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Developing a contamination susceptibility index for the Goreangab Dam in Namibia

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ABSTRACT

The convenience and quality of life provided by dams is highly dependent on the quality of the retained water. Human intervention plays an important role in defining the quality of the retained water as expanding human populations have a large impact on the surrounding environment and the, quality of impounded water. The types and extent of human activities taking place in and around the dam will generally have an effect on the unique physical and chemical properties of water within the reservoir, thereby affecting the biodiversity and related functions thereof.

Therefore, the need for comprehensive water quality assessment and reporting tools including contamination susceptibility indices cannot be overemphasized. The study thus aimed at developing a contamination susceptibility index for the Goreangab dam by evaluating the effects of anthropogenic activities on surface water quality through the analysis of the physico-chemical properties of the water column and sediments, an aquatic invertebrate evaluation and pollution risk assessment, using the Pollution Load and the wastewater presence, recreational impact, agricultural impact, size of the watershed, transportation avenues, industrial impact and vegetative ground cover, (WRASTIC) indices.

Analytical experimental studies were used as references to methods employed in this research. Water, aquatic invertebrates and sediment samples were collected from 6 sampling sites, selected on the basis of their exposure to anthropogenic activity. The quality parameters investigated included dissolved oxygen, pH, total dissolved solids, chemical oxygen demand, temperature, electric conductivity and select heavy metals Pb, As, Fe, Zn, and Hg. Water and sediment samples were analysed using the Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) and X-ray fluorescence (XRF) methods respectively. These were compared to the allowable limits stipulated in the Namibian Water Act (Act No. 54 of 1956). With the exception of TDS, Electric Conductivity and COD all other physical parameters recorded levels below the national set standard.

Metal composition in the water column were all below the allowable limits, decreasing in the order Fe > Zn > Hg > Cd > As > Pb. The sampling stations upstream recorded higher average concentrations of metals in comparison to the downstream areas.

The Pollution Load Index (PLI) results indicated deteriorating quality of soil sediments for all sampling stations, with higher deterioration upstream as these areas were privy to sewage and wastewater effluent. The aquatic invertebrate inventory and identification results categorised upstream Goreangab dam as a seriously modified habitat with very poor water quality whereas the downstream areas were found to be moderately modified. The average heavy metal concentrations were found to be below allowable limits for most of the sampling sites. Based on bio-monitoring and soil analyses results, there was indication of poor and deteriorating water quality at all sampling stations.

The WRASTIC index indicated that the watershed was at high risk of contamination with a score of 51 and also identified five (5) of the sampling stations as risky areas serving as entry points for pollutants into the dam. The WRASTIC score is subject to a 3-year waver, indicating that the dam will be at a higher risk sooner as activity around the watershed continues to increase. The overall study results suggest that anthropogenic activity is a major factor in the contamination of the watershed and contributes greatly to its vulnerability. Regular screening

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of the Goreangab dam for sources of pollution will need to take place, along with continuous quality monitoring and assessment for the successful protection and restoration of the dam.

1. Introduction

1.1. Anthropogenic activities and surface water pollution

The contamination of water resources in highly populated areas has become a global concern, limiting the resources' availability. The presence of both inorganic and organic contaminants in water bodies may result in several health problems and in certain cases, lead to the entire loss of aquatic ecosystems (Bartzas et al., 2015). The impacts of surface water contamination are more noticeable in arid areas, as they continually experience rainfall shortages, high evaporation rates and in various cases (e.g. in Sub-Saharan Africa) lack adequate water storage facilities (Du Pisani, 2004). Pollution of water resources is one of the most clamant issues affecting our ecosystem and nearly all fresh water bodies are at risk of contamination due to human population expansion and developmental activities in and around them (Bordoloi and Baruah, 2014).

The quality of freshwater at any point on a landscape reflects the combined effects of many processes along water pathways (Wildi et al., 2010). Surface waters are most exposable to anthropogenic pollution, due to the accessibility for the disposal of wastewaters (Ali et al., 2016). Anthropogenic influences are known sources of water pollution and include urban, industrial and agricultural activities, (Snaddon, 1998). Population growth, followed by an increase in the number of settlements and the growth of industry, particularly along watersheds, that dump waste into surface waters, cause a decline in the quality of surface waters (Masere et al., 2012).

The decrease in water quality does not only prove to be expensive when it comes to treatment and possible reclamation, poor water quality is also detrimental to human health (Meybeck and Helmer, 1996). Surface water pollution has thus become a major concern across the world (Ali et al., 2016). Due to extensive anthropogenic inputs of nutrients, sediments and other water contaminants, the quality of surface water has deteriorated in many countries in the past few decades, (Mohammed A, 2014). New approaches towards achieving sustainable water resources management have thus been developed internationally (Sikder et al., 2015). Quality monitoring and pollution risk assessment of water resources have therefore become keynote procedures in the global agenda for environmental protection.

Water resource systems are subject to different impacts by anthropogenic pollution. Their intrinsic susceptibility to pollution may not allow them to resist pollution impacts brought about by the different types of contaminants that access the system (Diamantino et al., 2007). Quantifying water quality in a specific grade by using dominant parameters is therefore important, as this can explain the current extent of pollution with accuracy. The use of water contamination indices is therefore critical in the protection, assessment and restoration of water quality for catchment areas (Sikder et al., 2015). Vulnerability assessments and water quality indices are considered as key elements in the sound management of water resources (Sikder et al., 2015; Yan et al., 2015), as they can be used to simplify expressions of complex sets of pollution variables in the rivers, streams and lakes (Sikder et al., 2015).

Assessing the susceptibility of water resources to contamination is essential in that, it is not only a function of the intrinsic properties of the water flow system, but also of the proximity of contaminant sources and their particular characteristics that potentially increase the load of specific contaminants in aquifers (Bartzas et al., 2015). Pollution risk assessment is a tool which aids in identifying targets by recognizing hazards, assessing their severity and prioritizing them so as to find ways to tackle them (Liu et al., 2018).

1.2. WRASTIC and pollution load index

WRASTIC is a pollution risk assessment method that was developed by the New Mexico Environmenttal Department Drinking Water Bureau (NMED/DWB) for the evaluation of watershed susceptibility to surface water contamination in any hydrogeologic setting based on major watershed characteristics and land uses (Report of New Mexico Water Utility Public Water System # 12345 New Mexico Environment Department -, 2004). The WRASTIC Index is the only method that offers a free location overall assessment of the risk status of a surface water body by grading up to seven different parameters which include human and animal wastewater, entertainment and recreational activities, agricultural and industrial activities, size of the area, road and transportation and vegetation density (Diamantino et al., 2007; Mirzaei et al., 2016). WRASTIC is very effective as a rating system for surface water bodies, as it determines the susceptibility of a water system to pollution. The method helps water resource planners and managers in assessing pollution vulnerability and identifying risk areas related to different pollution sources (Rud, 2019).

