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Seasonal river channel water exchange and implications on salinity levels in sand dams: Case of semi-arid Kitui Region, Kenya

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Abstract

This paper presents results of a study on the variations of salinity levels (and associated physico-chemical parameters) in sandbeds of seasonal rivers found in the semi-arid region of Kenya. The study sought to investigate the interaction between water in river sandbeds and bank storage and how this interaction influences salinity levels in sand dams and shallow wells in semi arid lands. The results of the study show that there is a significant relationship between water quality parameters in dry river sandbeds and the corresponding water quality parameters in shallow wells and sand dams. Within river sandbeds, the dry season salinity ranged from 0.9 to 12.8% while the wet season salinity ranged from 0.4 to 1.1%. The wet season total dissolved solids (TDS) concentrations ranged from 77.8 to 272 mgl^{-1}. The dry season TDS concentrations were high ranging from 227 to 3,320 mgl^{-1}. The wet season water conductivities were however low ranging from 155.9 to 539 $\mu S.cm^{-1}$ as compared to the dry season conductivities that were high ranging from 455 to 6,640 $\mu S.cm^{-1}$. As compared to the river channel sandbeds, water in shallow wells and sand dams was characterized by relatively high levels of physico-chemical parameters with salinity ranging between 1.5% and 6.5% and TDS concentrations ranging from 396 to 1,680 mgl^{-1}. The level of salinity in sand dams and shallow wells tends to be much higher than those in the stream channel sandbed. Also, within the river channel sand beds, the levels of salinity were mostly within the minimum allowable limit for drinking water except in extended drought periods. The relatively high salinity, TDS concentrations and conductivity were attributed to mineralization of water due to entrapment, ground water recharge and solubisation of minerals from soils. The study shows that the flow of water within sand bed matrix is characterized by low hydraulic conductivities and water fluxes and this has important implication on the salinity levels in sand beds of seasonal rivers.

Keywords: Sandy river channel; water exchange; bank storage; salinity; Kitui, Kenya

1. Introduction

The sandy seasonal rivers in arid and semi arid lands of Africa are important sources of water to communities and their livestock. These river systems traversing most of the dry Sahelian region of Africa flows for short period during rainy period and are mostly without streamflow for a long dry period. During dry seasons, water is obtained from the dry sandy river channels by digging, scooping or excavating sand to access water trapped within the sand layer matrix. The seasonal rivers store a significant volume of water in their sandy channels and it is this water that usually sustains local communities and their livestock, including wildlife during periods of prolonged drought. Without this water, life would be impossible in most of the Sahelian region of Africa, where piped water supply are unheard of. Inaccessibility of most of the arid and semi arid areas and thin population distribution means it is not economical to extend piped water supply in remote arid and semi arid lands (ASALs). However, despite the important role played by seasonal rivers in Africa, few or no studies have been undertaken to unravel their hydrologic and water quality characteristics. As such, there is scarcity of data and information on the variation of salinity in sandy river channels of Africa. Studies on such rivers are required to advice on the water resources and agricultural development programmes in arid and semi arid lands. The studies on seasonal rivers of ASALs that are available have focused mainly on soil erosion processes (cf. Kithia, 2002). The main driving forces that act in shaping the seasonal variation of water quality and particularly salinity in such river systems are still little understood for most African river systems.

