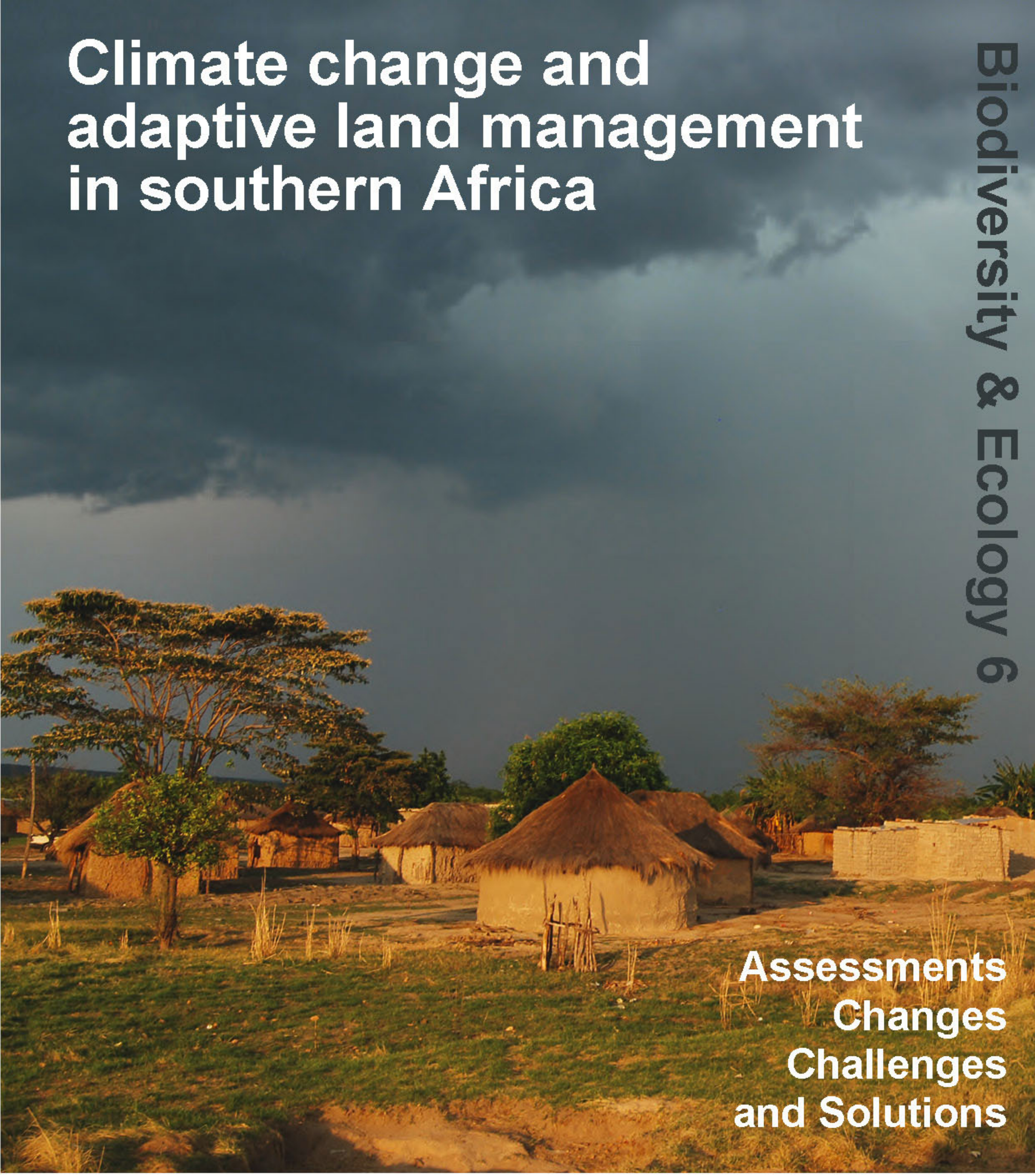
Climate change and adaptive land management in southern Africa

Biodiversity & Ecology 6



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Changes
Challenges
and Solutions

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Climate change and adaptive land management in southern Africa

Assessments, changes, challenges, and solutions

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Determinants of spatio-temporal variability of water quality in the Barotse Floodplain, western Zambia

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Abstract: Developing a water quality database for the Upper Zambezi Basin is becoming crucial for ensuring strengthened water resources monitoring and management in the face of potential threats posed by anthropogenically induced effects of land use and climate change. To realise this goal, it is important to establish factors that control the variation of water quality. Thus, in this study, we analysed water quality and stream sediment parameters to infer their spatio-temporal variation between 2014 and 2015 in the Barotse Floodplain, western Zambia. It was found that the concentrations of heavy metals (i.e., copper, lead, cadmium, mercury, arsenic, zinc, and chromium) were mostly below detection limits (< 0.002 mg/l) and fell within the World Health Organization (WHO) and Zambia Bureau of Standards (ZABS) guidelines for drinking water. This suggested that current large-scale mining activities taking place upstream of the Barotse Floodplain have no effect on this important water resource. It was the potentially geogenically derived elements, particularly calcium, that were observed to be predominant and appeared to be influenced by physical parameters, especially pH. Seasonal nutrient recruitment was also noted to be active and attributed to land use change and flood inundation patterns. Nitrates spiked up to > 24 mg/l in the year 2014, which experienced higher floods. This value dropped to < 0.5 mg/l in 2015, possibly as a result of below-normal rainfall that led to lower floods. Analysis of bacteriological results indicated that anthropogenic activities affected water quality. All sampling points close to communities registered a too-numerous-to-count (TNTC) concentration of faecal and total coliforms (> 200 coliforms/100 ml). An assessment of the sediment yields predicted by the Soil and Water Assessment Tool (SWAT) and measured turbidity suggested the likely existence of a stronger relationship in the upstream areas and near the confluence of the Zambezi and the Luanginga Rivers than within and after the main floodplain. Because of the limited sampling period, however, this phenomenon was not conclusively assessed. Nevertheless, the observed lower turbidity levels and element concentrations in the floodplain may be a strong indicator of a critical role that the Barotse Floodplain plays as a natural sink.