Sediments are important sinks for trace metals. They also act as a non-point sources of pollution and have the potential to release the sediment-bound metals and other pollutants to overlying waters, in turn adversely affecting aquatic organisms. Testing of both water and sediment samples within a waterbody is therefore essential in obtaining a more defined picture of its quality and health (Goher et al., 2014). The Pollution Load Index (PLI) technique is used to assess heavy metal contamination in a study areas sediment. The method takes into account the metal concentration in individual samples, the number of metals investigated and a contamination factor, giving an accurate overview of the sediment health in a water body. The contamination factor is the ratio of the metal concentration in comparison to the background value (value of the metal equal to the world surface rock average). The PLI, positively demonstrates simplicity as the results are easily interpreted, a PLI value greater than one (>1), is indicative of a polluted reservoir whereas a PLI less than 1 ($<$) indicates minimal pollution risk.

1.3. The Goreangab Dam

Namibia is considered to be the driest country in sub-Saharan Africa (De Bruine and Rukira, 1997). The average annual rainfall in Windhoek, the country's largest city, is estimated at approximately 360 mm/annum, and these are limited to convective showers during the rainy season which generally lasts from October to April (De Bruine and Rukira, 1997; Du Pisani, 2004). This is coupled with high evaporation rates averaging 3400 mm/annum, which result in fresh water resource deficits over most of the country (Du Pisani, 2004). Windhoek is reliant on three surface water dams, for approximately 70% of its potable water with the Goreangab Dam supplementing irrigation (Du Pisani, 2004; Lehmann, 2010). Due to the excessive pollutant emissions, the water quality of the Goreangab Dam has failed to meet the national standard criteria (Du Pisani, 2004; De Bruine and Rukira, 1997). Pollution is therefore a notable factor placing stress on the water scarcity issue experienced in the country (Lehmann, 2010).

In 2004 it was reported that the quality of the Goreangab Dam water had deteriorated to a point where the raw water design parameters were far exceeded, and that usage thereof would result in unsatisfactory final water quality specifications (Du Pisani, 2004). There are currently no scientific studies highlighting sources of pollution or the continued deterioration in water quality of the Dam. Moreover, there is no information on the vulnerability status of the reservoir (which is crucial for holistic monitoring, control and protection of the reservoir), correlation of the reservoirs water quality to surrounding anthropogenic activity or the risk they pose to the Dam; most studies focus on comparison of the physico-chemical parameters with water quality standards. This study therefore, focused on determining the susceptibility level of the Goreangab Dam to contamination by making use of the WRASTIC index and other pollution risk assessment methods, identifying, the possible sources and level of contamination and identify entry ways of contaminants into the catchment.

2. Materials and methods

2.1. Study area

The Goreangab Dam is situated in the north-western suburbs of Namibia's capital city, Windhoek. It dams the ephemeral Arebbusch River, its tributary as well as the Gammams River, which both run across Windhoek. The dam lies between 22° 31′ 0″ S latitude and 17° 1′ 0″ E longitude, with a total surface area and height above sea level of 1.1 km^2 and 17 m respectively, (Ogunmokun et al., 2000).

The location of the Goreangab Dam can be seen in Fig. 1 below.

Land use within the catchment area is predominantly urban and a significant proportion of the catchment area is dominated by low cost and informal residential areas. Industries, inflow from the Gammams River and residents around the dam area, have been among the greatest contributors of pollution loads to the dam over the years (De Bruine and Rukira, 1997). Ogunmokun et al. (2000) noted that the water quality of the dam has drastically deteriorated due to contamination by organic pollutants from the river beds, rendering the dam water unusable as a water source for the city, as it had previously been.

2.2. Catchment assessment/physical observation of possible sources of contamination

Catchment assessment was the primary activity conducted for this study and it formed the basis for selecting the sampling stations. Transient walks were undertaken along the catchment area to observe different anthropogenic activities taking place in and around the dam. Sampling points were selected based on their exposure to anthropogenic activity during catchment assessment, the WHO checklist and tables for catchment assessment manual was used in this study. The activities were recorded as a means to establish the extent of their contribution to the deteriorating quality of the dam water, as they are considered to be sources of anthropogenic waste.

Various anthropogenic activities were noted from the catchment assessment these included, car washes, dumping of waste and wastewater by the informal settlement residents, open defecation, agricultural, industrial, and farming activities taking place in close proximity to the study area. Other factors observed included signs of soil erosion, burst sewage pipes and recreational activities taking place within the dam area. The selected sampling points can be seen in Fig. 2, below. Fig. 3 shows visible eutrophication at sampling point 5 at the Goreangab Dam. Fig. 4 shows raw sewage water from a broken pipe flowing into the Goreangab Dam.

2.3. Sampling

The grab sample technique was used to collect water samples every two (2) weeks for a period of three (3) months from six (6) selected sampling points across the Goreangab Dam. Samples were collected during the rainy season, as inflow was at a maximum (295.8 mm). A total of two samples were collected at each site during every sampling campaign. This comprised of a surface sample and a bottom sample (1 m deep and close to the dam floor). This was done to document any physico-chemical differences between the two samples, as impurities tend to settle at the bottom of the dam. Physical parameters such as pH, dissolved oxygen, chemical oxygen demand, temperature, salinity and electrical conductivity were measured on site using a Hach Pocketpro + multi-meter and the water samples were immediately acidified with 2 ml concentrated HNO_3 for sample preservation. The samples were then placed in a cooler box with ice packs before being transported to a laboratory for analysis.

Sediment samples were collected using hand auger equipment from the top of the dam floor in compliance with the International Atomic Energy Agency protocol. A total of 24 samples were collected from the six (6) sampling sites. Four (4) sediment samples were collected from each sampling site every month from January–April 2018. The lapses in time were given to allow the sedimentation of possible pollutants present. It was important to collect undisturbed surface sediments so as to note the effects of the present events on its quality. The soil samples were taken to the Ministry of Mines and Energy laboratory for XRF analysis of metal concentrations. The soil samples were heated at 105 °C for 24 h in an oven before being pulverized and subjected to the Portable XRF Analyser for determining the concentration of metals present.

2.4. Aquatic invertebrate inventory & identification for observation of aquatic invertebrates

Aquatic invertebrates were collected from all six sampling stations. Due to their short life cycles and relative immobility, macroinvertebrates are great biological indicators for reservoir health. The benefit of a short life cycle means that recent changes in water quality are reflected in the macroinvertebrate population. Whereas relative immobility indicates difficulty in relocation. Aquatic macroinvertebrates cannot quickly move to another habitat if the one they reside in becomes polluted. This rather stationary life creates great opportunity to use them for water quality assessment.

A wooden handle sweeping net was used to collect samples. Samples were collected after physically disturbing the area for about 5 min,

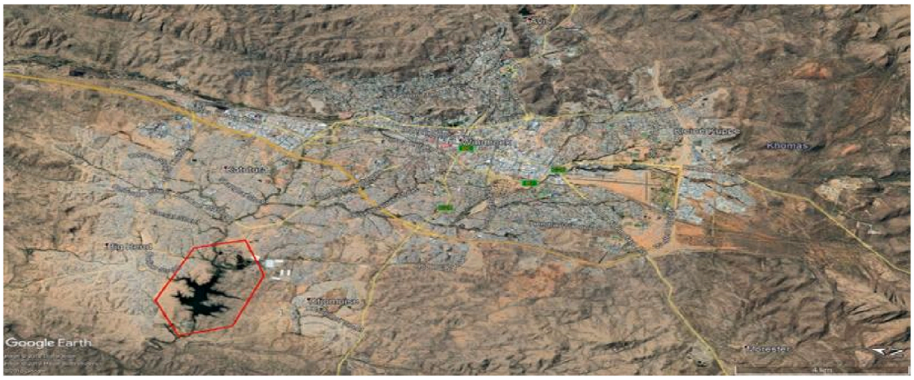

Fig. 1. Location of the Goreangab Dam in Windhoek.

