

**MEASUREMENT AND COMPARISON OF REFRACTIVE INDEX OF THE
WATER SAMPLES COLLECTED FROM DIFFERENT SURFACE WATER
SOURCES IN NAMIBIA**

**A THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE**

OF

THE UNIVERSITY OF NAMIBIA

BY

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22 September 2015

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ABSTRACT

Refractive index is an important optical parameter that exhibits the optical properties of materials. Single-Diffraction Method (SDM) and Abbe's Refractometer Method (ARM) have been used for the measurements of refractive indices of twelve water samples collected from different surface water sources in Namibia. SDM employs a diffraction grating, rectangular glass cell and Ne-He laser emitting a monochromatic light of 632.5 nm. Refractive indices of water samples were measured without knowledge of refractive indices of the diffraction grating and the rectangular glass cell, and without measuring the angles of refraction, reflection and diffraction of the laser light. Experimental values obtained for refractive indices of the twelve water samples are presented. By comparison of refractive index values from SDM and ARM, their refractive index uncertainties values were lower than 0.1. This uncertainty error could be attributed to SDM instrument limitation error. More-over, turbidity, salinity, hydrogen ions (pH) and density values were measured for the water samples. From the statistical model, there exist non linear regression between salinity, pH and turbidity and the results from refractive indices from both methods. However, a linear correlation between SDM and ARM refractive index values was found to exist. Moreover, the correlation seems to exist between refractive index and density of water samples which is more notable in sea water samples. The root test was found to be 0.9535~1 for refractive index measurements from SDM and ARM.

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ABBREVIATIONS

UNAM: University of Namibia

SDM: Single-Diffraction Method

DDM: Double-Diffraction Method

ARM: Abbe's Refractometer Method

TDS: Total Dissolved Salts

EC: Electrical Conductivity

NAMWATER: Namibia Water Supply

UV: Ultra-Violet

NI: Near- Infrared

TIR: Total Internal Refraction

EM: Electro-Magnetic

He-Ne: Helium Neon

Ne-lamp: Sodium Lamp

GPS: Global Position System

n_{2a} : Refractive index from ARM

n_{2g} : Refractive index from SDM

S: Sample

LIST OF CONSTANTS

$$\epsilon_0 : 8.854 \times 10^{-12} \text{F/m}$$

$$e : 1.602 \times 10^{-19} \text{C}$$

$$\pi : 3.142$$

$$c : 3.0 \times 10^8 \text{m/s}$$

$$m_e : 9.109 \times 10^{-31} \text{kg}$$

ACKNOWLEDGEMENTS

First of all, I would like to acknowledge my supervisor Prof Shyam Singh for the effort and sleepless night we invested in this work. Secondly, I would like to acknowledge financial support from the NJSTP for NSFAP of Namibia for providing me with a grant that helped me to carry out this thesis work. I would like to appreciate the Dr R Steenkamp (HOD: Physics Department), Dr M. Backes, Mr. E. Tjingaete, Mr. E. E Taapopi and the entire department members for their support in many different ways to this thesis. Thanks you Dr Heike Wanke who helped with some of the instruments that were used to measure some of the data. Finally, Thanks to the University of Namibia for helping me with research funds for attending an ALOP workshop in Mauritius, and providing fuels, accommodation as well as transport that was used in the field for collection of samples.

DEDICATION

This thesis is dedicated to Ndinelao Laningaombala Shafudah. It was a great opportunity to have a lovely sister who has been exceptionally doing well in the house especially taking care of my parents at the farm. The effort that Ndinelao put in deserves dedication for this important piece of work. Thank you very much lovely sister for the good smiles you have given me and your effort to prepare breakfast upon returning from the field.

Thanks to my parents Matheus Josephina and Moses Shafudah for taking care of me and allow me to develop as a student throughout my career especially at University level by investing your energy and motivational words. Lastly, I dedicate this thesis work to friends due to the effort in introducing me to the word of God in my life at the time of my thesis writing.

May almighty God bless you all!

DECLARATIONS

I, Shafudah Natangue Heita, declare hereby that this study is a true reflection of my own research, and that this work, or part thereof has not been submitted for a degree in any other institution of higher education.

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Shafudah Natangue Heita

1. INTRODUCTION

1.1. Orientation of the proposed study

Optics is a branch of physics which deals with the study of light propagation in materials. The propagation of light rays is due to the change in the state of a new medium. Refractive index is an important optical parameter to analyse light rays traversing through media (Ariponnammal, 2012). These light rays can be from Ne lamp, re-directed sun light beam, laser beam and so on. Refractive index is used in the study of materials, chemicals, water purification, health examination and solid state physics, just to mention a few.

Moreover, refractive index is an important characteristic component among other physical constants that can help with preventing adulteration in liquids as this physical parameter varies with different liquids, solids and impurities (Singh, 2013). Specifically, a recent economic study carried out employs the use of refractive index in the prevention of oil adulteration during the refinery of oil in the energy industry (Ariponnammal, 2012).

There are various methods available for the measurement of this parameter and most of these methods have been reported in most literatures in the last fifty decades. To the benefit of this research and its study, some of the traditional methods that were employed for the measurements of refractive indices of samples are simple and efficient to use (Singh, 2004). However, not all the methods discussed in literatures are accurate enough for the measurements of refractive indices of materials and

liquids. In addition to that, some of the available optical techniques such as spectrometer and telescope are generally too expensive to measure refractive index and some of them need additional parameters for determination of refractive indices of samples (Singh, 2004).

An inexpensive method for measuring refractive index of liquid by using two hollow prisms was also reported in the last decade (Singh, 2005). Apart from the method of using two hollow prisms, a new standard method for calibration of Abbe's Refractometer Method has been developed for applications in food, water and chemical analysis (Verkouteren, & Leigh, 1996). Abbe's Refractometer Method (ARM) is one of the traditional and a simple tool used to measure refractive indices of liquids.

Other methods used in the past to measure the refractive index of pure water in UNAM physics department employ simple and inexpensive Single-Diffraction Method (SDM) and Double-Diffraction Method (DDM). DDM was used to measure refractive indices of water samples at different temperature as well as refractive index of some organic liquids such as Acetone and Paraffin.

Although many methods have been used to measure refractive index of samples, some methods are complicated and expensive to maintain. For instance, the Double Displacement Method has shown promising results for its determination of refractive index of liquids. However, this method was limited to visible light and a telescope or eyes were normally used to locate the point at which the refracted beam changes its

direction (Nemoto, 1992). This is somehow demanding and incorporating a telescope makes the method expensive to use in remote areas such as in the northern part of Namibia.

Due to the nature of our samples, it is imperative to employ different methods that work on different physical principles to measure refractive index of water samples. Therefore, two methods of different nature will be used to measure refractive index of water samples from different surface water sources in Namibia.

The measurements and comparison of refractive indices of water samples obtained using two different techniques would be vital for this research because measuring instrument are subjected to varying degrees of instrumentation error and their uncertainties. The results of refractive indices from these two methods will be compared for water samples collected over wide area. In addition to refractive index measurements, the effect of other parametric factors that influence water quality will be investigated as well.

1.2. Parametric factors that influence water quality

1.2.1. Refractive index

Refractive index of a medium takes into account the ratio between the phase velocity of light wave propagation in a reference medium and the phase velocity in the medium itself. Mathematically, its definition is expressed as $n = c/v_{medium}$ (Young,

Sears, & Freedman, 2008). This optical parameter is highly related to the density by the Lorentz equation (Yata, Hori, Kawaskatsu, & Minamiyama, 1996).

Refractive index can be analytically determined by using a quick chemical method. According to Yata, et al (1996), these results can be achieved by determining the density distribution of fluid in the test cell in a vertical direction. This is in contrast to first determining other components such as pressure, volume and temperature measurements. It was further shown that the measurements of refractive index is an imperative tool to examine the behavior of fluids in the critical region in which gravity contribute to the varying properties in the vertical direction.

Importantly, transparent and non-magnetic materials refractive index was related from the interaction of an electrical field of the propagating wave and the permittivity ϵ of the particular medium. In this content, refractive index is denoted mathematically by (Yata, *et al*, 1996):

$$n = \sqrt{\epsilon_r} = \sqrt{\epsilon/\epsilon_0} \quad \text{Equation 1}$$

where ϵ_0 is the permittivity of vacuum and it is equal to $10^7 / (4\pi c_0^2) \text{ Fm}^{-1}$ (Young, *et al*, 2008). There are various important factors that affect the refractive index of samples.

It is well-known that for an impinging monochromatic laser light on the sample under measurement, there exist a constant wavelength at which the beam is operating

at a certain constant pressure and temperature. Thus changes in the speed of the incoming light beam affect refractive index of that particular sample. Theoretically, wavelength and density of samples are factors that can affect the refractive index of samples. However, it's known that density of samples is affected heavily by temperature, composition and volume.

1.2.2. Temperature

Refractive index is affected by changes in the temperature of a sample. Various experiments investigated the effect of refractive index on the temperature. For some, this was observed through the temperature coefficient factor of refractive index. Temperature coefficient factor of refractive index is defined as dn/dt from the graph of relationship between sample temperature and refractive index measurements. It is known that temperature coefficient of refractive index of light is altered by wavelength changes and temperature due to the relationship between these parameters. Therefore, the abbe's number also changes with temperature. Hence the change in abbe's number influences the change in refractive index.

Most authors have developed ways of demonstrating the temperature coefficient factor for refractive index determination. However, the best method for demonstrating temperature coefficient factor is by investigating absolute coefficient measurement under vacuum condition. Other authors have ranked the relative

coefficient measurement ambient air as the best condition. In our study, the Temperature will be kept at room temperature of all samples parameters.

1.2.3. Wavelength

It is important to understand the role that water and other liquids play in the lives of living organism and the ecosystem that people live on. Water is the main component of interstitial fluid, plasma of blood, intercellular fluid, etc. The optical properties of water are very significant in solving problems of biomedical optics. Particularly, wavelength dependence of the refractive index determines spectral dependence of refractive index of tissue interstitial fluid that in turn defines the wavelength dependence of scattering properties of tissues (Edlén, 1966). It's a fact that the wavelength of light interfere with molecules of water. A good example of wavelength interaction with water molecules happens in the formation of rainbow.

The wavelength dependence of the refractive index of water is discussed in many literatures. Most of the results have been obtained in the visible and near-infrared spectral ranges. However, most recent studies have extended the results to near Ultraviolet (UV) ranges. In the near-UV, Visible and Near-Infrared (NI) spectral ranges, the wavelength dependence of refractive index of water is described by Scot equation. For ARM and SDM, monochromatic laser light at a fixed wavelength and Sodium lamp (Ne lamp light of same intensity) is used (e.g. 632.5 nm was used in a low power laser for Single-Diffraction Method). Hence the effect of different

wavelengths of light on refractive index will be kept at constant for the measurements of refractive index of all water samples.

1.2.4. Salinity

Fundamentally, salinity is defined as the amount of dissolved ions/salts in the water body. Different water body yield different salinity because of different surface soils that the water body contains and the elements that are constituents of that body depend on surface run off water. Ideally, it's believed that ocean water has the highest amount of chloride ions than any other water body in the world because of vast solid chloride it forms e.g. calcium chloride. The problem with determining the salinity of water samples is associated with the measuring instruments. The measurement of salinity of water body is a daunting task because not all the ions in water contribute to salinity. Infact, only chloride ion contributes much to salinity of water bodies.

It is of high significance in Chemistry and Biological Science to measure salinity as a quality water control parameter for natural water. Therefore, salinity together with pressure, temperature, and hydrogen ions, density, turbidity and wavelength of light beam effects on refractive index of water bodies was not investigated together ever. Nevertheless, it's known that salinity is proportional to conductivity. Conductivity is defined as the capability of water to pass electrical flow. Therefore, by measuring conductivity of water, it will determine how high or low in electrical flow the water body contains.

There exist two main methods of measuring salinity of water samples. The first method is Total Dissolved Salts (TDS) in the water body. The second method is by determining Electrical Conductivity of water samples. This is achieved by passing electrical current between two plates (it's also known as EC method). TDS is a complex method to estimate salinity of water samples and it cannot be used in the field in the same circumstance in which the portable instrument for measuring salinity via EC operates. Therefore, an EC method will be used to measure the salinity of water samples in this research. The unity in which the portable instrument expressed salinity is $\mu\text{s}/\text{cm}$ at 25 C° (room temperature).

1.2.5. Hydrogen ions (pH)

pH is defined as the concentration of hydrogen ions in the solution. In Physics and Chemistry and other Science disciplines, pH is denoted as;

$$\text{pH} = \log [\text{H}^+] \text{ and } \text{pH} = -\log [\text{H}_3\text{O}^+]$$

The amount of hydrogen ions affects the composition and volume of water samples. Therefore, hydrogen ions effects on refractive index were never investigated.

Table 1. The range of pH scale from acidic to basic

pH range	Result
1.0 to 6.9	Acid Solution
7.0	Neutral Solution
7.1 to 14.0	Base Solution

Therefore it is vital to measure the pH value of all water samples collected and compare these results to the refractive index of these samples.

1.2.6. Turbidity

Turbidity is a measure of water turbid. Water turbid is defined as to the amount of solid material suspended in water. Ideally, solid materials settle at the bottom of the water. Sampling method for extraction of water samples with turbidity measurement in mind proves in the past to be complicated. This is due the nature in which different water sample solid suspension materials behaves. Impinging a monochromatic light laser beam on solid particles will be decreased on its passage through the water due to the interaction with these materials.

In most cases, turbidity affects the color and the nature of the water body. High turbidity increases water temperatures because suspended particles absorb more heat. This in turn reduces the concentration of dissolved oxygen because it's known from Biological Science that warm water holds less oxygen than cold water.

Since there exist a relationship between turbidity and temperature. It is imperative to investigate the effect of turbidity on the refractive index of water samples. High turbidity also reduces the amount of light penetrating the water. The effect of refractive index for all water samples by using SDM and ARM in which refractive index results will be compared to respective turbidity measurements will be investigated.

