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# Namibian Land Use Changes and Nutrient Water Quality of the Okavango River

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**Abstract**

Over the past twenty years, the Kavango Region in Namibia has experienced a ninety percent population increase, land use change from forests and grasslands into settlements and agricultural lands, which included increased irrigated commercial farming activities along the Okavango River. These human activities were expected to cause some impact on the water quality of Okavango River. Landsat TM images for years 1990 and 2011 were classified using unsupervised classification process to determine the changes in land use. Water quality parameters measured for three months at six sampling points along the river, and climatic data was obtained. Eleven percent land use change from shrub and grasslands into settlements and agricultural lands was observed. Irrigated area increased by over hundred percent and area under forest, shrubs and grass have decreased by over eleven percent between 1990 and 2011. Linear regression was used to analyse correlation between reach length and water nutrient concentration. A high negative correlation between nutrient load and reach length indicated that the reach was attenuating the inflow nutrient load. Analysis of variance showed statistically significant differences in oxidized nitrogen levels between 1993 and 2012, but there were no statistically significant differences in total phosphorus and total nitrogen during the same period. The study showed that the land use changes in the Kavango Region had low impact on the water quality of the Okavango River.

**Keywords:** Land use change, Namibia, Nutrient water quality, Okavango River

## 1. Introduction

The natural environment is continuously changing due to both natural causes and also due to anthropogenic activities.

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In societies guided by modern principles of economic growth, it is inevitable that habitats will experience environmental degradation (Andersson, 2006). Development and population growth are directly linked with the availability and quality of fresh water resources (Ashton and Braune, 1999). The quality of surface water has decreased in many countries over the past few decades (Mattikalli and Richards, 1996). As the human population increase the impact of migration and urbanisation, industrial growth and agriculture usually have effects on quality of water in rivers receiving return flows.

The Okavango River's headwaters are located in the Angolan highlands in Cuando-Cubango Province, and stream flow is mainly generated in Angola. It flows for more than 600 km as Cubango River, before joining with a major tributary called Cuito River on the Angolan-Namibian border. The Cuito contributes about 45% of all the water that the Okavango delivers every year to the in land delta in Botswana, while the remaining 55% is provided by the Cubango. The mean annual discharge rates of the Cubango/Okavango measured at Rundu is 5500 $Mm^3$ and the Okavango's total mean annual runoff is 10000 $Mm^3$. Namibia contributes almost no surface water to the Okavango, although the length of the Cubango in the Namibian section is about 415 kilometres, because they drain predominantly semi arid and arid areas (el Obeid & Mendelsohn, 2001; OKACOM, 2010). The Okavango River is a perennial river with two distinctive flow regimes, the high flow season (peaking in April) and low flow season (lowest in November) with two transition periods between the two seasons.

The Kavango Region in Namibia, the study area is a broad sandy plateau, dominated by Kalahari sandy soils, with an average slope gradient of less than 0.07%. Infiltration rates are high, due to coarse granular textures and lack of surface crust development. Overland flow can be expected to be minimal even on slopes with up to 5% inclination, hence chances of surface runoff carrying nutrients from the Kalahari sandy soils into the river may be low (Ministry of Environment and Tourism, 2000 and Andersson, 2006).

Trewby (2003) noted that human activities that cleared land were most extensive and visible in the Kavango Region of Namibia. From 1991, the Kavango Region experienced a 90% population increase to 222,500 in 2011, (National Planning Commission, Namibia, 2012). Sixty eight percent (68%) of the population of the Kavango Region are living within a locus of 10 km from the Okavango River.

Urbanisation, rural settlements, irrigated agriculture, tourism and other economic activities, water use, clearance of land and utilization of natural resources are increasing (Mendelsohn, 2009). Namibia is the only country using the Okavango River water for irrigated commercial agriculture, which increased from 300 Ha (Trewby, 2003) to over 2600 ha in 2012 as shown in Table 1.

The continuous modification and land cover/use changes in the Okavango River basin could be causing water pollution through inorganic fertilizers, pesticides and accelerated soil erosion (Trewby, 2003; Mendelsohn and el Obeid, 2004 and 2009; OKACOM, 2010). Kay et al. (2010) estimated that agriculture was responsible for more than 50% of nitrate and 30–50% of phosphorus pollution in some catchments. Monteagudo et al. (2010), found out that irrigated agriculture tend to pollute rivers more than non-irrigated agriculture in south-central Spanish rivers. Water quality monitoring studies by Trewby (2003) and Andersson (2006), who sampled suspected highly polluted points on the Okavango River, concluded that the level of pollution was low, and hence the river system was coping with the pollution load. Trewby (2003) suspected that the 300 Ha irrigated commercial agriculture was contributing more nutrient pollution than any other land use.

Also, OKACOM (2012) identified large scale irrigated agriculture as the most potent human activity to cause the greatest impact on the Okavango River's natural systems. Mmualefe (2010) observed that pesticides were present in sediment and water samples in the pan handle (Namibia/Botswana border), which showed existence of pollution from human activities outside Botswana. Duda and El-Ashry (2000) predicted that the basin will have serious water shortages by 2025. Therefore in the event of higher water abstractions and more nutrient load from increasing anthropogenic activities, the resilience of the river on nutrient attenuation may be overstretched. Trewby (2003) stated that the Okavango River's threshold of nutrient pollution was unknown. Hence, frequent studies on the impact of the human activities on river water quality could be important for formulation of appropriate strategies for sustainable resources utilization and management in the Okavango River basin.

