Conceptualising the hydrology of tropical wetlands to aid habitat management in northern Zambia

Kennedy, M. , Racey, P. , Iason, G. , Chama, L. and Soulsby, C.

Water Efficiency Conference 2016

Conceptualising the hydrology of tropical wetlands to aid habitat management in northern Zambia

Michael Kennedy[1*], Paul Racey[2], Glenn Iason[3], Lackson Chama[4], Chris Soulsby[1]

[1]School of Geosciences, University of Aberdeen, Aberdeen, AB24 3UF, UK School of Energy, (Current Address: School of Energy, Construction and Environment, Coventry University, Coventry, CV1 5FB, UK;
[2]School of Biological Sciences, University of Aberdeen, Aberdeen, AB24 2TZ, UK;
[3]The James Hutton Institute, Craigiebuckler, Aberdeen, AB15 8QH, UK;
[4]Kasanka National Park, PO Box 850073, Serenje, Zambia;

ABSTRACT

Climate change and human population increase may potentially negatively impact river systems and associated biodiversity and ecosystem services related benefits in sub-Saharan tropical countries. Kasanka National Park, Zambia, provides valuable freshwater habitats for rare species and valuable income to local communities through ecotourism. A hydrological study was carried out (2006-2008) utilising tracers to investigate hydrological pathways, and potential threats to the freshwater habitats. Spatial and temporal variability in terms of hydrological tracers was seen across the park, with varying importance of rainfall inputs to different habitats, and dependent upon preceding wet season levels of precipitation. The findings should be developed further to aid management of habitats and water resources from both a nature conservation and sustainable human livelihood perspective.

Keywords: Biodiversity; dambo; ecosystem services; freshwater; hydrochemistry

1. INTRODUCTION

Factors including climate change and population growth are expected to put increased pressure on water resources in some sub-Saharan regions, potentially threatening drinking water and agricultural irrigation supplies (e.g. [1,2]). Other factors including high stream densities, inter-seasonal discharge fluctuation, and extensive floodplains often result in high biodiversity in tropical river systems (e.g. [3,4,5]). However, ecosystem services provided by tropical rivers and associated habitats have received little attention to date but are important for livelihood support [6,7], and can provide income generation via ecotourism for poor communities [8]. Conservation is essential to protect these benefits [9], but an integrated catchment management approach is needed based on an informed scientific understanding [10].

Zambia is home to the headwaters of the Zambezi and Congo rivers, and their numerous tributaries and associated extensive wetlands [7]. It is a poor, lower-middle income country, which also has the highest predicted human population growth in the world [11]. Hence, the need to monitor and protect Zambian rivers is pressing, although recent work by the authors [5,12] represents the first systematic baseline river surveys conducted in the country.

Previous process-based hydrological investigations in the region have focused on “dambos” (seasonally saturated wetlands) which often form important seasonal headwaters of river

* Tel.: +44 (0)2477 659093.
E-mail address: michael.kennedy@coventry.ac.uk.

systems in southern Africa (e.g. [13,14]). Aspects of groundwater recharge and flow are also generally understudied and uncertain [13,1]. Hydrochemical and isotopic tracers have proven utility in hydrological up-scaling studies, when combined with appropriate hydrometric data [15]. Different solutes can ascertain the provenance of hydrological sources which sustain rivers and wetlands [16], whilst stable isotopes of H and O can be used to infer the timing and mixing of major water fluxes [17,18]. This approach (of which this study represents an early stage of development) can be used as a basis for conceptualization of system function, and in turn, for developing predictive models to aid management decisions.

The study was carried out in the 470 km^2 Kasanka National Park (KNP), on the Central African Plateau in Zambia (Fig. 1). KNP is considered particularly important for its varied freshwater habitats [19], and a seasonal influx of up to 10 million straw-coloured fruitbats (*Eidolon helvum*) (e.g. [20,21]). It is also important for high densities of puku antelope (*Kobus vardonii*), and a visible population of the semi-aquatic sitatunga antelope (*Tregelaphus spekei*) [19]. KNP supports significant ecotourism which benefits local communities within one of the poorest districts of Zambia. Perceived threats include reduced precipitation and flooding, illegal burning, and increased farming in headwater dambos. The park has an elevation between 1200-1286 m [19], an underlying granitic geology with sandy, low fertility soils. Long term average precipitation is approx. 1200 mm yr^{-1} [20], and max. daytime temperatures average 27°c to 38°c [19].