1.2.7. Density

The density of materials is a parameter that is proportional to mass of that material in a given volume. Mathematically, this parameter is denoted as;

$d=m/v$, where m is the mass of the sample and v is the volume of that particular sample. Scientific measurements of pure water were found to be density of $1.000g/cm^3$. An impurity dissolved in pure liquid would increase or decrease its density.

Density is an important physical characteristic of matter and all objects have distinct densities and that it can increase or decrease as the result of actions taken on the object or certain dissolved impurities (Tang, & Munkelwitz, 1994). s. The effects of density are important in our universe, which is why the effect of density on refractive indices of water samples is necessary to be investigated in this research.

1.3. Snell's Law

In optics, Snells Law forms a very important parametric equation. When an incident beam enters a new medium with certain velocity and at a certain angle, its velocity changes upon landing in a new medium, hence its transmitted beam changes the propagation angle at a normal line. This transmitted beam is also known as the refracted ray. Therefore, the ratio of $velocity_1/velocity_2 = \sin\theta_2/\sin\theta_1=n_1/n_2$ is termed as Snells Law or Law of Refraction.

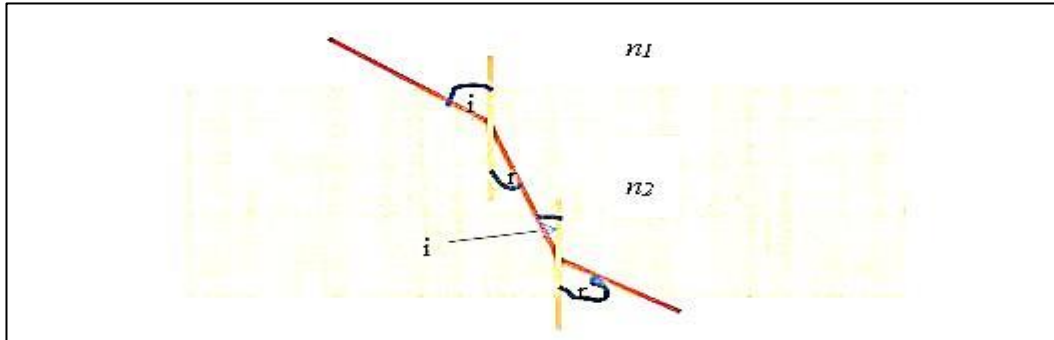


Figure 1: The schematic diagram of incoming light ray between two medium forming an angle of incidence and an angle of refraction.

Snells Law is very important in obtaining refractive index due to the fact that propagation speed and an incoming light ray do not have to be measured. This concept will form part of SDM to measure refractive index of water samples. The principle of refraction develop a unique concept that is called Total Internal Refraction (TIR). This happens when the critical angle is greater than the incidence angle. The theory of optical fibers is built on this principle.

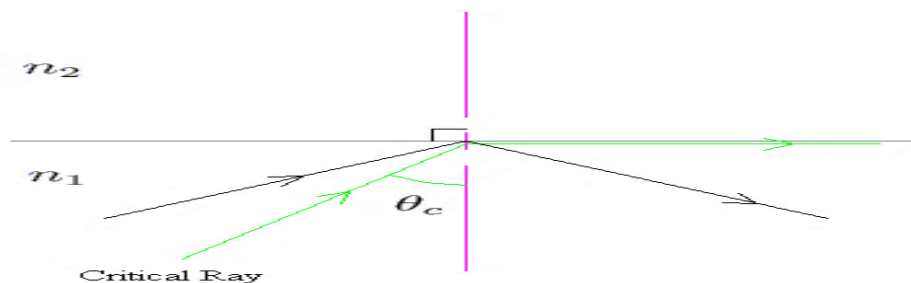


Figure 2: The schematic diagram of Total Internal Refraction with critical angle θ_c .

1.3.1. Optical Interference and Diffraction

From elementary Physics, it's well-known that any ray emerging on a surface of an object is reflected, transmitted or attenuated/absorbed. The transmitted ray forms a very important part of interference. Young-Douglas slit and Fresnel bi-prism have demonstrated the principle of diffraction in early experiments to measure fringe width. Fringe is basically bands of light forming a point on the screen. This phenomenon is attributed to diffraction.

Most importantly, the term diffraction tends to be only used for single slits single slits, while multiple diffraction of light rays yields interference which is only observed in double and multiple slits, just like diffraction gratings. The process of diffraction happens normally due to deviation of light rays from straight line paths in which an oncoming beam meets an obstacle and passes around it. Consequently, laser emits a special beam which is coherent. This phenomenon is important for the interference of laser light when it emerges on a high resolution diffraction grating. The phenomena of diffraction are fundamental to interference of light rays.

Interference of light rays only happen in multiple slits such as diffraction grating. When conducting experiments with diffraction gratings, it's important for the grating to have a high resolution because the higher the resolution, the better the fringes (points) it forms. SDM to be employed in the measurements of water samples is based on this principle.

1.3.2. Diffraction grating

In optics, there exist special optical components with a periodic structure that diffract light into beams which tend to travel in different directions (Singh, 1999). The wavelength of the oncoming laser light and the spacing of the grating influence the direction of the beams (Singh, 1999). It's for this reason that gratings are used in spectrometer due their special properties. Grating equation relates the angle incidence, grating spacing and the diffracted beam. Together with snells law, the equation form part of the SDM. This will be discussed in chapter 3.

1.3.3. Abbe's refractometer

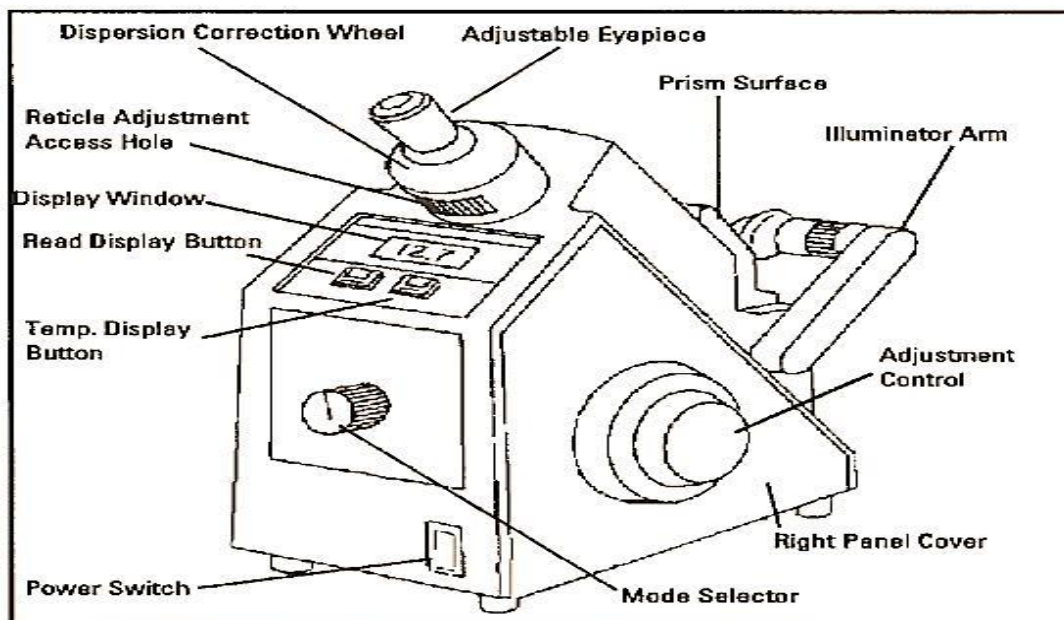


Figure 3: Schematic diagram of a traditional Abbe's refractometer with all its components.

A refractometer can be defined as a tool that is used to measure the refractive index of samples. Abbe's refractometer is a common refractometer that is classified as common and traditional equipment for laboratory applications. This instrument measures the refractive index with a normal precision of 10^{-4} . However, its usage is almost limited by vapor or humid condition. Using an Abbe's refractometer, the liquid sample is sandwiched into a thin layer between an illuminating prism and a refracting prism (Figure 3). The refracting prism is made of a glass with a high refractive index and the refractometer is designed to be used with samples having a refractive index smaller than that of the refracting prism.

A light source is projected through the illuminating prism, the bottom surface of which is ground, so each point on this surface can be thought of as generating light rays traveling in all directions. Figure 4 shows that light traveling from point A to point B will have the largest angle of incidence θ_i and hence the largest possible angle of refraction θ_r for that sample. All other rays of light entering the refracting prism will have smaller θ_r and hence lie to the left of point C. Thus, a detector placed on the back side of the refracting prism would show a light region to the left and a dark region to the right.

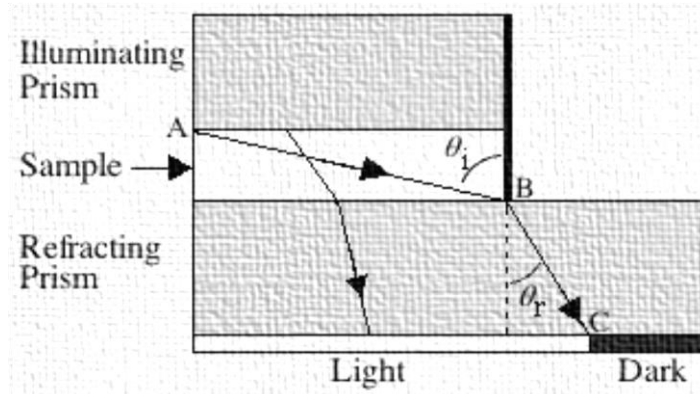


Figure 4: The schematic diagram of the cross-section view of a sandwiched sample which illuminated by light rays in an Abbe's refractometer.

The detector placed on the back side of the refracting prism would show a light region to the left and a dark region to the right. Samples with different refractive indices will produce different angles of refraction and this will be reflected in a change in the position of the borderline between the light and dark regions. Upon appropriately calibrating the scale, the position of the borderline can be used to determine the refractive index of liquid samples.

1.4. Statement of the problem

Several traditional methods have been employed to measure refractive index of liquids and most of these methods have been expensive and may not always be available locally (Singh, 2002). Therefore, there is a need to obtain refractive index of surface water in different water sources in Namibia with a newly developed technique at UNAM and compare the results measured with that of Abbe's

Refractometer Method. Abbe's Refractometer Method will be employed as a standard method.

Like other techniques, Abbe's refractometer is very expensive and may not always be available in schools and training centers in Namibia. Hence, there is a need for a simple and inexpensive method that can be used to measure refractive index of water samples. To the best of our knowledge, no research was done on the measurement of water samples collected from different surface water sources in Namibia.

1.5. Objectives of the study

One of the objectives of this study is to measure refractive index of water samples collected from different surface water sources in Namibia with SDM developed at UNAM and compare the results with that of existing traditional ARM. Another objective is to determine the relationship between the salinity of samples, pH, density and turbidity of the sample with their refractive indices. The existence of a linear proportionality between these factors will also be investigated under this study. The results from these two methods will then be analysed by Excel 2013.

1.6. Significance of the study

This project will enhance the new SDM developed at UNAM to be used to carry out experimental work in measuring refractive index of different liquids and impurities. It will investigate how refractive indices of water samples measured with

two methods vary. Refractive index will be linked to impurities. Refractive index may provide information on the pollution and contamination of water.

The following may happen in future: enhancement of the research activities and facilities in contemporary optics and laser applications at the University of Namibia. The project will provide motivation to continue advanced comprehensive research and develop new inexpensive local techniques for measuring refractive index of other materials state e.g. solids.

1.7. Limitation of the study

Sampling will only be done during rainy season as most surface water sources do not keep water throughout the year. Due to the small sample size of the study, the research findings will not be generalized to all surface water sources. Despite that, valuable information of qualitative and quantitative nature will be generated through the study.

2.1. Preliminary Studies

There are many measurements reported in the visible wavelength region for refractive index of water, liquids and air (Daimon, 2007). The study of refractive index and its measurements are vital for the studies of unknown impurities. Various techniques for determining refractive indices of liquids have been discussed (Singh, 2002; Singh, 2004).

It's empirical that measurements of physical constants are performed by simple and low cost techniques (Shafudah & Singh, 2015b). Most of the past optical studies have produced literatures for several applications of refractive index of samples. As time has passed, most of these methods need to be improved or new method need to be developed to yield high standard of accuracy. This literature study is going to review different methods that were used to measure refractive index of specimens in the past three decades. Most of these methods that will be discussed employ lasers and their principles. Therefore, it's important for us to understand the study of lasers and their different types.

Laser is one of the great inventions in the history of optics and material analysis that attracted interests in various field of studies such as chemistry, medicine, media, to mention a few (Shafudah, & Singh, 2015a). It's well-known that when atoms get excited, their electrons moves up higher energy levels and then return back to ground state. This transition of atoms in different level from stimulated emission contributes to population inversion. Hence, when stimulated emission occurs in the presence of

population inversion, the photon emitted will have same frequency and phase. This emitted light under that condition is called laser (Shafudah, *et al*, 2015a).

2.2. Methods for measuring refractive index

The number of experimental methods that were used for the measurements of the refractive index of materials and fluids in laboratories and industries are of high significance and most of them have contributed to modern optical figures for certain materials. In this literature review, some of these methods and their experimental set-up will be discussed.

Young, *et al* (2008) have described the concept of minimum deviations and snells laws in which they clearly linked the following equations below. Light passing through an isotropic solid material in form of liquid or crystal can be expressed as.

$$n_2 = n_1 \sin((A+D)/2) / \sin(A/2) \quad \text{Equation 2}$$

where A is the angle of prism and D is the angle minimum deviation as shown in figure 5. Taking in consideration that the incoming ray has n_1 whose refractive index is for air, the n_1 is equal to one.

