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Influence of water quality on benthic macroinvertebrates in a groundwater-dependent wetland

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Benthic invertebrates communities are frequently used as indicators of aquatic ecosystem health since many species are sensitive to pollution and abrupt changes in their environment. Limited knowledge exists on the interlinkages of hydrological dynamics, water quality and the ecological character of groundwater-dependant ecosystems especially in developing countries. In this study we assessed the sensitivity of benthic macroinvertebrates to water quality dynamics in the Barotse Floodplain, a groundwater-dependant wetland. Benthic invertebrates were sampled in the dry season using the kick-net method at selected points upstream, mid-stream and downstream. The selection of sampled points was based on an initially conducted water quality survey that characterized the wetland into mainly two water types, NaHCO₃ (upstream) and CaMgHCO₃ (downstream). Canonical Correspondence Analysis (CCA) was used to investigate the influence of water quality on macroinvertebrate subclass-taxa level. Furthermore, factor analysis was used to derive the processes propagating the observed water quality variability. It was established that the composition and diversity of macroinvertebrate communities at subclass-taxa level was influenced by effects of the wetland flood pulse, salinity (mineralisation) from groundwater input and biogeochemical processes during the expansion and contraction of the floodplain-river exchange. This study has demonstrated that biomonitoring was effective in capturing the natural processes/regimes of the environmental (such as flooding) and thus has potential to be used for monitoring extreme effects of phenomenon such as climate change. It is recommended that, the families, genus and species taxonomic levels are needed to improve the understanding of responses of the subclass-taxa level and the detection of specific contamination signatures, to ensure wetland conservation and protection. Integrated water resources management for wetlands thus should incorporate biomonitoring conjunctively with traditional methods to ensure vital ecosystems are not compromised at the expense of maximizing the economic and social welfare of humanity.

KEYWORDS

Barotse Floodplain, canonical correspondence analysis (CCA), factor analysis, flood pulse, sub-class taxa, wetland conservation

1. Introduction

Long regarded as wastelands, wetlands are now recognized as important features in the landscape (Nikolić et al., 2009). Wetlands are among the most productive ecosystems in the world, compared to rain forests and coral reefs (Balwan and Kour, 2021). They fulfill a variety of roles in the landscape such as providing a habitat for a range of biodiversity, modulating flow and influencing water quality (Reid et al., 2005; Nikolić et al., 2009). These roles can be classified into provisioning, regulatory, cultural and supportive ecosystem services (Reid et al., 2005). Provisioning services include products obtained from the ecosystem such as food, water, timber, fiber or genetic resources (Layke et al., 2012). Regulatory services include air quality regulation, climate regulation, water purification, disease regulation, pest regulation, pollination and natural hazard regulation (Balasubramanian, 2019). Cultural services include benefits that people obtain from the ecosystem related to spiritual enrichment, recreation, ecotourism, formal and informal education, inspiration and cultural heritage (Hernández-Morcillo et al., 2013; Csurgó and Smith, 2021). Supportive services include basic ecosystem processes of nutrient cycling and primary productivity that may in turn lead to other services (Bello et al., 2010; Mace et al., 2012). Many of these services are directly connected to the presence and activity of specific organisms, microorganisms, or metazoa (especially macroinvertebrates). Although many scientific studies such as Bird and Day (2010), Sinchembe and Ellery (2010), Lehner et al. (2021), Winton et al. (2021), have highlighted the importance of wetland ecosystems, most wetlands worldwide have suffered from extensive exploitation in the past century. The world's wetlands are hanging onto a thinning lifeline, with only 13% (Gardner and Finlayson, 2018) of their former extent remaining. Worldwide, more than 50 % of wetland resources have been lost because of human activities in river floodplains, deltas and estuaries (Bobbink et al., 2006). Examples of human activities include agriculture due to fertile soils, construction of flood control structures, drainage for agriculture, excavation of peat for fuel and the modification and straightening of river channels for navigation (Bobbink et al., 2006). In some densely populated regions in developed countries, more than 80% of the wetlands have been lost or severely degraded. Wetlands in Africa probably conform to this picture but data on trends in African Wetland extent is limited (Davidson, 2014). These habitats are rarely monitored sufficiently due to a lack of utility of cost-efficient tools especially in poorly resourced countries (Simaika et al., 2021).

Several studies have demonstrated that biological methods are valuable in determining natural and anthropogenic influences on water resources and habitats as biota responds to stressors from multiple spatial or temporal scales (Weigel and Robertson, 2007; Kurthen et al., 2020; Tampo et al., 2021). Furthermore, the use of aquatic organisms in ecological studies has shown to be more effective than using environmental variables alone, because the aquatic community integrates structural and functional characteristics that reflects the health of the studied wetland (He et al., 2020; Tampo et al., 2020). Therefore, there is an increasing awareness of the application of ecological thresholds for natural resource management (Sundermann et al., 2015; White et al., 2021). Several metrics and biotic indices have been developed

and used across the world (Lowe et al., 2013; He et al., 2020; White et al., 2021). Singh and Saxena (2018) argued that the use of biotic indices as a tool for river quality assessment was more useful in evaluating river health than the conventional national water quality assessment standard practices in many countries. Macroinvertebrate responses to the change in aquatic ecosystem condition are universally recognized, and their responses are used in indices to monitor freshwater ecosystem for integrity, aiding in decision-making in management (Lunde and Resh, 2012; Lowe et al., 2013; Tampo et al., 2021; White et al., 2021).