Resumo: É cada vez mais crucial o desenvolvimento de uma base de dados sobre a qualidade da água da bacia superior do Zambezi, de modo a garantir a monitorização e gestão reforçada dos recursos hídricos face a potenciais ameaças, causadas pelos efeitos antropogénicos resultantes do uso das terras e das alterações climáticas. De modo a materializar este objectivo, é importante estabelecer factores que controlam a variação da qualidade da água. Assim, neste estudo, analisámos a qualidade da água e os parâmetros dos sedimentos da corrente, de modo a inferir a sua variação espacio-temporal entre 2014 e 2015 na Planície Aluvial de Barotse, na Zâmbia Ocidental. Verificou-se que as concentrações de metais pesados (i.e. cobre, chumbo, cádmio, mercúrio, arsénio, zinco e crómio) encontravam-se essencialmente abaixo dos limites de detecção (< 0.002 mg/l), sendo abrangidas pelas normas da Organização Mundial da Saúde (OMS) e da Zambia Bureau of Standards (ZABS) para a água potável. Isto sugere que as actividades mineiras actuais de grande escala a decorrerem a montante da Planície Aluvial de Barotse não têm nenhum efeito neste importante recurso hídrico. Os elementos potencialmente geogénicos, particularmente o cálcio, foram observados como predominantes, parecendo ser influenciados por parâmetros físicos, em especial o pH. O recrutamento sazonal de nutrientes foi também observado como activo e atribuído às alterações do uso da terra e aos padrões de inundação. Os nitratos aumentaram até > 24 mg/l no ano de 2014, o qual sofreu inundações mais elevadas. Este valor caiu para < 0,5 mg/l em 2015, possivelmente devido à ocorrência de precipitação abaixo do normal, que resultou em inundações menos acentuadas. A análise dos resultados bacteriológicos indicou que as actividades antropogénicas afectaram a qualidade da água. Todos os pontos de amostragem perto de comunidades registaram concentrações de coliformes fecais e totais incontáveis (Too-Numerous-To-Count ou TNTC) (> 200 coliforms/100 ml). Uma avaliação dos rendimentos dos sedimentos previstos pela Ferramenta de Avaliação do Solo e da Água (SWAT) e turbidez medida sugere a provável existência de uma relação mais forte nas áreas a montante e junto à confluência dos rios Zambezi e Luanginga que no interior da e após a principal planície aluvial. No entanto, devido ao período limitado de amostragem, este fenómeno não foi definitivamente avaliado. Não obstante, os baixos níveis de turbidez observados e a concentração de elementos na planície aluvial podem possivelmente ser um forte indicador do papel crítico da Planície Aluvial de Barotse como um sumidoro natural.

Introduction

Floodplains are of great cultural and economic importance, as most early civilisations arose in fertile floodplains (Polunin, 2014). Throughout history, people have exploited the floodplains for their rich resources, particularly the alluvial soils, which support crop production. Consequently, floodplains have served as focal points for urban development (Naiman et al., 2005). Floodplains are described as dynamic systems that are shaped by repeated erosion and deposition of sediments, inundation or prolonged hydroperiods during rising water levels, and complex ground-surface water exchange processes. This dynamic nature makes floodplains among the most biologically productive and diverse ecosystems on Earth (Gregory et al., 1991; Naiman & Décamps, 1997; Tockner & Stanford, 2002; Naiman et al., 2005). A study of the spatial extent of all tropical wetlands reveals that 2.5 to 3.5% of Earth's surface is wetlands, with areas of > 10^6 km^2 in South America and 10^5 km^2 in Africa (Tockner & Stanford, 2002; Zuijdgeest et al., 2015).

Wetlands or floodplains are widely regarded as important locations for the uptake and transformation of nutrients and sediment in fluvial landscapes (Noe & Hupp, 2007). Research by Ahiablame et al. (2010) describes sediments as probably the most influential determinant of the ability of the system to process and sustain nutrient loads. This is because floodplains are frequently thought of as sinks of inorganic nutrients and sources of organic nutrients — in other words, nutrient transformers (Noe & Hupp, 2007). Moreover, many agrochemicals, heavy metals, and nutrients chemically bind to sediments, which provide a transport mechanism for these contaminants as well as substrate where they react (Lovett et al., 2007). Zuijdgeest et al. (2015) also crucially point out that flows are restricted in most lakes and floodplains systems; hence, particles have time to settle.

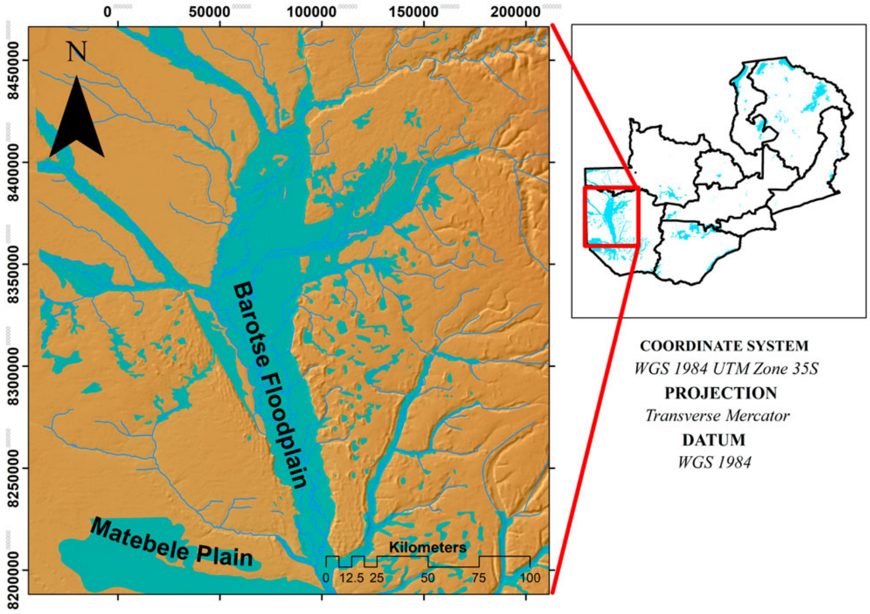

Figure 1: Location of the Barotse Floodplain in the western part of Zambia.

The agrochemical, heavy metal, and nutrient contaminants may be caused by anthropogenic perturbations, which can lead to alterations of the physical, chemical, and biological properties of the water body (Bilotta & Brazier, 2008). Nutrient contaminants can be categorised with respect to where they are being discharged. Writing on 'modeling the relationship between land use and surface water quality', Tong & Chen (2002) state that runoff from different types of land use may be enriched with different kinds of contaminants, which may come from agricultural lands enriched with nutrients, highly developed urban areas (mines inclusive) enriched with rubber fragments, oil, and heavy metals as well as sodium and sulphates from road de-icers. Only contaminants resulting from agricultural land use and mining activities are relevant in the present study area.

In this study, we assessed spatio-temporal variations in water quality parameters of the Barotse Floodplain in light of increasing anthropogenic activities such as farming around this water resource, and mining activities upstream in the Kabombo River Basin of north-western Zambia.

Study location

The Barotse Floodplain is found within the Upper Zambezi Basin (UZB). The basin lies between latitudes 11°S and 19°S, and longitudes 18°E and 27°E, which covers part of western Zambia (Fig. 1). The floodplain measures approximately 240 km long and 34 km wide. According to Turpie et al. (1999), the total wetland area is estimated at 1.2 million hectares.