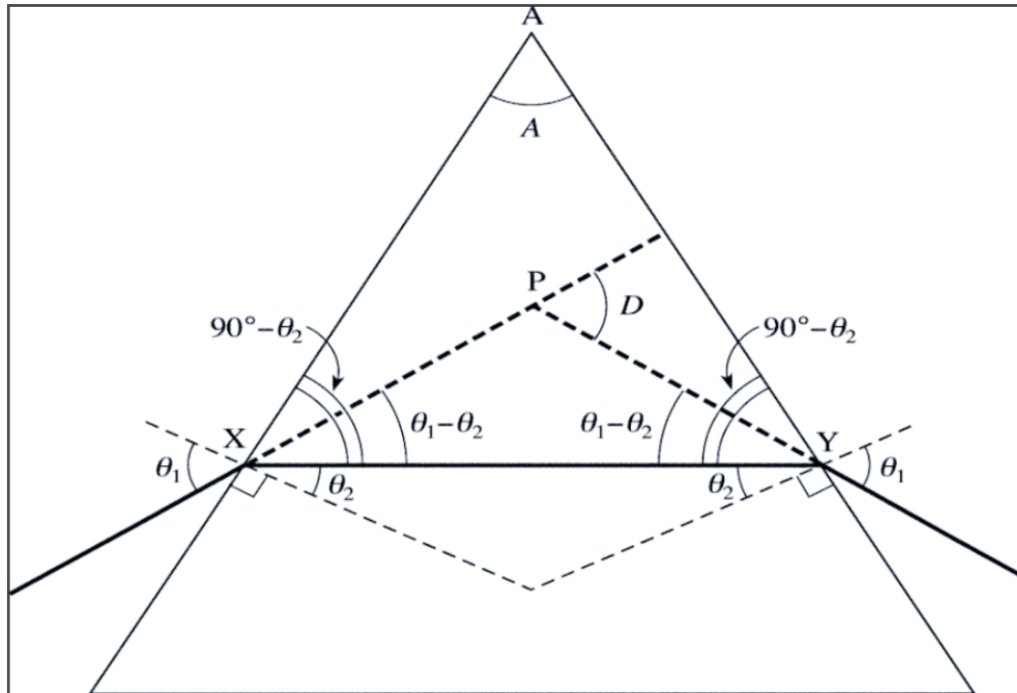


Figure 5: The schematic diagram of a hollow triangular prism for minimum deviation.

It's known that the condition for minimum deviation is given by:

$$\theta_1 = \theta_2 \quad \text{Equation 3}$$

where θ_1 and θ_2 are the angle of incidence and the angle of refraction respectively.

This implies that the incident and refracted angles at which the beam enters and leaves the prism respectively are equal. This is the condition for minimum deviation that must be satisfied.

Hence, the nature of the refractive and incident angle becomes;

$$A = \theta_1 - \theta_2 = 0 \quad \text{Equation 4}$$

The measurements of the angles of minimum deviation and the angle of prism are achieved by a sodium lamp and a spectrometer. Chandra & Bhaiya (1983) continued their work on the method discussed above for the measurements of refractive index by measuring refractive index of more specimens.

The modified minimum deviation method involves keeping the angle of the prism constant while measuring angle of incidence only. The effect of the triangular prism wall was neglected under these modifications. The following equations describe how best Chandra *et al* (1983) achieved their results.

$$A = \theta_1 + \theta_2 = \theta \quad \text{Equation 5}$$

$$n = (\sin^2 \delta + (1 + \sin \delta \cot \theta)^2)^{1/2} \quad \text{Equation 6}$$

δ is the angle of deviation

θ is the angle of incidence.

The method measured refractive index of liquids whose refractive index is in the range of $(1.3 < n < 1.6)$.

Minimum-deviation refractometer presented at the maximum precision level by using a medium precision spectrometer equipped with a Gauss ocular and auto-collimation experiments was performed (Bhaiya, *et al*, 1983). It was concluded that the experimentation error for the refractive index of solid samples of a single determination should not exceed 3×10^{-4} . However, for liquid sample where

temperature coefficients are relatively high, the probable uncertainty was estimated to be around 4×10^{-6} for water. Nevertheless, spectrometer test used at National Bureau of Standards calibrated glass prism have obtained the precision of this instrument with uncertainties within 2×10^{-6} (Tilton, 1929).

Lilton (1929) also suggested that the level of precision of index determination for liquids used in the immersion procedure should ideally be much higher than the precision of index determination aimed for solid materials. However, a study of uncertainties for refractive index of solids determined by the immersion method and considered for the minimum-deviation method of refractive index was found to be superior to any other for solids. Effort can be made for single determinations with a probable routine and precision to improve the method incase replicate measurements are made.

On the other hand for liquid samples, which have relatively high refractive index variation with temperature precision of 1×10^{-4} is about the limit obtainable. As a major use of the minimum-deviation method in mineralogical work is in calibrating liquids for the immersion method of refractive index determination, it is important to know importance precision (Lilton, 1929). The immersion method assumes particular important investigations of rock-forming minerals because of the impossibility of obtaining fragments that are large enough for preparation.

Singh (2005) reported a simple method of measuring refractive index of liquids by employing two identical hollow prisms (or one hollow prism and the other solid prism). The method need additional instrument such as Helium-Neon laser and spectrometer. The proposed method does not need additional knowledge of refractive index of the prisms. However, the known value of refractive index of a certain liquid in one of the hollow prism was used.

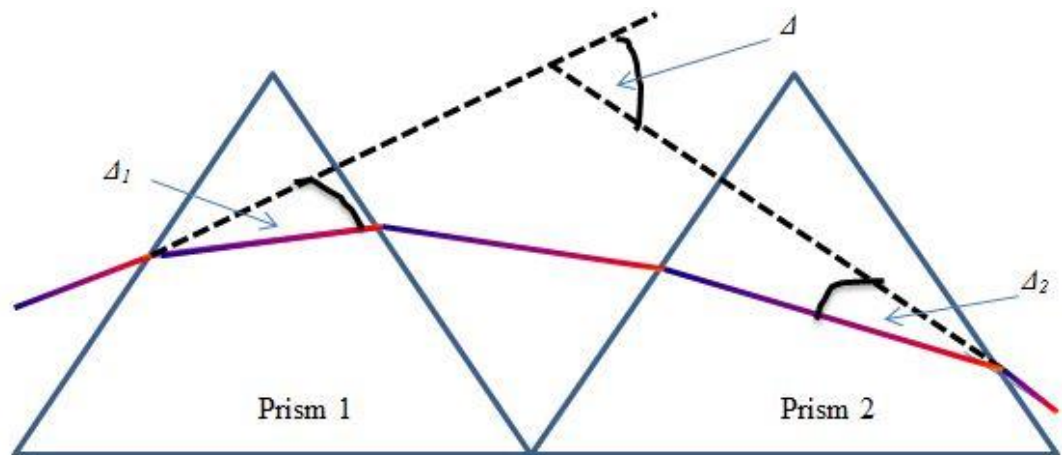


Figure 6: The schematic diagram for method of measuring refractive index of liquids by employing two identical hollow prisms.

The known refractive index of a liquid in a prism is fundamental for reference prism. Just like the method of minimum deviation with one prism, the following mathematical expression can be deduced from the deviation method using two identical prisms.

$$\Delta_1 = (n_1 - 1) A \text{ and } \Delta_2 = (n_2 - 1) A$$

Equation 7

where Δ_1, Δ_2 are deviation produced by prism 1 and prism 2 respectively

$$\Delta = \Delta_1 - \Delta_2 \quad \text{Equation 8}$$

$$= (n_2 - n_1) A \quad \text{Equation 9}$$

Refractive index of an unknown liquid is given by;

$n_2 = \Delta/A + n_1$, given that the refraction angle of prism 1 is A_1 and the refractive angle of prism 2 is A_2 , the following formula can be delivered;

$$n_2 = (\Delta + n_1 A_1 + A_2 - A_1) / A_2, \quad \text{Equation 10}$$

As in figure 6, the prisms are mounted together, therefore;

$$\Delta_1 = (n_1 - 1) A \text{ and } \Delta_2 = (n_2 - 1) A \quad \text{Equation 11}$$

$$\Delta = \Delta_1 + \Delta_2 = (n_2 + n_1) A - n_1 A \quad \text{Equation 12}$$

$$n_2 = (\Delta - n_1 A_1 + A_2 + A_1) / A_2 \quad \text{Equation 13}$$

The refractive index of liquids was measured by placing it in a shallow tray on the table with a glass plate (Singh, 2005). For the results of refractive index to be achieved, the glass plate must be horizontal in the tray. It was important to make sure the glass plate was horizontal by use of a spirit level and a blu-tack. As shown in figure 7, Helium-Neon laser was refracted off the surface of the glass and this yielded a spot of light on a vertical wall.

Interference of diffraction of two similar gratings and the measurement of refractive index of a thin mica sheet was proposed by Singh (2004).

$$n_2 - 1 = n_1 (\lambda/t) \text{ hence, } n_2 = 1 + \lambda/t \quad \text{Equation 16}$$

G_1 and G_2 are similar gratings and n_2 is the refractive index of a mica sheet, λ is the wavelength of a beam, t is the thickness of the mica sheet and n_1 is the refractive index of air.

Interference Refractive Index Method is one of the recent method employed to measure refractive index of samples in solid state (Singh, 2004). This method measures refractive index of samples without the knowledge of angle of refraction as well as grating resolution. The most important parameter is the knowledge of the thickness of the sheet that can be measured by either a vernier calliper or a micrometre screw gauges as well the wavelength of a monochromatic light. The scientific value for the refractive index of air is known to be one.

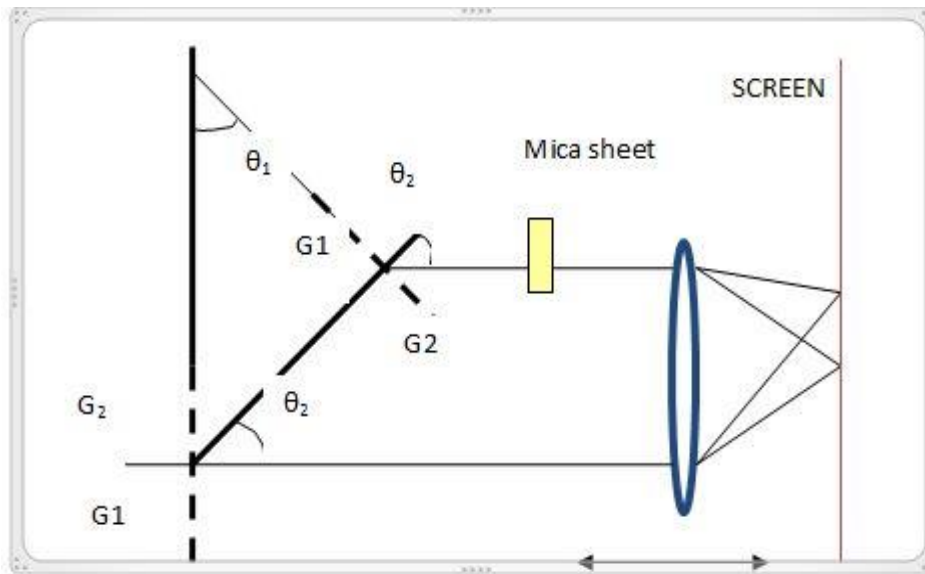


Figure 8: The schematic diagram of the experimental set up for the measuring refractive index of a mica sheet.

Singh (2004) measured refractive index of a mica sheet where a monochromatic light was shone on the mica sheet and angle of refraction was investigated by both gratings of the same high resolution. This method was found very successful for the measurement of refractive index due to its high precision and accuracy. But due to its nature, it cannot be used to measure refractive index of liquid samples. This means that the method is only suitable for measurement of refractive index of solid samples.

In addition to other methods for measuring refractive index of both liquid and solids that were proposed such as accurate measurement of the refractive indices of solids and liquids by the Double Layer Interferometer Khasana and Nassif (2000), a more

similar method of interference of diffraction of two similar grating that measure refractive index of solid only was proposed. This method was known to be called the Two Beam Method. This technique determines refractive index of both liquids and translucent solids (Nemoto, 1992). The two beam method would be good for the study of refractive Index of other solid materials as this will not be only limited to liquid samples as well.

For the case of material analysis, the following method has been used. For instance, digital holography method was used to investigate the two-dimensional profile of index of refraction produced by the photorefractive process. The proposed technique gives a direct and quantitative two-dimensional profile of index of refraction in photorefractive structures (De Angelis, *et al*, 2006).

Moreover, Refractive Index of materials such as BaTi205 glass was measured by the Focal Method (Masuno, Inoue, Yu, & Arai, 2010). Apart from the Focal Method, the study on femtosecond laser-induced refractive index modification of multicomponent glasses such as borosilicate, aluminum–silicate and heavy metal oxide glasses were reported (Bhardwaj, *et al*, 2005).

An accurate refractive index method was used to measure and verify refractive index of liquids samples against their respective pure liquids. This method employs a refractometer, a low power laser, high resolution grating, a light reflecting mirror and a position detector. By mounting a position detector on a refractometer, very accurate instrument to detect diffraction of light in different water samples with different refractive index is ensured (Singh, & Shafudah, 2014). The method is based on refraction and reflection of light. The position detector determines the impurity in liquid directly based on its refractive index (Singh, *et al*, 2014).