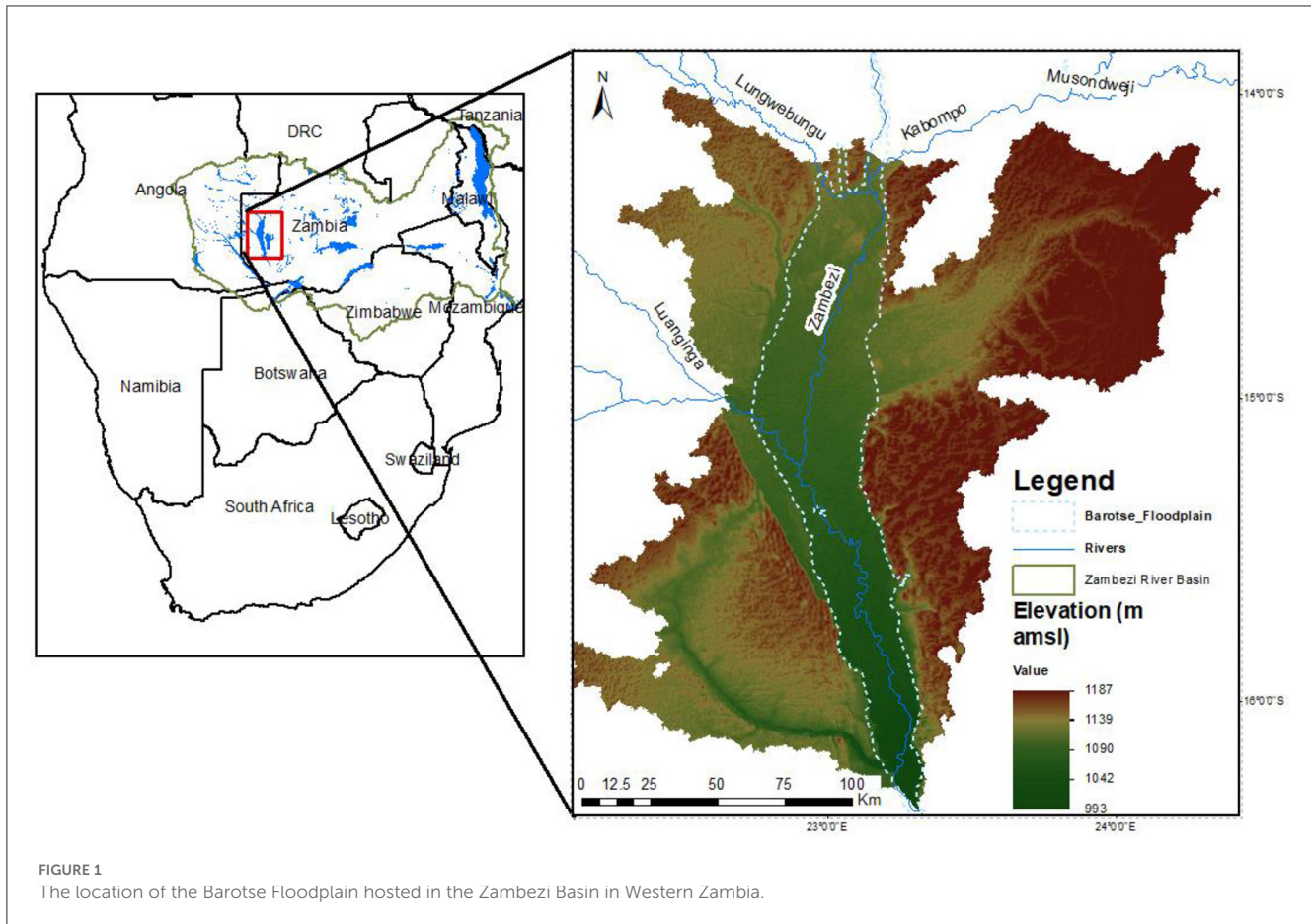
Despite the development and application of a variety of biotic indices, scores, and metrics based on macroinvertebrates for water quality and ecosystem health assessment in developed countries, the literature provides limited information on the biological assessment and monitoring of groundwater-dependent freshwater ecosystems. Ecosystems can be defined as groundwater-dependent when the whole or part of their water demand is supplied by groundwater and, in the absence of it, the ecosystem functions are impaired, leading to fundamental alterations of the structure of the ecosystem itself (Orellana et al., 2012). Groundwater organisms live in energy-limited habitats with comparably predictable environmental conditions. Thus, they may be very sensitive to anthropogenic impacts and environmental changes. This sensitivity would make them potential candidates as bioindicators that could provide decision-makers and groundwater managers with useful information on ecosystem status (Griebler et al., 2010), as an important cultural ecosystem service. In this study, we investigate a groundwater-dependent floodplain to establish the sensitivity of benthic macroinvertebrates to the water quality dynamics. Specifically, the study investigates the effectiveness and robustness of the use of macroinvertebrates in the Barotse Floodplain in monitoring and assessment of water quality. We hypothesized that the Barotse Floodplain hosts benthic macroinvertebrates communities which are sensitive not only to the water quality dynamics but the hydrological processes facilitating surface-groundwater interactions. The outcome of this work would be useful in supporting bio-assessment programmes of the wetland.

2. Materials and methods

2.1. The Barotse Floodplain and river system

The Barotse Floodplain is a wetland located between -13.97906 to -19.31646 ° S and 22.05326 to 24.77531 ° E in Western Zambia, approximately 597 km west of Zambia's capital city, Lusaka. The floodplain is in the Barotse sub-catchment of the upper Zambezi River Basin (Figure 1). The Barotse Floodplain stretches more than 230 km from north to south. Its width extends to about 30 km though it reaches a width of 50 km in some areas during peak flooding with an inundation area of more than 770,000 hectares (Zimba et al., 2018). The actual size of the wetland is unknown but is estimated to be 1.2 million hectares (Chomba et al., 2021).

The Barotse Floodplain is hosted on flat plateau topography with an average slope of only 0.015 %. It is generally covered by the Kalahari sands. The elevation over the floodplain ranges from 1187 m above sea level in the north-eastern part, to 993 m above



sea level in the southern part. The drainage pattern is a trellis with all major rivers which include the Luanginga, Lungwebungu and Kabompo (Figure 2), being the main tributaries of the Zambezi River. Due to the floodplain's gentle slope, the Zambezi River flows in the plain with numerous meanders (Figure 2). According to Deneut et al. (2014), the Barotse Floodplain has a long-term average inflow of 845 m³/s on the Zambezi at Lukulu (Figure 2) and midstream, the Luanginga contributes an average of 63 m³/s at Kalabo. The Zambezi River flows downstream to Senanga (Figure 2) averaging 1029 m³/s. Evaporation rates for the wetland are estimated at 1,578 mm/annum (Beilfuss, 2012) and percolation to groundwater is poorly constrained. The key factors affecting utilization of the wetland are the timing and extent of the annual flooding of the Zambezi River, and the timing and consistency of the rains. The Barotse Floodplain annually floods in the rainy season peaking in April and receding by July.

