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Physicochemical Properties and Macronutrients Status of Water From Mukumbura and Zhoubvunda Rivers' Floodplain Shallow Wells In The Zambezi Valley, Northern Zimbabwe

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ABSTRACT

Floodplains are a sink of pollutants from surrounding areas, yet they provide sources of water for irrigating crops, and human, livestock and wildlife drinking. In semi-arid areas, floodplains are usually the only sources of water particularly during the dry season when upland wells dry up. The objective of this study was to determine the suitability of the water from shallow wells for crop use and drinking. Total dissolved solids (TDS), pH, electrical conductivity (EC) and selected macronutrients concentrations in shallow wells' water in Zambezi Valley floodplains, northern Zimbabwe were determined. Water samples were collected at depths between 2.7 and 3.3 m in November 2015. Water pH was measured using Adwa pH/mV/ISE and temperature meter; EC and TDS using Adwa EC/TDS and temperature meter; Mehlich 3 extracted Ca, Mg, K, and Na concentrations were determined using atomic absorption spectrometry, phosphates were measured using the ascorbic acid procedure, while sulphates were determined using the barium sulphate method. Data from water analyses were subjected to ANOVA. Water pH ranged from 6.94 to 7.73; EC ranged from 137.67 to 220.00 µScm-1; and TDS ranged from 114.67 to 173.43 mgl-1. Macronutrient concentrations (mgl-1) were: 23.33 to 64.23 for Ca; 19.23 to 23.60 for Mg; 0.34 to 1.50 for K; 14.46 to 19.05 for Na; 3.03 to 5.87 for phosphates and 1.12 to 6.12 for sulphates. Plant nutrient concentrations were very high for phosphates, normal to high for Ca, normal for the rest. Electrical conductivity, TDS and pH were within normal range for crop use. The water quality met the World Health Organization and the Standards Association of Zimbabwe specifications for drinking water. Satisfactory crop productivity is achievable using the water for irrigation purpose but measures should be taken to minimize accumulation of phosphates and Ca.

Keywords: Capillary rise, Groundwater, Smallholder farming and Water quality

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INTRODUCTION

The Zambezi Valley is prone to flooding because of its low altitude (less than 400 m above sea level) and relatively flat terrain (Anderson et al., 1993). Flooding in this area occurs due to overflowing water in meandering tributaries of the Zambezi River and backflow at confluences. The floodwater, which originates from the highveld and surrounding areas, is often loaded with essential plant mineral nutrients (Chimweta et al., 2018). Flooding provides groundwater that is essential for flood-recessing cropping, irrigation and drinking water for people and livestock. Farmers take advantage of the fertile alluvial soils to grow crops without applying fertilizers. The alluvial soils are a major reservoir for plant nutrients, however, it has been shown that some of these nutrients, particularly those that exist in anionic form are leached into the groundwater (Fisher and Reddy, 2001). In semi-arid areas, particularly where shallow water tables exist, evapotranspiration tends to increase salinity in near-surface layers of the soil and this may lead to crop damage through plasmolysis. Salinity quickly build-up in surface layers if the salt content of the water is already too high. Therefore, for optimum crop growth, the

Figure 1. Map of study area.

groundwater should contain essential plant nutrients at acceptable levels and in the correct balance. Degradation of water quality due to high salinity and excessive nutrient content causes stunted growth of crops, alters species composition and decreases the health of aquatic systems (Shannon and Grieve, 1999; Ouyang, 2012). Although, eutrophication of surface water bodies has been extensively studied by Arheimer et al. (2012), similar studies on groundwater in cultivated floodplains of developing countries have not been given adequate consideration.

In addition, whilst most literature from temperate regions referred to excessive nutrient enrichment as a serious problem (Ouyang, 2012) and measures are actually put in place to counteract the resultant negative effects, a different approach may have to be adopted in the largely nutrient-deficient ecosystems of Sub-Saharan Africa. Moreover, studies in the region should consider the suitability of the floodplain water for human consumption. Although access to clean water is a basic right, it remains a major issue, particularly in rural areas in sub-Saharan Africa, which has the lowest levels of drinking water coverage, at 64% in 2012 (WHO, 2014; UN, 2014). Although the coverage is better in Zimbabwe; 19% of the rural population does not have access to clean water (WHO, 2014). In semi-arid areas, the proportion of the population without access clean water may increase in the dry season when other sources of clean water dry-up and people resort to floodplain shallow wells, which are a natural sink of pollutants from surrounding areas. Due to the multiple uses of water from floodplain shallow wells, there is a need to generate information on water quality both from a crop use perspective and from the drinking water for humans and livestock point of view. Therefore, the objective of this study was to determine the suitability of water from Muzarabani floodplain shallow wells for human drinking and crops use, based on selected chemical properties such as pH, total dissolved solids (TDS), electrical conductivity (EC) and selected macronutrients concentrations.