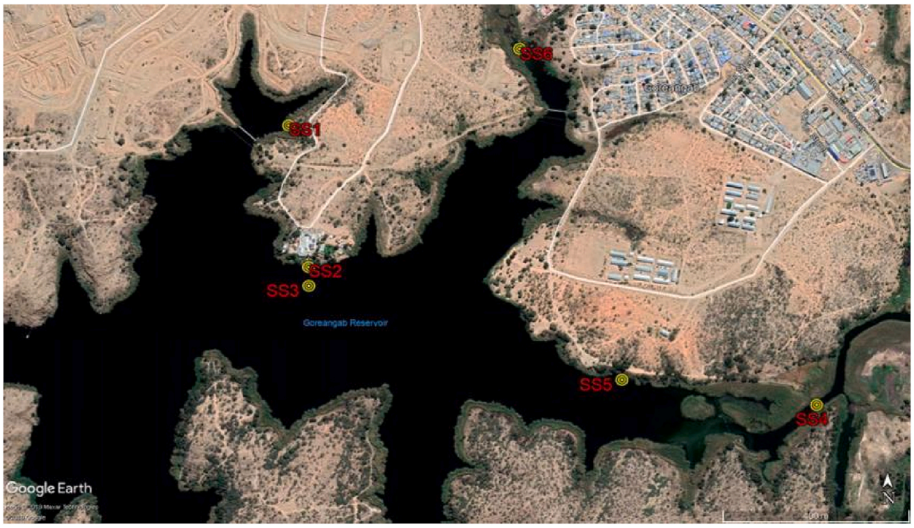

Fig. 2. Sampling points at Goreangab Dam.

Fig. 3. Visible eutrophication at the Goreangab Dam.

Fig. 4. Raw sewage water flowing into the Goreangab Dam.

before using the scooping net. This was done for three different habitats being the rocky, sandy and vegetation types. The samples were then rinsed and the content was placed onto a white plastic tray and group invertebrates identified using the Dichotomous key and magnifying glass for identification of very small invertebrates. The invertebrates that were identified on location were placed in sample cells with Ethyl alcohol for detailed identification in the laboratory.

2.5. Laboratory & data analysis

Water samples were analysed according to the US Standard methods for the Examination of Water and Wastewater (Eaton, A. D., Clescreri, L. S., & Greenberg, 1999). The samples collected from all 6 sampling sites were analysed for heavy metals. Samples were analysed by ICP-OES, which is the abbreviation for Inductively Coupled Plasma Optical Emission Spectrometry, it is a type of optical emission spectrometry. ICP-OES is mainly used for samples with high total dissolved solids (TDS) or suspended solids, making it a great method for analysing ground water, wastewater, soil, and solid waste and drinking water.

Samples were analysed for lead, copper, mercury, cadmium, iron and zinc with a Thermo Scientific-iCAP 6000 series (ICP-OES) spectrometer. The carrier gas used was argon (Ar) with combustion taking place at 10 000 K. Detection limits for the three heavy metals measured by ICP – OES were set as follows: Fe (0.022 ppm), Pb (0.002 ppm), Ni (0.001 ppm), As (0.06 ppm), Cd (0.0005 ppm) and Zn (0.0009 ppm).

Sediment samples were processed and analysed at the Ministry of Mines and Energy laboratory, by means of a using a Thermo Scientific XRF Niton XL3t 950 model analyser. Sediment analysis was conducted using XRF (X-ray fluorescence), which is a non-destructive analytical technique used to determine the elemental composition of materials. XRF analysers determines the elemental chemistry of a sample by measuring the fluorescent/secondary X-rays emitted from a sample upon its excitement by a primary X-ray source.

2.6. Data analysis

2.6.1. Analyses of water and sediments quality data

Statistical analysis of raw data was conducted to determine the means and standard deviation for both water quality parameters and sediments characteristics. Pearson's (r) correlation was used to determine how closely the physical and chemical parameters were related. Correlation matrices were also used to determine which of the heavy metals co-existed with one another, what their likely sources were and if metals in the sediment and the water column were co-effective in the dam. The PLI & CF levels were calculated to determine metal contamination levels from the sediment samples collected at the dam. Invertebrate analysis and the WRASTIC index were used to determine the health status of sampling stations and to determine its vulnerability to pollution as well as to identify risky regions in the dam, respectively.

Raw data for soil samples was also validated using Descriptive Statistics. The XRF data was analysed using the PLI method to quantify the relativity of the pollution levels amongst the different sampling stations. The actual observations were then divided with the background geochemical values of each heavy metal to compute the Contamination Factor (CF) and Pollution Load Index (PLI) using e equation (3.1) and (3.2) shown below.

$$CF = {}^{SampleConcentration}/_{BackgroundConcentration} \tag{3.1}$$

$$PLI = (CF_1 \times CF_2 \times CF_3 \ldots\ldots\ldots CF_n)^{1/n} \tag{3.2}$$

where n is the number of metals being investigated.

2.6.2. Analysis of invertebrates and risk assessment data

An Aquatic invertebrate identification and inventory was conducted to measure the biological condition of the dam. The mini SASS uses the Average Score to measure the biological condition of the water body and this scoring system was used as a point of reference during this study. By marking the sample invertebrates' species off the group list, the sensitivity scores are added up and then divided by the number of groups identified at each sampling site to get the average Score. The Average Score is then used to interpret the health status of the particular site by comparing the obtained data to reference Ecological Categories which indicate the sensitivity level of each group of species to pollution. The deterioration of a water system is directly proportional to the decrease of aquatic invertebrates found in the system.

From the water samples, mean concentrations and correlation coefficient of heavy metals were used to relate their concentration to the conditions and activities in proximity to sampling stations. Also, for heavy metals in sediment the mean concentration and correlation coefficients were used to assess the presence of metals in relation to the sampling stations and their co-existence with other metals. CF and PLI were also used as indicators for assessing the contamination level of metals with respect to sampling stations, in addition to the WRASTIC index.

2.6.3. The WRASTIC index

To evaluate watershed susceptibility to surface water contamination the WRASTIC index was used. The sensitivity rank to pollution considers three categories, i.e., high, moderate and low sensitivity of the surface water system. In the WRASTIC method, 7 parameters as wastewater presence namely (W), recreational impact (R), agricultural activities (A), size of the watershed (S), transportation paths (T), industrial impact (I) and vegetation cover (C) are investigated. A value between 1 and 5 is determined for each parameter except for case I (Industrial Impact), which varies from 1 to 8. These parameters are weighted and combined to indicate the overall vulnerability of the watershed to contamination. The equation for determining the WRASTIC Index for any watershed is:

$$\text{WRASTIC Index} = \text{WRWW} + \text{RRRW} + \text{ARAW} + \text{SRSW} + \text{TRTW} + \text{IRIW} + \text{CRCW} \tag{2.1}$$

where: R = Rating factor and W = Weight factor.

