1)(1,0,2)$_{12}$ model and their standard errors are presented in Table 11. The forecast residual ACF, time plot, Normal Q-Q plot and histogram are displayed in Figure 5.4.

Table 11 Maximum likelihood estimates of the SARIMA (1,0,1)(1,0,2)$_{12}$ model and their standard errors

Coefficients	Estimate	Standard Error
Constant	31.1735	12.1868
Ar1	0.6135	0.1168
Ma1	-0.5122	0.1265
Sar1	0.9852	0.0006
Sma1	-0.9154	0.0270
Sma2	0.0502	0.0264

$\hat{\sigma}_e^2 = 1505$, log likelihood=-7371.98, AIC=14758.13

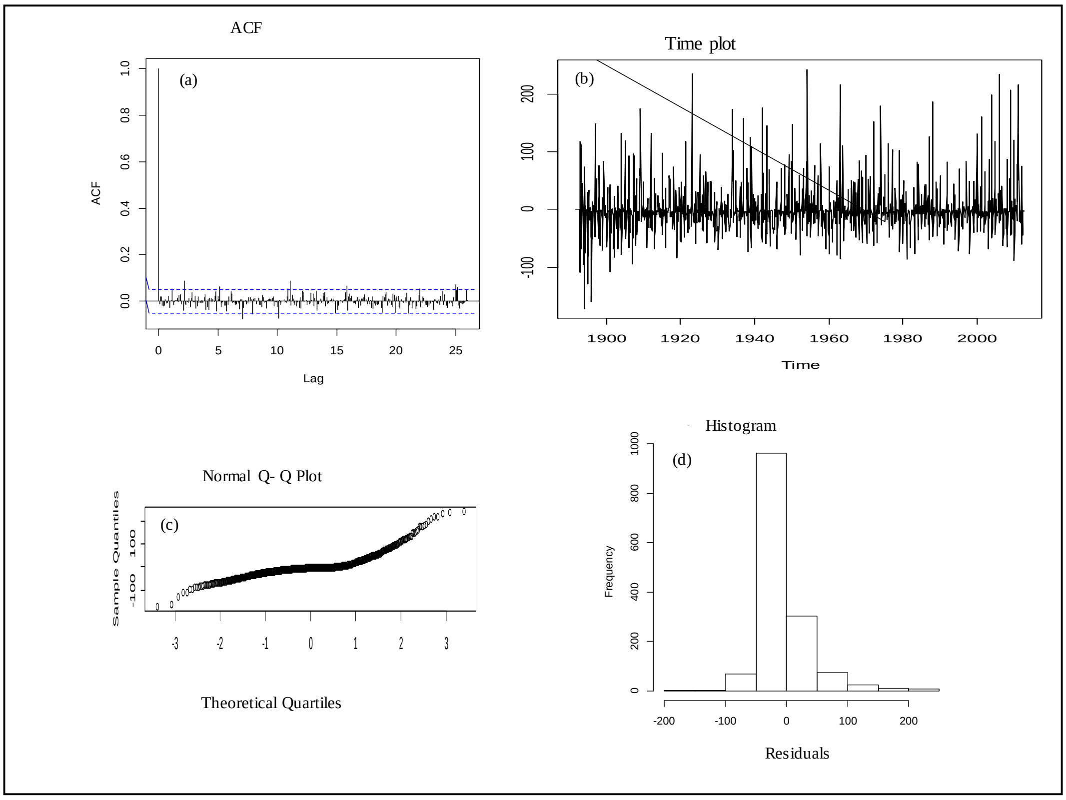


Figure 5.4 Diagnostics for the SARIMA (1,0,1)(1,0,2)$_{12}$ fit on the rainfall data a) ACF of forecast residuals; b) Forecast residual time plot; c) Normal Q- Q plot of forecast residuals; d) Histogram of forecast residuals

The ACF of the residuals shows no serious violations of model assumption suggesting that this model is good (Ljung-Box Chi-squared statistic = 0.1877, p-value = 0.6648). On the basis of the developed model, the forecasted monthly rainfall along with the 95% confidence intervals is as shown in Figure 5.5. The actual forecast values with their corresponding confidence intervals are listed in Annex 13.

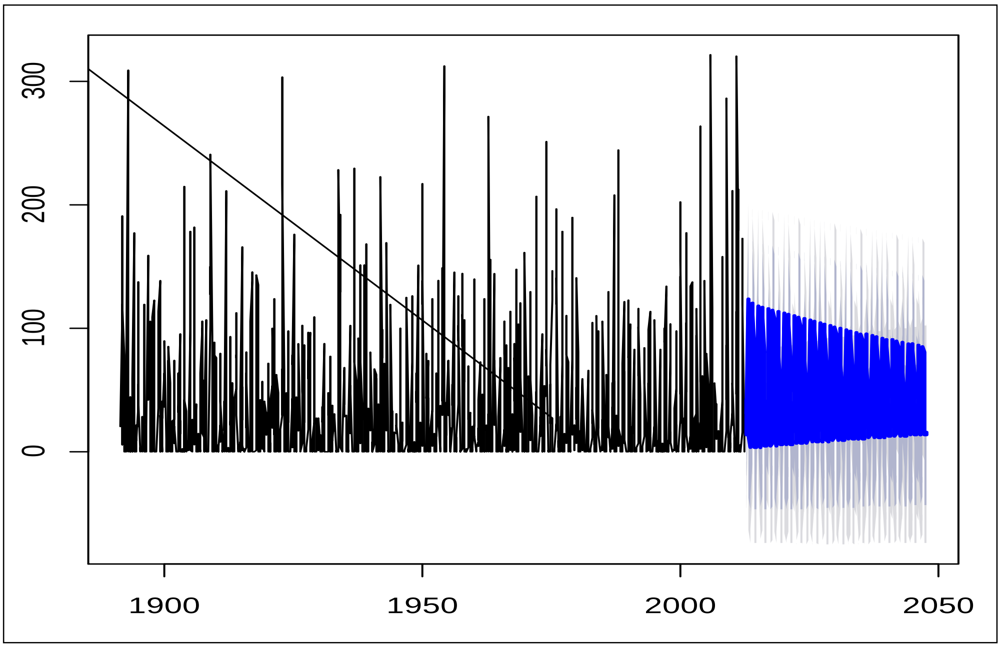


Figure 5.5 Windhoek Monthly Rainfall forecast with 95% confidence Interval

5.2 Windhoek Water Demand Forecasting

The time series plot and autocorrelation function of Windhoek's water demand are presented in Figure 5.6**.** The series was non-stationary with an upward trend but no seasonality. The autocorrelation function had a considerable number of spikes outside the 95% confidence band, which were slowly tailing off.

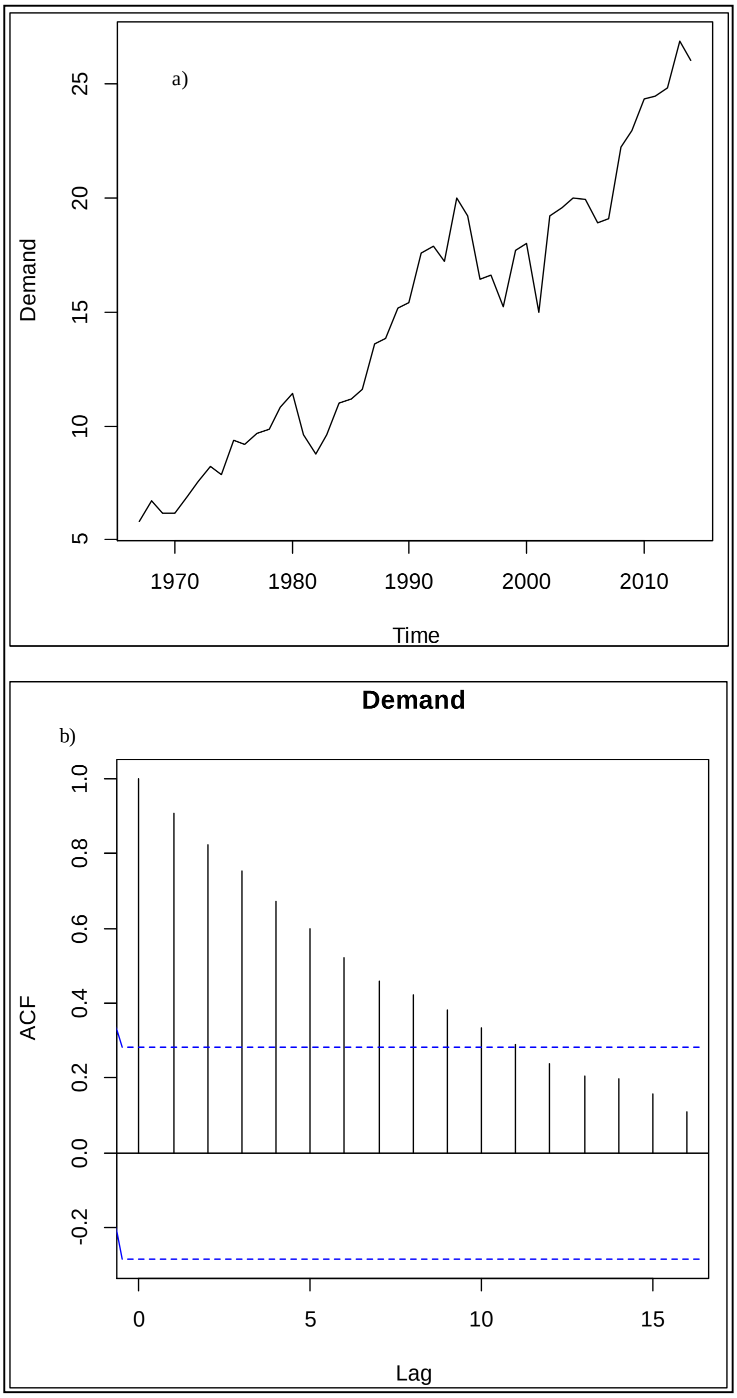


Figure 5.6 a) Time Series Plot, and b) ACF of Windhoek's Annual Water Demand (M m^3)

However, after differencing once, the data was stationary as evidenced by ACF (See Figure 5.7). The ACF had one significant spike at lag 1 suggesting a moving average component of order 1 i.e. MA(1), and no significant spikes in the partial autocorrelation function since all the spikes fell within the 95% confidence limits suggesting no autoregressive component.

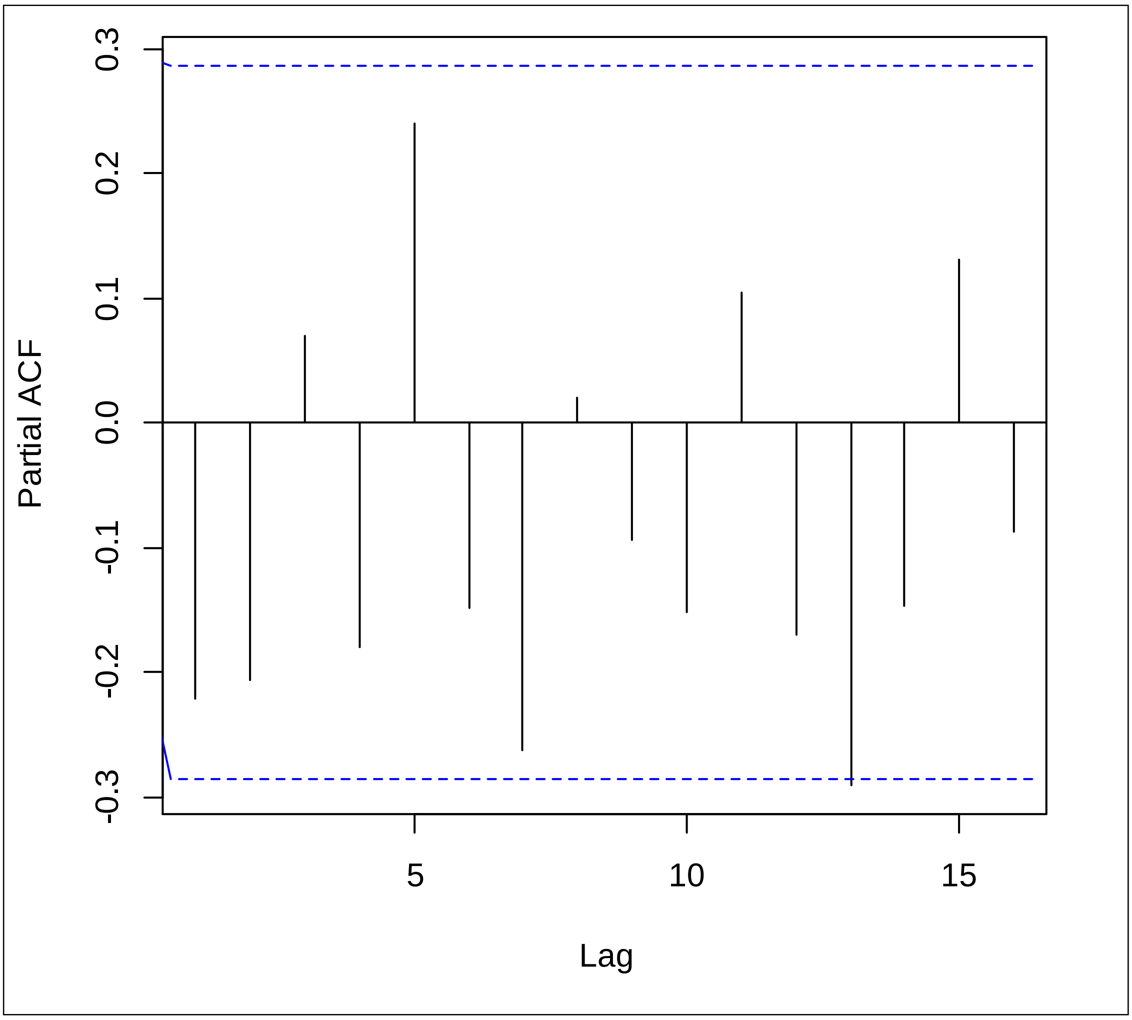


Figure 5.7 Partial Auto Correlation Function (PACF) of the referenced Windhoek Water Demand Series

This was confirmed by the *auto.arima* optimal model results which highlighted the ARIMA (0,1,1) with drift as the best model with the coefficient estimates and their corresponding standard errors summarized in Table 12.

Table 12 ARIMA (0,1,1) coefficient estimates and their corresponding standard errors

Model Component	Estimate	Standard Error
MA(1)	-0.2981	0.1514
Drift	0.434	0.1362

σ^2Estimate=1.734, Log-likelihood=-77.52, AIC=161.04

The model diagnostics were carried out using residual analysis and suggested good model adequacy. The residual plots are given in Figure 5.8. The ACF of the residuals, supported by the Box-Ljung test, did not reveal any significant autocorrelation ($\chi^2 = 0.0024, p = 0.877$). The plot of residuals versus time order did not seem to suggest non-constant variance. The normal probability plot was fairly straight and the histogram of the residuals did not seem to grossly violate the normality assumption.

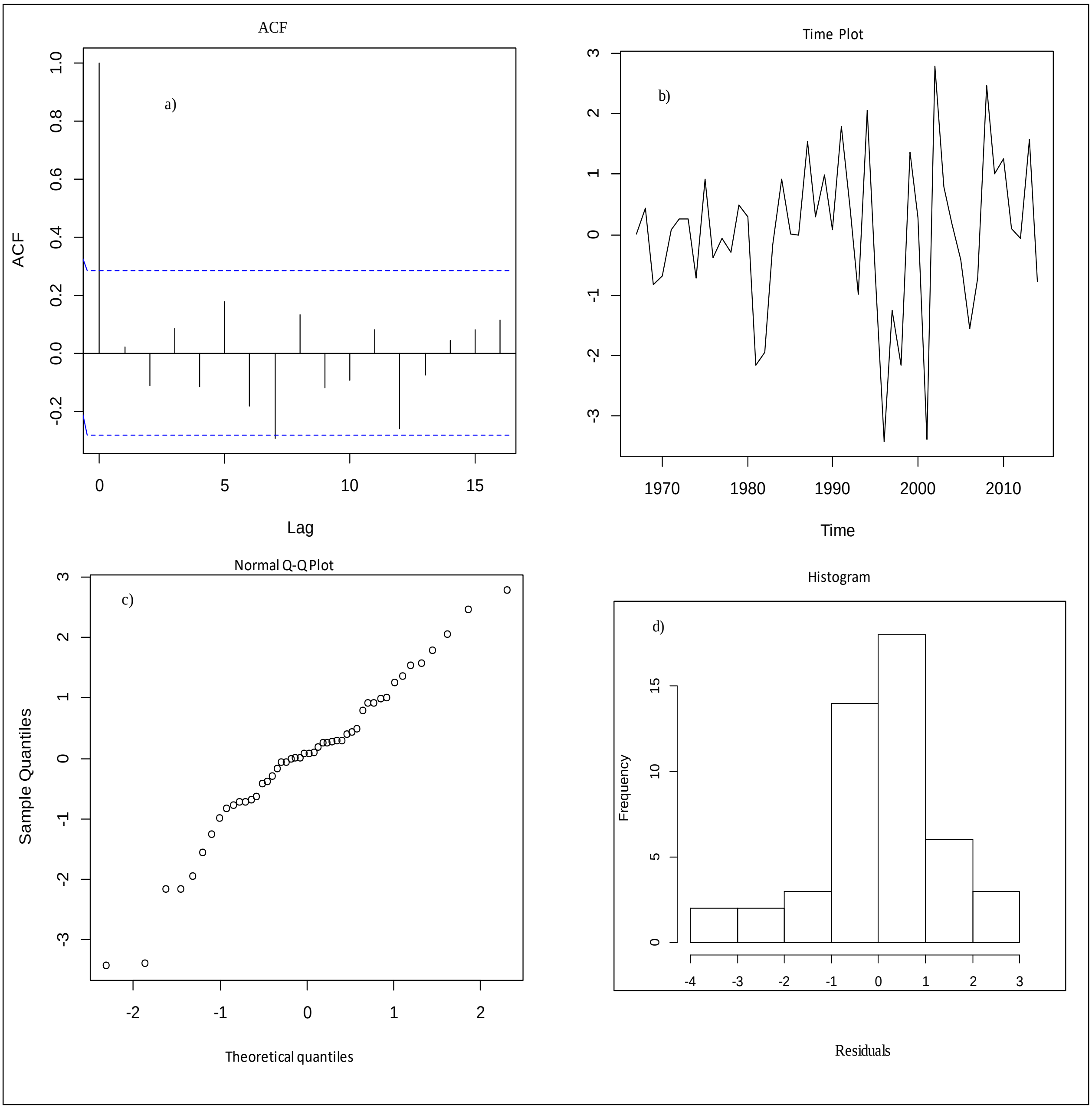


Figure 5.8 Diagnostics for the ARIMA(0,1,1) fit on the Windhoek Water Demand Data a) ACF of forecast residuals; b) Forecast residual time plot; c)Normal Q- Q plot of forecast residuals; d) Histogram of forecast residuals

The model was then deployed to forecast water demand for the Windhoek up to 2050.

The forecasts are plotted in Figure 5.9.

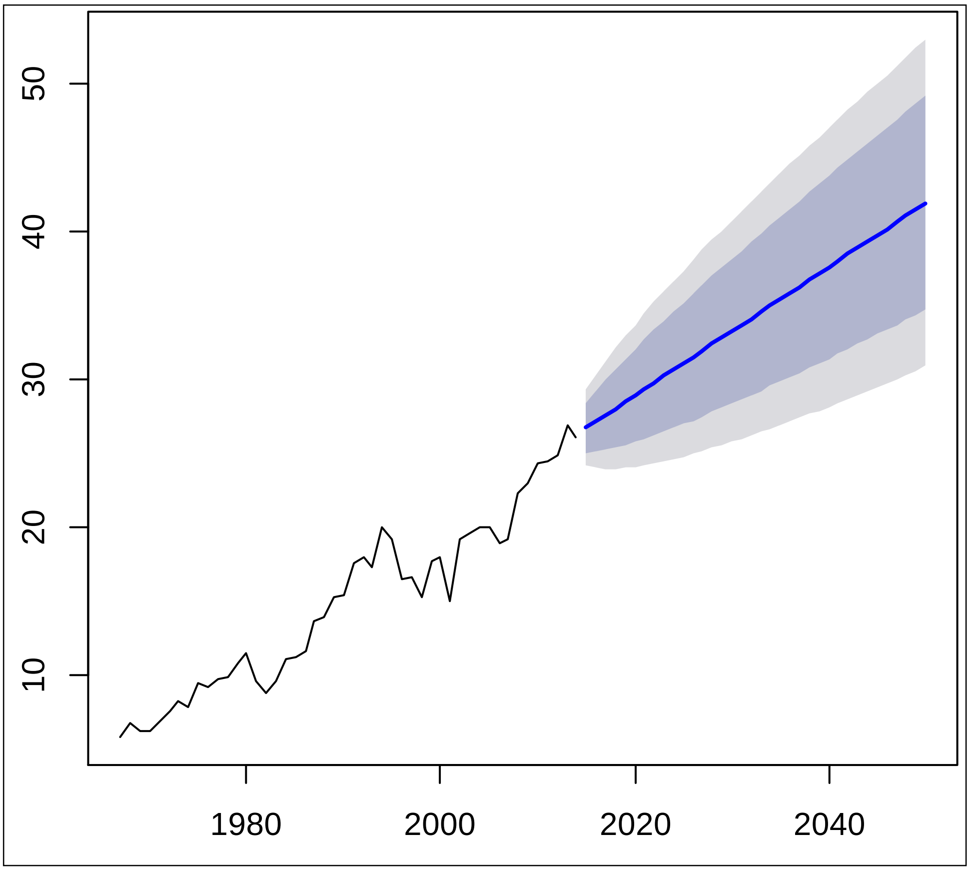


Figure 5.9 Windhoek Water Demand Forecast from the ARIMA (0,1,1) Model

The individual annual forecast figures together with their corresponding 95% confidence intervals are listed in Table 13. The forecasts suggest that water demand for Windhoek will have more than doubled by 2050 compared to the 2014 demand.

Table 13 Water Demand (M m^3) Forecasts for Windhoek with corresponding 95% Confidence Intervals

Year	Demand Forecast (M m^3)	95% Confidence Interval (M m^3)	
2015	26.71	24.12	29.29
2016	27.14	23.98	30.30
2017	27.57	23.93	31.21
2018	28.01	23.94	32.07
2019	28.44	23.99	32.89
2020	28.88	24.07	33.68
2021	29.31	24.17	34.45
2022	29.74	24.30	35.19
2023	30.18	24.44	35.92
2024	30.61	24.59	36.63
2025	31.05	24.76	37.33
2026	31.48	24.94	38.02
2027	31.91	25.12	38.71
2028	32.35	25.32	39.38
2029	32.78	25.52	40.04
2030	33.22	25.73	40.70
2031	33.65	25.95	41.35
2032	34.08	26.18	41.99
2033	34.52	26.40	42.63
2034	34.95	26.64	43.27
2035	35.39	26.88	43.90
2036	35.82	27.12	44.52
2037	36.25	27.37	45.14
2038	36.69	27.62	45.76
2039	37.12	27.87	46.37
2040	37.56	28.13	46.98
2041	37.99	28.39	47.59
2042	38.42	28.66	48.19
2043	38.86	28.92	48.79
2044	39.29	29.19	49.39
2045	39.73	29.47	49.99
2046	40.16	29.74	50.58
2047	40.59	30.02	51.17
2048	41.03	30.30	51.76
2049	41.46	30.58	52.35
2050	41.90	30.86	52.93

5.3 Okahandja Water Demand Forecasting

Figure 5.10 shows the time series plot and the ACF of the Okahandja water demand data which revealed that the data was not stationary (Ljung-Box Chi-squared = 6.5731, p = 0.01035) and it exhibited an upward trend.

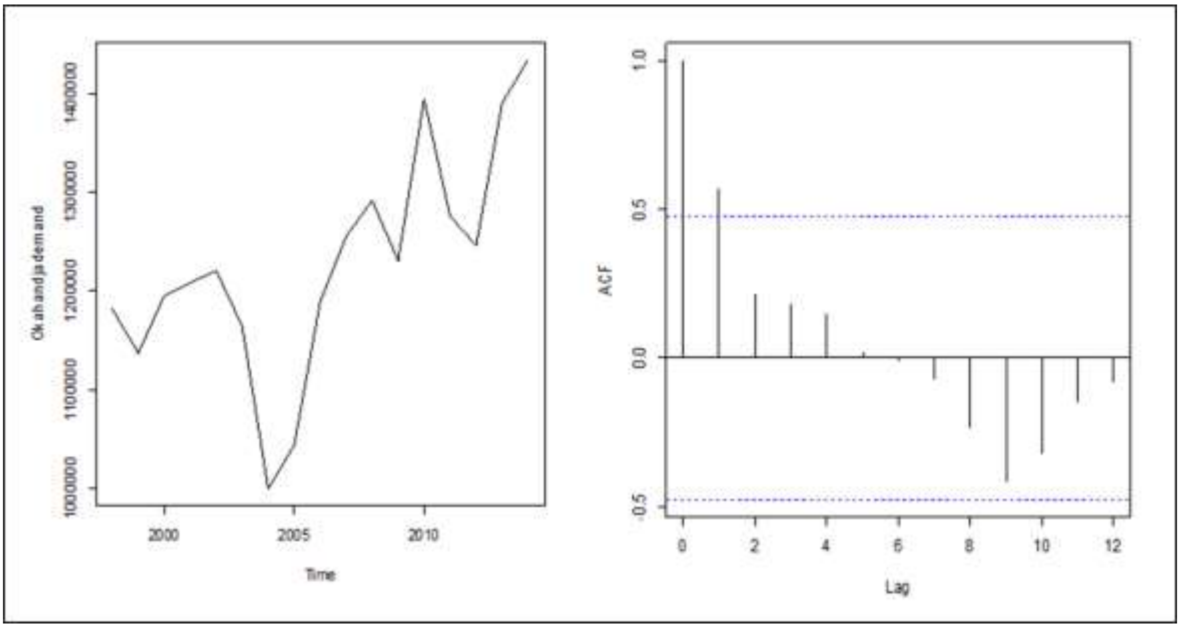


Figure 5.10 Time Series plot and ACF of Okahandja annual water demand (m^3)

The series was differenced once to remove the trend and it became stationary (Ljung Box statistic χ^2= 0.179, p = 0.6716). Figure 5.11 shows the time series plot of the first difference and the corresponding ACF.

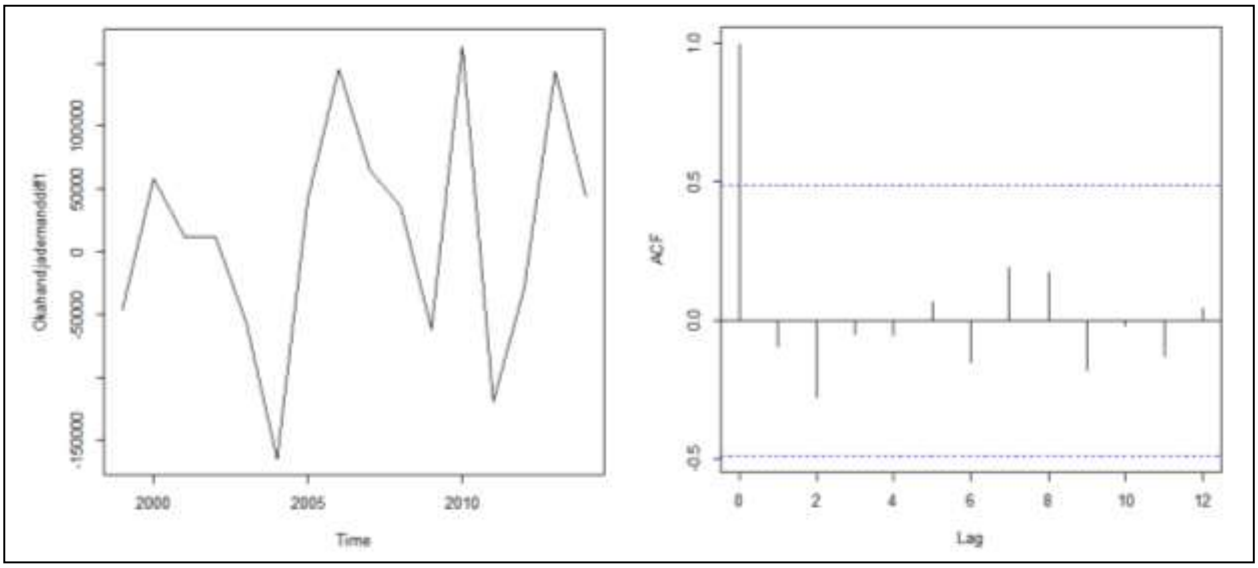


Figure 5.11 Time series plot of the first difference and the corresponding ACF of the Okahandja Water Demand

The partial autocorrelation function (PACF) for the differenced series had no significant spikes (see Figure 5.12). This was also supported by *auto.arima* modelling results which gave the ARIMA (0,1,0) with drift as the best model.

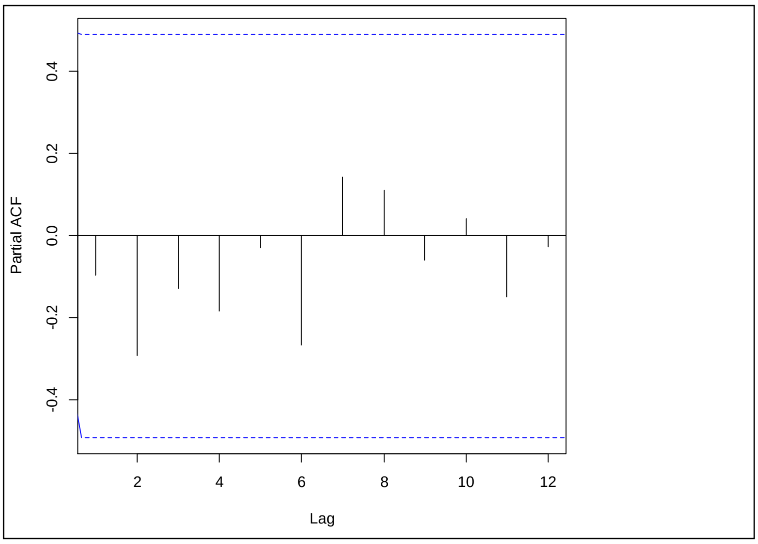


Figure 5.12 The partial autocorrelation function (PACF) for the differenced series of the Okahandja Water Demand Series

The coefficients for this best model had the following characteristics: Drift = 15731.94, Standard error = 23198.48, log likelihood = -192.37 and AIC = 388.74. The model was then deployed to generate water demand forecasts up to 2050 for Okahandja. The plot of the forecast figures is given in Figure 5.13.

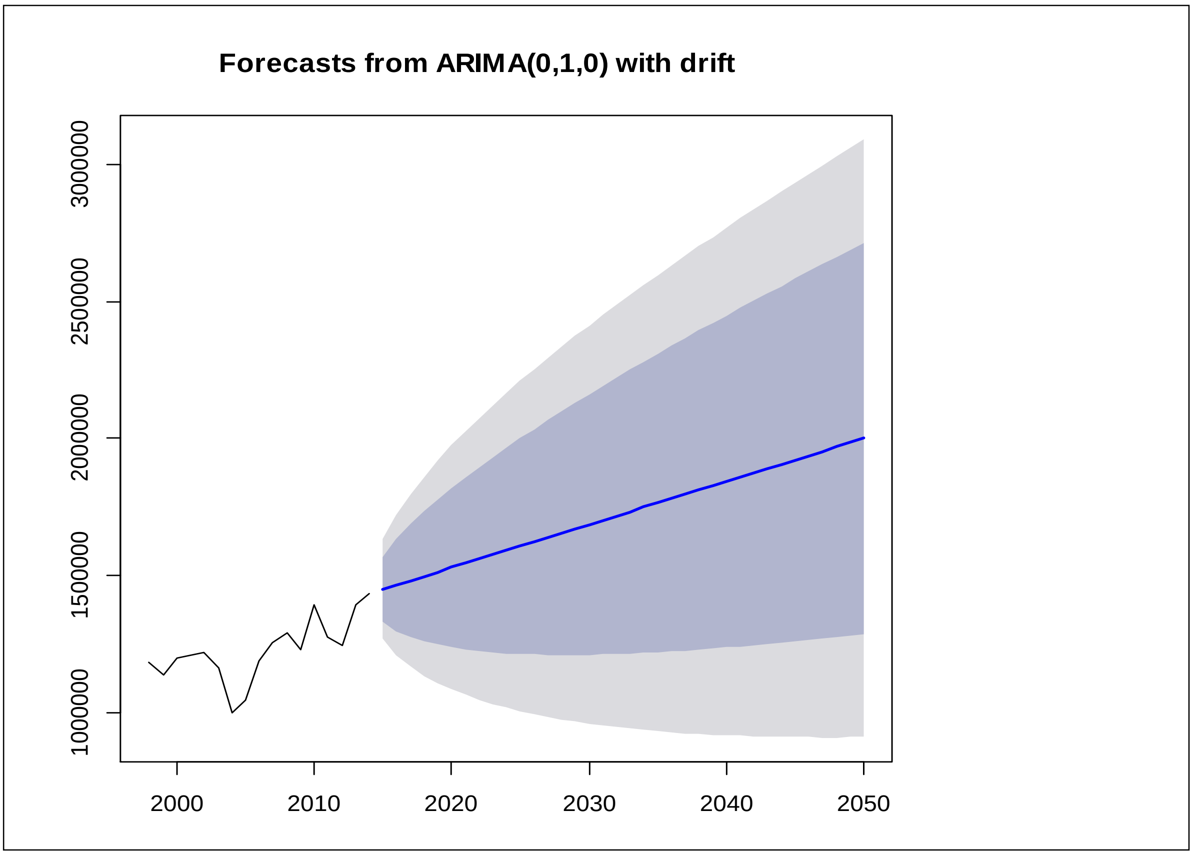


Figure 5.13 Plot of forecast values for Okahandja annual water demand (m^3)

Diagnostic plots for this model are presented in Figure 5.14. The ACF of residuals suggests absence of serial correlation among the residuals (Box-Ljung test χ^2= 0.1911, p = 0.662). The plot of residuals versus time order (Fig 5.14b) did not show any funnelling out indicating constant variance. The normal Q-Q plot was fairly straight and the histogram of residuals did not seem to grossly violate the normality assumptions.

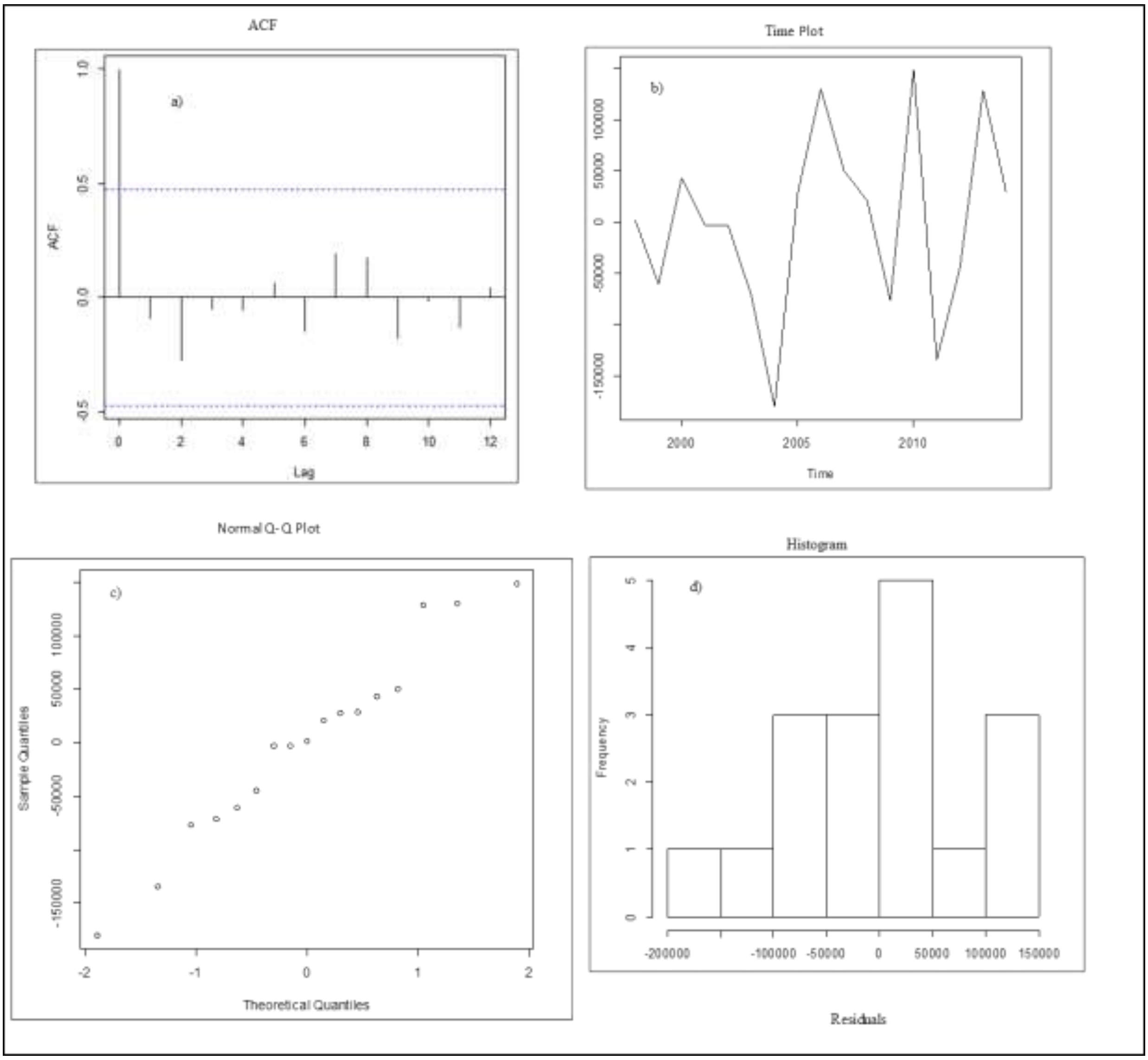


Figure 5.14 a) forecast residuals acf, b) plot of forecast residuals versus time order, c) forecast residuals normal Q-Q plot, and d) forecast residuals histogram.

5.4 Water Evaluation And Planning (WEAP) Modeling Results

A snapshot of the results is shown in Figure 5.15 indicating the built up WEAP model and the four main interface areas of the model namely schematic, data, results and scenario explorer. Figures 5.16 to 5.19 depict some of the sample snapshot results from the WEAP model.

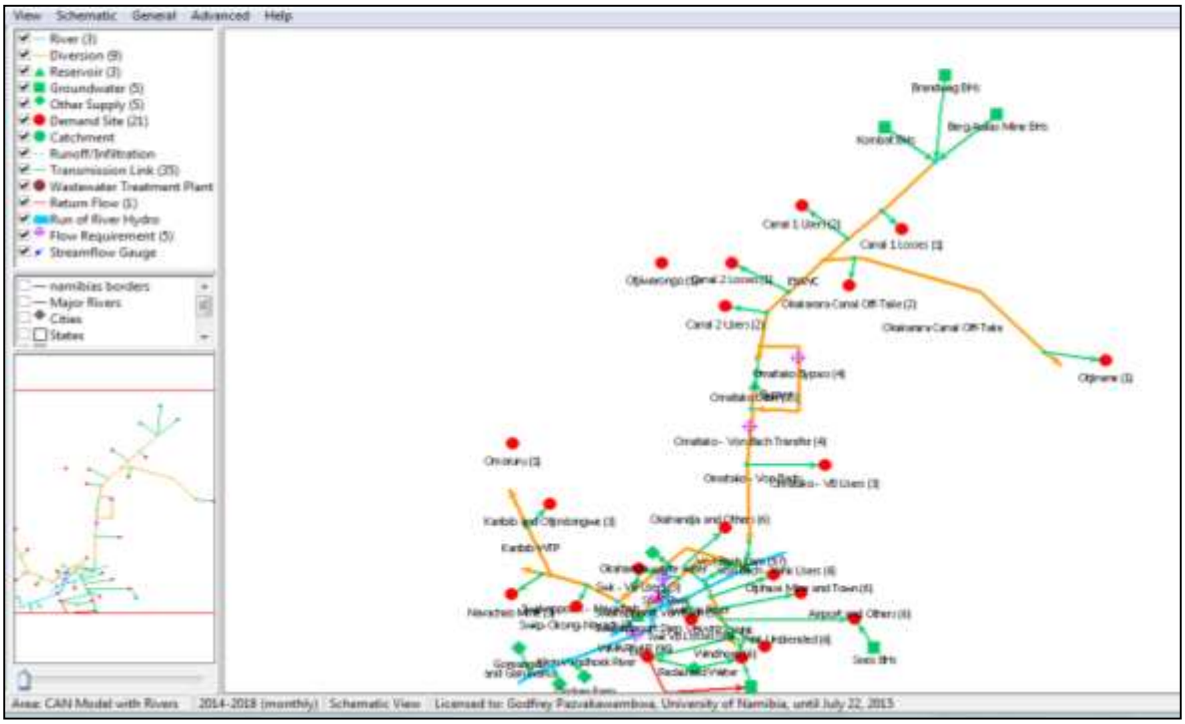


Figure 5.15: Typical WEAP representation of CAN and USB schematic areas-topology of the water system

Validating model: Based on the parameter estimation tool (PEST) of WEAP that help produce results that match historical data records, the reference scenario was used to simulate previous dams' capacities and outflows and these results were compared with the historical data records and the CAN model input figures. These results were used as the basis of calibrating and validating the WEAP model and has been verified with measured hydrometric readings. The future simulated dams' capacities and outflows are indicated on Figure 5.16.

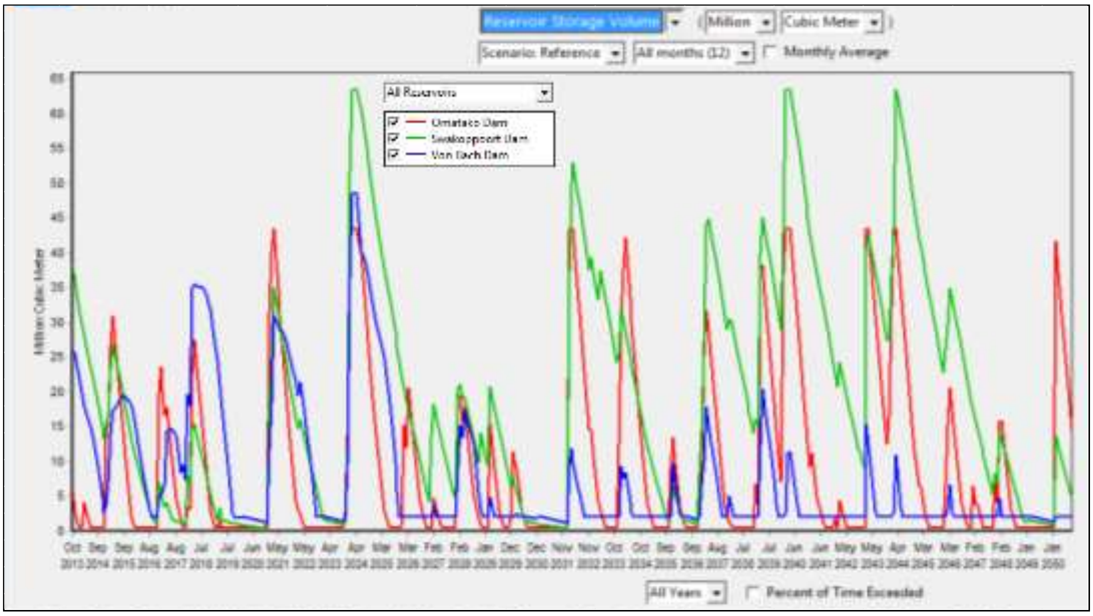


Figure 5.16 Simulated inflows and dam capacities of the WEAP model.

The projected unmet water demands for the CAN areas are shown in Figure 5.17 for 2014 to 2050. From this figure, it can be seen that Windhoek had the highest estimated water supply deficit of more than 50 Mm^3 in 2050 if the currently developed water sources are not augmented.

The modelled conservative pollution loads in form of total suspended solids (TSS) discharged from the Windhoek tributaries and traced to the Swakop River reaches just before it discharges into Swakoppoort Dam are presented on Figure 5.18. On these scenarios, it was assumed that there was a no decay rate of the pollution load. The TSS was also assumed a conservative pollution parameter. Lastly, Figure 5.19 depicts the simulated total suspended solids pollution loads with a first order decay (0.5 per day), carried by tributaries that flow from Windhoek City and traced to the Swakop River reaches just before it discharges into Swakoppoort Dam.