2.2. Data collection and analytical procedures

2.2.1. Selection of sampling site

The selection of macroinvertebrate sampling site was based on previous water quality assessments by Nyambe et al. (2018)

and Banda et al. (2023). Nyambe et al. (2018), which showed that the Barotse Floodplain had higher concentrations of total dissolved solids (TDS) in surface water between Lukulu and Mongu (upper reach) compared to Mongu to Senanga (lower reach). The distinct variation in TDS led to a sampling design that focused on the two reaches of the catchment. Banda et al. (2023) showed that the floodplain was a groundwater dependant ecosystem with the upper reaches receiving groundwater discharge, whereas, in the lower reaches, surface water was draining to the groundwater. Based on our hypothesis, macroinvertebrate sampling points were set up to cover the upper, middle and lower reaches of the floodplain as shown in Figure 2. A total of 12 sampling sites were thus selected purposively. The sites were not evenly distributed across the wetland because of safety issues attributed to hippos and the lack of appropriate suitable habitat sites for invertebrates. Sampling was done in the dry season in two phases; six stations were covered per phase. Phase one was done between 18 to 20 May, 2022 and phase two, 20 to 25 June, 2022. A sample per site was collected per site during the sampling. In the wet season, the main river channel (Zambezi) breaks banks during the wet season, which then floods most of the outlined floodplain region. The flood water alters habitats rendering invertebrate sampling during the wet season inefficient.

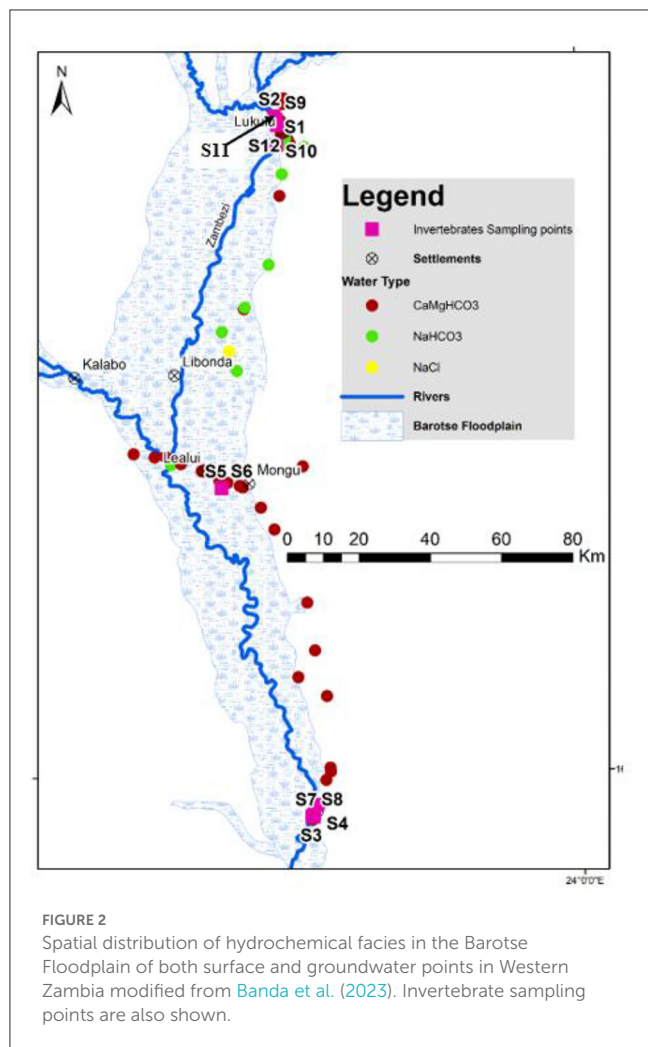


FIGURE 2 Spatial distribution of hydrochemical facies in the Barotse Floodplain of both surface and groundwater points in Western Zambia modified from Banda et al. (2023). Invertebrate sampling points are also shown.

TABLE 1 Interpretation of ZISS Scores associated with ASPT for water quality monitoring.

ZISS Score	ASPT	Class
> 100	> 6	Water quality natural; habitat diversity high
< 100	> 6	Water quality natural; habitat diversity reduced
< 100	< 6	Border line good/ bad water quality.
50 – 100	< 6	Some deterioration in water quality
< 50	Variable	Major deterioration in water quality

2.2.2. Macroinvertebrate collection and identification

Benthic macroinvertebrates were sampled using a Kick-net (square opening, 33 cm of diameter; mesh size, 320 μm) in lentic and lotic habitats. Samples were taken from both sides of the river- bank and combined into one composite sample following the protocol described by Lowe et al. (2013). Sampling was performed by placing the mesh against the current and removing the substrate upstream of the sleeve and kicking up the gravel on the bed of the river with the Kick-net. Collected samples were then placed on a white tray for sorting and screening of aquatic insects. Samples were

TABLE 2 Invertebrate taxonomic metrics results based on observations from sampled sites in the Barotse Floodplain.

Place	ID	H	ZISS	D
Lukulu	S1	1.89	39.50	0.45
Lukulu	S2	1.37	51.80	0.45
Senanga	S3	1.83	36.00	0.53
Senanga	S4	1.69	35.50	0.53
Mongu	S5	1.99	43.00	0.67
Mongu	S6	1.37	34.80	0.67
Senanga	S7	0.34	63.00	0.76
Senanga	S8	0.33	66.15	0.80
Mongu	S9	0.32	36.00	0.55
Mongu	S10	0.33	39.60	0.60
Lukulu	S11	0.34	37.65	0.41
Lukulu	S12	0.34	41.42	0.45

then preserved in 10% formalin and transferred to the laboratory for species identification. Specimens were then identified at subclass-taxa level using a trinocular Stereomicroscope. The photographic guide to the aquatic macroinvertebrates of Zambia developed through the Southern African River Assessment Scheme (SAFRASS) Project (Lowe et al., 2013) was used to support the identification.