Generally agricultural activities and deforested lands are the major non-point sources of sediment, pesticides, nutrients, and pathogens, which are difficult to measure and control (FAO, 2005).

Monitoring pesticide pollution from farms was more costly compared to monitoring nitrates, the main component of nitrogen pollution from inorganic irrigated farms; hence Williamson et al. (1999) recommended nitrates as an indicator of pollution from farms for both nutrients and pesticides. Mathuthu et al (1997) and Zaranyika (1997) monthly measured physical and chemical water quality parameters that included nitrates and phosphates, on selected points along a river passing through industrialized urban settlements and agricultural areas. The parameters were used as indicators for assessing impact, sources and levels of pollutants on water quality levels of pollution. Therefore periodic measurements of nutrient concentration can be appropriate for assessing impact of non-industrialised settlements and agricultural activities on water quality of the Okavango River.

The Okavango River passes through a semi-arid zone, where the most densely populated non-industrialised settlements are located and intensive agricultural activities are practiced. OKACOM and independent researchers have suggested that the irrigated commercial farms with highly permeable sandy soils could be polluting the river with nutrients more than any other land use. Annually, the irrigated farms produce two crops (maize and wheat), with a nitrogen application rate of about 400 kg/ha per crop, which was more than twice average amounts applied in South Africa (Jéan du Plessis, 2003) and USA's corn belt (John Sawyer, 2007 and Alley et al., 2009). In the past 10 years, the human activities along the river have been increased and intensified, especially irrigated agriculture increased from 300 Ha to 2600 Ha, but there were no recent studies on impact of the land use changes on the river system. Using a land cover change assessment and nutrient measurement in the river, the study sought to find out the extent to which the activities had changed the riparian zone of the river, and if there was a corresponding change in the river water quality. A statistically significant increase in nutrients in the river reach was considered as an appropriate indicator of the impact of the human activities on water quality in the study area.

## 2. Methods and Materials

Land cover/use change detection along the Okavango River as a ratio (percentage) between the years 1990 and 2011 was determined.

Measurements of selected water quality parameters were done on-site and grab samples were used in laboratory analyses. Land cover changes, regression correlation and analysis of variance of nutrient water quality parameters with reach length were done.

## 2.1. Land Use Change Detection

Images for years 1990 and 2011 were downloaded from the United States Geological Survey (USGS) website (http://glovis.usgs.gov/) and some ground truthing was done before classification and land cover change detection. The images were from the same season and obtained during the same time of the day, had the same spatial spectral and radiometric resolution of 30 m (Mouat, et al., 1993). During the classification stage, the images were analysed in order to determine the main type of land cover/use during the particular years of interest. Enhancement and pre-processing, histogram matching, mosaic, unsupervised classification and majority filtering processes were done using ERDAS Imagine 9.1.

Data processing and classification was done with ArcGIS 9.2 and ILWIS softwares. Two analysis tools 'Extract' and 'Overlay' were used to determine the land cover change matrix and changed areas for the years 1990 and 2011. The clip function was used to determine change of individual land cover class from year 1990 to 2011. The information classes identified from the images used in the study were water, bare soil and settlements, healthy vegetation (Forest), dry vegetation (shrubs and grassland) and cultivated land. The land cover change detection determined the degree and percentage change between the two images. Bare soil and settlements were classified as one because it was difficult to distinguish the two features. Cultivated land on both sides of the river included both irrigated commercial farms and small scale subsistence dry land farms.

## 2.2. Sampling Sites

From upstream to downstream; the sampling points were located at Katwitwi (at Namibian/Angola border), Bunya, Kaisosi, Ndonga, Mbambi and Kwetze close to the panhandle, where it leaves Namibia, entering Botswana, as shown in Figure 1. The reach was the most densely populated part of the river basin upstream of the Okavango delta, and the only area with intensive irrigated commercial agriculture.