Methods

In this study, surface water quality and stream sediments of the Barotse Floodplain were characterised during low and high flows. Water samples were collected across the floodplain and tested for their physical, bacteriological, and chemical characteristics. These samples were collected in triplicate at each point and preserved for different laboratory analyses: one sample for anion analysis, another for cation analysis, and the third for bacteriological analysis. Two percent (2%) of 250 ml of nitric acid was added to water samples meant for cation analysis. Acidification of water samples preserved most trace metals and reduced precipitation, microbial activity, and sorption losses to container walls. Bacteriological samples were taken in glass bottles whereas physiochemical samples were stored in plastic bottles. The principal method used for bacteriological analysis was the membrane filtration (MF) method.

Before the collection of water samples, the bottles were rinsed three times together with their respective lids. The depth at which the samples were collected was approximately 50 cm from the water surface, and the same water was used for rinsing. The samples were immediately put into cooler boxes containing ice packs upon completing the collection protocols at each site. In addition, in situ measurements were simultaneously conducted using multi-metres. Multi-metres measured the following physical parameters: dissolved oxygen (DO), temperature, electrical conductivity (EC), and pH. The samples preserved for laboratory analyses were transported to the University of Zambia within 48 hours. A record of each sampled site was created by taking photographs and geographical coordinates. The latter were also used to plot the sampling points using ArcGIS.

Stream sediment samples were collected alongside water quality samples. These two sample types were mostly collected at the same locations. Where it was not practical to collect them at the same water quality locations, an alternative site was chosen within a few metres. These samples were collected using a perforated scoop. They were immediately closed in sampling bottles and placed into the cooler boxes for soil samples. Stream sediments were tested only for their chemical elements using atom atomic absorption spectophotometry (AS) or X-ray fluorescence (XRF). The data presented in this paper were collected over a two-year field campaign: during the wet (April to June) and dry (September to October) seasons of 2014 and 2015. A summary of the methods used is given in Figure 2.

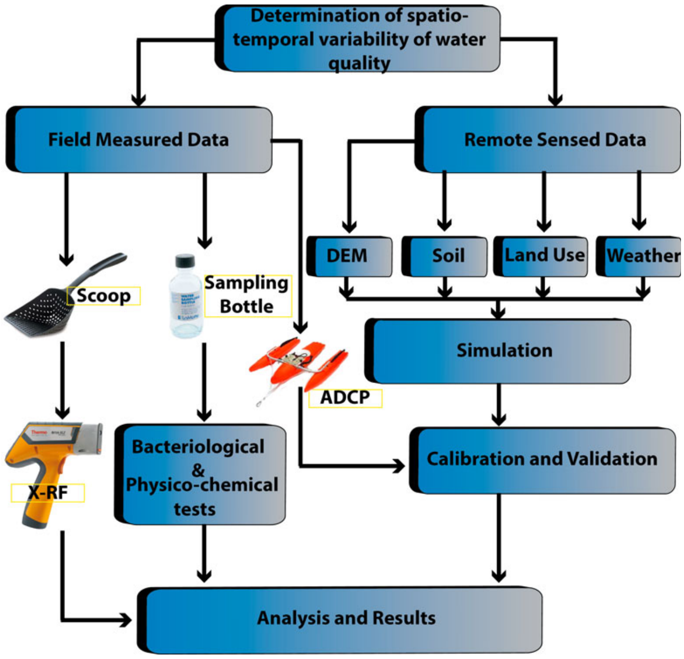

Figure 2: A flow chart illustrating the methods used in this study, which included use of the Acoustic Doppler Current Profiler (ADCP), X-ray fluorescence (X-RF), and remote sensing.

As shown in Figure 2, two types of datasets were used: (1) field-measured data and (2) remote sensing data. Field-measured data were water and stream sediment samples, which were collected using sampling bottles and the scoop, respectively. Elemental constituents in the riverbed sediments were measured to compare with what was in the water. Collected remote sensing data were used for land cover classification and as input into the Soil Water and Assessment Tool (SWAT) model. The model was used to estimate hydrological flows and sediment yields. It was calibrated with stream discharge, which was measured using the acoustic Doppler current profiler (ADCP) (Fig. 2). Land cover change was estimated from supervised classification of Landsat satellite imagery between 1984 and 2015.

Results

In this paper, the results of our findings are presented using representative spatial distribution of sampling points from which (1) bacteriological and physical parameters, (2) variability of agricultural nutrients, (3) heavy metals, (4) non-heavy metals and anions, and (5) sediment yields are described and interpreted.

Representativeness and spatial distribution of sampling points

Sampling points were selected around the Barotse Floodplain (Fig. 3). The basic element of the approach was to characterise water quality parameters from the perspective of transects: (1) Mongu-Kalabo from the Mulambwa Harbour in Mongu to the Luanginga River Harbour in Kalabo Town, (2) Mongu-Lukulu on the northern part of the main Zambezi River to Lukulu, (3) Mongu-Senanga on the eastern side of central floodplain (main Zambezi River) to Senanga, and (4) the Sioma-Kalabo on the western side of the central floodplain (main Zambezi River) from Sioma through the Matebele Plain to Kalabo. Samples were also taken in the middle of the main Zambezi River channel from Mongu to Senanga. The distribution of these points is shown in Figure 3.

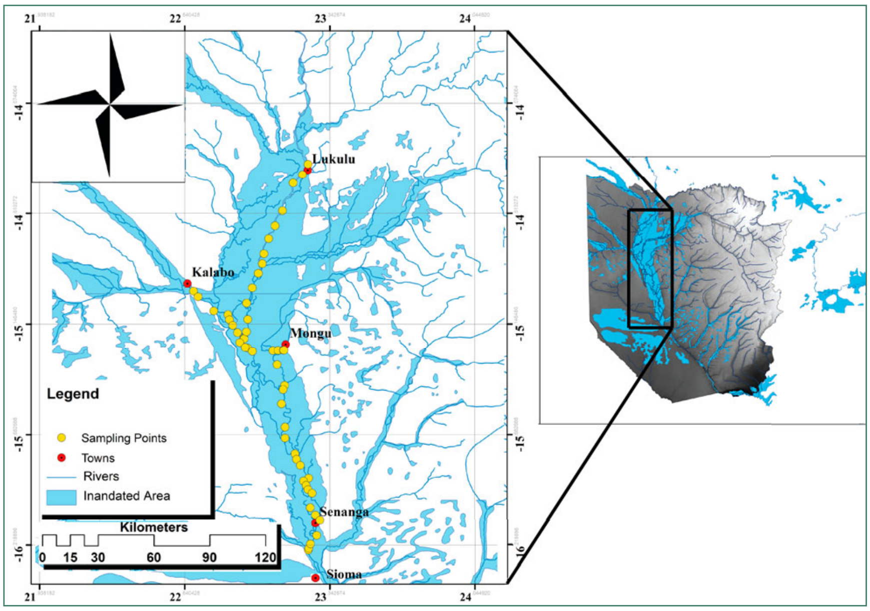

Figure 3: Spatial distribution of sampling points in the Barotse Floodplain, western Zambia.