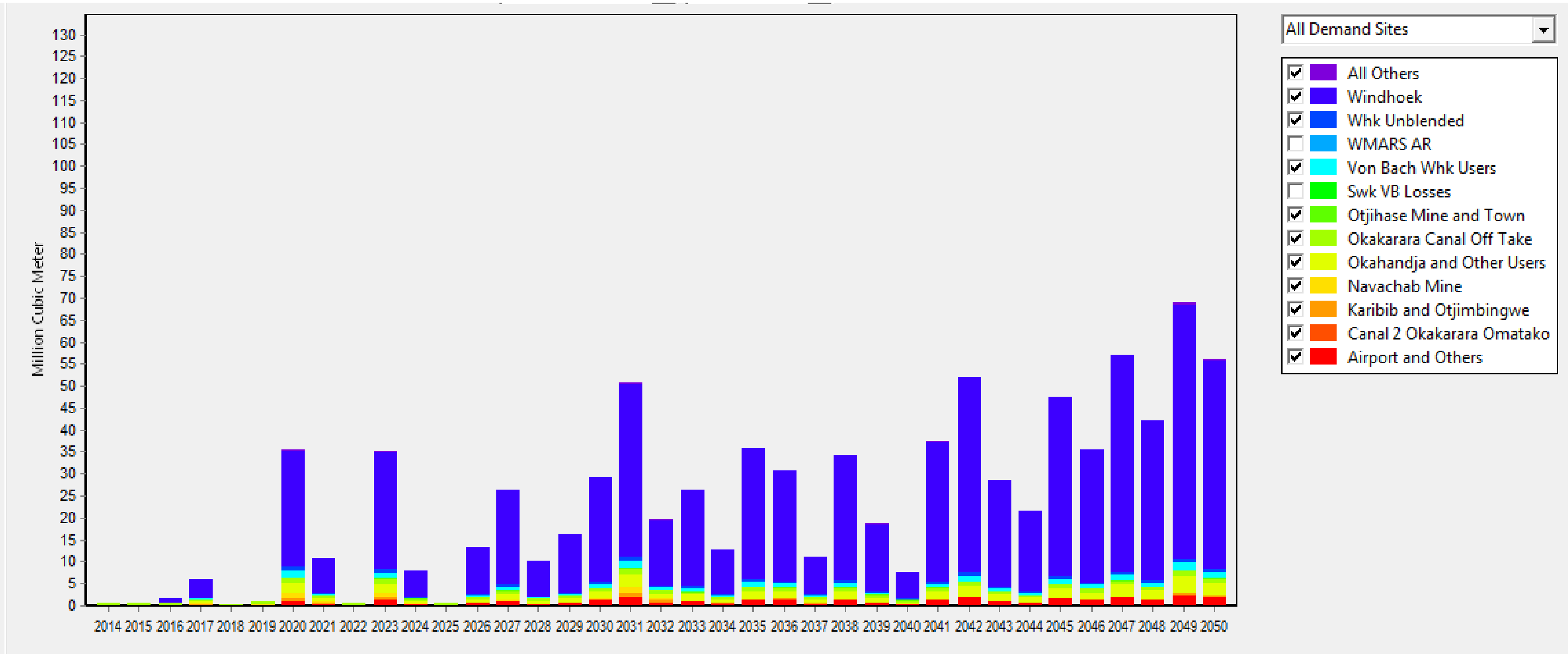


Figure 5.17 Projected Unmet Demands for CAN from 2014 to 2050

Figure 5.18 Projected Total Suspended Solids in the Klein Windhoek River Reaches and Swakop River (Without Decay Rate) (2014 to 2018)

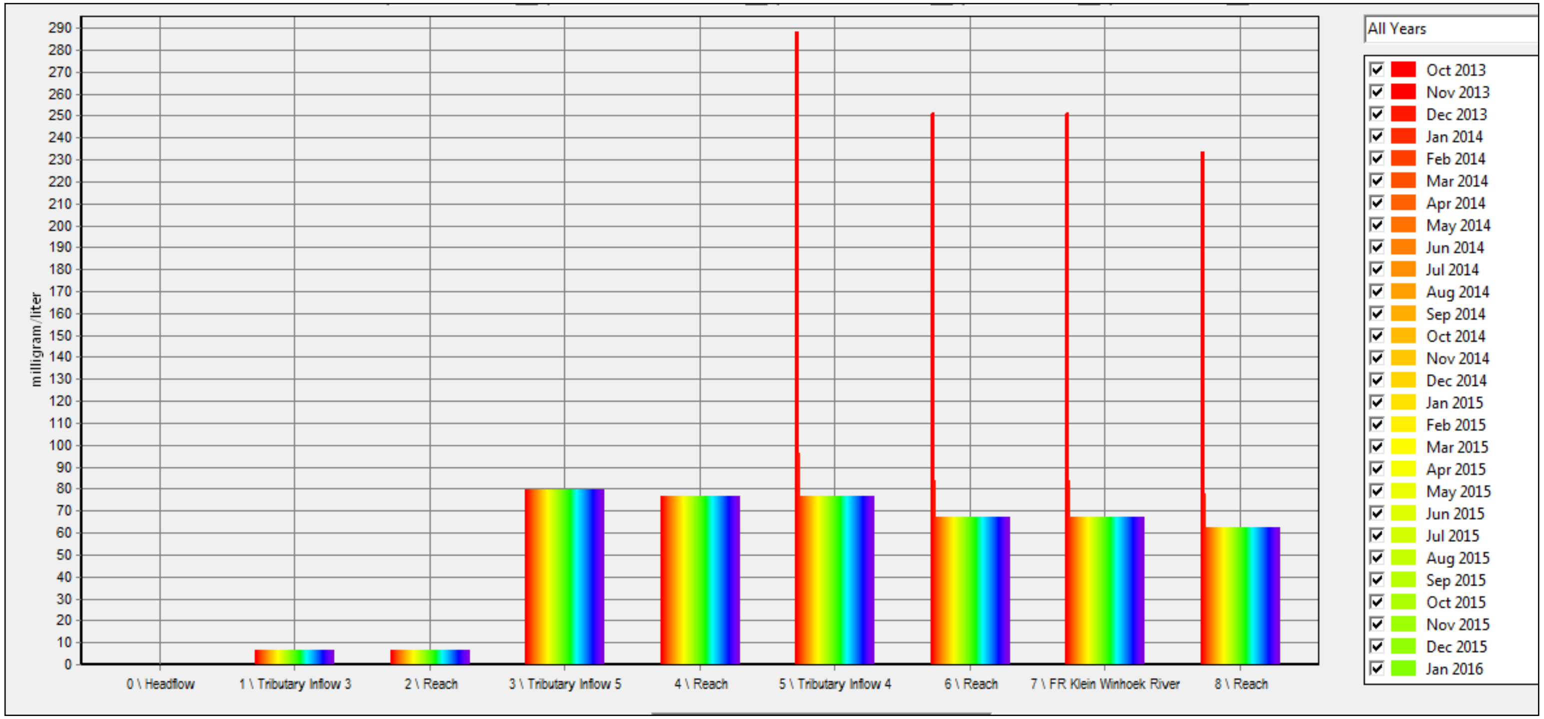


Figure 5.19 Simulated Total Suspended solids with seasonal flows and Effects of Decay Rate (0.5 per day as given in the WEAP model)

The model assumed some flows in the Swakop River and its tributaries yet in reality, the rivers is highly ephemeral. This limitation hindered the full application of the WEAP water quality modelling in the USB.

5.5 Discussion

It should be noted that there serious gaps in the water quality monitoring data obtained from the institutions and used in the WEAP model. There are few consistent monitoring points and data for the receiving water within the USB. River flow measurements were not taken at the time the samples were collected at the sampling points. The rates of river flow should have accompanied the samples that were taken in order to accurately determine the concentration of the pollution. The WEAP model assumes steady state flows of the rivers. However, although there were flows at some of the sampling points, for example at the Goreangab Dam the flows were intermittent, and only in isolated flood incidents would it reach the Swakoppoort Dam otherwise it becomes subsurface flow. As mentioned in Section 5.4, the conservative point source parameters of pollution were assumed in the model (e.g., TSS i.e. was assumed to be cumulative, regardless of the intermittent nature of the rivers). It was not possible to determine the pollution nutrient loads entering into the downstream Swakopppoort Dam due to the absence of river flow measurements. Besides, the Swakop River in connection with other ephemeral rivers and streams only flows immediately after flash floods thereby carrying heavy pollutant loads downstream. Even the artificial continuous effluent discharge streams immediately become sub surface streams.

Given the stationarity in the rainfall time series, the surface water sources as well as the natural recharging of the aquifers should be considered conservatively given the sparsity, high variability, scarcity and unpredictability of the rainfall in the

USB. Thus, artificial recharge of aquifers should be fully optimized especially the Windhoek aquifer which is the biggest known in the USB. The projected upper limits of the water demands on the CAN (Windhoek and Okahandja) based on ARIMA modelling are presented in Table 14.

Table 14 Projected Water demands on the CAN (Okahandja and Windhoek)

Year	**Windhoek City**		**Okahandja Town**	
	Annual Water Demand Estimate (m^3)	**Upper 95% limit**	**Annual Water Demand Estimate (m^3)**	**Upper 95% limit**
2015	26.70	29.29	1.45	1.63
2020	28.80	33.68	1.53	1.97
2025	31.05	37.33	1.61	2.21
2030	33.22	40.70	1.69	2.38
2040	37.56	46.98	1.84	2.77
2050	41.96	52.93	2.00	3.09

The population of Windhoek was 340,000 in 2011 and the projected figure for 2030 is 645,000 (Namibia Statistics Agency, 2011). Based on the estimated per capita daily water consumption of 206 litres per day, and the population projection of 645,000 for 2030, the annual estimated demand for Windhoek City will be 48,497 Mm^3/a that is, = (365 x 206 x 645,000/1,000) m^3/a.

For planning purposes, the upper confidence limit gives a better insight on water demand preparedness e.g. 52.93 Mm^3/a for Windhoek in 2050. Starting from 2040 to 2050, the water demand projections differ probably due to the difficulty and increased uncertainty in making such long range forecasts for water demands.

5.6 Adaptive Initiatives of Optimizing and Enhancing the Windhoek Rechargeable Aquifer Storage Capacity to Improve Water Security in the USB

The current available fresh water sources in the USB do not meet the growing water demand due to aridity, occasional droughts and rainfall variability. These sources are also being threatened by pollution as presented in Chapter 4. Unless these sources are optimized to get the maximum yield, Windhoek may run dry. Therefore, applying adaptive water governance principles to the water reuse and natural and artificial recharging of the Windhoek aquifer may enhance and optimize water security of the city.

5.6.1 Results of Preliminary Supply and Demand Water Balance Analysis of the CAN

The data used in this section were obtained from Namibia Water Corporation (2013). The prevailing water sources of the CAN and their percentage contribution and suppliers (agents) are depicted in Figure 5.20. The potential growth in water sales on the Von Bach – Windhoek scheme is shown on Figure 5.21.

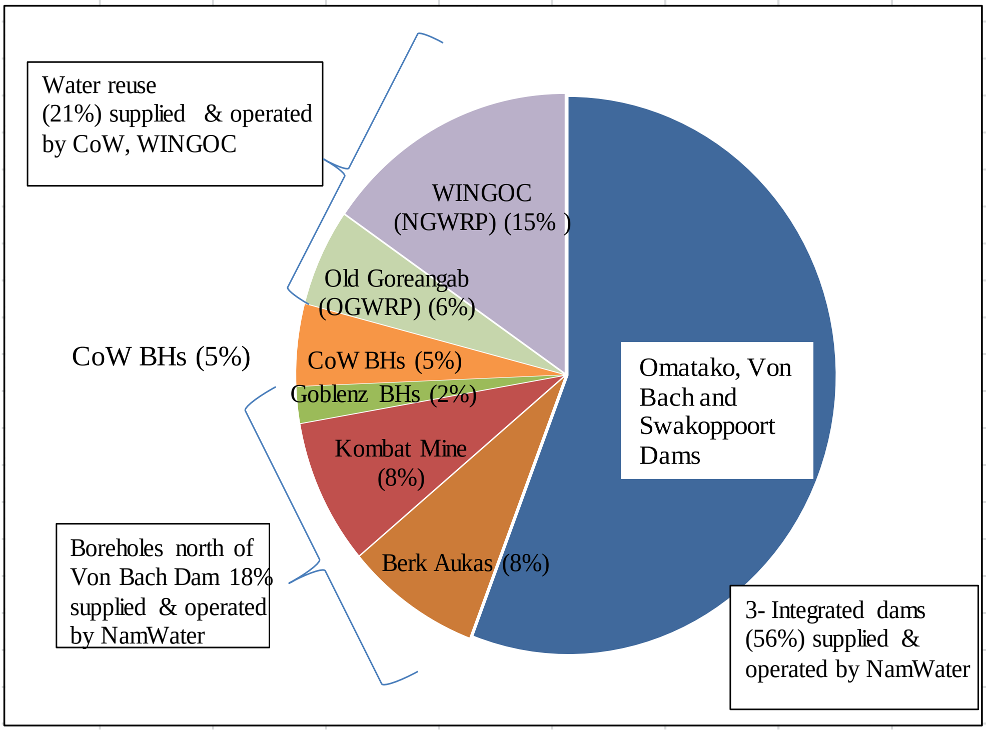


Figure 5.20 Present Water Sources of the CAN, Percentage Contribution and the Supplier

The demand / supply water balance in 2013 from various sources of the CAN (from which Windhoek is supplied) was computed as depicted in Table 15. The Von Bach -Windhoek historical water sales (2009 to 2013) have an increasing trend averaging 4.7% annual growth. A significant proportion of water for drinking was contributed from water reuse (15%). If more of these resources can be developed and made available, it would reduce the looming water supply shortage that Windhoek may face, especially given the high rainfall/runoff variability of Namibia.

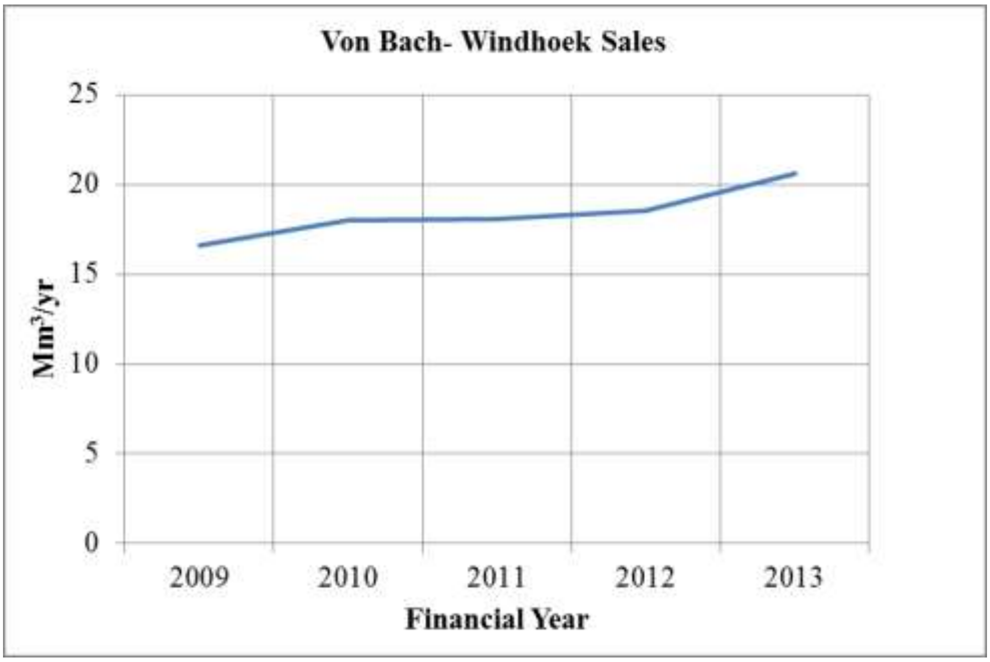


Figure 5.21 Snapshot of the potential growth in sales on the Von Bach – Windhoek water supply scheme.

Although there has been considerable water reclamation for potable use, water reuse has potential to also address water pollution associated with the Goreangab Dam as will be discussed later in this section.

Equally, the developed water resources in the USB indicate that they are "*running on rims*" to meet the demands as depicted by the water balance (Table 15) i.e. only 1.3 Mm^3 in 2013 was "unallocated". This represented 3.7 % of the proxy demands and would be the only additional supply cover available based on maximum yield of the developed sources. However, without even running any sensitivity analysis this would mean that any reduction of the actual available yield of the 3-integrated dams from the maximum of 20 Mm^3 used in the water balance calculation would result in the water being inadequate. In a snapshot, this implies more sources should be developed as soon as possible. The water demand of the USB has reached the threshold of the sources indicating that a slight failure of the developed sources will result in water supply shortages to the USB, that make up the major demand centres (85%) of the CAN system.

Table 15 Typical recorded (representative) supply and demand water balance of the CAN in 2013 (Namibia Water Corporation [NamWater], 2013)

Demand /Supply Description	**Water Demand (Mm^3)**	**Supply Mm^3)**	**Balance (Mm^3)**
North of Von Bach (Karst) supply boreholes		6.5	
Consumers north of Von Bach	-3		3.5
3- integrated dams supply		20	
Okahandja demand (USB)	-2		21.5
Otjihase to Airport consumers demand (USB)	-1.2		20.3
Karibib, Navachab & small consumers demand	-2.1		18.2
Windhoek demand (USB)	-26.1		**-7.9**
Windhoek boreholes supply		1.7	**-6.2**
WINGOC- Reclamation supply (NGWRP) &		5.5	**-0.7**
Old Goreangab Reclamation supply (OGWRP)		2	1.3
Total	**34.4**	**35.7**	**1.3**

5.6.2 Discussion

The water supply system of USB has various reservoir facilities that include three integrated dams namely Von Bach, Omatako and Swakoppoort. Hydrologically, these surface storage facilities are already optimized in that they are operated to give the minimum evaporation. The 95% yield of the dams calculated as discrete units gives a total yield of 13 M m^3. The operation of the three reservoirs is such that water is timely transferred to the least evaporated Von Bach Dam, thus the 95% yield stretches to 20 M m^3 (NamWater, 2010b) (Figure 5.22).

However, it should be noted that the mean total annual inflow of the three dams is estimated at 50 Mm^3 while their total full supply capacity is 155 Mm^3 (Figure 5.22). The mean, median and full supply capacity of the three-dam system annual inflows are also depicted in Figure 5.22. Because of the high storage ratio of the dams, and the high variability of the three reservoirs' annual inflows, the inflows are usually inadequate to fill the dam seasonally. The high storage ratio results in high residence time as well as salinization of the water in the dams during drought periods.

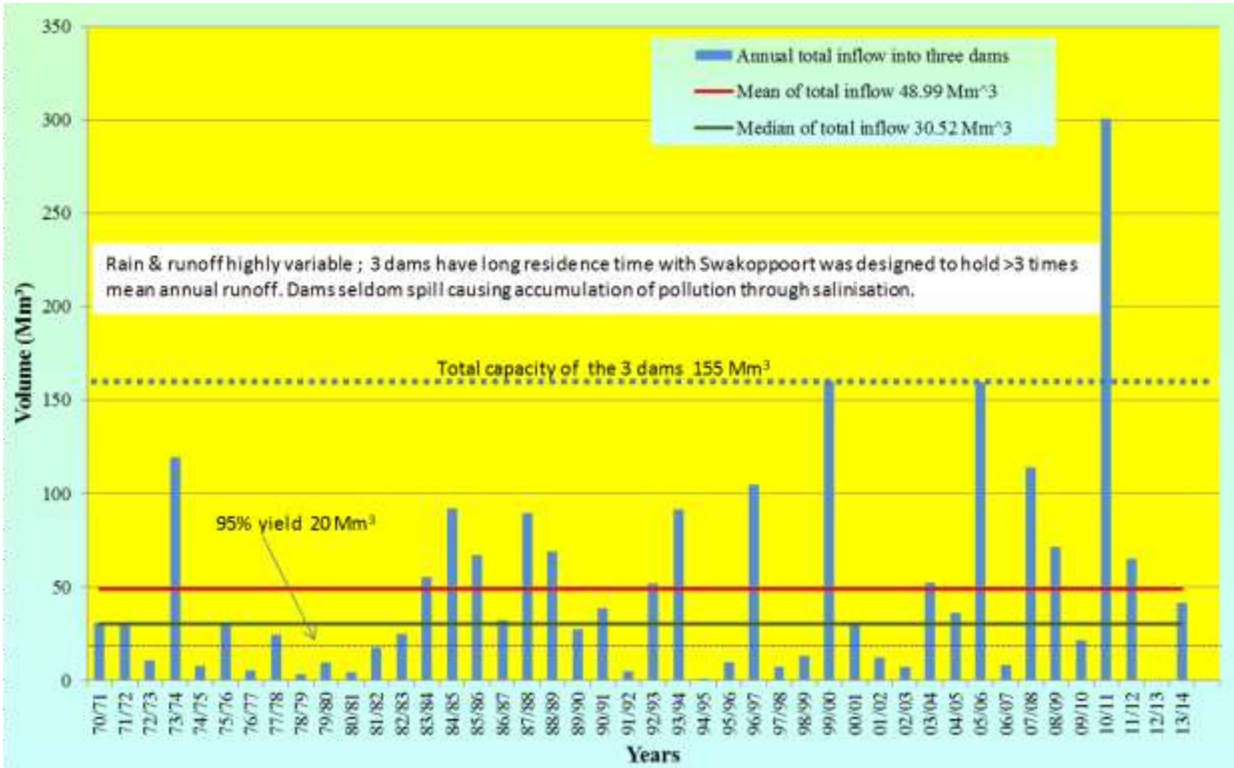


Figure 5.22 The Three Dam System's Annual inflows, Capacity, 95% yield and Total Capacity (adapted from Namibia Water Corporation [NamWater], 2013)

However, the three dams' mean total annual inflow, "rapid yield" can be timely stored in the Windhoek Rechargeable Aquifer Storage (WRAS) if the recharging capacity and facilities are matched with the yearly obtainable rapid yield and a portion of the rapid yield could be released to the downstream users and environment. According to Namibia Water Corporation [NamWater] (2010b), the existing practice had no planned water releases downstream of Swakoppoort Dam. As discussed earlier in Chapter 2 Section 2.3.1, the WRAS characteristics, still being studied, may have a potential capacity of 112 Mm^3. By utilizing the "rapid yield" water from the 3-integrated dams, the potential storage of WRAS can be used to store treated water for abstraction when required. Further optimization of the WRAS may also be achieved by storing any runoff whose infiltration into the WRAS can be enhanced artificially. In order to achieve this, runoff detention ponds, retention ponds and check dams can be strategically constructed in river sections in and around the Windhoek Rechargeable Aquifer (WRA) to enhance both natural and artificial recharge.

5.6.3 Adaptive Initiatives for the Optimization of the Windhoek Rechargeable Aquifer Storage (WRAS) and Windhoek Supply Sources

A new optimized water balance of the inflows and out flows of the WRA serving as a storage facility is constructed and proposed in this study as a contribution to new knowledge and is described as follows and as depicted in Figure 5.23:

1. Minimize the total outflows (O) from the dams i.e. minimize the evaporation and overflows from the three integrated dams as well as Goreangab Dam reservoirs by increasing and quickly effecting seasonal transfers into the WRAS.
2. Maximize and enhance the rainfall / runoff infiltration (R) into the WRAS i.e. construct runoff detention ponds, retention ponds and check dams.

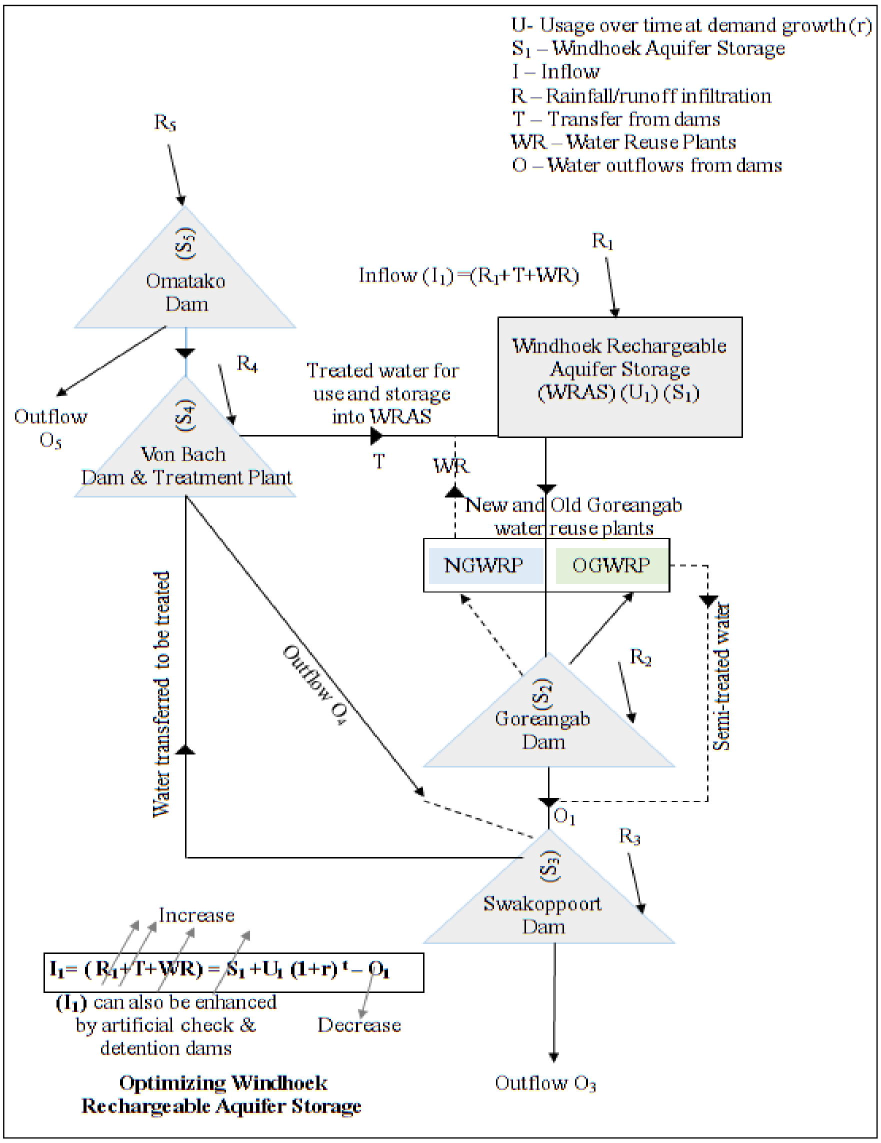


Figure 5.23 Optimized and Adaptive Sustainable Water Governance Strategy

3. Maximize and enhance the "rapid yield" water from the 3-integrated dams, treat and bank into the WRAS
4. Increase transfer of treated water from the water reuse reclamation plants.
5. Implement water demand measures that will keep water usage at appropriate levels.

It should be noted that the water balance model used assumed that the outflow losses through seepage from the aquifers and dams are insignificant given that the Windhoek Rechargeable Aquifer bed rock has low permeability (Murray & Tredoux, 1998).

5.6.4 Summary

In conclusion, there may be potential to adaptively manage and optimise the WRAS as a means to sustainably improve water supply security to Windhoek. Once the estimates of WRAS are more firmed, the optimization can be numerically computed in another further study.

The next section of the study is a complimentary initiative of taking Goreangab Dam as a pollution detention and check dam to control pollution into the larger Swakoppoort Dam. This initiative may adaptively be suitable for the USB given the aridity and ephemeral nature of the rivers feeding into Goreangab Dam as well as the downstream rivers.

5.7 Adaptive Initiatives of Optimizing the Goreangab Dam as a Water Pollution Detention and Check Dam

The quality of Goreangab Dam water has deteriorated to a point where the raw water is currently only abstracted for treatment at the OGWRP and used for irrigation. By applying responsible engineering instead of abandoning and leaving the Goreangab Dam water becoming more polluted, the Goreangab Dam collection of polluted water can theoretically provide ways to keep the effluent out of streams, thus reducing pollution of surface water downstream and as well as the groundwater (Asano, 1998; Asano 2002). With the vexing problems of increasing water shortages and environmental pollution, a realistic framework can emerge for considering reclaimed water processing not only as a water resource but an opportunity to curb water pollution downstream.

The initiatives that are hereby suggested to optimize the Goreangab Dam entail combining the advantages of two existing infrastructure namely: the New Goreangab Water Reclamation Plant (NGWRP) and the Old Goreangab Water Reclamation Plant (OGWRP) which is located on the left side of the Goreangab dam embankment, that treats water from the polluted Goreangab Dam and from the Otjomuise Wastewater Treatment Works, located within 1 km downstream of Goreangab Dam. The two facilities can be utilized conjunctively, to treat all the water in the dam as described below.

The OGWRP can be used to treat all the water from the Goreangab dam thus preventing water pollution flows and spill overs from running down to the downstream Swakoppoort Dam. Surplus treated water above the irrigation water demand of the City (see Section 2.3.3) can be released downstream to Swakoppoort Dam and/or, depending on the quality of final product water, may be transferred upstream to the runoff detention ponds, retention ponds and check dams feeding the WRAS as discussed in section 5.6.3. The polluted residue or sludge in the Goreangab Dam can *be cleaned up* by either using dredging machines or letting it dry up. The dried sludge should then be moved to land fill sites. This initiative will take advantage of the existing 3.6 Mm^3 Goreangab Dam as a *water pollution detention/check dam* to clean up the pollution from Windhoek. This clean up exercise should be carried out occasionally, say once in 7 years depending on the pollution levels in the reservoir. The high residence time as well as salinization of the water in the Goreangab and Swakoppoort Dams during drought periods can also be minimized. The other advantage of cleaning the Goreangab Dam is that the less polluted newer inflows into the dam can be blended to be part of the raw water source of the potable New Goreangab Water Reclamation Plant (NGWRP). This initiative will also enhance water security of Windhoek in that the once abandoned Goreangab Dam water will be added to the usable drinking water sources. For this initiative to be operational, a detailed and thorough environmental clearance process will be required.

The suggested increased transfer of treated water from the water reuse reclamation plants into the WRAS in Section 5.6.3 assumes the consumers are comfortable in using both direct and indirect reused water for drinking. This issue of consumer choice was further interrogated in the next Chapter (6) through a survey carried out on the social acceptability and related ethical and health issues of water reuse in Windhoek. With increasing pollution of the raw water sources for water reuse for drinking, it is important to understand the concerns, views and perceptions of stakeholders/consumers from a water governance perspective.

5.8 Initiatives to have a Unified Governance for Bulk Water Supply in Windhoek

Several agencies are collectively supplying Windhoek with potable water (Table 16 and Figure 5.20). The Windhoek Municipality owns, operates and supplies bulk water to and from the Windhoek Rechargable Aquifer boreholes. WINGOC, jointly owned by Windhoek Municipality and a Germany company, is contracted to operate the NGWRP. NGWRP supplies ±21% of the bulk drinking water to Windhoek while NamWater treats and supplies ±74% of the bulk water from the three integrated dams. The remainder comes from the Windhoek boreholes.

Table 16 Agencies and their Contribution to the USB and the type of Water Governance Institutions

Water Source Description	Approximate Yield	Total % Contribution	Supplying Agent	Type of Water Governance Institution
Surface Water				
Omatako, Von Bach; Swakoppoort Dams (95% assured yield)	20	56	NamWater	Limited Company; 100% State Owned
Groundwater				
Berg Aukes Mine & Boreholes; Kombat Mine; Goblenz Boreholes; Seeis Boreholes;	6.7	18		
CoW Aquifer/Boreholes;	1.7	5	CoW	Public Authority
Recycled Water				
Old Goreangab Recycling Plant; New Goreangab Reclamation Plant	7.5	21	Wingoc under Public Private Partnership	Public Private
	35.9	100		

The prevailing institutional set up may not encourage the full optimization of the WRAS facility and beneficiation from an integrated bulk water supply system comprising the Windhoek Rechargeable Aquifer Storage (WRAS), three integrated dams and New Goreangab Reclamation plant. For instance, if NamWater or WINGOC is to supply treated water for storage in the WRA, payment for this treated water may only be fully realised only when Windhoek Municipality will have abstracted this water and sold it to its consumers. It can be argued that neither the Windhoek Municipality nor NamWater may be willing to pre-finance and facilitate the storage of treated water in the WRA as this will upset the individual entity's cash flows. Although, Windhoek Municipality may be the overall benefeciary of this initiative in ensuring water secutity, the Windhoek Municipality may be reluctant to pay upfront for the banked water in the aquifer. When operated by several bulk water supply agencies, as is the present situation, the initiative to optimize the full storage of the WRA may not be fully realised.

Moreover, if the Goreangab Dam were to be used as a pollution detention/check dam to protect the Swakoppoort Dam, the required occassional cleaning of the Goreangab Dam would result in considerable cost that may be difficult to apportion among Windhoek Municipality, NamWater and WINGOC. Additional complexity of this initiative under the current institutional setting is that, WINGOC with its closeness to Goreangab dam will be at a greater advantage in the competition for a Windhoek water market, because new water sources that may in future be developed by NamWater are much further away and would be more expensive than the WINGOC option. If this scenario becomes a reality, NamWater is likely to suffer on cashflows and lost sales. It is therefore, recommended that there should be a single unified agent supplying bulk water to Windhoek. This may eliminate/ reduce the financial challenges as seen under the multi supplier system now in operation. Windhoek Municipality can continue to sell water, as a retailer to its customers.

5.9 Summary

This study used monthly rainfall data from 1891 to 2012 to forecast future monthly rainfall up to 2050 using a SARIMA model. The model was used to predict rainfall values for 36 years into the future that can help management and policy makers to map strategies, priorities and proper use of water resources in Windhoek.

The ARIMA models were used to forecast both Windhoek and Okahandja water demands till 2050. The forecast for the biggest water demand centre in the USB i.e. water demand for Windhoek in 2050, would more than double the existing demand in 2014 (26 Mm^3 to 52.93 Mm^3).

The WEAP model reduced the complexity and visualisation of multiple scenario development and adaptation and understanding of conjunctive use of groundwater and surface water as well as Windhoek reclaimed water. The model provided a framework for addressing and communicating the technical, multilateral, institutional and political issues among stakeholders within the USB.

The WEAP forecast results indicated that the multiple water sources in the Upper Swakop Basin and CAN area will not be able to supply adequate water into the future because of the growing demand (see Figure 5.17). The current developed sources within the USB and the CAN are already constrained and require augmentation if water is to be supplied sustainably. Assuming the baseline scenario where the historical hydrometric conditions will be mirrored, a shortfall of about 70 Mm^3 will be required by 2050 to satisfy the envisaged growing demands.

There was a challenge of using WEAP to model the water quality of ephemeral streams in the USB considering that these rivers only flow during peak floods periods Modelling pollution of reservoirs or dams was not within the capacities of WEAP version 3.43 that was used (although a special encrypted subroutine could have been developed and linked to the WEAP model). However, WEAP may be used in the determination of maximum allowable pollution load at the reservoir entry and also to allocate the allowable level of pollution among different sources to achieve required water quality standards.

In conclusion, the envisaged water supply (quantity) deficits to the USB, where Windhoek is biggest demand centre due to the fast-growing water demand, require an urgent mix of solutions. The water demand of Windhoek has nearly surpassed the developed supply sources. The study proposed two strategic approaches to augment the drinking water supplies. One approach is to embark on the “management solution”. This solution included water demand measures as well as to embark on initiatives to optimize and enhance water reuse, the three integrated dams, and conjunctively make use of the WRAS. Complementary initiatives that should reduce and control water pollution were recommended to include the use of Goreangab Dam as a pollution check dam to prevent further pollution of the Swakoppoort Dam.

The second approach i.e. the supply oriented “resources solution”, acknowledges that the developed water resources supplying the USB are already strained to meet current demand and would need augmentation for projected future demands. Therefore, the USB may require to be linked to the sustainable water sources that could include the perennial Okavango River basin transfer source.

The objective number 2 which was to evaluate the adequacy and availability of drinking water sources in the USB, has been adequately investigated by the discussion above. The next chapter looked at the stakeholders’ perceptions on water reuse for potable purposes.

CHAPTER SIX

6 ASSESSMENT OF THE ETHICAL, SOCIAL AND HEALTH ACCEPTABILITY PERCEPTIONS OF WATER REUSE FOR POTABLE PURPOSES IN WINDHOEK

6.1 Demography

Of the 100 respondents to the questionnaire with 86% response rate, 61.3% were male and 38.7% were female. Most of the respondents (52%) were young (aged 18-34); with 37.3% in the 35-54 age group and the remaining 10.7% were above 55 years of age. The majority of respondents were blacks (81.1%), followed by whites (13.5%), coloureds (4.1%) and others (1.3%). Most of the respondents had achieved tertiary education level (89.3%). The sample comprised of professionals (64.9%), university students (20.3%), while the remaining were general workers and others (14.8%). The majority of the respondents earned more than N$ 5,000 per month (79.3%) and came from households with more than three family members (84%).

6.2 Knowledge of Respondents on Water Resources

Although 88% of the respondents knew that the Municipality of Windhoek supplies them with drinking water, 30.1% did not know the source of this water and only 26.1% knew that one of the drinking water sources was NGWRP reclamation plant. About 67% of the respondents were familiar with the concept of water reuse.

6.3 Acceptance of Water Reuse

Given the semi-aridity of Namibia, 78.9% of the respondents saw the need to purify water from waste water treatment plants for the purpose of drinking.

6.3.1 General Acceptance

There were average levels of acceptance to use reclaimed water for certain uses. For household purposes acceptability levels were swimming pools (47%), washing cars (69%), lawn and garden watering (70%), toilet flushing (71%), and fisheries (51%). With regard to environmental restoration (wetland enhancement) the acceptance of water reuse was (56%). For municipal uses, acceptance levels were as follows: maintaining fountains (62%), swimming pools (51%), recreational (56%), flushing waste water pipes (74%) and firefighting (73%). With regard to industrial and commercial uses, water reuse acceptability levels were as follows: car washes (66%), dust control (68%), mixing concrete (63%) and cooling power plants (68%). For landscape irrigation purposes the acceptability levels were: irrigation of school grounds (66%), public parks (69%), golf courses (69%), and industrial parks (69%). For agricultural irrigation, water reuse acceptability levels were: irrigation of commercial nurseries (65%), non-food crops (66%) and food crops (65%). The results for the respective acceptance of water reuse for different kinds of activities are given in Figure 6.1.

6.3.2 Willingness to use reclaimed water for specific purposes

The willingness to use the reclaimed water in whole or blended with treated water from freshwater sources were rated (from 0 to 10, with 0 being totally unwilling and 10 being totally willing) for different water uses as shown in Figure 6.2. The least popular willingness to use the wholly reclaimed water was for drinking (mean rating 5.53, standard deviation 3.91).

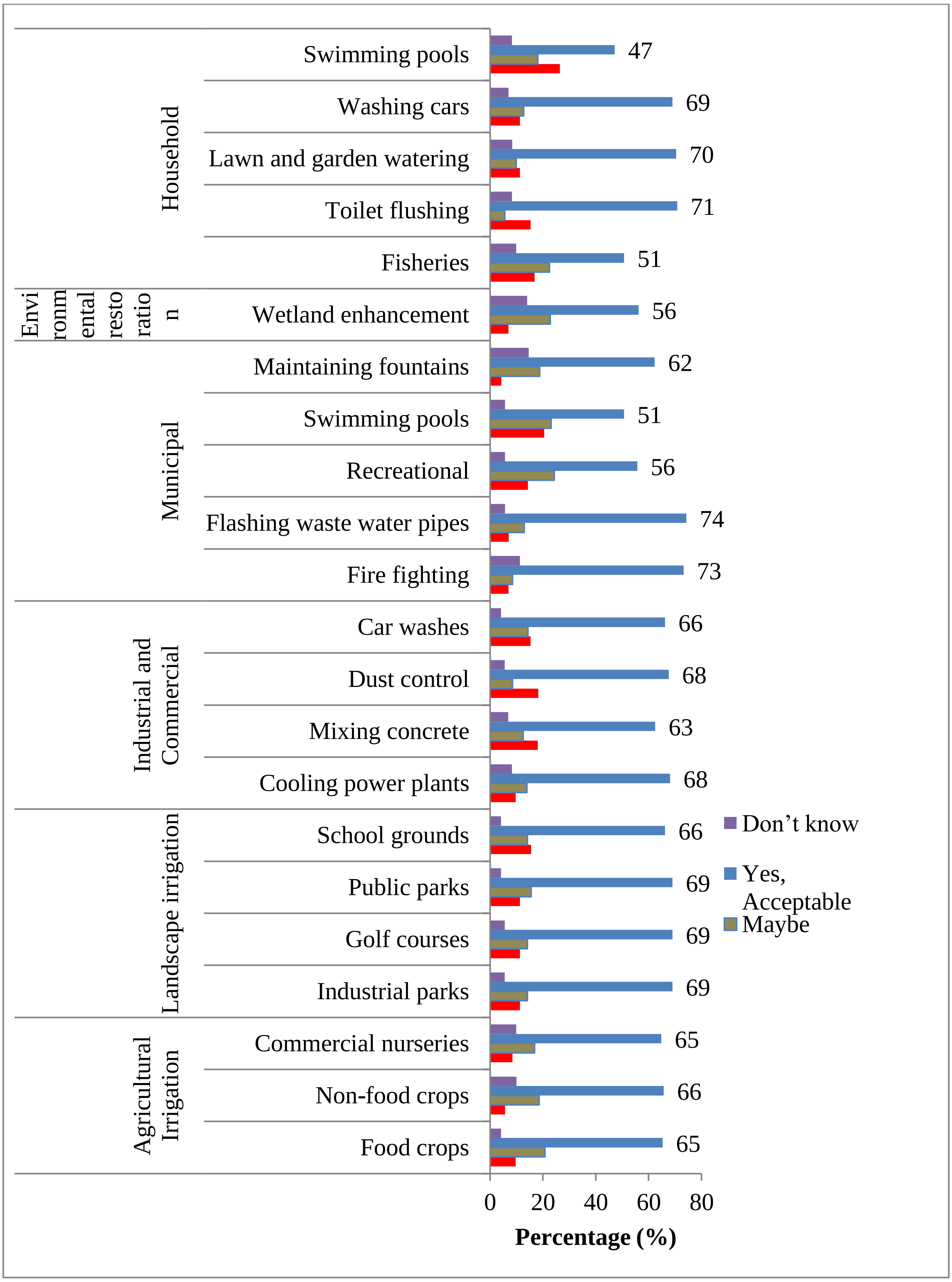


Figure 6.1 Acceptability of purified water from sewerage treatment plants for various uses.

However, the respondents were slightly more willing to drink the reclaimed water if it were blended with treated water from groundwater and dams (mean 5.73, standard deviation 3.5). The highest willingness ratings for reclaimed water use were for irrigation of vegetables (mean 7.87, standard deviation 2.92) and lawns (mean 7.54, standard deviation 3.29). The respondents also did not mind using it as drinking water for pets and showering (mean 7.38, standard deviation 3.27) though they showed less enthusiasm for using it for cooking (mean 6.49, standard deviation 3.76).

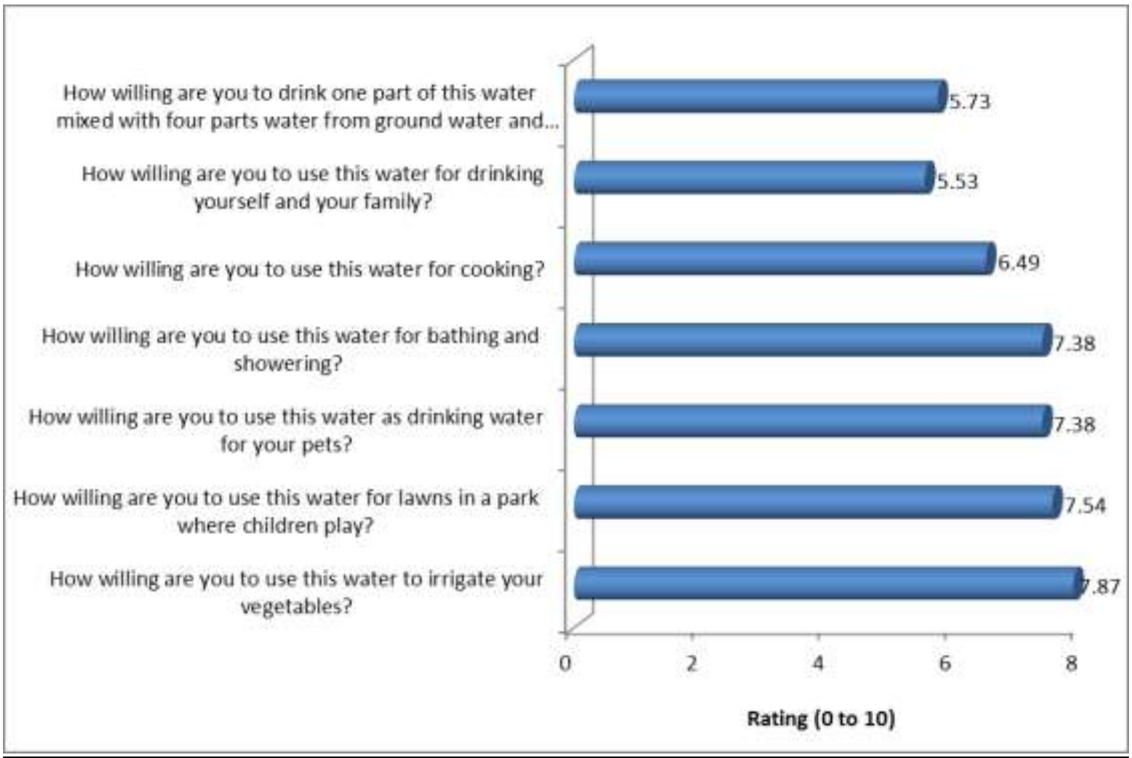


Figure 6.2 Willingness rating (0 to 10) for Water Reuse for Specific Purposes

6.3.3 Attitude to drinking recycled water if there was no other alternative

Only 53.5% of the respondents indicated that they would only drink recycled certified water to stay alive if they had no choice and 16.9% would resort to buying bottled water, while 28.2% indicated that they would fit additional tap filters to further clean the water (Figure 6.3).