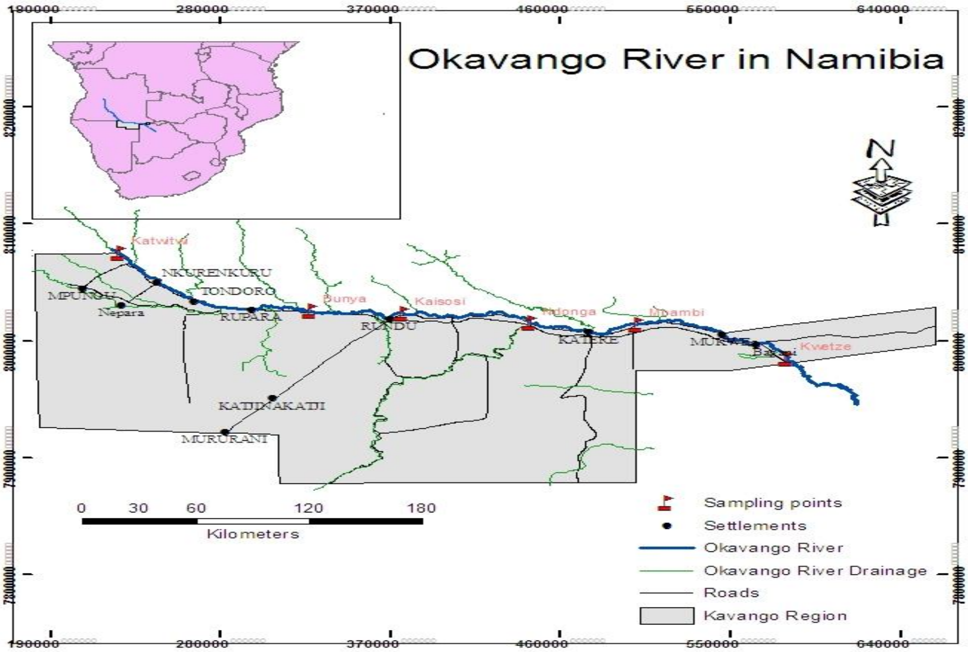


**Figure 1: Okavango River and Sampling points in the Kavango Region in Namibia**

Sampling was done at Katwitwi to observe the quality of water from Angola, while at Mbambi sampling was to observe if there was a change in water quality after the Cuito and Okavango River confluence, situated 15 kilometres upstream of Mbambi. Other sampling sites were downstream of potential major pollution sites along the river, especially urban settlements and big commercial agriculture as shown in Table 1. There were many small settlements like rural villages and dry land agricultural plots between the sampling points, which were considered to be minor sources of nutrients as individual units compared to the sources listed in Table1. No sampling was done after confluences of tributaries origination in the semi arid areas of Namibia and Angola because the tributaries were dry during the study period, hence insignificant.

**Table 1: Reaches, Sampling Sites and Possible Major Sources of Nutrient Pollution**

| Reach | Reach Length (km) | Major Nutrient Sources | Size |
|---|---|---|---|
| Katwitwi- Bunya | 120 | Irrigation Schemes | 300 Ha |
| Bunya-Kaisosi | 60 | Rundu Town | 81500 people |
| | 60 | Irrigation Schemes | 730 Ha |
| Kaisosi-Ndonga | 10 | Irrigation Schemes | 130 Ha |
| Ndonga-Mbambi | 140 | Irrigation Schemes | 700 Ha |
| Mbambi-Kwetze | 90 | Irrigation Schemes | 750 Ha |

2.3. Water Quality Parameters

Sampling was done once in a month for three months from January to March 2012. Accessing from the Namibian side and using a speed boat, samples were taken from the middle of the main stream. In-situ measurements were done using a potable HACH multimeter HQ40d for the following parameters; Dissolved Oxygen (DO, accuracy of ±1 %), pH (accuracy of ±0.2%), Salinity and Total Dissolved Solids (TDS, accuracy of ±0.5), Temperature and Electrical Conductivity (accuracy of ±0.5 %). A potable HACH turbidometer 2100P was used to measure turbidity (accuracy of ± 2%). Analysis was done for Total Nitrogen, Nitrate, Nitrite and Total Phosphorus. Samples for measuring nitrogen and phosphorus were collected from the Okavango River, kept in a cool box with ice while in the field and during transportation to Windhoek (800km distance) for analysis. The analysis was done according to the procedures described in the American Public Health Association guidelines (APHA, 1995). In situ water quality test and water samples were collected at six sites shown in Figure 1.

Linear and polynomial regressions for nitrogen and phosphorus concentration against reach length and time were done. The linear regression correlation coefficient r = +1 showed that the regression equation (trend line) truly represented the set of water quality data and the nutrient was increasing with reach length, while r = -1 showed that the nutrient was decreasing with reach length. A polynomial correlation coefficient r = 1 showed that the regression equation (trend line) truly represented the set of data.

An analysis was done for temporal statistical differences between monthly average nitrogen and phosphorus levels obtained at the same sampling sites in the seasons; autumn (March) 2012, autumn 1993, autumn 1994 and winter and spring 2002.

Nitrate and nitrite water quality data (2002 to 2011) was obtained from Namibia Water Corporation's (NamWater) water treatment plant for Rundu Town. Data on river water flow rate (1945 to 2012) was obtained from the Namibian Ministry of Water, Agriculture and Forestry, and only the data from Rundu gauging station was available.

## 3. Results and Discussion

### 3.1. Landsat Images and Image Classification

A comparison of the 1990 and 2011 classified images, showed that cultivated land had increased by 9% and bare land had also increased by 2%. Forest, Shrubs and grassland had reduced with 3% and 9% respectively during the same period. Area covered by water increased by 1%. Figure 2 and Figure 3 show the classified images of the study area. Table 2 show the area of the classified land cover classes for years 1990 and 2011.