MATERIALS AND METHODS

The Study Area

The study was conducted in Muzarabani Communal Area in Centenary District, between latitudes 16.00 and 16.176oS, and longitudes 31.170 and 31.197oE (Figure 1). Musengezi, a tributary of Zambezi River, is the major river in the area. The area receives most of its rainfall between December and March and the mean annual

Figure 2. Cattle waiting to drink water from a wooden trough at a floodplain shallow well along Zhoubvunda River in northern Zimbabwe.

rainfall is 650 mm. The mean annual temperature is 25oC and the area is frost free (Pwiti, 1996). According to the FAO/UNESCO soil classification, the soils in the area are Calcaric Cambisols, Eutric Vertisols, Vertic Cambisols, Chromic Cambisols, Calcic/Chromic Luvisols (Anderson et al., 1993). The soils generally have high agricultural potential.

The vegetation is typically dry savanna, dominated by Colophospermum mopane Kirk ex Benth., Ziziphus mauritiana Lam., and Combretum, Sterculia and Vachellia (previously Acacia) species. Dominant grasses include spear grass (Heteropogon contortus (L.) and Digitaria species. Maize (Zea mays L.), cotton (Gossypium hirsutum L.) sorghum (Sorghum bicolor L. Moench), and pearl millet (Pennisetum glaucum L. R.Br.) are the major upland rain-fed crops. The major crop grown in the floodplains is maize and the other crops include cowpeas (Vigna unguiculate (L.) Walp.), sugar beans (Phaseolus vulgaris L.), watermelon (Citrullus lanatus (Thunb.) Matsum. and Nakai, pumpkins (Curcubita spp.) and sweet potatoes (Ipomoea batatas L.). Dominant livestock species are cattle (Bos taurus L.), Goats (Capra aegagrus hircus L.), Sheep (Ovis aries L.). Elephants (Loxodonta spp.) and buffaloes [Syncerus caffer (Sparrman, 1779)] usually visit the floodplain area in the dry season in search of water and green vegetation or inadvertently stray into the area from Mavhuradonha range or Mozambique (Chimweta et al., 2019). Seasonal floods, which mostly occur between January and February, are a frequent phenomenon in this area. In addition to the low-lying nature of the area, its location between the Kariba dam upstream and Cahora Bassa dam downstream predisposes the area to human–engineered flooding (Mavhura et al., 2013). Within the study area, farmers usually use groundwater and the fertile alluvial soils in adaptation to frequently occurring droughts. In addition to providing drinking water to human beings, floodplain wells are also livestock watering hotspots (Figure 2).

Experimental Design

Site Selection and Description

Wells were randomly selected from a list of functional shallow wells that were used for irrigating crops, and human and livestock drinking water supply in the floodplains, along Zhoubvunda and Mukumbura Rivers. The selected wells were Kamufumu (16.176oS, 31.196oE); Machona (16.011oS, 31.190oE), Tada (16.011oS, 31.193oE), Masora (16.011oS, 31.192oE), and Kajunge (16.011oS, 31.194oE). Two reference shallow wells located at homesteads outside the floodplains were also selected viz Mavedzenge (16.00oS, 31.17oE.) and Mutsitsa (16.018oS, 31.197oE) as controls.

Sampling of Water

In preparation for sampling, bottles were rinsed twice with a solution of 1:1 HCl (Fadiran et al., 2008), and twice with de-ionized water in the laboratory. Water samples were collected from five (5) shallow wells along Zhoubvunda and Mukumbura Rivers floodplains and two (2) shallow wells from upland homesteads that were within 1 km of the floodplains in November 2015, prior to the onset of the rainy season. Six replicate samples in