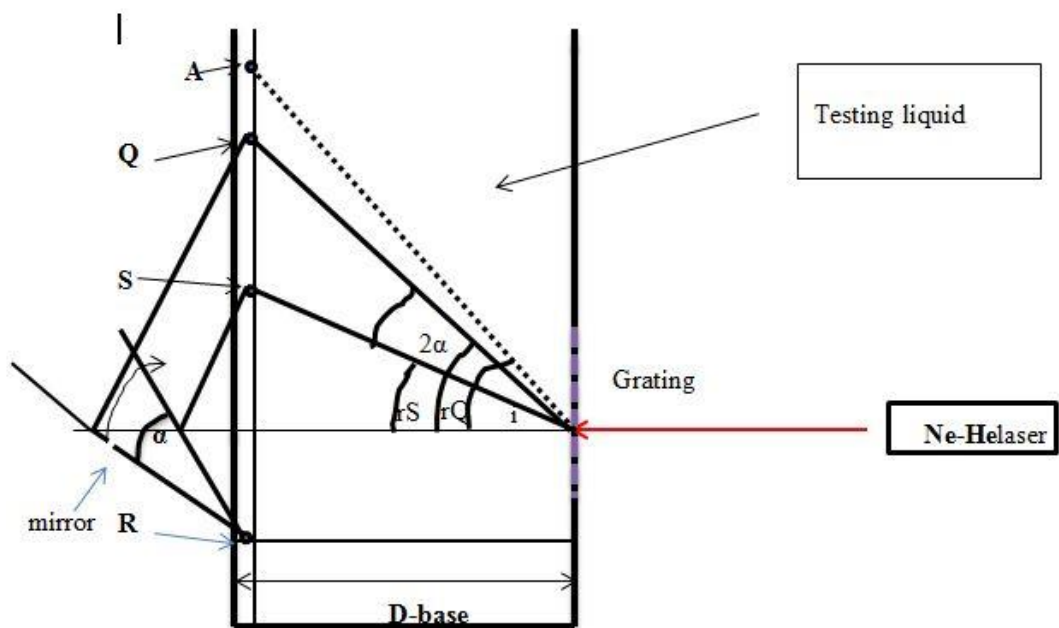


Figure 9: The schematic diagram of a Multipurpose Refractometer.

The following mathematical equation is used to obtain the refractive index of an unknown liquid. Point Q is the reference point for first order diffraction at the grating.

$$\sin i = \lambda/D \quad \text{Equation 17}$$

$$nQ = \lambda/D \sin rQ \quad \text{Equation 18}$$

$$nS = \lambda/D \sin rS \quad \text{Equation 19}$$

Maximum intensity is attained at point S by rotating the mirror through a small angle. The greater the gap between point S and Q, the high the amount of impurities in the liquid measured (Singh, *et al*, 2014). If nQ and nS are equal, the liquid has no impurity. The refractometer is also able to check the adulteration of liquids instantaneously by employing a position detector that has a high accuracy for measuring the intensity of spot formed and hence computing refractive index from this was made easy.

Michelson Interferometry Method has been used to determine refractive index of specimens since the 19th century (Michelson, 1887). The technique is an optical instrument and form part of traditional techniques. Albert Michelson discovered the principle of interferometry in 1881 and hence pioneered much of the work to Michelson interferometer. The technique was widely used for the measurements and the development of important experimental results that formed part of modern

physics (Michelson, 1928). This task was acquired due to the versatility, precision and high accuracy of the Michelson Interferometer.

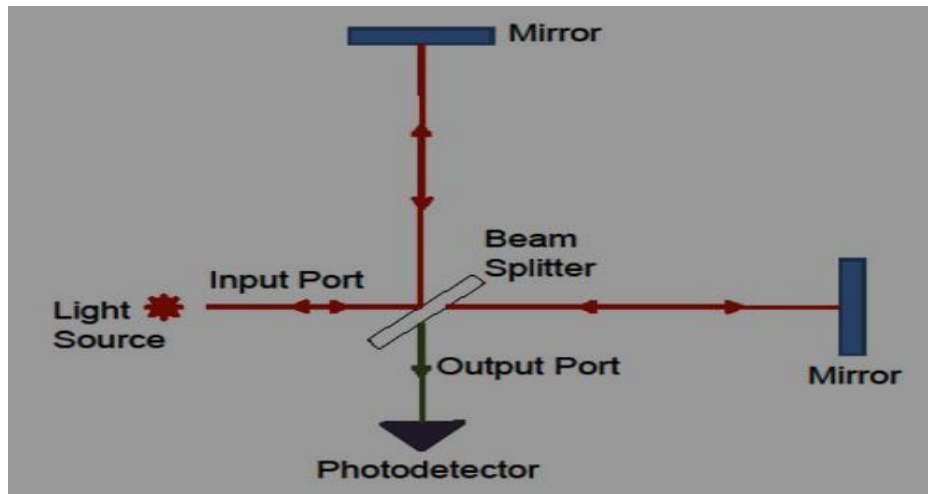


Figure 10: The schematic diagram of a Michelson Interferometer.

There are other several measurements that were obtained from the Michelson Interferometer. These measurements were: The study of important parameter such as hyperfine structures in line spectra and developments of special theory of relativity. Further use of Michelson interferometry method involves the measurements of tidal effect that the moon imposes on the earth.

The diffraction of light was a well-known principle that was explained in classical Electromagnetic theory since light was categorized as an electromagnetic wave. The diffraction pattern emanated first from single and then from double slits. Electromagnetic waves with wavelength λ from a single light-source, like a laser travels to two narrow slits of equal distance from the source where d are the distance between the slits. Light travels from the slits to a detection screen as shown in figure 8.

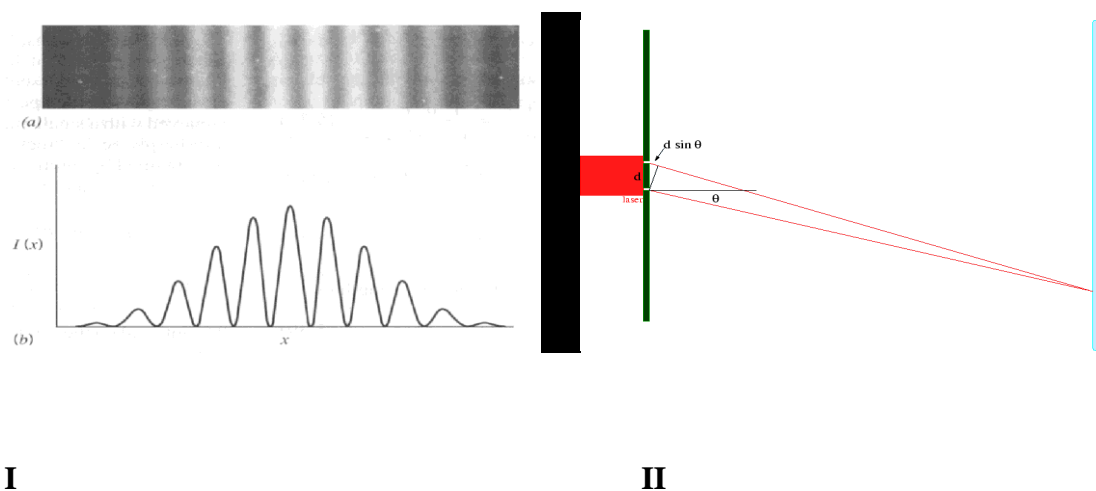


Figure 11: (I, II): The schematic diagrams for double slit diffraction.

According to simple experiments carried out in laboratory for diffraction in single slits, few observations were made and the following results have been noted. The center of the diffraction pattern occurs at the location on the screen of equal distance from each slit. At this distance, the two slits appear to be in phase as well as the waves interfere in a constructive phase. At this point, intensity is at maximum for constructive interference.

Some distance off this center of the diffraction pattern, there will be destructive interference between waves from the two slits and the intensity will be zero. Looking at figure 11, and assuming that the distance to the screen is much greater than d for light detected at an angle θ , then extra distance traveled from slit 1 is just $d\sin\theta$. Thus, the angle of the first minimum can be found from the equation to be.

$$d\sin\theta = \lambda/2 \quad \text{Equation 20}$$

The maximum paths differs from the slits differ by an integer number of wavelengths.

$$d\sin\theta = m\lambda \quad \text{Equation 21}$$

Where m is the number of trials

Similarly, there will be no diffraction if the integration paths differ by half integer number wavelengths.

$$d\sin\theta = (m+1)\lambda/2 \quad \text{Equation 22}$$

The principle of DDM from a high resolution grating emanated from this principle that is adopted in single slits.

The mathematical theory of this method to measure refractive index of impurities in liquids were developed at UNAM was reported Singh and Shafudah (2014). The method employs two rectangular glass cells, two high resolutions grating and two low power lasers properly aligned. However, this method requires a position detector for precise measurements.

DDM and SDM works on the same principle except the difference in the number of gratings and rectangular glass cells employed. Although SDM is a newly developed method with inexpensive materials, it was only used to measure refractive index of pure water. Therefore, the method needs to use over wide range different samples and compare its results to ARM.

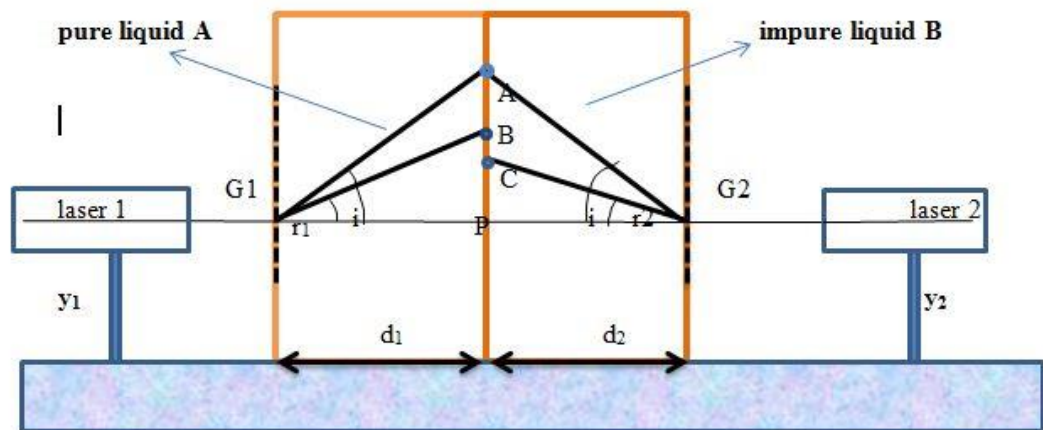


Figure 12: The schematic diagram of Double Diffraction Method

$y_1 = y_2$, for proper alignment of the two monochromatic laser beams

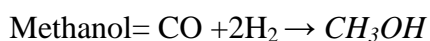
$d_1 = d_2$, the width of rectangular cylinders, hence refractive index of an impurity is given by;

$$n_2 = b/c \sqrt{\frac{1 + \tan r_2}{1 + \tan^2 r_1}}$$

Equation 23

Abbe's Refractometer Method (ARM) was used to measure the refractive index of popular alcoholic drinks in Namibia with different percentage of alcohol (Shafudah, Nuumbembe, & Kambo, 2015). The range of alcohol percentage for the selected drinks was chosen from 3% to 45%. The correlation between alcohol percentage and refractive index was investigated. Alcohol is any organic compound whose molecule contains one or more hydroxyl groups attached to a carbon (Solomon, Fryhle, & Snyder, 2014; Jackson, Schuster, 1987). This study proposed ARM as a quick and reliable method to measure refractive index of popular alcoholic drinks in Namibia.

There are various common alcohol compounds that are part of a mono hydroxyl class. These compounds includes, Methanol, Propyl alcohol, Ethanol, Isopropyl alcohol, Butyl alcohol, Sec-butyl alcohol, Tert-butyl alcohol, Pentyl alcohol, Hexyl alcohol, Cyclo-pentanol, Cyclo-hexane, Benzyl-alcohol, Ethylene-glycol, Propylene glycol, Trim ethylene glycol and many others. Methanol had been at most time produced by the destructive distillation of wood heated to a high temperature in the absence of air (Nemoto, 1992). Today most of the methanol is being produced by the catalytic hydrogenation of carbon monoxide which takes place under high pressure and temperature of 200-300 Kpa and 300-400 °C respectively (Salomon, et al, 2014).



Equation 25

House hold alcohol measurements and studies are based mainly on ethanol. This is the only type of alcohol that human being consumes. Ethanol is produced from the fermentation of sugar mixed with yeast and water (Liskens, & Jackson, 1988). The

enzymes contained in yeast promote a long series of reactions that ultimately convert a simple sugar to ethanol ($C_6H_{12}O_6$).

Ethanol can be produced also by fermentation of grains and other agricultural sources such as switch grass and sugarcane [Liskens, et al, 1988]. Apart from it being an alcohol for human consumption, it can also be combined with gasoline in varying proportions and used in internal combustion of engines (Jackson, et al, 1987).

Other alcoholic drinks such as Whisky and Beers are produced from the mixtures of sugar and water by the process of distillation. Recent study on the production of wines outlines many different varieties of a single species of grape. However, there exist other types of alcohol such as soft drink with low percentage of alcohol and they are composed of sugar, carbon dioxide, phosphate, antioxidants, cadmium, mercury, and lead with an acidic hydrogen ion ranging between 3 to 5. Despite the variation in brewing ingredients, most of these alcoholic drinks contain ethanol as a predominant compound.

Table 2. Name of alcoholic drinks, refractive indices and percentage of alcohol per volume. The alcoholic drinks range from soft drinks (castle-lite) to hard drinks (e.g whisky, blendy).