The seasonal rivers of Kitui region of Kenya can be said to be representative of typical seasonal rivers found in arid and semi arid Sahelian belt of Africa. These rivers are important in Kitui region of Kenya where shortage of water is a major drawback for rural and urban development. Seasonal rivers of Kitui region have been sources of water for majority of the people and livestock in the county for many generations. In order to address the chronic shortage of water to rural communities in the county, an effort is now being focused on the exploitation of seasonal rivers through construction of sand dams and shallow wells within sandy channels. Such development programmes need to be based on the assessment of suitability of water for domestic, livestock and agricultural uses, particularly small-scale irrigation. Sand dams and shallow wells have a potential as a source of water to local communities in ASALs (Borst and De Haas, 2006: Beimers et al., 2001a-b; Burger et al., 2003; Munyao et al., 2004; Puttemans, 2004). There have however been little concern on water quality of sandy seasonal rivers, sand dams and shallow wells in arid and semi arid lands. This lack of concern is partly based on the assumption that there are no major anthropogenic drivers of water pollution in arid and semi arid lands and that natural factors, mainly hydrogeo-chemical and catchment factors, are the only determinant of water quality in seasonal rivers. However, the anthropogenic influences are progressively becoming important in arid and semi arid lands of Kitui and these can longer be overlooked (cf. Abila et al., 2012). In the past, sand dams in Kitui have been constructed in unsuitable locations where water quality does not meet the WHO Drinking Water Standards (WHO, 1998). This has been attributed to lack of hydrological studies to establish the site suitability in terms of water quality. Although sand dams constructed within sandy river channels and shallow wells constructed on the banks of seasonal rivers are becoming important features in arid and semi arid Kitui County, there is a need to establish the extent to which interaction between seasonal rivers and bordering groundwater aquifers and bank storage influences salinity of water in sandy river channels and how this subsequently influences salinity levels in sand dams and shallow wells constructed near them. Such studies are required to inform the processes for selection of sites for sand dams and shallow wells in to order to ensure the most suitable sites are chosen. The need for baseline studies to establish the levels of salinity and related parameters such conductivity and total dissolved solids (TDS) in sandy river channels in dry periods cannot therefore be over-emphasised. Water availability to communities, livestock and wildlife is most critical in dry periods. In addition to the fact that the results of the study will help in safeguarding community health and avoid unsustainable projects in ASAL, from scientific point of view, studies of this nature also helps in tracking anthropogenic influences in ASALs. This is important in view of rapid population growth and expansion and recent campaigns to open up arid and semi-arid for development in Africa and Kitui region in particular.

In this paper, the physico-chemical parameters such as salinity, TDS, and conductivity have been used to describe the overall water salinity in sandy river channels of Kitui. Conductivity provides an indication of the level and source of dissolved ions (Vaishal and Punita, 2013). High levels of dissolved solids in water are associated with high amount of ions in water and hence high salinity levels (Bhattet al., 1999). While anthropogenic factors are important in determining the level of conductivity, increasing levels of conductivity and cations are usually attributed to the decomposition and mineralization of organic materials (cf. Abida, 2008). Conductivity has been used as a standard water quality parameter (APHA, 1992; Massdam and Smith, 1994). At high streamflows, the TDS concentrations is diluted by surface runoff and for most rivers there is an inverse correlation between discharge rate and TDS concentration (Charkhabi and Sakizadeh, 2006; Srivastava et al., 2011). River water with high total dissolved solids (TDS) are unpalatable and potentially unhealthy (Vaishal and Punita, 2013). Past studies elsewhere have shown that the concentration of salinity usually decrease in rainy season as a result of dilution effect by the surface runoff (cf. Srivastava et al., 2011). However, there is very little data and information on the levels of salinity within the sandy river channel water during dry seasons for most of the rivers in arid and semi arid regions of the world including Africa and Kitui region where this study was undertaken. Most of the available data and information is for water in flowing streams and these have been obtained in rainy seasons when seasonal rivers flow for a brief period. The processes influencing the variability of the salinity levels in the water trapped within the sand column within the river channel has not been extensively investigated in past studies. This study therefore sought to establish the processes influencing the variation of salinity levels in sandy river channels during dry seasons in the semi arid Kitui region of Eastern Kenya.

2. Description of the Study Area

2.1 Location

This study was undertaken in seasonal rivers traversing Kitui County in Eastern Kenya. The region has a surface area of 30,496 km^2 (Figure 1). The main town is Kitui which is located about 160 km South East of Nairobi-Kenya's capital city. The topography of the county can be divided into upland and lowland zones. The upland area includes the Yatta Plateau in the west and the Kitui Mountains in the East. Elevations in the Kitui upland area vary between 600 and 1800 m above sea level. The Lowland area which covers the majority of the county is a gently eastward-sloping peneplain with elevation varying from 400 to 600 m above sea level. Few isolated inselbergs are found in this zone (Borst and de Haas, 2006).

2.2 Climatic conditions

The climate of Kitui region is generally hot and dry with erratic and unreliable rainfall typical of arid and semi-arid climatic zones. The region experiences two rainy seasons with two peaks in April during the long rains and November during the short rains. The long rains occur in the period between March and May while the short rains occur in the period between October and December. The rest of the year is usually hot and dry. The mean total annual rainfall range between 750 and 1150 mm. Air temperature ranges between 16^{o}C and 34^{o}C with mean maxima of 28^{o}C and minima of 22^{o}C (Horst and de Hass, 2006). The potential evaporation rates are high ranging between 1500 and 1600 mm.yr^{-1}. The prevailing winds are the north-east and south-east monsoon winds that reverse direction seasonally.