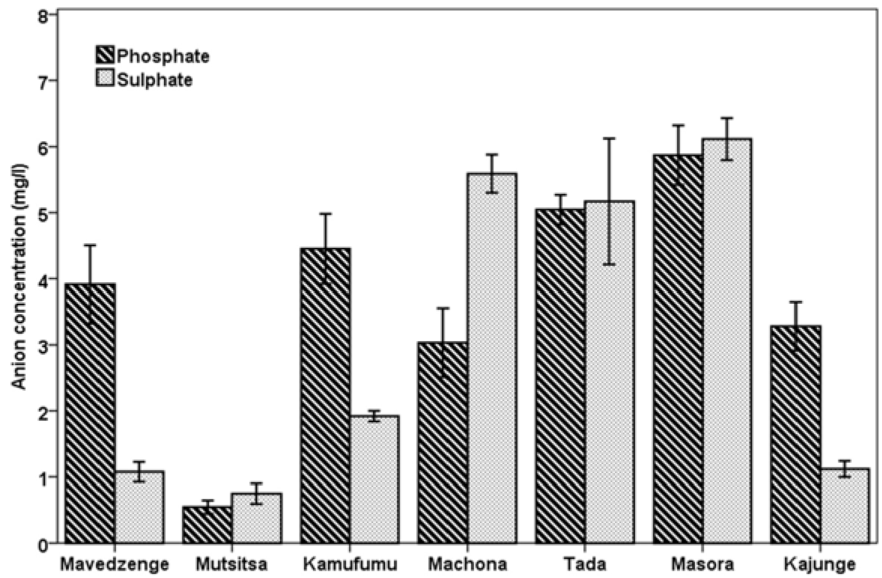

Figure 3. Concentration of phosphates and sulphates in water from Muzarabani floodplain shallow wells in northern Zimbabwe. Error bars represent standard deviations.

500-ml bottles were taken at each well using a clean plastic container. Thus, a total of forty-two (42) samples were collected. At each well, sampling bottles were rinsed thrice with water from the well before filling them with water to the required mark. Groundwater table was measured using a clean measuring tape soon after sample collection. After each measurement, the measuring tape was thoroughly rinsed using de-ionized water. The samples were immediately pretreated with 2.5 ml of 10% HNO3 per bottle (Masime et al., 2013), ferried within 24 h of collection and kept refrigerated at 4oC (Fadiran et al., 2008).

Laboratory Analysis

Water pH was measured using the Adwa pH/mV/ISE and temperature meter (model AD300, Romania). Total dissolved solids and EC were measured using the EC/TDS and temperature meter (model AD300, Romania). Phosphates were measured using the ascorbic acid procedure (Murphy and Riley, 1962) while sulphates were determined using the barium sulphate method (Krug et al., 1977). The concentration of phosphates and sulphates were read using the UltraViolet Spectrophotometer (Thermoscientific model GENESYS 10S UV-VIS, United States of America). Potassium (K), Ca, Mg and Na were extracted using the Mehlich 3 procedure (Ziadi and Tran, 2008) and concentrations were read using the Atomic Absorption Spectrophotometer (Thermoscientific model ICE 3000 series, China).

Data Analysis

Data from water analysis were subjected to One-way Analysis of Variance using IBM SPSS Version 21 of 2012. Means were separated using LSD post hoc test at 0.05% significance level.

RESULTS

Macronutrient Concentration

Phosphate concentration in sampled floodplain wells ranged from 3.03 to 5.87 mgl-1 (Figure 3). Mavedzenge reference well phosphate concentration, 3.91 (0.59) mgl-1, was in the range of the floodplain wells' concentration ($P > 0.05$) whilst Mutsitsa reference well concentration, 0.55 (0.10) mgl-1, was significantly less ($P < 0.05$) than the values obtained for all the wells. Sulphates in the floodplain wells ranged from 1.12 to 6.12 mgl-1. Except for Kajunge well, sulphates concentration in all the sampled floodplain wells exceeded ($P < 0.05$) that of reference wells. Water from floodplain wells had relatively close Ca concentration, with values between 51.71 and 64.23 mgl-1, except for Machona well that had a Ca concentration of 23.43 mgl-1 (Figure 4). Mavedzenge reference well had higher Ca concentration than Mutsitsa reference well, 71.57 (16.26) mgl-1 versus 22.84 (11.53) mgl-1. Mavedzenge reference well Ca concentration was similar ($P > 0.05$) to concentration in Kamufumu, Tada and Masora wells. Mutsitsa reference well Ca concentration was lower ($P < 0.05$) than that of all floodplains except Machona. Magnesium concentration in floodplain wells was between 19.93 and 23.60 mgl-1. Mavedzenge reference well had a lower ($P < 0.05$) Mg concentration (15.74 (2.14) mgl-1) than floodplain wells, and that of Mutsitsa well, 20.20 (2.10) mgl-1 was in the range of the floodplain wells. Similarly, Mavedzenge reference well had a lower ($P < 0.05$) Na concentration, 15.83 (0.43) mg l-1, than Mutsitsa