The higher the WRASTIC Index total, the higher the surface water pollution potential.

3. Results and discussion

3.1. Physico-chemical parameters

3.1.1. pH, temperature and chemical oxygen demand

The pH is an important variable in water quality assessment as it influences many biological and chemical processes within a water body, and all processes associated with water supply and treatment. It also affects the solubility of many chemicals. The recorded pH levels for all the sampling stations were acidic throughout the sampling period. Sampling site 2 (SS2) proved to be the most acidic with an average pH value of 4.96 whereas Sampling site 4 (SS4) recorded the least acidic average.

Despite variations between and within the different sampling stations, all pH values measured were within the maximum permissible limit of 11 as stipulated by the National Standard. No alkaline conditions (high pH values, above 7) were recorded at any of the sampling points during the duration of the study. Consumption of such acidic water could have adverse effects on the digestive and lymphatic systems of humans. The recorded surface water results are in agreeance with the fact that Windhoek is a fast-growing industrial location, of which such areas are generally characterized by high presence of CO_2 and SO_2. Acid rain is resultant of the mixture of these compounds with rain water. pH is primarily controlled by the balance between carbon dioxide, carbonate and bicarbonate ions as well as other natural compounds in polluted waters. Changes in pH can indicate the presence of certain effluents, particularly when continuously measured and recorded, together with the conductivity of a water body. The acidity of the dam can therefore be attributed to acidic rain, release of carbon dioxide from bacteria in the water or storm water runoff.

Chemical oxygen demand (COD) is one of the most important parameters to use for determining the degree of pollution of domestic and industrial waste water. It is also one of the most commonly used parameters in studying environmental pollution. The average COD values measured during the sampling period were between 592 and 851 mg/l. The low level of DO indicates pollution in the Goreangab Dam water. Therefore, high COD values are also expected, which is indeed observed in the comparative average values of the different samples (Fig. 5), with samples indicating a high level of organic pollution in the Goreangab Dam.

The high Chemical Oxygen Demand (COD) could be due to the reduction in the required retention capacity caused by silt build-up and organic overloading in the dam. Silt build-up and organic overloading could be attributed to wastewater flowing into the dam from the Gammams wastewater treatment plant (SS4), as well as the occurrence of car washes and domestic activities taking place at SS6. The high concentrations of COD measured at the dam are suggestive that there are various sources of organic matter possibly from the anthropogenic activities taking place around the dam e.g. sewer manholes spillages, car washes, recreational activities and buildings located along the Gammams river and the Goreangab Dam itself. In addition, bacterial decomposition rates are decreased with lowering of temperature levels which in turn result in higher residual COD levels.

Temperature also has an impact of several physical parameters such as the pH and solubility of gases in water, which generally decreases with an increase in temperature. Higher temperatures observed upstream and at SS2 (downstream) is as a result of exposure to the suns radiation, as the areas are well exposed to the atmosphere with not much overhead vegetation. Several external factors could also have an effect on temperature such as sample time collection. Samples collected in the morning would generally have lower temperatures than samples collected at noon. The lower temperatures recorded downstream were likely caused by the mixing of water as well as cooling affects brought about naturally by wind. Heat is also lost to the atmosphere. The average Temperature measurements are presented in Fig. 6, below.

3.1.2. *Electrical conductivity and total dissolved solids*

Total Dissolved Solids (TDS) give an indication of the presence of inorganic salts and small amounts of organic matter in water whereas Electrical Conductivity (EC) can be defined as the measure of a water body's capacity to conduct electrical current. The sources of material in TDS and EC can come from nature, i.e. geological condition and seawater, and from human activities, i.e. domestic and industrial waste. Electrical Conductivity (EC) is directly proportional to TDS, this is due to the presence of both charged and uncharged ionic species in water. These species increase the level of dissolved substances in the water system. Both TDS and EC indicate the presence of mineral salts.

The highest average amounts for both EC and TDS were recorded at (SS1), which is an inlet to the Goreangab Dam. Elevated TDS readings can be attributed to various, possibly human induced sources of ions such as fertilizers from lawns, runoff from roads and organic matter from wastewater treatment plants. Fig. 7 shows average EC and TDS levels measured during the sampling period.

3.1.3. *Heavy metals*

Iron presented the highest level of metal detected during the sampling season. Iron exists naturally in rivers, lakes, and underground water. It may also be released to water from natural deposits, industrial waste, refining of iron ores, and corrosion of iron containing metals. The combination of naturally occurring organic material and iron can be found in shallow wells and surface water. The relative high value of iron at the dams' inlets average at SS6 = 4.32 mg/l and 0.44 mg/l at SS4 is suggestive that it may be due to the corrosion of metal along the incoming waterways.

Arsenic and Lead were the least detected heavy metals across all sampling stations. All sampling stations recorded average values well below the National Standard of the 1956 Water Act for both metals. Lead was only detected at two sampling stations, SS5 and SS6, with the latter being the higher of the two average values at a concentration level of 0.0071 mg/l. The presence of Pb is probably from gas stations. Arsenic is mobilised in the environment through a combination of natural processes such as weathering reactions and biological activity, as well as through a range of anthropogenic activities such as the combustion of fossil fuels.

Zinc within the water column, was detected at every sampling station. Two of the sampling stations (SS2) and (SS3) recorded values below the set national limit. All other sampling stations recorded an average zinc value above the National Standard of the Water Act 1956, SS6 recorded the highest average zinc concentration of 0.166 mg/l. According to Fernandez-Iuqueno et al. (2013), the presence of zinc in a water system can be attributed to the use of fertilizer around and upstream of the Goreangab dam. The high concentrations of zinc at the dams' inlets may be of industrial origin as the Gammams river flows through an industrial area transporting waste into the dam. Other sources for the zinc include steel production (motor vehicle mechanics use steel) or from the burning of waste materials which occurs in certain areas around the Goreangab Dam.