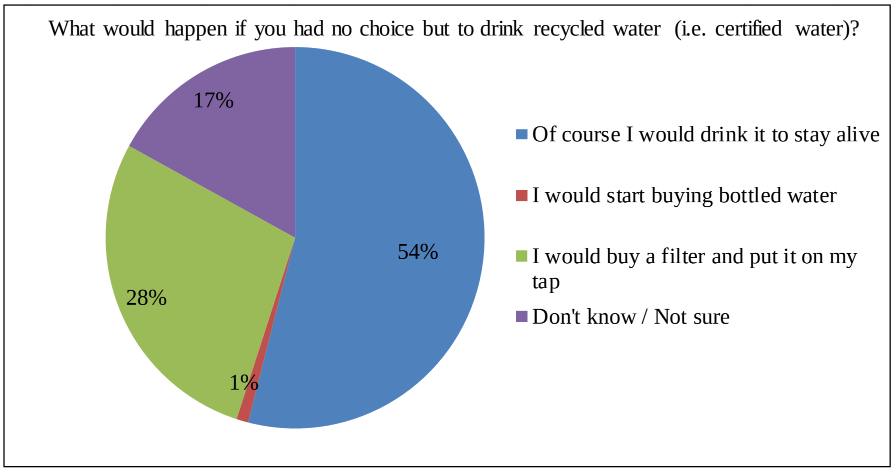


Figure 6.3 Respondents' Attitude to drinking recycled water if there was no other alternative

6.3.4 Respondents' Trust in WINGOC's Quality Control Measures

There was a general trust (60%) in the knowledge of WINGOC's professionals in using the technology and meeting water quality requirements. The results are presented in Figure 6.4. Irrespective of scientific and engineering water quality assurance considerations, the respondents' perceptions on acceptance of drinking water from a water reuse plant, were largely influenced by the lack of publicity of the daily water quality information on the water reuse (52.2%); prejudicial beliefs and fears (21.7%); visual imagery/ disgusting factor (17.4%) and to a lesser extent, historical or anecdotal information (8.7%). A high proportion (80%) of the respondents believed that increased local participation and ownership by all stakeholders in the management of the water resources will not only raise awareness and improve the stewardship about the fresh water resources but this could increase the level of acceptance of recycled water. Lahnsteiner and Lempert (2007) also concluded that the Windhoek public may accept such initiatives if properly informed, despite initial health and aesthetic concerns.

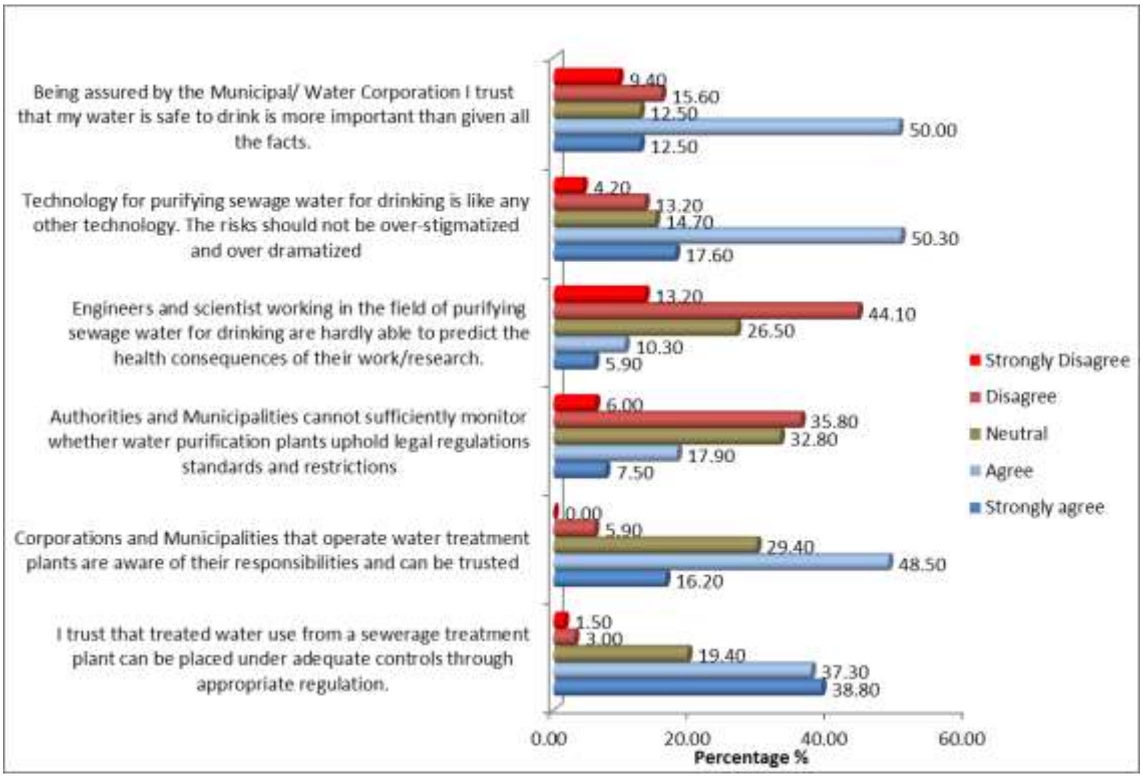


Figure 6.4 Trusting the Service Provider's Quality Control

The NGWRP and Windhoek Municipality have special health standards that formed the Private Management Agreement between them. These standards, however, are not well articulated in the Water Resources Management Act (2013). The water quality compliance, control and monitoring is carried out by NGWRP and/or Windhoek Municipality in accordance with the Private Management Agreement. Some parameters, like emerging endocrine disrupters, are not regularly checked because of lack of water quality laboratories in Windhoek to determine these parameters. The ability of NGWRP to individually check and monitor in real time, the suspected health endocrine disrupting compounds require sophisticated equipment, and expertise and is costly. The endocrine disrupting compounds include those from personal care products, garden products, flavouring, total oestrogens (hormones) pharmaceuticals, nutrients and salts whose analytical tests according to the responses, can only be done outside Namibia. Julies et al. (2013) emphasised that Namibian samples to determine the presence of these special parameters, for instance, on Cytotoxicity and Immunotoxicity, where Lactate dehydrogenase (LDH) is measured with a chromogenic LDH assay kit, it is done in Europe and South African laboratories on intermittent basis. However, 75.7% of the respondents saw the need to institute a board of experts to certify the product water over and above the regular water quality control checks by Windhoek Municipality. It is interesting to note that the public respondents would like this board to include representatives of the public media and other multi-sectorial stakeholders (Figure 6.5).

According to the expert responses (key stakeholders), the product water quality from NGWRP is compliant 96% of the time. NGWRP reuse plant has been ISO 9001 certified since 2008. However, information on the results of product water can only be accessed with confidentiality undertakings. There are no billboards and no websites where these results can be accessed notwithstanding this lack of easy access to information, there are water quality barriers built into the NGWRP plant, which include physical, organo-leptic, and pathogenic (bacteriological and viral) barriers. This multi-barrier approach processes include the following: Powdered Activated Carbon (PAC) dosing; pre-oxidation and pre-ozonation; flash mixing; enhanced coagulation and flocculation; dissolved air floatation (DAF); dual media rapid gravity sand filtration; ozonation; biologically activated carbon (BAC) filtration; granular activated carbon (GAC) filtration; ultra-filtration; chlorination disinfection and stabilization (Lahnsteiner & Lempert 2007). The five barriers ensure that the reuse water achieve the DOC values of < 1 mg/L.

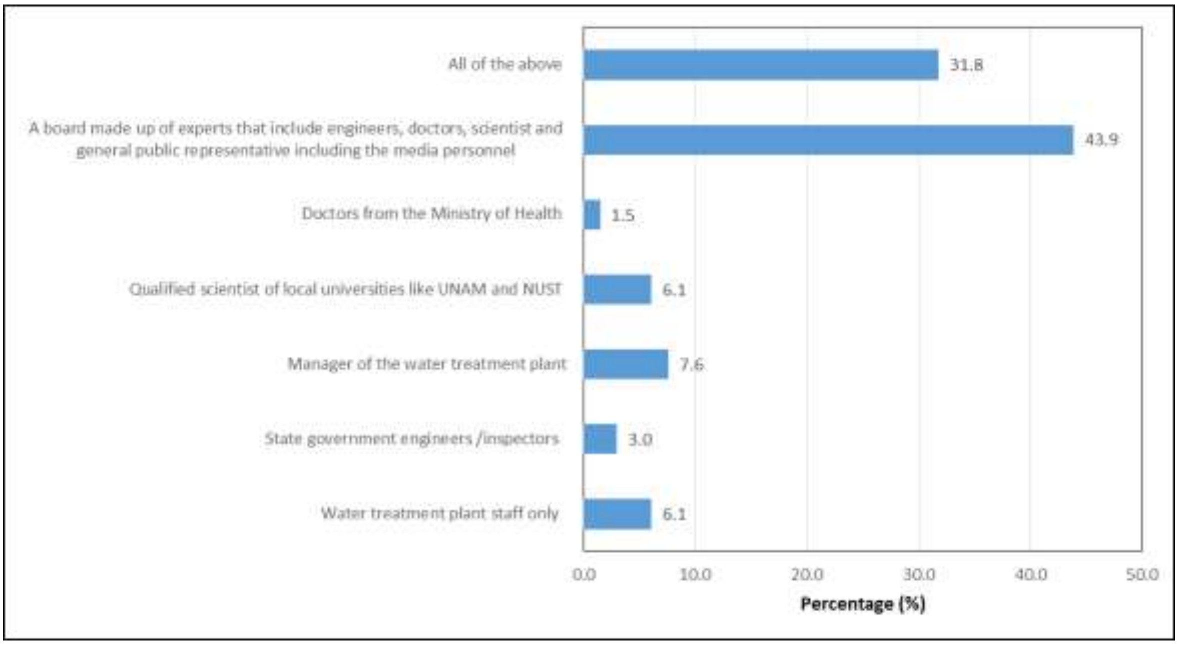


Figure 6.5 Opinions on Certification of Drinking Water Treated from Sewage Water

The quality of raw water source that feeds the plant is from Gammams domestic wastewater treatment plant and varies seasonally. The improvement of the raw water quality from Gammams wastewater treatment plant would result in less water reuse plant stoppage and disruptions. The feeling of key stakeholders on the Goreangab Dam reservoir being abandoned since 2009 as a raw water source due to deteriorated water quality was that this source should be continued as a raw water source by improving the management of the upstream catchment of the Upper Swakop Basin. Chapter 5 outlined initiatives to continuously make use of Goreangab Dam and prevent its raw water quality from continuously deteriorating. The key stakeholders indicated that blending the product water from the water reuse plant with treated water from other sources improves the water quality, marketability and acceptance of the water. The key stakeholders perceived no harm in use of unblended reuse water and highly recommended it for drinking. However, due to operational and contractual obligations they indicated that blending is necessary. They also indicated that the yearly blending ratio of the treated water supplied to Windhoek could be increased and the blended water is distributed across the city except the Northern Industrial area. The fears of the key stakeholders on the quality assurance of the treated water included quality reduction due to poor maintenance of the reuse plant, possibility of WINGOC prioritising commercial interest in producing water from the plant at the expense of quality and health issues (Friedler & Lahav, 2006; Biswas, 2012; Abdel–Dayen et al., 2011). They however, did not consider the "yuck factor" perceptions as an issue given the water scarcity in Windhoek.

6.4 Summary

Moderate public willingness exists in Windhoek to drink treated and certified reclaimed water reuse. From this survey conducted in 2013, slightly above half (53.5%) of the respondents were willing, if they had no choice, to drink water treated and certified reclaimed water to keep alive; 16.9% would resort to drinking bottled water and 28.2% would buy a filter and put it on the tap. Greater than 60% of respondents had trust and assurances of the safety of certified recycled water from the NGWRP water reuse plant. Public acceptance can be enhanced with improved public communication of the results of the product water from water reuse plant. Nearly half (43.5%) of the general respondents wished there could be public bill boards (public media and websites) sharing information of the product water quality. The involvement of all stakeholders affecting or affected by activities related to the direct or indirect water reuse for drinking is required to improve the water quality sources of recycled water and the routes of exposure. Proper effective awareness and educational programmes should be aimed at reducing discharge of hazardous chemicals from households. Communities should be educated to refrain from carelessly dumping point and non-point sources of water pollution. By tracing recycled water and fresh water systems from source, water pollution risks can be minimised.

Even though performance contracts on water quality and health standards exist at NGWRP, proper legislation is required for water reuse for drinking. An independent board with appropriate knowledge and expertise that includes media and public representatives should carry out regular field audits of water quality to eliminate the health hazards and risks. In accordance with integrated water resources management principles, Upper Swakop Basin Committee should encourage appropriate utilisation of reclaimed water. Avenues to sustainably augment the fresh water resources with water reuse should also be promoted. It is also recommended that investigations on how different social groups accept water reuse for drinking in Windhoek can be undertaken in further studies. Objective number 3 as outlined in Chapter 1, which was to assess the ethical, social and health acceptability views and perceptions of water reuse for drinking in Windhoek has been adequately investigated in this chapter.

CHAPTER SEVEN

7 QUALITATIVE ASSESSMENT OF WATER GOVERNANCE STRUCTURES, PARTICIPATION, AND THE OVERALL EVALUATION OF WATER GOVERNANCE IN THE USB

Chapters 4 to 6 indicated water quality and water quantity concerns as related to water security in the USB and the need for a more effective water governance. Three workshops were carried out as part of this study to assess the water governance structures and participation in the USB and the results are presented in this chapter.

7.1 Workshop 1:

This section shares the major findings of the stakeholder workshop that was organised to engage stakeholders in the appraisal of water quality and security challenges in the basin.

7.1.1 Assessment of Stakeholder Engagement on the Appraisal of Water Quality and Water Security Challenges in the USB

The results from the three-day workshop contributed by all stakeholders (industry, government, engineers, scientist, hydrologists, non-governmental organizations, environmentalists, *etc*.) indicated that water sources in the USB were being polluted and there was urgent need to protect the water resources sustainably. Both point and non-point "artificial stream" sources of pollution (see Figures 7.1 to 7.4) were seriously causing hyper eutrophication of Swakoppoort Dam water (see Figure 7.5). It was noted that there is inadequate awareness and lack of stakeholder participation as some sectors were not represented.

The participants also noted that there are geographical, political, social and scalar fragmentations in the USB which need to be addressed. The legal framework for water management was not fully operational and required harmonization with other existing and upcoming laws. One such upcoming law is the Pollution Control and Waste Management Bill, third Draft (2003). The need to strengthen the water quality monitoring system including the information management was evident.

Wastewater "artificial flowing river pollution" from the CBD into public stream that cross the Robert Mugabe Avenue near TransNamib Railway Station in Windhoek (2011)

Figure 7.1 Typical Source of Pollution from Windhoek CBD

Stakeholders agreed that the polluted and untreated wastewater generated from the basin should not be discharged into natural water courses. Unless efforts are increased to prevent these flows, these discharges will eventually reach the Goreangab and Swakoppoort Dams and pollute these drinking water sources.

“Artificial flowing stream” of point and point sources of pollution in Katutura and eventually discharging into Goreangab Dam in Windhoek.
The litter (pollution) emanated from Independence Centre Shopping Mall and are collected via a storm drain discharging into a public stream

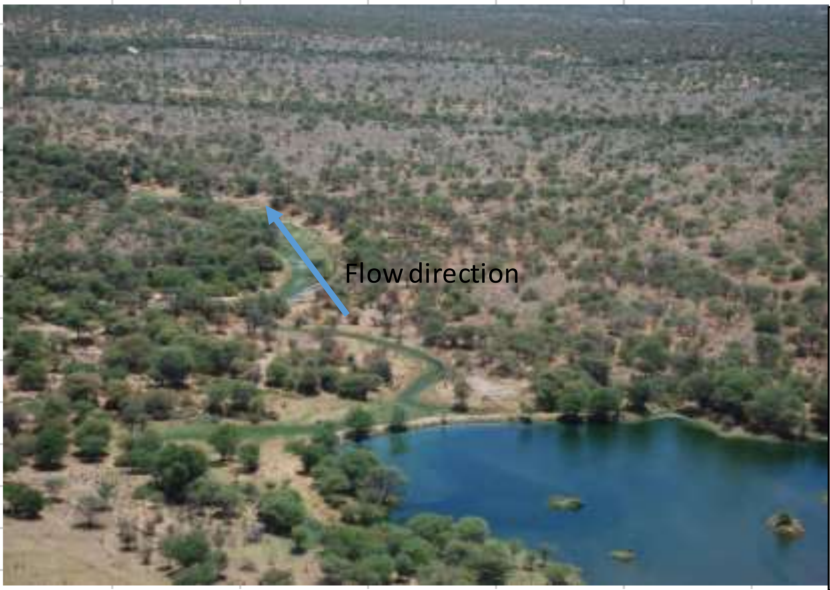
Figure 7.2 Typical Point Sources of Pollution in Katutura, Windhoek

Non-Point /Point sources of “perennial artificially flowing” pollution stream in Katutura, Windhoek

Figure 7.3 “Artificial and Perennial” Stream in Katutura, Suburb Recreational Park (UN Plaza)

The stakeholders noted that the Swakoppoort Dam water is hypertrophic with extremely high levels of algae (Table 17 and Figure 7.5), while the upstream

Goreangab Dam water is no longer fit to be used as source water at the Goreangab reclamation plant.



Okahandja Town Oxidation Ponds with an "*Artificial stream*" from the overflowing oxidation ponds flowing towards Swakoppoort Dam.

Figure 7.4 Okahandja Oxidation Pond Spilling Toward Swakoppoort Dam (2011)

Hypertrophic Swakoppoort Dam water is pumped to Von Bach Dam for treatment of potable water to be supplied to Windhoek and other customers

Figure 7.5 Swakoppoort Dam Algae Picture (2011)

The algal status of Swakoppoort Dam indicates high levels of blue-green (BG), toxic (TOX), green algae (GA) types. Instead, treated effluent from the Gammams Wastewater Treatment Plant is preferred to be used at the reclamation plant.

Table 17 Highest sampled Algal counts (total cells/ml) of Swakoppoort Dam between July and September 2010 (adapted from Honga, 2012).

Algal Genera	Type	Sampling Depth (m)			
		2.4	**6.4**	**10.4**	**14.4**
Anabeana	BG; FC; TO; TOX	14, 849			
Coelastrum	GA	5,657			
Cryptomonas	GA; TO;	707	141		
Cyclotella	CD; FC; TOX	707		354	
Desmodesmus	BG; TO; TOX	2,015,235		1,414	
Microcystis	GA;	1,414	417.189	830,843	431,331
Oocystis	GA; TO;		4,525	2,828	2,970
Pediastrum					707
Total blue green cells/ml		2,030,084	417,189	830,843	431,331
Total cell/ ml		2,038,569	421,856	835,439	435,008

Key: CD (Cyanophyceae Diatomophyceae); TO (Taste and Odour-producing); FC (Filter-Clogging)

Losing Swakoppoort Dam, which is part of the integrated three-dam system supplying the Central Area of Namibia (CAN) including Windhoek, to pollution will compromise the security of water supply to the Central Area of Namibia (including the whole of the USB) as well as hurt the economy. It should be noted that based on data from Namibia Water Corporation [NamWater], (2015), there are persistent longitudinal trends in algal prevalence in both Swakoppoort and Von Bach Dams as indicated on Figure 2.6. In comparison, the algal counts at Swakoppoort Dam seem to be higher (in both prevalence and magnitude) than at Von Bach Dam.

If not controlled, the Swakopoort Dam's pollution status will continue to make the dam water unusable for drinking water and equally contaminate Von Bach Dam water through the transfer of water. Another concern by the stakeholders was that the Omatako Dam water, though still in an uncontaminated catchment, will be mixed with Von Bach Dam water that is already deteriorating (Figure 7.6).

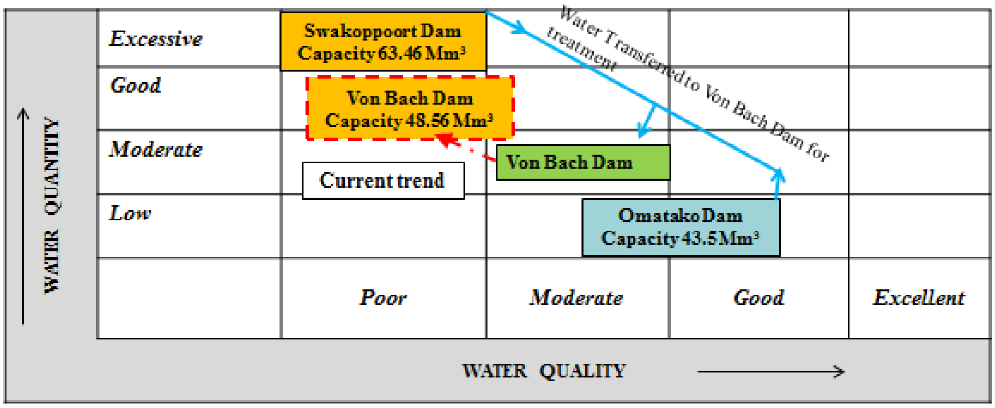


Figure 7.6 Water Security: Quantity - Quality Matrix3-Dam-System

During the workshop, the stakeholders shared information on the observed total phosphate nutrients with the potential to be loaded into Swakoppoort Dam as depicted in Figure 7.7. Although the phosphate and nitrogen pollution loads may be the critical contribution into the eutrophication of the Swakoppoort Dam, other factors that may include sunlight could be driving or limiting algae growth. With a very long retention time in the dams, phosphate is not being flushed out and is accumulating in the dam. Since these rivers are ephemeral, the downstream increase in total phosphate could be due to evaporation and salinization, since the rivers are usually intermittent. However the increases are located at discharge points from Ujams wastewater treatment plant, Meatco Tannery, and Namib Poultry Industries discharges which are also downstream.

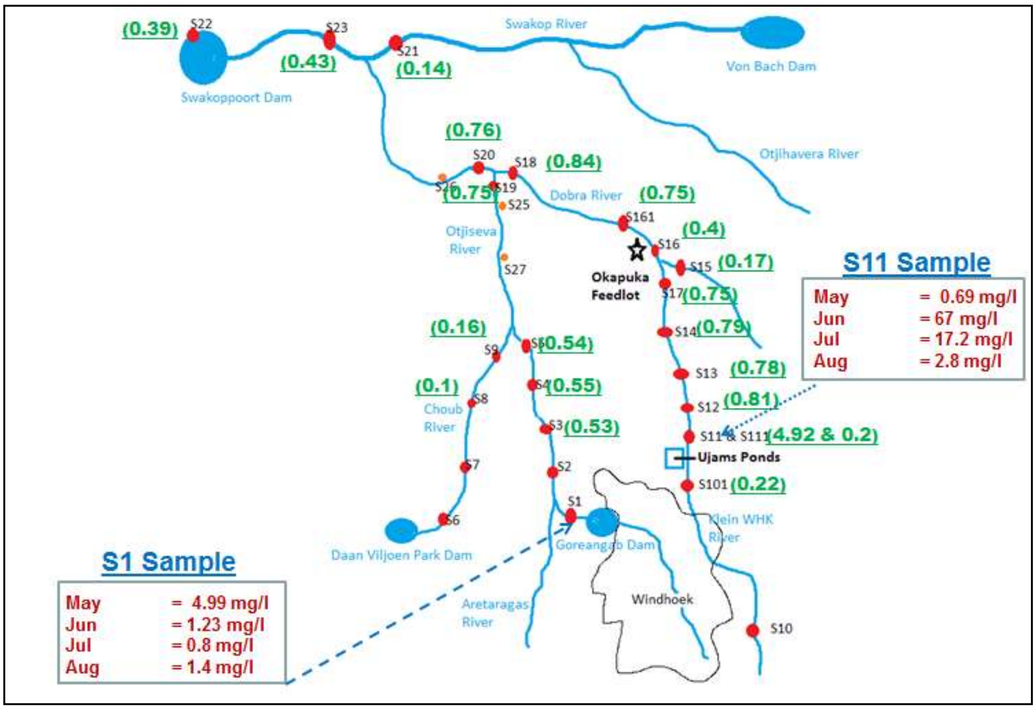


Figure 7.7 Total Phosphate Nutrient Loads in the Upper Swakop Basin (Shinana, 2011)

7.1.2 Summary of Stakeholder Views and Opinions

According to workshop participants, the Ujams Industrial Wastewater Treatment plant operated by the Windhoek Municipality, the Okapuka Meatco Tannery, and Gammams Domestic Wastewater Treatment Plant as well as the downstream Goreangab Dam, owned by the Windhoek Municipality, were the potential pollution hot spots. The stakeholders concurred that institutional and legal challenges included misalignments and gaps in the legal framework. The challenges are elaborated below:

1. The laws and legal instruments that are dealing with water-related and environmental issues in the Basin are not harmonized.
2. The finalization of pending Bills into gazetted Acts, for example the Water Resources Management Bill (2004), was imperative for the sustainable management of the Basin.

3. Water and environmental institutions are not aligned and their responsibilities are not streamlined to be able to respond to the pollution challenges of the Basin at every level. Thus effective responsiveness is lacking.
4. The urban, industrial, mining and farming authorities and entities are uncoordinated in efforts to control water pollution.
5. There is no basin-wide integrated water resources management institution. Integrated river basin management is still absent.
6. There is no water governance management, research and development within the USB.
7. New developments in the USB were uncoordinated and not integrated with all the role players. There are administrative, geographical, municipal and utility fragmentations. For instance, the stakeholders discussed that the Namibia Poultry Industries were established without adequate and timely involvement of all the water sector ministries.
8. Lack of democratic, inclusive, transparent, responsive and accountable system that allows for open communicative basin-wide planning, decision making and management taking into consideration disparities evolving from the legacy of the apartheid system and cultural realities.
9. Possibility of abuse of process and corrupt practices in water management system due to lack of an all-inclusive integrated stakeholder private-public sector and civic society institution
10. There is bureaucratic fragmentation of responsibilities whereby “silo” ministries or sectors are making major sectoral decisions without input from major

stakeholders. These “silo” ministries latently are reluctant to share or collaborate with other ministries for the common good.

11. Low awareness among stakeholders and water users on the water quality and quantity management challenges of the Upper Swakop Basin.
12. Low appreciation of the collective basin-wide policy, strategy, goals, responsibilities and ownership of the water resources and their sustainability.
13. Technical information on the Basin water resources and quality (information centre and library, access and reporting and management systems) is only confined to statutory and utility institutions.
14. There exists a technical management decision support model on the 3-dam-system of the CAN which analyses only the quantity of water available without assessing the quality of the blended water from the three dams. There is no pollution control adaptive management decision model and information.
15. There exists a weak regulation and monitoring system with regard to control of water pollution possibly from low budget allocation.
16. Water quality policing, enforcement and sanctioning are not supported and driven by the local stakeholders and this may not be sustainable.
17. There are concerns and low interest in funding the upgrades of wastewater treatment plants by both municipal polluters and individual entities.
18. The economic dimension and efficient use of existing developed freshwater resources and the long term spin offs of keeping a healthy Upper Swakop Basin is still low among the majority of the stakeholders. The benefits that can be realized are the effective and sustainable service provision, intergenerational

beneficiation and deferring the investment of developing new expensive water sources.

7.1.3 Recommendations of the Workshop

The improvement road map and initiatives from the workshop included:

1. Carrying out a water quality assessment of Upper Swakop Basin.
2. Raising awareness among the stakeholders on the water quality situation of the basin.
3. Formulating a basin management strategy that will inform the creation of the Basin Management Committee.
4. Immediate remediation of the pollution hot spots by the responsible stakeholders, even before the Basin Management Committee is in place.
5. Preparing a position paper to Cabinet proposing a policy on the decentralization / relocation of wet industries (industries like breweries and poultries requiring large amounts of water). It is suggested that these industries should be located where there are adequate water resources. The responsibility of preparing the position paper was assigned to the line ministry, MAWF.
6. Carrying out water governance research in the basin.
7. Further areas of research proposed at the workshop were assessing the levels of endocrine disrupting chemicals (EDCs) and dissolved organic carbon (DOCs), and their implications on the drinking water sources in the USB.

Following the outcome of the workshop participants' views, tools were prepared as part of the study and were used in the compilation of the terms of reference (through NamWater) on the next stages of the formation of the Basin Management Committee. Section 7.2 presents the results of the 7 ”I”s' tool application and Workshop 2 that guided the formation of the Basin Management Committee. Section 7.3 presents the results of 7 ”I”s’ tool application and Workshop 3 that guided the formation of the Basin Executive Committee. The results of the overall evaluation of the water governance structure in the USB are then presented in Section 7.4.

7.2 Results of Workshop 2: Formation of the USB Committee and the use of the 7 “I”s Tool for Mapping Stakeholders and Nominating Members

The process of forming the USB Basin Management Committee was lengthy (more than three years) and challenging as summarised on the timeline on Figure 7.8

7.2.1 Development of the 7 “I”s Tool

Prior to the workshop held on 20 February 2014, the researcher finalised the 7 “I”s tool which was then used in Workshop 2. Based on the formulated conceptual framework as discussed in Chapter 2 **(**Rogers & Hall, 2003; Pahl-Wostl et al., 2008b; Tropp, 2007; Uhlendahl et al., 2011), a systems adaptive approach was used to analyse and contextualize the water governance issues in the USB as raised by participants in Workshop 1 (section 7.1.2) which resulted in the design of what is termed the 7 “I”s tool in this study. The 7 “I”s’ tool is based on a solid conceptual and theoretical framework of the linkages and inter-marriages among the governance issues within the domains contemporary to the USB study area. The 7 “I”s tool is based on a theoretical summary of the literature on interactions of the water governance themes and issues (adaptive and solution-oriented research (ASOR) approaches (Pahl-Wostl et al., 2013; Wiek, & Larson, 2012); institutions, people’s actions and inactions, and physical water systems and delivery challenges) in clearer logical integrated perspectives and views. The tool results are presented in Sections 7.4.2 and 7.6.5.

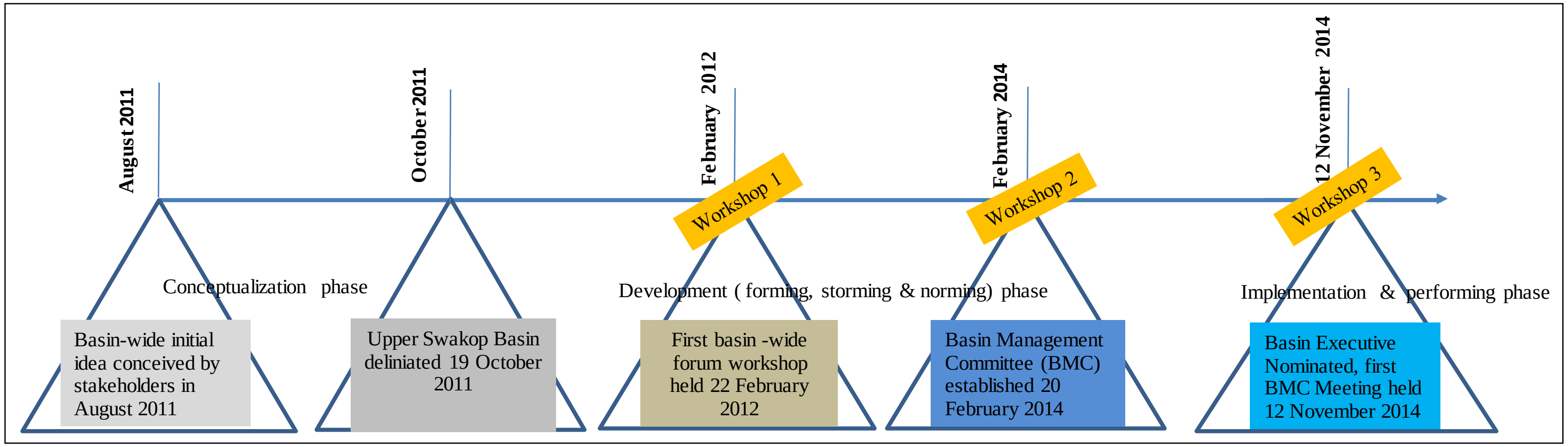


Figure 7.8 Timeline for the USB Committee Formation

7.2.2 Application of the 7 "I"s tool on Mapping Stakeholders and Nominating Members

The adaptive water governance 7 "I"s tool for mapping stakeholders and nominating members as applied to the USB is depicted in Figure 7.9. This adaptive water governance tool was used to help the stakeholders visualize the need to ensure that each domain of the stakeholders was represented in the Basin Management Committee and where there were gaps, to ensure that the missing stakeholders would be co-opted later. The tool was also used to reveal the stakeholder segments that were significant to be strongly represented in the Basin Management Committee to make an impact of the original objectives and drivers.

The key sector representatives invited to form the USB Management Committee nominated organisations representing each sector to comprise the USB Management Committee. The numbers in each segment indicates nominated organisations forming the USB Management Committee (see Figure 7.9 and Table 18).

The 7 "I"s Tool segments represented the following: The first (1) stakeholder segment "I" is the *Influencing,* which should include central, regional, and especially local political power and will that influence, either positively or negatively, decisions at the basin level. Good stewardship of the basin water resources rests to a large extent on the local political power. In the USB Management Committee, Windhoek and the Okahandja Municipal officers represented this segment.

Despite being invited, there were no representatives from the Ministry of Works and Transport, Ministry of Local Government, Ministry of Urban and Rural Development and the Ministry of Environment and Tourism.

The second stakeholder segment "I", the *Interested/infected/impacted and impacting* segment was represented by the Namibia Hospitality Association (tourism sector); Namibia Breweries (Industry sector); NamWater (bulk water supplier affected by source-water quality); Namibia Agricultural Union (farmers sector) and Navachab Mine (supplied with water from the polluted downstream Swakoppoort Dam).

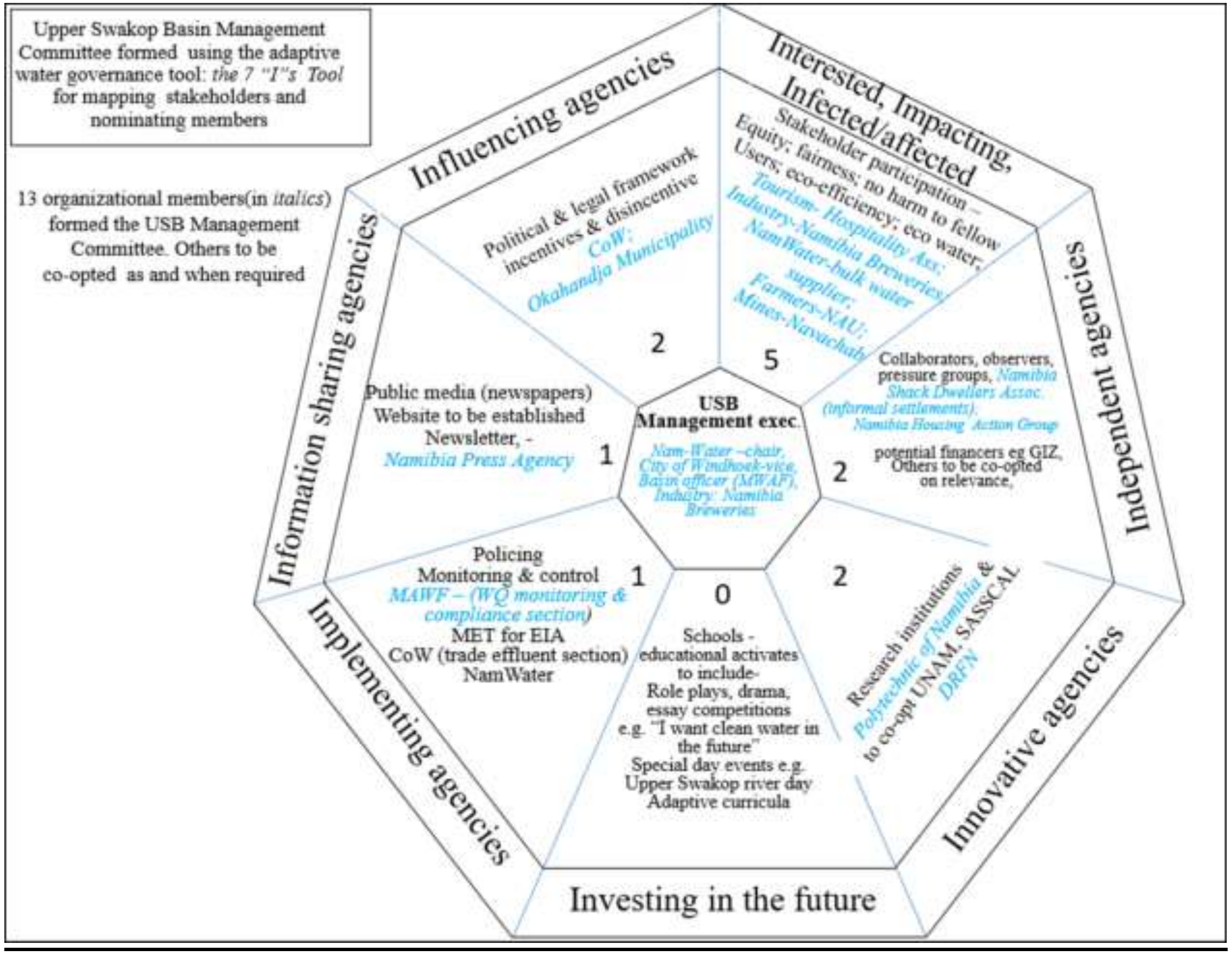


Figure 7.9 Upper Swakop Basin Management Committee Formed Using the Adaptive Water Governance Tool: the 7 "I"s Tool for Mapping Stakeholders and Nominating Members.

This segment included those involved with joint planning, cooperative actions, sharing benefits and implementing river integration. This stakeholder segment had the highest total of five (5) key different members represented. This participation level could also signify the complexity of challenges the USB is experiencing. All these sectors should be satisfied without causing "harm" to each other.

The third stakeholder segment "I", *Implementing Institutions,* should be carrying out monitoring, policing and compliance activities to control water pollution in the basin. This stakeholder segment is also responsible for the planning, development and management of water supply sources and infrastructure. In the Upper Swakop Basin Committee, this segment was represented by only MAWF who are the primary water sector responsible ministry. Other secondary or complementary agencies that were represented included the town councils and NamWater. The absence of other ministries like Ministry of Mines and Energy, Environment and Tourism is a challenge to the coordinating role of MAWF as their input should also be incorporated.

The fourth stakeholder segment "I", *information sharing agencies,* should carry out responsible reporting and informing on activities of the USB with initial strong emphasis to control water pollution in the basin. This segment includes all public media (local newspapers, radio stations and televisions); all those involved with the creation of websites, newsletters, bill boards and proposed *Water Supply and Quality Customer Care Centre* (WSQCCC). In the Upper Swakop Basin Committee this segment was represented by Namibia Press Agency who in particular showed interest in environmental matters.

The fifth stakeholder segment "I", *innovative agencies,* should carry out applied research on activities of the USB with initial strong emphasis on controlling water pollution in the basin. This segment includes all tertiary bodies that include universities and research bodies. In the Upper Swakop Basin Committee this segment was represented Desert Research Foundation of Namibia and NUST. Other institutions like University of Namibia, NCRST, SASSCAL etc. will be co-opted later.

The sixth stakeholder segment "I", *independent bodies,* should collaborate, observe and/or create pressure groups on related water management activities of the USB with initial strong emphasis on controlling water pollution in the basin. This segment's role includes mobilizing funding the water sector and capacitating it, and may include international collaborators. In the Upper Swakop Basin Committee, this segment was represented by Namibia Shack Dwellers Association (informal settlements and whose residents may not have adequate sanitation) and the Namibia Housing Action Group (whose concerns is to make sure there is adequate housing and servicing of areas that should be developed for residential areas especially in towns and cities).

The seventh stakeholder segment "I" is the *investing in the future bodies* that should take care of the inter-generational sustainability of water governance. The investing-in-the-future bodies include basic education schools. The school's curricula should be designed and adapted to include water management activities. The education activities in the schools should include role plays; drama; essay competitions about water issues e.g. "I want clean water in the future" and special day events e.g. Upper Swakop River Day (USRD). It was worrisome that during the formation of the Upper Swakop Basin Committee this segment was not represented.

7.2.3 Summary of Workshop 2

Based on the adaptive water governance *7 "I"s Tool* developed by the researcher, key sectoral stakeholders in the USB were identified; categorised and subsequent representative organisations were nominated to form the USB Management Committee. These processes were done towards achieving a more meaningful balanced water governance framework and representation as shown on Table 18.

Table 18 Nominees Forming the USB Management Committee

Key sectors invited on the forming of the USB Management Committee	**Nominated organisations representating sectors in the USB Management Committee**	**7 " I" Tool Water Governance Segment Categories**
Farmers (e.g. NAU)	NAU (1)	Interested, impacting/infected/affected
Bulk Water Suppliers(e.g. NamWater, WINGOC)	NamWater (1)	
Industries e.g. Meatco, Namibia Breweries	Namibia Breweries (1)	
Tourism	Tourism - Hospitality Association (1)	
Mines e.g. Navachab	Navachab (1)	
Public media	Namibia Press Agency (1)	Information sharing agencies
Local authorities	CoW & Okahandja municipality (2)	Influencing agencies
Collaborators /observers /pressure groups	Shack Dwellers Association, GIZ (2)	Independent agencies
Research institutions e.g UNAM, DRFN, Polytechnic of Namibia (now changed to NUST), SASSCAL	DRFN, Polytechnic of Namibia (now changed to NUST) (2)	Innovative Agencies
Primary and secondary education	no nomination	Investing in the future
Policy Parent Ministries e.g. MET, MAWF	MAWF -*were the only one who attended* (1)-	Implementing agencies
Total number of nominees	**13**	
Key: NAU - Namibia Agricultural Union; NUST - Namibia University of Science & Technology;		
SASSCAL-Southern African Science Service Centre for Climate Change and Adaptive Land Use		

Due to logistical reasons, the invitations of both primary and secondary education representatives could not be confirmed and these were not represented during both Workshops 2 and 3.

7.3 Workshop 3: Nomination of USB Executive Management Committee, Induction, Formulation of the Constitution and Introduction of the strategic plan.

7.3.1 Results of Workshop 3

Workshop 3 discussions and deliberations resulted in the final drafting of the USB constitution; the nominations of the USB Executive Committee (five elected members with each having a maximum term of two years). Following a consensus endorsement by the USB Management Committee, the draft constitution was submitted to MAWF to be approved by the Minister, as required by the Water Resources Management Act (2013). Based on the draft Constitution, the ballot-elected five executive committee members comprised of the Chairperson (NamWater nominee); Vice Chairperson (Windhoek Municipality nominee), Treasurer (Namibia Breweries nominee); Secretary (Windhoek Municipality nominee but now WINGOC employee), while the researcher was nominated as the *Basin Program officer,* to continue advising on the basin strategy. The MAWF Basin Support Officer responsible for the USB was an ex officio member to the Executive Committee. During this workshop the researcher gave a summary of the strategic issues of the Upper Swakop Basin as per the two previous workshop results. The researcher also presented a strategic planning and management approach for USB based on the situation assessment of water quality and quantity and governance issues of the basin. The researcher also introduced new concepts of setting up water pollution prevention *Industrial Wastewater Stewardship Zones Committees* (IWSZC) as transparent, water pollution control and self-monitoring among industrial wastewater discharge permit holders. This concept was in principle accepted by the stakeholders. Due to technical inadequacy of the water quality information across the whole basin the researcher also proposed to the stakeholders, to have the basin committee employ a *water quality and pollution prevention specialist* on a limited contract to set the required monitoring programme, databases and create a common information and decision-making platform for the USB on water quality issues.