2.2.3. Ecological metrics

In this study, three categories of metrics were determined; taxonomic richness, tolerance measure and diversity indices (Tampo et al., 2021) were used. The selection of these metrics were based on their simplicity and reliability for assessing the water quality of the river as well as their suitability to detect anthropogenic disturbances as outlined by other studies (Agboola et al., 2019, 2020; Tampo et al., 2021). In this study, specifically, we used Shannon-Weiner Diversity Index (H), Zambia Invertebrate Scoring System (ZISS) and Simpson Diversity Index (D) to represent diversity, tolerance measure and taxonomic richness, respectively. The H was calculated using Equation 1:

$$H = \sum_{i=1}^s p_i \ln p_i \tag{1}$$

Where:

H = Shannon-Weiner Diversity Index

s = Number of species

p_i = Proportion of individuals of each species belonging to the i^{th} species of the total number of individuals.

Zambia Invertebrate Scoring System (ZISS) is equivalent and adapted from the South African Sensitivity Score (SASS) as explained by Lowe et al. (2013). ZISS scores are used in combination with average score per taxon (ASPT) to derive the alteration to the aquatic environment (Table 1). ASPT is calculated

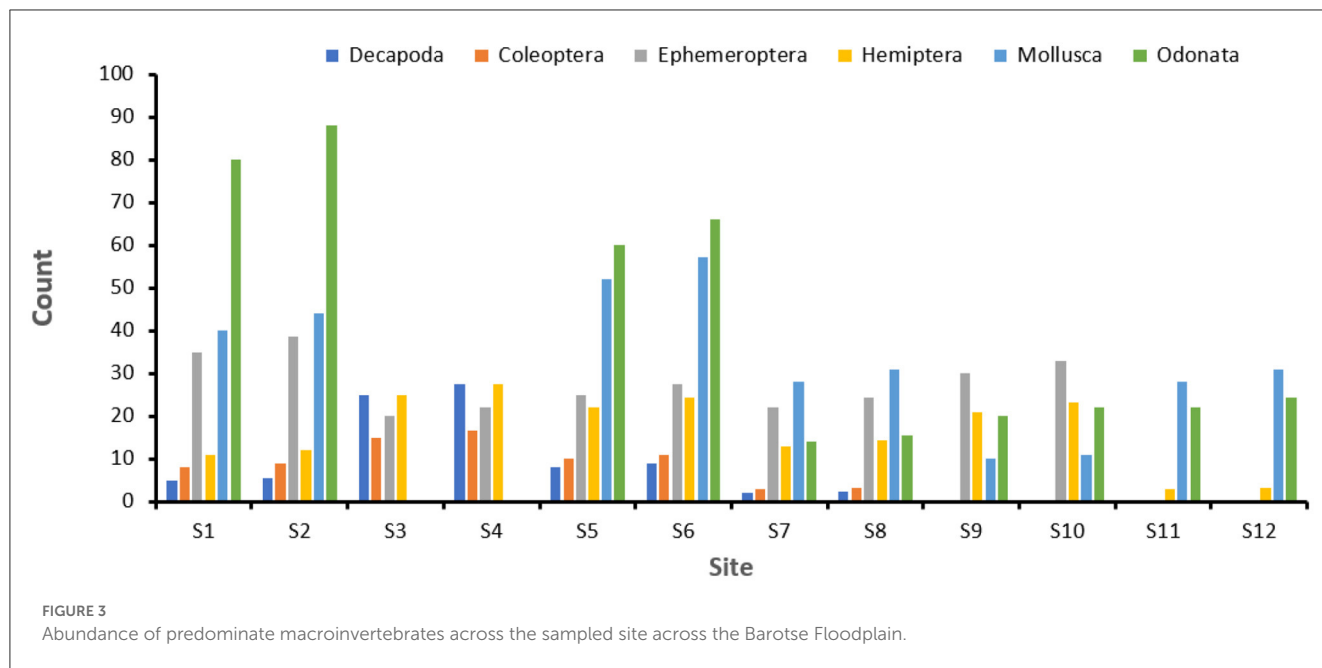


TABLE 3 Descriptive statistics of water quality parameters.

	DO	EC	pH	Temp	TDS	HC03	Ca	K	Mg	Na	SO ₄
Units	Mg/L	μs/cm		°C	Mg/L	Mg/L	Mg/L	Mg/L	Mg/L	Mg/L	Mg/L
Number	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
Minimum	4.70	47.90	6.50	21.60	53.94	25.90	3.00	1.00	1.00	1.00	2.00
Maximum	8.85	200.00	9.51	28.50	82.45	216.40	42.00	116.60	26.00	11.00	8.00
Sum	79.12	1225.77	93.48	297.30	772.14	1276.40	170.45	206.80	98.00	61.00	50.00
Mean	6.59	102.15	7.79	24.78	64.35	106.37	14.20	17.23	8.17	5.08	4.17
Variance	1.52	2832.94	0.81	8.57	94.75	3317.52	109.00	1376.92	44.33	7.90	5.06
Stand. dev	1.23	53.23	0.90	2.93	9.73	57.60	10.44	37.11	6.66	2.81	2.25

as shown in Equation 2 (Lowe et al., 2013):

$$ASPT = \sum_{i=1}^{I=S} \frac{(n_i \times a_i)}{N} \tag{2}$$

Where:

- S = Total number of taxa in the sample
- n_i = Coded abundance in the ith scoring taxon
- a_i = Sensitivity score for the ith taxon (SASS scoring table), and
- N = Total number of taxa contributing to the SASS score

Simpson's Diversity Index (D) is a measure of diversity which takes into account the number of species present, as well as the relative abundance of each species (Guajardo, 2015). As species richness and evenness increase, so diversity increases. It is calculated as shown in Equation 3.

$$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)} \right) \tag{3}$$

Where:

- D = Simpson's Diversity Index
- n = the total number of organisms of a particular species
- N = the total number of organisms of all species

The value of D ranges between 0 and 1. With this index, 1 represents infinite diversity and 0, no diversity. In this assessment, D was referenced to as Simpson's Richness (D).