The highest values for Mercury were recorded for sampling stations SS1-SS3. The sampling points (SS1-SS3) are all located downstream from the inlets into the dam. Mercury occurs naturally within the earth's crust and combines with other elements to form inorganic mercury compounds. Therefore, the major source of mercury in the Goreangab

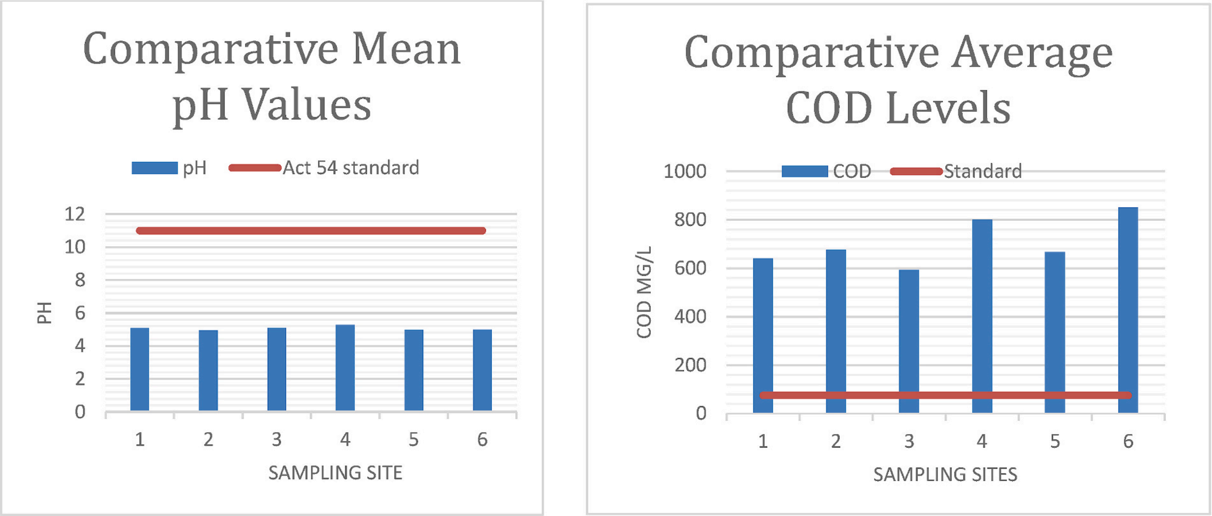

Fig. 5. Comparative average pH and COD concentrations at Goreangab Dam.

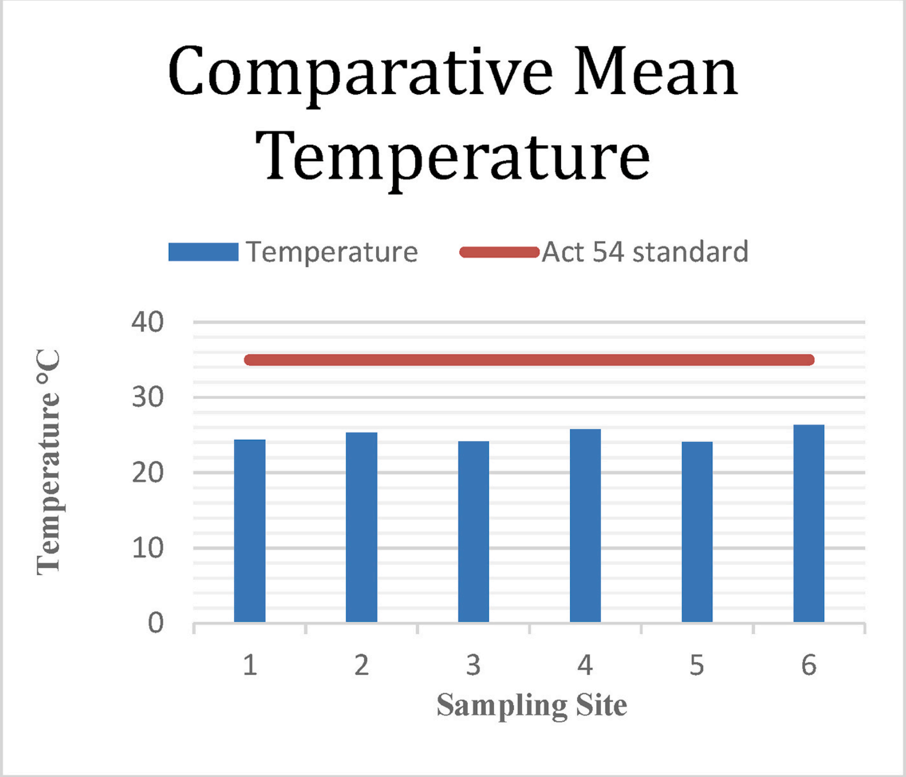

Fig. 6. Comparative average temperatures of the Goreangab Dam.

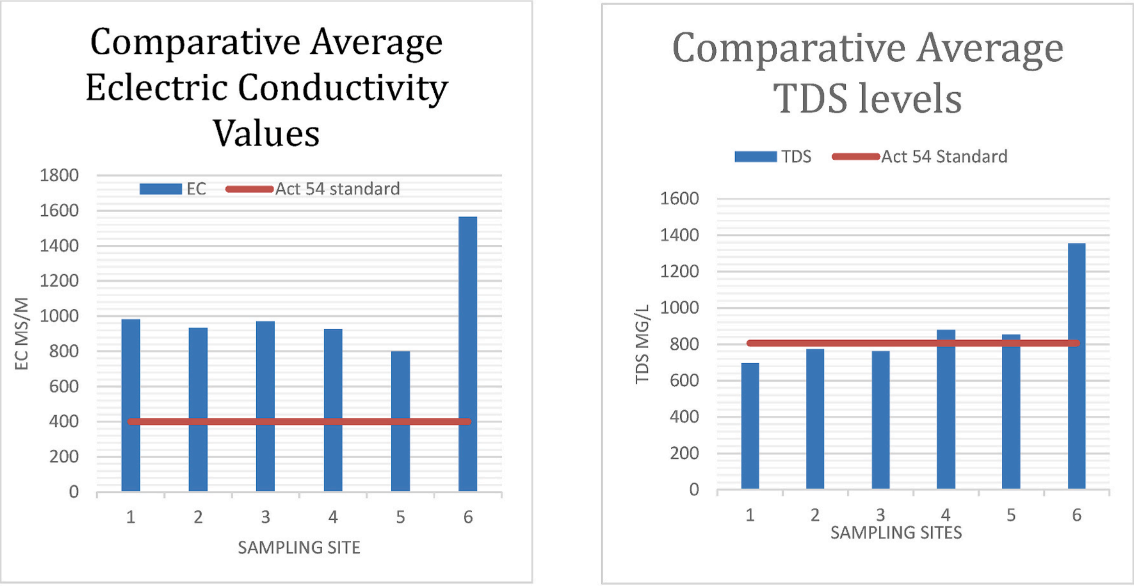

Fig. 7. Comparative EC and TDS values.

should be from the natural degassing of the earth's crust. The presence of mercury in the dam, by way of anthropogenic activities could be attributed to the dumping of household waste along the banks of marshes and rivers flowing into the dam (SS4 & SS6). The use of mercury is known to be widespread in industrial processes and in various household products (e.g. batteries, lamps and thermometers).

Cadmium was detected across all sampling stations, except SS3 (See Fig. 7). Cadmium is found in water supply systems as a result of the deterioration of galvanized plumbing, industrial waste contamination, or certain fertilizer. Overall, most metal concentrations ranged below the stipulated National standard. However, dilution could have influenced the obtained results. Sampling occurred during the summer/rainfall season and the flow of rainwater into the dam could, thus have played a role in diluting metal concentrations in the dam. Comparative iron, zinc, mercury and cadmium levels can be seen in Fig. 8, below.