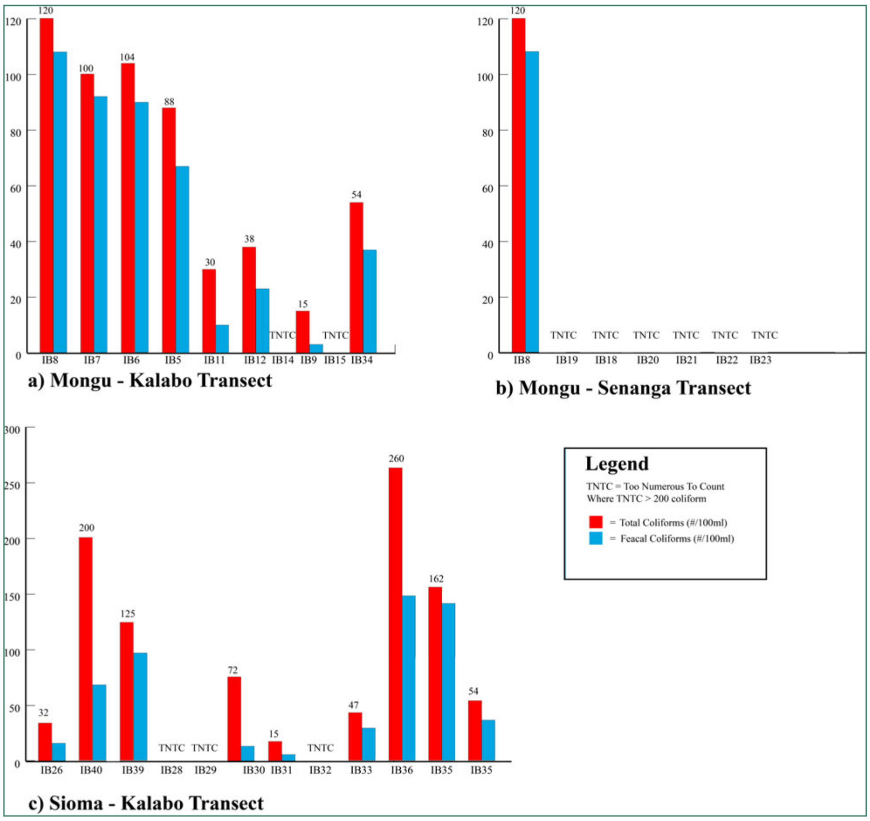

Figure 4: Faecal and total coliform distribution along (a) Mongu-Kalabo transect, (b) Mongu-Senanga transect, and (c) Sioma-Kalabo transects for the 2014 wet-season field campaign in the Barotse Floodplain, western Zambia.

A total of 124 surface water samples were collected for physical, chemical, and bacteriological analysis. Another set of 124 stream sediment samples were also collected. Water and stream sediment samples were taken at the same or nearly the same location depending on the practical feasibility presented at each location.

Bacteriological and physical parameters

Results indicate that faecal and total coliforms were too numerous to count (TNTC) at many sampling points (Fig. 4). In this study, both total and faecal coliforms were considered TNTC if the number of coliforms in a 100 ml sample exceeded 200. The observed high concentrations of these bacteriological indicators were not surprising, as most of these areas were associated with increased anthropogenic activities. For instance, along the Mongu-Senanga transect, human activities such as livestock rearing, sawmilling, open defecation, and sewerage disposal into the streams were identified as being sources of water contamination. The hot spots along this transect were found to be at Sianda stream (IB 18), Sefula Rice Irrigation Scheme (IB 19), Litoya Bridge (IB 20), Mapungu flood area (IB 22), and a sewerage disposal site (IB 23) from the Senanga Secondary School sewer line. Similarly, coliforms were TNTC at sampling points on the Sioma-Kalabo and Mongu-Kalabo transects, which are affected by human activities. The hot spots on the former transect included places where human beings obtained water for their domestic uses. It was also observed that in some cases animals (mainly cattle) also accessed these same points or adjacent areas when meeting their drinking requirements. These were found at Nakatwalenge Basic School (IB 28), Sinungu Basic School (IB 31), and Sikana Basic School (IB 32). The hot spot location on this last transect was found at Mongu Habour (IB 15).

Physical parameters of temperature and DO at all the sampling points in the Barotse Floodplain were also analysed. It was found that the DO was lowest (1.24 mg/l) at Sinungu Basic School (IB 31). This is attributed to animal manure, which is used as fertiliser in the gardens nearby. On the other hand, DO was highest (7.62 mg/l) at Sesheke-Senanga Bridge (IB 25) because of the absence of anthropogenic materials that deplete DO. The temperature was nearly constant from Matongo Hydrometric Station (IB 1) to a stream locally known as Charleton (Jauteni) in Limulunga (IB 17) and then fluctuated after this point (Fig. 5).

Variability of agricultural nutrients

Among the agricultural nutrients, nitrate was found to be relatively higher, particularly in the 2014 wet season (Fig. 6), which experienced higher floods than the 2015 wet season. Others such as total

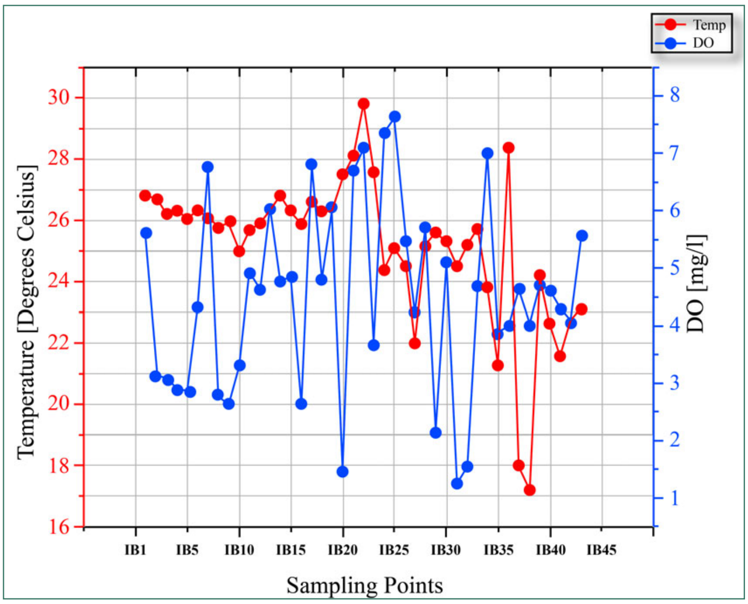

Figure 5: Dissolved oxygen (DO) and temperature variation at different sampling points in the Barotse Floodplain, Western Zambia