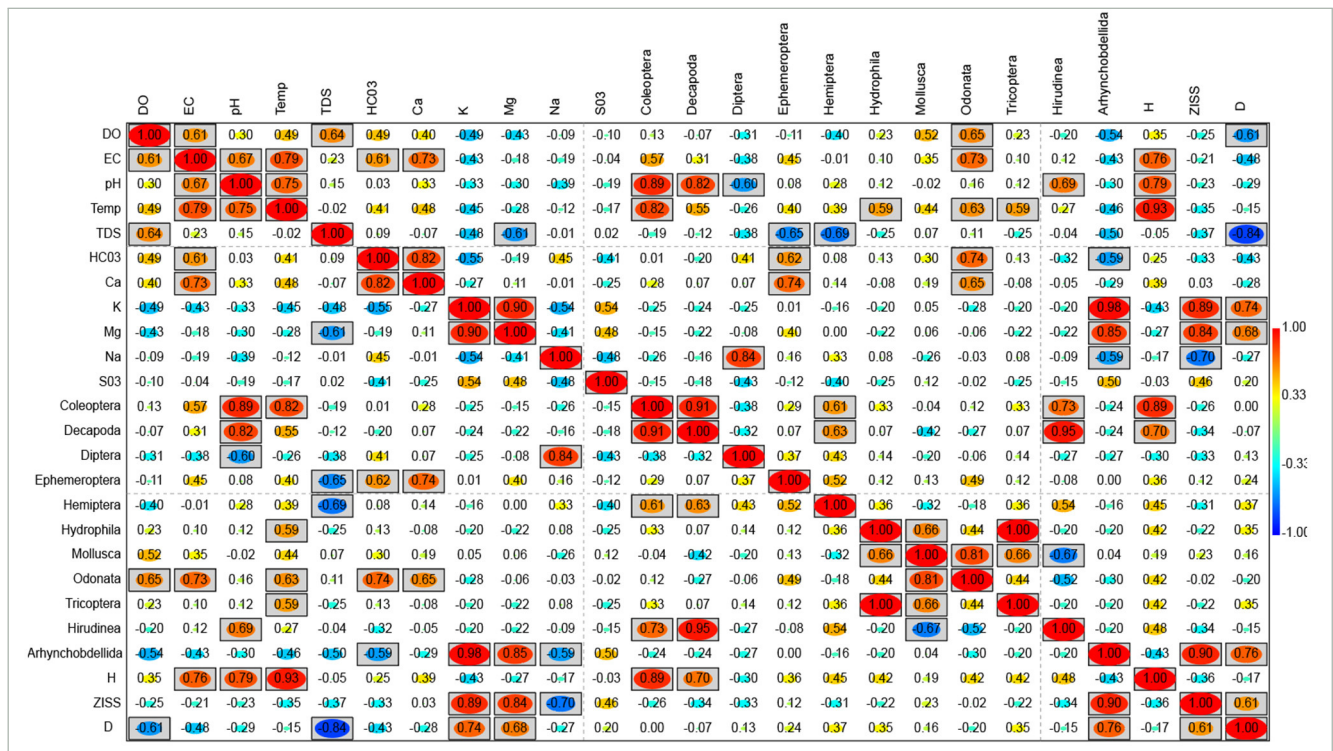
2.2.4. Water quality analysis

At each site, water quality parameters such as temperature, pH, electrical conductivity (EC), dissolved oxygen (DO) and even for total dissolved solids (TDS) were measured insitu using the Wissenschaftliche Technische Werkstätten (WTW) water quality multimeter. Measurements were done once at each site After the *in situ* measurement, one 0.5 L of water per site was taken in a plastic bottle and stored in a refrigerator at 4°C for analysis of chemical parameters in the laboratory. Major and minor ions analysis was conducted at ITemba Lab in South Africa, using a titration method to determine Ca²⁺, Mg²⁺, HCO₃⁻ and Cl⁻, Ultraviolet (UV)-spectrophotometric method for SO₄²⁻, NO₃⁻, PO₄³⁻, and Flame Emission Spectrophotometer for K⁺ and Na⁺.

2.2.5. Statistical analysis

The canonical correspondence analysis (CCA) was applied to establish the relationship between water quality parameters

TABLE 4 Pearson correlation plot of water quality, macroinvertebrates and metrics from the Barotse Floodplains.



Correlation values in boxes indicate significance (P < 0.05). The colors are a visual expression of correlation from high to low as per the legend.

and macroinvertebrate abundance; and to identify water quality parameters affecting the macroinvertebrate community. The analysis was performed with PAST software (Version 4.12, released December, 2022) with the dataset of water quality parameters and the abundance of macroinvertebrate community at the subclass-taxa level. Pearson’s correlation analysis and factor analysis (FA) between macroinvertebrate data and water quality variables were used to assess the potential of macroinvertebrate taxa and metrics detected in this study to serve as bioindicators for the river’s environmental condition investigated. The FA was performed using principal components as a factor extraction method and then rotated with a varimax. The factor loadings were considered for the explanation of correlations among variables and to explain underlying processes controlling the observed water quality. Pearson correlation and FA were computed using MINTAB (version 18.1) for Windows.