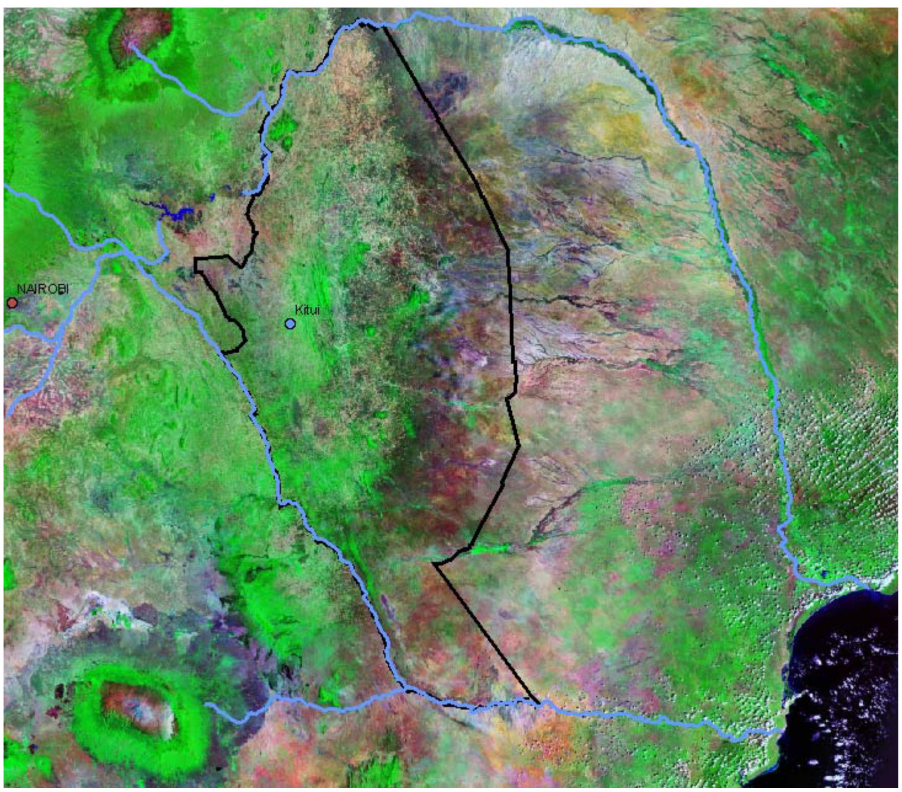

Figure 1: Satellite image of southern region of Kenya including Kitui County region (Source: USGS and NASA)

2.3 Vegetation types

Vegetation of Kitui is characterised by scrublands and wooded bushland. The hilltops are usually characterised by upland dry forest ecosystems dominated by *Drypetes*, *Combretum*, *Vepris* and *Croton* species (Lind & Morrison, 1974). The lower zones of the Kitui hills are covered with *Acacia-Commiphora* and *Strychnos*-*Combretum* or *Commiphora* bushland vegetation type (Lind & Morrison, 1974). At higher altitudes between 1200 and 1800 m above sea level, the vegetation is dominated by *Croton megalocarpus*, *Rawsonia lucida*, *Manilkara discolor* and *Drypetes* species, resulting in semi-evergreen dry upland forests.

2.4 Geological characteristics

Kitui region is located within the Mozambique belt in the basement complex system consisting mainly of metamorphic rocks (Nyamai et al., 2003). The main rock types include well foliated biotite gneiss, migmatites and schists. In some places, mafic granulites rich in garnets and black minerals, iron ore and pyroxenes have weathered into deep fresh red soils rich in black heavy sands. Kunkar limestone river banks of seasonal river cutting valleys in areas occupied by metamorphic rocks. The sediments in river beds mostly consist of well sorted and mature sand without or with minimal silt/clay content.

2.5 Surface water resources

Kitui region has limited surface water sources due to relatively low rainfall. The major sources of water are seasonal rivers such as Thua, Tiva, Kalundu, Nzeeu, Mikuyuni and Mwita Syano (Figure 2). These seasonal rivers are characterized by expansive sandy river channels with sand of variable particle size distribution ranging from fine to coarse sand with gravels and stones. The rivers flow only during rainy seasons and are usually dry for extended periods of drought that are common in Eastern Kenya. Most of the seasonal rivers generally become dry within one month after the rainy season (cf. Borst and De Haas, 2006). The only perennial rivers are Athi river to the west border and Tana river to the north border of the county. Majority of the seasonal rivers of Kitui drain into the Tana River Basin to the east (Figure 2).