The researcher also proposed to the stakeholders, the multi-purpose objective and strategic approach to water quality monitoring, control and management in USB as highlighted in Table 19. The proposed four types of the multi-purpose objective water quality assessment are: 1) *preliminary surveys and background monitoring*; 2) *potential river impact and extreme parameter value surveys*; 3) *operational and emergency surveys*; 4) monitoring for *trend and modelling*.

The rest of the long term strategic issues would be part of a continuous process that requires the basin-wide integration. The whole strategy framework is summarized in Figure 7.10.

Table 19 Strategic Water Quality Monitoring Approaches Proposed to be applied to the USB

	Type of Assessment	Assessment Objective	Water Quality Measurement /parameter	Potential measurement sites	Organisation to benefit	Monitoring Budget
1	*Preliminary surveys and background monitoring* prior to designing and establishing a routine monitoring programme	to enable design and establishment of a routine monitoring program	all potential troublesome parameters	all extreme measurement areas and additional potential hot spots to be added by the stakeholders; See also extreme parameter maps and tables in chapter 5	all stakeholders in the USB	high
2	*Potential river impact* and *extreme parameter value surveys that will decimate excessive nutrients (N&P); salts and hydrocarbons*	identify and locate major spatially ditributed problem water quality descriptors to:1) *control pollution in the USB*; 2)*eradicate algal blooms sources and* 3) *improve river ecosystem & reverse degraded river habitat*	DO; TN; TP TSS; total recovable hydrocarbons, oil and grease; salts and contaminants from tannaries	sewage treament plants;tannaries; industrial waste water plants; degreasers & motor vehicle repair sites; also mines; See extreme parameter maps and tables in chapter 5	NamWater; Windhoek Reclamation plant and all USB	moderately high
3	*Operational & Emergency surveys* and *Early warning surveillance*	rapid; continuous invetory and assessment	all potential troublesome parameters	critical water use locations i.e Gorengab; Swakoppoort Von Bach abstraction dams; all effluent discharging industries and tannaries	CoW; Okahandja; Windhoek reclamation plants; NamWater; MAWF and all USB	high
4	*Trend and Modelling monitoring*	to establish long-term evolution of pollution (concentration and loads) as well as silt surveys	nitrates; salts; EDCs; borehole contaminants	strategic sites on rivers; dams point and non point sources of pollution	CoW; Okahandja; Windhoek reclamation plants; NamWater; MAWF and all USB	is dependent on the parameters being investigated

After the presentation and deliberations, the workshop participants resolved that these strategic processes should include continuous:

1. **Analyses** of past, present and future challenges and issues i.e. (the **direction** and **focus**) on water quality (pollution); quantity (adequacy) and governance. The analyses should be multi-disciplinary, participatory and well-coordinated.

Formulation of basin management strategies (Cohen & Cyert, 1973; Clarke & Fuller, 2010; Bamberger et al., 2014) based on specific, measurable, achievable, solution-targeted and time-framed work plans that could be short or medium or long term.

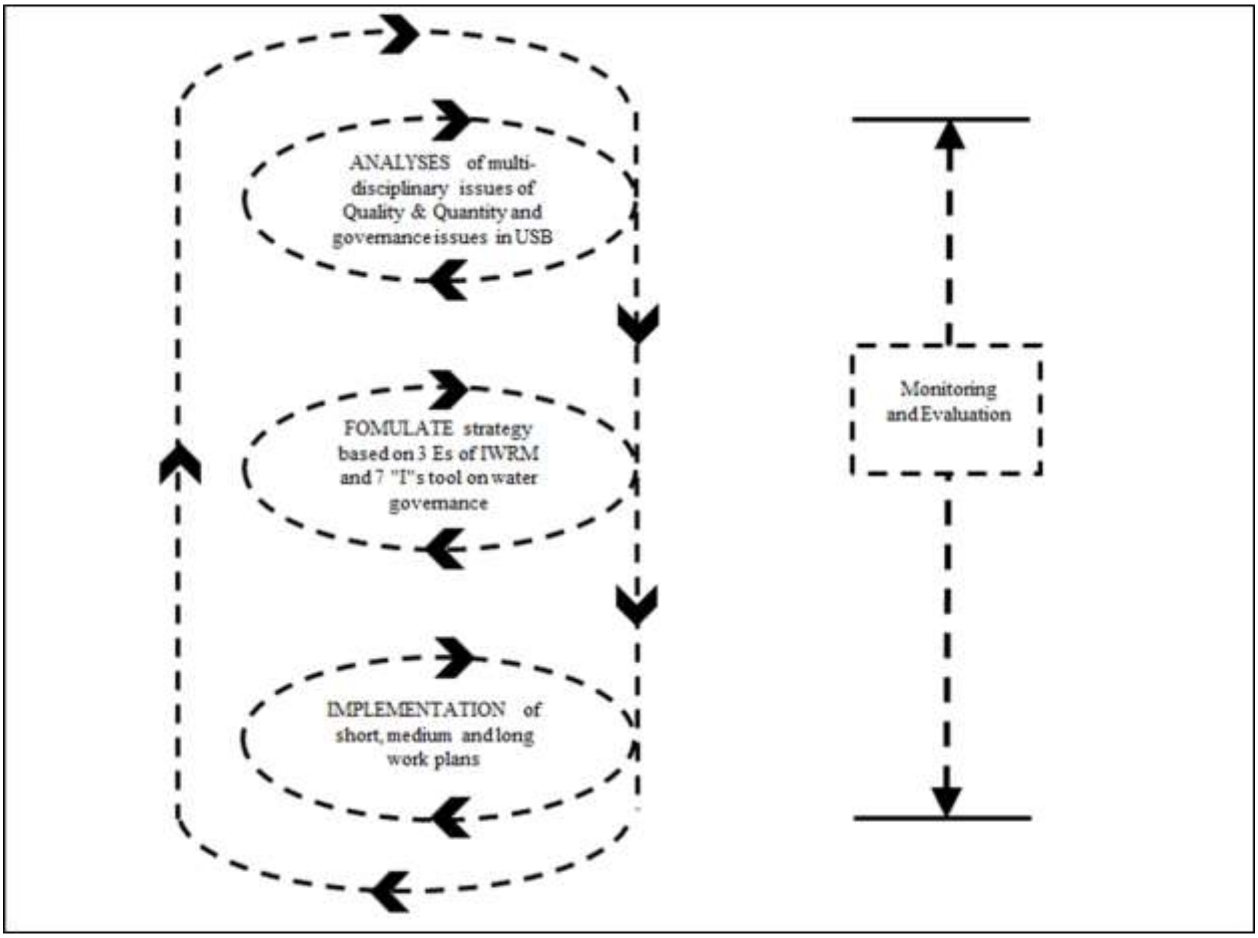


Figure 7.10 Strategic Framework for USB

2. These strategies should be coordinated, **prioritized** and founded on the three Es' of IWRM (i.e. **E**conomic efficiency, **E**quitable access; and **E**nvironmental sustainability (Lenton & Muller, 2012; Biggs et al., 2013**)** as well as the 7 "I"s tool of water governance as developed in this study.
3. **Implementation** (Freeman, 2010; Bamberger et al., 2014; Clarke & Fuller, 2010) and execution of the strategies that constitute the segments of the 7 "I"s tool of water governance**.** The USB should have coordinated, adaptive, sustainable and research-based solutions to basin management issues.
4. **Monitoring and evaluation** (Freeman, 2010) of the cross-functional decisions on complex internal and external multi-disciplinary issues within the basin to

gain superior performance, broader views and better stakeholder-based stewardship of the resources.

7.3.2 Discussion

Before looking into the long term strategic issues and processes of the USB, there the researcher guided a discussion on current issues and challenges that are symptoms of major water governance issues. The USB has a mix of complex multiple freshwater sources surpassed by local demand. There is also ever growing distance of developable water resources from basin transfers to the USB. While the demand is escalating, the water pollution and quality challenges threaten water security in the basin. The absence of information sharing; the lack of common data infrastructure; the inadequate information to guide and underpin critical management decision making may pose serious challenges to deal with, especially the continuing water pollution within the USB. The USB's strategic planning should thus facilitate water pollution data access, data integration, coordination and visualization by providing *evidence-based maps*, and data models that identify hot-spots of environmentally degraded points and the strategic monitoring points. The enforcement, policing and monitoring of pollution issues should be tightened on the "polluter pays" and self-monitoring incentivized / dis-incentivized discharge effluent permitting system. The USB Management Committee should put in place clear pollution indicator targets. The absence of coordinated research in the basin should be looked into and replaced with a system that fosters the oneness and integrated nature of the whole water cycle improvement. This should be done alongside a resource library and or information centre; hosting of solution-oriented-research and innovations events, lobbying; advocacy; workshops and raising awareness. Basic and primary education in the USB should also be linked to a strategic solution of water basin governance. Industries and residential suburbs in the basin should be encouraged to cluster those of same locations to encourage water sensitive cities, eco-water and eco- efficiency and better stewardship of the water resources and the basin.

The pollution endemic in the USB is a reflection of a long history of unsustainable, mismanaged and disjointed "silo" sectors that require enhanced technical coordination, stakeholder participation and sustainable approaches. The USB's long term strategic planning and management should build on trust, transparency, accountability and commitment. Active responsiveness and pro-activeness blended with multi-sectoral communication should be the core values that shape the vision, mission and future performance.

From the workshop deliberations, and from previous chapters, it became strategically imperative to assess and evaluate (a) the legal and institutional frameworks (b) especially their influence on water governance and (c) the adequacy of the technical capacity of implementing agencies in the USB using *7 "I" tool* kit. The following sections give these evaluations.

7.4 Evaluation of the Legal Framework

7.4.1 Analysis of the Evolving legal framework for Water Governance in the USB

To further understand the contribution of *influencing and implementing agencies* (*7 "I" tool component* in Section 7.7) in water governance issues of the USB, an analysis of the evolving legal framework was carried out.

From Workshops 1, 2 and 3 the USB, requires improved water governance with regard to the legal framework, administrative and institutional capacity and operational processes. Establishing institutional coordination among the various stakeholders, especially the implementing ministries in the management of water in the USB, is challenging and has not been practically as successful as the acceptance of the water governance principles. Contextualising the USB's newly formed water governance institution, it is the researcher's opinion that MAWF's functions is too centralized thereby only allowing the river basin committees like USB Management Committee to play advisory roles. The advantage of more centralised government institution is that it may avoid the process of managing several local level stakeholder institutions which could lead to an increase in bureaucratization of existing systems. In addition, there may be less cost associated with planning and management processes (Uhlendahl et al., 2011). Keeley and Scoones (2003) further argue that the introductions of participatory approaches tend to reduce the power vested in the state who in many cases try to balance power in favour of the historically marginalized and underprivileged stakeholders who cannot participate effectively (Swatuk, 2005b). Thus, for a successful USB management, the integrated river basin governance should allow for both top-down and bottom-up management.

In the Namibian context, just like in the Republic of South Africa, where fresh water is scarce and variable, the political pillar has been addressed in the National Constitution where Article 95 (1) contains a de facto statement of IWRM principles embracing environmental protection and development based on sound and sustainable economic and social equity. This pillar has been expanded in the National Water Resources Management Act (2013) with the ultimate responsibility for IWRM vested in the Ministry of Agriculture, Water and Forestry.

Similar to its SADC neighbours, South Africa (Allan, 2003; Ashton & Turton, 2005); Botswana, Zambia, and Zimbabwe (Swatuk, 2005a), and based on the National Water Policy (2000), the government of Namibia showed its political will for embracing IWRM by compiling the IWRM Plan for Namibia (Namibia, I.P.J.V., 2010) and enacting the Water Resources Management Act (2013). To further strengthen the political pillar of IWRM, the Government is guiding and supporting the formation of river basin management committees at different basis as required under Part 5 of the Water Resources Management Act (2013).

Notwithstanding Namibia's political support for IWRM, the legal/institutional pillar of water governance in the USB has unresolved vertical and horizontal integration issues. For example, the IWRM Plan for Namibia (Namibia, I. P. J. V., 2010) and the Water Resources Management Act (2013) legally recognise the natural jurisdiction over water resources protection, use, development and management. However, the Regional Council Act (1992), the Local Authorities Act (1992); the Traditional Authorities Act (2000); the Decentralization Enabling Act (2000) and Environmental Management Act (2007) recognise the regional council, local authorities and traditional authorities as water management bodies within their jurisdictional areas. Equally, the Pollution Control and Waste Management Bill, third Draft (2003), under the Ministry of Environment and Tourism (MET) is aimed at promoting sustainable development; and providing for the establishment of the Pollution Control and Waste Management Unit (PCWMU) that encompass pollution control related to water issues. This brings vertical and horizontal overlaps and duplication with MAWF. In the Water Resources Management Act (2013), the river basin committees are weaker advisory institutions compared to the structures espoused by the superseded Water Resources Management Act (2004). In the later 2013 Act, devolution of water governance functions and autonomy to the stakeholder-based Basin Management Committees are limited. However, the Water Resources Management Act (2013) recognises that local municipals can become agencies responsible for supplying their own potable water and managing wastewater within their jurisdictional areas. This is a form of decentralisation with regard to water management and governance. On horizontal integration, MAWF's IWRM efforts under the Water Resource Management Act (2013) will need to be neatly coordinated and integrated with the Environmental Management Act (2007). The quasi-advocacy and collaborative function of the river basin committees may have been driven by the ephemeral nature of internal river basins of Namibia. The other reason for weaker river basin committees could be attributed to their lack of capacity to deal with water issues. This would result in additional cost of setting up accountable, substantive, legislative function of the river basin institutions. Integration is the key governance process to address fragmentation in managing water in the USB context. Molle (2008), GWP (2010) and Cohen and Davidson (2011) argued for a more context-driven application of these integrated water resource management (IWRM) principles rather than making them the norm for good water governance because in most cases, the basin institutions have low management capacity. Hirsch et al. (2006) highlighted the main problems that basin management seeks to address as geographical, bureaucratic, social, scalar and political fragmentations. Using and managing water without reference to the basin, in particular, the USB, would result in fragmentation.

Contextually, Livingston (2005) mentioned that challenges with institutional changes can be prompted by 1) interest group politics where institutions are in disequilibrium to gain favourable political outcomes; 2) equity; 3) economic goals and efficiency, and 4) Social welfare, especially access to resources to those disadvantaged groups as happened in South Africa (Backeburg, 2005).

However, balancing social welfare objectives of water governance (e.g. trust, social capital, poverty eradication and environmental sustainability interests) with other goals like cost recovery could be a problem faced by many developing countries (Leach & Sabatier, 2005). The institutional changes can be hierarchically categorized into water administration, water policy, and water laws. Broadly, water laws and water policies delineate and outline management approaches while administrative rules relate to use, provision, monitoring and enforcement within the broader set of laws and policies (Saleth & Dinar, 2004). Because the water governance institutions are nested and their structures are interdependent on the related institutions at many levels, institutions governing water changes may become uncoordinated, conflicting and fragmented (Mckay, 2005) and the change processes may stop at any point owing to political, social and economic obstacles. These obstacles may include: a) changes in the perception of the needed institutional change; b) political articulation of needed changes; c) steps taken to make changes in water institutions operational and d) the actual impact of the institutional change (Saleth & Dinar, 2004).

Heyns (2005) cited the Namibian case where the need for change has been perceived and politically articulated (Water Act, 2004). Unfortunately, the efforts were frustrated operationally primarily owing to the lack of manpower capacity and funding. Analytically, these envisaged water institutional changes in Namibia were both constrained and enabled by past institutional configurations, culminating into the repealing of the Water Resources Management Act (2004) and the adoption of the

Water Resources Act (2013). Elsewhere, Uhlendahl et al. (2011) and Sievers (2006) concluded that some of the challenges in Zambia are sectorial water governance with weak linkages between institutions and lack of legislation.

While at the national level Namibia has articulated and decentralized river basin legal institutions, the devolution of governance function and autonomy have been limited and are still evolving. To marry and fit this institutional arrangement with the USA's bottom-up IWRM framework approach, where there is a historical wealth of ad-hoc collaboration, watershed management effort that reflect a high degree of technical cooperation (Leach & Sabatier, 2005) may be presumptive. The USB, without a strong history of voluntary informed technical collaboration may face challenges (Ballweber, 2006). There is no better marketing of the Namibian IWRM framework than having a successful USB water governance institution that will improve the water quality management in the basin. However, in South Africa (Swatuk, 2005b) and Zimbabwe (Latham, 2002) governments, and water reform processes reflect a highly political nature without a proper recovery of the natural resources management and protection. In these cited examples, there is reluctance to devolve power to stakeholders. Maybe the Namibian government was suspicious that already empowered actors who dominate new institutions are touting broad-based participation to maintain their power. The general fear is that politics and water governance stand at the centre of sustainable national localized river basin management in Southern Africa.

7.4.2 Qualitative Comparison of the Basin Committee as Envisaged in the Two Acts (Legal Reforms and Framework)

In this section, the basin management committee functions and composition intended by the Water Resources Management Act (2004) will be compared with those of the Water Resources Management Act No. 11, 2013 to further assess the contemporary contribution of *influencing agencies* (*7 "I"s tool component* in Section 7.7) of water governance in the USB.

1. The 2004 Act Section 12 required a Regional Council to second a nominee for each Basin Management Committee within its jurisdictional area whereas the 2013 Act, section 25, there is no such obligation. Instead, in the 2013 Act, the Basin Management Committee's responsibility is to coordinate water related plans from the Regional Councils and local authorities falling within their basin.
2. The 2004 Act did not refer to a formation of a basin management sub-committee which is included in Section 26 of the 2013 Act.
3. In Section 13 of the 2004 Act, the envisaged Basin Management Committees were supposed to have functions decentralised by MAWF i.e. to protect, develop, conserve, manage, and control water resources within its management area. The 2013 Water Resources Management Act, Section 23, implies that the basin committee functions only in an advisory capacity to the Minister. In the former act, it was mandatory for the Basin Management Committee to prepare an Integrated Water Resources Management plan for its management area to be submitted to the Minister, whereas the 2013 Act only emphasises the drafting of the integrated management plan.

4. In the 2004 Act, Section 12, the Minister was to ensure that every Basin Management Committee is broadly represented from *all interested persons* whereas the 2013 Act Section 129 d) indicates that the Minister *may regulate* in relation to the composition of the Basin Management Committees including institutions, organizations, or bodies to be represented in the membership of the Basin Managements Committees. The 2013 Act appears to have reduced the devolution of powers and functions to the basin management committees, maybe largely because of the lack of capacity in the lower levels.

The river basin institutional arrangement envisaged in the Water Resources Management Act of 2004 had better stakeholder empowerment in that the river basin management committees were to be responsible for the formulation of the regional water master-plans. On the contrary, the basin management institutions' roles in the Water Resources Management Act (2013) are only advisory to the role of the centralized Directorate of Water Resources Management which is responsible for the integration of the water resources management plan. Also the decentralised irrigation boards proposed in the Water Resources Management Act of 2004 were omitted in the Water Resources Management Act of 2013.

7.4.3 Analysis of the Role of the USB Management Committee with Regard to Pollution Control as Outlined in the Water Resources Management Act 2013 (Enabling Legal and Institutional Frameworks).

This section assesses how enabling the legal and institutional framework is to the USB Management Committee for pollution control (contribution of *influencing agencies* and *Interested/Impacting/Infected/Affected, 7 "I"s tool components* in Section 7.7).

The absence of clauses in the 2013 Act for the water basin committee to legally influence MAWF's decision pertaining to discharges in the USB may cause operational and legal seams and gaps that can result in uncoordinated water quality management within the basin. In Sections 69 to 72 of the Act there is no obligation for application of discharge permits to be pre-assessed and be recommended via Basin Management Committee in line with the Integrated Basin Management Plan. Moreover Sections 73 to 75 on permit renewals do not require any specific input of the Basin Management Committees. References are only made to the general public to comment on the application for renewals, thereby ignoring the potential inputs and functions of the Basin Management Committee. This oversight not to have the specific input from the basin management committee on discharge permit applications and renewals could deny basin management committee the opportunity of timely input to improve water quality of the basin.

On the water governance institutional changes affecting building towards river basins, Tapela (2002) on the Save catchment in Zimbabwe, and Dungumaro and Madulu (2003) on the catchments in Tanzania, highlight the difficulties inherent in overlaying a new institution on top of a variety of other existing institutions with different jurisdictional boundaries (local and regional councils). The authors' conclusions suggest that participation in water governance issues is nothing more than a quick branding to legitimize changes predetermined by central government. This cosmetic participation and aligned inclusiveness could also be similar in the USB. In Southern Africa, river basin institutions were mainly donor dependent (Dube & Swatuk, 2002; Manzungu, 2002) as seen in Namibia in the case of the formation of Cuvelai, Kuiseb, Omaruru, Orange-Fish River Basin Committees *etc.* suggesting either under capacity or little commitment and lack of trust by the central government of the successes of the committees. This lack of trust could be attributed to historical issues and disparities (Funke at al., 2007). These cases discussed above showed that water governance is critical to water related ecosystems and transcends political boundaries within complex spectrum of social actors and forces. They highlight limitations of actors (advisors and technical mandates) in river basin management institutions who find themselves not able to create enhanced integration that includes cooperation, inclusivity and holistic stakeholder participation notwithstanding the norms of transparency and trust entrenched in the policies.

7.5 Evaluation of the Institutional framework

7.5.1 Evaluation of the Institutional Framework for Water Governance in the USB

An evaluation of the institutional framework for water governance was carried out to understand the role of *implementing agencies* (*7 "I"s tool* component in Section 7.7) on water governance. To elaborate on the strengths and weaknesses of the existing institutional framework**,** the envisaged water sector institution based on the Water Resources Management Act of 2004, is shown in Figure 7.11. Although the 2004 Act was repealed and replaced by the Water Resources Management Act of 2013, it was more decentralised than the latter. The hydrological basin delimitations in the USB are different from geo-political boundaries; and these results in conflicts and/or overlapping responsibilities. While the existing Local and Regional Authorities are powerful decentralized institutions, the Water Resources Management Act of 2013 indicates their subjection (during the drawing up of river basin plans) to the less powerful newly formed river basin committees and sub-committees. This may have the potential to undermine the Local and Regional Authorities power and energies unless the river basin institutions were powerful platforms to also lobby their water plans and budgets to central government.

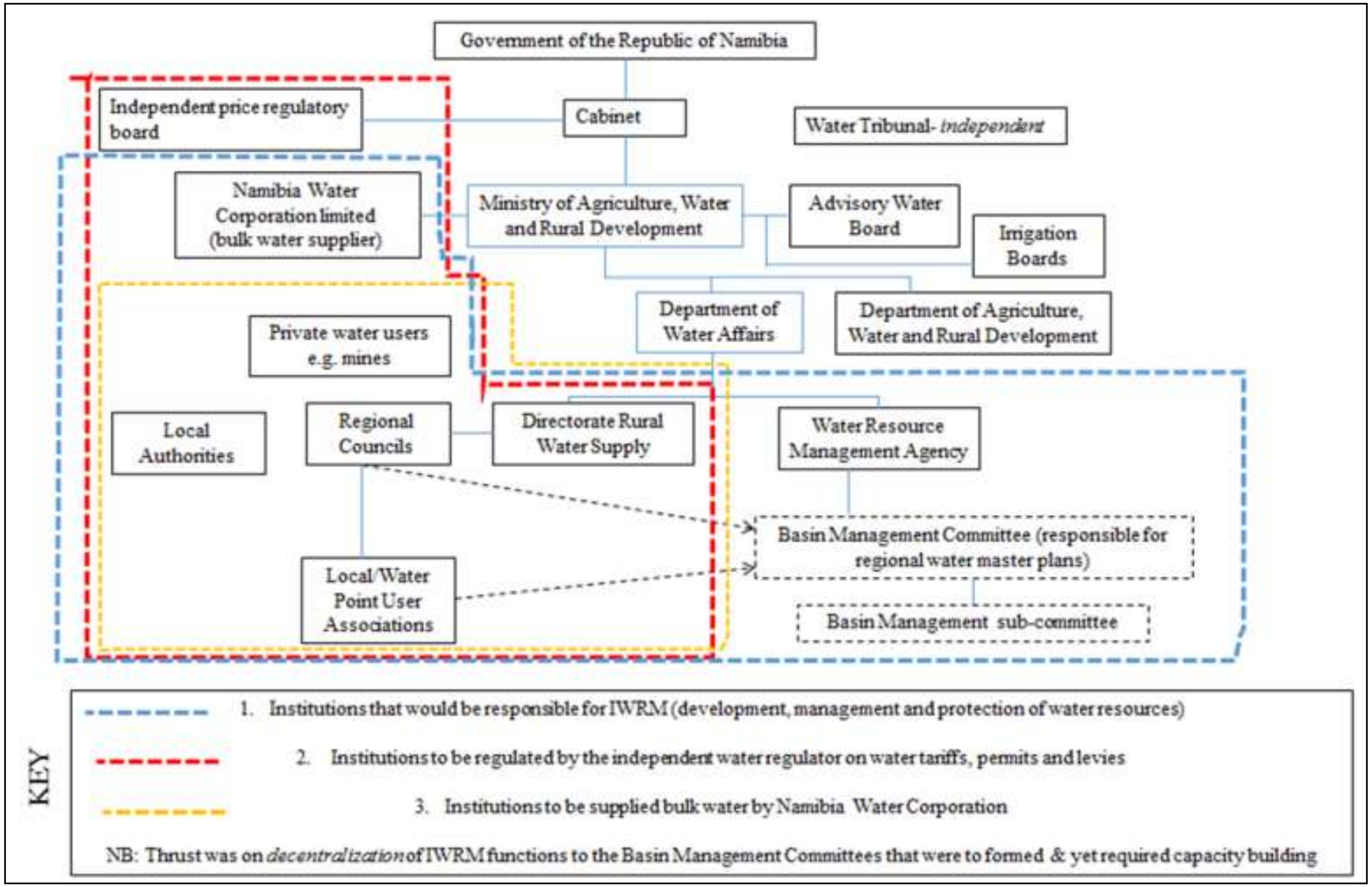


Figure 7.11 Envisaged Water Sector Institution based on the Water Resources Management Act of 2004 that was repealed.

In which case, these Local and Regional Authorities' may later be unwilling to participate in the basin committees because of potentially unfulfilled expectations. Though the USB Management Committee is to advise the Minister of MAWF on issues pertaining to water resources within the basin, the connection route of the basin institution to the Minister is long (see Figure 7.12 showing water section only) and may defeat its relevance. The responsible authorities for water quality monitoring and management in the USB are shown in Figure 7.13.

Figure 7.13 shows the key institutions and their existing technical staffing for water quality monitoring and management in the USB which reveals an under capacity of the required technical staff. Windhoek Municipality had one water pollution policing officer in 2014 to monitor all the industries in the city while Okahandja Municipality did not have an officer only designated for water pollution monitoring and control. As will be discussed later, MAWF had so many vacant posts in 2014 that when filled should be responsible for ensuring that monitoring, control and compliancy is carried out in the USB among other basins.

7.5.2 Snapshot Analysis of Adequacy of Technical Capacity of MAWF Institutions Responsible for Water Resources Management in the USB.

A cross-sectional analysis of adequacy of technical capacity of MAWF as a key *implementing* institution (*7 "I"s tool* component in Section 7.7) was carried out. The strengths and weaknesses of MAWF's Directorate of Water Resources Management's personnel in 2014 are presented in Table 20.

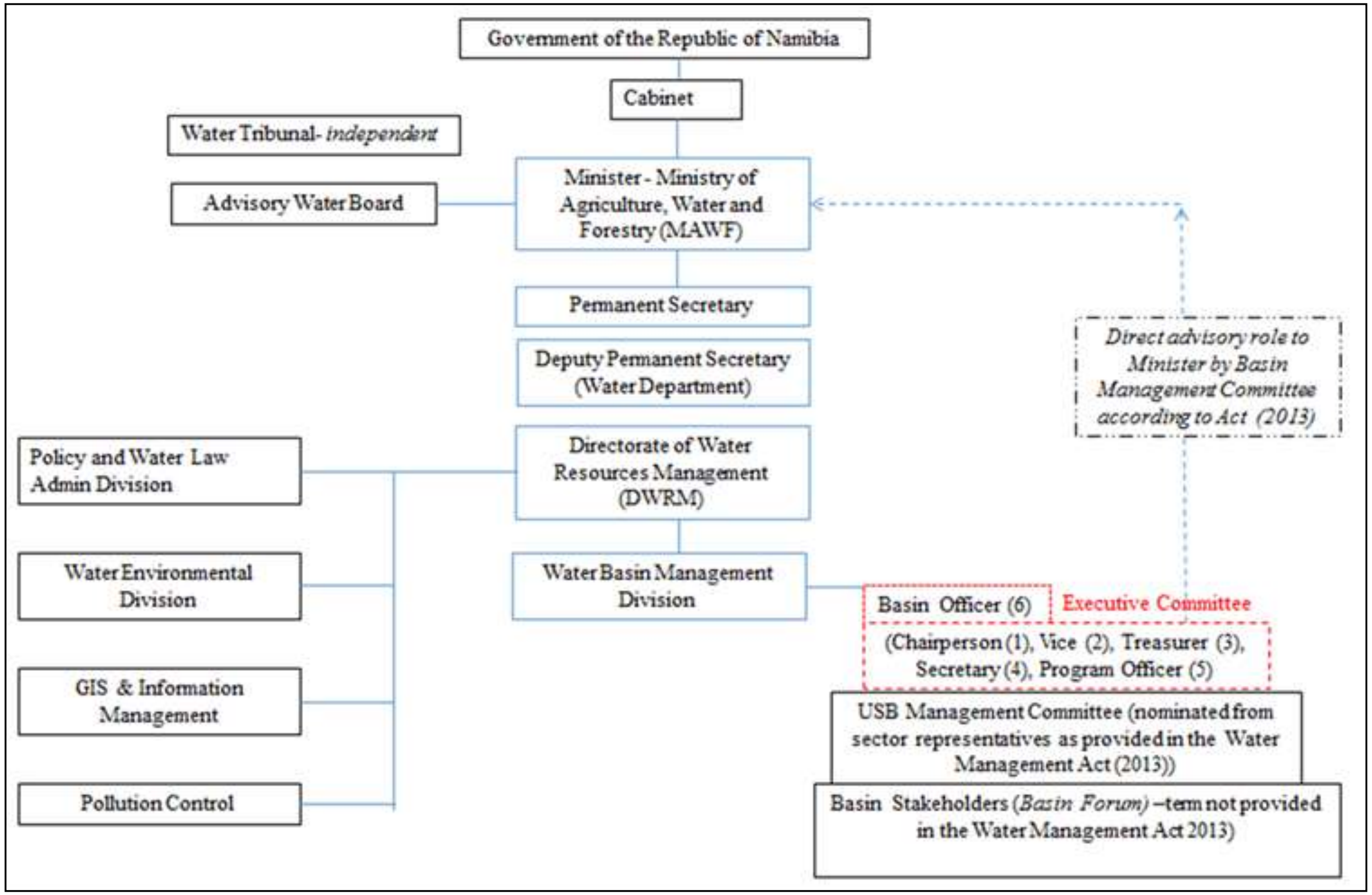


Figure 7.12 The Envisaged USB Management Committee Organogram and its Connectivity to MAWF According to Water Resources Management Act (2013

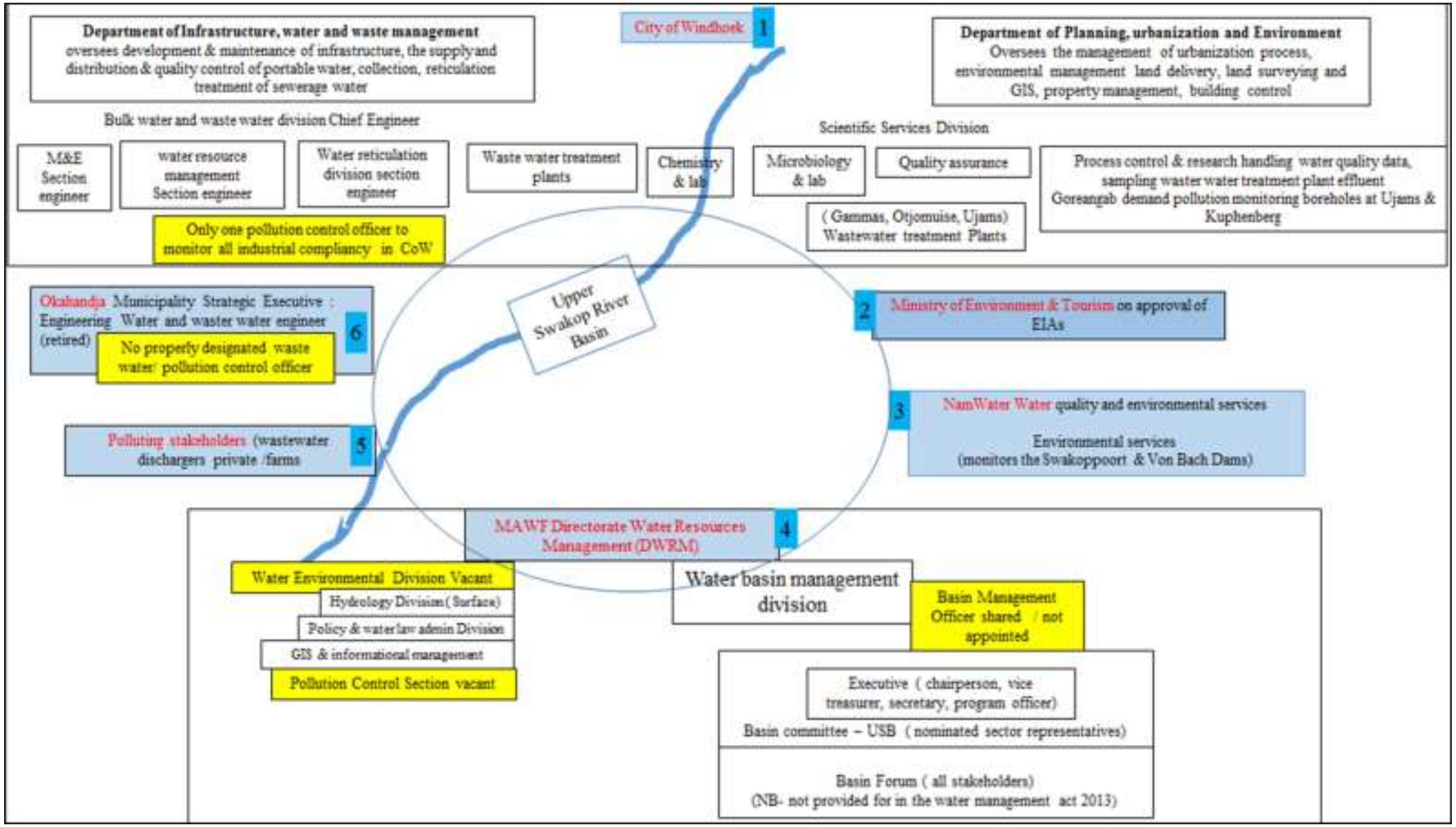


Figure 7.13 Personnel (Coloured Yellow) of Implementing Agencies Responsible for Water Quality Monitoring and Management in the USB (*could be under staffed*)

Table 20 Snapshot Analysis of the Directorate of Water Resources Management Personnel of MAWF in 2014 (See Organogram on Annex 14)

Division	Number of Post in Division	Number of Vacant Post in Division	Division Personnel Strength* (%)	Sub- division	Number of Posts in Sub-Division	Filled Posts	Sub-division Personnel Strength * (%)
Water Basins Management	41	35	15	International Waters	7	0	0
				Central Water Basins	11	3	27
				Southern Water Basins	7	1	14
				Northern Water Basins	14	1	7
Water Environment	39	17	56	Water quality control & Investigations	7	0	0
				Pollution Control & Investigations	12	2	17
				Water Ecology	11	5	45
				Laboratory Services	5	5	100
Policy & Water Law & Administration	35	9	69	Water Law Enforcement	8	0	0
				Permit Administration	13	13	100
				Water Resources Accounts and Policy Development	10	9	90
				GIS and Water Information Management Systems	3	3	100
Hydrology (Surface Water)	48	15	69	Surface Water Resources Management	7	0	0
				Hydrological Investrigations and Flood Managment	7	5	71
				Hydrological Information Systems	8	6	75
				Hydrological Network and Data Collection	1	1	100
Geohydrology (Groundwater)	54	15	72	Groundwater Management	22	19	86
				Groundwater investigations	20	14	70
				Maintenance Support	11	5	45

Note: *Personnel Strength = Filled Posts in subdivision / Total Post in Sub-division (%)

The division with the weakest personnel number is the Water Basin Management Division, with 15% strength. This is likely to result in the poor coordination of the river basin committees by MAWF. Both the local basins are thinly staffed and international basins no staff at all. The Water Environmental Division is averagely staffed (56% strength) overall though the Water Quality Control and Investigation Sub-Division has no staff at all and the Pollution Control and Investigation Sub – Division is at 17% strength. The Water Law Enforcement Sub–Division also has no staff. These three subdivisions have a strong effect on the capacity of MAWF to control pollution in river basin.

The Surface Water Resource Management Sub – Division also has no staff which might have influenced the lack of pro-planning of the augmentation of water resources development to the USB. The analysis did not look at the experiences and skills of personnel of filled posts neither the positions to be filled due to data that was not readily available. The lack of experience and skills of these key personnel to control pollution and to plan the augmentation of water resources development to the USB have strong negative influence on the building blocks of good water governance as discussed in Chapter 2.

7.6 Results of Evaluation of Participation in Water Governance Issues in the USB

An evaluation of participation in water governance issues in the USB was conducted to assess the involvement of *interested/ impacting and affected parties* (*7 "I" tool* component in Section 7.7) in decision making. The level of participation by stakeholders was both consultative and informative (see Table 21). Major stakeholder groups were represented and involved in workshops 1, 2, and 3 except for some key ministries. The scenario workshops comprised presentations and group discussion platforms. Overall, the influence of stakeholders' participation on the final basin management decisions was considerable. An analysis of the participatory processes as captured during the workshops based on the ADVISOR conceptual framework is summarised in Table 21.

Table 21 Analysis of the Participatory Processes in the USB based on the ADVISOR Conceptual Framework (Antunes et al., 2009)

Participatory Aspect	Qualitative Assessment	Workshop 1	Workshop 2	Workshop 3
Level of participation in workshops	Consultative	yes	yes	yes
	Informative	yes	yes	yes
Major stakeholder groups involved	Regional & local Authorities & town councils	yes	yes	yes
	Water organisations	yes	yes	yes
	Industries,	yes	yes	yes
	Local populations	yes but few	Yes but few	Yes but few
	Media	yes	yes	yes
	International organisations/ Collaborators	yes	yes	yes
	MAWF	yes	yes	yes
	Ministry of Health and Social Services	no	no	no
	Ministry of Mines and Energy	no	no	no
	Ministry of Environment and Tourism	Just came to present and left	no	no
	Ministry of Rural &Urban Authorities	no	no	no
	Ministry of Works and Transport	no	no	no
	Basic and Tertiary Education Institution	Tertiary only	Tertiary only	Tertiary only
Participatory Platform	Presentations & group discussions	yes	yes	yes
Overall influence of Participation on the final decisions	Participation had a major influence during both workshops	yes	yes	yes
Participation selection procedure	Open invitations	somewhat	somewhat	somewhat
	Stakeholders (purposive)	yes	yes	yes

7.7 Overall Assessment of Water Governance of the USB

This section assesses the overall water governance of the USB based on the 7 “I” tool based on results of this study.

7.7.1 Assessment of Each 7 "I"s Tool Segment

7.7.1.1 Segment Evaluation (7 "I"s tool)

The USB water governance was evaluated and scored for each of the *7 "I"s tool* segments as outlined below.

Assessment of the influencing agencies in the overall water governance of the USB (score 3/5)

The score covers a stable functional legal and workable enabling environment that fosters public sector leadership and is determined to see sustainable water resources development and management. With the adoption of IWRM principles of water management sectors in Namibia, there are fairly good political and legal framework incentives to foster better water governance in the USB even though there is limited decentralization.

Assessment of the Interested/Impacting/Infected/Affected in the overall water governance of the USB (score: 1/5)

The non-use of effective economic tools like the 'polluter pays principle' combined with lack of stakeholder awareness, knowledge, and public involvement in decision-making in the USB have resulted in less emphasis being placed on a holistic water security and water use efficiency for all. There is serious harm to "downstream" water users as depicted by the pollution of water in the Goreangab, Swakoppoort and Von Bach Dams, streams in the basin and underground water.

There is also cyclic harm and threat to the drinking water supply security of the major demand centres in the USB that include Windhoek and Okahandja. Water pollution from the towns and industries seem to go unchecked and unabated and is made worse by lack of a proper stakeholder forum to foster adaptive and solution oriented research interventions. The Interested/Impacting/Infected/Affected segment entails stakeholder joint planning, cooperative actions, sharing benefits and implementing river integration. Besides the pollution challenge in the USB, the fresh water resources being developed to supply the USB are inadequate as indicated in Chapter 5. It is also interesting to note that Windhoek Municipality and Okahandja Municipality constitute part of this segment because they are discharging effluent into the basin's streams and dams.

Assessment of Independent Bodies in the overall water governance of the USB (score: 1/2)

Both water resources quality and quantity challenges in the USB have had very little attention from independent collaborative bodies. However, one success story in the USB is the private public partnership and involvement on the investment and operations of the New Goreangab Water Reuse Plant.

Assessment of Innovative Agencies in the overall water governance of the USB (score: 1/3)

Previous research and this study's results on USB are adding value to understanding the water governance of the USB. However, there is very little research coordination and collaboration as well as few refereed publications on researches carried out on the basin.

Assessment of Investing in the Future in the overall water governance of the USB (score: 1.5/4)

There seems to be little interest to systematically involve basic education institutions in especially the pollution educational remedial activities of the basin. This was evident during the USB committee formation where schools and the Ministry of Education stakeholders were not invited.

Assessment of Implementing Agencies in the overall water governance of the USB (score: 1.5/7)

The pollution of Goreangab and Swakoppoort Dams as well as subsequent abandonment of Goreangab Dam as a source of drinking water are clear indication of poor responsiveness on the part of the technical and institutional implementing agencies that control and manage water pollution currently. It was noted in the course of this study that each institution involved (Municipalities of Windhoek and Okahandja, MAWF, NamWater and MET) worked in silos, and that these institutions collected water pollution data that were not standardized among themselves. In some instances, the data were not sharable, easily retrievable and accessible. The data were also incomplete and not continuous. For instance, in one organization, the data were paper based and stored in several files.

Thus, the low score of the implementing agencies indicated lack of flexible and adaptive information exchange processes. The lack of a common database for pollution assessment and non-sharing of information and procedures used in gathering available data by different agencies are vivid evidence of lack of adaptive and coordinated management style that can lead to improvement of the sustainable development and management of the USB. These institutions are expected to have been more accountable, responsive and adaptive to the pollution problems so as to prevent an almost irreversible pollution crisis in the basin.

Assessment of Information Sharing in the overall water governance of the USB (score: 1.5/4)

There is no common database in the USB to share common challenges, neither is there common forum to inform about water pollution.

7.7.2 Summary Evaluation (7 "I"s tool)

Table 22 and Figure 7.14 shows the summary tabulated and graphical assessment of the overall water governance performance rating based on the 7 "I"s tool. The political will and legal framework of the USB was given a rating of 3 out of 5. Innovative agencies scored of 1 out of 3 as there were limited local and international researches. It also emerged there could be little or no coordinated solution oriented research within the USB. Inclusiveness of independent bodies was rated 1 out of 2 as GIZ are interested in industrial stewardship programs in the basin. Investing in the future and systematic involvement of basic education institutions may not be well coordinated to ensure *inter-generational* sustainability. The upholding and preservation of the *unitary principle of the water resources* may not be observed and practised for now in the USB. The implementing agencies had a score of 1.5 out of 7. This is due to inadequacy of technical capacity of inter-ministerial coordination and key developmental issues. Such inadequacy can result in little accountability, responsiveness, poor systematic planning and implementation of the management of the resources. The information sharing segments was rated at 1.5 out of 4. This was because of no existence of common databases and information sharing platforms for both the public and technical experts from the various stakeholders. The Interested/Impacting, Infected/ Affected segment had the least score of 1 out of 5 due to downstream and upstream causing of harm to other stakeholders. The overall rating on water governance in the USB was 10.5 out of 30 which is unsatisfactory.