Work was undertaken using hydrometric and tracer methods to provide a baseline assessment of hydrological functioning, to understand the temporal and spatial variability of precipitation, and examine mechanisms of groundwater and wetland recharge and the relative importance of hydrological processes to the main river corridors.

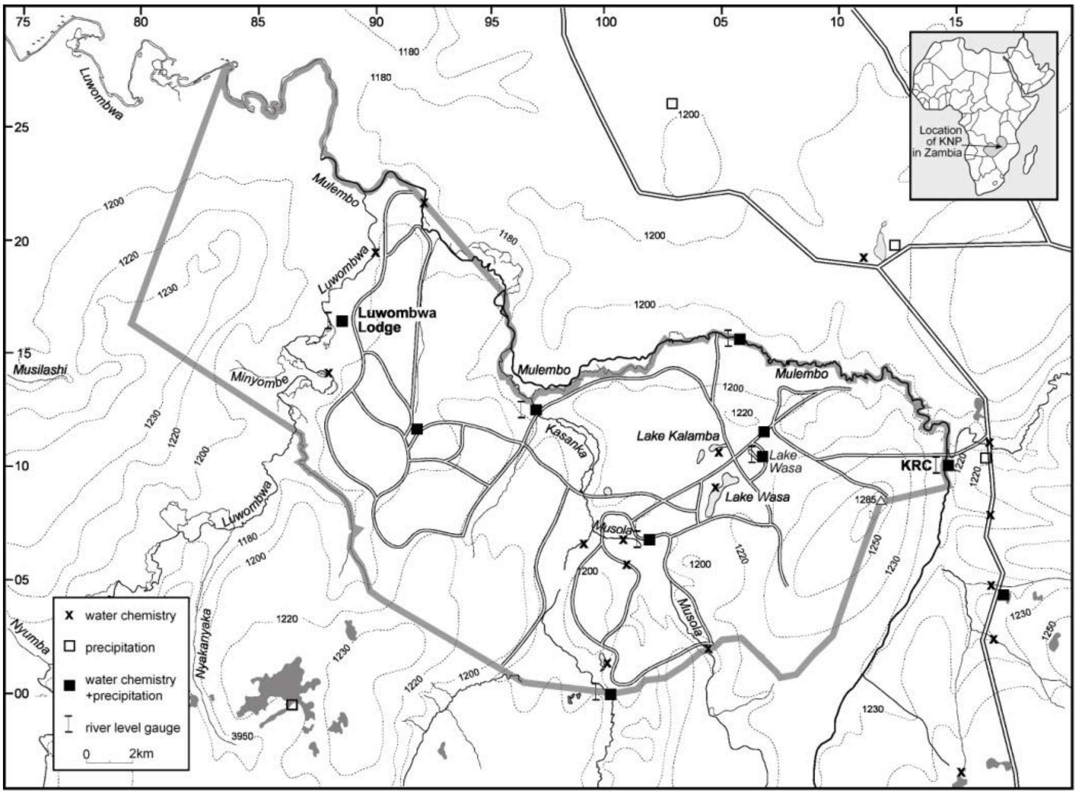

Fig. 1. Map of Kasanka National Park showing sample locations. (Park boundary indicated by solid grey line), and location of Zambia in Southern Africa; KRC = Kasanka Research Centre (© Crown copyright Ordnance Survey. All rights reserved).

2. METHODOLOGY

Precipitation was recorded at 0800hrs each day from 2005 to 2008 at locations in KNP (Fig. 1) using 100mm graduated gauges. Hourly air temperature in the shade was recorded from 1st October 2006 at Kasanka Research Centre (Fig. 1) using a -20°C to 50°C thermometer.

Water sampling was conducted May 2005 to January 2008 at locations shown in Fig. 1. Sampling during the 2005/6 wet season (and until late May 2006) was carried out at approximately two weekly intervals. The frequency of sampling was then reduced to approximately six weekly and four weekly intervals during subsequent dry and wet seasons respectively.

pH and electrical conductivity (EC) were measured, to aid physic-chemical differentiation of samples, using portable Hanna meters, or occasionally, immediately on return to the lab using a Jenway desktop meter. Where sites were easily accessible, measurements were taken from a depth of approximately 10cm; otherwise samples were drawn using a collecting bucket.

Gran alkalinity [22] was measured as adapted by McCartney and Neal [15] for sub-Saharan dambos as a measure of end-member contribution to water-bodies, with higher values generally indicative of longer water residence within soils and aquifers. 60ml LDPE sample bottles were filled and sealed at each site (to minimise carbon dioxide degassing, which increases pH). Samples were filtered through Whatman GF/C filter papers, and alkalinity was determined by acidimetric titration over pH range 3.0 to 4.5 using a Jenway desktop meter. For oxygen isotopes, which can act as a conservative tracer of water source, 5ml glass vials were filled and sealed at each sample point (to exclude evaporative loss), and samples were analysed at the Scottish Universities Environmental Research Centre (SUERC).