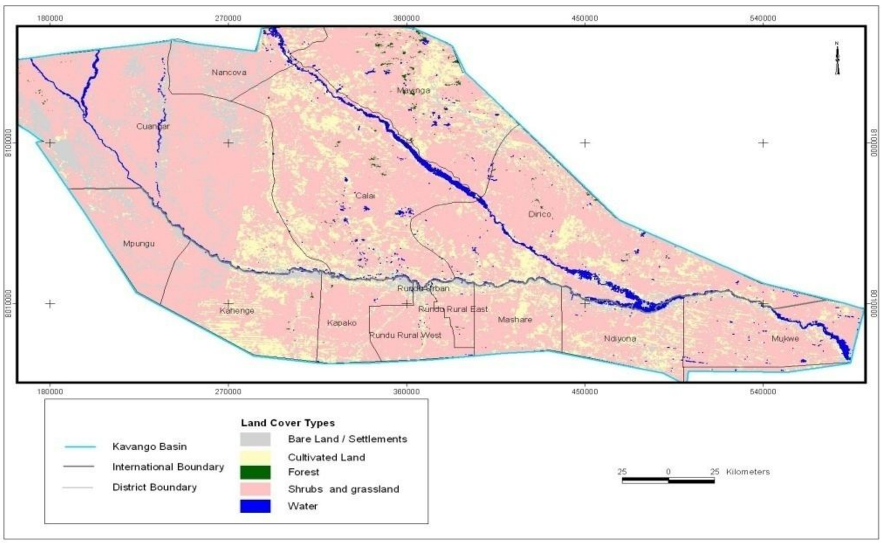


**Figure 2: 1990 Classified image of the study area in Okavango River Basin**

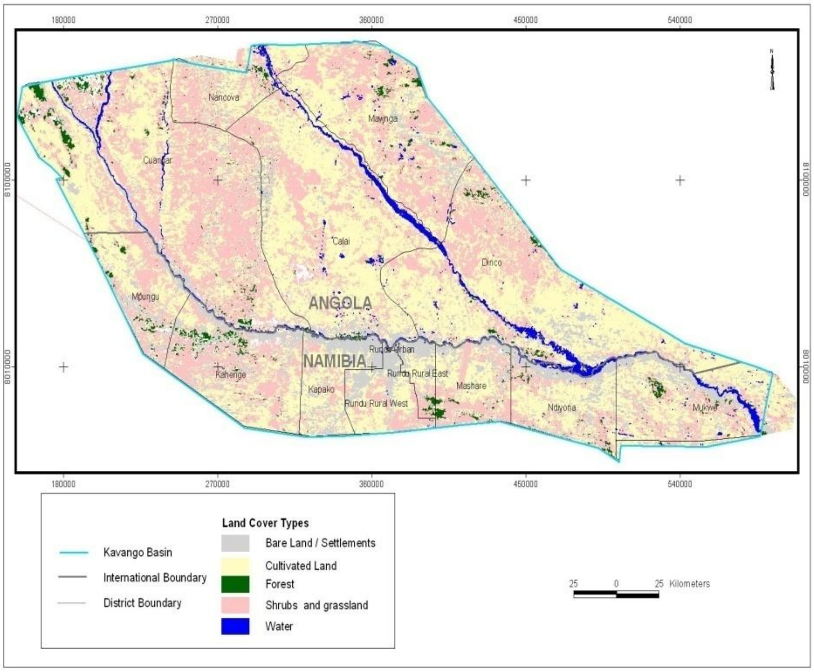


**Figure 3: 2011 Classified image of the study area in Okavango River Basin**

**Table 2: Land Cover Changes in area ($km^2$) and Percentage from 1990 to 2011**

| **Land Use / Cover Types** | **Coverage** | | | | **Cover Change** | |
|---|---|---|---|---|---|---|
| | **1990** | | **2011** | | **1990-2011** | |
| | **$Km^2$** | **%** | **$Km^2$** | **%** | **$Km^2$** | **%** |
| Bare Land / Settlement | 1878.19 | 13 | 2101.93 | 14 | 224 | 2 |
| Cultivated Land | 5596.34 | 38 | 6871.79 | 47 | 1275 | 9 |
| Forest | 927.72 | 6 | 549.60 | 4 | -378 | -3 |
| Shrubs and Grassland | 5596.34 | 38 | 4352.21 | 30 | -1244 | -9 |
| Water | 557.03 | 4 | 680.08 | 5 | 123 | 1 |
| ***Total*** | 14555.62 | 100 | 14555.62 | 100 | | |

## 3.2. Land Cover Change Detection and Assessment

When the two classified maps for years 1990 and 2011 where overlaid to determine the land cover changes, the resultant map showed that some shrub and grassland had changed to bare soil and settlement.

Also, some shrub and grassland had changed to cultivated land. The changes were mainly along the Okavango River on the Namibian side.

### 3.3. Okavango River Flow Regime, Rainfall, Runoff and Nutrients

The water quality data was collected during the low flow to high flow transition period; hence the river flow rate was on a rising limp but fluctuating. Rundu gauges' average flow was 450 $m^3/s$ in January, 600 $m^3/s$ in February 2012, and 514 $m^3/s$ in March. Table 3 show the flow rate and nutrient concentration in different years from 1984 to 2012. The same period (December to March) also coincided with the rainy season in the Kavango Region. The Kavango Region, from December 2011 to March 2012 received 530.6 mm of rainfall which was below average of 577 mm. Potential evaporation was more than 2600 mm/a. Overland flow was expected to be low on the well drained Kalahari sandy soil, with no crusting properties and a flat topography of 0.07% (Andersson, 2006; Ministry of Environment and Tourism, 2000). Therefore subsurface water movement might be the only mode of flow of water from agricultural fields into the Okavango River.