Table 22 Detailed assessment of the overall water governance structures and attributes in the USB

	7 "I"s Component	Attributes	Attribute Presence: No = 0; Limited = 0.5; Yes = 1	Score	Total Score
1	**Influencing**	Political Will	yes	1	**3/5**
		Enabling legal framework	yes	1	
		Incentives/Disincentives for eco-water sustainability (regulations)	no	0	
		Upholding rule of law (Compliance and enforcement)	Limited*	0.5	
		Decentralization	Limited	0.5	
2	**Interested/Impacting/ Infected/Affected**	Stakeholder prticipation, ownership and conducive forum	Limited	0.5	**1/5**
		Stakeholder awareness and knowledge	Limited	0.5	
		No 'serious harm to downstream users'	no	0	
		No 'threat to water sources downstream becoming "unusable"'	no	0	
		Stakeholders contribution to making decision for the better	no	0	
3	**Independent bodies**	Inclusivenes and international collaboration (WINGOC PPP Company, ADB, GIZ)	Limited	0.5	**1/2**
		Inclusiveness and local collaboration (DRFN)	Limited	0.5	
4	**Innovative agencies**	Link with local research Institutions	Limited	0.5	**1/3**
		Link with international research institutions	Limited	0.5	
		Coordinated solution oriented research	no	0	
5	**Implementing Agencies**	presence of interministerial coordination	no	0	**1.5/7**
		adequacy of technical capacity	no	0	
		accountability	no	0	
		responsiveness critical & urgent issues	Limited	0.5	
		integration style of management	Limited	0.5	
		systematic planning approach	no	0	
		Financing (Capital, Operation and Maintenance)	Limited	0.5	
6	**Information Sharing**	Communicativeness	Limited	0.5	**1.5/4**
		Updating databases	Limited	0.5	
		Sharing Information and related network in the basin	no	0	
		Information sharing with the public	Limited	0.5	
7	**Investing in the future**	Promotion and Inclusion of the unitary water principle at basic education levels	Limited	0.5	**1.5/4**
		Promotion and inclusion of the water sustainability principle at the basic education levels	Limited	0.5	
		Schools involvement in the management issues of the basin	no	0	
		Basin water stewardship principles at the basic education levels	Limited	0.5	
	Overall Water Goverance Score for the USB =(3.0+1+1+1+1.5+1.5+1.5+1.5)/(5+5+2+3+7+4+4)=10.5/30				**10.5/30**

* The evidence & prevalence of water pollution parameters above threshold limits (see Annex 11), indicate policing & enforcement may be interpreted as limited.

This may conflict with process of trying to achieve full stakeholder participation. On another perspective, the water basin governance institutions lack drive and remain only donor driven with very little funding from government. There is inadequate technical skills and capacity in the water sector institutes which should be addressed for the success of water governance in the basin.

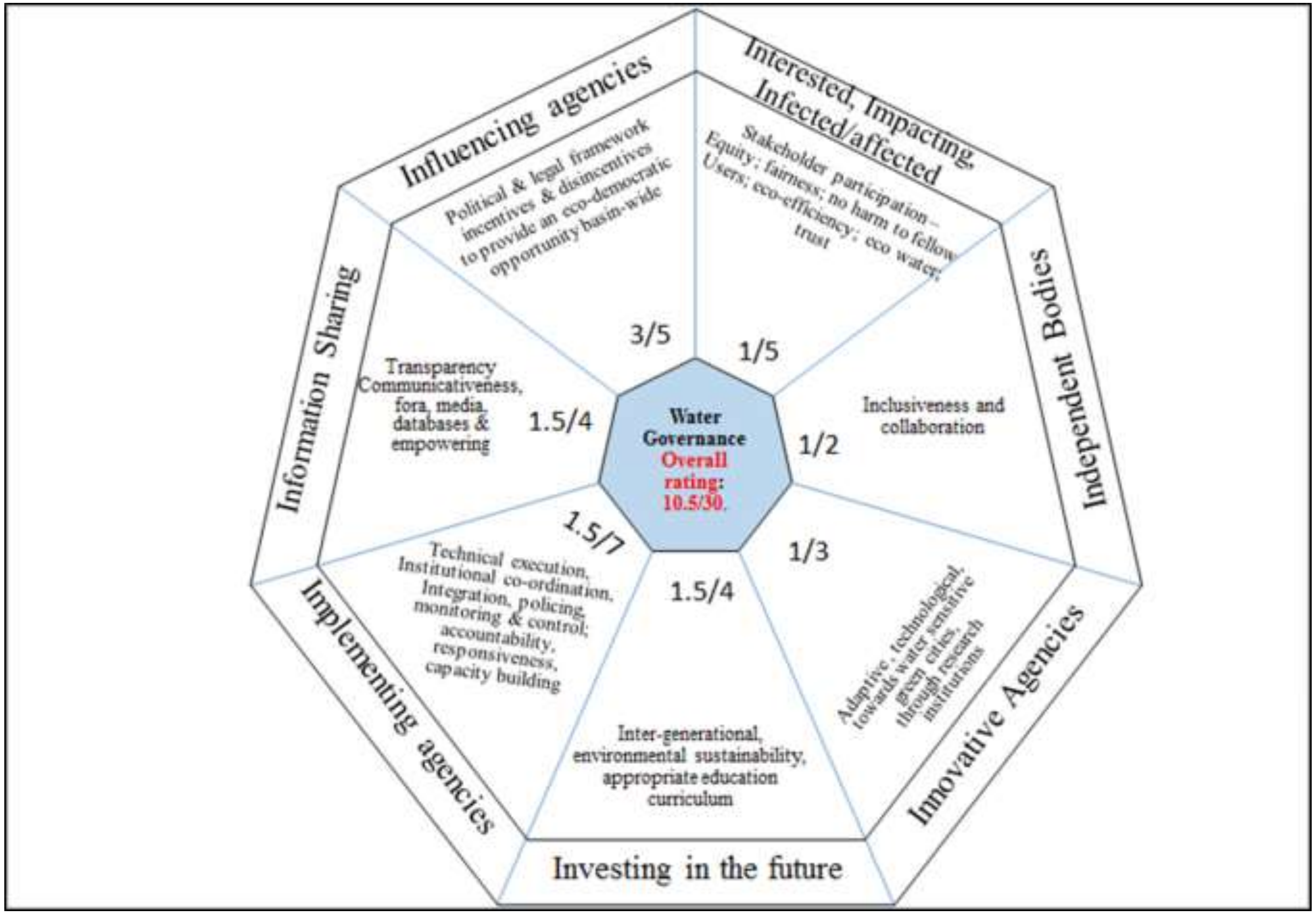


Figure 7.14 Overall Water Governance Performance Rating in the USB Based on the 7 "I"s Tool

Landuse elements may need to be practically considered in managing water resources in the basin. The legal and institutional fragmentation challenge between MET and MAWF, brought about by the Draft Pollution Control and Wastewater Management Bill (2003) still to be finalized under MET, may be cause for concern.

The 7 "I"s adaptive water governance tool developed in this study was used to map stakeholders in the USB and to identify underrepresented sectors in the USB Management Committee that need to be included to have an effective committee. The 7 "I"s adaptive water governance tool was also used as a simple integrative evaluation instrument to assess the overall water governance of the basin resulting in an overall rating of 10.5 out of 30. Major areas of weakness were: the *implementing agencies*; *Interested, infected / affected agencies or parties*; *investing in the future (intergenerational)* segments and the information sharing segments. Thus, this water governance tool based evaluation is reflective of the water governance challenges of the USB.

With regard to the basin pollution monitoring, control and management programme, the existing responsible institutions in the USB who have been operating may need a strong change agent in the form of the newly formed basin management committee to improve their accountability. Without proper capacity building of these existing institutions and their employees to monitor and control pollution in the basin efforts, to improve the quality of water within the basin can be minimal. Thus, there is need for an expert *change agent* that should be introduced through the USB Management Committee. Due to budgetary limitations of USB Management Committee, the researcher advises that a water quality and pollution specialist be appointed for the USB on a contract basis (say one year) to:

- Establish a common database with standardized formats of sampling; collection, processing recording and managing the water quality data. A resource library or information centre should be established later to host of solution-oriented-research
- Initiate events, lobby and; advocate for proper water governance of the USB; arrange workshops and raise awareness.
- Ensure the formation of two subcommittees on 1) Water Quantity 2) Water Quality from the USB committee as a forum of discussion and decision making bodies to recommend issues pertaining to the basin.

This specialist can be housed at MAWF or NamWater but the required budget should be provided by MAWF with collaboration of willing industries.

The objective number 4 as outlined in Chapter 1, which was to assess water governance structures, participation, and overall assessment of water governance processes and outcomes, was adequately investigated by the discussion above.

Chapter 8 gives the conclusion and recommendations of the whole study.

CHAPTER EIGHT

8 CONCLUSIONS AND RECOMMENDATIONS

A study on the governance of the water resources of the Upper Swakop Basin in Namibia has been presented. The results and outcomes of the study's four objectives are adequately addressed in Chapters 4 to 7. The unique contribution of this study is the way in which different research methods (models, statistical analysis, quantitative and qualitative measures etc.) were used and triangulated to analyse the water governance issues at the USB which had, hitherto, not been attempted before. The study's conclusions and recommendations based on the study objectives are presented below:-

8.1 Water Pollution Outcomes and Extreme Water Quality Parameter Values of Sampled Points in the USB

There is serious water pollution in the Upper Swakop Basin as depicted by the extreme values of water quality parameters in Chapter 4. These extreme values, indicative of massive wastewater pollution of various sampled sites, were used in flagging areas that need immediate attention and remedial action which are Okapuka Tannery and Namib Poultry Industries. The points of extreme parameter values and their spatial distribution in the USB were plotted on GIS maps which made it easy to visually identify areas of serious pollution concern in the USB. Based on this study outcome, it is hereby recommended that:

8.1.1 Hypothesis 1: Analysis of variance (ANOVA) results indicated that the spatial variance in water quality parameter values {chlorine ($p=0.007$), Iron ($p<0.001$), and copper ($p=0.041$)} at 12 sites (Section 4.3), unless explained by the natural geo-physical characteristic of the river basin especially for metals, should be further investigated.

8.1.2 The *assessment pollution extreme parameter values* of the pollutants should be used as a quick approach of evaluating pollution levels of any polluted river catchment/basin. This assessment, as was used in this study for the USB, would assist in identifying the worst polluters and in making appropriate recommendations of remedial measures.

8.1.3 Water pollution control in the USB needs to be improved by developing proper monitoring and compliancy strategy supported with recruitment of adequate number of skilled implementing staff and enhancing the capacities of the stakeholders. Based on the findings of the water governance assessments carried out and findings in this study (Sections 7.3 and 7.5), it is recommended that the adaptive strategic water quality monitoring, control and management as well as sampling programme for Upper Swakop Basin as given in full in Annex 12, be adopted. The programme should have multi-purpose, all-inclusive objectives as outlined in Table 19. If adopted, this adaptive water quality control strategy will mainly benefit the USB stakeholders in controlling water pollution and in pursuing good water resources governance.

8.1.4 The remedial strategy to control water pollution in the USB should specifically look at the impact of agro-based (as well as wet) industries, intensive landuses and other related water pollution sources in the USB. Water resources governance policy preventing industries from further polluting the downstream Swakoppoort Dam should be formulated. Further studies on tracing the source of extreme sodium pollution loads at Okapuka Tannery in the basin and linking this to the potential water pollution in Swakoppoort Dam. The study recommends a policy review with regard to future location of agro-based industries and their water pollution impact to water sources on the USB.

8.1.5 There be setting up of *Industrial Wastewater Stewardship Zones Committees* (*IWSZC)* as transparent, water pollution control and self-monitoring committees among Windhoek and Okahandja industrial wastewater discharge permit holders (Section 7.3).

8.1.6 There be piloting of a new concept of utilizing the smaller already polluted Goreangab Dam, which receives polluted water from Windhoek and is situated upstream of Swakoppoort Dam, as a *pollution detention* and *check dam* as well as a *clean-up dam* for the downstream dam. A study on the feasibility this new concept should be carried out. If the concept proves to be successful, it could be used to solve the problem of polluted dams downstream of "city river catchments" elsewhere.

8.2 Water Resources Adequacy and Optimization in the USB

Hypothesis 2: The time series of the rainfall in Windhoek area was stationary (SARIMA (1,0,1) $(1,0,2)_{12}$; Ljung-Box statistic = 0.1877, p-value = 0.6648).

The study found that the currently developed sources supplying the CAN integrated water supply area can only supply 35 Mm^3/a leaving a simulated deficit of 70 Mm^3/a (with the integrated multiple - sources not optimized) by 2050. Windhoek was identified as the biggest demand centre that would be affected by the envisaged water supply deficits to the USB due to its fast growing demand. Based on the ARIMA modelling of the Windhoek water demand it was found that additional drinking water sources outside the USB are required to augment its demand of 26.7 Mm^3 per annum in 2015 to a projected demand of 52.93 Mm^3 per annum in 2050.

8.2.1 More adaptive governance initiatives (resource planning and multi-source optimization of the water sources is required to counter the water deficits) should be explored on the available secondary sources for water security and the sustainable development of the USB.

8.2.2 The water security in the USB should be enhanced by optimizing the Windhoek Rechargeable Aquifer Storage capacity.

8.2.3 The three institutions (WINGOC; Windhoek Municipality and NamWater) that supply bulk drinking water to Windhoek should be unified (within the city) into a single water governance institution to optimize and integrate these multiple sources.

8.3 Modelling Water Quality in the USB

The WEAP model was used in the study as a strategic water resources planning tool due to the complexity of the multiple sources of drinking water to the USB especially supplying Windhoek. The WEAP model was used effectively to complement the time series modelling results in determining the levels of water deficits in the USB, especially in Windhoek. However, the WEAP model was found to be deficient in predicting the water quality parameter values of the downstream Swakoppoort Dam. The non-uniform flow in the ephemeral Upper Swakop River and its tributaries could not be modelled properly in WEAP. The absence of continuous hydro-metric flow data at the entry points of the pollutants into the USB resulted in data gaps and were insufficient for the model inputs. It is therefore proposed that the WEAP model only be used where adequate flow data are available or be adjusted to cater for ephemeral rivers.

8.4 Perception on Water Reuse:

From the survey conducted in 2013 on acceptability and perceptions of water reuse for drinking purpose in Windhoek, the levels of public willingness for water reuse were moderate (54%) though more stakeholders inclusiveness and participation is required on their acceptability. Greater than 60% of respondents trusted and are assured of the safety of certified recycled water from the NGWRP water reuse plant. Slightly less than half (43.5%) of the general respondents wished there could be public bill boards (public media and websites) sharing information of the product water quality.

8.4.1 Since there was moderate acceptance of reclaimed water for drinking, Windhoek Municipality, WINGOC and Upper Swakop Basin Committee should together explore the utilisation of reclaimed water for other purposes except for drinking purposes even considering dual domestic pipeline system. Avenues to sustainably augment the fresh water resources with water reuse should also be promoted even the use to recharge aquifers. However, for Windhoek water reuse for drinking purpose to gain full acceptability more stakeholders' inclusiveness and participation is required. The involvement of all stakeholders affecting or affected by activities related to the direct or indirect water reuse for drinking is required to improve the water quality sources of recycled water and the routes of exposure. Proper effective awareness and educational programmes were proposed at reducing discharge of hazardous chemicals from households and carelessly discharging point and non-point sources of water pollution. By tracing recycled water and fresh water systems from source, water pollution risks can be minimised.

8.4.2 Further studies should be carried out on how different socio - economic groups accept water reuse for drinking in Windhoek.

8.4.3 Notwithstanding the performance contracts that exist between Windhoek Municipality and WINGOC on water quality and health standards, proper legislation is required for water reuse for drinking and other purposes. An independent board with appropriate knowledge and expertise that includes media and public representatives should carry out regular field audits of product water quality to eliminate the health hazards and risks.

8.5 Water Governance based on the 7 "I"s Adaptive Water Governance Tool Evaluation

As discussed in chapter 7, despite the desire to achieve skilled; research oriented; decentralized; inter-governmental coordinated institutions; there has been ambiguity; fragmentation; inefficiency and technical skills gaps in both the water sector and the related reforms in Namibia. Water basin governance exists in Namibia as centralized water governance institutions within the MAWF structures, although there have been efforts to decentralize into river basin management institutions. With the noted under-capacity of MAWF - the implementing agency, it is difficult to see where the capacity for the proposed basin institutions will be sourced and this may be the reason for MAWF remaining as a centralised body in water management sector. Given the centrality of MAWF and mere advisory role of the USB committee, it may be doubtful if the basin management committee will be effective in the water governance improvement of the basin. However, the proposed *Industrial Wastewater Stewardship Zones Committees*, if approved and functional, will adaptively support the initiatives of the USB committee. There appears to be a challenge of fragmentation of activities between MET and MAWF regarding the integration and coordination as well as enabling legal and institutional framework. These challenges could have resulted from the unresolved Draft Pollution Control and Wastewater Management Bill (2003) still to be finalized under MET. When this bill is enacted into law MET will also be in charge of water pollution control.

As part of new knowledge, the study developed the 7 “I”s adaptive water governance tool that was used in the mapping stakeholders in the USB into their responsible segments and helped identify underrepresented sectors in the USB's management committee in order to have an effective and sustainable committee. The 7 “I”s adaptive water governance tool was also used as a simple integrative evaluation instrument to assess overall water governance of the basin. This assessment of the water governance of the USB resulted in unsatisfactory overall rating of 10.5 out of 30. The major areas of weakness identified were: the implementing agencies; Interested, infected / affected parties; information sharing; innovation and investing in the future (intergenerational) segments. The ratings of influencing (political) and independent bodies were satisfactory. Thus, the 7 “I”s adaptive water governance tool was found to be reflective of the water governance challenges of the USB.

8.5.1 It is recommended that *the 7 “I”s adaptive water governance tool* developed in the study can be used in evaluating the governance level of other similar basins. However further research and refinement of the model especially on the rating of the segments on the overall governance assessment may be required.

8.6 Basin management strategy

As a follow up to the outcomes of the four objectives of the study, a basin management strategy was proposed to improve security of water sources for the USB based on identified gaps. The recommended basin management strategy (Annex 12) was formulated in two phases. Phase 1 that would address urgent issues included water quality monitoring programme as follows:

8.6.1 In addition to the proposed establishment of *Industrial Wastewater Stewardship Zone Committees (IWSZC)*, all key stakeholders in USB should be involved in addressing its water resources challenges as depicted in the study by the 7 "I"s governance evaluation tool. There is need to establish a water quality monitoring and pollution control sub-committee supported by a water quality and pollution prevention specialist; basin monitoring sites and network; database and information dissemination stakeholder network (see Figure 0.1 in Annex 12).

8.6.2 The USB water bodies should be declared as "sensitive areas" incorporating pollution remedial models that are eco-water and eco-efficient and promote water sensitive green city approaches.

8.6.3 The proposed strategy encapsulated the polluter pays principle and promoted the building of capacity of the pollution control unit.

8.6.4 Water pollution sampling, data collection and information sharing (inter-institutional) should be standardized across the whole basin to improve accountability, communication and trust.

8.6.5 Phase 2 of the proposed water quality monitoring programme strategy recommended: the establishment of standard operating procedures (SOPs), environmental standards, and Strategic Environmental Assessments (SEA) as well as developing a Water Supply and Quality Customer Care Centre (WSQCCC)

REFERENCES

Abdel-Dayem, S., Taha, F. & Choukr-Allan, R. (2011) *Water Reuse in the Arab World: From Principle to Practice.* A summary of the proceedings of the expert consultation. Dubai UAE.

Abudu, S., Cui, C.L., King, J.P., Abudukadeer, K. (2010). Comparison of performance of statistical models in forecasting monthly stream flow of Kizil River, China. *Water Science and Engineering*, 3(3) 269–281.

Adamowski, J., & Karapataki, C. (2010). Comparison of multivariate regression and artificial neural networks for peak urban water-demand forecasting: evaluation of different ANN learning algorithms. *Journal of Hydrologic Engineering*, *15*(10), 729-743.

Ahmad, S., & Prashar, D. (2010). Evaluating municipal water conservation policies using a dynamic simulation model. *Water Resources Management*, *24*(13), 3371-3395.

Alexakis, D. (2008). Geochemistry of stream sediments as a tool for assessing contamination by Arsenic, Chromium and other toxic elements: East Attica region, Greece. *European Water*, 21 (22) 57-72.

Allan, J. A. (2003). Virtual water-the water, food, and trade nexus. Useful concept or misleading metaphor? *Water International*, *28*(1), 106-113.

Allan, J.A. (2001). The Middle East Water Question: Hydropolitics and the Global Economy; I.B. Tauris & Co Ltd: London, UK.

Amakali, M., & Shixwameni, L. (2003). River basin management in Namibia. Physics and Chemistry of the Earth, Parts A/B/C, 28(20), 1055-1062.

Amoo, S. K., & Skeffers, I. (2008). The rule of law in Namibia. Human rights and the rule of law in Namibia. Windhoek: Macmillan Namibia, 17-38.

Anderies, J., Walker, B., & Kinzig, A. (2006). Fifteen weddings and a funeral: case studies and resilience-based management. *Ecology and Society*, *11*(1).

Aneeshkumar, N., & Sujatha, C. H. (2009). *Phytoplankton pigment signatures as a biomarker in a tropical estuary* (Doctoral dissertation, Cochin University of Science and Technology).

Anonymous (2007, 21 March). Title of article? *Cape Times South Africa*.

Ansari, H. (2013). Forecasting seasonal and annual rainfall based on non-linear modelling with Gamma test in North of Iran, *International Journal of Engineering Practical Research*, 2 (1) 16-29.

Antunes, P., Kallis, G., Videira, N., & Santos, R. (2009). Participation and evaluation for sustainable river basin governance. *Ecological Economics*, *68*(4), 931-939.

Araral, E., & Wang, Y. (2015). Does water governance matter to water sector performance? Evidence from ten provinces in China. *Water Policy*, *17*(2), 268-282.

Armitage, N., Fisher-Jeffes, L., Carden, K., Winter, K., Naidoo, V., Spiegel, A., ... & Coulson, D. (2013) Framework and Guidelines., South Africa.

Asano, T. (2002). Water from (waste) water- the dependable water resource. Water Science & Technology, 45(8), 24.

Asano, T. (Ed.). (1998). *Wastewater Reclamation and Reuse: Water Quality Management Library* (Vol. 10). CRC Press.

Ashton, P. J., Hardwick, D., & Breen, C. M. (2008). Changes in water availability and demand within South Africa's shared river basins as determinants of regional social-ecological resilience. *Burns, MJ & Weaver, AvB*, 279-310.

Ashton, P., & Turton, A. R. (2005). Transboundary water resource management in southern Africa: opportunities, challenges and lessons learned. *Wirkus, L*, 5-32.

Authority, Environmental Protection [EPA]. (2005). Strategic Advice on Managed Aquifer Recharge using Treated Wastewater on the Swan Coastal Plain. Environmental Protection Authority, Bulletin 1199, Perth, Western Australia.

Babu, S.K.K., Karthikeyan, K., Ramanaiah, M.V., Ramanah, D. (2011). Prediction of rain-fall flow time series using Auto-Regressive Models. *Advances in Applied Science Research*, 2(2) 128–133.

Backeburg, G.R. (2005). Water institutional reforms in South Africa, *Water Policy*, 7 107–123.

Balling, R. C., Gober, P., & Jones, N. (2008). Sensitivity of residential water consumption to variations in climate: an intra urban analysis of Phoenix, Arizona. *Water Resources Research*, *44*(10).

Ballweber, J. A. (2006). A comparison of IWRM frameworks: the United States and South Africa. *Journal of Contemporary Water Research & Education*, *135*(1), 74-79.

Bamberger, P. A., Biron, M., & Meshoulam, I. (2014). *Human resource strategy: Formulation, implementation, and impact*. Routledge.

Banks, A. S. (1976). Cross-national time series, 1815-1973 (No. 7412). Inter-university Consortium for Political and Social Research.

Baril, P., Maranda, Y., & Baudrand, J. (2006). Integrated watershed management in Quebec (Canada): A participatory approach centred on local solidarity. *Science and Technology, 53* (10), 301-307.

Bielsa, J., & Cazcarro, I. (2014). Implementing integrated water resources management in the Ebro River Basin: from theory to facts. *Sustainability*, *7*(1), 441-464.

Biggs, D., & Williams, R. (2001). A case study of integrated water resource management in Windhoek, Namibia. *Frontiers in urban water management: Deadlock or hope? Frontières de la gestion de l 'eau urbaine: Impasse ou espoir?*, 10

Biggs, E. M., Duncan, J. M., Atkinson, P. M., & Dash, J. (2013). Plenty of water, not enough strategy: how inadequate accessibility, poor governance and a volatile government can tip the balance against ensuring water security: the case of Nepal. *Environmental Science & Policy*, *33*, 388-394.

Billings, R. B., & Agthe, D. E. (1998). State-space versus multiple regression for forecasting urban water demand. *Journal of water resources planning and management*, *124*(2), 113-117.

Billings, R. B., & Jones, C. V. (2008). *Forecasting urban water demand*. American Water Works Association.

Biswas, A. K. (2008). Integrated water resources management: Is it working?. *International Journal of Water Resources Development*, *24*(1), 5-22.

Biswas, A. K., & Tortajada, C. (2010). Future water governance: problems and perspectives. *Water resources development*, *26*(2), 129-139.

Biswas, A.K. and Kirchherr, J. (2012). UBM's Future Cities:'Toilet to Tap' will solve urban water woes. http:/www.ubmfuturecities.com/author.asp?section_id=217&doc_id. (Accessed 4 August 2013).

Blaine, J. G., Sweeney, B. W., & Arscott, D. B. (2006). Enhanced source-water monitoring for New York City: historical framework, political context, and project design. *Journal of the North American Benthological Society*, *25*(4), 851-866.

Blomqvist, A. (2004). How can stakeholder participation improve European watershed management: the Water Framework Directive, watercourse groups and Swedish contributions to Baltic Sea eutrophication. *Water policy*, *6*(1), 39-52.

Bolong, N., Ismail, A. F., Salim, M. R., & Matsuura, T. (2009). A review of the effects of emerging contaminants in wastewater and options for their removal. *Desalination*, *239*(1), 229-246.

Botes, A., Henderson, J., Nakale, T., Nantanga, K., Schachtschneider, K., & Seely, M. (2003). Ephemeral rivers and their development: testing an approach to basin management committees on the Kuiseb River, Namibia. *Physics and Chemistry of the Earth*, Parts A/B/C, 28(20), 853-858.

Bougadis, J., Adamowski, K., & Diduch, R. (2005). Short-term municipal water demand forecasting. *Hydrological Processes*, *19*(1), 137-148.

Brauer, N., O'Geen, A. T., & Dahlgren, R. A. (2009). Temporal variability in water quality of agricultural tailwaters: Implications for water quality monitoring. *Agricultural water management*, *96*(6), 1001-1009.

Bressers, H., & Kuks, S. (2004). Integrated governance and water basin management (pp. 247-265). Springer Netherlands.

Brown, J., Cavill, S., Cumming, O., & Jeandron, A. (2012). Water, sanitation, and hygiene in emergencies: summary review and recommendations for further research. *Waterlines*, *31*(1-2), 11-29.

Brown, R. R., & Clarke, J. M. (2007). *Transition to water sensitive urban design: The story of Melbourne, Australia*. Melbourne, Australia: Facility for Advancing Water Biofiltration, Monash University.

Brunner, R., & Lynch, A. (2013). *Adaptive governance and climate change*. Springer Science & Business Media.

Butler, D., & Memon, F. A. (Eds.). (2006). *Water demand management*. Iwa Publishing, London.

Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N., & Smith, V. H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological applications*, *8*(3), 559-568.

Carter, J., & Howe, J. (2006). Stakeholder participation and the water framework directive: The case of the Ribble Pilot. *Local environment*, *11*(02), 217-231.

Cashman, D., Foster, C., McCluskey, K., & Zhang, Y. (2014). Identifying Opportunities to Reduce Water Pollution and Encourage Voluntary Compliance in Windhoek, Namibia. *Undergraduate Interactive Qualifying Project No. E-project-050814-051919). Retrieved from Worcester Polytechnic Institute Electronic Projects Collection: http://www. wpi. edu/Pubs/E-project/Available/E-project-050814-051919/unrestricted/City_-_Final_IQP_Report. pdf*.

Chang, H., Parandvash, G. H., & Shandas, V. (2010). Spatial variations of single-family residential water consumption in Portland, Oregon. *Urban Geography*, *31*(7), 953-972.

Chapman, D. V. (Ed.). (1996). Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring, 2nd Edition, Spon Press, Abingdon, Great Britain.

Chattopadhyay, S., Chattopadhyay, G. (2010). Univariate modelling of summer-monsoon rainfall time series: Comparison between ARIMA and ARNN. *Comptes Rendus Geoscience*, 342(2) 100–107.

Chauret, C., Armstrong, N., Fisher, J. Sharma, R., Springthorpe, S. & Sattar, S. (1995). Correlating cryptosporidium and Giardia with microbial indicators, *Journal American Water Works association (AWWA*), *87* (11), 76-84.

Chen, Z., Ngo, H. H., & Guo, W. (2013). A critical review on the end uses of recycled water. *Critical reviews in environmental science and technology*, *43*(14), 1446-1516.

Chorus, I. and Bartram, J. (1999). Toxic Cyanobacteria in Water: a Guide to Public Health Significance, Monitoring and Management. Für WHO durch E & FN Spon /Chapman & Hall, London, 416 pp. retrieved 16 March 2012 from: http://www.who.int/water_sanitation_health/resourcesquality/toxicyanbact/en/index.html.

Clark, G. M., Mueller, D. K., & Mast, M. A. (2000). Nutrient Concentrations and Yields in Undeveloped Stream Basins of the United States'. *Journal of the American Water Resources Association*, *36*(4).

Clarke, A., & Fuller, M. (2010). Collaborative strategic management: strategy formulation and implementation by multi-organizational cross-sector social partnerships. *Journal of Business Ethics*, *94*(1), 85-101.

Cohen, A. & Davidson, S. (2011). The Watershed Approach: Challenges, Antecedents, and the Transition from Technical Tool to Governance Unit: *Water Alternatives* (2011) 4(2): 1-14 Retrieved 16 March 2012 from www.water-alternatives.org.

Cohen, K. J., & Cyert, R. M. (1973). Strategy: Formulation, implementation, and monitoring. *Journal of Business*, 349-367.

Cohen, N. (Ed.). (2011). *Green Cities: An A-to-Z Guide* (Vol. 4). Sage.

Collischonn, W., Haas, R., Andreolli, I., & Tucci, C.E.M. (2005). Forecasting river Uruguay flow using rainfall forecasting from a regional weather predicted model, *Journal of hydrology*, 305 (1-4) 87-98.

Colvin, J., Ballim, F., Chimbuya, S., Everard, M., Goss, J., Klarenberg, G., & Weston, D. (2008). Building capacity for co-operative governance as a basis for integrated water resource managing in the Inkomati and Mvoti catchments, South Africa. *Water SA*, *34*(6), 681-689.

Correll, D. L. (1998). The role of phosphorus in the eutrophication of receiving waters: A review. *Journal of Environmental Quality*, *27*(2), 261-266.

Creswell, J. W. (2009). Editorial: Mapping the field of mixed methods research. *Journal of Mixed Methods Research*, *3*(2), 95-108.

Davies-Colley, R. J., & Smith, D. G. (2001). Turbidity Suspeni) Ed Sediment, And Water Clarity: A Review1.

De Stefano, L. (2010). Facing the water framework directive challenges: a baseline of stakeholder participation in the European Union. *Journal of environmental management*, *91*(6), 1332-1340.doi:10.1021/es040504n.

Demetropoulou, L., Nikolaidis, N., Papadoulakis, V., Tsakiris, K., Koussouris, T., Kalogerakis, N., & Theodoropoulos, K. (2010). Water framework directive implementation in Greece: introducing participation in water governance–the case of the Evrotas River Basin management plan. *Environmental Policy and Governance*, *20*(5), 336-349.

Department of Water Affairs (DWA), Hydrology Division, Namibia (1988): *http://download.polytechnic.edu.na/pub2/SOER/water/Fig2-15Evaporation.pdf* down loaded on 4 June 2015.

Department of Water Affairs [DWA], (2015). Hartbeespoort Dam Remediation Programme, South Africa. Accessed on 4 June 2015

http://www.harties.org.za/problem.aspx.

Dodds, W. K., Carney, E., & Angelo, R. T. (2006). Determining ecoregional reference conditions for nutrients, Secchi depth and chlorophyll a in Kansas lakes and reservoirs. *Lake and Reservoir Management*, *22*(2), 151-159.

DRFN (2008). Final Report Climate Change Vulnerability and Adaptation Assessment Namibia.

DRFN (2011). Annual report 2010-201, Windhoek, Namibia.

du Pisani, P. L. (2006). Direct reclamation of potable water at Windhoek's Goreangab reclamation plant. *Desalination*, *188*(1), 79-88.

Dube, D., & Swatuk, L. A. (2002). Stakeholder participation in the new water management approach: a case study of the Save catchment, Zimbabwe. *Physics and Chemistry of the Earth, Parts A/B/C*, *27*(11), 867-874.

Dungumaro, E.W., Madulu, N. F. (2003). Public participation in integrated water resources management: the case of Tanzania. *Physics and Chemistry of the Earth, Parts A/B/C, 28*(20), 1009-1014.

Dutra, E., Giuseppe, F. D., Wetterhall, F., & Pappenberger, F. (2013). Seasonal forecasts of droughts in African basins using the Standardized Precipitation Index. *Hydrology and Earth System Sciences*, *17*(6), 2359-2373.

El-Khoury, G. (2014). Water resources in Arab countries: selected indicators. *Contemporary Arab Affairs*, *7*(2), 339-349.

Esplugas, S., Bila, D. M., Krause, L. G. T., & Dezotti, M. (2007). Ozonation and advanced oxidation technologies to remove endocrine disrupting chemicals (EDCs) and pharmaceuticals and personal care products (PPCPs) in water effluents. *Journal of Hazardous Materials*, *149*(3), 631-642.

European Commission [EC] (1998). Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. Official Journal L 330., 05/12/1998 P. 0032 – 0054.

European Commission [EC] (2000). EC Directive 2000/60/EC of the European parliament and of the council establishing a framework for the community action in the field of water policy, *Official Journal. European. Communities (22. 12. 2000) (2000)*, pp. 1–72

Falkenmark, M., Berntell, A., Jägerskog, A., Lundqvist, J., Matz, M., & Tropp, H. (2007). On the verge of a new water scarcity: A call for good governance and human ingenuity. Stockholm International Water Institute (SIWI).

Faul, A. K., Julies, E., & Pool, E. J. (2013). Oestrogen, testosterone, cytotoxin and cholinesterase inhibitor removal during reclamation of sewage to drinking water. *Water SA*, *39*(4), 00-00.

Feld, L. P., & Voigt, S. (2003). Economic growth and judicial independence: cross-country evidence using a new set of indicators. *European Journal of Political Economy*, 19(3), 497-527.

Fontdecaba, S., Grima, P., Marco, L., Rodero, L., Sánchez-Espigares, J. A., Solé, I., & Zubelzu, J. (2012). A methodology to model water demand based on the identification of homogenous client segments. Application to the city of Barcelona. *Water resources management*, *26*(2), 499-516.

Franks, T. & Cleaver, F. (2007). Water Governance and Poverty: A Framework for Analysis, *Progress in development Studies*, 7 (4) 291-306.

Freeman, R. E. (2010). *Strategic management: A stakeholder approach*. Cambridge University Press.

Fresner, J., & Engelhardt, G. (2004). Experiences with integrated management systems for two small companies in Austria. *Journal of Cleaner Production*, *12*(6), 623-631.

Friedler, E. & Lahav, O. (2006). Centralized Urban Waste Water Reuse: What is the Public Attitude? *Water Science and Technology*, 54 (6-7), 423-430.

Fritsch, O., & Benson, D. (2013). Integrating the principles of integrated water resources management? River basin planning in England and Wales. *International Journal of Water Governance*, *1*(3-4), 265-284.

Funke, N., Oelofse, S. H. H., Hattingh, J., Ashton, P. J., & Turton, A. R. (2007). IWRM in developing countries: Lessons from the Mhlatuze Catchment in South Africa. *Physics and Chemistry of the Earth, Parts A/B/C*, *32*(15), 1237-1245.

Gain, A. K., Rouillard, J. J., & Benson, D. (2013). Can integrated water resources management increase adaptive capacity to climate change adaptation? A critical review. *Journal of Water Resource and Protection*, *5*(04), 11.

Galaz, V. (2007). Water governance, resilience and global environmental change--a reassessment of integrated water resources management (IWRM). *Water Science & Technology*, *56*(4).

Gerber, P., Opio, C., & Steinfeld, H. (2007). Poultry production and the environment—a review. *Animal Production and Health Division, Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla*, *153*.

Ghaffour, N., Missimer, T. M., & Amy, G. L. (2013). Combined desalination, water reuse, and aquifer storage and recovery to meet water supply demands in the GCC/MENA region. *Desalination and Water Treatment*, *51*(1-3), 38-43.

Ghaffour, N., Missimer, T. M., & Amy, G. L. (2013). Technical review and evaluation of the economics of water desalination: current and future challenges for better water supply sustainability. *Desalination*, *309*, 197-207.

Girija, T. R., Mahanta, C., & Chandramouli, V. (2007). Water quality assessment of an untreated effluent impacted urban stream: the Bharalu tributary of the Brahmaputra River, India. *Environmental monitoring and assessment*, *130*(1-3), 221-236.

Gleick, P. H. (Ed.). (2014). *The World's Water Volume 8: The Biennial Report on Freshwater Resources* (Vol. 8). Island Press.

Gober, P. (2010). Desert urbanization and the challenges of water sustainability. *Current Opinion in Environmental Sustainability*, *2*(3), 144-150.

Goitom, H. (2012). Namibia: Environmental Management Act Takes Effect Four Years After Adoption; Global Legal Monitor, The Law Library of Congress, USA.

Goldin, J. A. (2010). Water policy in South Africa: trust and knowledge as obstacles to reform. *Review of Radical Political Economics*, *42*(2), 195-212

Gooch, G. D., & Baggett, S. (2013). IWRM in the Swedish context: a voluntary move to IWRM principles or a legal necessity to comply with the European Union Water Framework Directive. *International Journal of Water Governance, 1*(3-4), 361-378.

Goudie, A., & Viles, H. (2015). Landscapes. In *Landscapes and Landforms of Namibia* (pp. 3-25). Springer Netherlands.

Government of the Republic of Namibia [GRN] (1992a). Regional Councils Act No. 22 of 1992.

Government of the Republic of Namibia [GRN] (1992b). Local Authorities Act No. 23 of 1992, Gazette No. 470.

Government of the Republic of Namibia [GRN] (2008a). Okahandja Municipality: Determination of Charges, Fees, Rates and Other Monies. Gazette No. 372.

Government of the Republic of Namibia [GRN] (2007). Environmental Management Act No.7 of 2007, Gazette No. 3966.

Government of the Republic of Namibia [GRN] (2010). Municipality of Windhoek Sewerage Tariffs and Drainage Regulations, Gazette No. 4603.

Government of the Republic of Namibia [GRN] (1956). Water Act No. 54 of 1956.

Government of the Republic of Namibia [GRN] (1971). Water Research Act No. 34 of 1971,

Government of the Republic of Namibia [GRN] (2003). Pollution Control and Waste Management Bill, third Draft.

Government of the Republic of Namibia [GRN] (1997). Namibia Water Corporation Act No. 12 of 1997.

Government of the Republic of Namibia [GRN] (1993). Water Supply and Sanitation Sector Policy.

Government of the Republic of Namibia [GRN] (2000a). Decentralization Enabling Act.

Government of the Republic of Namibia [GRN] (2000b). Traditional Authorities Act.

Government of the Republic of Namibia [GRN] (2004a). Water Resources Management Act.

Government of the Republic of Namibia [GRN] (2008b). Water Supply and Sanitation Policy.

Government of the Republic of Namibia [GRN] (2013). Water Resources Management Act, Gazette No. 11.

Government of the Republic of Namibia [GRN] (2000c). National Water Policy. Windhoek, Namibia.

Government of the Republic of Namibia [GRN] (1970). Mountain Catchment Areas Act No. 63 of 1970.

Government of the Republic of Namibia [GRN] (1990). Assignment of Powers Act No. 4 of 1990, Gazette No.12.

Government of the Republic of Namibia [GRN] (2004b). Vision 2030, National Planning Commission, Windhoek, Namibia.

Government of Zimbabwe (1998). Water Act, Government No.36.

Griffin, R.C., Chang, C. (1991) Seasonality in community water demand. *West Journal of Agricultural Economics* 16(2), 207–217.

Gupta, J., Pahl-Wostl, C., & Zondervan, R. (2013). 'Glocal'water governance: a multi-level challenge in the anthropocene. *Current Opinion in Environmental Sustainability*, *5*(6), 573-580.

GWP, (2010). IWRM application:www.gwp.org/challenge/what-is-IWRM/IWRM-Application/. Retrieved 16 March 2012.

Haraseb, B.B., & Müller, B. (2012). Workshop Presentation on Basin Management in Namibia, Okahandja, 16-18 November 2012.

Harlan, S. L., Yabiku, S. T., Larsen, L., & Brazel, A. J. (2009). Household water consumption in an arid city: affluence, affordance, and attitudes. *Society and Natural Resources*, *22*(8), 691-709.

Hasse, D., & Nuiss, H. (2007). Does urban sprawl drive changes in the water balance and policy? The case of Leipzig *(*Germany). 1987–2003, *Landscape and Urban Planning*, 80, 1–13.

Havekes, H. J. M., Hofstra, M., van der Kerk, A., & Teeuwen, B. (2013). *Building blocks for good water governance*. Water Governance Centre (WGC).

Hedelin, B. (2007). Criteria for the assessment of sustainable water management. *Environmental Management*, *39*(2), 151-163.

Hellegers, P., Immerzeel, W., & Droogers, P. (2013). Economic concepts to address future water supply–demand imbalances in Iran, Morocco and Saudi Arabia. *Journal of Hydrology*, *502*, 62-67.

Hellegers, P., Soppe, R., Perry, C., Bastiaanssen, W. (2010). Remote sensing and economic indicators for supporting water resources management decisions. *Water Resources Management*, 24(11), 2419–2436. doi:10.1007/s11269-009-9559-2.

Herrera, M., Torgo, L., Izquierdo, J., & Pérez-García, R. (2010). Predictive models for forecasting hourly urban water demand. *Journal of hydrology*, *387*(1), 141-150.

Herrfahrdt-Pähle, E. (2010a). South African water governance between administrative and hydrological boundaries. *Climate and Development*, *2*(2), 111-127.

Herrfahrdt-Pähle, E. (2010b). *The transformation towards adaptive water governance regimes in the context of climate change*.

Heyns, P. (2005). Water Institutional Reforms in Namibia, *Water Policy*, 7 89-106.

Hill, M. (2013). A Starting Point: Understanding Governance, Good Governance and Water Governance. In Climate Change and Water Governance (pp. 17-28). Springer Netherlands.

Hirsch P., Jensen K.M., Boer B., Carrard N., FitzGerald S., & Lyster R. (2006). National Interests and Transboundary Water Governance in the Mekong, in collaboration with DANIDA, University of Sydney.

Hirsch, D. (2012). *Civil society participation in development and budget processes in Uganda* (Doctoral dissertation, uniwien).

Hoekstra, A. Y., & Chapagain, A. K. (2011). *Globalization of water: Sharing the planet's freshwater resources*. John Wiley & Sons.

Honga, E. (2012). Dam and River Water Quality, presentation on the Upper Swakop Basin Workshop, 8-10 February 2012, Windhoek, Namibia.

Hooper, B. P. (2003). Integrated Water Resources Management and River Basin Governance, Universities Council on Water Resources, *Water Resources Update, Issue 126, 12-20*.

Hooper, B. P. (2005). *Integrated river basin governance: learning from international experiences*. IWA publishing.

House-Peters, L. A., & Chang, H. (2011). Urban water demand modeling: Review of concepts, methods, and organizing principles. *Water Resources Research*, *47*(5).

House-Peters, L., Pratt, B., & Chang, H. (2010). Effects of Urban Spatial Structure, Sociodemographics, and Climate on Residential Water Consumption in Hillsboro, Oregon1. *Journal of The American Water Resources Association*, *46*(3).

Hroncich, J.A. (1999). Water Quality and Treatment: A handbook for Community Water Supplies, Surface Water, American Water Works Association, McGraw-Hill, New York.

Htike, K. K., & Khalifa, O. O. (2010, May). Rainfall forecasting models using focused time-delay neural networks. In *Computer and Communication Engineering (ICCCE), 2010 International Conference on* (pp. 1-6). IEEE.