From the study data it was observed that heavy metal concentrations decreased in the order SS4 > SS6 > SS5 > SS2>SS1>SS3. The concentrations of As, Fe, Pb and Zn in the water samples, are highly correlated across all sampling sites. Hg and Cd shared a moderate non-linear relationship, indicating that it was very unlikely that they were from

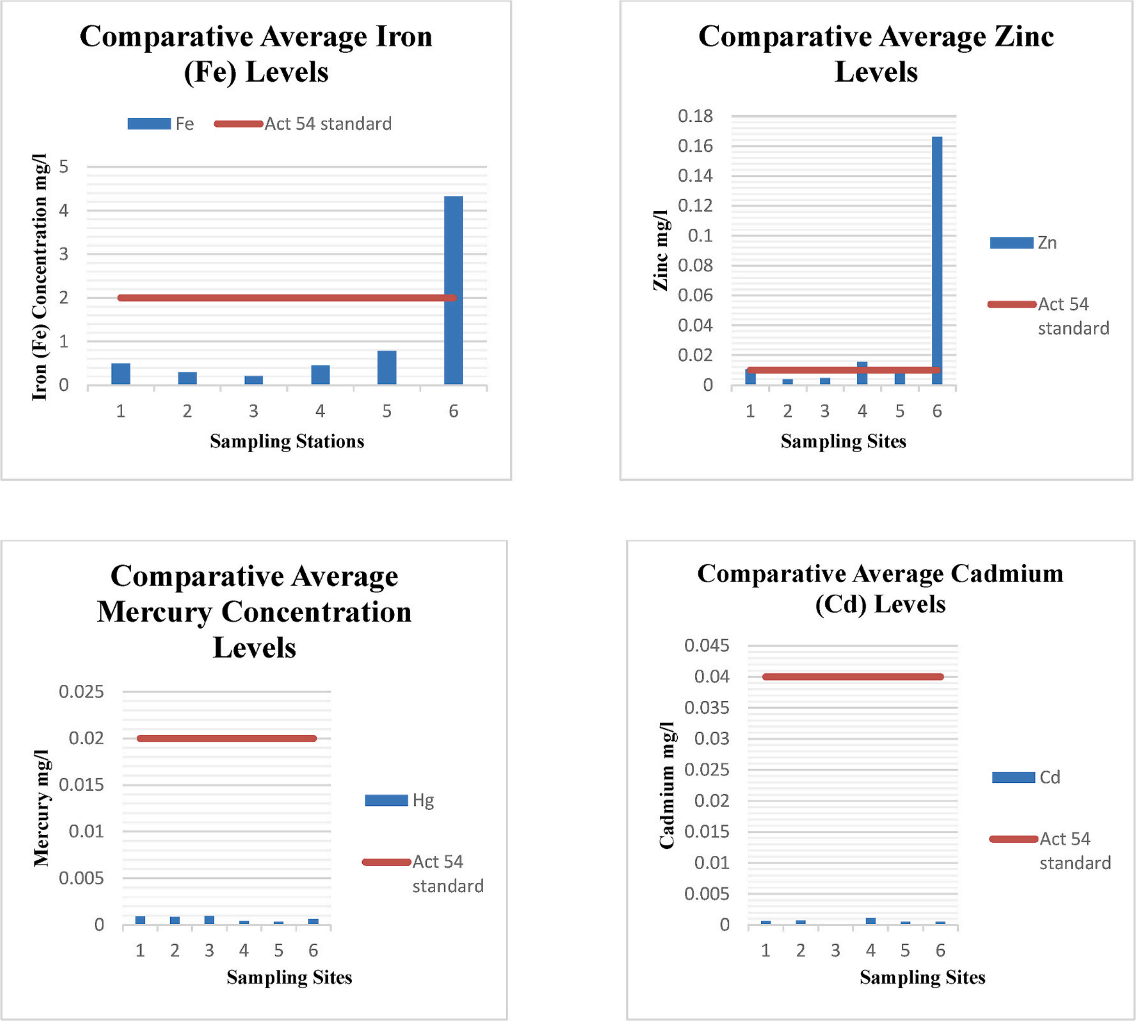

Fig. 8. Comparative Iron, Zinc, Mercury and Cadmium levels.

the same source, however they had no correlation to any other metal. The study further indicated that the concentration of the heavy metals at the Goreangab dam was higher at the inlet sampling stations in comparison to the sampling stations further downstream.

3.2. *Correlation between metal occurrence in the water column and physical parameters*

Table 3.1. Indicates the strong correlation that exists between most of the physical parameters and heavy metals found in the sampled water. However, dissolved oxygen and pH showed a strong non-linear relationship and no correlation at all respectively. From the actual observations, the mode pH value is 5.36 which is indicative of an acidic water system. As a water body becomes more acidic, the number of fish and aquatic plants generally decrease. The physical results thereof, demonstrate that there is a deterioration in the quality of the reservoir. Low DO levels were observed through all the sampling stations. The low dissolved oxygen levels are often a casualty of excessive algae growth caused by phosphorus. The Goreangab catchment can therefore be described as eutrophic. Eutrophication leads to inadequate decomposition within the water column which causes a decrease in the amount of oxygen available to organisms. The high levels of COD at the different

Table 3.1
Correlation between chemical and physical parameters in water.

	Fe	*Cd*	*Zn*	*As*	*Pb*	*Hg*	DO	TDS	Temp	EC	COD	pH
Fe	1											
Cd	−0.08	1										
Zn	0.99	−0.06	1									
As	0.88	−0.38	0.9	1								
Pb	0.99	−0.11	0.99	0.91	1							
Hg	−0.17	−0.46	−0.1	−0.01	−0.11	1						
DO	−0.91	−0.07	−0.9	−0.8	−0.89	0.52	1					
TDS	0.95	−0.27	0.95	0.87	0.96	0.07	−0.77	1				
Temp	0.65	0.53	0.7	0.49	0.66	−0.2	−0.67	0.74	1			
EC	0.93	−0.13	0.96	0.89	0.95	0.12	−0.76	0.88	0.7	1		
COD	0.73	0.55	0.75	0.54	0.71	−0.5	−0.83	0.82	0.92	0.66	1	
pH	−0.33	0.37	−0.3	−0.14	−0.32	−0.1	0.19	−0.22	0.12	−0.2	0.14	1

sampling stations is indicative that there are large amounts of oxidizable organic material in the water, thereby leading to reduced DO levels. The High EC and/or TDS levels demonstrate the presence of dissolved inorganic substances within the water system. All other physical parameters were within the National Standards' set limitations however this does not mean that they do not interact effectively in the dam water with one another.

3.3. Sediment quality

3.3.1. Metal presence in sediment

Various studies have shown that heavy metal concentrations are naturally higher in sediment than in water. This could be because the suspended sediment will absorb the pollutants from the water which then lower the concentration of the metals in the water column. pH is one of the parameters that will affect the share of bioavailable forms of metals in soil. The mean concentration of metals (Fig. 9) detected in the dam in decreased concentration order was found to be; Ni > Cr > Zn > Pb > Cu. About 87% of the select metals detected in the dams' sediments were above the EPA standards. Concentrations of the different metals varied amongst the different sites with sites (SS4), (SS5) & (SS6) generally having recorded the highest concentration levels for most of the selected metals. The relative high values of Cu in the dams upstream/inlet areas ranged from 37 mg/kg to 65.5 mg/kg, these values could be due to effluent from either a metal alloy industry or domestic effluent. The Goreangab dam catchment area is mostly used for irrigation and recreation, which are also contributors to pollution in the dam. With the former exacerbating the issue through extraction.