**Table 3: Temporal Average Flow Rate ($m^3/s$) and Nutrient Concentration (mg/l). For data obtained in 1990, 1993 and 1994, more precise dates e.g. the month the data was obtained were not available, but the season (Hay, et al., 2000). The (-) symbol represented unavailable data.**

| Season | Year | Flow rate | Total P | Total N | Oxidized -N |
|---|---|---|---|---|---|
| Autumn (March) | 1984 | 570.3 | 0.065 | >0.77 | - |
| Autumn | 1990 | 269.4 | - | - | - |
| Autumn | 1993 | 160.0 | 0.071 | - | 0.35 |
| Autumn | 1994 | 158.2 | 0.039 | - | 0.27 |
| Winter (May) | 2002 | 272.5 | 0.083 | 1.39 | 0.49 |
| Autumn (March) | 2011 | 724.6 | - | - | 0.60 |
| Autumn (March) | 2012 | 513.9 | 0.045 | 0.8 | 0.60 |

### 3.4. Phosphorus Water Quality

The longitudinal trend showed that total phosphorus decreased from upstream to downstream, with the highest observed value of 0.09 mg/l in March at Katwitwi. The lowest value of 0.03 mg/l in both February and March respectively was observed at Mbambi. The values recorded were similar to results obtained by Andersson (2006) who recorded 0.067 - 0.096 mg/l.

Trewby (2003) recorded higher-values of 0.1 - 0.2 mg/l for total phosphorous. According to Hay et al., (2000) total phosphorus in 1993 and 1994 range was 0.007 to 0.401 mg/l and the values obtained in 2012 were less than 0.1 mg/l, which was good for aquatic life. Effluent and water standards in South Africa stipulate that phosphate levels must not exceed 0.1 mg/l for the protection of aquatic life (Kempster et al., 1980). Figure 4 showed that in February, the total phosphorus increased between Ndonga and Kwetze which indicated a net addition of phosphorus. Generally phosphorus was attenuated to 0.03 mg/l in the February and March despite different initial levels and flow rates.

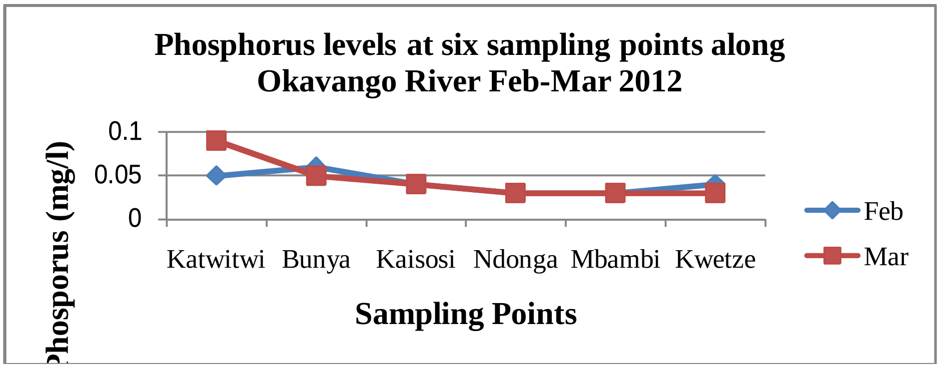


**Figure 4: Total Phosphorus Levels at six Sampling Points along Okavango River (Jan-Mar 2012)**

3.4.1. Longitudinal Variation of Phosphorus

Figure 4 showed that there is longitudinal natural attenuation of phosphorus in the Okavango River. Using monthly average levels, the Katwitwi-Ndonga reach had the highest longitudinal attenuation rate indicated by a steepest gradient. In the Ndonga-Kwetze reach, in February, a linear correlation coefficient r = +0.797 and a correlation coefficient r = +1 on a polynomial trend line, indicated an addition of phosphorus into the river. In March total phosphorus had no longitudinal variation which indicated that addition and attenuation rates were equal. The likely source of the additional phosphorus could be but not limited to irrigation schemes because the reach had the biggest area under irrigation. The higher phosphorus value was obtained at Kwetze, hence probably more sampling points between Ndonga and Kwetze could have helped in locating the source.

Increased mainstream flow rate due to inflows from the Cuito tributary could also have reduced the phosphorus attenuation rate.

### 3.4.2. Analysis of Variance of Phosphorus

For the Katwitwi-Ndonga reach, an analysis of total phosphorus using one-way ANOVA for the months of February and March 2012, the F-value was 1.195 and the P- value was 0.316, at a 5% confidence level. This showed that there were no statistically significant differences in phosphorus concentration between the months of February and March in 2012. On the Ndonga-Kwetze reach there was no statistical significant difference in phosphorus concentration between the months of February and March 2012. A higher F- value for the Katwitwi-Ndonga reach indicated a higher variation of phosphorus between sampling sites, but there were no statistically significant differences in total phosphorus concentration between sampling points at a 5% confidence level in the two reaches. (Mosteller, et al, 1983 and Lapin, 1997). The insignificant statistical difference in phosphorus concentration indicated that phosphorus concentration had no significant monthly temporal variation, and different flow rates (February-600 $m^3/s$ and March-515 $m^3/s$) had little impact on phosphorus concentration.