3. Results

3.1. Macroinvertebrate diversity

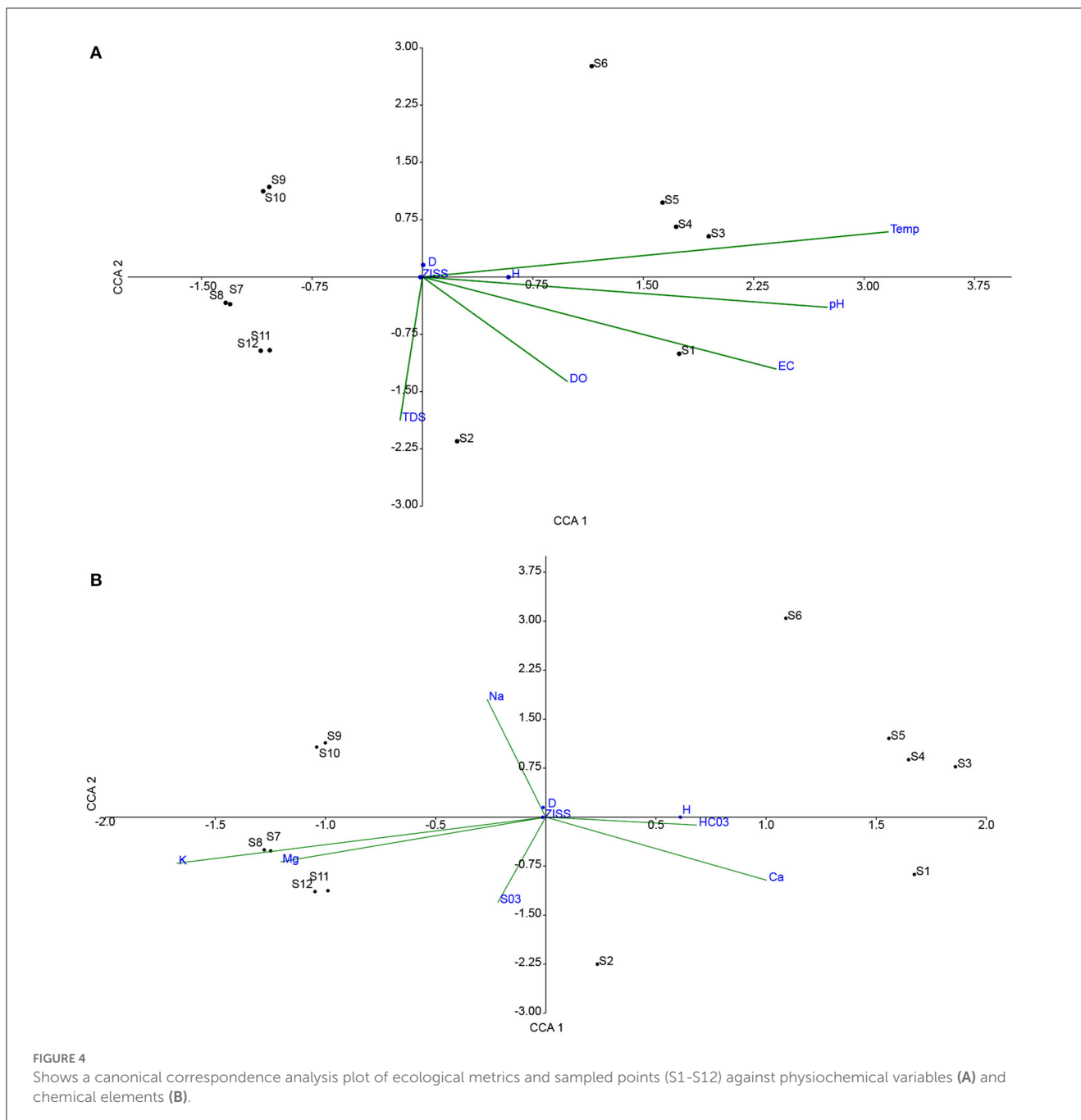
The macroinvertebrate abundance and diversity was expressed as taxonomic metrics as shown in Table 2. High Shannon-Weiner Diversity Index values were found upstream compared to the downstream, which meant there were more diverse species in the upstream habitats compared to the downstream. D has values between 0.4 and 0.7, which was interpreted as moderate to moderately high degree species

heterogeneity (Guajardo, 2015) from upstream to downstream. Odonata, Mollusca, Decapoda, Hemiptera, Ephemeroptera and Coleoptera (Figure 3) are the most predominant across the sites.

3.2. Status of water quality

Descriptive summary statistics of the sampled points provide an overview of variations in water quality across the sampled points (Table 3). DO (dissolved oxygen) varies between 4.7 and 8.9 mg/L with a small standard deviation of 0.4. EC (electrical conductivity) varies between 47 and 200 μS/cm, with the standard deviation of 52 indicating relatively large variation of EC from upstream to downstream. pH ranged from 6.5 to 9.5 (neutral toward alkaline condition), with a mean value of 7.8. TDS (total dissolved solids) ranged from 53.9 to 82.5 mg/L with a mean value of 64.3 mg/L. The variation trends of most of major ions such as Ca²⁺, Mg²⁺, Na⁺, K⁺, HCO₃⁻, SO₄²⁻ are similar to EC and in the range of natural water quality. The concentration of Cl⁻ and minor ions such as NH₄⁺, NO₂⁻, Fe, PO₄³⁻, and Mn²⁺ was below the detection limits and therefore have not been shown in Table 2.

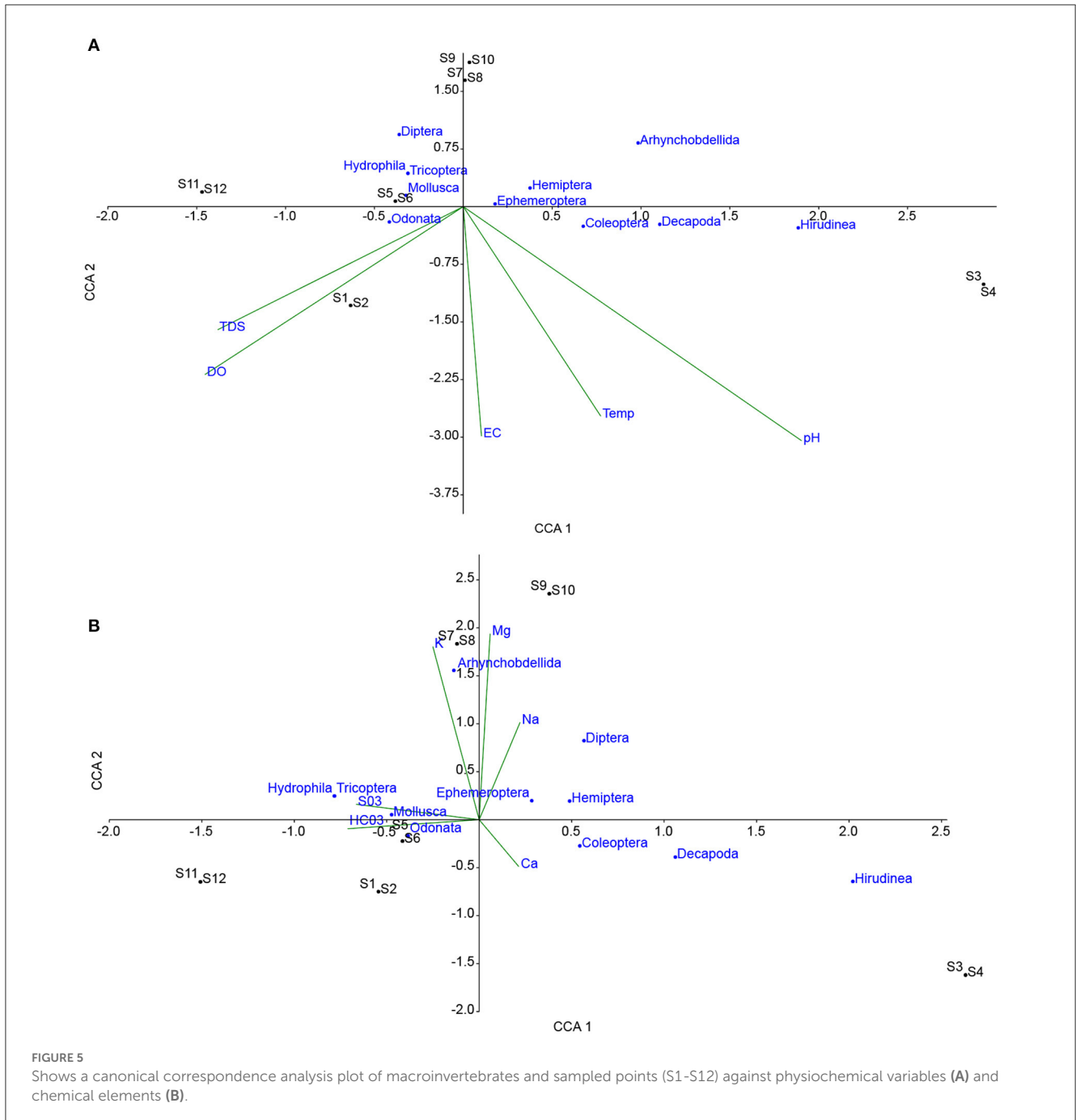
Table 4 shows the correlation plot of water quality, macroinvertebrates and metrics from the Barotse Floodplains. The various macroinvertebrates were classified into sensitive, tolerant and resistant based on positive and significant correlation to water quality elements. Odonata; Ephemeroptera, and Arhynchobdellida were placed in the sensitive to water