Chromium occurs in various forms, the most common being Cr (III) which occurs naturally in sediment, plants and animals, is its most stable form. Cr (VI) is a toxic form of the metal. The High levels of Cr in the Goreangab dam sediments can be attributed to industrial effluent carried into the dam during runoff. Chromium levels were excessively high with no significant fluctuations between the different sampling points. The highest mean Cr concentration level was recorded at the confluence of the Gammams River with the Goreangab dam (SS4) which was a staggering value of 400 mg/kg.

Ni and many other metals naturally exist in the earth's crust. The visible erosion and erosion along the river banks (Gammams River) could also contribute towards the metals' presence in the dam along with anthropogenic activities. High concentration Ni could be due to effluent from food processing industries where it is employed as a catalyst and pigment. The levels of Ni in the dams' sediments was much higher towards the downstream area of the dam, where sediments would generally have settled in much higher volumes as a result of run-off.

Goreangab dam showed significantly higher concentrations of Pb

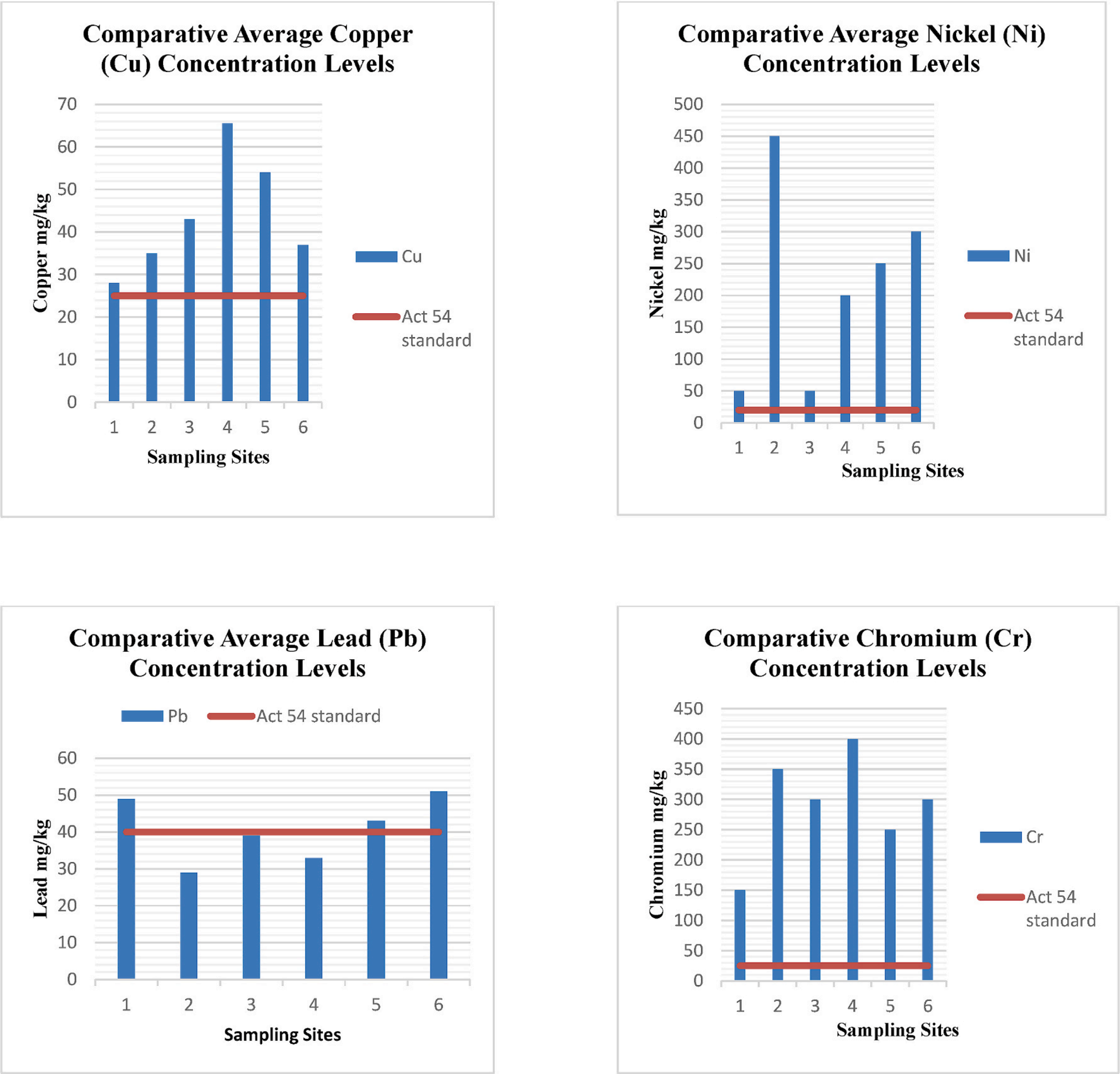

Fig. 9. Comparative average copper, nickel, lead and chromium concentration levels.

and Zn in the sediment than in the water. The dam is used as a recreation resort where motorboats are used on a regular basis for fishing and other recreational activities. This could be a factor that influenced the higher concentration of Pb and Zn within the catchment. There was also not much variation between the average amounts of metals recorded for the different sampling stations. The inlet areas at the dam (SS4) & (SS6) recorded average values of 33 mg/kg & 189 mg/kg, 51 mg/kg & 131 mg/kg for Pb and Zn respectively. The comparison of metal concentrations in the water body revealed that the amounts of elements accumulated in the sediments was several times higher than those in the water column of the dam itself, suggesting that the sediments of the Goreangab dam act as a sink for many pollutants entering catchment.

All metals recorded were present at high levels in the dams' sediment, with most exceeding the maximum allowable EPA levels. The entry ways to the dam, (SS4); (SS5) & (SS6), recorded the highest average values for most of the metals except for Nickel which was found to be highest further downstream at (SS2). The concentration of heavy metals in the upstream sampling stations appeared to be relatively high in comparison to those measured downstream. These results suggest that anthropogenic activities upstream may contribute greatly to the accumulation of heavy metals over time. Oil and grease (from barbecue areas/mechanics) were also evident during the sampling process at the upstream sites, where the soil samples were black in colour which were demonstrative accumulation as a result of direct dumping/spilling of greasy substances in those areas. Accumulation of industrial effluent in the sediments could also be attributed to unlawful discharge by relevant producing activities along the Gammams River.

3.3.2. Pollution load index (PLI)

The Pollution Load Index (PLI) was calculated from the contamination factor values of metals in the sediment samples. The contamination factor is a measurement of the level of contamination by given toxic substance (metals). The PLI gives an indication of site quality. The pollution load index provides simple comparative means for assessing a site or area quality (0.0) indicates perfection, 1.0 indicates only baseline levels of pollutants present and >1.0 indicates progressive deterioration of the site.