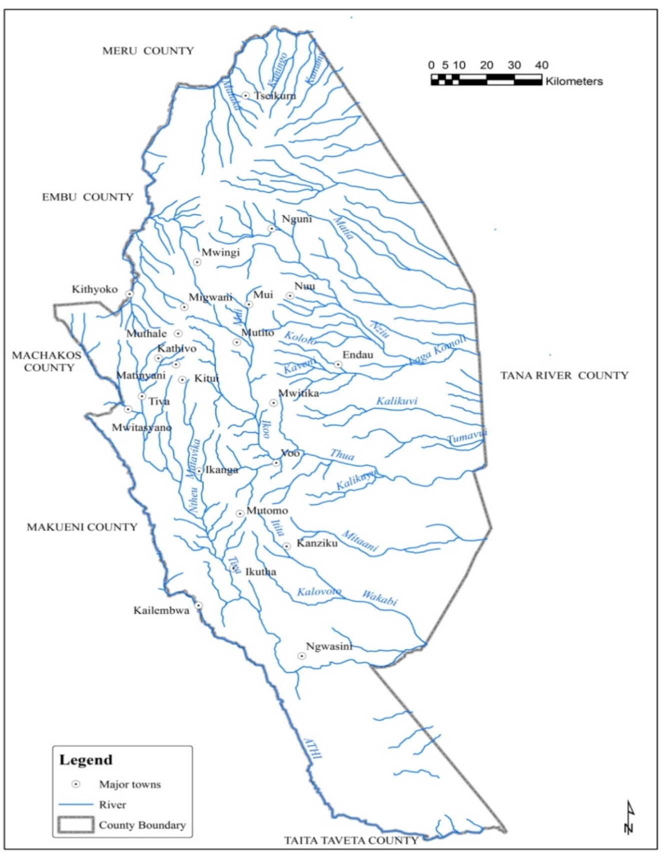

Figure 2: Map of Kitui region showing the drainage system. The study was undertaken in Tiva and Thua river sub-basins.

1.1 Population and socio-economic activities

The population in the Kitui County has been estimated to be 1,060,000 and the population density is relatively low being about 33 people per km. The vast majority of the local economy is based on subsistence agriculture with the practice of mixed farming being common in the upland parts of the county. Rainfed agriculture is an extremely challenging activity given the low rainfall in the county which is often poorly distributed on spatial-temporary basis. Kitui region has enormous potential for development of mining industries in view of its vast mineral resources such as coal, iron ore, marble, graphite, gypsum, gemstones, sand, among others.

2. Methodology

2.1 Measurement of physic-chemical parameters

This study was undertaken in the major seasonal rivers traversing Kitui county, namely Mwitasyano, Kauwi, Nzeeu, Kalundu and Tiva (Figure 2). The main water quality parameters that were measured in these rivers are total dissolved solids (TDS) concentration, conductivity and salinity. In addition, other parameters such as turbidity and temperature were measured since these are important in explaining variability of salinity and conductivity in rivers. Turbidity was measured directly in the field using Hanna Instruments HI93703 Microprocessor turbidity meter capable of measuring turbidity in the range of 0 to 1000FTU. TDS concentrations, Salinity, Temperature and Conductivity were also measured directly in the field using Martini Instruments Mi306 EC/TDS/NaCl/Temperature meter. The study was undertaken in the period between March 2013 and December 2015 in both dry and wet seasons.

2.2 Obtaining water samples

The targeted sampling sites were dry river channels sandbeds where water occurs beneath the surface. Thus, the study relied on scoop holes dug by the local communities to access water in sandbeds for domestic and livestock uses. The scoop holes were of variable sizes with depth ranging from 0.1 to 2 m and width ranging from 0.3m to 1m. Some of the scooping holes functioned like shallow wells within the sandy channels. The shallow wells targeted in this study were mostly those located within the sandy river channels including those located on the river banks or flood plains. The width of shallow wells ranged from 0.5 to 1.5m and the depths ranged from 2 to 10m. The water samples in relatively deeper wells were obtained by using a hand pump or using a bucket lowered into the well to bring water to the surface, following which measurements of salinity, TDS concentrations and conductivity were undertaken. For shallow wells < 0.5 m deep, the measurements were undertaken directly by lowering the measuring probe into the water.