quality category. Odonata captures the highest variability in different water quality variables. Ephemeroptera, and Arhynchobdellida seem to be sensitive to mineralisation or salinity conditions. Several of the invertebrates can be classified as resistant as they respond to some of the water quality variables (one or two at most) and include: Coleoptera, Decapoda, Diptera, Hemiptera, Hydrophila, Tricoptera, Hirudinea. Mollusca can be classified as tolerant and does not show any significant response or relationship to the water quality variables. Furthermore, all the metrics (Shannon-Wenner diversity at subclass-taxa level (H), ZISS and D) show response to the water quality variability with H being the most sensitive of them.

3.3. Influence of water quality on macroinvertebrate communities

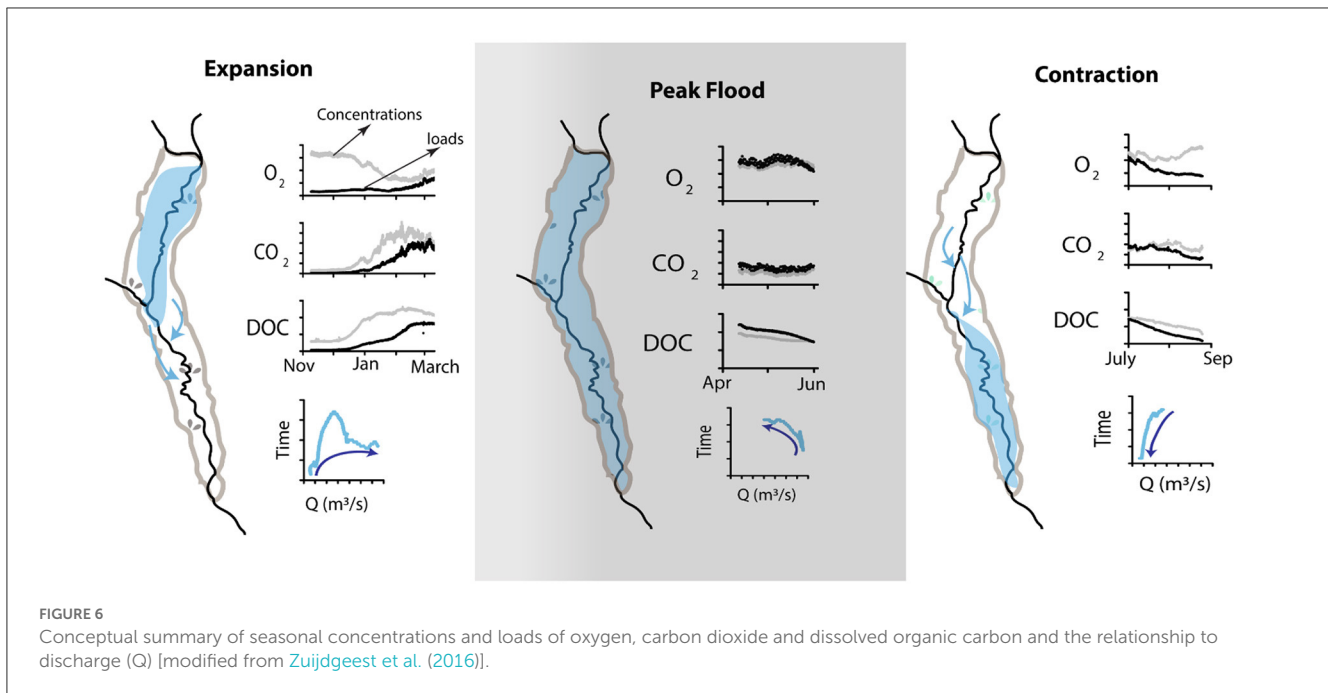
CCA plots in Figures 3, 4, indicate the influence of water quality variables on metrics and macroinvertebrate communities, respectively. In Figure 4A, shows that temperature, pH, and EC are strongly correlated to the H with the DO and TDS showing weak association. The highest influence was from temperature followed by pH then EC. ZISS and D have similar properties owing to their position on the plot. D was strongly influenced negatively by TDS and DO, implying that with increased species diversity there was a reduction in TDS and DO. In Figure 4B, it can be observed that H was positively correlated to Ca^{2+} and HCO_3^- with



a higher influence from the Ca^{2+} . However, Mg^{2+} , Na^+ , K^+ were negatively correlated to H, with the largest deviation attributed to the K^+ . Figure 5A shows the response of macroinvertebrates to the physio-chemical elements (pH, EC, DO, TDS, and Temp). The majority of the macroinvertebrates have a negative or no correlation with the water quality element except for Odonata (DO, TDS) and Coleoptera, Decapoda and Hirudinea influenced by pH, temp and EC. On the other hand, the majority of the chemicals seem to have a positive influence on the macroinvertebrates as shown in Figure 5B. Therefore, Mg^{2+} has a higher influence compared to K^+ and Na^+ . Coleoptera, Decapoda and Hirudinea are sensitive to Ca^{2+} .