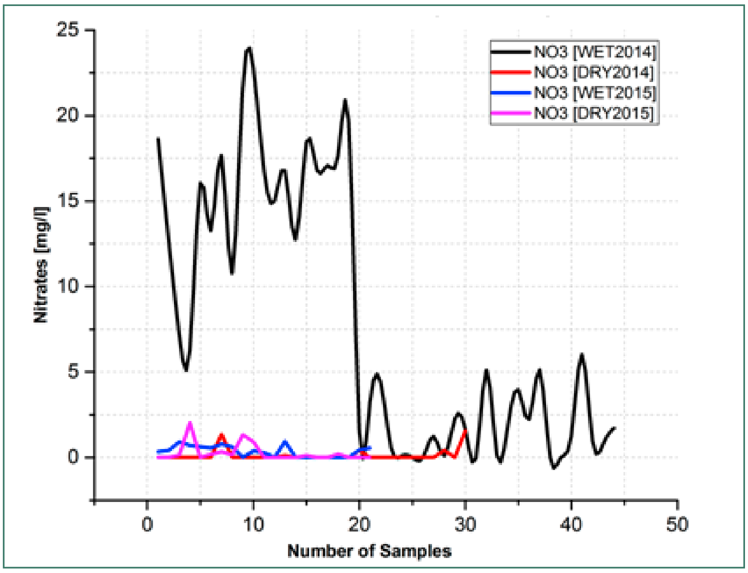

Figure 6: Seasonal values of nitrate concentration in water along the Mongu-Kalabo transect in the wet and dry seasons of 2014 and 2015, Barotse Floodplain, western Zambia.

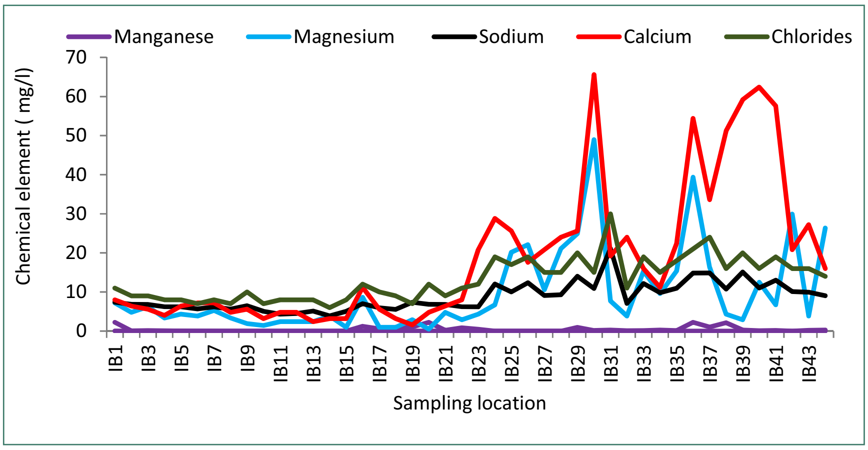

Figure 7: Variation of some non-heavy metals and the anion of chloride at sampling points in the Barotse Floodplain, western Zambia.

phosphates (< 0.01 mg/l) and nitrites (< 0.001 mg/l) were found to be negligible in concentration. From these results, nitrates were considered to be the highest main nutrient supporting the growth of agricultural crops such as maize and vegetables grown in the Barotse Floodplain. Figure 6 also suggests that nitrate nutrients are significantly mobilised and replenished during higher flood seasons.

The source of the nitrate was suspected to be agriculture-related activities around the floodplain. For instance, the local people (mainly Lozi) keep a lot of cattle within the floodplain during the dry season and also practice a complex flood agriculture system. The animals are moved to the highlands and margins of the floodplain during the wet season. It was noted that the year 2014 experienced higher flood levels than 2015. The observed higher concentration of nitrates shown in Figure 6 was therefore attributed to increased mobilisation and recruitment of this element from anthropogenic sources during the higher floods of 2014, whereas in 2015 the source was restricted to small areas around the floodplain.

Heavy metals

On the environmental impact of upstream large-scale mining, particularly in the Kabombo River Basin of north-western Zambia — a tributary of the Zambezi River upstream from the Barotse Floodplain — it was found that concentrations of heavy metals (i.e., copper, lead, cadmium, mercury, arsenic, zinc, and chromium) were negligible (< 0.002 mg/l) and within the World Health Organization (WHO) and Zambia Bureau of Standards (ZABS) standards for potable water in both the water and stream sediment samples. This indicates that water quality within the floodplain is still in its natural state in relation to mining contaminants.

Non-heavy metals and anions

It was instead the concentrations of anions of chlorides, and cations of calcium, magnesium, and sodium that were found to be relatively high in the water samples (Fig. 7).

The relatively elevated levels of concentrations of these elements (Fig. 7) were attributed to a number of factors and processes. For instance, levels of sodium and chloride, which lead to salty water, were found to be high in isolated ponds. These form salt pans as a result of the high rates of evaporation during the dry season. An example of such a feature is the Sisima salt pan, located on the Matebele Plain. One of the water quality samples [Sisima Salt Pond (IB 37)] was taken from this location and contained some of the highest amounts of sodium and chloride (Fig. 7). These elements were also found to be high in places where intensive anthropogenic activities such as gardening were taking place [e.g., Sinungu Basic School (IB 31)]. High concentrations of magnesium were associated with the presence of organic materials and animal waste at some sampling locations [e.g., Libuba Stream at Nambwae Basic School (IB 30)]. It was also suspected, however, that geogenic factors could be influencing high concentrations of magnesium. For instance, a high concentration of magnesium was found in one of the samples [Lukona Basic School (IB 36)], which was taken from a borehole. Seasonal trend analysis of these elements was carried out to understand their variability. In this paper, however, we present such an analysis using calcium, which was frequently the most abundant element in both water and stream sediments.

The trends in calcium concentration on the Mongu-Senanga transect indicated that the medians were $Q_{2wet} = 5.2$ mg/l and $Q_{2dry} = 2.6$ mg/l for the wet and dry seasons of 2014, respectively, and $Q_{2wet} = 14.4$ mg/l and $Q_{2dry} = 13.3$ mg/l for the wet and dry seasons of 2015, respectively. This transect indicted a positive skewness for both seasons — that is, $Q_3 - Q_2 > Q_2 - Q_1$, or mode < median < mean (Fig. 8), where Q stands for quartiles — that is, upper (Q_3), median (Q2), and lower quartiles (Q_1).