## 3.5. Nitrogen Water Quality

During the sampling period, total nitrogen levels were ranging between 0.7 – 1.4 mg/l from January to March. Reduced nitrogen (organic nitrogen and ammonium) varied between sampling points with Katwitwi recording the highest readings of 0.8 mg/l and 0.7 mg/l in January and February respectively. Figure 5 show the nitrogen level at six sampling points from January to March 2012.

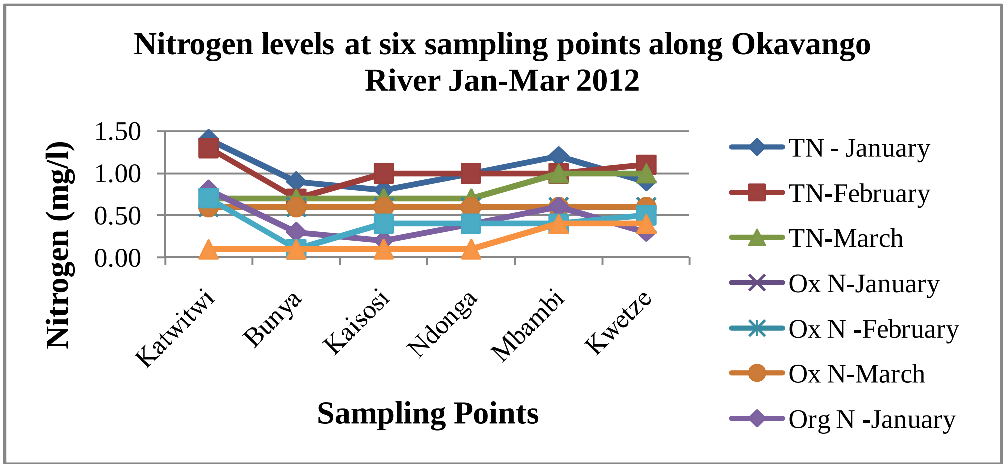


**Figure 5: Oxidized ($NO_2^-$ & NO), Reduced ($N_{org}$ & $NH_4^+$) and Total Nitrogen concentration (mg/l) at six sampling points along Okavango River (January-March 2012). TN=Total Nitrogen, Ox N=Oxidized Nitrogen, Org N=Reduced Nitrogen**

The average total nitrogen in the Okavango River was 2.9 mg/l in 2002 and 1.1 mg/l in 2012, a decrease of 1.8 mg/l from 2002 to 2012. Oxidized nitrogen was 0.60 mg/l in 2012; 0.5 mg/l for nitrate and 0.1 mg/l for nitrite. The average oxidized nitrogen in the Okavango River during the increasing flow period was 0.28 mg/l in 1993, 0.34 mg/l in 1994 (Hays, et.al, 2000), which showed an increase of 0.29 mg/l from 1993 to 2012. At the Rundu Town water treatment plant, Namibia Water Corporation (NamWater), (2012) recorded an average nitrate concentration less than 0.5 mg/l between 2002 and 2011, while Trewby (2003) obtained an average of 0.23 mg/l for oxidized nitrogen. But NamWater (2012) recorded 1.5 and 1.4 mg/l on 09/01/2007 and 22/04/2008 respectively. The spikes in nitrate concentration indicated that nitrogen levels had temporal fluctuations in both low flow and high flow periods. Probably the 2.9 mg/l of total nitrogen obtained by Trewby (2003) may have been recorded in periods when the nitrogen content was higher. Between 1990 and 2012 total nitrogen was less than 10 mg/l, which was within Namibia's Group A limit for Excellent Water Quality Standards for drinking water.

### 3.5.1. Longitudinal Variation of Nitrogen

Higher total nitrogen levels at Katwitwi and an increase at Mbambi, after the confluence with the Cuito River, showed that inflows from Angola contributed higher total nitrogen into the Katwitwi-Kwetze reach. The lower nitrogen level at Kwetze showed that there was a net uptake of total nitrogen in the Katwitwi-Kwetze reach. Total nitrogen decreased with increase in reach length on the Katwitwi-Ndonga reach. On a most fitting polynomial trend line, in January the correlation coefficient r = -0.959, in February r = -0.991 were obtained. A constant total nitrogen value in March indicated that there was no net reduction of nitrogen into the river mainstream.

Monthly average flow rate fluctuated between January and March and a correlation to total nitrogen levels showed a lower linear correlation coefficient (r = +0.684) compared to a polynomial trend line that gave a correlation coefficient r = +1. February had the highest average total nitrogen and the highest average flow rate (600 $m^3/s$) while March had 515 $m^3/s$ and January had 450 $m^3/s$, the lowest average flow rate. Despite the different flow rates, between January and March there were no statistically significant changes in nitrogen levels, which indicated that flow rate had weak influence on nitrogen attenuation on the Katwitwi-Ndonga reach. On the Ndonga-Kwetze reach, the positive gradient of the linear trend line showed that in February and March, there was a net increase in total nitrogen with increase in reach length. Since the Cuito contributes 45% of flow into the Okavango River, probably the increased flow (after the Cuito confluence) and increased organic nitrogen (in Figure 4) decreased nitrogen attenuation rate in the Ndonga-Kwetze reach. The constant amount of oxidized nitrogen indicated that upload and attenuation rate of oxidized nitrogen were equal.