3.4. Water quality controls and processes

Factor analysis was used to investigate the underlying processes that influence the observed water quality influencing macroinvertebrate abundance and diversity. Four factors that explain 85% of the variability were extracted. Factor 1, accounted for 23% of the variability with a high factor loading from Ca^{2+} , HCO_3^- and the EC. This was likely attributed to hydrological flow regimes (flooding) depositing large volumes of sediments into the floodplain from the upstream regions increasing turbidity and thus the chemical composition (predominantly Ca^{2+} and HCO_3^-). Factor 2, explained 22% of the variability, was likely



attributed to salinity (mineralisation processes) because of the significant loading from K^+ , Mg^{2+} , Na^+ , HCO_3^- , SO_4^{2-} . Factor 3, explained 20% of the variability, with factor loading mainly attributed to pH, temperature and EC. This was likely related to dissolved organic matter fluxes as biogeochemical processes occurred during contraction and expansion of river-floodplain flow dynamics. Factor 4, has a high factor loading of DO and TDS attributed to peak flooding, when DO and turbidity accumulate.

4. Discussion

4.1. Benthic macroinvertebrate response to environmental variables

Based on the foregoing, the composition and structure of the macroinvertebrate communities are probably influenced by the flood pulse, salinity (mineralisation) from the groundwater input and biogeochemical processes during the expansion and contraction of the floodplain-river exchange. These processes have led to a composition of macroinvertebrates that include: Odonata, Mollusca, Ephemeroptera, Hemiptera, Decapoda, and Coleoptera (most abundant to least). CCA and FA showed that Odonata and Mollusca were influenced by TDS and DO, which was driven by the flood pulse and biogeochemical processes. [Zuijdggeest et al. \(2016\)](#) demonstrated that as the Barotse Floodplain undergoes hydrological expansion, that increases the oxygen, carbon dioxide and dissolved organic carbon loads as shown in [Figure 6](#). This would increase the DO and pH that would stimulate an increase in dissolved solids. The dynamics of water quality evolve further during expansion and contraction as shown in [Figure 6](#). Decapoda, Hemiptera, Ephemeroptera and Coleoptera were influenced by EC, temperature and pH as shown by the CCA plot in [Figure 5A](#) and the chemical analysis related to Factor 1 and 2 ([Table 3](#)).

These macroinvertebrates are thus responding to salinity and the flood pulse dynamics. Salinity in this system was attributed to mineralisation due to water-rock interactions ([Banda et al., 2019](#)) in groundwater system which subsequently discharges to the surface water. Odonata such as some dragonflies leave just the tip of their abdomen exposed above the water surface and pump air into the internal gills hence adapting to alterations in water quality particularly, the reduction in dissolved oxygen ([Thorp and Rogers, 2010](#)). Similarly, Mollusca, Decapoda, Hemiptera, Ephemeroptera and Coleoptera have adapted their body structures to tolerate water quality, habitat and flow alterations ([Asmamaw et al., 2021](#); [Tampo et al., 2021](#)). Several of the invertebrates can be classified as resistant as they responded only to some of the water quality variables (one or two at most) such as Coleoptera, Hemiptera and Decapoda. The authors postulate, subject to further investigation, that these invertebrates maybe responding to effects of biogeochemical processes driven by the organic matter input during expansion and contraction phases of the floodplain. This is in agreement with studies such as [Mezgebu et al. \(2019\)](#), who showed that Decapoda responds strongly to organic contamination.

The observed macroinvertebrates community composition shows a unique distinct pattern in response to the complex hydrological exchange, water quality and biogeochemical processes at play in the Floodplain. Odonata, Mollusca, Ephemeroptera, Hemiptera, Decapoda, Coleoptera thus can be regarded as unique macroinvertebrate assemblage for this system. This is similar to a study by [Wood et al. \(1999\)](#) in the United Kingdom, who observed unique macroinvertebrates assemblages in groundwater-dependant water pools. However, some open questions still remain as to how much groundwater discharge was required to maintain the macroinvertebrate assemblage, and the timing/frequency in which it would be required to sustain as an ecosystem. Such as evaluation would be critical, especially for the determination of environmental flow requirements of the Floodplain.

5. Conclusion and implications

This study has shown that the Barotse Floodplain has a unique assemblage of macroinvertebrates that includes: Odonata, Mollusca, Ephemeroptera, Hemiptera, Decapoda, Coleoptera. These macroinvertebrates communities are influenced by the effects of the flood pulse, salinity (mineralisation) from groundwater input and biogeochemical processes during the expansion and contraction of the floodplain-river exchange. This study demonstrated that biomonitoring was effective in capturing natural regimes of the environment (such as the flooding), thus has potential to be used for monitoring extreme effects of phenomena such as climate change. It is recommended that, the use of the families, genus and species taxonomic levels in bio-monitoring is needed to improve the understanding of responses on the subclass-taxa level and the detection of specific contamination signatures, to ensure wetland conservation and protection. Environmental flow assessments of the groundwater-dependant such as this one, thus should strive to establish the timing/frequency of groundwater discharge required to sustain the unique macroinvertebrate assemblage. 'Blanket' management interventions such as no groundwater abstraction for commercial use may not be practical to implement.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

This study was approved by the University of Zambia Natural and Applied Sciences Research Ethics Committee.

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Author contributions

KB conceived the manuscript and wrote the paper with VN. VN, MM, IC, and KB collected and analyzed the data. IN corrected the English language. IN and MC supervised the study and contributed valuable comments to the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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