The PLI for this study indicated progressive deterioration for all sampling sites. This is indicative that the anthropogenic activities in and around the catchment area and along water systems flowing into the dam largely contribute to its pollution thereby increasing its vulnerability. Recreational activities, socio-economic activities, sewage, dumping of waste and agricultural activities that occur in close proximity to the dam all contribute to the deterioration in the dam waters quality. From sampling data, it can also be seen that entry ways into the dam are prone to contributing high levels of pollutants especially during the rainy season as there is no formal regulation with the dumping of waste along these pathways.

Bedload sediments are known to retain metals thereby resulting in soil contamination, which is directly linked to metals suspended in the water column. Although water samples indicated lower levels of metals the sediment samples proved otherwise. It is, however, very unlikely that ground pollution can occur in the dam due to soil attenuation properties. The Goreangab dam is primarily susceptible to eutrophication and the loss of habitat and aquatic species, as demonstrated by the study.

3.4. Biodiversity of aquatic invertebrates

Organisms will usually inhabit an area because the conditions provided by the said environment are conducive for their survival and allows for the reproduction of the aquatic species. Therefore, the absence of aquatic organisms in the water systems is an indication of poor water quality. The results of the study followed a trends similar to those observed by Ikhu-Omoregbe et al. (2014) who found re-establishment of aquatic organisms further downstream. The area is situated further downstream from the inlets into the dam and was characterized by much less anthropogenic activity. The site was also characterized by a high diversity of vegetation that provide an ideal habitat for most invertebrates which anchor to stems and roots of aquatic plants.

Of all the stations sampled, the True Flies and leeches were the most predominant invertebrates' present. The low levels of invertebrate diversity observed during the sampling season is suggestive that the selected sampling stations are more prone to pollution, resulting in the absence of invertebrates. These sites may therefore be classified as unhealthy in the order SS6>SS4>SS5>SS2>SS3>SS1, this also represents the level at which each of the sampling stations contributes to the pollution of the dam.

The ecological state of any water system is affected by both natural and anthropogenic activities, activities such as soil erosion, illegal dumping of waste, dumping rubble from construction sites etc. all have negative effects on the ecology of the water system. When waste is washed down a river during the rainy season it contributes to the sediment bedload and accumulation; adversely impacting the habitat of organisms inhabiting these waters. Harrison, Norris, & Wilkinson (2007) stated that upstream channel erosion can kill aquatic flora and reduce available habitat for benthic organisms. Apart from altering physical habitat, sand accumulation can also change the flow regime of the river which ultimately affects the composition of macro invertebrates. The existence of macroinvertebrates in the water body is mainly influenced by the distribution of food resources and availability as well as a conducive habitat. The absence of these will lead to the reduction of species biodiversity.

3.5. The WRASTIC index

In this study the WRASTIC index was used for risk assessment of water resource pollution, in this study. The equation for determining the WRASTIC Index for any watershed is given by Equation. (2.1): The higher the WRASTIC Index, the higher the surface water pollution potential. WRASTIC index uses very simple features that are weighted considering their influence in surface water pollution. From the results obtained in Table 3.2. The water quality of the Goreangab dam is of a poor quality as it is rated as being at a high risk of contamination with an index total of (51). Table 3.3 shows the Sensitivity/vulnerability ranks for the WRASTIC Index which were used to define the Goreangab Dams vulnerability to pollution. It should be noted that this criterion is subject to a three-year waver. According to the calculated index (51), the watershed is highly vulnerable to pollution with specific contribution from human activities on the hydrological environment. These being high volume of discharged sewage into the basin, high levels of recreational and industrial activities in the region, the small size of the watershed and the existence of transport routes along its tributaries. The adverse effects of land use change may also exacerbate the problem. Monitoring and controlling human activities in the watershed will be a necessity in improving the ecological conditions in the dam.

Table 3.2

Calculation of WRASTIC index for the Goreangab dam.

Studied Factors	Determined rate for the study area
Wastewater discharge (W)	Discharge of industrial wastewater into the river network (5)l
Recreational impact (R)	Motorized activity allowed on water (5)
Agricultural impact (A)	2 activities present (2)
Size of Watershed (S)	<38.85 km^2 (1)
Transportation Avenues (T)	State highway or other paved avenues through watershed area (3)
Industrial Impact (I)	Industry has a moderate discharge or moderate impact on surroundings (4)
Vegetative Cover (C)	35–50% Ground Cover (2)
WRASTIC Index for study area	51 (High Risk)

Table 3.3
Sensitivity/vulnerability ranks for the WRASTIC Index.

WRASTIC Index	Sensitivity Rank
greater than 50	high risk
26–50	moderate risk
Less than 26	Low

4. Conclusion

Based on the study results, the identified anthropogenic activities taking place in and around the Goreangab catchment included land clearing, operation of automobile repair shops, car washes, recreational activities, small-scale crop farming, irrigation, fishing, car washes, waste dumping, open defaecation, release of waste water from the Gammams Wastewater treatment plant and sewage from local residencies in the area. All six selected sampling stations proved to be pollution risky zones with the extent of contribution decreasing in the order SS4 > SS6 > SS5 > SS2> SS3>SS1 (upstream to downstream).

Excess nutrient loads, leading to eutrophication is one of the dominant issues in the catchment. The significant pressures relating to excess nutrients are primarily from waste water (domestic) and run-off during the rainy season. Hydro-morphological (or physical) conditions (including the input of high levels of fine sediment from storm water) and poor habitat quality was also a major issue in the dam.

The results obtained during the study (physico-chemical results, physical observations of eutrophication & visible pollution, WRASTIC index and PLI), have highlighted that there is significant work necessary to protect and restore water quality at the dam. Regular screening of freshwater sources for pollutants should take place on a regular basis. Based on these results obtained from the study and the conclusions reached, the following recommendations were formulated:

- Systematic investigation is recommended to monitor metal loading and change in the dams' sediment quality.
- Making use of mathematical models to predict the effects of planned mass construction on the ecological status of the dam and also on its water and sediments' quality, its content of heavy metals and the metals' mobility between the water and sediment, in addition to the lake biodiversity are necessary.
- Amongst the observed sources of pollution of the Goreangab dam, human activities such as defecation and dumping of untreated waste were very prominent. Thus, proper measures e.g. education, training, installation of mobile toilets and bins should be put in place to discourage the users from polluting the water in order to bring about improved health.
- The City of Windhoek should put systems in place to ensure that human activities and waste disposal complies with National Environmental Standards and National Standard Drinking Water Quality guidelines of domestic and industrial waste discharge.
- Continuous quality monitoring and assessment of aquatic ecosystems should be conducted at all freshwater systems. This will establish some checks and balances for pollution control through catchment risk assessment and biological monitoring of aquatic systems and also serve as a measure to protect and preserve the biodiversity of aquatic plants and animals within the catchment.
- Regulation and policing of illegal dumping of solid and liquid wastes in the dams' tributaries should be conducted thereby protecting their ecological integrity thus preventing pollutants from being transported to the Goreangab Dam.

Credit author statement

Deolfa Jose Moisès: Investigation, Resources, Compilation of Original Draft **Nnenesi Kgabi**: Conceptualization, Methodology, Review & Editing, Supervision: **Earl Lewis:** Co-supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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