### 3.5.2. Analysis of Variance of Nitrogen

One way analysis of variance of total nitrogen between sampling points in the Katwitwi- Ndonga and the Ndonga-Kwetze reaches showed that statistically, at a significance level of 5%, there were no significant differences in the nitrogen concentration along the reach lengths. The respective F- values 1.455 and 1.188 for the two reaches were close to 1.0, which indicated a low variation of total nitrogen concentration between sampling points (Mosteller, et al, 1983; Lapin, 1997). Also, at a significance level of 5% there were no statistically significant differences in concentration between the months January to March 2012 in the Katwitwi-Ndonga reach.

For the Ndonga-Kwetze reach, there were no statistically significant differences in total nitrogen levels from January to March 2012 (Mosteller, et al, 1983; Lapin, 1997). Therefore monthly average total nitrogen levels in the Katwitwi-Ndonga reach and Ndonga-Kwetze reach were statistically similar during the study period, despite the different flow rates.

3.5.3. Analysis of Variation of Nitrogen between 1993 and 2012

Comparing the 2002 and 2012 total nitrogen levels, at a significance level of 5%, total nitrogen had a statistically significant temporal difference because the F-ratio = 38.25 obtained was greater than $F_{1,12}$-value = 4.75, and the observed P-value was 0.00. In 2002 nitrogen measurements were done during the high to low flow period of May to December, whereas the 2012 values were measured during the low to higher flow transition period. This probably explained the nitrogen concentration decrease of 1.1 mg/l between December 2002 and January 2012, and the statistically significant difference in total nitrogen.

Between 1993 and 2012, in the same autumn season, oxidized nitrogen had a statistically significant difference at 5% level, and also between autumn 1994 and autumn 2012. There was no statistically significant difference at 5% level between 1993 and 1994. Trewby (2003) showed that the difference in oxidized nitrogen concentration between 1993 and 2002 was statistically significant at a significance level of 0.1%, but not significant at a 5% level. Between 1993 and 2012 there was a statistically significant increase in oxidized nitrogen, but total nitrogen did not increase. Therefore the increased irrigated agricultural activities and increased human population had low impact on nitrogen water quality.

The increase in oxidized nitrogen was in agreement with (Mvungi et al., 2003; FAO, 2005) who stated that increase in intensive agricultural activities and settlements in river basins, cause increase in mainstream nutrient load. The increase in oxidized nitrogen of 0.29 mg/l between 1993 and 2012 could be an indication that some human activities had little but increasing impact on nutrient water quality. Since the water quality was still within acceptable limits for total nitrogen (less than 10 mg/l), according to Namibian Water Standards for drinking water, therefore the Okavango River was able to cope with the nutrient load.

### 3.6. Other Water Quality Parameters from Katwitwi to Kwetze in 2012

There was a little change in longitudinal and temporal patterns on the water quality of the Okavango River during the period from January to March 2012. All water quality parameters were well within the Group A Drinking Water Standards of Namibia. Table 5 has the average of longitudinal water-quality results from January to March 2012. Dissolved solids, pH and conductivity had low variation. Conductivity showed a slight decreasing trend from upstream to downstream which was an indication of lower total dissolved solids and higher overall water-quality (Lal, 1997). Mbambi had the lowest dissolved oxygen (2.02 mg/l), pH (6.69) and turbidity (2.05 NTU), but highest electrical conductivity (37.5 µS/cm) and TDS (17.65 mg/l). Dissolved oxygen had a peak concentration at Bunya and the lowest at Mbambi (2.02 mg/l), which was below the USEPA (1998) recommended instantaneous concentration of 5 mg/l for aquatic life. The contribution of the Cuito River might have caused the changes in water quality at Mbambi.

**Table 5: Summary of Water Quality Results (monthly Mean of Six Sites, and 'x' Means no data Available)**

| Water Parameter | January | | February | | March | |
|---|---|---|---|---|---|---|
| | **Mean** | **S.E±** | **Mean** | **S.E±** | **Mean** | **S.E±** |
| Dissolved Oxygen (mg/l) | 6.25 | 0.49 | 6.21 | 0.33 | 5.45 | 0.71 |
| Conductivity (µS/cm) | 32.45 | 1.36 | 33.67 | 0.26 | 29.48 | 0.73 |
| pH | 7.03 | 0.1 | 7.1 | 0.05 | 7.39 | 0.1 |
| Total Dissolved Solids (mg/l) | 15.16 | 0.58 | 15.34 | 0.5 | 13.78 | 0.34 |
| Turbidity (NTU) | 2.82 | 0.23 | 2.91 | 0.42 | 1.94 | 0.37 |
| Temperature | 27.46 | 0.31 | 26.78 | 0.25 | 27.83 | 0.19 |
| Total Nitrogen (mg/l) | 1.03 | 0.09 | 1.02 | 0.08 | 0.8 | 0.06 |
| Total Phosphorus (mg/l) | x | x | 0.04 | 0.005 | 0.05 | 0.01 |

The variance of electrical conductivity, turbidity and temperature were statistically significant at 5 % significance level with the P-values of 0.036, 0.042 and 0.035 respectively.