#	Name of Alcohol	Alcohol %	Refractive Index (n)
1	CAPTAIN MORGAN (whisky)	43.0	1.3579
2	GILBEY'S GIN	43.0	1.3681
3	KLIPORIFT	43.0	1.3689
4	GORDON'S	43.0	1.3679
5	RICHELIEU	43.0	1.3691
6	BERTRAMS	43.0	1.3693
7	AMARULA	17.0	1.4033
8	NEDERBERG	12.5	1.3579
9	SMIRNOFF	7.0	1.3611
10	CAPTAIN MORGAN (beer)	6.0	1.3608
11	SAVANNA DRY	6.0	1.3602
12	HUNTER'S DRY	5.5	1.3614
13	CASTLE LAGER	5.0	1.3520
14	HUNTER'S GOLD	4.5	1.3570
15	WINDHOEK DRAUGHT	4.0	1.3520
16	WINDHOEK LAGER	4.0	1.3499
17	CASTLE LITE	4.0	1.3497

*All refractive indices were measured at room temperature (25°C)

Refractive index values measured by ARM were close to that of ethanol ($n=1.3600$), except for the Amarula drink which had a value of $n=1.4033$, which could be attributed to high level turbidity of the drink, which stems from ingredients usually used in the brewing process. The refractive indices observed have further proven the predominance of ethanol in most alcohols. From the polynomial function that defines the distribution for alcohol versus refractive index. The root test was found to be 0.668~1. Therefore, a correlation between refractive index and the alcoholic percentage by volume was found in most of the drinks measured

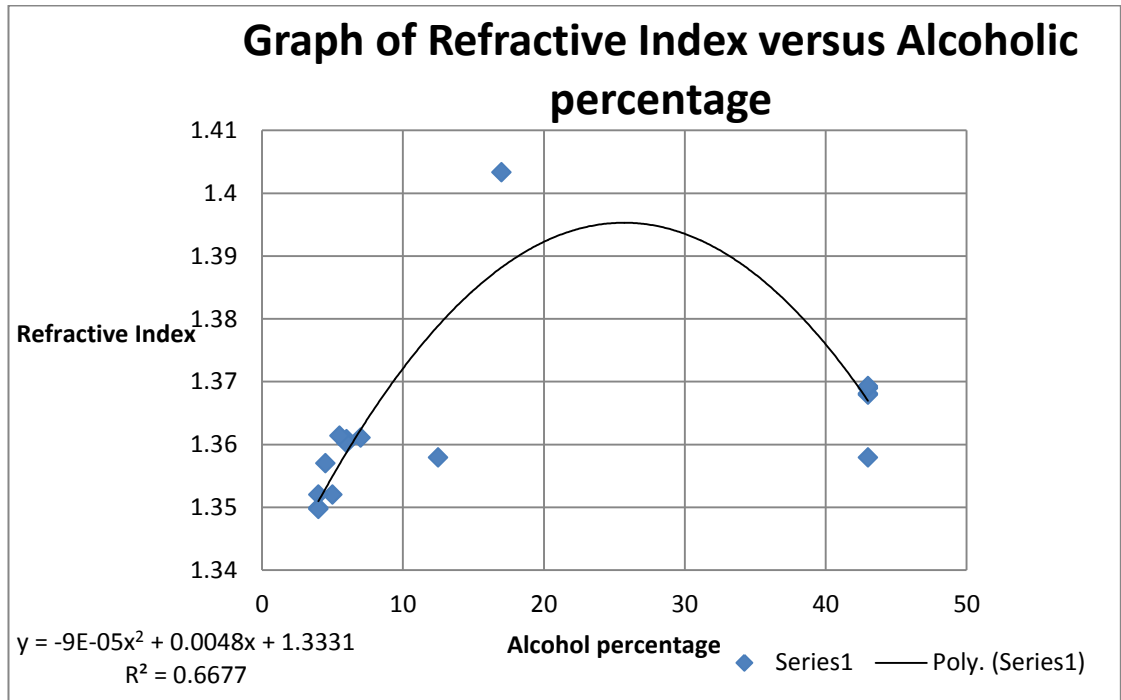


Figure 13: The diagram of refractive index of alcoholic drinks versus their respective alcohol percentage volume. The graph is defined by a polynomial function whose root test was found to be $\sim 0.7 \sim 1$ (Shafudah, *et al*, 2015).

Plasma is a medium with gas in it. It is also known that plasma is the fourth state of matter which is different from other state of matter due to fact that it has free electrons in it. This implies that plasma has no restoring force. An expression for the dielectric constant of plasma can be obtained by setting vacuum frequency (ω_0) to zero and n to the number density of electrons, n_e , hence we have equation 26.

$$\epsilon = 1 - \frac{\omega_p^2}{\omega^2} \quad \text{Equation 26}$$

where ω_p is called plasma frequency

$$\omega_p = \sqrt{\frac{n_e e^2}{\epsilon_0 m_e}} \quad \text{Equation 27}$$

For frequencies above the plasma frequency, the dielectric constant of plasma is less than unity. Hence, the refractive index is termed negative;

$n = \sqrt{\epsilon}$, which is also less than unity. This would seem to imply that high frequency electromagnetic waves can propagate through a plasma with a velocity c/n which is greater than the velocity of light in a vacuum. These phenomena seem to contradict principle of relativity.

However, frequencies below the plasma frequency, the dielectric constant was found to be negative, which implies that the refractive index is imaginary. The real part of Refractive Index is termed positive Refractive Index (most common in material) and the imaginary part of refractive index is termed negative refractive index (meta-materials).

Earliest meta-materials worked in the microwave regime as well as centimetre wavelengths of the electromagnetic spectrum. This material was designed in the form of a split-ring resonators and conducting straight wires (Smith, Pendery, & Wiltshire, 2004). The unit cells of meta-material were arranged in a two-dimensional repeating pattern which produces a crystal-like geometry. Unit cells and lattice spacing were smaller than the radiated electromagnetic wave.

This structural design produced the first left-handed material in which both permittivity and permeability of the material were negative (Smith, & Kroll, 2000). Resonant behaviour of the unit cells was part of the structure the system relied on mostly. This materials form part of negative refractive index, a special property of refractive index that happens in plasma.

The areas from which the water samples were taken are very crucial for the impurities that the water samples contain. Different areas have different geological historical formations and thus different mineral composition in the soil that the surface water source contains (Burke, Denison, Hetherington, Koepnick, Nelson, & Otto, 1982). Hence, turbidity, salinity, pH and density of water samples are heavily affected by the mineral and human impact that this influence puts on water bodies. Therefore, it is crucial that study the environment from the samples were extracted to understudy the impacts these on our parameters under study. Sea water soil and continental water soil have different elements.

Geological oceanography is a study of ocean science that attempts to explain a lot about how the oceans formed. The expansion of oceans and how they tremendously change has been reported. The density, pH, salinity of sea water is known to be, 1.025g/cm, (7.4 to 8.4) and 599nM respectively. Our earth was formed from the combination of gas, particles, light and heavy elements that we nowadays find in the

periodic table. Heavy elements are formed as a result of explosion of the famous event we call supernova. Major constituent elements of sea water are chloride ions, sodium ions, sulphate ions, and magnesium and calcium ions (Broecker, 1971).

Eventually, this amorphous mass of gas and particles started to consolidate and cool. But cooling was hindered by a continual bombardment of meteors and other space debris, which kept the surface of our planet a molten. At this high temperature, gases were absorbed into the molten rocks. While at high intense pressure deep inside the Earth held the gases within the magma until it reached the surface.

Most of dust particles and some gases were released in the atmosphere. These gases are termed excess volatiles, and the major constituents are water, nitrogen, carbon dioxide and hydrogen chloride. Additional heating from gravitational compression and the decay of radioactive elements kept the earth in a semi-molten state. Due to high density, some iron in the earth was pulled toward the core as the result of gravity. The process of sinking created even more heat through friction. Conversely, lighter minerals such as silicon, magnesium, aluminum and various oxygen-based compounds floated toward the surface.

When the surface eventually cooled, forming a crust, the earth has divided into the layers; namely, inner and outer core, mantle and crust. The volatiles were released through volcanic activity in a process called outgassing. Due to the fact that earth was hotter in its interior, the magma contained a lot of elements that evaporate then the current earth situation.

Therefore, sea water has a high percentage of chloride ions and manganese ions, just to mention a few. Some of these ions form salt that we use in our daily life. Sea water has a high percentage of salinity than any other water collected from surface and underground water on a continental crust. However, salinity of sea water is not homogenous throughout the world. This difference is attributed to run off water near sea water, human impacts, pollution, and carbon dioxide excessive in atmosphere and climate change and other global geochemistry factors.

Continental water involves all types of water such as underground water, lake water and any open water. This water is influenced by the soil and the minerals in which they were extracted. Major constituent elements of surface water are HCO ions (58), Ca ions (15), Cl ions (7.8), K ions (2.3), Mg ions (6.3), and Sodium ions (3.7) with an approximated TDS (proportional to salinity) of 120 (Donald, 1997). However, these constituents of surface water are different in ground water. Ground water is composed of the following elementally ions; HCO ions (200), Ca ions (50), Cl ions (20), Kions (3), Mg ions (7), Sodium ions (30) and TDS of 350 (Donald, 1997)

3. RESEARCH METHODOLOGY

The research will be divided into two parts; the first part deals with measuring refractive index of water samples and the second part deals with comparing the refractive index from both techniques.

The proposed method measures refractive index of liquids using a rectangular glass cell, a transmission grating and He-Ne laser. Transmission grating was mounted on the cell and a 330nm He-Ne laser was shone normally to the grating. When the cell was clean and empty, the first order diffraction form a spot at point C (figure 14) and the direct light spot was observed at point A (figure 14). The impurity has n_2 Refractive Index and once poured in the glass cell, the refracted light was observed at point B (figure 14). The refractive index for an empty glass cell (air) was given by n_1 and it was assumed to be equal to one.

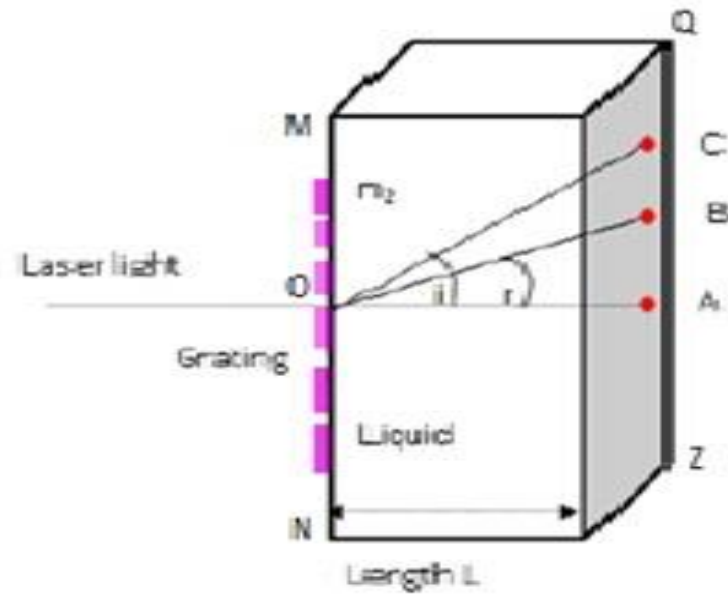


Figure 14: The schematic diagram of Single Diffraction Method.



Figure 15: Schematic diagram of a picture of a Single Diffraction Method set up.

As described in 1.3.3, Abbe's refractometer was used as a standard instrument to measure the refractive indices of twelve water samples collected from different surface water sources in Namibia.

Sampling bottles with a capacity of two litres each were used to collect water from different surface water sources. The following places were chosen considering the difference in salinity that their surface water sources may contain. Sampling was done by means of direct water extraction. These surface water sources were: UNAM garden water tap (Karas Region), Otjondeka pond (Karas region), Walvis Bay and Swakopmund Ocean (Erongo Region), Ruacana falls (Karas region), Oshakati Canal (Oshana Region), Eembaxu Lake (Ohangwena Region), Khorixas swamp (Omaheke Region), Eendadi Pond Water (Ohangwena region), Oshandi Well water (Ohangwena region), Oheti Lake (Ohangwena region) and Eenhana Lake (Ohangwena region) with the only exception of well water as underground water sources.

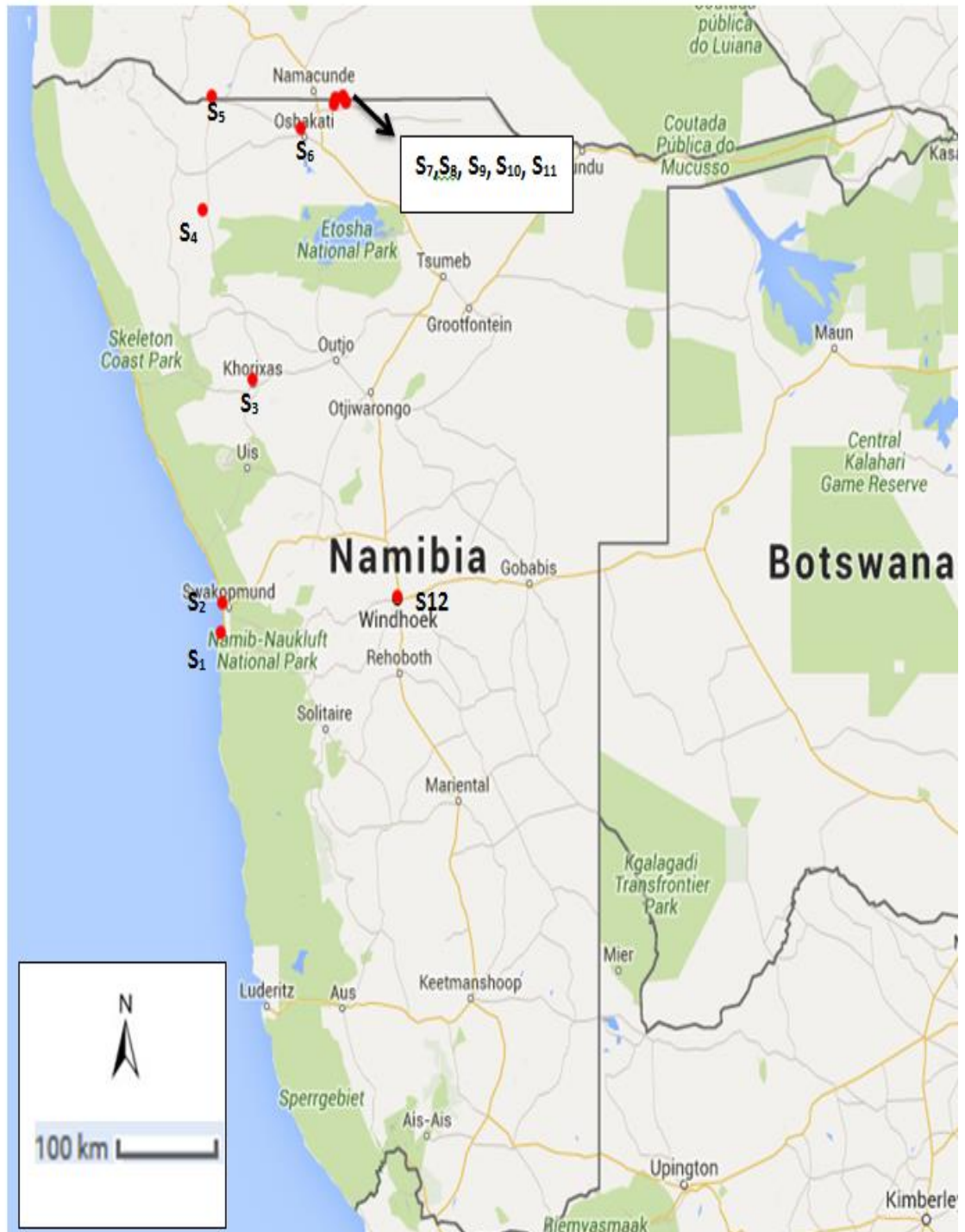


Figure 16: The schematic diagram of locations of samples in Namibia

Firstly, samples were collected in two litres capacity bottles and their locations of water sources were recorded by a GPS. Secondly, places from which the samples were extracted were labelled on container at the time of sample extraction. Thirdly, samples collected were filtered to remove dust, sand and all other solid particles that might damage the instrument upon measuring of their refractive indices. After transportation of samples, they were then kept at the temperature (25°C) in a storage room.