It was observed that there was a considerable increase in calcium concentration from the 2014 wet season to the 2015 wet season. Similar trends were observed from the 2014 dry season to the 2015 dry season. However, there was a general decrease in calcium concentration for seasonal changes within the years (Tab. 1).

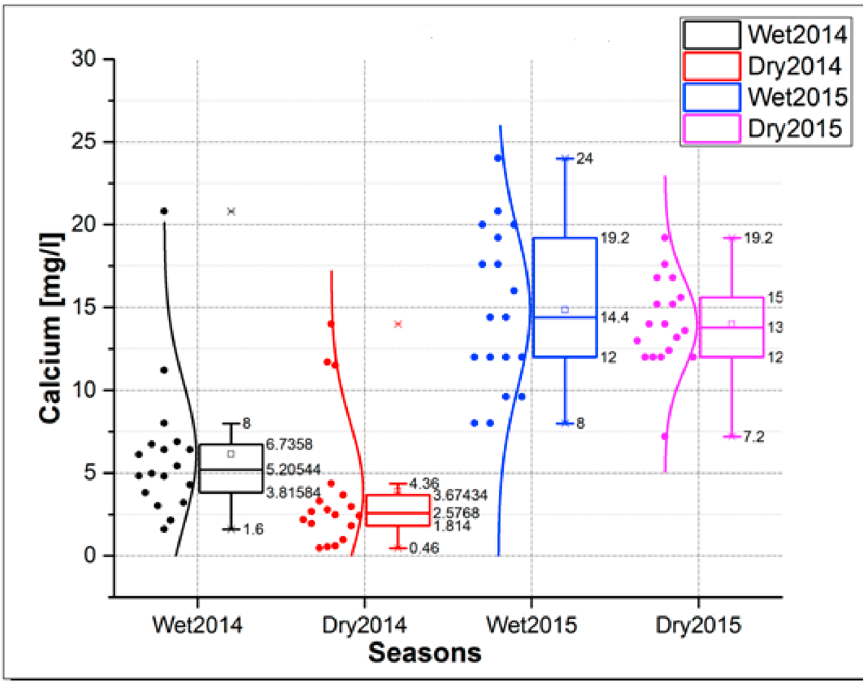

Figure 8: Box plot distribution of calcium concentration on the Mongu-Senanga transect (main Zambezi River) for the wet and dry seasons of 2014 and 2015.

Mongu-Senanga Transect				
2014 Wet Season		*2015 Wet Season*		*Yearly % Δ*
Q_3	6.7	Q_3	19.2	+185.0%
Q_2	5.2	Q_2	14.4	+176.6%
Q_1	3.8	Q_1	12	+214.5%
2014 Dry Season		*2015 Dry Season*		
Q_3	3.7	Q_3	15	+308.2%
Q_2	2.6	Q_2	13	+404.5%
Q_1	1.8	Q_1	12	+561.5%
Seasonal %Δ 2014	−45.5%	Seasonal %Δ 2015	−21.9%	
	−50.5%		−9.7%	
	−52.5%		0.0%	

Table 1: Percentage changes in calcium concentration on the Mongu-Senanga transect based on 2014 and 2015 yearly changes (Δ) as well as within-the-year seasonal changes (Δ).

The observed seasonal changes in calcium concentration were attributed to complex factors such as variations in the flow regimes between the wet and the dry seasons, and plant uptake of calcium. For instance, calcium is brought into the floodplain system through overland flows and is used up by plants in the formation of new tissues such as roots and shoots. Furthermore, the seasonal variation of calcium was also attributed to changes in the physical parameters of the water, particularly pH. Lower pH favours the dissolution of calcium. It was noted that the pH was mostly lower than 6.9 along the Mongu-Senanga transect (Fig. 9) during the low flows (i.e., dry season) of 2015, which coincided with a period when the concentration of calcium was high (~15mg/l).

The spatially distributed pH values in Figure 9 were generated using kriging, a geostatistical technique in ArcGIS. Assessment of the predictive accuracy of the technique indicated that the mean square error (MSE) was 0.22 and 0.20 during the low and high flow periods, respectively.

Sediment yields and physical water quality parameters

It was found that the sub-basins within the main floodplain experienced high rates of sedimentation (Fig. 10) as generated by the Soil and Water Assessment Tool (SWAT).

The spatial locations of the hot spot areas where sedimentation is high within

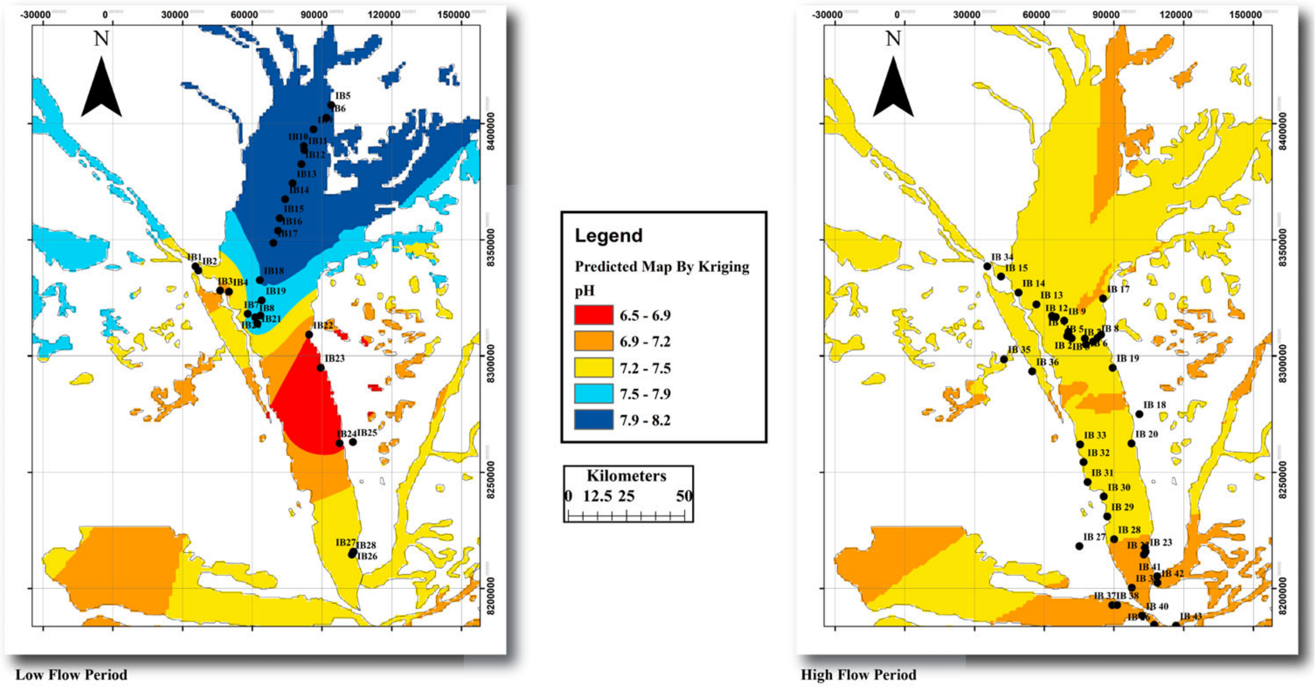

Figure 9: Spatially modelled pH distribution in the dry and wet seasons, Barotse Floodplain, western Zambia.