### 3.7. Comparison of Water Quality Status of Okavango River from 1993 to 2012

Generally the water quality of Okavango River was uniform with low downstream longitudinal differences within the water-quality parameters measured during the sampling period in 2012. Trewby (2003) and Andersson (2006) also observed the same scenario.

The average nitrogen level in the Okavango River in 2002, and 2012 was 2.9 and 0.95 mg/l respectively. The trend showed a decrease of 1.1 mg/l from 2002 to 2012. The average phosphorus level in the Okavango River in 2002, 2006 and 2012 was 0.22, 0.07 and 0.04 mg/l respectively. The trend showed a decrease of 0.177 mg/l from 2002 to 2012. The average temperature of mainstream water in 2002, 2006 and 2012 was 27.5, 27.3 and 27.4 °C respectively. There was a decrease of 0.15 °C between 2002 and 2012. The average electrical conductivity in 2002, 2006 and 2012 was 42.28, 42.23 and 38.87 μS/cm respectively. The trend showed a decrease of 10.41μS/cm between 2002 and 2012. The average pH of the water in 2002 and 2012 was 7.03 and 7.17 respectively while in 2006 it was 6.17. The average dissolved oxygen in 2002, 2006 and 2012 was 6.57, 6.64 and 5.97 mg/l respectively. The general trends showed that dissolved oxygen dropped at Kaisosi and Ndonga, then increased again toward Kwetze. The overall trend of dissolved oxygen showed a decrease of 0.6 mg/l from 2002 to 2012. In 2006 there was a decrease at Ndonga to 5 mg/l and in 2012 there was a decrease at Mbambi to 2.02 mg/l.

Trewby (2003) collected in December, and Andersson (2006) collected in October. Both data sets were obtained in the dry season, when river flow was expected to be low. This study was done during a low to high flow transition period, which could be the reason for some of the differences in water quality. Therefore similar studies during the low flow period and comparison of findings could give more insight into the natural attenuation characteristics of the Katwiti- Kwetze reach.

### 3.8. The Effects of Land Cover/Use Changes on Okavango River Water Quality

The results for land cover/use changes showed that there was an increase in bare land and settlement class along the south part of Okavango River. Trewby (2003) also observed that there was excessive clearing associated with the growth of Rundu Town although this seemed to have negligible effect on the water-quality.

Urban settlements and irrigated commercial farms were expected to contribute significant amounts of nutrients into the river, but this was contrary to findings. The reach adequately attenuated nutrients, which vindicated Meck et al. (2011) who advocated for appreciation of the role that the natural environment plays in protecting ecosystems from the impact of human development.

Management of domestic wastewater in the river reach could also be an important reason why there were low levels of nutrients in the mainstream. For example, since 2010, waste water from Rundu Town was treated mainly in sewage ponds located 10 km away from the mainstream, where it evaporated. Hence sewage ponds did not contribute nutrients through direct return flows to the river, a possible major source of phosphorus (Young, ett.al, 1998; Parks et. al, 1994). Return flows from farms (predominantly through subsurface flow) might contain low phosphorous since overland flow from the farms into the mainstream was insignificant (FAO, 2005). Generally transports of nutrients from farms into mainstreams through groundwater contamination develop gradually for several years (20 to 30 years) before it becomes apparent. Hence, management practices also take long to effectively combat nutrient contamination (Covert, 2014). Therefore further studies may be necessary in order to fully understand the nutrient transport through subsurface return flows, quantities of nutrients leached, nutrients retention in the soil, nutrient uptake by plants and nitrogen losses into the atmosphere in the farms of the Okavango River basin.

The statistically significant increase in oxidized nitrogen could be from, but not limited to, leached nutrients from irrigated commercial farms. Nitrogen fertilizer application rates were more than twice the recommended rates in South Africa and USA. For a target of 10 t/Ha grain yield, Kavango farmers apply an average of 400 kg nitrogen per hectare of maize. The recommended application rate in South Africa was 170 kg/Ha nitrogen for target maize yields of 8 t/Ha (Jéan du Plessis, 2003). The same rates were recommended in USA's Corn Belt (John Sawyer (2007) and Alley et al., 2009). Further investigations that partition and analyse transport of the applied nitrogen might be crucial for predicting the long term destiny of excess nitrogen applied in the irrigated farms.

## 4. Conclusion

Between 1990 and 2011, the Okavango River basin had land cover/use changes and a population increase that led to increased settlements and dry land and irrigated agricultural activities especially in the Kavango Region of Namibia.

The changes had insignificant effect on nutrient water quality of Okavango River in the autumn season. A statistically significant increase in oxidized nitrogen levels could not be solely attributed to the changes in human activities. Water flows from Angola were of excellent quality (according to Namibian Standards), but had higher total nitrogen and total phosphorus which were attenuated and passed on to the Okavango delta (in Botswana), with a lower nutrient load.

There was a decrease in total phosphorus and total nitrogen concentration with increase in reach length, and in particular the Katwitwi-Mbambi reach attenuated nutrients at a higher rate than the Mbambi- Kwetze reach. The differences showed that the Cuito tributary divided the Katwitwi-Kwetze reach into two sections that had different nutrient attenuation characteristics.

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