Huitema, D., Mostert, E., Egas, W., Moellenkamp, S., Pahl-Wostl, C., & Yalcin, R. (2009). Adaptive water governance: assessing the institutional prescriptions of adaptive (co-) management from a governance perspective and defining a research agenda. *Ecology and society, 14*(1), 26.

Hung, N.Q.,Babel, M.S.,Weesakul, S. & Tripathi, N.K. (2009). An artificial neural network model for rainfall forecasting in Bangkok, Thailand, *Hydrological. Earth. System. Science*, 13, 1413-1425.

Hurlimann A. (2008). *Community Attitudes to Recycled Water Use: an Urban Australian Case Study Part 2, CRC for Water Quality and Treatment*, Research Report No 56. Australia.

Jaji, M. O., Bamgbose, O., Odukoya, O. O., & Arowolo, T. A. (2007). Water quality assessment of Ogun River, south west Nigeria. *Environmental monitoring and assessment*, *133*(1-3), 473-482.

Jakasa, T., Androsec, I. & Sprcic, P. (2011). Electricity price forecasting –ARIMA model approach, Proceedings of the International Conference on the European Energy market (EEM) 25-27 May 2011, Zagreb, Croatia page 222-225.

Jenkins, M.W., Marques, G.F., Lelo, F.K., & Miller, S.N. (2005). WEAP as a participatory tool for shared vision planning in the river Njoro watershed in Kenya, Proceedings of the World Water and Environmental Resources Congress: Impact of global change, May 15-19, Anchorage, AK.

Jiang, Y. (2009). China's water scarcity. *Journal of Environmental Management*, *90*(11), 3185-3196.

Jones, J., & Brett, M. T. (2014). Lake nutrients, eutrophication, and climate change. In *Global Environmental Change* (pp. 273-279). Springer Netherlands.

Jonnalagadda, S. B., & Mhere, G. (2001). Water quality of the Odzi River in the eastern highlands of Zimbabwe. *Water Research*, *35*(10), 2371-2376.

Juahir, H., Zain, S. M., Yusoff, M. K., Hanidza, T. T., Armi, A. M., Toriman, M. E., & Mokhtar, M. (2011). Spatial water quality assessment of Langat River Basin (Malaysia) using environmetric techniques. *Environmental monitoring and assessment*, *173*(1-4), 625-641.

Julies, E.M., Pool, E.J., Faul, A.K., Amutenya C. (2013). Endocrine disrupting chemicals in various wastewater treatment and reclamation plants in Namibia, Paper presented at 9th IWA Conference, 27 to 31 October, Windhoek.

Kallis, G., Videira, N., Antunes, P., Pereira, Â. G., Spash, C. L., Coccossis, H., ... & Mexa, A. (2006). Participatory methods for water resources planning. *Environment and Planning C: Government and Policy*, *24*(2), 215-234.

Kangira, J. (2012). Praiseworthy values in President Hifikepunye Pohamba's epideictic speech marking Namibia's 20th anniversary of independence.

Kanna, M., Prabakharan, S., & Ramachandran, P. (2010). Rainfall forecasting using Data Mining Technique, *International Journal of Engineering Technology*, 2 (6) 397-401.

Karuaihe, S., Wandschneider, P., & Yoder, J. (2012). Water bill estimation when price is cryptic: experience from Windhoek, Namibia. *South African Journal of Economics*, *80*(2), 264-286.

Kaufman, A. (2006). Introduction to Citizen participation in Science and Technology, Procida Training workshop, Italy.

Kaufmann, D., A. Kraay, & Mastruzzi, M. (2005). Governance Matters IV: governance Indicators for 1996 -2004, World Bank

Kaufmann, D., Kraay, A., & Mastruzzi, M. (2009). Governance matters VIII: Aggregate and individual governance indicators, 1996-2008 (June 29, 2009), World Bank Policy Research Working Paper No. 4978.

Kaufmann, D., Kraay, A., & Zoido-Lobatón, P. (2000). Governance matters. Finance Dev, 37(2), 10.

Kavishe, D. (2015). Workshop Presentation on Namibian Economic Outlook, 15 January 2015, Windhoek, Namibia.

Kayizzi-Mugerwa, S., Shimeles, A., & Yaméogo, N. D. (2014). *Urbanization and Socio-Economic Development in Africa: Challenges and Opportunities*. Routledge.

Keeley, J., & Scoones, I. (2003). *Understanding environmental policy processes: Cases from Africa*. Earthscan.

Kemker, C. (2013). Dissolved Oxygen, Fundamentals of Environmental Measurements. Fondriest Environmental.

Knieper, C., Holtz, G., Kastens, B., & Pahl-Wostl, C. (2010). Analysing water governance in heterogeneous case studies—experiences with a database approach. *environmental science & policy*, *13*(7), 592-603.

King Committee on Corporate Governance, & Institute of Directors (South Africa). (2002). *King Report on Corporate Governance for South Africa, 2002*. Institute of Directors in Southern Africa.

Koehler, B., & Koontz, T. M. (2008). Citizen participation in collaborative watershed partnerships. *Environmental management*, *41*(2), 143-154.

Komatsu, E., Fukushima, T., & Shiraishi, H. (2006). Modeling of P-dynamics and algal growth in a stratified reservoir—mechanisms of P-cycle in water and interaction between overlying water and sediment. *Ecological Modelling*, *197*(3), 331-349.

Koontz, T. M., & Johnson, E. M. (2004). One size does not fit all: Matching breadth of stakeholder participation to watershed group accomplishments. *Policy Sciences*, *37*(2), 185-204.

Kostas, B., & Chrysostomos, S. (2006). Estimating urban residential water demand determinants and forecasting water demand for Athens metropolitan area, 2000-2010. *South-Eastern Europe Journal of Economics*, *1*(1), 47-59.

KrishnaKumari, M. B., Nandhini, R., & Kanmani, S. (2016). Analysis of water quality in Buckingham Canal. *International Journal of Research and Engineering (IJRE)*, *3*(3), 40-44.

Lahnsteiner, J., & Lempert, G. (2007). Water management in Windhoek, Namibia. *Water Science & Technology*, *55*(1), 441-445.

Lankford, B., Bakker, K., Zeitoun, M., & Conway, D. (2013). *Water security: Principles, perspectives and practices*. Routledge.

Larson, M. G. (2006). Descriptive statistics and graphical displays. *Circulation*, *114*(1), 76-81.

Laryea-Adjei, G. Q. M. (2007). *Decentralization Plus Pluralism for Basic Services Provision: Water and Sanitation in Ghana*. Eburon Uitgeverij BV.

Latham, C. J. K. (2002). Manyame Catchment Council: a review of the reform of the water sector in Zimbabwe. *Physics and Chemistry of the Earth, Parts A/B/C*, *27*(11), 907-917.

Lavière, I., Lafrance, G. (1999). Modelling the electricity consumption of cities: effect of urban density. *Energy Economics*, 21, 53–66.

Law, I.B. (2005). Portable Reuse- What are we afraid of? IBL Solutions http://www.psmithersmyriver.com/docs/potable_reuse/potablereuse.pdf (accessed 04 August 2013).

Leach, W. D., & Sabatier, P. A. (2005). Are trust and social capital the keys to success? Watershed partnerships in California and Washington. *Swimming upstream: Collaborative approaches to watershed management*, 233-258.

Lee, C. S., & Chang, S. P. (2005). Interactive fuzzy optimization for an economic and environmental balance in a river system. *Water research*,*39*(1), 221-231.

Lee, S. J., & Wentz, E. A. (2008). Applying Bayesian Maximum Entropy to extrapolating local-scale water consumption in Maricopa County, Arizona. *Water Resources Research*, *44*(1).

Lee, S.-J., E. A. Wentz, and P. Gober (2010), Space-time forecasting using soft geostatistics: A case study in forecasting municipal water demand for Phoenix, Arizona, Stochastic Environ. *Resour. Risk Assess*., 24, 283–295, doi:10.1007/s00477-009-0317-z.

Lennox, J., Proctor, W., & Russell, S. (2011). Structuring stakeholder participation in New Zealand's water resource governance. *Ecological Economics*, *70*(7), 1381-1394.

Lenton, R., & Muller, M. (2012). *Integrated water resources management in practice: Better water management for development*. Routledge.

Letterman, R. D. (Ed.). (1999). *Water quality and treatment: a handbook of community water supplies*. American Water Works Association, McGraw-Hill Professional.

Levite, H., Sally, H., & Cour, J. (2003). Testing water demand management scenarios in a water stressed basin in South Africa: Application of the WEAP model, *Physics and Chemistry of the earth*, 28, 779-786.

Lindim, C., Pinho, J. L., & Vieira, J. M. P. (2011). Analysis of spatial and temporal patterns in a large reservoir using water quality and hydrodynamic modeling. *Ecological Modelling*, *222*(14), 2485-2494.

Litke, D. W. (1999). *Review of phosphorus control measures in the United States and their effects on water quality*. US Department of the Interior, US Geological Survey.

Liu, J., Daily, G.C., Ehrlich, P.C., & Luck, G.W. (2003). Effects of households dynamics on resource consumption and biodiversity, *Nature*, 421, 530–533.

Livingston, M. L. (2005). Evaluating changes in water institutions: methodological issues at the micro and meso levels. *Water Policy*, *7*(1), 21-34.

Loukas, A. (2010). Surface water quantity and quality assessment in Pinios River, Thessaly, Greece. *Desalination*, *250*(1), 266-273.

Loukas, A., Mylopoulos, N., & Vasiliades, L. (2007). A modeling system for the evaluation of water resources management strategies in Thessaly, Greece. *Water Resources Management, 21*(10), 1673-1702.

Lubell, M., & Edelenbos, J. (2013). Integrated water resources management: A comparative laboratory for water governance. *International Journal of Water Governance*, *1*(3-4), 177-196.

Lund & Seleenbinder Consulting Engineers (2014) Augmentation of Water Supply to the Central Area of Namibia and the Cuvelai, Memorandum Report Part 1 to MAWF.

Magadza, C. (2003). Water resources management and water quality monitoring in an African setting. In *Guest Forum: Readout No 27, 1* (Vol. 13).

Magadza, M. (2009, April 5). Regulating Ramatex: Authorities Shut Out as Malaysian Investor Threatens Namibian Environment, *CorpWatch*, Windhoek, Namibia.

Mahsin, M., Akhter, Y., & Begum, M. (2012). Modelling rainfall in Dhaka Division of Bangadesh using time series analysis, *Journal of mathematical modelling and application*, 1 (5) 67-73.

Manzungu, E. (2002). More than a headcount: towards strategic stakeholder representation in catchment management in South Africa and Zimbabwe. *Physics and Chemistry of the Earth, Parts A/B/C, 27*(11), 927-933.

Mapani, B. S. (2005). Groundwater and urbanisation, risks and mitigation: The case for the city of Windhoek, Namibia. *Physics and Chemistry of the Earth, Parts A/B/C, 30*(11), 706-711.

Mara, D. (2013). *Domestic wastewater treatment in developing countries*. Routledge.

Martin, C. A., P. S. Warren, and A. P. Kinzig (2004), Neighborhood socioeconomic status is a useful predictor of perennial landscape vegetation in residential neighborhoods and embedded small parks in Phoenix, AZ, *Landscape Urban Plann*., 69, 355–368.

Matengu, K. K. (2003). The diffusion of modern technologies in Namibia. In *43rd European Congress of the Regional Science Association, University of Jyväskylä, Finland*.

Matiwane, M. (2012). *Public Participation as governance: the role of catchment forums in water governance* (Doctoral dissertation, Faculty of Science, University of the Western Cape).

Maude, A. (2012). Defining and explaining sustainable development and sustainability: a review of curriculum guides and school texts. In *Schooling for Sustainable Development:* (pp. 49-63). Springer Netherlands.

Mauludiyanto, A., Hendrantoro, G., Purnomo, M.H., Ramadhany, T., & Matsushima, A. (2010). ARIMA modeling of tropical rain attenuation on a short 28-GHz terrestrial link. *IEEE Antennas and Wireless Propagation Letters*,9 223–227.

Mays, L. W. (2001). *Stormwater collection systems design handbook*. McGraw-Hill Professional.

McIntyre, O. (2015). Benefit-sharing and upstream/downstream cooperation for ecological protection of trans-boundary waters: opportunities for China as an upstream state. *Water International*, *40*(1), 48-70.

McKay, J. M. (2005). Water institutional reforms in Australia. *Water policy*, *7*(2), 35-52.

Megdal, S. B., Dillon, P., & Seasholes, K. (2014b). Water Banks: Using Managed Aquifer Recharge to Meet Water Policy Objectives. Water, 6(6), 1500-1514.

Megdal, S. B., Gerlak, A. K., Varady, R. G., & Huang, L. Y. (2014a). Groundwater Governance in the United States: Common Priorities and Challenges. Groundwater.

Meher, J., & Jha, R. (2013). Time-series analysis of monthly rainfall data for the Mahanadi River Basin, India. *Sciences in Cold and Arid Regions (SCAR)*, *5*(1), 73-84.

Melidis, P., Akratos, C. S., Tsihrintzis, V. A., & Trikilidou, E. (2007). Characterization of rain and roof drainage water quality in Xanthi, Greece. *Environmental monitoring and assessment*, *127*(1-3), 15-27.

Milly, P. C. D., Julio, B., Malin, F., Robert, M., Zbigniew, W., Dennis, P., & Ronald, J. (2007). Stationarity is dead. *Ground Water News & Views*, *4*(1), 6-8.

Ministry of Agriculture, Water and Forestry [MAWF] (2005). Basin management approach, a guidebook, Windhoek, Namibia.

Ministry of Agriculture, Water and Forestry [MAWF] (2015). Draft Internal Memorandum on Critical Water Shortages in the Central Area of Namibia (February 2015), Windhoek Namibia.

Ministry of Agriculture, Water and Forestry [MAWF], (2012). Draft Wastewater Discharge Permits Regulations, Windhoek, Namibia.

Ministry of Agriculture, Water and Forestry [MAWF], (2013). Basin Management Approach: A Guidebook, 2nd Edition.

Mitchell, B. (2015). Water Risk Management, Governance, IWRM and Implementation. In *Risk Governance* (pp. 317-335). Springer Netherlands.

Mitchell, V., McMahon, T. & Mein, R. *Environmental Management* (2003) 32: 735. doi:10.1007/s00267-003-2062-2

Molle, F. (2008). Nirvana concepts, narratives and policy models: Insight from the water sector. *Water Alternatives* 1(1): 131-156.

Moss, T. (2003). *Solving problems of 'fit'at the expense of problems of 'interplay'? The spatial reorganisation of water management following the EU Water Framework Directive* (pp. 85-121). VS Verlag für Sozialwissenschaften.

Mugatsia, E. A. (2010). *Simulation and scenario analysis of water resources management in Perkerra catchment using WEAP model* (Doctoral dissertation), Moi University, Kenya.

Mundial, B. (2004). Water resources sector strategy: Strategic directions for World Bank engagement. *Banco Mundial, Washington, DC*.

Murdock, S.H., Albrecht, D.E., Hamm, R.R., &Backman, K. (1991). Role of sociodemographic characteristics in projections of water use. Journal of Water Resources Planning Management, 117, 235–251.

Murni P., Kaercher J. D. & Nancarrow B.E. (2003). *Literature Review of Factors Influencing Public Perceptions of Water Reuse*, CSIRO Land and Water Technical Report 54/03, Australia.

Murray, E. C., & Tredoux, G. (1998). Enhancing Water Resources: Factors Controlling the Viability of Artificial Groundwater Recharge. In *WISA Biennial Conference and Exhibition*.

Namibia Meteorological Service (2015): Standards applicable to specific work areas, Accessed 20 June 2015. http://www.meteona.com/index.php/about-us,.

Namibia Statistics Agency (2011). *Namibia Population and Housing Census 2011 Report*, National Planning Commission, Government of the Republic of Namibia.

Namibia Water Corporation [NamWater] (2000). Hydrology Division, *Electronic* Hydrology Internal Folders on Characteristics of Dams, Windhoek, Namibia.

Namibia Water Corporation [NamWater] (2010a). Minutes on the Annual CAN Workshop, 2010. Windhoek, Namibia.

Namibia Water Corporation [NamWater] (2010b). Situation Assessment on Otjimbingwe Bulk Water Supply Scheme, NWC-C-SGWE108-03, Windhoek, Namibia.

Namibia Water Corporation [NamWater] (2011a). Bulk Water Supply Infrastructure Development and Capital Replacement Master Plan for the Central Water Supply Area of Namibia. NW/021/2010/0.

Namibia Water Corporation [NamWater] (2011b). Minutes on the Annual CAN Workshop, 2011. Windhoek, Namibia.

Namibia Water Corporation [NamWater] (2013). Hydrology Division, *Electronic* Hydrology Internal Folders on Water Demands on Von Bach Dam, Windhoek, Namibia.

Namibia Water Corporation [NamWater] (2015). Swakoppoort and Von Bach Dams Raw Water Quality, *Electronic* Water Quality Internal Folders, Windhoek, Namibia.

Namibia, I. P. J. V. (2010). Integrated water resources management plan for Namibia. *Integrated Water Resources Management Plan for Namibia*.

Namibia, Tarr, P. (1993). *Namibia's environmental assessment policy*. Directorate of Environmental Affairs, Ministry of Wildlife, Conservation, and Tourism.

Nare, L., Love, D., & Hoko, Z. (2006). Involvement of stakeholders in the water quality monitoring and surveillance system: The case of Mzingwane Catchment, Zimbabwe. *Physics and Chemistry of the Earth, Parts A/B/C, 31*(15), 707-712.

Naseem, S., Hamza, S., & Bashir, E. (2010). Groundwater geochemistry of winder agricultural farms, Balochistan, Pakistan and assessment for irrigation water quality. *European Water*, *31*, 21-32.

Nauges, C., & Thomas, A. (2003). Long-run study of residential water consumption. *Environmental & Resource Economics, European Association of Environmental and Resource Economists* 26(1), 25–43.

Nazari, Saeed; Mousavi, S. Jamshid; Behzadian, Kourosh; and Kapelan, Zoran, "Sustainable Urban Water Management: A Simulation Optimization Approach" (2014). *City Univerisity New York Academic Works.* http://academicworks.cuny.edu/cc_conf_hic/61

Newaya, T. P. (2010). *Rapid urbanization and its influence on the growth of informal settlements in Windhoek, Namibia* (Doctoral dissertation).

Nhapi, I. (2004). *Options for wastewater management in Harare, Zimbabwe*. CRC Press.

Nhapi, I. (2008). Inventory of water management practices in Harare, Zimbabwe. *Water and Environment Journal*, *22*(1), 54-63.

Nhapi, I. (2015). Challenges for water supply and sanitation in developing countries: case studies from Zimbabwe. In Understanding and Managing Urban Water in Transition (pp. 91-119). Springer Netherlands.

Nhapi, I., & Tirivarombo, S. (2004). Sewage discharges and nutrient levels in Marimba River, Zimbabwe. *Water SA*, *30*(1), 107-113.

Nhapi, I., Holch, W., Mazvimavi, D., Mashauri, D. A., Jewitt, G., Mudege, N., & Beukman, R. (2005b). Integrated water resources management (IWRM) and the millennium development goals: Managing water for peace and prosperity. *Physics and Chemistry of the Earth, Parts A/B/C, 30*(11), 623-624.

Nhapi, I., Siebel, M. A., & Gijzen, H. J. (2004). The impact of urbanisation on the water quality of Lake Chivero, Zimbabwe. *Water and Environment Journal*, *18*(1), 44-49.

Nhapi, I., Siebel, M. A., & Gijzen, H. J. (2005a). A strategic framework for managing wastewater: A case study of Harare, Zimbabwe. *Water international*, *30*(4), 456-467.

Nieto, P. G., Fernández, J. A., de Cos Juez, F. J., Lasheras, F. S., & Muñiz, C. D. (2013). Hybrid modelling based on support vector regression with genetic algorithms in forecasting the cyanotoxins presence in the Trasona reservoir (Northern Spain). *Environmental research*, *122*, 1-10.

Nürnberg, G. K. (1996). Trophic state of clear and colored, soft-and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. *Lake and Reservoir Management, 12*(4), 432-447.

Ogilvie, Ogilvie & Company. (2010). *Stakeholder/ Public Attitudes Towards Reuse of Treated Water,* Lake Simcoe Region Conservation Final Report. Canada.

OkaCom (2016). Environmental Monitoring Reports, http://www.okacom.org/observing-the-river/environmental-monitoring-reports.

Oram, B. (2010). Total dissolved solids and water quality. *Water Research Center.* Accessed 7 June 2014. *http://www. water-research. net/index. php/water-treatment/tools/total-dissolved-solids.*

Oram, B. (2014). Calculating NSF Water Quality Index. Water Research Center: Monitoring the Quality of Surfacewaters,[en línea]. Accessed July 2015

Ostrom, E. (2015). *Governing the commons*. Cambridge university press.

Otok, B.W., & Suhartono, F.R. (2009). Development of rainfall forecasting model in Indonesia by using ASTAR, transfer function, and ARIMA methods. *European Journal of Scientific Research*, 38(3) 386–395.

Pahl-Wostl, C. (2007). Transitions towards adaptive management of water facing climate and global change. *W4ater resources management*, *21*(1), 49-62.

Pahl-Wostl, C. (2009). A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change*, *19*(3), 354-365.

Pahl-Wostl, C., & Knieper, C. (2014). The capacity of water governance to deal with the climate change adaptation challenge: Using fuzzy set Qualitative Comparative Analysis to distinguish between polycentric, fragmented and centralized regimes. *Global Environmental Change*, *29*, 139-154.

Pahl-Wostl, C., Craps, M., Dewulf, A., Mostert, E., Tabara, D., & Taillieu, T. (2007). Social learning and water resources management. *Ecology and Society, 12 (2), 2007*.

Pahl-Wostl, C., Gupta, J., & Petry, D. (2008b). Governance and the global water system: A theoretical exploration. *Global Governance: A Review of Multilateralism and International Organizations, 14*(4), 419-435.

Pahl-Wostl, C., Holtz, G., Kastens, B., & Knieper, C. (2010). Analyzing complex water governance regimes: the management and transition framework. *Environmental Science & Policy*, *13*(7), 571-581.

Pahl-Wostl, C., Lebel, L., Knieper, C., & Nikitina, E. (2012). From applying panaceas to mastering complexity: toward adaptive water governance in river basins. *Environmental Science & Policy*, *23*, 24-34.

Pahl-Wostl, C., Mostert, E., & Tàbara, D. (2008a). The growing importance of social learning in water resources management and sustainability science. *Ecology and Society*, *13*(1), 24.

Pahl-Wostl, C., Vörösmarty, C., Bhaduri, A., Bogardi, J., Rockström, J., & Alcamo, J. (2013). Towards a sustainable water future: shaping the next decade of global water research. *Current Opinion in Environmental Sustainability*, *5*(6), 708-714.

Parker, C. (2009). Administrative law in Namibia, its current state, challenges, and proposals for law reform. Comparative and International Law Journal of Southern Africa, 42(1), 115-127.

Parkinson, J., & Mark, O. (2005). *Urban stormwater management in developing countries*. IWA publishing.

Patton, M. Q. (2002). *Qualitative research and evaluation methods* (3rd ed.). London: Sage Publications.

Payment, P., Waite, M., & Dufour, A. (2003). Introducing parameters for the assessment of drinking water quality. *Assessing microbial safety of drinking water, 47*.

Pejman, A. H., Bidhendi, G. N., Karbassi, A. R., Mehrdadi, N., & Bidhendi, M. E. (2009). Evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques. *International Journal of Environmental Science & Technology*, *6*(3), 467-476.

Pickett, S. T., Cadenasso, M. L., Grove, J. M., Groffman, P. M., Band, L. E., Boone, C. G., ... & Law, N. L. (2008). Beyond urban legends: an emerging framework of urban ecology, as illustrated by the Baltimore Ecosystem Study. *BioScience*, *58*(2), 139-150.

Qadir, A., Malik, R. N., & Husain, S. Z. (2008). Spatio-temporal variations in water quality of Nullah Aik-tributary of the river Chenab, Pakistan. *Environmental Monitoring and Assessment*, *140*(1-3), 43-59.

Qi, C., & Chang, N. B. (2011). System dynamics modeling for municipal water demand estimation in an urban region under uncertain economic impacts. *Journal of environmental management*, *92*(6), 1628-1641.

Rabenja, A. T., Ratiarison, A., & Rabeharisoa, J. M. (2009). Forecasting of the Rainfall and the Discharge of the Namorona River in Vohiparara and FFT Analyses of These Data. In *Proceedings, 4th International Conference in High-Energy Physics, Antananarivo, Madagascar* (pp. 1-12).

Rahaman, M. M., Varis, O., & Kajander, T. (2004). EU water framework directive vs. integrated water resources management: The seven mismatches. *International Journal of Water Resources Development*, *20*(4), 565-575.

Ramalho, R. (2012). *Introduction to wastewater treatment processes*. Elsevier.

Rauschmayer, F., Berghöfer, A., Omann, I., & Zikos, D. (2009). Examining processes or/and outcomes? Evaluation concepts in European governance of natural resources. *Environmental Policy and Governance*, *19*(3), 159-173.

Renzetti, S. (Ed.). (2002). *The economics of industrial water use*. Edward Elgar.

Rogers, P. (2002). Water Governance in Latin America and the Caribbean, Brazil, Inter-American development Bank.

Rogers, P., & Hall, A. W. (2003). *Effective water governance* (Vol. 7). Stockholm: Global Water Partnership.

Rosenberg, D. E., T. Tarawneh, R. Abdel-Khaleq, and J. R. Lund (2007), Modeling integrated water user decisions in intermittent supply systems, Water Resour. Res., 43, W07425, doi:10.1029/2006WR005340.

Rothman, D. W., & Mays, L. W. (2013). Water resources sustainability: Development of a multiobjective optimization model. Journal of Water Resources Planning and Management, 140(12), 04014039.

Ruppel, O.C., & Ruppel-Schlichting K. (2011). Environmental Law and Policy in Namibia, Legal Research and Development Trust of Namibia, Windhoek.

Rutashobya, D. G., & Wellens-Mensah, J. (2002). SADC-HYCOS Evaluation Mission Report. *Gaborone: South African Development Community*.

Saleth, R. M. & Dinar, A. (2004). The institutional economics of water: a cross-country analysis of institutions and performance, Edward Elgar, Cheltenham, UK.

Salgado, P. P., Quintana, S. C., Pereira, A. G., del Moral Ituarte, L., & Mateos, B. P. (2009). Participative multi-criteria analysis for the evaluation of water governance alternatives. A case in the Costa del Sol (Malaga). *Ecological economics*, *68*(4), 990-1005.

Sargent, D. J. (2001). Comparison of artificial neural networks with other statistical approaches. *Cancer*, *91*(S8), 1636-1642.

Savage, C., Leavitt, P. R., & Elmgren, R. (2010). Effects of land use, urbanization, and climate variability on coastal eutrophication in the Baltic Sea. *Limnology and Oceanography*, *55*(3), 1033.

Savenije, H. H. G., & van der Zaag, P. (2008). Integrated water resources management: Concepts and issues. *Physics and Chemistry of the Earth, Parts A/B/C, 33*(5), 290-297.

Scarpa, D. J. (2004). Hydrology: Science and Practice for the 21st Century, *British Hydrological Society, 2*, 147-152.

Schad, T. M. (1998). Water policy: Who should do what. *Water Resources Update*, *111*, 51-61.

Scheren, P. A. G. M., Zanting, H. A., & Lemmens, A. M. C. (2000). Estimation of water pollution sources in Lake Victoria, East Africa: Application and elaboration of the rapid assessment methodology. *Journal of environmental management*, *58*(4), 235-248.

Schneider, U., Becker, A., Finger, P., Meyer-Christoffer, A., Ziese, M., & Rudolf, B. (2014). GPCC's new land surface precipitation climatology based on quality-controlled in situ data and its role in quantifying the global water cycle. *Theoretical and Applied Climatology, 115*(1-2), 15-40.

Scholz, J. T., & Stiftel, B. (Eds.). (2010). *Adaptive governance and water conflict: new institutions for collaborative planning*. Routledge.

Schoumans, O. F., Bouraoui, F., Kabbe, C., Oenema, O., & van Dijk, K. C. (2015). Phosphorus management in Europe in a changing world. *Ambio*, *44*(2), 180-192.

Schutte, F. (2005). Handbook for the operation of water treatment works. The Water Research Commission, The Water Institute of Southern Africa, Pretoria. *Science and Technology, Water Supply*, 3 (4) 1-10.

Scott, C. A., Meza, F. J., Varady, R. G., Tiessen, H., McEvoy, J., Garfin, G. M., ... & Montaña, E. (2013). Water security and adaptive management in the arid Americas. *Annals of the Association of American Geographers*, *103*(2), 280-289.

Seely, M., Henderson, J., Heyns, P., Jacobson, P., Nakale, T., Nantanga, K., & Schachtschneider, K. (2003). Ephemeral and endoreic river systems: Relevance and management challenges. *Transboundary rivers, sovereignty and development: Hydropolitical drivers in the Okavango River basin. Pretoria*.

Serrano, J. D. (2012). Institutional Barriers for Effective Water Governance in Mexico: Study of the Central Gulf Hydrological Administrative Region X. In *Water Resources in Mexico* (pp. 457-472). Springer Berlin Heidelberg.

Shamsnia, S.A., Shahidi, N., Liaghat, A., Sarraf, A., & Vahdat, S.F. (2011). Modeling of weather parameters using stochastic methods (ARIMA Model) (Casestudy: Abadeh Region, Iran). International Conference on Environment and Industrial Innovation, 12 282–285.

Shinana, A. K. (2011). *Identification of nutrient sources causing algae blooms in Swakoppoort Dam*, Unpublished BSc Honours Thesis, University of Namibia, Windhoek Namibia.

Shrestha, S., & Kazama, F. (2007). Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. *Environmental Modelling & Software*, *22*(4), 464-475.

Sievers, P. (2006, January). Zambia Water Sector: Challenges for integrated water resources management in Zambia. In *Danida Water Sector Seminar*.

Singh, K. P., Malik, A., & Sinha, S. (2005). Water quality assessment and apportionment of pollution sources of Gomti river (India) using multivariate statistical techniques—a case study. *Analytica Chimica Acta*, *538*(1), 355-374.

Sirunda, J. J., & Mazvimavi, D. (2014). The Effects of Water Transfer from Swakoppoort and Omatako Dams on the Water Quality of Von Bach Dam, Namibia. In *Combating Water Scarcity in Southern Africa* (pp. 79-118). Springer Netherlands.

Sirunda, J.J. (2010). The Effects of Water Transfer from Swakoppoort and Omatako Damon the Trophic State of the Recipient Von Bach Dam, unpublished Master of Science Thesis, University of Western Cape, RSA.

Smakhtin, V.; Revenga, C.; & Döll, P. (2004). A pilot global assessment of environmental water requirements and scarcity. *Water International*, 29, 307-317.

Smith, A., Ali, M. (2006). Understanding the impact of cultural and religious water use. Water Environmental Journal, 20, 203–209.

Stahre, P. (2006). *Sustainability in urban storm drainage. Planning and examples, Svenskt Vatten*. ISBN 91-85159-20-4.

Stampoulis, D., Anagnostou, E. N., & Nikolopoulos, E. I. (2013). Assessment of high-resolution satellite-based rainfall estimates over the Mediterranean during heavy precipitation events. *Journal of Hydrometeorology, 14*(5), 1500-1514.

Steytler J, (2014, October). Namibia population projections report 2011-2041 press release, *The Namib times*, 7 October 2014.

Stockholm Environmental Institute (2014). WEAP Water Evaluation And Planning system. https://www.sei-international.org/weap

Stockner, J. G., Rydin, E., & Hyenstrand, P. (2000). Cultural oligotrophication: causes and consequences for fisheries resources. *Fisheries*, *25*(5), 7-14.

Swatuk, L. A. (2005a). From "project" to "context": Community based natural resource management in Botswana. *Global Environmental Politics, 5*(3), 95-124.

Swatuk, L. A. (2005b). Political challenges to implementing IWRM in Southern Africa. *Physics and Chemistry of the Earth*, Parts A/B/C, 30(11), 872-880. *Tap*, 46-51.

Tapela, B. N. (2002). The challenge of integration in the implementation of Zimbabwe's new water policy: case study of the catchment level institutions surrounding the Pungwe–Mutare water supply project. *Physics and Chemistry of the Earth, Parts A/B/C, 27*(11), 993-1004.

Thompson, S. E., Harman, C. J., Troch, P. A., Brooks, P. D., & Sivapalan, M. (2011). Spatial scale dependence of ecohydrologically mediated water balance partitioning: A synthesis framework for catchment ecohydrology. *Water Resources Research*, *47*(10).

Torregrosa, T., Sevilla, M., Montaño, B., & López-Vico, V. (2010). The integrated management of water resources in Marina Baja (Alicante, Spain). A simultaneous equation model. *Water resources management*, *24*(14), 3799-3815.

Tortajada, C. (2006). *Water Governance with Equity: Is Decentralisation the Answer? Decentralisation of the Water Sector in Mexico and Intercomparison with Practices from Turkey and Brazil* (No. HDOCPA-2006-15). Human Development Report Office (HDRO), United Nations Development Programme (UNDP).

Tortajada, C. (2010). Water governance: a research agenda. *Water resources development*, *26*(2), 309-316.

Tortajada, C., & Joshib, Y. K. (2013). Water Resources Management and Governance as Part of an Overall Framework for Growth and Development. *International Journal of Water*, *1*, 285-306.

Travel News Namibia (2012, 3 July). Kuiseb Basin Management Committee – the first of its kind in Namibia. Retrieved 7, July 2015 from: *http://www.travelnewsnamibia.com/news/kuiseb-basin-management-200/.*

Tropp, H. (2007). Water governance: trends and needs for new capacity development. *Water Policy*, *9*, 19.

Tsakiris, G., & Alexakis, D. (2012). Water quality models: an overview. *European Water*, *37*, 33-46.

Tsakiris, G., Spiliotis, M., Paritsis, S., & Alexakis, D. (2009). Assessing the water potential of karstic saline springs by applying a fuzzy approach: the case of Almyros (Heraklion, Crete). *Desalination*, *237*(1), 54-64.

Tu, J. V. (1996). Advantages and disadvantages of using artificial neural networks versus logistic regression for predicting medical outcomes. *Journal of clinical epidemiology*, *49*(11), 1225-1231.

Turalam, G.A. & Ilalee, M. (2010). Time series analysis of rainfall and temperature interaction in coastal catchments, *Journal of mathematics and statistics*, 6 (3) 372-380.

Turton, A. R., Hattingh, J., Claassen, M., Roux, D. J., & Ashton, P. J. (2007). Towards a model for ecosystem governance: an integrated water resource management example. In *Governance as a trialogue: Government-society-science in transition* (pp. 1-28). Springer Berlin Heidelberg.

Uhlendahla, T., Salianb, P., Casarottoc, C., & Doetschd, J. (2011). Good water governance and IWRM in Zambia: challenges and chances. *Water Policy*, *13*(6), 845-862.

UNDP Water Governance Facility 2007.

UNDP Water Governance Facility, 2013.

UNDP Water Governance Facility, 2014.

United Nations Environment Programme (2010). Improving the Quantity, Quality and Use of Africa's Water, Retrieved 13 March 2012 from: *na.unep.net/atlas/africaWater/.../africa_water_atlas_123-174.pdf.*

United Nations, Department of Economic and Social Affairs, Population Division (2014). *World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352). (Accessed 4 August 2015)*

United States Environmental Protection Agency [USEPA] (2005). Water and energy savings from high efficiency fixtures and appliances in single family homes. USEPA, Washington.

Jac/van der Gun. (2012). *Groundwater and global change: trends, opportunities and challenges*. UNESCO.

van der Merwe, B. F. (1999). Report of the Namibian Ministry of Agriculture. *Water and Rural Development and City Engineer (Water Services) City of Windhoek to the International Conservation Union on Water Demand Management, Country Study Namibia.*

van der Zaag, P., & Savenije, H. H. (2000). Towards improved management of shared river basins: lessons from the Maseru Conference. *Water Policy*, *2*(1), 47-63.

Van Rensburg, F. (2006). *Urban water security in the city of Windhoek* (Doctoral dissertation, Stellenbosch: Stellenbosch University).

Vedachalam, S., & Mancl, K. M. (2010). Water Resources and Wastewater Reuse: Perceptions of Students at the Ohio State University. *The Ohio Journal of Science*, *110*(5), 104-113.

Videira, N., Antunes, P., Santos, R., & Lobo, G. (2006). Public and stakeholder participation in European water policy: a critical review of project evaluation processes. *European Environment*, *16*(1), 19-31.

Vogel, R. M., Rudolph, B. E., & Hooper, R. P. (2005). Probabilistic behavior of water-quality loads. *Journal of Environmental Engineering*, *131*(7), 1081-1089.

Walker, B. L., L. H. Gunderson, A. Kinzig, C. Folke, S. Carpenter, and L. Schultz (2006), A handful of heuristics and some propositions for understanding resilience in social-ecological systems, *Ecol. Soc*., 11(1), 13.

Wang, X., & Yin, Z. Y. (1997). Using GIS to assess the relationship between land use and water quality at a watershed level. *Environment International*, *23*(1), 103-114.

Wang, Y., & 王雨. (2014). The embeddedness of governing the commons: a game theoretic perspective on cooperation, coordination and trust in water sharing interactions. *HKU Theses Online (HKUTO)*.

Wanielista, M., Baldassari, T., Ryan, P., Rivera, B., Shah, T., & Stuart, E. (2008). Feasibility Study of Waste Tire Use in Pollution Control for Stormwater Management, Drainfields and Water Conservation in Florida. *Seminole County Florida and State DEP*.

Water quality guidelines for South Africa, First Edition 1996.

Watkins, K. (2006). Human Development Report 2006-Beyond scarcity: Power, poverty and the global water crisis. *UNDP Human Development Reports (2006)*.

Wegner, T. (2010). *Applied business statistics: Methods and Excel-based applications*. Juta and Company Ltd, South Africa.

Wentz, E. A., & Gober, P. (2007). Determinants of small-area water consumption for the city of Phoenix, Arizona. *Water Resources Management*, *21*(11), 1849-1863.

Wiek, A., & Larson, K. L. (2012). Water, people, and sustainability—a systems framework for analyzing and assessing water governance regimes. *Water Resources Management*, *26*(11), 3153-3171.

Williams, R. (1997). Water Reuse-a Global Perspective. *Australasian Pollution and Waste Management*, *3,* 46-49.

Wong, J. S., Zhang, Q., & Chen, Y. D. (2010). Statistical modeling of daily urban water consumption in Hong Kong: Trend, changing patterns, and forecast. *Water resources research*, *46*(3).

World Bank (2002). *Upgrading of low income settlements,* country assessment report, Namibia

World Bank (2007). *Atlas of Global Development*. Glasgow Harper Collins.

World Bank (2015). Gini Index (World Bank Estimate), World Bank POVCAL data Accessed October 2015 from: *http://iresearch.worldbank.org/PovcalNet/index.htm?2*.

World Health Organization. (2008). *Guidelines for drinking-water quality [electronic resource]: incorporating 1st and 2nd addenda, vol. 1, Recommendations*. World Health Organization. Retrieved 24 May 2014 http://apps.who.int/iris/bitstream/10665/204411/1/9789241547611_eng.pdf

World Meteorological Organization (wmo) Extranet (2015) accessed 20 August 2015,| www.wmo.int.

Wright, R. T., & Nebel, B. J. (2005). *Environmental science*. Pearson Custom Publishing.

Yang, H., Faramarzi, M., & Abbaspour, K. C. (2013). Assessing freshwater availability in Africa under the current and future climate with focus on drought and water scarcity. In *Proceedings of the 20th International Congress on Modeling and Simulation, Adelaide, Australia* (pp. 1-6).

Yates, D., Purkey, D., Sieber, J., Huber-Lee, A., Galbraith, H., West, J., ... & Rayej, M. (2009). Climate driven water resources model of the Sacramento Basin, California. *Journal of Water Resources Planning and Management*, *135*(5), 303-313.

Yilmaz, B., and Harmancioglu, N.B. (2010). Multicriteria decision making for water resources management: A case study of the Gediz river basin, Turkey, *Water SA* (5) 563-576.

Yin, R. K. (2003). *Case study research: design and methods*. 3rd ed. Applied social research methods series vol.5. London: Sage Publications.

Zaaruka, B. P., & Fedderke, J. W. (2011). Measuring Institutions: Indicators of Political and Economic Institutions in Namibia: 1884-2008 (No. 236).

Zhang, H. H., & Brown, D. F. (2005). Understanding urban residential water use in Beijing and Tianjin, China. *Habitat International*, *29*(3), 469-491.

Zhang, Z. Z., Wang, L., Jiang, R. X., LIU, Z., & Zhang, L. (2006). Practicable process option for small towns wastewater treatment [J]. *Water Sciences and Engineering Technology*, *6*, 022.

ANNEX 1 Wastewater Discharge regulations in the USB

Information required by DWAF for each Discharge Permits Application (MAWF, 2012)

WASTEWATER TREATMENT AND EFFLUENT DISPOSAL PERMIT

(a)

INTRODUCTION
- Name of applicant
- Responsible person: full name and telephone number
- Postal Address
- Type of Establishment
- Method of disposal

PREVIOUS PERMITS
- Type of permit
- Date of issue
- Date of expiry
- Duration period

PERMIT APPLICATION
- Application in terms of which sections
- Type of wastewater treated water produced
- Type of effluent disposal
- Type of sludge treatment
- Type of sludge disposal

SOURCES OF WATER SUPPLY
- Type: River, Borehole (how many)
- Is the water treated
- Supplier abstraction permit
- Quantity and quality of water received
- Industrial water or domestic water
- Quantity per capita
- Places of distribution

OBJECTIVES
- To regulate the disposal of effluent produced
- To focus on the rational use of water in Namibia
- To prevent groundwater pollution from the effluent on disposal of site.
- To encourage the conservation and re-use of water

To encourage efficient and effective water use through water demand management

WATER MANAGEMENT: REGIONAL AND EFFICIENT USE
- Water balances (reticulation system, sewerage system, wastewater treatment and disposal)
- Water metres in place
- Water saving devices
- Level of awareness
- Abstraction Management Plan
- Water Management Plan

Water conservation measures
- Method use to clean vehicle
- Unaccounted for water (whether known)

BACKGROUND

Location and Geographical Data
- Region
- Jurisdictional Area
- GPS data (co-ordinates)
- Temperature
- Evaporation
- Rainfall
- Distance of system to the source of water supply, household etc.
- Prevailing wind direction

Population
- Total number
- Number connected to the serving system

WATER PURIFICATION PROCESS (Potable)

Number of purification systems for the same catchments area
Kind of system
Process flow diagram
Process description
Chemicals used
- Type of chemical
- Amount and Process of dosage
- Frequency of dosage

Operation of the system

Information required by DWAF for each Discharge Permits Application (MAWF, 2012)

- **Technical details**
  - Quantity of water supply per day or month m3
  - Design capacity
  - Average Dry Weather flow
  - Site plan of; water purification area in relation to source of abstraction or watercourse and distribution points.
  - Lay out plan of the system with all dimensions and capacities.
  - Places and amounts of distributions

Water distribution network
- Places and capacities of distributions
- distances of distributions

Process evaluation
Water Balance
- Water balance around the catchments area
- Water balance around the purification process
- Water balance around the water supply network

Drinking Water quality assessment
- Performance efficiency through final product quality assessment

Wastewater Produced

i) Type of effluent produced (Wash water, Brine etc)
ii) Wastewater and effluent disposal exemption permit
iii) Type of treatment system
iv) Process flow diagram
v) Process description
vi) Chemical used
vii) Operation of the system

Technical details
a. Quantity of wastewater disposed every day or month m3
b. Flow measurements: Average Dry Weather Flow (ADWF), Peak Wet Weather Flow (PWWF), Design Capacity
c. Design flow
d. Site plan of; wastewater treatment area, irrigation area and point of final disposal in relation to watercourse.
e. Lay out plan of the system with all dimensions and capacities.

viii) Process evaluation
ix) Water Balance
- *Water balance around the wastewater treatment system*

x) Effluent quality assessment
- *Performance efficiency through final product quality assessment*

xi) Final effluent disposal
- *Method of disposal; evaporation , irrigation, soakaway, into a river course*
- *Total quantity*

xii) If irrigation

(b)
- *Method of irrigation*
- *Type of crops irrigated*
- *Size of irrigated area in hectares*
- *Permit for irrigation*
- *Quantity and quality of irrigation water*

ii) Sludge disposal
- *Frequency of desludging*
- *Quality evaluation*
- *Quantity generated*
- *Method of disposal*
- *Shortcomings/challenges*

iii) Other products
iv) Measures taken to prevent pollution
v) Final effluent disposal
  - *Method of disposal; evaporation , irrigation, soak away, into a river course*
  - *Total quantity*

vi) If evaporation
  - *Type of lining applied*

vii) If irrigation
  - *Method of irrigation*
  - *Type of crops irrigated*
  - *Size of irrigated area in hectares*
  - *Permit for irrigation*
  - *Quantity and quality of irrigation water*

xviii) Measures taken to prevent pollution

Solid Waste
- Size of the site
- Responsible authority
- Frequency of removal
- Type of waste
- Final disposal method: buried, burned, mixed etc.
- Shortcomings/challenges

WASTEWATER TREATMENT PROCESS (effluent)

Number of treatment systems
Kind of system
Process flow diagram
Process description
Chemical used
Operation of the system

- **Technical details**
  - Quantity of wastewater disposed every day or month m3

Information required by DWAF for each Discharge Permits Application (MAWF, 2012)

- Flow measurements: Average Dry Weather Flow (ADWF), Peak Wet Weather Flow (PWWF), Design Capacity
- Design flow
- Site plan of; wastewater treatment area, irrigation area and point of final disposal in relation to watercourse.
- Lay out plan of the system with all dimensions and capacities.