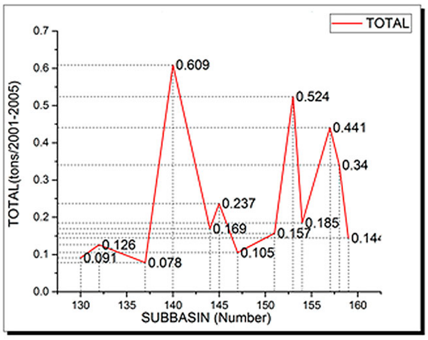

Figure 10: SWAT-estimated sediment accumulation for the years 2001 to 2005 for the sub-basins falling within the Barotse Floodplain.

the floodplain are shown in Figure 11. These areas (coloured brown) are sub-basins 140, 153, 157, and 158. Sub- basin 158 hosts the rice fields at Sefula Irrigation Scheme. The high rate of sediment accumulation has led to frequent clogging of irrigation channels in these fields.

The potential cause of increased sedimentation in the floodplain was attributed to land cover changes as forested land was turned in agricultural land. A study by Zimba et al. (2018), which was conducted within the same broader framework (i.e., SASCCAL Task 191: Developing a water quality and quantity database for western Zambia) as the present work, found that between 1984 and 2015, forest cover declined by about 10%, which translates to an annual reduction rate of about 0.3% (Fig. 12). Since the soil type in the area is sandy in nature, minor changes in forest cover can lead to high rates of sedimentation and an overall change in water quality. Furthermore, conversion of forest to agricultural land and other uses was suspected to be another source of nutrients that enrich the floodplain in the wet season.

Further analysis was done on the water quality samples. This analysis was on the total solids (TS), which is a sum of total suspended solids (TSS) and total dissolved solids (TDS). This calculation was done to infer the conveyance of sediment within the floodwaters. Results (Fig. 13) show that the Mongu-Kalabo transect has more TS being transported during the wet season (April 2014) than

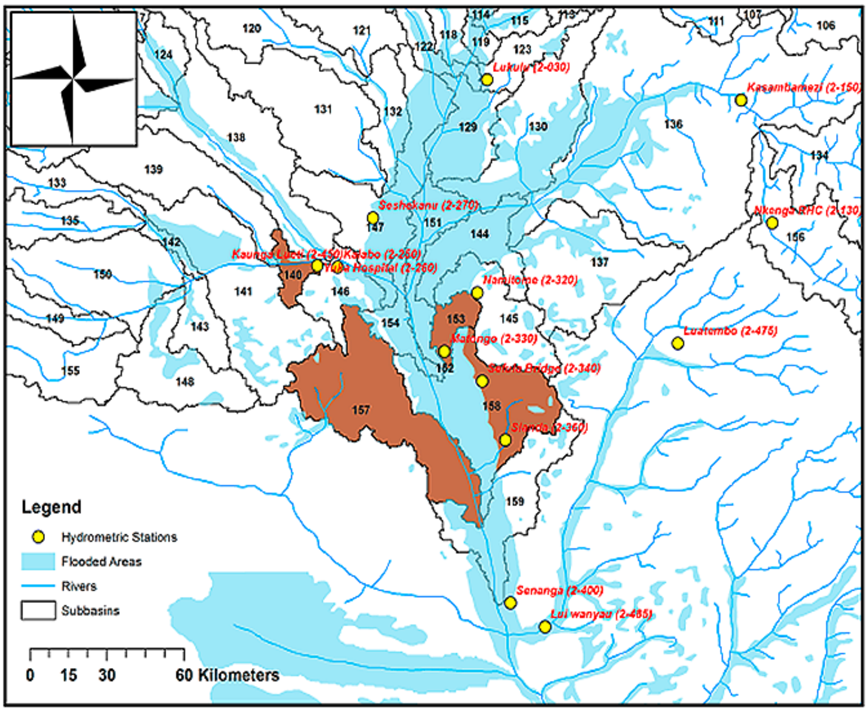

Figure 11: Spatial visualisation of the sub-basins highly impacted by sedimentation (brown-coloured areas), as simulated by the SWAT model.

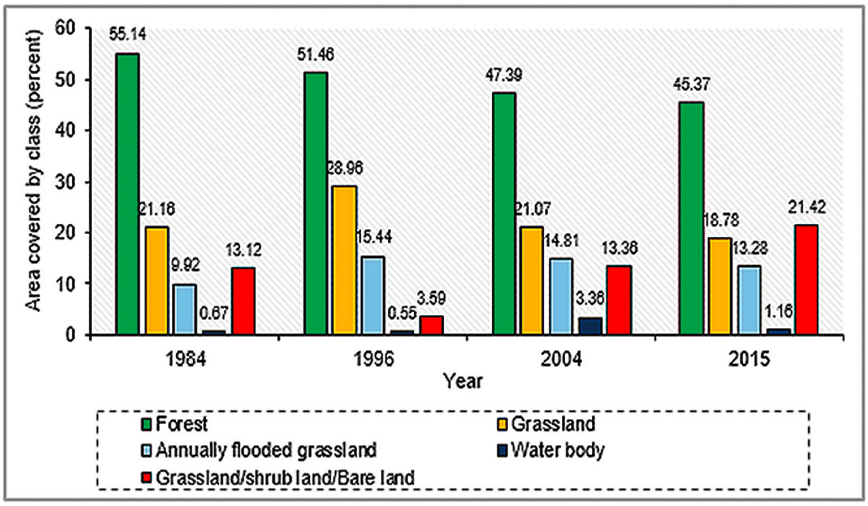

Figure 12: Land cover change between 1984 and 2015 in the Barotse sub-basin, western Zambia (Zimba et al., 2018).