Consequently, the temperature, pH and salinity, density and turbidity this samples were then measured by means of, a thermometer, pH meter, salinometer turbidity meter and computing of density from volume and masses of these samples, respectively. Finally, measurements were made three times on each sample to eliminate random errors and ensure high degree of precision and accuracy. The average of three measurements will be computed to find refractive index in both methods. The standard deviation for the measurements of refractive index was also computed.

3.3.1. Procedures for measuring pH of water samples

- Firstly, buffer of pH value of 4 was used to calibrate the pH meter.
- Deionised water solution were used to clean the tip of the pH meter pointer by inserting it in the solution.

- The sample under measurement was discarded and the beaker was rinsed with pure water and then rinsed again with the next sample to be measured.
- For every measurement of a new sample, calibration by buffer was done.
- For every time the pH meter needle is inserted in the deionised water solution, the pointer is wiped gently to dry it completely.
- Similar proceedings were performed for the measurements of all other samples.



Figure 17: The schematic diagram of pH meter and samples

- The pH readings for the twelve samples were recorded three times and then an average reading was calculated.
- Standard deviation for pH measurements was computed as well.

3.3.2. Procedures to determine refractive index of water samples

3.3.2.1. Method 1: SDM

Using Snell's law for refraction (Young, *et al*, 2008) at the cell wall MN of figure 14 yields;

$$n_1 \sin i = n_2 \sin r \quad \text{Equation 28}$$

The effects of the thickness of the walls of the thin glass cell was neglected and the refractive index of air was taken as $n_1 = 1$.

The diffraction grating equation (Young, Freedman, & Sears, 2008) is given by;

$$d \sin i = m \lambda \quad \text{Equation 29}$$

where d is the grating constant, λ is the wavelength of laser light and m is the order of the diffraction.

Taking $m = 1$, equations 28 and 29 can be combined to yield the following equation,

$$\begin{aligned} n_2 &= \sin i / \sin r \\ &= (\lambda/d) / \sin r \\ &= (\lambda/d) / (AB/OB) \\ &= (\lambda/d) [(AB)^2 + L^2]^{1/2} / AB \end{aligned} \quad \text{Equation 30}$$

In this equation, L is considered to be the external width of the rectangular glass cell.

Since the grating was mounted on the glass cell as shown in figure 14, refractive index of the water sample can be calculated from Snell's law of refraction at the glass wall MN as given by the formula below;

$$n_2 = \sin i / \sin r = (AC/OC) / (AB/OB) = (AC/AB) (OB/OC)$$

$$\begin{aligned}
&= (AC/AB) [((AB)^2 + (OA)^2)^{1/2} / ((AC)^2 + (OA)^2)^{1/2}] \\
&= (AC/AB) [((AB)^2 + L^2) / ((AC)^2 + L^2)]^{1/2}
\end{aligned}
\tag{Equation 31}$$

One can show that *equation 28* and *equation 29* are similar for $m = 1$. Therefore, from the grating *equation 29*, $\sin i = \lambda/d$ and $\sin i = AC/OC$ from figure 14 as the length OA is at right angle to the cell walls. The distance AB , AC , and BC can be obtained on the paper scale attached to the glass cell wall QZ . The external width L was measured accurately with a Vernier caliper.

3.3.2.2. Method 2: ARM

- Twelve of 3ml pipettes were used during the experiment which 1ml volume of each sample was sandwiched between the jaws of the refractometer.
- The procedure was repeated three times and then an average was obtained for each sample.
- The refractive index was obtained directly from the scale of the instrument.
- Similarly, the standard deviation for each sample was computed.
- The Abbe's refractometer that was used has an accuracy of 10^{-4} .



Figure 18: The schematic diagram of experimental set up of Abbe's refractometer

3.3.3. Procedures for measuring salinity of water samples

The salinometer is an instrument that gives approximate values of salinity of liquids. As it was discussed in chapter 1, salinity can be approximated from the readings obtained by a salinity meter (salinometer). The following procedures were contacted during the process of obtaining the readings for the salinity of the water samples.

- Pure water was used to standardise the equipment before the readings were taken
- There temperature at the time of measurement was recorded (room temperature).
- The salinometer needle was immersed in the first water sample named S_1 .
- Little time was needed to allow the instrument to stabilize.
- After the instrument stabilised, measurements of salinity was then recorded.

- Before the next sample was measured, the salinometer needle was rinsed with standard water and then with the next sample.
- The readings were taken similarly to the first step for obtaining the reading as discussed above for all twelve sets of samples.
- The same procedure was done three times for each sample and only an average reading was recorded.
- The standard deviation was also computed.

3.3.4. Procedure to determine the density of water samples

- To determine the density of liquids under measurement, the known volume of sample was used for all samples.
- The mass of the cylinder was determined when the cylinder was empty
- The known volume was poured in the cylinder and weighed.
- The actual mass was obtained by subtracting the mass of a cylinder from the total mass of the cylinder and a water sample.
- From the mass and the volume , the density was calculated by dividing mass over the volume
- The same procedures were performed for all twelve samples under measurements.

3.3.5. Procedure for measuring Turbidity of water samples.

- Turbidity is measured by a turbidity meter.
- The solution of the water sample was homogenised to ensure distribution of all suspended materials evenly.
- Quickly the turbidity meter was inserted in the sample solution of 300ml
- This proceeding was done for all twelve samples.
- After the turbidity meter stabilized, the reading was taken for the measurement.
- Deionised water was used to clean the turbidity meter pointer and rinsed with the next sample

3.4. Research ethics

All contributing parties will be acknowledged in this research. Samples will be collected from approved water sources by NAMWATER branches in all regions that were under research.

3.5. Data analysis

A mathematical approach as stipulated in 3.3.2.1 was used to determine the Refractive Index of water samples for SDM. However, ARM gives the refractive index directly from the instrument by total reflection and no mathematical

calculation is required. The following statistical methods were employed in the analysis of data.

4. RESULTS

The following results were obtained from the measurements that were conducted at the University of Namibia in the physics department in collaboration with the geology departments.

4.1. ARM Measurements

Table 3. The readings of refractive index measured by Abbe's refractometer

Sample s	Refractive e index(n_1 a)	Refractive e index(n_2 a)	Refractive e index(n_2 a)	ave_{na}	Av. St dv
S₁	1.3380	1.3370	1.3390	1.3380	0.0010
S₂	1.3390	1.3370	1.3380	1.3380	0.0010
S₃	1.3319	1.3329	1.3309	1.3319	0.0010
S₄	1.3310	1.3310	1.3310	1.3310	0.0000
S₅	1.3312	1.3312	1.3312	1.3312	0.0000
s₆	1.3310	1.3310	1.3310	1.3310	0.0000
s₇	1.3312	1.3313	1.3310	1.3312	0.0002
S₈	1.3315	1.3315	1.3315	1.3315	0.0000
S₉	1.3310	1.3310	1.3310	1.3310	0.0000
S₁₀	1.3311	1.3310	1.3311	1.3311	0.0001
S₁₁	1.3315	1.3315	1.3315	1.3315	0.0000
S₁₂	1.3311	1.3310	1.3301	1.3307	0.0006

4.2. SDM Measurements

Table 4. The readings of refractive index measured by Single Diffraction Method.

Samples	n_{1g}	n_{2g}	n_{3g}	av_{ng}	Av. St dv
S₁	1.339	1.339	1.339	1.339	0.0000
S₂	1.337	1.339	1.338	1.338	0.0010
S₃	1.332	1.331	1.333	1.332	0.0010
S₄	1.330	1.330	1.330	1.330	0.0000
S₅	1.331	1.331	1.331	1.331	0.0000
S₆	1.331	1.331	1.331	1.331	0.0000
S₇	1.331	1.331	1.334	1.332	0.0017
S₈	1.332	1.332	1.332	1.332	0.0000
S₉	1.331	1.331	1.331	1.331	0.0000
S₁₀	1.330	1.333	1.330	1.331	0.0017
S₁₁	1.332	1.332	1.332	1.332	0.0000
S₁₂	1.332	1.332	1.332	1.332	0.0000

4.2. Turbidity Meter Measurements

Table 5. The readings of turbidity measured for twelve samples collected from different surface water sources in Namibia.

Samples	t₁	t₂	t₃	Ave.Turbidity(utm)	Av. St dv
S₁	15.9	15.8	15.9	15.87	0.06
S₂	14.98	14.97	15.2	15.05	0.13
S₃	129	128	128.7	128.57	0.51
S₄	96.8	96.7	96.6	96.70	0.10
S₅	6.58	6.56	6.59	6.58	0.02
S₆	42.0	42.0	41.8	41.93	0.12
S₇	5.2	5.4	5.6	5.40	0.20
S₈	199	201	200	200.00	1.00
S₉	65.3	65.2	65.4	65.30	0.10
S₁₀	32.0	32.0	33	32.33	0.58
S₁₁	35.0	35.0	34	34.67	0.58
S₁₂	0.65	0.65	0.62	0.64	0.02

4.1. Salinity Meter Measurements

Table 6. The readings of salinity measured for twelve samples collected from different surface water sources in Namibia.

Samples	S_{a1}	S_{a2}	S_{a3}	Ave. Salinity(US/cm)	Av. St dv
S₁	53.20	53.40	53.30	53.30	0.10
S₂	52.10	53.40	53.20	52.90	0.70
S₃	253.10	253.00	253.00	253.03	0.06
S₄	247.20	247.10	247.00	247.10	0.10
S₅	81.00	79.80	80.00	80.27	0.64
S₆	2.69	2.71	2.70	2.70	0.01
S₇	233.00	233.00	233.00	233.00	0.00
S₈	213.00	214.00	213.00	213.33	0.58
S₉	521.00	520.00	522.00	521.00	1.00
S₁₀	315.20	315.00	315.00	315.07	0.12
S₁₁	555.00	557.00	555.00	555.67	1.15
S₁₂	812.00	812.00	813.00	812.33	0.58

4.2. pH Meter Measurements

Table 7. The readings of pH of twelve samples collected from different surface water sources in Namibia.

Samples	p₁	p₂	p₃	Av. pH	Av. St dv
S₁	7.57	7.58	7.57	7.57	0.01
S₂	7.36	7.35	7.37	7.36	0.01
S₃	7.8	7.9	7.8	7.83	0.06
S₄	7.5	7.55	7.54	7.53	0.03
S₅	7.57	7.56	7.59	7.57	0.02
S₆	7.57	7.57	7.58	7.57	0.01
S₇	7.04	7.03	7.04	7.04	0.01
S₈	7.84	7.84	7.84	7.84	0
S₉	7.21	7.2	7.22	7.21	0.01
S₁₀	7.95	7.95	7.94	7.95	0.01
S₁₁	7.77	7.74	7.74	7.75	0.02
S₁₂	7.82	7.82	7.82	7.82	0

4.3. Density Measurements

Table 8. The readings of density of twelve samples collected from different surface water sources in Namibia

Samples	d₁	d₂	d₃	Ave. Density(g/cm³)	Av. St dv
S₁	1.0140	1.012	1.013	1.0130	0.0010
S₂	1.0120	1.0111	1.0102	1.0111	0.0009
S₃	0.9880	0.988	0.9887	0.9882	0.0004
S₄	0.9860	0.986	0.9861	0.9860	0.0001
S₅	0.9860	0.986	0.9862	0.9861	0.0001
S₆	0.9880	0.9881	0.988	0.9880	0.0001
S₇	0.9881	0.988	0.988	0.9880	0.0001
S₈	0.9820	0.9821	0.982	0.9820	0.0001
S₉	0.9840	0.9841	0.984	0.9840	0.0001
S10	0.9820	0.9821	0.982	0.9820	0.0001
S11	0.9861	0.9861	0.9859	0.9860	0.0001
S12	0.8960	0.8961	0.896	0.8960	0.0001

4.4. Graphs and Interpretation

4.6.1. Refractive index from SDM and ARM versus each other

Table 9. Refractive index from SDM and ARM.