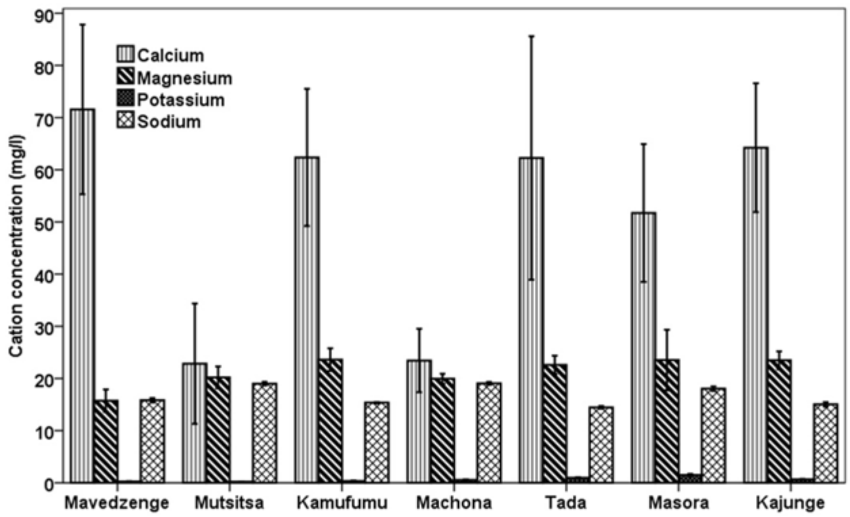

Figure 4. Concentration of Ca, Mg, K and Na in Muzarabani floodplain shallow wells water in northern Zimbabwe. Error bars represent standard deviations.

Table 1. Mean (standard deviation) pH, TDS and EC of water from muzarabani floodplain wells.

Site	Altitude (m)	Depth of Water Table (m)	pH	TDS (mg l-1)	EC (µS cm^{-1})
Mavedzenge	327	7.5	6.95 (0.11)[a]	199.17 (31.53)[a]	205.50 (23.54)[ac]
Mutsitsa	345	5.8	7.49 (0.03)[b]	156.17 (10.30)[bd]	205.50 (15.96)[ac]
Kamufumu	352	2.95	6.94 (0.11)[a]	152.17 (16.77)[b]	220.00 (17.26)[a]
Machona	328	3.30	7.67 (0.14)[cd]	142.50 (11.95)[b]	180.33 (12.14)[be]
Tada	330	2.80	6.99 (0.08)[a]	114.67 (5.28)[c]	183.33 (11.34)[de]
Masora	331	3.10	7.73 (0.04)[d]	137.50 (11.52)[b]	137.67 (14.69)[f]
Kajunge	328	2.70	7.24 (0.06)[e]	173.43 (18.14)[d]	196.86 (8.53)[ce]

reference well, 19.00 (0.33) mg l-1 and all the floodplain wells. Mutsitsa reference well had similar Na concentration to that of Machona, but higher ($P < 0.05$) concentration than the rest. The floodplain wells' Na concentration was between 14.06 and 19.05 mg l-1. Floodplain wells K concentration was between 0.34 and 1.50 mg l-1. Mutsitsa reference well had lower ($P < 0.05$) K concentration (0.22 mg l-1) than all floodplain wells whilst Mavedzenge reference well had K concentration 0.25 (0.02) mg l-1) similar to Kamufumu floodplain well, but lower than the rest. Each floodplain well had a different K concentration from the others.

pH, TDS and EC of Water Samples

Floodplain wells' pH ranged from 6.94 to 7.73 and the pH of reference wells fell between 6.95 and 7.49 (Table 1). Mavedzenge reference well recorded the highest TDS value of 199.17 mgl-1 while Mutsitsa reference well's TDS was within the range of floodplain wells, with values that ranged from 114.67 to 173.43 mgl-1. The EC of water was similar ($P < 0.05$) for the two reference wells and fell in this range (Table 1).