2.3 Determination of channel morphology

The stream morphology was determined through measurement of the gradient, width and depth of the river channel including the depth of the sand matrix within the river channel. The data on the width and depth of the river channel and thickness of sand matrix enabled determination of the cross-sectional areas. The nature of river banks was determined through study of the materials that make the banks including bank height and stability.

2.4 Determination of sediment characteristics

The sediment characteristics were established through particle size analysis of sediment samples drawn from the river channel. Sediment particle size distribution were then used to obtain the median sediment particle sizes for specific sites. The shallow wells were dug mainly in unconsolidated materials consisting of sand, gravels and in some instances clay loamy soil. Some wells had their bottom reaching the consolidated formations consisting mainly of foliated gnesiss which was either fractured or unfractured.

2.5 Determination of streamflow rates

The streamflow at a given river cross-section was established through determination of the river cross sectional area and the stream flow velocity. The maximum streamflow was obtained using the manning equation 1.

$$Q = 1/n\ A\ R^{2/3}\ S^{1/2}\ (\tag{1}$$

Where: Q = maximum discharge in riverbed section (m^3/s); n = Manning roughness coefficient of riverbed; A = wetted cross-sectional area (m^2); P = wetted perimeter (m); R = hydraulic radius (m) = A/P, and, S = slope of riverbed (m/m). The purpose of determining streamflow/river discharge rates was to estimate the potential for recharge of the sandy channel beds.

2.6 Water fluxes in dry sandy channels

The sand matrix within the river channels and the banks of the rivers can be considered as unconfined aquifers and therefore the groundwater hydraulics related to unconfined aquifers were applied in this study in the estimation of permeability and subterranean flow rates (also see Todd, 1980; Wilson, 1990; Raghunath, 1990, 2010 and Subramanya, 2008). The water within the sand matrix flows at very low velocities. The rate of flow was determined using Darcy's law. Darcy's Law is a generalized relationship for flow in porous media. It shows that the volumetric flow rate is a function of the flow area, elevation, fluid pressure and proportionality constant. The discharge Q through the sand matrix was computed using the following equation 2:

$$Q = AK\frac{dh}{L} \tag{2}$$

The hydraulic conductivity K within the sandy matrix was computed from the equation

$$kp = K \tag{3}$$

In above equations, K is the hydraulic gradient (ms^{-1}), s is the slope of the hydraulic gradient, A is the cross-sectional area (m^2), p is the porosity of the medium. The slope of hydraulic gradient s was computed using the equation 4

$$s = \frac{dh}{dL} \tag{4}$$

Where is dh is change in elevation and dL is the distance. Transmissibility $\boldsymbol{T}$ was computed from the equation $Q = TBs$ to represent the flow rate per day through unit cross-sectional area under unit hydraulic gradient. The cross-sectional area A of the saturated thickness of the sand matrix in the river channel is YB, where Y is the saturated thickness of the sand matrix B is the width of the river channel.

2.7 Determination of hydraulic Conductivity (K)

Hydraulic conductivity (K) describes the ease with which water can move through the sand matrix pore spaces. It depends on the intrinsic permeability of the sand material, the degree of saturation, the type of sand/soil, porosity, and the configuration of the soil pores (Todd, 1980). Hydraulic conductivity K was estimated using Hazens empirical equation 5 shown below;

$$K = C(D_{10})^2 \tag{5}$$

Where C is the Hazen's empirical coefficient, which ranges between 0.0 and 1.5 with a mean value of 1.0. D is particle size diameter in mm and K is the hydraulic conductivity expressed in cm.s^{-1}. D_{10} is the diameter of the 10 percentile grain size of the material.