Ave _{na}	Av _{ng}	X	Y
		Av. Stdv	Av.St dv
1.3380	1.339	0.000	0.0010
1.3380	1.338	0.001	0.0010
1.3319	1.332	0.001	0.0010
1.3310	1.330	0.000	0.0000
1.3312	1.331	0.000	0.0000
1.3310	1.331	0.000	0.0000
1.3312	1.332	0.002	0.0002
1.3315	1.332	0.000	0.0000
1.3310	1.331	0.000	0.0000
1.3311	1.331	0.002	0.0001
1.3315	1.332	0.000	0.0000
1.3307	1.332	0.000	0.0006

As clearly demonstrated (figure 19), average value of the refractive index for all twelve water samples measured by both methods ranged from 1.3310 to 1.3380. There exists a linear correlation between ARM and SDM measurements of refractive index defined by a linear equation as indicated in figure 19. The root test was found to be 0.9535 ~1. This is good enough to suggest that both methods are accurate for the measurements of the refractive index of water.

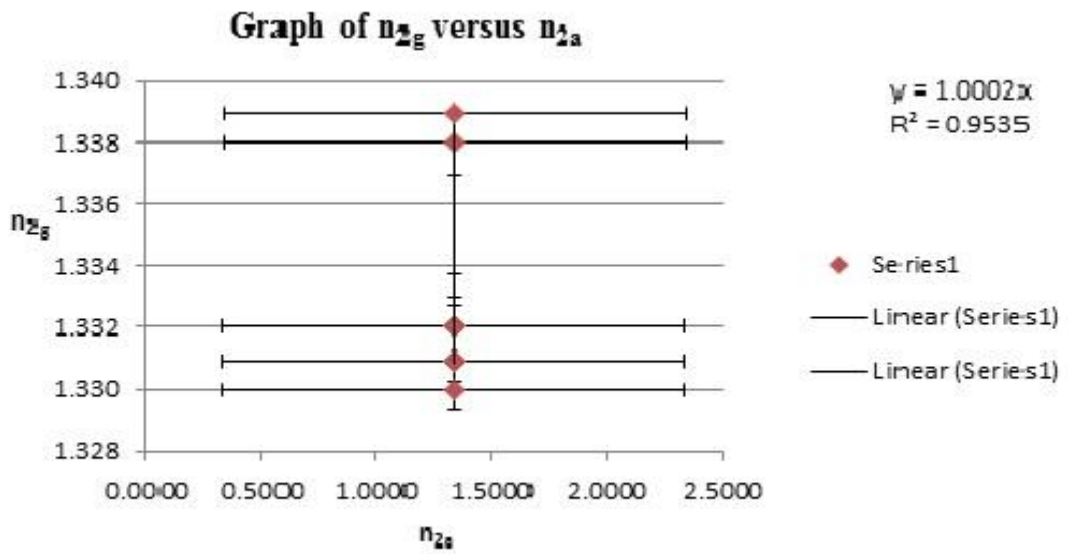


Figure 19: The schematic diagram of the graph of refractive index from SDM versus ARM.

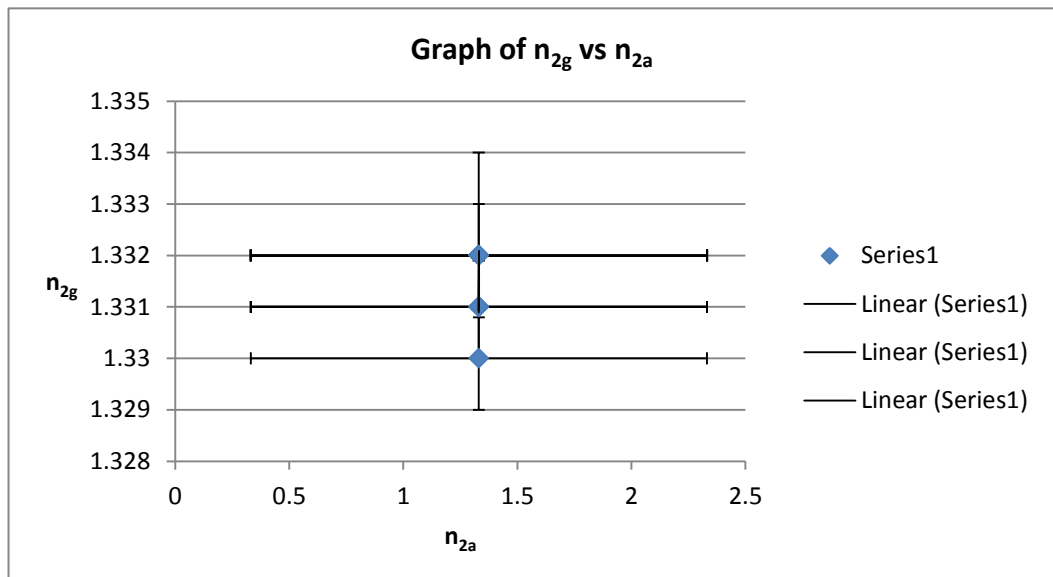


Figure 20: The schematic diagram of the graph of refractive index from SDM versus ARM without sea water samples.

4.6.2 Salinity and Refractive index

Table 10. The refractive index from ARM and salinity of samples.

Ave. Salinity(US/cm)	Ave _{na}	X	Y
		Av.Stdv	Av. St dv
53.30	1.3380	0.0010	0.01
52.90	1.3380	0.0010	0.01
253.03	1.3319	0.0010	0.06
247.10	1.3310	0.0000	0.03
80.27	1.3312	0.0000	0.02
2.70	1.3310	0.0000	0.01
233.00	1.3312	0.0002	0.01
213.33	1.3315	0.0000	0.00
521.00	1.3310	0.0000	0.01
315.07	1.3311	0.0001	0.01
555.67	1.3315	0.0000	0.02
812.33	1.3307	0.0006	0.00

The graph suggests the non-existence of a linear correlation between refractive index data and the salinity of the water samples. However, even if there is no correlation, additional data are needed to confirm if the non-existence of correlation is attributed to the notion of refractive Index not as a function of salinity. The root test yielded a very small number. A linear function and a power function were drawn in figure 22 to estimate the non-regression pattern which is attributed to the shifts of refractive Index with salinity.

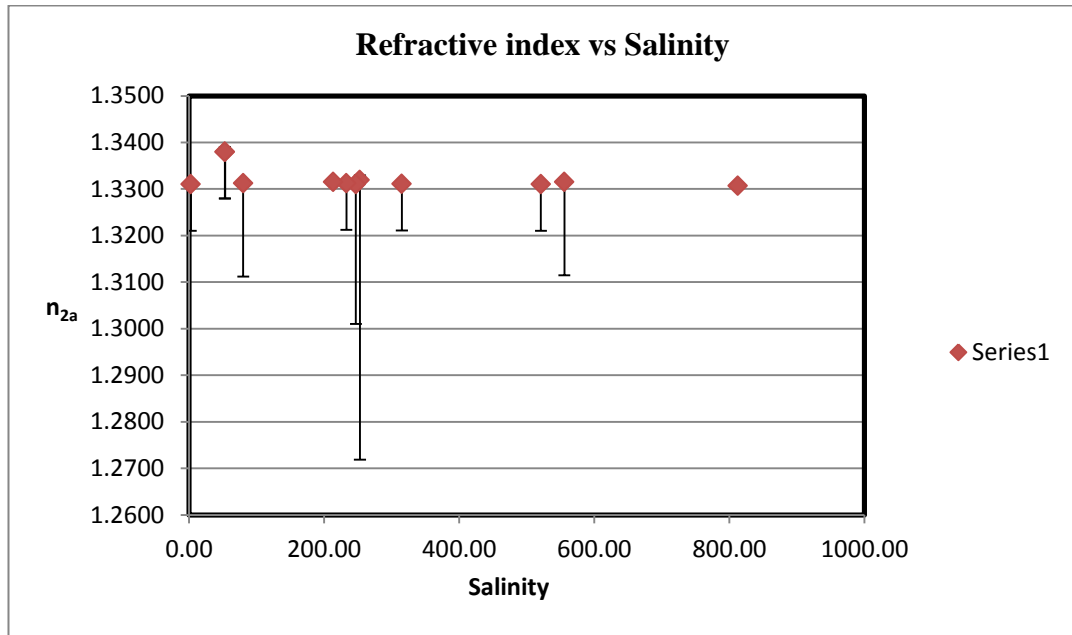


Figure 21: The schematic diagram for a graph of the refractive index from ARM and the salinity of all twelve water samples

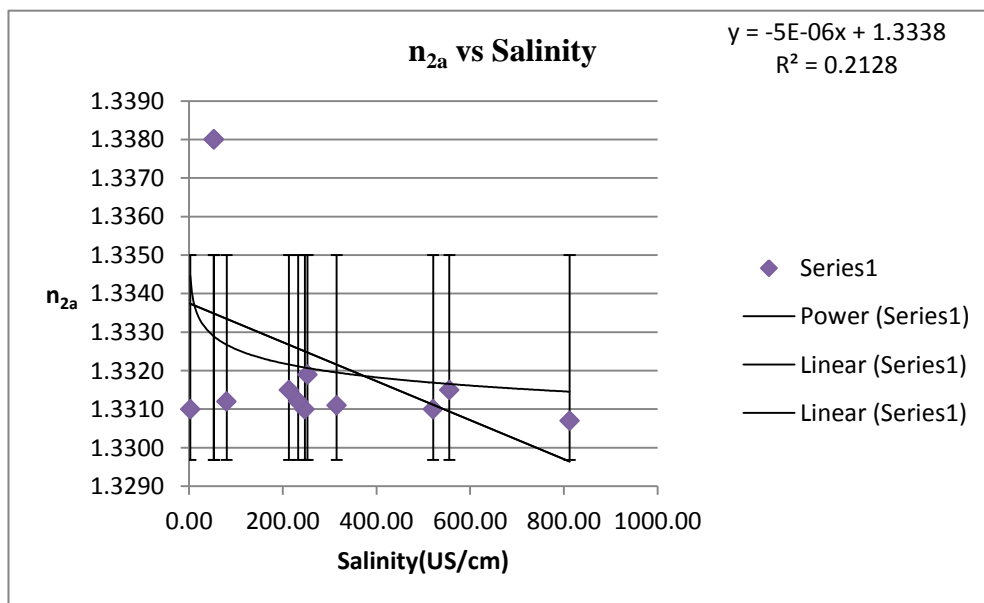


Figure 22: The schematic diagram of the graph of refractive index and the salinity of water samples defined by a root test of 0.2.

4.6.3 Density and Refractive index

Table 11. The density and the refractive index of liquid samples measured.

Ave.Density	Ave _{na}	X	Y
		Av. Stdv	Av. St dv
1.0130	1.3380	0.001	0.0010
1.0111	1.3380	0.0009	0.0010
0.9882	1.3319	0.0004	0.0010
0.9860	1.3310	0.0001	0.0000
0.9861	1.3312	0.0001	0.0000
0.9880	1.3310	0.0001	0.0000
0.9880	1.3312	0.0001	0.0002
0.9820	1.3315	0.0001	0.0000
0.9840	1.3310	0.0001	0.0000
0.9820	1.3311	0.0001	0.0001
0.9860	1.3315	0.0001	0.0000
0.8960	1.3307	0.0001	0.0006

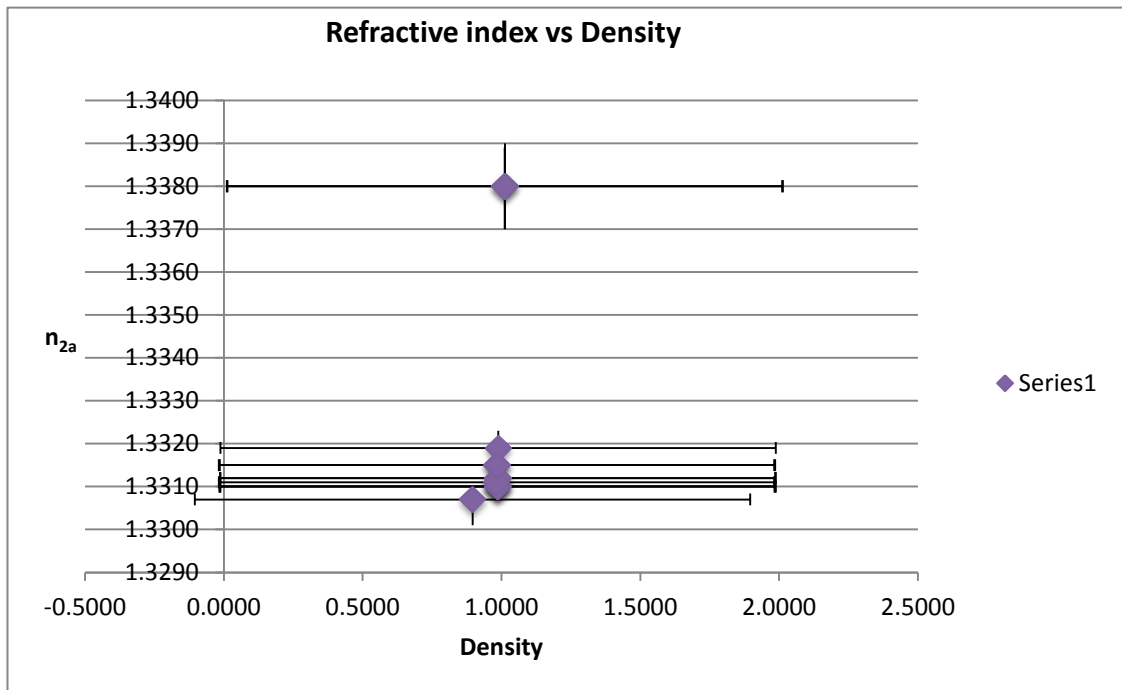


Figure 23: The schematic graph of refractive index and the density of water samples

Clearly from figure 23, the average values of refractive index and density are concentrated at some coordinates except for sea water samples. However, the density was measured to be $\pm 1.000 \text{ g/cm}^3$. Even though it's known that density of pure water is 1.000 g/cm^3 , there were no values of density measured to be exactly equal to that of pure water. This is a clear suggestion that the water samples were having impurities in them. Therefore, for different water samples, different values of refractive index were obtained. For these values of refractive index and density, there seem to exist a linear correlation as shown from figure 23 above. The increase of sea water density was attributed to the increase in its refractive index.