3. RESULTS AND DISCUSSION

Table 1 summarises the hydrochemical variability across all river, lake and groundwater sites sampled between September 2005 and November 2007 (Figure 1), with the maximum annual precipitation measured being more than double the minimum. Rivers had the widest range for pH, whilst groundwaters had the lowest values. Mean EC was lowest for rivers, but overall ranges were high for rivers, lakes and groundwaters. The same pattern was observed for alkalinity, but lakes had the lowest maximum vales measured (around two-thirds of the maximum value recorded river). Rivers and lakes had similar mean oxygen isotope signatures, though rivers tended to remain less enriched with δO18, whilst lakes were far more seasonally variable, probably due to dry season preferential evaporation of δO16 [17].

Table 1. Summary of main climatic and hydrochemical variables in KNP and KGMA for sampling period September 2005 to November 2007. († Temperature values for January to December 2007 at Kasanka Research Centre (KRC): see Fig. 1).

Variable	Mean	Minimum	Maximum
Annual Precipitation (mm)	1438	754	1884
Monthly mean temperature (°c) †	22.2	17.9	25
pH			
Rivers	7.21	5.38	8.90
Lakes	6.91	5.84	8.36
Groundwaters	6.58	5.06	8.09
EC (µS cm^3 s^{-1})			
Rivers	95	3	535
Lakes	131	6	500

Groundwaters	136	5	539
Alkalinity (µEq l^{-1})			
Rivers	1187	33	5844
Lakes	1609	168	3943
Groundwaters	1516	70	5323
Oxygen Isotope Ratio ($\delta^{16}O$: $\delta^{18}O$)			
Rivers	-5.5	-8.6	-5.2
Lakes	-0.1	-8.6	6.7
Groundwaters	-5.6	-9.5	-0.4

Sampling has shown that a number of the surface water-bodies in KNP are highly responsive to precipitation, and that water levels may take 1 or more years to recover following a year with below-average precipitation. For example, Lake Wasa I, a seasonal dambo (see Figure 1), was very responsive to local precipitation: 2005/6 precipitation at Wasa Camp was below the regional average, and a minimum lake level of 60cm was recorded at the end of the 2006 dry season. Lake level showed a rapid and sustained response to above average precipitation in the subsequent two wet seasons (Fig. 2).

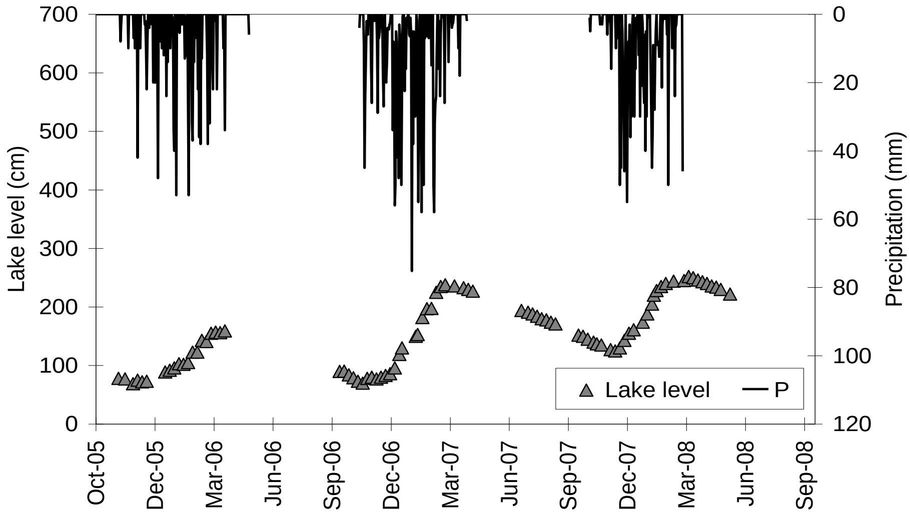

Fig. 2. Daily precipitation at Wasa Camp and Wasa 1 lake level

Figure 3 provides an example of the application of δ16O:δ18O ratios as a possible tracer of water source and movement. To Summarise:

- Values for $\delta^{18}O$ remained consistently depleted for all of the main river sites, in contrast to lake sites (Table 1).
- For the Luwombwa River (Fig. 3), the general trend between May and November 2005 was an enrichment of $\delta^{18}O$, most likely due to selective evaporation and uptake of the lighter $\delta^{16}O$ isotope [17].
- Following a wet season with below-average precipitation (2005/6) there was an evident strong influence of precipitation on the main Luwombwa river channel: the depletion and re-enrichment with $\delta^{18}O$ shown in the precipitation was mirrored, with a lag of several weeks, by river δ16O:δ18O ratios. The influence of precipitation appeared less pronounced during the May-November 2006 dry season.
- Differences in isotopic values between the upstream (Yewe) site and the two downstream sites were observed in May 2006 (Fig. 3), with downstream values similar to those for the groundwater sample (approx. 30 m. from the 'Lodge' main river site), indicating that connectivity between groundwater and rivers is likely to be both seasonally variable, and spatially variable over small scales.

- Small-scale spatial and temporal variability in flow connectivity between various waterbodies should therefore be considered in the context of protecting biodiversity and associated ecosystem services [23] from potential anthropogenic impacts such as abstraction for farming and industrial intensification [11].

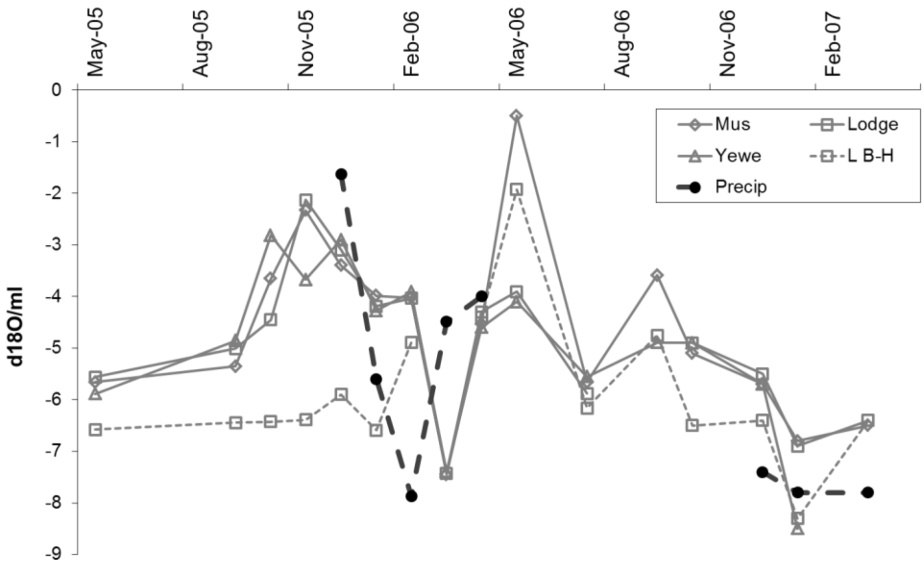

Fig. 3. River δ18O values from sites along the Luwombwa River and from ground water (L B-H) and precipitation (Precip: from KRC) samples (see Fig. 1 for locations).

4. CONCLUSION

This study has provided a first attempt at understanding hydrological processes within a little studied region of sub-Saharan Africa, and has concluded that the processes are spatially and temporally complex even over short distances, and to a large degree are precipitation-driven during dryer periods. Whilst hydrochemical variability exists between different waterbody types, connectivity also exists between them. Successful management of freshwater resources and associated habitats within KNP (and the wider region) therefore needs to utilise information about current climatic conditions, along with information from the years immediately preceding, whilst recognising that local factors (e.g. geology) may control connectivity. Further work should provide discharge estimates to be calculated. In conjunction with hydroclimatic monitoring this might allow useful end member mixing analysis, and provide insight into potential impacts of climate change and anthropogenic pressures.

ACKNOWLEDGEMENTS

Thanks to Kasanka Trust, members of 2006 Glasgow University and 2007 Aberdeen University expeditions to KNP, technical staff at Aberdeen, and Martin Stanley (Hollyhill Trust) for co-sponsoring the work. The project was funded under Darwin Initiative grant 13/001.

COMPETING INTERESTS

No competing interests.

REFERENCES

[1] MacDonald A, Davies J, Calow R, Chilton, J. Developing Groundwater: A guide for Rural Water Supply. UK: ITDG Publishing, Schumacher Centre for Technology and Development; 2005.