2.8 Determination of permeability (k)

The permeability (k) was defined as the flow per unit cross-sectional area of the sand matrix when subjected to a unit hydraulic head per unit length of flow (i.e. per unit hydraulic gradient). Using data on the value of hydraulic conductivity (*K*), the permeability (*k*) was calculated as:

$$\kappa = K \frac{\mu}{\rho g} \quad (6)$$

Where k is the permeability (m^2), K is the hydraulic conductivity (ms^{-1}), μ is the dynamic viscosity of water (1×10^{-3} $kgm \cdot s^{-1}$, ρ = the density of water ($kg.m^{-3}$), and g is the acceleration due to gravity ($m.s^{-2}$)

2.9 Determination of transmissivity (T)

The transmissivity (T) was used to estimate how much water can be transmitted horizontally in a sand matrix within the river channel. Transmissivity was estimated by multiplying hydraulic conductivity (K) by the saturated thickness of the sand matrix in the river channel (d):

$$T = K\, d \quad (7)$$

In the equation 7, T is the transmissivity (m^2s^{-1}), K is the hydraulic conductivity ($m.s^{-1}$) and b is the thickness of the saturated layer of the sand matrix aquifer (m).

3. Results

3.1 Flow of subterranean water through sandy channel

The results of computation of flow related parameters according to Darcy's equations described earlier are shown in Table 1. The permeability values within the sand matrix column in the river channels were low generally ranging from 1.3 to 3.8 x 10^{-8} ms^{-1}. The highest permeability rates were measured in Tiva and Mui river sandy channels. The hydraulic conductivity rates ranged from 11,644 to 32,000 $cm.day^{-1}$ that translates to a range of from 116 to 320 $m.day^{-1}$. Transmissivity values were low as they ranged from 0.02 to 1.0$m^2.s^{-1}$. The flow through the porous sand media within the sandy river channels computed according to Darcy's law ranged from 0.004 to 0.1 $m^3.s^{-1}$. These results show that water flows through the sand matrix in sandy river channels at a rather slow rate. This low rate of flow has implications on the entrapment of subterranean water in the sand matrix and subsequently on the salinity levels in the river channels during dry seasons.

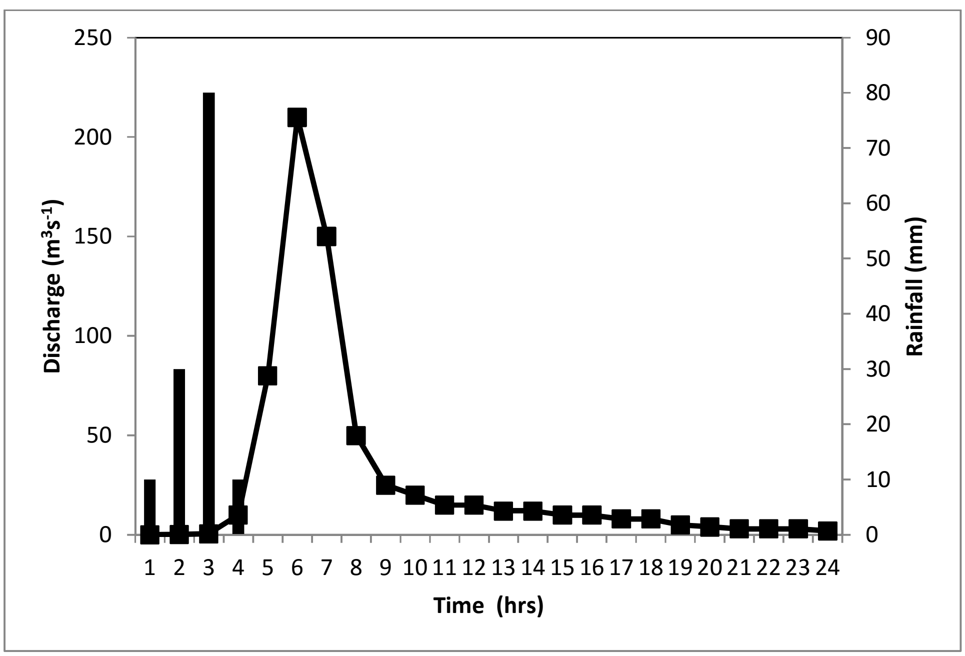

Figure 2: Typical streamflow hydrograph of sandy seasonal rivers of Kitui. The graph shows the pattern of seasonal flow at Kalundu river in the period between 28th and 29th March 2013. The rapid rise and fall of

streamflow following rainfall storm is evident. The sand matrix is recharged during the long recession that follows cessation of streamflow.

Table 1: The computation of the water flow related parameters in dry sandy channels.