4.6.4 Turbidity

Table 12. The turbidity and refractive index measured.

Ave. Turbidity(utm)	Ave _{na}	X	Y
		Av. Stdv	Av. St dv
15.87	1.3380	0.0010	0.06
15.05	1.3380	0.0010	0.13
128.57	1.3319	0.0010	0.51
96.70	1.3310	0.0000	0.10
6.58	1.3312	0.0000	0.02
41.93	1.3310	0.0000	0.12
5.40	1.3312	0.0002	0.20
200.00	1.3315	0.0000	1.00
65.30	1.3310	0.0000	0.10
32.33	1.3311	0.0001	0.58
34.67	1.3315	0.0000	0.58
0.64	1.3307	0.0006	0.02

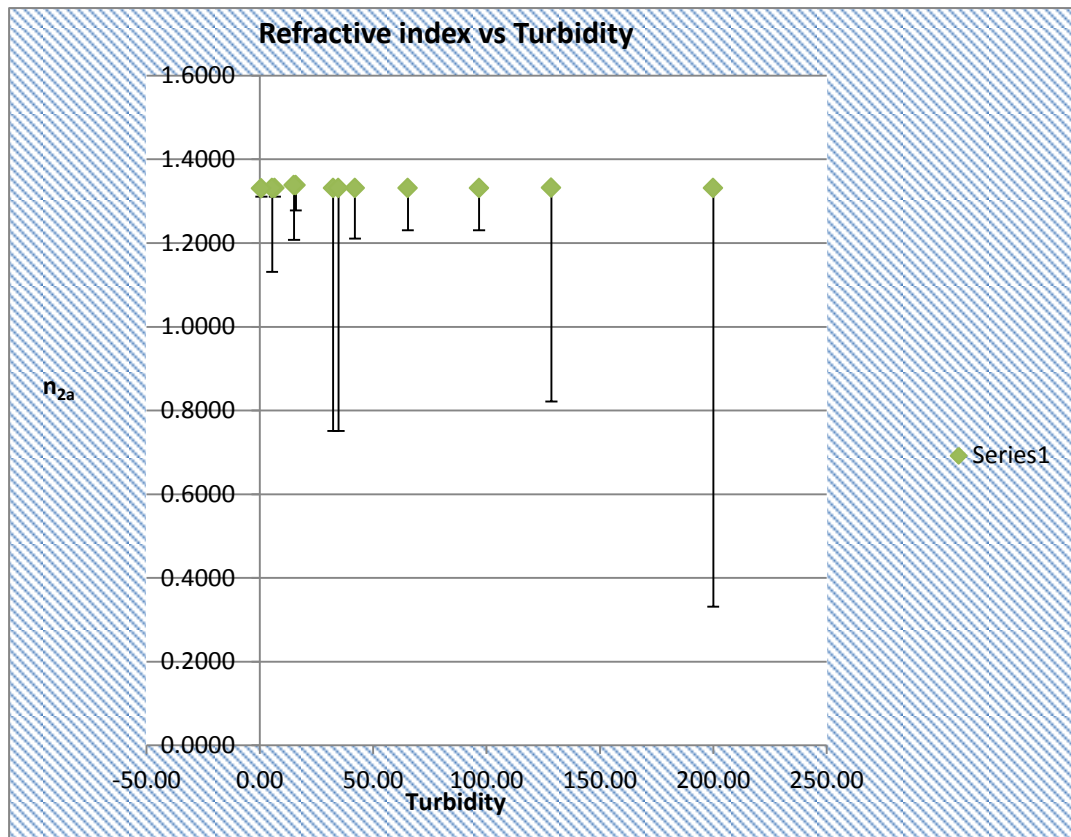


Figure 24: The schematic of a graph of the refractive index and the turbidity of water samples

As seen from figure 24 above, there exist no correlation between refractive index and turbidity of water samples. Indeed, high pH was recorded in S_8 (mud, pond water) with no clear cut difference in refractive index comparing to other measurements of other samples. The turbidity of sea water was found to be ~ 15.87 . This is the fourth lowest turbidity although the refractive index of sea water is the great in all sample measurements

4.6.5. Hydrogen ions

Table 13. The pH and refractive index measured.

Av.pH	Ave_{na}	X	Y
		Av.Stdv	Av.St dv
7.57	1.3380	0.0010	0.01
7.36	1.3380	0.0010	0.01
7.83	1.3319	0.0010	0.06
7.53	1.3310	0.0000	0.03
7.57	1.3312	0.0000	0.02
7.57	1.3310	0.0000	0.01
7.04	1.3312	0.0002	0.01
7.84	1.3315	0.0000	0.00
7.21	1.3310	0.0000	0.01
7.95	1.3311	0.0001	0.01
7.75	1.3315	0.0000	0.02
7.82	1.3307	0.0006	0.00

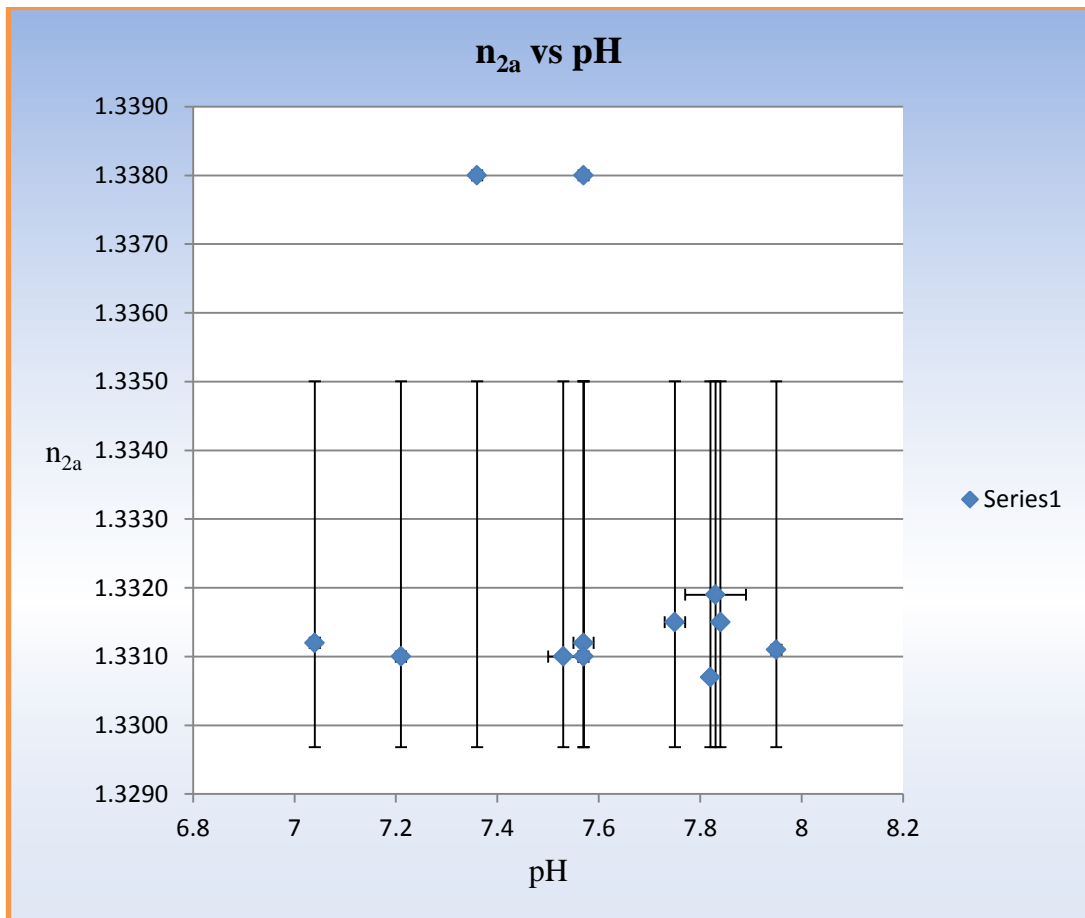


Figure 25: The schematic diagram of the graph of refractive index and the pH for the water samples measured.

As seen from figure 25 above, there exist no correlation between refractive index and pH. Indeed, high pH was recorded in S₈ (mud, pond water) with low refractive index comparing to other measurements of other samples. The pH of sea water was found to be ~7.5. This is attributed to the fact that sea water are only mainly rich in chloride ions. The refractive index of sea water is high in all sample measurements and hence there exist nonlinear correlation between refractive index and pH. However for S₈, high turbidity and high pH was investigated in our results.

5. DISCUSSIONS

Two quick methods for measuring refractive indices of liquids have been used for the measurements of refractive index of water samples collected from different surface water sources in Namibia. The range for the refractive index of water samples is 1.3100 to 1.3800. As can be seen from the setup of SDM (figure 14), point A and C are fixed for a particular diffraction grating. The position of the point B varied depending upon the angle of refraction.

Since the angle of refraction will depend upon the type of water sample used, then position of point B will be different for different water sample for a particular grating mounted. There were several precautions to locate the position of point A easily. Hence fixed positions of points A and C were formed. Also by calibrating the position of B only, refractive index of water samples was found only by knowing the position of B and C. Thus, it was sufficient to use vernier scale to show refractive indices of water samples instantaneously.

Therefore, SDM can also be used provide quick measurements of the refractive index of water samples instantaneously in a production of bulk measurements of liquids for industrial use. Due to the nature of the method, it will be very suitable for school teachers and undergraduate students in remote areas. ARM measurements are of high accuracy but due to the costs involved in purchasing and maintaining the equipment, it will be difficult for it to be used in remote areas. However, due to the

comparison made from the values made by ARM and SDM, it clear that refractive index can be obtained from these methods with less cost involved.

6. CONCLUSIONS

The aim of this study was to measure and compare the refractometer accurate readings to that of SDM for the measurement of refractive index of water samples collected from different surface sources in Namibia. The specific goal was to measure the refractive index of the water sample with an accuracy of 10^{-4} in refractive index units. Apart from refractive index measurements, other quality water control parameters were also measure.

These parameters were; salinity, turbidity, pH and density. The following facts have been deduced from the data. Refractive index measured from SDM and ARM were correlated and the correlation was defined by a linear equation of the form; $y = 1.2x + 0$. The root test was found to be $0.9535 \sim 1$. Root test has ensured the existence of a linear correlation between these two methods. Refractive index was not found to be proportional to the salinity of the water samples measured.

Refractive index was not found to be proportional to the turbidity of the water samples measured. This could be attributed to unequal distribution of suspended materials in water even though the samples were homosounised prior to measurements. Refractive index was not found to be proportional to the level of Hydrogen ions in the water samples measured. However, for some samples, e.g. S₈, the trend between turbidity and hydrogen ion existed. This could be attributed to high amount of hydrogen ions in the pond water. The density of sea water was found to be greater than 1.000 g/cm^3 . Literature value for density of sea water has always been

greater than one. This is clearly an interpretation of theoretical value of density of sea water from literatures available.

For the density of sea water, there exists a linear correlation to its refractive index for the samples under study. High density was found in sea water samples than any other samples with their respective high refractive index as investigated in figure 23. Most of the water hydrogen ions measurements are averaging at ~ 7.5 (neutral or slightly alkali). There is no alarm for communal farmers as most of this water samples are human and animal consumed. Acidic water measurement of water samples could be a serious problem to the household community. However, there was no measurements of pH lower than 7 for all water samples.

7. RECOMMENDATION

Recommendations

Based on the research findings from this study, the following comments underlined key aspects in order to improve on future studies. Therefore, the following recommendations are made.

Researchers

- The average refractive index from both methods was found to be within the minimum error that is recommended (error less than 10%). There is a need to measure more samples in future to confirm with the amount of the current results approximated.
- It should be noted that human being and animal exposure to these water samples e.g. inform of dietary intake, has not been taken into account in this study. Therefore, consideration should be made to calculate the overall risk that animals and human being consuming this water samples are exposed too.
- It is also recommended to sample at monthly interval in order to observe the monthly trends that could potentially have an impact on chemical (salinity) and Hydrogen composition in the water samples.

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APPENDIX

S1: Walvisbay, lagoon prominende lodge, Namibia, 25 degree

GPS reading

Location: 0446897 S

7460718 E

Elevation: 6m

S2: Swakopmund, strand street, Namibia

GPS reading

Location: 0450863 S

7491753 E

Elevation: 11m

S3: khorixas, Namibia

GPS reading

Location: 0440863 S

7791753 E

Elevation: 2000m

S4: Kaokoland pond, Otjondeka Village

GPS reading

Location: 0434330 S

7901226 E

Elevation: 1276m

S5: Ruacana District, Ruacana fall

GPS reading

Location: 0416952 S

8076508 E

Elevation: 801m

S6: Oshakati, Canal

GPS reading

Location: 0557883 S

8042217 E

Elevation: 1101m

S7: Eendadi Village, Well

GPS reading

Locations: 0621423 S

8066426 E

Elevation: 1105m

S8: Oshandi Pond, Ondobe District

GPS reading

Location: 0622133 S

8068714 E

Elevation: 1106m

S9: Oheti Lake, Ondobe District

GPS reading

Location: 0628376 S

8069498 E

Elevation: 1115m Salinity:

S10: Embaxu Lake, Ondobe District

GPS reading

Locations: 0623456 S

8063992 E

Elevation: 1105m

S11: Eenhana River, Eenhana District

GPS reading

Locations: 0641921 S

8066867 E

Elevation: 1109m

S12: UNAM main campus, Tap

GPS Reading

Location: 2236395 S

1705100 E

Elevation: 1687m