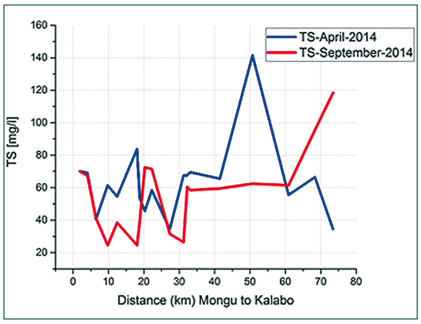

Figure 13: Variation of TS concentration in the wet and dry seasons of 2014 along the Mongu-Kalabo transect.

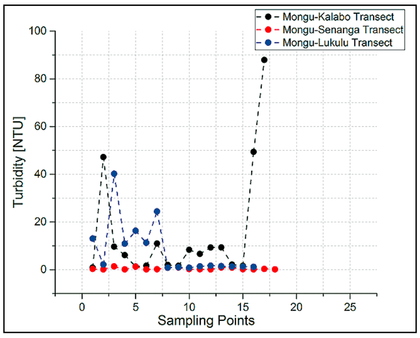

Figure 14: Turbidity in the Luanginga River (Mongu–Kalabo transect) and main Zambezi River (Mongu-Lukulu transect) compared to main Zambezi River along the Mongu-Senanga transect.

in the dry season (September 2014) emanating from the Luanginga River to the Zambezi River. Similar trends were observed along the other transects, particularly from Lukulu to Mongu and Mongu to Senanga.

It was observed that turbidity was high in the Luanginga River (Mongu-Kalabo transect) and main Zambezi River (Mongu-Lukulu transect). This was attributed to the huge amount of sediment that is recruited as water from various tributary streams confluence upstream from these rivers. Within the main floodplain, however, vegetation acts like a porous barrier, forcing the sediments to be deposited on the riverbanks and sieving out some of the sediments. This process was assumed to be responsible for finally reducing turbidity within and after the floodplain along the Mongu-Senanga transect (Fig. 14).

Discussion

The variations in the chemical elements in the floodplain were noted to be closely linked to flood inundation patterns. This trend included high nitrate and calcium concentrations attributed to recruitment occurring during higher floods. These findings are in agreement with previous studies conducted in the same area. For instance, Zurbrügg (2012), who studied the biogeochemistry of the Barotse Floodplain and the dam-impacted Kafue Wetland, observed a high seasonal variability in calcium concentration. Similarly, Zuijdgeest et al. (2015) found high concentrations of nitrate in the flood season in the Barotse Floodplain. They also observed that other agricultural nutrients such as phosphorus were largely close to the limit of detection. It should be noted, however, that the aforementioned studies did not attribute the variability of these elements to any particular processes. Nevertheless, our hypothesis that the variability of elements is associated with flooding patterns is reasonably supported by numerous studies on fundamental processes of wetland functions. For instance, it has been shown (e.g., Sinkala et al., 2002) that the variability of elements in a wetland is part of natural processes that serve to maintain the unique ecological functions of these water bodies. Schot & Wassen (1993) noted that floodplains tend to have dense vegetation during the wet season, as the available calcium supports tissue development.

The observed low levels of mining-related element concentration suggested that the water quality of the floodplain is not yet under threat from the mining sources of contamination in the northern part of the basin. Zuijdgeest et al. (2015) noted that the Kafue Flats and the Barotse Floodplain differ in anthropogenic influence and considered the latter to be pristine in large parts. This view was also upheld by other researchers such as Zurbrügg (2012) and Nyoni (2014).

Anthropogenic economic activities (e.g., farming, wetland grazing, and deforestation) within the floodplain seem to be the major predicators of biophysical water parameters. It was noted that sampling points near settled areas registered high peaks of bacteriological contamination. Since the Barotse Floodplain is a major source of livelihood for the local people, it is expected that such anthropogenic pollution will increase with population growth. An increase in population means that a significant part of the floodplain will be overexploited for its rich resources, which include fertile soils, fauna, and flora. For instance, sedimentation in some of the locations (e.g., Sefula Rice Scheme) was found to be significantly high and was attributed to increased conversion of forest to agricultural land. The number of people settling in the floodplain has since been increasing steadily. Mutonga (2013) has also noted that sedimentation in the Barotse Floodplain will likely increase with population growth and that unpredictable floods arising from climate variability will exacerbate diseases and hunger because of the destruction of crops.

Although anthropogenic activities were noted to have adverse effects on biophysical water quality, evidence also suggests that this was part of seasonal trends. For instance, low dissolved oxygen and high bacteriological contamination were observed in non-settled areas during the low flows or dry season. These trends were also noted by Nyoni (2014). This implies that the system 'cleanses' itself during high-flow periods. Similarly, certain diseases such as malaria that were found to be predominant during low flows were very low during high flow periods (Banda et al., 2015). This is because stagnant water during the dry season creates a conducive environment for microbiological organisms to replicate as flood levels regress.

Conclusion

This study was aimed at assessing the determinants of spatio-temporal variations in selected water quality parameters in the Barotse Floodplain. These included bacteriological and physiochemical parameters. All of these parameters varied significantly across the study area and over time (i.e., wet and dry seasons). Drivers of these changes are attributed to both anthropogenic and natural processes. Increased activities such as deforestation and agricultural production around this critical water resource were related to high nutrient loading, low DO, and bacteriological contamination of water, especially in settled water courses. Sedimentation was also observed to be on the increase as the result of these activities. Future economic pressures in and around the floodplain are likely to exacerbate this scenario. On the other hand, the change in water quality parameters was also related to natural processes such as low and high flooding patterns. These processes are critical in the 'renewal' of biogeochemical processes and ecological balance of the floodplain. For instance, high recruitment of some elements (e.g., calcium and nitrate) occurred in the wet season. This process serves many functions, including replenishing nutrients in the soils, that have been sustaining flood agriculture among the local people in the Barotse Floodplain for decades. It is therefore important that this balance be maintained and that the system not become overloaded by economic activities. Despite current baseline data indicating that the Barotse Floodplain is still in a pristine state, continuous monitoring is encouraged because of upstream large-scale copper mining, increased population in the area, and resulting increased anthropogenic activities.

Recommendations

The study recommends to relevant institutions and stakeholders that:

- water quality sampling should continue to be done seasonally by the Water Resources Management Authority (WARMA) in light of increased economic activities around and upstream of the floodplain;
- development of a plan to halt deforestation in the catchments surrounding the floodplain should be done urgently by the Forestry Department in the Ministry of Lands and Natural Resources working together with the Ministry of Agriculture and Livestock to reduce sedimentation and overall poor water quality; and
- the Zambia Environmental Management Agency (ZEMA), working together with WARMA, should focus on water pollution plans to halt any incoming heavy metal pollution from the large-scale copper mining upstream in Zambia's Northwestern Province.

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