Process evaluation
Water Balance
- Water balance around the water reticulation and sewerage system
- Water balance around the wastewater treatment plant

Effluent quality assessment
- Performance efficiency through final product quality assessment

Final effluent disposal
- Method of disposal; evaporation , irrigation, soak away, into a river course
- Total quantity

If irrigation
- Method of irrigation
- Type of crops irrigated
- Size of irrigated area in hectares
- Permit for irrigation
- Quantity and quality of irrigation water

Sludge disposal
- Frequency of desludging
- Quality evaluation
- Quantity generated
- Method of disposal
- Shortcomings/challenges

Solid Waste
- Size of the site
- Responsible authority
- Frequency of removal
- Type of waste
- Final disposal method: buried, burned, mixed etc.
- Shortcomings/challenges

Other products
Measures taken to prevent pollution

(c) **RELEVANT REGULATIONS OF COMPLIANCE**
- MET Policy
- Ministry of Health and Social Service
- Ministry of Mines
- Legal Authorities
- P.T.O.
- Title Act

INVESTIGATIONS
- Frequency of site visits
- Format of information received(yearly report)
- Frequency of report back from permit holder
- Information received from permit holder
- Any irregularities
- The responsible person, rank

FUTURE DEVELOPMENT
- Envisaged future expansion
- Kind of expansion
- The magnitude of expansion
- Quantity of wastewater increase
- By when the process will be increased

DECOMMISSIONING
- Decommissioning plan for all wastewater treatment plants applied for
- Decommissioning of water purification plants applied for

ANNEX 2 Windhoek Municipality Effluent Discharge Regulations (Government of the Republic of Namibia [GRN], 2010).

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Limits on the concentration of some physical and chemical pollutants – Industries draining to Ujams Treatment Plant.

Parameter	Range & Limits		Base Value	Unit
	Min.	Max.		
PHYSICAL				
pH	6	10.5	3	pH unit
Electrical Conductivity (EC) at 20 °C		500	30	mS/m
Suspended Solids (SS)		1000	500	mgSS/l
INORGANIC (NON-METALLIC)				
Cyanide (CN)		20	20	mgCN/l
Sulphides as (S)		50	50	mgSH-S/l
Sulphate as (SO_4)		150	80	mgSO_4/l
Total alkalinity as ($CaCO_3$)		2000	1500	mg/l as$CaCO_3$
METALS (Group 1)				
Cadmium as (Cd)		20	20	mgCd/l
Chromium as (CrO_3)		20	20	mgCrO_3/l
Cobalt as (Co)		20	20	mgCo/l
Copper as (Cu)		20	20	mgCu/l
Iron as (Fe)		50	50	mgFe/l
Manganese as (Mn)		20	20	mgMn/l
Nickel as (Ni)		20	20	mgNi/l
Zinc (Zn)		20	20	mgZn/l
Total metals (Excluding Iron and Sodium)		50	50	Tot.Metals1/l
METALS (Group 2)				
Arsenic as (As)		5	5	mgAs/l
Lead as (Pb)		5	5	mgPb/l
Mercury as (Hg)		5	5	mgHg/l
Selenium as (Se)		5	5	mgSe/l
Total metals (Group 2)		20	20	Tot.Metals2/l
IMPORTANT BIOLOGIC TREATMENT POLLUTANTS				
Chemical Oxygen Demand (COD)		5000	5000	mgCOD/l
Total Kjeldahl Nitrogen as (N)		120	120	mgN/l
Total Phosphate as P		35	35	mgP/l
Anionic surface active agents		500	500	mgASAA/l
Fats, Oil & Grease		2000	2000	mg/l
Formaldehyde as (HCHO)		50	50	mgHCHO/l
Phenol		5	5	mgPhenol/l

Limits on the concentration of some physical and chemical pollutants – Industries draining to Gammams Water Care Works.

Parameter	Range & Limits		Base Values	Unit
	Min.	Max.		
PHYSICAL				
pH	6.5	9.5	3	pH unit
Electrical Conductivity (EC) at 20 °C		80	30	mS/m
Suspended Solids (SS)		200	500	mgSS/l

Windhoek Municipality Effluent Discharge Regulations Continued.

INORGANIC (NON-METALLIC)				
Bromine		0.5		mgBr/l
Cyanide (CN)		0.2	20	mgCN/l
Flouride		2		mgF/l
Sulphides as (S)		25	50	mgSH-S/l
Sulphate as (SO_4)		100 above influent	80	mgSO_4/l
Free Chlorine as (Cl_2)		1		mgOCl-/l
Total alkalinity as ($CaCO_3$)		500	1500	mg/l as$CaCO_3$
METALS (Group 1)				
Cadmium as (Cd)		0.5	20	mgCd/l
Chromium as (CrO_3)		0.5	20	mgCrO_3/l
Cobalt as (Co)		0.5	20	mgCo/l
Copper as (Cu)		1	20	mgCu/l
Boron		0.5	50	mgB/l
Iron as (Fe)		10	20	mgFe/l
Manganese as (Mn)		5	20	mgMn/l
Nickel as (Ni)		4	20	mgNi/l
Zinc (Zn)		5	50	mgZn/l
Total metals (Excluding Iron and Sodium)		20	50	Tot.Metals1/l
METALS (Group 2)				
Arsenic as (As)		0.25	5	mgAs/l
Lead as (Pb)		2	5	mgPb/l
Mercury as (Hg)		0.005	5	mgHg/l
Selenium as (Se)		0.5	5	mgSe/l
Silver		0.1		mgAg/l
Total metals (Group 2)		10	20	Tot.Metals2/l
IMPORTANT BIOLOGIC TREATMENT POLLUTANTS				
Chemical Oxygen Demand (COD)		900	500	mgCOD/l
Total Kjeldahl Nitrogen as (N)		100	120	mgN/l
Total Phosphate as P		10	35	mgP/l
Anionic surface active agents		300	500	mgASAA/l
Fats, Oil & Grease		500	2000	mg/l
Formaldehyde as (HCHO)		10	50	mgHCHO/l
Phenol		5	5	mgPhenol/l

D Radio-active pollutants

The Council reserves the right to limit or prohibit the total mass of any radioactive substance discharged within 24 hours into the sewers from any premises.

Windhoek Municipality Effluent Discharge Regulations Continued.

C Penalty for exceeding Limits on the concentration of some physical and chemical pollutants – Industries draining to Ujams Water Care Works.

An additional tariff is payable with respect to industrial effluents exceeding the minimum and/ or maximum concentration of the measured items listed below. The specific charge for each item is different and depends on its relative effect on the wastewater treatment process as well as the subsequent reclaim potential of the treated wastewater. The formula used for calculating a specific penalty charge as per the formula set out hereunder.

$$L_3 = \frac{Q_i \cdot (UnitCost) \cdot (P_i - Limit_i)}{BaseUnit_i}$$

Base Unit - determines how much the concentration of a particular pollutant is exceeding the predetermined concentration limit or range. The base unit is used to adjust the charge for a specific pollutant.

Unit Cost – disincentive cost unit is a unit cost that applies to each base unit that a specific pollutant is exceeding a specific concentration limit or range. This disincentive cost unit is used to adjust the charge for all selected pollutants.

P_i – is the average parameter concentration of the sample originating from the relevant premises, as determined for the relevant month measured.

$Limit_i$ – is the Limit/Standard for the different parameters as determined for the different Municipal Treatment Works as per Limit/Standards tables hereunder.

Incentive discount rate determination for the treatability of certain qualifying industrial effluents.

Treatability of industrial effluents based on TKN:COD ratio

Meaning	**TKN/COD range: Min**	**Max**	**%Discount**
Excellent	0.000	0.029	α
Good	0.040	0.059	β
Average	0.060	0.089	0
Poor	0.090	0.120	0
Very Poor	> 0.12		

The values of α and β are reviewed and updated by the City of Windhoek at own discretion.

ANNEX 3 Okahandja Municipality Effluent Discharge Tariffs and approaches (Government of the Republic of Namibia [GRN], 2008a)

No. 372 Okahandja Municipality: Determination of charges, fees, rates and other monies

11	**SEWERAGE**		
11.1	Basic - any site, building site or piece of land with or without improvements where sewerage connections are available		
	Monthly		
	For the first 1500m² or part thereof	35.00	40.25
	For every additional 1000m² or part thereof	15.00	17.25
	Maximum		
11.2	**Unit Levy**	100.00	115.00
11.2.1	Private Houses and Flats	30. 00	34.50
11.2.2	Church and Halls	25.00	28.75
11.2.3	Schools, Colleges, Hostels for Every 10 Students or part thereof	45.00	51.75
11.2.4	Hotel: for every 4 rooms	110. 00	126.50
11.2.5	Business Offices and Hospitals: for every W.C.	30.00	34.50
11.2.6	Abattoir	1280.00	1472.0
11.2.7	Jail and Police Stations for every W.C.	25.00	28.75
11.2.8	Meat Processing Factory	2300.00	2645.00
11.2.9	Bone and Creamery Factory	850.00	977.50
11.2.10	Industries, Workshops for every W.C.	50.00	57.50
11.2.11	Sport and Showgrounds for every W.C.	17.00	19.55
11.2.12	All other sites	23.00	26.45
11.3	**Factories and Industrial Effluent**		
	The Levy in cent per cubic meter must be calculated as follows:		
11.3.1	A) P.W. less than 250mg/1 effluent levy	PW x 0.14 per m³	PW x 0.16 per m³
11.3.2	B) P.W. above 250mg/1 effluent levy	0.22 + 0.40 per m³	0.22 + 0.46 per m³
11.3.3	A) Kjeldal N equivalent or less than 150mg/1 effluent levy	N x 17 per m³	N x 20 per m³
11.3.4	B) Kjeldal N above 150mg/1 effluent levy	(N-150) x .27 + 0.32 per m³	(N-150) x .27 + 0.37 per m³
The above formula is as follows: PW= permanganate and = itrogen. In each case the appropriate levy is the highest value calculated in respect of 11.1 and 11.2			

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11.4	**SEWERAGE BLOCKING**		
11 4.1	For the disconnectin and sealing off of a private sewerage from a public sewerage	450.00	517.50
11.4.2	At the request of a consumer to open a blocked drain	211.30	243.00
11.4.3	Connetion fees: private lots/small holdings	795.00	914.25
11.4.4	Pumping	229.60	264.04
11.5	**GENERAL**		
	Fees/monies not specifically provided for - actual cost + 15%		
12	**SAND PER LOAD ON REQUEST**	220.00	253.00
13	**SANITATION**		
13.1	Pump and Tank	229.60	264.04
13.2	Basic Min Levy per month	245.00	281.75

ANNEX 4 R Syntax for Rain Time Series Modelling

```
> library (foreign)
> wrain=read.spss(file.choose(),to.data.frame=T)
> raintimeseries
```

```
> plot.ts(raintimeseries)
> raintimeseriescomponents=decompose(raintimeseries)
> raintimeseriescomponents$seasonal
> plot(raintimeseriescomponents)
> rainseriesforecasts=HoltWinters(raintimeseries,beta=FALSE,gamma=FALSE)
> rainseriesforecasts
> rainseriesforecasts$fitted
> plot(rainseriesforecasts)
> rainseriesforecasts$SSE
>library("TTR")
> raintimeseriesSMA12=SMA(raintimeseries,n=12)
> plot.ts(raintimeseriesSMA12)
> library("forecast")
> rainseriesforecasts2=forecast.HoltWinters(rainseriesforecasts,h=9)
> rainseriesforecasts2
> plot.forecast(rainseriesforecasts2)
> acf(rainseriesforecasts2$residuals)
> acf(rainseriesforecasts2$residuals, lag.max=50)
> Box.test(rainseriesforecasts2$residuals,lag=50,type="Ljung-Box")
> plot.ts(rainseriesforecasts2$residuals)
> library(foreign)
> wrain=read.spss(file.choose(),to.data.frame=T)
> raintimeseries=ts(wrain,frequency=12,start=c(1891,10))
> plot.ts(raintimeseries)
> raintimeseriesdiff1=diff(raintimeseries, differences=1)
> plot.ts(raintimeseriesdiff1)
> acf(raintimeseries)
> raintimeseriesdiff2=diff(raintimeseriesdiff1, differences=1)
> plot.ts(raintimeseriesdiff2)
> acf(raintimeseriesdiff2, lag.max=312)
> acf(raintimeseriesdiff2, lag.max=50)
> acf(raintimeseriesdiff2, lag.max=50, plot=FALSE)
> pacf(raintimeseriesdiff2, lag.max=50)
> library (forecast)
> auto.arima(raintimeseries)
> rainseriesarima=auto.arima(raintimeseries)
> raintimeseriesforecasts=forecast.Arima(rainseriesarima,h=420)
> plot.forecast(raintimeseriesforecasts)
> raintimeseriesforecasts
> acf(raintimeseriesforecasts$residuals, lag.max=312)
> Box.test(raintimeseriesforecasts$residuals,type="Ljung-Box")
> plot.ts(raintimeseriesforecasts$residuals)
> plotForecastErrors(raintimeseriesforecasts$residuals)
```

ANNEX 5 Okahandja Demand Forecasting R syntax

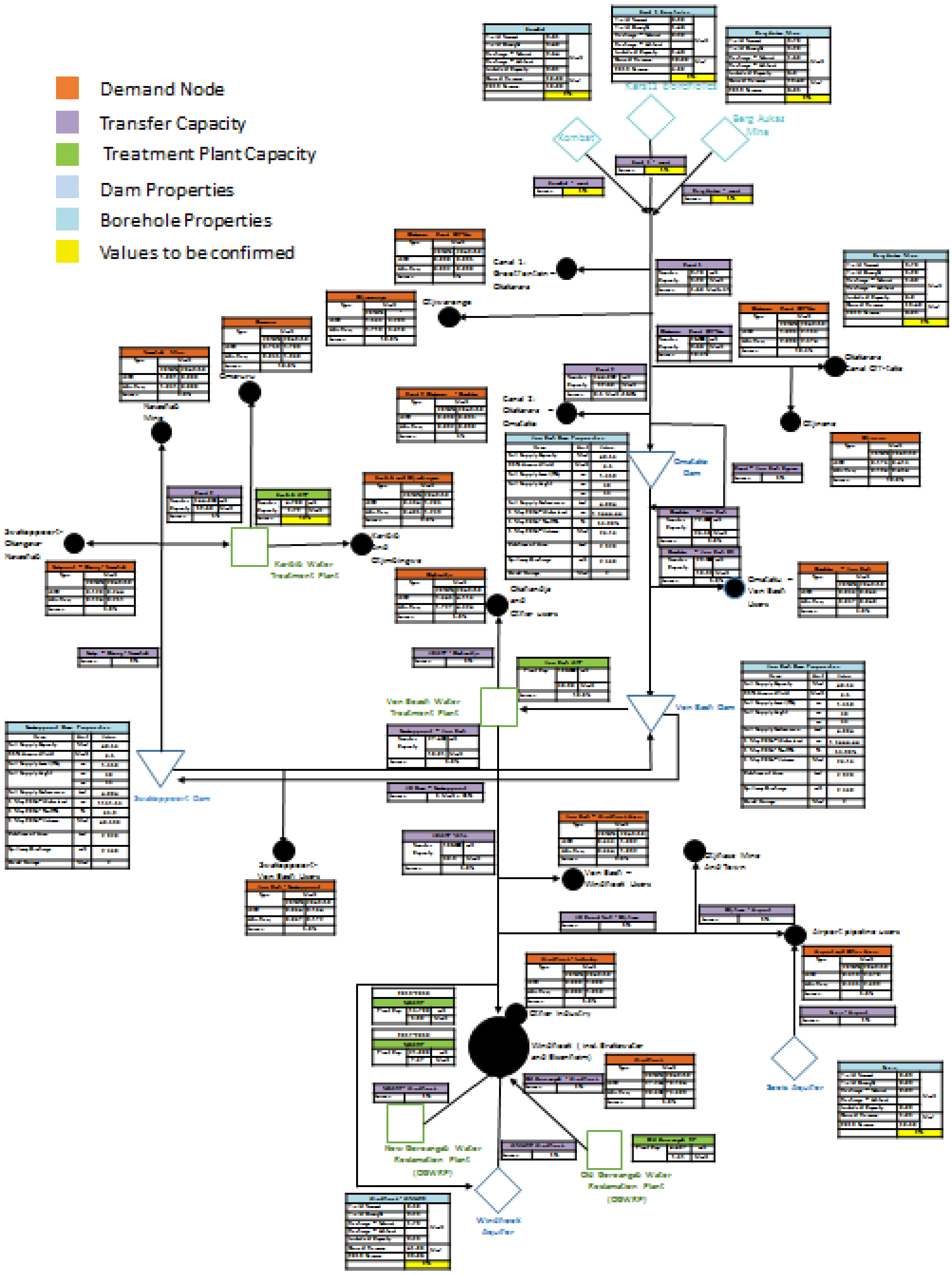
R syntax for Okahandja water demand time series modeling

```
> library(foreign)
x=c(1182489,1136963,1195651,1208160,1220800,1164656,1000476,1043632,1189
470,1255376,1291951,1230833,1394872,1275634,1246347,1390289,1434200)
>Okahandjademand=ts(x,frequency=1,start=c(1998))
> Okahandjademand
> plot.ts(Okahandjademand)
>acf(Okahandjademand)
> Box.test(Okahandjademand,type="Ljung-Box")
> Okahandjademanddiff1=diff(Okahandjademand, differences=1)
> plot.ts(Okahandjademanddiff1)
> acf(Okahandjademanddiff1)
> Box.test(Okahandjademanddiff1,type="Ljung-Box")
> pacf(Okahandjademanddiff1)
> library (forecast)
> auto.arima(Okahandjademand)
> Okahandjademandarima=auto.arima(Okahandjademand)
> Okahandjademandforecasts=forecast.Arima(Okahandjademandarima,h=36)
> plot.forecast(Okahandjademandforecasts)
> Okahandjademandforecasts
> acf(Okahandjademandforecasts$residuals)
> Box.test(Okahandjademandforecasts$residuals,type="Ljung-Box")
> plot.ts(Okahandjademandforecasts$residuals)
> hist(Okahandjademandforecasts$residuals)
>qqnorm(Okahandjademandforecasts$residuals)
```

ANNEX 6 Water demand forecast for the CAN areas up to 2050

Date	Kambazembi (Canal Off-take)	Navachab	Karibib	Okahandja	Windhoek	Windhoek - Industry	Otjihase	Airport Pipeline Users	Canal 1	Canal 2	Omataku - Von Bach Users	Swakoppoort - Von Bach Users	Swakoppoort - Okongava - Nacachab Users	Von Bach Windhoek	Otjiwarongo	Omaruru	Otjinene	total CAN
2013	1.89	1.00	0.39	1.65	27.26	0.00	0.28	0.32	0.09	0.09	0.04	0.06	0.12	0.63	1.56	0.76	0.18	36.32
2014	1.90	1.12	0.41	1.72	27.34	0.20	0.30	0.43	0.08	0.08	0.03	0.08	0.12	0.87	1.53	0.76	0.18	37.15
2015	1.91	1.22	0.49	1.63	29.29	0.40	0.30	0.63	0.08	0.08	0.03	0.10	0.13	0.92	1.57	0.79	0.19	39.76
2016	1.92	1.32	0.60	1.72	30.30	0.60	0.30	0.78	0.08	0.08	0.03	0.13	0.13	1.13	1.61	0.82	0.19	41.75
2017	1.93	1.42	0.69	1.80	31.21	0.80	0.30	0.89	0.08	0.08	0.03	0.14	0.13	1.15	1.66	0.86	0.20	43.36
2018	1.94	1.50	0.75	1.86	32.07	1.00	0.30	1.01	0.08	0.08	0.03	0.15	0.14	1.39	1.70	0.89	0.20	45.10
2019	1.96	1.55	0.78	1.92	32.89	1.00	0.30	1.15	0.08	0.08	0.03	0.15	0.14	1.41	1.75	0.93	0.21	46.32
2020	1.97	1.55	0.94	1.97	33.68	1.00	0.30	1.31	0.08	0.08	0.04	0.16	0.15	1.43	1.79	0.96	0.22	47.62
2021	1.98	1.55	0.96	2.03	34.45	1.00	0.30	1.48	0.08	0.08	0.04	0.16	0.15	1.45	1.83	0.99	0.22	48.74
2022	1.98	1.55	0.97	2.07	35.19	1.00	0.30	1.64	0.08	0.08	0.04	0.16	0.16	1.46	1.88	1.02	0.23	49.81
2023	1.99	1.55	0.99	2.12	35.92	1.00	0.30	1.78	0.08	0.08	0.04	0.16	0.16	1.48	1.93	1.05	0.24	50.86
2024	2.00	1.55	1.00	2.17	36.63	1.00	0.30	1.89	0.08	0.08	0.04	0.16	0.17	1.50	1.98	1.08	0.24	51.87
2025	2.01	1.55	1.02	2.21	37.33	1.00	0.30	1.97	0.08	0.08	0.04	0.16	0.17	1.52	2.03	1.11	0.25	52.84
2026	2.02	1.55	1.03	2.25	38.02	1.00	0.30	2.02	0.08	0.08	0.04	0.16	0.18	1.54	2.09	1.15	0.26	53.77
2027	2.02	1.55	1.05	2.29	38.71	1.00	0.30	2.06	0.08	0.08	0.04	0.16	0.18	1.56	2.15	1.18	0.27	54.69
2028	2.03	1.55	1.06	2.33	39.38	1.00	0.30	2.08	0.09	0.09	0.04	0.16	0.19	1.59	2.20	1.22	0.28	55.58
2029	2.04	1.55	1.08	2.37	40.04	1.00	0.30	2.10	0.09	0.09	0.04	0.16	0.19	1.61	2.26	1.25	0.28	56.46
2030	2.05	1.55	1.10	2.41	40.70	1.00	0.30	2.12	0.09	0.09	0.05	0.16	0.20	1.63	2.32	1.29	0.29	57.35
2031	2.06	1.16	1.10	2.45	41.35	1.00	0.30	2.15	0.09	0.09	0.05	0.16	0.21	1.66	2.37	1.32	0.30	57.80
2032	2.06	0.78	1.11	2.49	41.99	1.00	0.30	2.18	0.09	0.09	0.05	0.16	0.21	1.67	2.42	1.34	0.30	58.23
2033	2.07	0.39	1.12	2.53	42.63	1.00	0.30	2.21	0.09	0.09	0.05	0.16	0.21	1.68	2.47	1.37	0.31	58.65
2034	2.07	0.00	1.12	2.56	43.27	1.00	0.30	2.24	0.09	0.09	0.05	0.16	0.21	1.68	2.52	1.40	0.32	59.08
2035	2.08	0.00	1.13	2.60	43.90	1.00	0.30	2.27	0.09	0.09	0.05	0.16	0.21	1.69	2.57	1.42	0.32	59.88
2036	2.09	0.00	1.13	2.63	44.52	1.00	0.30	2.30	0.09	0.09	0.05	0.16	0.22	1.70	2.62	1.45	0.33	60.67
2037	2.09	0.00	1.14	2.67	45.14	1.00	0.30	2.33	0.09	0.09	0.05	0.16	0.22	1.70	2.67	1.48	0.34	61.47
2038	2.10	0.00	1.15	2.70	45.76	1.00	0.30	2.37	0.09	0.09	0.05	0.16	0.22	1.71	2.72	1.51	0.34	62.27
2039	2.10	0.00	1.15	2.74	46.37	1.00	0.30	2.40	0.09	0.09	0.05	0.16	0.22	1.72	2.78	1.54	0.35	63.06
2040	2.11	0.00	1.16	2.77	46.98	1.00	0.30	2.43	0.09	0.09	0.05	0.16	0.22	1.72	2.83	1.57	0.36	63.85
2041	2.12	0.00	1.17	2.80	47.59	1.00	0.30	2.44	0.09	0.09	0.05	0.16	0.23	1.73	2.88	1.59	0.36	64.60
2042	2.12	0.00	1.17	2.84	48.19	1.00	0.30	2.46	0.09	0.09	0.05	0.16	0.23	1.74	2.92	1.61	0.37	65.33
2043	2.12	0.00	1.17	2.87	48.79	1.00	0.30	2.47	0.09	0.09	0.05	0.16	0.23	1.75	2.96	1.63	0.37	66.07
2044	2.13	0.00	1.18	2.90	49.39	1.00	0.30	2.49	0.09	0.09	0.05	0.16	0.23	1.75	3.01	1.66	0.38	66.80
2045	2.13	0.00	1.18	2.93	49.99	1.00	0.30	2.50	0.09	0.09	0.05	0.16	0.23	1.76	3.05	1.68	0.38	67.54
2046	2.14	0.00	1.19	2.97	50.58	1.00	0.30	2.51	0.09	0.09	0.05	0.16	0.24	1.77	3.10	1.70	0.39	68.27
2047	2.14	0.00	1.19	3.00	51.17	1.00	0.30	2.53	0.09	0.09	0.05	0.16	0.24	1.78	3.15	1.72	0.40	69.00
2048	2.14	0.00	1.19	3.03	51.76	1.00	0.30	2.54	0.09	0.09	0.05	0.16	0.24	1.79	3.19	1.74	0.40	69.73
2049	2.15	0.00	1.20	3.06	52.35	1.00	0.30	2.56	0.10	0.10	0.05	0.16	0.24	1.79	3.24	1.77	0.41	70.46
2050	2.15	0.00	1.20	3.09	52.93	1.00	0.30	2.57	0.10	0.10	0.05	0.16	0.24	1.80	3.29	1.79	0.41	71.18

ANNEX 7 Simplified Schematic with Basic/Baseline Supply and Demand Inputs fed into the WEAP Model (see print on A3.)



ANNEX 8 Stakeholder/Public Views and Perceptions on Water Reuse for Drinking: Questionnaire

Water reuse is recycled water that is separated from waste water and highly treated so that it can be used again. Water reuse is being practised in Namibia, in particular, Windhoek. This is because fresh water resources are scarce in this semi-arid country. This research survey investigates the social, health and ethical perspectives of water reuse in Windhoek. This questionnaire is anonymous and is aiding a Unam Student research topic on water governance in the Upper Swakop Basin.

A: Demographic Information

A1.**Gender**: 1. Male 61 2.Female

A2. **Age group** (years) 1.18 to 24 25.3% 2. 25 to34 3. 35 to 44 4. 45 t0 54 5. 55 and above

A3 **Race** 1. Black 2. White 3. Coloured 4. Other

A4. **Religion** 1. Atheist 2. Catholic 3. Protestants 4. Other

A5. **Education** 1. No formal education 2. Primary 3. Secondary 4. Tertiary

A6. **Occupation** 1. Student 2. General worker 3. Professional 4. Other

A7. **Household size** (number) 1. One 2. Two 3. Three 4. Four 5. Five 6. More than five

A8. **Income category (per month NAD**) 1. < 1000 2. Between 1001 and 5000 3. 5001-20000 4. Above 20 000.

A9.On average how much do you pay for your water per month (NAD)………………………………………..?

A10 **Residential Suburb**:

B: Knowledge of water resources and uses

B1. **Who supplies the drinking water for your home?**

1. Windhoek Municipality 2. NamWater 3. Drink Bottled Water 4. Other

B2. Do you know from which drinking water sources you are supplied?

1. Ground water (Windhoek aquifer and Grootfontein areas) 2 Dams (Von Bach, Swakoppoort, Omatako) 3. WINGOC Reclamation plant (Grey and Black Water Reuse from Gammams Wastewater Treatment Plant) 4. Don't know

B3. How familiar are you with the concept of reusing purified water from waste water treatment plants? Please circle your degree of familiarity.

Not familiar 1 2 3 4 5 Very familiar

B4. Do you think there is need to reuse purified water from waste water treatment plants for drinking in Windhoek 1. Yes 2. No

B5. Please indicate with a tick how familiar you are with the following terms

	Never heard of the term at all	Heard the term but don't know its meaning	Know what the term means
Potable water			
Waste Water			
Grey water			
Reclaimed water			

Black water			
Storm water			
Aquifer Recharge			
Non-potable water			

B6 Please indicate which uses of purified water from sewage treatment plants would be acceptable and not acceptable to you

Uses	Not Acceptable	Maybe	Yes, Acceptable	Don't know
Agricultural Irrigation				
Food crops				
Non-food crops				
Commercial nurseries				
Landscape irrigation				
Industrial parks				
Golf courses				
Public parks				
School grounds				
Industrial and Commercial				
Cooling power plants				
Mixing concrete				
Dust control				
Car washes				
Municipal				
Fire fighting				
Flashing waste water pipes				
Recreational				
Swimming pools				
Maintaining fountains				
Environmental restoration				
Wetland enhancement				
Fisheries				
Household				
Toilet flushing				
Lawn and garden watering				
Washing cars				
Swimming pools				

B7. Recycled drinking water is pure and safe. It is a product of natural process and human ingenuity. Scientists and engineers discovered how rivers, springs, ground and

sunlight purified water and re-created the same processes as water treatment facilities and minimized the variation and risks in the natural processes. They install multiple barriers and warnings to stop health hazard water from reaching peoples' houses. The result is pure safe recycled drinking water. Assuming recycled water from a municipal water treatment plant has been provided to you. This water is certified as safe by a panel of water scientists from the municipality and has a good taste. On a scale of 0 to 10, how willing are you to use this water for each different application listed below:
Please rate your willingness on a scale of 0 to 10

a. How willing are you to use this water to irrigate your vegetables? …….
b. How willing are you to use this water for lawns in a park where children play? ….
c. How willing are you to use this water as drinking water for your pets? ….
d. How willing are you to use this water for bathing and showering? ….
e. How willing are you to use this water for cooking?
f. How willing are you to use this water for drinking yourself and your family?
g. How willing are you to drink one part of this water mixed with four parts water from ground water and dams……

B8. What would happen if you had no choice but to drink recycled water (i.e. certified water?)

A. Of course I would drink it to stay alive
B. I would start buying bottled water
C. I would buy a filter and put it on my tap

B9 Answer the following Questions

	Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
I trust that treated water use from a sewerage treatment plant can be placed under adequate controls through appropriate regulation.					
Corporations and Municipalities that operate water treatment plants are aware of their responsibilities and can be trusted					
Authorities and Municipalities cannot sufficiently monitor whether water purification plants uphold legal regulations standards and restrictions					
Engineers and scientist working in the field of purifying sewage water for drinking are hardly able to predict the health consequences of their work/research.					
Technology for purifying sewage water for drinking is like any other technology. The risks should not be over-stigmatized and over dramatized					

Being assured by the Municipal/ Water Corporation I trust that my water is safe to drink is more important than given all the facts.					

B10 Drinking water treated from sewage water by municipality or a water corporation should be certified by: Circle your best answer.

1 Water treatment plant staff only

2 state government engineers /inspectors

3 manager of the water treatment plant

4 qualified scientist of Local Universities like UNAM and Polytechnic of Namibia

5 doctors from the ministry of health

6 A board made up of experts that include (engineers, doctors, scientist and general public representative including the media personnel

7 all of the above

B11. Due to growing population, fresh water availability and quality of drinking water is becoming a key concern. Which of the following strategies do you think can be adopted to improve water security and sustainability of sources for Windhoek?

1. Reduce water losses and wastages at household level and on the public water network.
2. Improve catchment management to lessen pollution of fresh water sources
3. Improve technology and monitoring barriers and checks on treating sewage water for water reuse for drinking
4. Use waste water reuse for all other uses other than drinking

B12. Irrespective of scientific and engineering based considerations, public perceptions to accept the drinking water from a water reuse plant that surpasses drinking water standards are shaped and influenced by: Tick your best response

1. historical or anecdotal information
2. visual imagery / disgusting factor
3. prejudicial beliefs –fears
4. lack of public confidence and publicity of daily water quality information on the water reuse treatment plant by an independent regulator against acceptable standards and norms

B13. Increased local ownership, involvement, participation can raise awareness and stewardship about the fresh water resources available and acceptable uses of recycled water. This can help on programmes that oversee the sustainability of the water resources. Do you agree?

Strongly agree neutral disagree disagree strongly

B14. As a resident of Windhoek City which discussion have you been involved in with regard to your drinking water? Tick your best answer

1 Non assurance of continued water supply due to drought

2 Water quality fears that include pollution of our dams and treated sewage water reuse for drinking

3 The cost of water

4 all of the above
5 none of the above

B15 What maybe your fears if any or confidence on water reuse for drinking?

ANNEX 9 Water Quality Control, Health & Ethical Statutory Framework on Water Reuse for Drinking in the Upper Swakop Basin, Namibia

Water reuse is recycled water that is separated from waste water and highly treated so that it can be used again. Water reuse is being practised in Namibia, in particular, Windhoek. This is because fresh water resources are scarce in this semi-arid country. This research survey investigates the social, health and ethical perspectives of water reuse in Windhoek. This questionnaire is targeted to *Government Water quality and legal specialists; WINGOC Plant managers & quality inspectors, Windhoek City Health and Water Quality Specialists and NamWater water Quality specialists*) and is aiding a UNAM Student's research topic on water governance in the Upper Swakop Basin.

A: Legal health Standards: Since water reuse for drinking has international paranoia and Namibia (WINGOC) has been a pacesetter for several years since established as far back as 1968.

1) Are there separate standards (regulations & procedures) for water reuse for drinking developed so far from the experience of the WINGOC plant that can be used elsewhere in Namibia and worldwide? (*copy of the Standards is appreciated)*...
....
....
2) If so has it been enshrined in the **draft Namibia Water Resources Management Act (2012**) or will there be separate regulations from a conventional treatment plant?
....
....
....
3) Who does the day to day water quality compliance control and monitoring?
....
....
4) How good are the time series product water *(time series results of product water appreciated*)

....
....
....

5) Is there an independent water quality monitoring institution that checks and verify compliance on water quality standards? (**yes or no**)………………………………………
6) At what intervals are the checks carried out by the independent inspector?

a) Real time b) hourly *c*) daily *d*) weekly e) other specify…………………

B: Acceptance and Ethical Issues

1) How transparent are the product water quality results? Are the water quality results accessible to the public to the public/stakeholders?
   a) Accessible with confidentiality undertaking
   b) Accessible without confidentiality undertaking
   c) Not accessible for security reasons

d) Not accessible for other reasons

2 Do you have a billboard and website where these results are accessed given the stigma/paranoia that might exist against water reuse for drinking? [**yes or no**] Any other information tool in use?

3 What are the Water Quality barriers built on the plant? …………………………..

4 How to check against hormones ;emerging, endocrine disrupters; (attachment plant schematic diagram appreciated)

5 How do you check against plant and human incidental & accidental failures ………………………………………………………………………………… … …………………………………………………………

6 How do you check against human incidental negligent failures for now and in future?

Explain further ……………………………………………………………………………

7 What is the source water for water reuse for drinking at the WINGOC plant ………………………..

a) Gammams wastewater treatment plant b) Goreangab Dam c) other

8 What is the quality of source raw water for the plant?..................................(raw water quality data preferred)

a) Good quality b) deteriorating quality c) seasonally varying d) bad quality

9 What is the preferred quality of source raw water for the plant?..................................(*raw water quality data preferred*)

10 Would the river catchment management upstream of the Goreangab dam (Upper Swakop Basin) have a positive impact on the operation and product water quality of the plant? ………………………………………which are the likely improvement avenues? Circle where applicable

a) Less treatment chemical s and plant barrier checks to be applied

b) Less incidental accidents

c) Less source water quality fluctuations

d) Less plant stoppages and water supply disruptions leading to water availability & security

e) Social buy in and acceptance of the product drinking water from the water reuse plant

C: Blending drinking treated water from a Water reuse Plant with water treated from another Plant/groundwater.

1 What is the prime driver for blending? Circle where applicable

a) Regulations;

b) Marketing the acceptability of the product water.

c) Other reasons specify…………………………………………………………………..

2 What is the blending ratio?..how is the blending scheme?..(*schematic diagram preferred*.)

3 Is the blending all across the city distribution network [**yes or no**] or it is only feasible to certain distribution network line (Show on the schematic above).

4 How is the acceptability entertained among the socially different groups?

a) Do not know
b) Well accepted
c) Will check later with surveys.

5 Water reuse for drinking may be scientifically acceptable but has practical detail difficulties. I strongly recommend that the product water should be used for (tick the best response)

a) None-drinking purposes like industrial and mining; toilet flushing uses etc.
b) Used for drinking but the product water should be blended
c) Used for drinking water even without blending.
d) I have a different view that I will elaborate below:………………………………………………………………

6 What are your fears /confidence in water reuse for drinking?

ANNEX 10 Workshop 1 Questionnaire

ANNEX 9: USB Water Security Workshop (8-10 Feb 2012) Evaluation Questionnaire:

Participant Name (optional):________________ Email (Optional)_________________

Date: _____________

Please indicate your Registration Type: □ Business □ Local Authority. □ State Corporation
□ State Govt. □ Non-profit □ University □ Other (please explain)
Job Title: ______________________________________

Years in present position? <1 1-3 3-5 5+

Workshop Content (Circle your response to each item.)

1=Strongly disagree 2=Disagree 3=Neither agree nor disagree 4=Agree 5=Strongly agree

N/A=Not applicable

1. I was well informed about the objectives of this workshop

1 2 3 4 5 N/A

2. This workshop lived up to my expectations. 1 2 3 4 5 N/A

3. The content is relevant to my job. 1 2 3 4 5 N/A

4. The content is relevant to raise awareness of protecting our water sources.

1 2 3 4 5 N/A

5. The content is relevant to highlight missing links in protecting our water.

1 2 3 4 5 N/A

Workshop Design (Circle your response to each item.)

6. The workshop objectives were clear to me. 1 2 3 4 5 N/A

7. The workshop activities stimulated my learning and involvement. 1 2 3 4 5 N/A

8. The activities in this workshop opened opportunities for my practical involvement and sufficient feedback in water management 1 2 3 4 5 N/A

9. The difficulty level of this workshop was appropriate 1 2 3 4 5 N/A

10. The pace of this workshop was appropriate. 1 2 3 4 5 N/A

Workshop Presenters, Facilitators & Organization (Circle your response to each item.)

11. Quality of the overall preparation and presentation (good use of audio-visual means, flipcharts, etc., energetic & flexible facilitation; helpfulness). 1 2 3 4 5 N/A

11b Quality of group work and discussions 1 2 3 4 5 N/A

12. Please rate the following:
a. Overall Presenters/ facilitators Quality □ Excellent □ Very Good □ Good □ Fair □ Poor
b. Use of time □ Excellent □ Very Good □ Good □ Fair □ Poor
c. Workshop Facility □ Excellent □ Very Good □ Good □ Fair □ Poor
d. Hotel Accommodations □ Excellent □ Very Good □ Good □ Fair □ Poor □ N/A
e. Food □ Excellent □ Very Good □ Good □ Fair □ Poor
f. Invitations □ Excellent □ Very Good □ Good □ Fair □ Poor
g. Registration Process □ Excellent □ Very Good □ Good □ Fair □ Poor
h. Transport & site visit □ Excellent □ Very Good □ Good □ Fair □ Poor □ N/A

Additional Comments:

____

____

Workshop Results (Circle your response to each item.)

12. I will be able to use and disseminate information of what I learned in this workshop

1 2 3 4 5 N/A

13. What is least valuable about this workshop?

14. What is most valuable about this workshop?

15. I support the establishment of a coordinated, integrated Upper Swakop river basin Committee as the way forward 1 2 3 4 5 N/A

16. I and my organisation take full responsibility and commitment to be involved in protecting water pollution of the Upper Swakop Basin. 1 2 3 4 5 N/A

17. Overall, did you find the workshop informative and valuable to incentivise participatory and sustainable Upper Swakop basin management?
1 2 3 4 5 N/A

Water today, Water tomorrow; We will email a summary of the event shortly. Is there any other feedback or information you would like to receive or give?

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……………………………………………………………………

ANNEX 11 Descriptions of the Location Sites with Water Pollution Extreme Value Parameters (in italics); above permissible limit (in red) and MAWF proposed permissible limits (2012 (in blue)

CODE	DESCRIPTION	LAT	LONG	DATE	TIME	CODING	DOmg_l	mV	pH
	Proposed MAWF Permissible limit (2012)						**>75%saturation**		**6.5-9.5**
114	Ujams (Water Works) Treatment Plant Final Effluent	-22.48216	17.08131	2011/10/27		DWA306	*0.1*	-173	7.7
116	Ujams treatment plant raw wastewater	-22.49173	17.08253	2011/10/27		DWA308	*0.1*	-300	6.4
117	TransNamib Plant Effluent	-22.543385	17.081079	2011/10/26		DWA296	*0.1*	-100	*5.9*
122	Okapuka Meatco Tannery Waste Water/Effluent Primary Pond	-22.34758	17.03942	2013/01/31		DWA947	*0.1*	*-441*	8.2
123	Okahandja Oxidation Pond Waste Water	-22.014496	16.887255	2007/03/07		DWA6146	*0.1*	-314	7.8
124	Okapuka Meatco Tannery Wastewater /Effluent Final pond	-22.34566	17.04047	2013/01/31		DWA946	*0.1*	-378	9
128	Namib Poultry Industries Abattoir Septic Tank- Final effluent	-22.318419	17.038618	2012/06/04		DWA591	2	5.4	7.1
129	Swakoppoort Dam Surface Water Sny River Inflow	-22.19199	16.56062	2012/05/22		DWA530	8		7.7
130	Swakoppoort Dam Surface Water Swakop River Inflow	-22.20329	16.5863	2012/05/22		DWA529	6.6		7.8
131	Swakoppoort Dam Surface Water Middle Of Dam	-22.2093	16.5451	2012/05/22		DWA528	7.1		8.1
132	Swakoppoort Dam Location 1: Centre Arm	-22.12072	16.32939	2011/04/19		DWA09			7.8
133	Okapuka Meatco Tannery Borehole -North	-22.3434370	17.0428040	2010/07/23		DWA8198			6.6
134	Okapuka Meatco Tannery Borehole North West	-22.342583	17.040355	2010/07/23		DWA8200			6.9
135	Okapuka Meatco Tannery Borehole South	-22.351654	17.040463	2010/07/23		DWA8199			6.8
136	Okapuka Meatco Tannery Evaporation Pond E1	-22.344796	17.041265	2010/07/23		DWA8197			8.1
137	Okapuka Meatco Tannery Evaporation Pond E11	-22.343148	17.040596	2010/07/23		DWA8201			8.9
138	Swakoppoort Dam Inflow Dam Site Water	-22.12219	16.35139	2011/04/19		DWA11			7.3
151	Gammams WWTP raw water	-22.52953	17.03351	2013/09/16		DWA 219	0.2	-352	7
155	Old Goreangab Water Reclamation Plant, final effluent	-22.52886	17.00721	2013/09/16		DWA223	5.9	142	7.5
158	Okapuka Meatco Tannery, raw water	-22.334758	17.039420	2013/09/19		DWA226	*0.1*	-579	*12.3*
159	Okapuka Meatco Tannery, final effluent	-22.3456600	17.0404700	2013/09/19		DWA227	*0.1*	-139	8.7
160	Ujams WWTP, final effluent	-22.48216	17.08131	2013/09/18		DWA228	*0.1*	-238	7.8
161	Namibia Dairies, final effluent	-22.584299	17.126907	2013/09/17		DWA229	*0.1*	-340	7.1
162	Nakara Tannery, final effluent	-22.513783	17.077304	2013/09/17		DWA230	*0.1*	-468	*9.7*
163	Namibia Beverages, final effluent	-22.5336294	17.081606	2013/09/17		DWA231	2.6	-109	*11.0*
168	Namibia Poultry Industry: Abattoir	-22.336041	17.047397	2013/09/18		DWA236	*0.1*	-239	6.0
169	Namibia Poultry Industry: Abattoir, final effluent	-22.335284	17.048860	2013/09/18		DWA237	*0.1*	-298	7.3
173	Borehole 3.1- Greencrisp	-22.0231	16.9034	23-Jun-11		DS32492			8.0
175	Borehole- Graceland	-22.0404	16.919	15-Feb-12		DS34334			7.6
176	Borehole- C Human	-22.0322	16.9303	15-Feb-12		DS34335			7.9
177	Borehole -Harmse Plot 51	-22.0678	16.8688	15-Feb-12		DS34336			7.6
181	Swakop River S21 EW7119	-22.11219	16.842250	4/5/2011		DS31698			7.6
182	Dusternbrook Guest Farm Borehole S26 EW7060	-22.26994	16.899590	3/29/2011		DS31577			7.6
187	Dobra Okapuka River Aug S16 EW7054	-22.34692	17.051440	8/31/2011		DS33211			9.5
190	Dobra Okapuka River Jul S161 EW7061	-22.31545	17.021060	7/8/2011		DS32570			8.8
191	Dobra Okapuka River Aug S161 EW7061	-22.31545	17.021060	8/31/2011		DS33212			9.3
193	Dobra Okapuka River Aug S18 EW7056	-22.29713	16.952680	8/31/2011		DS33215			9.2
197	Klein Windhoek River S101Aug EW7050	-22.49025	17.084880	8/31/2011		DS33209			8.5
201	Klein Windhoek River S11 Jun EW7047	-22.47046	17.083321	6/8/2011		DS32249			8
202	Klein Windhoek River S11 Jul EW7047	-22.47046	17.083321	7/8/2011		DS32569			8.2
203	Klein Windhoek River S11 Jul EW7047	-22.47046	17.083321	8/31/2011		DS33210			8.2
209	Gammams River S4 Aug EW7043	-22.45522	16.986280	8/31/2011		DS33208			8.3
222	Goreangab Dam SI Aug EW7213 to include	-22.536488	17.003000	8/31/2011		DS33206			8.7
	Goreangab Dam Extreme values (2008 -2014) points 1, 3,4, 5, 7 , & 10)	-22.536488	17.003000				*0.5*		10.5

NB: Except for nitrates and pH, most parameters are in red colour for the majority of the sites indicating that water quality parameters within the discharged wastewater and the receiving waters exceeded). Values within specifications are in blue.