[2] Sithole A, Murewi CTF. Climate variability and change over Southern Africa: impacts and challenges. Afr J Ecol. 2009; 47:17-20.
[3] Wantzen KM, Junk WJ. The importance of stream-wetland systems for biodiversity: a tropical perspective. In: Gopal B, Junk WJ, Davis JA, editors. Biodiversity in Wetlands: Assessment, Function and Conservation, vol. 1. Leiden: Backhuys Publication; 2000.
[4] Kennedy MP, Murphy KJ, Soulsby C, Lowe S, Gibbins C. 2012. Multiple-scale controls on physical and chemical habitat conditions and their influence on biotic assemblages in Zambian rivers. In: Proceedings of the British Hydrological Society 11th National Symposium: Hydrology for a Changing World, Dundee; 2012.
[5] Kennedy MP, Lang P, Tapia Grimaldo J, Varandas Martins S, Bruce A, Hastie A, et al. Environmental drivers of aquatic macrophyte communities in southern tropical African rivers: Zambia as a case study. Aquat Bot. 2015; 124:19-28.
[6] von der Hayden CJ, New MG. The role of a dambo in the hydrology of a catchment and the river network downstream. Prog Phys Geog. 2003; 28:544-564.
[7] Chabwela HN. Foreword. In: Jeffrey RCV, Chabwela HN, Howard G, Dugan PJ, editors. Managing the Wetlands of Kafue Flats and the Bangweulu Basin: Proceedings of the WWF-Zambia Wetlands Project Workshop. Switzerland: IUCN; 1992.
[8] Salum LA. Climate variability and change over Southern Africa: impacts and challenges. Afr J Ecol. 2009; 47:166-170.
[9] Gopal B, Junk WJ. 2000. Biodiversity in wetlands: an introduction. In: Gopal B, Junk WJ, Davis JA, editors. Biodiversity in Wetlands: Assessment, Function and Conservation, vol. 1. Leiden: Backhuys Publication; 2000.
[10] Gunston H. Field Hydrology in Tropical Countries: A Practical Introduction. UK: Intermediate Technology Publications; 1998.
[11] United Nations, Department of Economic and Social Affairs, Population Division. World Population Prospects: The 2015 Revision, DVD Edition. New York; 2015. Accessed 8 May 2016. Available: http://esa.un.org/unpd/wpp/Download/Standard/Population/.
[12] Kennedy MP, Lang P, Tapia Grimaldo J, Varandas Martins, S, Bruce A, Lowe S. et al. The Zambian Macrophyte Trophic Ranking scheme, ZMTR: a new biomonitoring protocol to assess the trophic status of tropical southern African rivers. Aquat Bot. 2016; 131:15-27.
[13] McCartney MP, Neal C, Neal M. Use of deuterium to understand runoff generation in a headwater catchment containing a dambo. Hydrol Earth Syst Sc. 1998. 2:65-76.
[14] McCartney MP. The water budget of a headwater catchment containing a dambo. Phys Chem Earth Pt B. 2000; 25:611-616.
[15] McCartney MP, Neal C. Water flow pathways and water balance within a headwater catchment containing a dambo: inferences drawn from hydrochemical investigations. Hydrol Earth Syst Sc. 1999; 3:581-591.
[16] Soulsby C, Rodgers P, Petry J, Hannah DM, Malcolm IA, Dunn SM. Using tracers to upscale flow path understanding in mesoscale mountainous catchments: two examples from Scotland. J Hydrol. 2004; 291:174–196.
[17] Kendall C, McDonnell JJ. Isotope Tracers in Catchment Hydrology. New York: Elsevier Science; 1998.
[18] Soulsby C, Tetzlaff D, Rodgers P, Dunn SM, Waldron S. Runoff processes, stream water residence times and controlling landscape characteristics in a mesoscale catchment: an initial evaluation. J Hydrology. 2006; 325:197–221.
[19] Jachmann H. Zambia's wildlife resources: a brief ecology. Lusaka, Zambia: Environmental Council of Zambia; 2000.
[20] Richter HV, Cumming GS. Food Availability and annual migration of the straw-coloured fruit bat (*Eidolon helvum*). J Zool. 2006; 268:35-44.
[21] Byng JW, Racey PA, Swaine, MD. The ecological impacts of a migratory bat aggregation on its seasonal roost in Kasanka National Park, Zambia. Afr J Ecol. 2009; 48:29-36.
[22] Gran G. Determination of the equivalence point in potentiometric titrations. Part II. Analyst. 1952; 77:661-671.
[23] Matthies BD, D'Amato D, Berghall S, Ekholm T, Hoen HF, Halopainen J, et al. An ecosystem service-dominant logic? – integrating the ecosystem services approach and the service-dominant logic. J Clean Prod. 2016; 124:51-64.