DISCUSSION

Nutrient concentration was very high for phosphates, normal to high for Ca, normal for Mg and low for K, Na and S in relation to irrigation water quality (Park et al., 2014). High phosphate levels were expected because P leaching often occurs in deep soils that have high organic matter levels (Sims et al., 1998). Thus in the organic matter rich floodplain soils, phosphates loading in shallow groundwater is likely to occur. Mavedzenge reference well had high phosphate concentration because of its proximity (< 300m) to the floodplain. In contrast, Fadiran et al. (2008) found much lower phosphate concentrations in a similar setup of low population and subsistence agriculture activity. Nolan and Stoner (2000) also reported low orthophosphate concentrations between 0.1 and 0.2 mgl-1 in shallow groundwater beneath agricultural land. From irrigation water quality perspective, the floodplain wells water had a low salinity hazard with EC value that are less than 250 µS cm-1 and normal pH (Table 2) (van Hoorn, 1971). Cation concentration was below the Standards Association of Zimbabwe (SAZ) critical limits for drinking water, which are 100 mgl-1 for Mg, and 200 mgl-1 for Na. Calcium levels were similar to those that were found in a separate study of spring wells, in Mavhuradonha range on the eastern side (Mavhuradonha High School) but much higher than those in the Mavhuradonha range on the western side (Wilderness Lodge) and Barassie Farm near Bindura Town (Figure 1 and Table 2). Magnesium

Table 2. Selected physical and chemical characteristics of spring water from three sites in Zimbabwe.

Parameters	Current study area	Other sites			Drinking-water specification requirements		[c]Irrigation water thresholds
	Muzarabani floodplain wells	Mavhuradonha range		Barassie	Highest desirable level	Maximum permissible	
		Mavhuradonha high school	Wilderness lodge				
[c]pH	6.94-7.73	7.5	8.1	6.7	6.0[a]	9.0[a] 9.2[b]	6.5-8.0
TDS (mgl^{-1})	114.67-173.43	403.5	291.5	173.5	500.0[b]	1500.0[b]	500
EC (μScm^{-1})	137.67-220.00	828.0	583.0	346.0	Not available	3000.0[a]	750
K (mgl^{-1})	0.34-1.50				Not available	Not available	20
Ca (mgl^{-1})	23.43-64.23	62.2	5.8	14.2	75.0[b]	200.0[b]	20
Mg (mgl^{-1})	19.93-23.60	42.8	42.9	10.3	50.0[b]	100.0[a] 150.0[b]	
Na (mgl^{-1})	14.06-19.05	18.9	2.7	16.6	Not available	200.0[a]	70
Phosphate (mgl^{-1})	3.03-5.87				Not available	Not available	1.2
Sulphate (mgl^{-1})	1.12-6.12	3.2	Not detected		200.0[b]	500.0[a] 400.0[b]	

levels (19.93 to 23.60) in Muzarabani floodplain wells were lower than those in the Mavhuradonha range that exceeded 40 mg l-1 but were more than double those at Barassie Farm. Barassie Farm spring well occurs in a commercial farm setting characterized by relatively high levels of agro-chemical application, therefore sulphate levels at this farm were well above those found in Muzarabani floodplain wells. In relation to drinking water standards, pH between 6.94 and 7.73 was less than the SAZ critical limit of 9.0 and within the acceptable range of 6.5 to 8.5 (WHO, 2011). Sulphates were also below the highest desirable concentration of 200 mg l-1 (WHO, 2011). Mutsitsa reference well was located upstream at a higher altitude and longer distance from the floodplain (Figure 1 and Table 1). Therefore, relative to Mutsitsa reference well, floodplain shallow wells exhibited more anion nutrient enrichment but the Mavedzenge reference well anion nutrient levels mostly occurred in the range of floodplain wells. This confirms that there is nutrient enrichment in floodplains in the study area. For macronutrients that exceeded threshold levels for irrigation water quality, Ca and phosphates, and Mg that existed at a concentration close to the threshold, fertilizer management should account for the amount contributed by irrigation water.

CONCLUSION

Based on the parameters considered in this study, it was concluded that satisfactory crop productivity is achievable using water from Muzarabani floodplain shallow wells under good management but measures should be taken to minimize accumulation of phosphates and Ca. From a drinking water perspective, the water quality parameters were below the SAZ and WHO maximum permissible limits and therefore safe for drinking by humans and livestock.

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