CODE	DESCRIPTION	LAT	LONG	Conductivity mS/m	Turbidity NTU	TDS mg/L	TSS mg/L	COD mg/L	BOD mg/L	SO_4 mg/L
	Proposed MAWF Permissible limit (2012)			**<75**	**<12**	**<500**	**<100**	**<100**	**<30**	**<40**
9	ST 13	-22.2730830	16.9000000							
13	ST 3	-22.3498830	17.0516000	560	1.6		4	99	4	903
14	ST 5	-22.3179000	17.0216330	507	11		36	176	15	758
29	ST 17 BH	-22.5409400	16.9453700	182.5	0.55	1113				105
31	ST 13 well	-22.2727400	16.8995500	263	1.1	1606				288
32	ST-10 well	-22.3164830	16.9569170	273	0.70	1620				305
34	ST 13 BH	-22.2725000	16.9000000	263	0.50	1668				204
35	ST 17 BH	-22.5409400	16.9453700	182.8	0.45	1090				108
36	ST 18 BH	-22.5384900	16.9449300	143.9	2.2	846				98
47	ST 9	-22.523617	16.993250	135.2	44	767	87	67	7	162
52	ST 20- Meatco Tannery river	-22.345000	17.043000	2480	76	*16167*	397	126	39	*3329*
53	ST 20 - Meatco Tannery river	-22.345000	17.043000	2540	188	*15925*	870	176	48	*3531*
54	ST 21	-22.339358	17.038457	373	7	2278	8	58	10	389
55	ST 21	-22.339358	17.038457	375	7	2232	11	65	11	401
56	ST 22	-22.335833	17.047222	250	58	831	60	393	40	47
57	ST23	-22.339444	17.043611	251	29	846	33	296	41	52
58	ST10 river	-22.317033	16.956317	130.7	9.5		787			120
62	ST10 well	-22.3164830	16.9569170	255	0.35		1618			253
64	ST12 BH	-22.5401500	16.9493000	147.1	0.1		897			67
65	ST12 BH	-22.5401500	16.9493000	145.4	0.1		886			69
66	ST13 BH	-22.2725000	16.9000000	224.9	3.4		1428			171
67	ST13 BH	-22.2725000	16.9000000	225.6	0.2		1527			169
69	ST13 well	-22.2727400	16.8995500	216.5	4.6		1360			214
70	ST19 river	-22.3457700	16.9723300	161.5	4.7		945			107
71	ST19 river	-22.3457700	16.9723300	179.8	3.9		1096			99
78	Namib Poutry Industries abattoir septic tank final effluent	-22.336041	17.047397	123.2	14		483	139	18	46
80	Okapuka Meatco tannery waste water effluent primary pond	-22.334758	17.039420	3480	350		*20869*	5327	*2940*	1779
81	Okapuka Meatco tannery waste water effluent final pond	-22.3456600	17.0404700	*23500*	610		*134714*	*18387*	*4020*	799
82	Chicken farm Hatchery raw waste water	-22.2809000	17.0292600	237	98		1900	876	39	89
86	Ujams Effluent	-22.4821660	17.0812830	309	230		1656	265	114	121
87	Elisenheim Farm river Water near NamPower	-22.4148240	17.0743550	298	9.1					
88	Okapuka bridge River water	-22.3477000	17.0519920	501	5.6					
89	Northern Industrial river water behind Namib Mills	-22.5375510	17.0823010	296.0	1.3					
90	Ujams treatment plant raw wastewater	-22.4917300	17.0825300	231	200		1230	1650	402	166
91	Ujams (Water Works) Treatment Plant Final Effluent	-22.4821600	17.0813100	332	98		1705	482	126	164
96	TransNamib Plant-Raw Effluent To The Plant At Trans Namib	-22.543385	17.081079	235	*1923*		2378	8483	402	179
97	TransNamib Plant-Final Effluent Of TransNamib Plant	-22.543385	17.081079	108.1	17		616	85	21	144
103	Okapuka Meatco Tannery Borehole -West	-22.3434370	17.0428040	2710.00	5		19390			1934
104	Khomas Region Waste Water Into River	-22.4327960	17.0755800	275.0	317		1505	773	198.0	24
107	Otjomuise Plant Raw Waste Water	-22.525994	17.002369	175.6	801		693	1817	402	103
111	Chicken Farm Hatchery Raw Waste Water	-22.2809	17.02926	237	98		1900	876	39	89
112	Swakoppoort Dam Surface Water Dam Wall	-22.2116	16.52772	90.5	5.6		558			

CODE	DESCRIPTION	LAT	LONG	Conductivity mS/m	Turbidity NTU	TDS mg/L	TSS mg/L	COD mg/L	BOD mg/L	SO_4 mg/L
	Proposed MAWF Permissible limit (2012)			**<75**	**<12**	**<500**	**<100**	**<100**	**<30**	**<40**
114	Ujams (Water Works) Treatment Plant Final Effluent	-22.48216	17.08131	332	98		1705	482	126	164
116	Ujams treatment plant raw wastewater	-22.49173	17.08253	231	200		1230	1650	402	166
117	TransNamib Plant Effluent	-22.543385	17.081079	235	*1923*		2378	8483	402	179
122	Okapuka Meatco Tannery Waste Water/Effluent Primary Pond	-22.34758	17.03942	3480	350		20869	5327	*2940*	1779
123	Okahandja Oxidation Pond Waste Water	-22.014496	16.887255	162.5	135		724	562	180	9
124	Okapuka Meatco Tannery Wastewater /Effluent Final pond	-22.34566	17.04047	*23500*	610		*134714*	*18387*	*4020*	799
128	Namib Poultry Industries Abattoir Septic Tank- Final effluent	-22.318419	17.038618	123.2	14		483	139	18	46
129	Swakoppoort Dam Surface Water Sny River Inflow	-22.19199	16.56062	93.1	12		605			
130	Swakoppoort Dam Surface Water Swakop River Inflow	-22.20329	16.5863	99.2	28		613			
131	Swakoppoort Dam Surface Water Middle Of Dam	-22.2093	16.5451	90.9	5.2		587			
132	Swakoppoort Dam Location 1: Centre Arm	-22.12072	16.32939	62.8	3.1		402			68
133	Okapuka Meatco Tannery Borehole -North	-22.3434370	17.0428040	*4030*	8.3		*28933*			*3277*
134	Okapuka Meatco Tannery Borehole North West	-22.342583	17.040355	2740	4.2		19171			*3254*
135	Okapuka Meatco Tannery Borehole South	-22.351654	17.040463	2900	407		19769			2106
136	Okapuka Meatco Tannery Evaporation Pond E1	-22.344796	17.041265	2280	1839		13786			*4706*
137	Okapuka Meatco Tannery Evaporation Pond E11	-22.343148	17.040596	*12230*	247		*69868*			1503
138	Swakoppoort Dam Inflow Dam Site Water	-22.12219	16.35139	53.7	93		381			68
151	Gammams WWTP raw water	-22.52953	17.03351	170	234	806	300	948	162	96
155	Old Goreangab Water Reclamation Plant, final effluent	-22.52886	17.00721	121.8	0.95	709	3	26	1	136
158	Okapuka Meatco Tannery, raw water	-22.334758	17.039420	3810	*4109*	*26096*	3850	*13817*	*2520*	1177
159	Okapuka Meatco Tannery, final effluent	-22.3456600	17.0404700	*16090*	766	*161028*	600	*26967*	*3540*	2847
160	Ujams WWTP, final effluent	-22.48216	17.08131	464	76	2361	114	296	30	90
161	Namibia Dairies, final effluent	-22.584299	17.126907	238	*3782*	1829	2450	6330	342	52
162	Nakara Tannery, final effluent	-22.513783	17.077304	3440	*2172*	*23608*	1900	*8817*	1620	2985
163	Namibia Beverages, final effluent	-22.5336294	17.081606	156.7	69	1426	160	832	26	60
168	Namibia Poultry Industry: Abattoir	-22.336041	17.047397	123.3	1470	690	1200	3948	330	28
169	Namibia Poultry Industry: Abattoir, final effluent	-22.335284	17.048860	177.6	61	638	100	330	15	23
173	Borehole 3.1- Greencrisp	-22.0231	16.9034	299	0.62	2003				370
175	Borehole- Graceland	-22.0404	16.919	88.1	2.5	590				31
176	Borehole- C Human	-22.0322	16.9303	312	0.45	2090				320
177	Borehole -Harmse Plot 51	-22.0678	16.8688	399	0.3	2673				420
181	Swakop River S21 EW7119	-22.11219	16.842250	35.1	302	235.17				68
182	Dusternbrook Guest Farm Borehole S26 EW7060	-22.26994	16.899590	263	0.468	1762.1				310
187	Dobra Okapuka River Aug S16 EW7054	-22.34692	17.051440	394	14.2	2639.8				710
190	Dobra Okapuka River Jul S161 EW7061	-22.31545	17.021060	332	5.5	2224.4				440
191	Dobra Okapuka River Aug S161 EW7061	-22.31545	17.021060	397	17.8	2659.9				730
193	Dobra Okapuka River Aug S18 EW7056	-22.29713	16.952680	402	14.2	2693.4				660
197	Klein Windhoek River S101Aug EW7050	-22.49025	17.084880	257	1.29	1721.9				520
201	Klein Windhoek River S11 Jun EW7047	-22.47046	17.083321	275	124	1842.5				105
202	Klein Windhoek River S11 Jul EW7047	-22.47046	17.083321	297	15.8	1989.9				158
203	Klein Windhoek River S11 Jul EW7047	-22.47046	17.083321	314	54.3	2103.8				180
209	Gammams River S4 Aug EW7043	-22.45522	16.986280	167.1	64.9	1119.57				270
222	Goreangab Dam SI Aug EW7213 to include	-22.536488	17.003000	148.7	14.3	996.29				230
	Goreangab Dam Extreme values (2008 -2014) points 1, 3,4, 5, 7 , & 10)	-22.536488	17.003000	1132	376	1005		305	18	195

CODE	DESCRIPTION	LAT	LONG	TP mg/L	Chloride mg/L	NO_3 mg/L	TKN mg/L	Na mg/L	COLOUR Pt-Co
	Proposed MAWF Permissible limit (2012)			<3	<70	<20	<33	<90	<15
9	ST 13	-22.2730830	16.9000000						
13	ST 3	-22.3498830	17.0516000	3.7	916	0.4999	2.5	1093	
14	ST 5	-22.3179000	17.0216330	4.7	808	0.4999	19	998	
29	ST 17 BH	-22.5409400	16.9453700		169	15		184	11
31	ST 13 well	-22.2727400	16.8995500		518	6.4		361	15
32	ST-10 well	-22.3164830	16.9569170		494	2.0		373	13
34	ST 13 BH	-22.2725000	16.9000000		566	20		278	11
35	ST 17 BH	-22.5409400	16.9453700		164	16		187	11
36	ST 18 BH	-22.5384900	16.9449300		96	7.8		183	10
47	ST 9	-22.523617	16.993250	2.5	153	4.6	4.2	71	
52	ST 20- Meatco Tannery river	-22.345000	17.043000	1.3	7191	1.1	31	3544	
53	ST 20 - Meatco Tannery river	-22.345000	17.043000	2	7885	1.5	44	3939	
54	ST 21	-22.339358	17.038457	3.8	491	1.8	21	598	
55	ST 21	-22.339358	17.038457	3.8	487	2.3	18	599	
56	ST 22	-22.335833	17.047222	9.1	214	0.4999	163	183	
57	ST23	-22.339444	17.043611	9.2	212	0.4999	188	179	
58	ST10 river	-22.317033	16.956317		173	1.6		180	13
62	ST10 well	-22.3164830	16.9569170		411	0.4999		404	9.999
64	ST12 BH	-22.5401500	16.9493000		124	14		132	9.999
65	ST12 BH	-22.5401500	16.9493000		122	14		133	9.999
66	ST13 BH	-22.2725000	16.9000000		450	16		250	9.999
67	ST13 BH	-22.2725000	16.9000000		453	16		256	9.999
69	ST13 well	-22.2727400	16.8995500		33	0.4999		367	13
70	ST19 river	-22.3457700	16.9723300		212	2.1		242	23
71	ST19 river	-22.3457700	16.9723300		250	2.2		277	23
78	Namib Poutry Industries abattoir septic tank final effluent	-22.336041	17.047397	27.0	103	37	55	78	
80	Okapuka Meatco tannery waste water effluent primary pond	-22.334758	17.039420	1.0	9975	0.6	1057	7540	
81	Okapuka Meatco tannery waste water effluent final pond	-22.3456600	17.0404700	1.0	67086	7.3	-1	55520	
82	Chicken farm Hatchery raw waste water	-22.2809000	17.0292600	20.0	175	0.4999	9.5	590	
86	Ujams Effluent	-22.4821660	17.0812830	61	355	0.4999	105	522	
87	Elisenheim Farm river Water near NamPower	-22.4148240	17.0743550						
88	Okapuka bridge River water	-22.3477000	17.0519920						
89	Northern Industrial river water behind Namib Mills	-22.5375510	17.0823010						
90	Ujams treatment plant raw wastewater	-22.4917300	17.0825300	14.0	335	1.8	103	319	
91	Ujams (Water Works) Treatment Plant Final Effluent	-22.4821600	17.0813100	59.0	389	1.5	115	534	
96	TransNamib Plant-Raw Effluent To The Plant At Trans Namib	-22.543385	17.081079	24.0	237	1.3	19	544	
97	TransNamib Plant-Final Effluent Of TransNamib Plant	-22.543385	17.081079	0.1	136	0.7	1.9	133	
103	Okapuka Meatco Tannery Borehole -West	-22.3434370	17.0428040		8561	0.7		4394	
104	Khomas Region Waste Water Into River	-22.4327960	17.0755800	48	220	1	121	405	
107	Otjomuise Plant Raw Waste Water	-22.525994	17.002369	28	160	1.4	153	164	
111	Chicken Farm Hatchery Raw Waste Water	-22.2809	17.02926	20	175	0.4999	9.5	590	
112	Swakoppoort Dam Surface Water Dam Wall	-22.2116	16.52772	0.5		0.7			

CODE	DESCRIPTION	LAT	LONG	TP mg/L	Chloride mg/L	NO_3 mg/L	TKN mg/L	Na mg/L	COLOUR Pt-Co
	Proposed MAWF Permissible limit (2012)			**<3**	**<70**	**<20**	**<33**	**<90**	**<15**
114	Ujams (Water Works) Treatment Plant Final Effluent	-22.48216	17.08131	59	389	1.5	115	534	
116	Ujams treatment plant raw wastewater	-22.49173	17.08253	14	335	1.8	103	319	
117	TransNamib Plant Effluent	-22.543385	17.081079	24	237	1.3	19	544	
122	Okapuka Meatco Tannery Waste Water/Effluent Primary Pond	-22.34758	17.03942	1	9975	0.6	1057	7540	
123	Okahandja Oxidation Pond Waste Water	-22.014496	16.887255	58	106	0.9	123	103	
124	Okapuka Meatco Tannery Wastewater /Effluent Final pond	-22.34566	17.04047	1	67086	7.3	-1	55520	
128	Namib Poultry Industries Abattoir Septic Tank- Final effluent	-22.318419	17.038618	27	103	37	78		
129	Swakoppoort Dam Surface Water Sny River Inflow	-22.19199	16.56062	0.4		0.6			
130	Swakoppoort Dam Surface Water Swakop River Inflow	-22.20329	16.5863	0.2		0.6			
131	Swakoppoort Dam Surface Water Middle Of Dam	-22.2093	16.5451	0.9		0.7			
132	Swakoppoort Dam Location 1: Centre Arm	-22.12072	16.32939		69	0.4999		82	34
133	Okapuka Meatco Tannery Borehole -North	-22.3434370	17.0428040		13331	27		8497	491
134	Okapuka Meatco Tannery Borehole North West	-22.342583	17.040355		7705	0.7		5707	41
135	Okapuka Meatco Tannery Borehole South	-22.351654	17.040463		8806	0.7		5945	47
136	Okapuka Meatco Tannery Evaporation Pond E1	-22.344796	17.041265		3914	0.7		4259	377
137	Okapuka Meatco Tannery Evaporation Pond E11	-22.343148	17.040596		33266	0.7		27800	1335
138	Swakoppoort Dam Inflow Dam Site Water	-22.12219	16.35139		55	1		68	121
151	Gammams WWTP raw water	-22.52953	17.03351	28	111	0.4999	94	148	
155	Old Goreangab Water Reclamation Plant, final effluent	-22.52886	17.00721	1.6	143	6.5	1.0	169	
158	Okapuka Meatco Tannery, raw water	-22.334758	17.039420	46	10488	3.2	726	7643	
159	Okapuka Meatco Tannery, final effluent	-22.3456600	17.0404700	29	75650	0.4999	409	64570	
160	Ujams WWTP, final effluent	-22.48216	17.08131	47	628	0.8	132	772	
161	Namibia Dairies, final effluent	-22.584299	17.126907	28	90	0.6	54	534	
162	Nakara Tannery, final effluent	-22.513783	17.077304	46	9628	0.8	467	8710	
163	Namibia Beverages, final effluent	-22.5336294	17.081606	19	70	-1	2.1	321	
168	Namibia Poultry Industry: Abattoir	-22.336041	17.047397	34	124	0.5	113	118	
169	Namibia Poultry Industry: Abattoir, final effluent	-22.335284	17.048860	42	166	0.7	121	147	
173	Borehole 3.1- Greencrisp	-22.0231	16.9034		250	8.9		440	11
175	Borehole- Graceland	-22.0404	16.919		63	6.6		71	0.999
176	Borehole- C Human	-22.0322	16.9303		370	18.7		520	0.999
177	Borehole -Harmse Plot 51	-22.0678	16.8688		450	12.6		730	0.999
181	Swakop River S21 EW7119	-22.11219	16.842250	0.14	11	1.6		23	4
182	Dusternbrook Guest Farm Borehole S26 EW7060	-22.26994	16.899590	0.16	450	20.7		285	9
187	Dobra Okapuka River Aug S16 EW7054	-22.34692	17.051440	0.35	560	2	2.9	790	62
190	Dobra Okapuka River Jul S161 EW7061	-22.31545	17.021060	2.9	400	2.7	13	640	51
191	Dobra Okapuka River Aug S161 EW7061	-22.31545	17.021060	0.3	560	0.6	3.6	750	65
193	Dobra Okapuka River Aug S18 EW7056	-22.29713	16.952680	0.09	590	0.5	3.5	810	68
197	Klein Windhoek River S101Aug EW7050	-22.49025	17.084880	0.02	240	3.7	0.6	440	16
201	Klein Windhoek River S11 Jun EW7047	-22.47046	17.083321	67	230	1.3	165	420	500.999
202	Klein Windhoek River S11 Jul EW7047	-22.47046	17.083321	17.2	250	0.4	135	510	383
203	Klein Windhoek River S11 Jul EW7047	-22.47046	17.083321	2.8	370	0.5	81	550	500.999
209	Gammams River S4 Aug EW7043	-22.45522	16.986280	0.09	240	4.4	7.5	235	54
222	Goreangab Dam SI Aug EW7213 to include	-22.536488	17.003000	1.4	230	1.6	4.7	210	163
	Goreangab Dam Extreme values (2008 -2014) points 1, 3,4, 5, 7 , & 10)	-22.536488	17.003000	5.7	175	3.5	19	209	240

ANNEX 12 Strategic Water Quality Monitoring, Control and Management in Upper Swakop Basin

As discussed in Section 7.5, the basin strategy is recommended to follow the outlined processes of analyses, formulation, implementation, monitoring and evaluation. However, the emphasis of this section is more on the analyses and formulation stages since all these stages require to be endorsed and approved by the USB Management Committee. Due to the time limitation of the study, the endorsement and implementation of the full strategy is recommended for further studies. The strategies recommended include regulatory programs, technical assistance, education, demonstration and piloting projects and training of local authorities on how to deal with pollution issues. Control strategies on sources of water pollution in urban runoff as well as enforcing primary and secondary wastewater treatment for the existing agro industries are also recommended. The initiative of **Best Management Practices (BMPs)** that minimize soil erosion and leaching of fertilizers and nutrients and the stipulation of the Total maximum daily Load (TMDL) be adapted and be implemented. The implementation of a strategic water quality monitoring, control and management in the Upper Swakop basin should be based on adaptive water governance approach. It should be all-inclusive as highlighted in Figures 0.1, 0.2 and Table 19 in Chapter 7. The proposed strategic organogram for water quality monitoring in the USB is presented in Figure 0.1. This structure was presented to the USB Sub-committee on Water Quality monitoring for adoption on 05 March 2015 and the idea of a pollution specialist was adopted. Possible recommended control strategies for algal growth are to regulate the maximum allowable level of phosphates soap (phosphate is a limiting nutrient); upgrade of sewage treatment plants; permitting point and non-point sources impacting on the watershed.

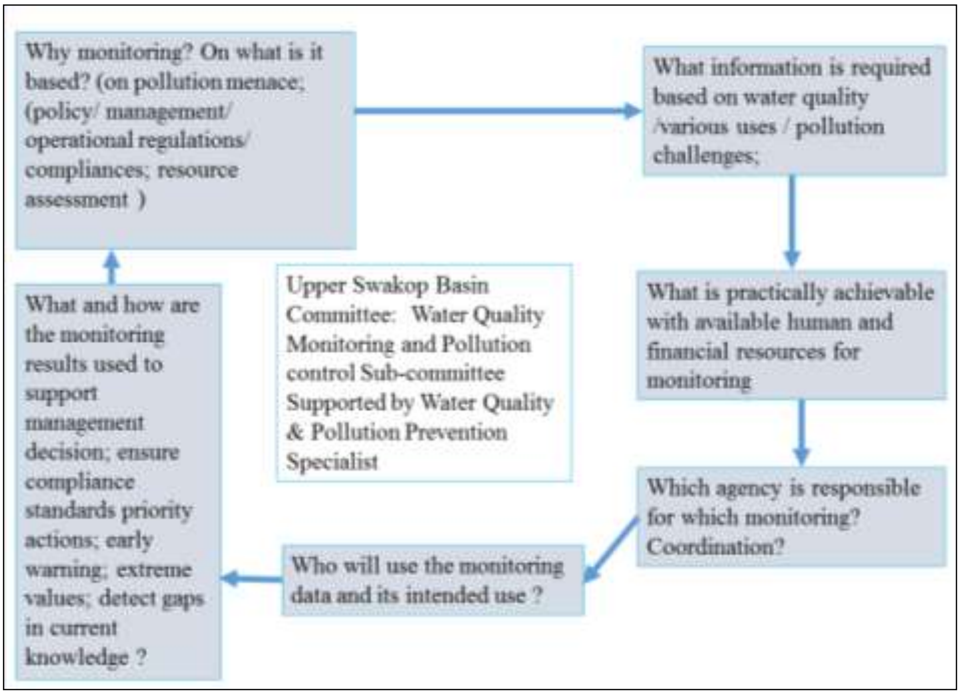

Figure 0.1 Upper Swakop Water Quality Monitoring Programme Strategy

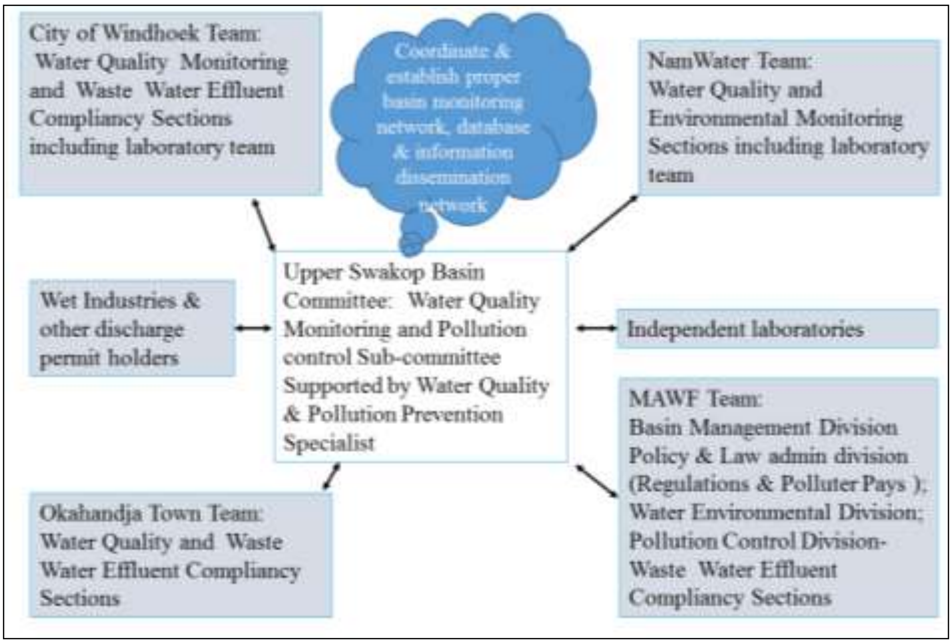

Figure 0.2 Proposed Strategic Organogram for Water Quality Monitoring in the USB

It is also proposed that the USB strategic water quality monitoring, control and management be phased out and follow the approaches and concepts highlighted in the following section.

Phase 1: 2015-2020

The first phase should include the following:

1. Involve all key stakeholders through the USB; the discharge permit holders; communication media; research institutions; collaborating agencies; as well as engage primary and secondary education stakeholders and learners.
2. Prevention, control and management of pollution in the USB are the responsibility of the governing institutions as well as civil society. It is proposed to the Basin Committee should promote the declaration of the USB water bodies, “WATER SENSITIVE AREAS”. These water bodies should include the Windhoek Aquifer; Goreangab; Von Bach and Swakoppoort Dams; Osona and Okahandja groundwater. These sensitive waters sources for drinking should receive special attention and protection from further pollution deterioration and eutrophication.
3. Ensure that every producer of pollution / discharger of wastewater have a permit and pay the full cost of treatment to reduce pollution loads to levels which will not cause environmental damage or loss of beneficial use to others, together with the cost of monitoring and management. The scale of charges for all dischargers (permit holders) should provide an incentive to reduce pollution.
4. Train, build and increase appropriate capacity of the pollution control unit (PCU) within the basin to improve on responsiveness, coordination and integration. Even though the Upper Swakop Basin is without a substantive budget it critically requires a Water Quality and Pollution Prevention Specialist on an initial contract of one year. The specialist can be assisted by a part time/ad-hoc field operator when carrying out field work.
5. Implement basin-wide standardization of the in-house and intra-office of sampling; data sheets; sample control procedures, quality assurance plans, control and audits and chain of custody.
6. All critical extreme pollution sources should be made known (spatially, in quantity, quality and effects/ damage evaluated), and information of such should be

made accessible and drawn in well managed information management system for the USB Management Committee and all relevant decision making stakeholders.

7. Remedial action on urban water pollution should be modelled on eco-water; eco-efficiency and water sensitive green cities approaches.

8. Improve the institutional information sharing programmes, accountability, responsibility, communication and trust.

9. Recommend the establishment of *Industrial Wastewater Stewardship Zones Committees* (*IWSZC)* that self-monitor the water quality and police on each other.

10. Foster education of the primary and secondary school children and share the importance of protecting the basin water bodies from pollution

Phase 2: 2021-2030

11. Establish SMART (Specific, measurable, attainable, realistic, timely) reduction of the amount of pollution parameter values and establish environmental quality standards.

12. Improve the adaptive and solution-oriented-research of the basin waters and related environment.

13. Introduce Strategic Environmental Assessment (SEA) as a pollution prevention initiative. Under SEA, formulate and implement policies that entail either "relocation" of extremely polluting wet industries especially agro industries. Or on the other hand, turn the "pollution' materials into a benefit through research. This can be done by taking advantage of the proposed *Industrial Wastewater Stewardship Zones Committees* (*IWSZC)*, where similar industries in the USB could investigate the possibility of establishing symbiotic factories, for instance it is recommended to look into the possibility of a combined phosphate-fertilizer plant to be derived from the manure and "pollution" from Meatco Tannery stock pens and Namib Poultry industries in the same neighbourhood.

14. If funding is available, facilitate the establishment of Water Supply and Quality Customer Care Centre (WSQCCC) in the USB. The centre should include the resource library and information centre.

Monitoring and Sampling Programme

The objective of the USB water quality monitoring system is to plan, establish and propose an effective operational water quality monitoring programme with the view to improve access to validated water quality data, information, coordinate and cement collaboration among stakeholders. Foster stakeholder participation by encouraging "industrial clustering" in monitoring and curbing pollution in the USB. The ultimate goal is to see the control of the pollution and improved water quality in the basin and enhance water security by implementing sustainable water governance.

The monitoring programme design should inform on the following:

1. the purpose and objectives of the programme-
2. Set up a comprehensive work plan
3. Choose appropriate technology
4. Institutional structure and affiliation on exchange of information
5. Design of the monitoring network and programme to include: identify monitoring points; sampling procedures, frequency of sampling; instruments and equipment; office work and laboratory facility coordination; quality assurance; data handling; reporting and dissemination of results; implementation and enforcing remedial action.

Main objectives of the WQM Programmes (source GEMS/Water 2008)

1. Enable assessments of the current state of water quantity and quality and its variability and its variability
2. Characterize the water in accordance with its individual pattern of physical and chemical characteristics, determined largely by the climatic, geomorphological and geochemical conditions prevailing in the drainage basin and the underlying aquifer; Develop composite indexes to assess source water quality (WQ).
3. Support decision-making and operational water management in critical situations and hot spot in the USB.
4. Model and determine trends in the quality of the aquatic environment and how the environment can restored. Background quality monitoring of the aquatic environment is also widely carried out, as it provides a means of comparing and assessing the results of impact monitoring.

5. Determine treatment options for polluted or undrinkable water.

6. Determine ecological flows – if it's required in the USB.

7. Evaluate the effectiveness of water management/remedial measures.

8. To identify the low-flow conditions and estimate the compensation of the water flow. The fundamental role of compensation water flow needs to be mentioned here, which, in a river, is the link between water-quality and water-quantity problems – Otjimbingwe community downstream are affected by impoundment of all the water at Swakoppoort Dam unless it spills. Should there be water releases downstream? Is this a priority? (NamWater, 2010b).

9. To provide the basis of the formulation of science-based environmental policies and also allow for evaluations of whether or not a policy has resulted in the desired effect and been cost-effective; this could be a further research question.

10. For rational planning of pollution-control strategies and their prioritization;

11. To assess the nature and extent of pollution control needed in different water bodies; -e.g. Meatco tannery boreholes that are polluted.

12. To evaluate effectiveness of pollution-control measures already in existence;

13. To evaluate water-quality trend over a period of time;

14. To assess assimilative capacity of a water body, thereby reducing costs of pollution control;

15. To understand the environmental fate of different pollutants;

16. To assess the fitness of water for different uses.

Responsibilities of the Water Quality and Pollution Prevention Specialist

1. Coordinate key sector players (MAWF, Municipalities of Windhoek and Okahandja, wet industries), collaborating agencies, participating laboratories and others not under his/her direct control

2. Procurement of necessary equipment and consumable supplies

3. Planning of water-quality monitoring activities

4. Arranging suitable transport from car hire firms

5. Training of staff on standardization and sampling sites and protocols

6. Preparation of training manuals

7. Safety in the field and in the laboratory

8. Preparation of Standard Operating Procedures (SOPs)

9. Organizing and managing central office facilities for the storage, handling, interpretation and distribution of data

10. Supervising and evaluating the performance of all staff

11. Reviewing and evaluating procedures

12. Preparation of reports and dissemination of the findings of the monitoring programme

Responsibilities in the field

1. Undertaking sampling expeditions in accordance with a planned programme
2. Obtaining samples according to SOPs
3. Sample handling: labelling sample bottles, preparing samples, etc.
4. Performing on-site measurements with proper devices
5. Maintenance of equipment used in the field
6. Performing field tests for selected variables

The UBS water quality management plan should consider adequate financial resources to facilitate monitoring for adaptive management decision-making. The UBS water quality management plan should demonstrate both the benefit of monitoring based on integrated water management and the remedial impacts on the environment and prevention of environmental and water quality challenges. A typical 1st order annual budget (can be trimmed where applicable) for monitoring is given in Table 01 below.

Table 01: Typical Water Quality Monitoring Budget for the USB in Financial Year (FY) 2016

No.	Item	Amount N$
A	*Salary*	
1	1 x WQ and Pollution Control Specialist (initially one year contract)	$1,000,000.00
2	1 x field support staff (ad-hoc)	$50,000.00
B	*Other items*	
3	Sampling Equipment (only basic)	$50,000.00
4	Samples analyses (provisional sum)	$1,000,000.00
5	Office rental (assume its provided by MAWF or NamWater)	$0.00
5	Transport -	$96,000.00
6	Training	$50,000.00
7	Consultancy	$100,000.00
8	Sub Total	$2,346,000.00
9	Preliminary and general 10%	$234,600.00
10	Contingencies 10%	$234,600.00
	Total	$2,815,200.00

The successful strategic water quality monitoring, control and management in the Upper Swakop Basin requires an integrated GIS-based monitoring and sampling network and analysis designed and continuously refined based on preliminary information of sampled sites and entities. The sampling programmes should be multiple-objective to assist major areas of regulation planning, research design, process controls and stakeholder responsibility and resource ownership. The sampling program must consider objectives of 1) sampling program and the respective types of samples (grab and composite); 2) sample collection methods (manual, automatic, remote sensing); 3) flow characteristics and measurements (this is virtually absent in the basin); and 4) selection and location of sampling points.

Sample control procedures and identification include: date, time, station location, sample tag number (including "split "sample), blank and duplicate tags).

Regulatory sampling programmes objectives should be performed to:

- Verify compliance with permit and self-monitoring data; support enforcement action; support permit revision and reissuance and support water quality standards and research.

The key for success of the USBs sampling program lies in good housekeeping, collection of representative samples, proper handling and preservation of samples and appropriate chain of custody procedures.

It should be noted that ground water monitoring is based on monitoring boreholes located after due consideration of the potential pollution, geological, hydrological, permeability, and geochemical and hydraulic conductivity properties of the sites.

Proposed factors to be considered in the USB sampling and monitoring programme

As was established in the study the purposes of pollution control are intended to identify extremes of pollution hence the sampling program should establish the following:

1. Parameters to be measured
2. Selection of appropriate sites (location) remembering that monitoring stations should be limited to control cost
3. Number of samples

4. The frequency of sampling and monitoring particular parameter may be discontinued or frequency reduced. However high frequency sampling of the drinking source-waters should be maintained. These sites include Gammams domestic wastewater effluent that is source-water for direct water reuse.

Urban water pollution control and management vary to a large extent on the efficiency of urban sanitation management. Neglect of sound urban water and sanitation planning, implementation and management makes it impossible to control non-point water pollution loading, waste water treatment and discharge. Unlike in dispersed settlements, towns and cities result in water pollution problems due to insanitation and unmanaged wastewater. The high concentration communities require planned, sustainable infrastructural facilities.

Lack of coordination among institutions in the USB whose activities affect the environment and control water pollution has debilitated the law enforcement of such regulation. Lack of maintenance coupled with lagging infrastructural planning of new urban settlements appears to make water pollution intractable problem in Windhoek and Okahandja informal settlements.

Water Control Pollution Strategy (WCPS) in the USB (approaches to Wastewater treatment)

WCPS and policies and legislation as well as environment should practically be interlinked to the physio-social-economic environment given the challenges in the USB where statutory instruments in form of effluent standards have not been implemented uniformly and efficiently.

The USB management Committee should support a water sensitive urban design approach, a new transitional water governance framework that should accommodate the complexity and uncertainty and mixed organisational cultures in the USB through embracing stepwise adaptive experimentation and learning-by-doing to change to sustainable urban water management practices that reduce water pollution. Employing adaptive water governance approaches in the USB, the BAT, BPT AIWPS, BATNEEC and ‘3 step strategies” approaches discussed earlier are recommended to be deployed in the USB to prevent and sustainably curb and manage water pollution in the basin.

Implement Strategic Environmental Assessment (SEA) as a Water Pollution Prevention Initiative

The strategic water quality management plan should look into water / land use issues such as proactively develop infrastructure services for houses prior to settling informal dwellers. The challenges of land overloading, generation of erosion and pollution from non-point sources, is difficult to remedy and restore.

In the USB, the MET is responsible for environmental clearance of companies that are establishing in the basin and municipalities of Windhoek and Okahandja and MAWF on the other hand are the water pollution control agencies that monitor and control the pollution. However, these agencies do not have a common forum and consultative review process that interrogates the goings on and the way forward. The absence of comprehensive and coordinated approach in development planning, and implementation processes in USB has created and continue to create challenges.

It is imperative that sound integrated environmental planning and management should initially be brought to foster development in a healthy and clean environment. Planning, control, and pollution control are two overlapping approaches in managing the environment. Planning is stronger on protection and prevention of potentially harmful developments. It does not enforce further restrictions on established and establishing industries when it becomes necessary. Pollution control and their agencies on the other hand, are based on situation assessment. A water pollution control system where there is no extensive consultation between these two approaches has gaps and results in insurmountable environmental problems.

Over and above the Ministry of Environment and Tourism approving environmental impact assessments (EIAs) without assessing SEAs does not address the cumulative effects on the environment The SEAs have to be carried out in the USB to take into account the complex integrated cumulative effects of potential water pollutants. This approach will also standardize decision making processes especially from local authorities and translate EIAs into USB management policy, plans and implementable objectives. This long term approach can also be adapted to respond to the rainfall and runoff variability and the uncertainty of climate change effects.

Zoning of Industries to Steward the River Basin in their Urban Areas

It is recommended that industries sharing the same location be clustered into *Industrial Wastewater Stewardship Zones Committees* and be encouraged to self-monitor on each other. These zones facilitate setting up environmental stewardship research funds, awareness and mobilization. This environmental and ecological interdependence and symbiosis and have better trade off against the usual industrial competitiveness.

For instance industries in Okahandja industrial area; Windhoek Southern industrial area; Northern industrial area and Brakwater and Prosperita areas can be encouraged to form separate IWSZC. There are opportunities for clustered industries to share and contribute to an environmental research fund, stewardship awareness and mobilization initiatives. In these zonal clusters, companies/ industries are recommended to be responsible and share information, effluent handling technologies and where applicable build a common wastewater treatment plant. For instance, the zone that appears to be troublesome pollution-wise, that is, the area where Meatco and Namibia Poultry Industries are situated can be recommended that the two industries build and share a waste water treatment plant. The zonal clusters facilitate incorporation of eco-water, eco-efficiency technologies and self-checking pre-treatment processes and promotion of water sensitive cities. In their pursuit of profitable economic ventures, industries like Meatco Tannery in the USB often create environmental water pollution problems in their trail. Needless to say industries should not be portrayed as villains due to improper environmental management, these industries benefit society in general who share the benefits of industrial development. However, the primary concern should be on unacceptable environmental practices. And these industries when properly monitored by fellow compatriot industries are likely to be encouraged to implement not only onsite pre-treatment facilities, but due to pressure, are likely to implement an effective full wastewater treatment plant.

In Windhoek an attempt to zone industrial areas separately during the planning is visible. However, some industries like the Ramatex Textile industry in Otjomuise area is not within the industrial zone area and its industrial effluent was being mixed with domestic effluent at Gammams domestic wastewater treatment plant since the Ramatex industrial effluent did not also have pre-treatment onsite.

ANNEX 13 Forecasted Monthly Rainfall with Confidence Intervals

	Point Forecast	Lo 80	Hi 80	Lo 95	Hi 95
Oct 2012	13.972650	-35.7396431	63.68494	-62.055741706	90.00104
Nov 2012	42.054254	-7.9121534	92.02066	-34.362771763	118.47128
Dec 2012	31.094962	-18.9667477	81.15667	-45.467815887	107.65774
Jan 2013	124.308056	74.2105264	174.40559	47.690496217	200.92562
Feb 2013	110.758766	60.6477620	160.86977	34.120599074	187.39693
Mar 2013	81.194976	31.0789023	131.31105	4.549055374	157.84090
Apr 2013	53.420378	3.3023958	103.53836	-23.228461134	130.06922
May 2013	13.538401	-36.5802984	63.65710	-63.111535459	90.18834
Jun 2013	3.605743	-46.5132276	53.72471	-73.044607747	80.25609
Jul 2013	3.624801	-46.4942712	53.74387	-73.025705144	80.27531
Aug 2013	3.440582	-46.6785276	53.55969	-73.209981887	80.09115
Sep 2013	6.715145	-43.4039797	56.83427	-69.935441586	83.36573
Oct 2013	14.387256	-35.8534305	64.62794	-62.449243634	91.22376
Nov 2013	41.302516	-8.9395012	91.54453	-35.536018347	118.14105
Dec 2013	33.012041	-17.2304765	83.25456	-43.827258548	109.85134
Jan 2014	120.235487	69.9927809	170.47819	43.395899165	197.07507
Feb 2014	113.220618	62.9778413	163.46339	36.380921981	190.06031
Mar 2014	82.948625	32.7058216	133.19143	6.108888182	159.78836
Apr 2014	51.246139	1.0033255	101.48895	-25.593613292	128.08589
May 2014	13.216420	-37.0263970	63.45924	-63.623337739	90.05618
Jun 2014	3.850588	-46.3922309	54.09341	-72.989172360	80.69035
Jul 2014	3.860888	-46.3819306	54.10371	-72.978872403	80.70065

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Jan 2050	83.221923	25.5958857	140.84796	-4.909495578	171.35334
Feb 2050	79.124620	21.4985245	136.75072	-9.006887899	167.25613
Mar 2050	61.432723	3.8066052	119.05884	-26.698818832	149.56426
Apr 2050	42.904055	-14.7220713	100.53018	-45.227499753	131.03561
May 2050	20.676787	-36.9493423	78.30292	-67.454772343	108.80835
Jun 2050	15.202967	-42.4231632	72.82910	-72.928593889	103.33453
Jul 2050	15.209232	-42.4168993	72.83536	-72.922330224	103.34079
Aug 2050	15.106968	-42.5191629	72.73310	-73.024593899	103.23853
Sep 2050	16.891856	-40.7342752	74.51799	-71.239706265	105.02342
Oct 2050	21.476469	-36.2532562	79.20619	-66.813526851	109.76647
Nov 2050	36.987151	-20.7436401	94.71794	-51.304475005	125.27878
Dec 2050	32.220556	-25.5106363	89.95175	-56.071683586	120.51280

ANNEX 14 MAWF Directorate of Water Resources Management Organogram (2014 -2015) Showing Vacant Posts in Green Colour-*Copy of Original*