	Tiva River sandy Channel	**Mui River sandy Channel**	**Ndokole River sandy channel**	**Mwitasyano river sandy channel**	**Kinunu River sandy channel**	**Kathokoe river sandy channel**
GPS location	37 M 375284 UTM 9842367	37M 0417459 UTM 9840102	37 M 0363961 UTM 9824857	37 M 0368957 UTM 9839062	37 M 0370204 UTM 9835855	37 M 0363203 UTM 9827199
Elevation (m)	1000	585	951	1011	1020	976
Grain size (D10) mm	0.5	0.5	0.5	0.4	0.3	0.4
Slope of hydraulic gradient (s) ($m.m^{-1}$)	0.01	0.02	0.02	0.05	0.02	0.02
Hydraulic conductivity (K) $cm.day^{-1}$	32400	32400	32400	20736	11664	20736
Permeability (k) $m.s^{-1}$	$3.8x\ 10^{-8}$	$3.8x\ 10^{-8}$	$3.8x\ 10^{-8}$	$2.4x\ 10^{-8}$	$1.4x\ 10^{-8}$	$2.4x\ 10^{-8}$
Transmissivity (T) $m^2.s^{-1}$	1.0125	0.27225	0.21375	0.0864	0.023625	0.0312
Porosity (%)	40	38	38	43	41	38
Darcy's Discharge through sand media (Q) $m^3.s^{-1}$	0.010125	0.005445	0.004275	0.00432	0.0004725	0.000624
Low streamflow Discharge (Q_f) $m^3.s^{-1}$	11.25	3.025	1.19	4.5	2.19	1.63
Width (m)	90	24.2	19	36	17.5	26
Sand medium Thickness B (m)	3	3	3	1	1	0.5
Sand matrix cross-sectional area (A) m^2	270	72.6	57	36	17.5	13
Nature of channel sediment materials	Fine, medium, coarse sand mixture	Fine to coarse sand.	Medium to coarse sand.	Fine to coarse sand.	Fine, medium, coarse sand.	Fine to coarse sand and gravels (0.1mm-2mm) and stones

The table shows the hydrologic parameters that were measured in the dry river channel sandbeds. The GPS location shows the exact location of the sampling site within the mentioned seasonal river system

3.2 Salinity variations within sand bed in sandy river channels in dry periods

The results of measurements undertaken during dry season showed that there are significant variations of salinity, TDS concentrations and conductivity within the sand matrix of seasonal rivers (Table 2). There were significant spatial differences indicating that streams have unique characteristics that contribute to the variability of water quality within the sand matrix. For seasonal rivers found in Kitui east within the Thua sub-basin, different streams yielded different levels of salinity, TDS and conductivity. Salinity ranged from 0.3 to 1.1%. The highest salinity was measured at Ngaluu river channel and the lowest salinities were measured at Kombuni, Mwinga, and Mwitika river channels. The TDS concentrations ranged from 77.8 mgl^{-1} to 272 $mgl^{-1.}$ The highest TDS concentration was measured at Ngaluu river channel and the lowest was measured at Kombuni river channel. The water conductivity ranged from 155.9 to 539 $\mu S.cm^{-1}$ with the highest conductivity being measured within Ngaluu sandy river channel and the lowest at Kombuni sandy river channel. The water turbidity ranged from 12.28 FTU to 1000FTU with the highest turbidity being measured at the Ngaluu and Mwinga sandy river channels. The high turbidity was attributed to the influence of surface runoff during rainy season that leads to deposition of clay mud in the river channels in certain sections. These results show that salinity, TDS concentration and conductivity are within the allowable limit for drinking water and irrigation (WHO, 1998). The low values were attributed to the influence of surface runoff while the highest values were attributed to geological influences and evapotranspiration.

Table 2: Water quality of sandy river channels in Kitui East within Thua River Basin

	Mui river	**Mwitika River**	**Ngaluu River**	**Maatheni River**	**Mwingi River**	**Mwinga River**	**Kombuni River**
TDS (mgl^{-1})	182	107.9	272	137.1	208	103.8	77.8
Conductivity ($\mu S.cm^{-1}$)	268.7	214.7	539	275.9	417	207.6	155.9
Salinity (%)	0.7	0.4	1.1	0.5	0.8	0.4	0.3
Temperature (*C)	27.8	26.6	28.6	32.7	33.5	30.5	26.1
Turbidity (FTU)	12.28	770	747	532	262	1000	16.15

The table shows the levels of salinity, conductivity, TDS concentrations, turbidity and temperature beneath the sand bed in various seasonal river channels. The water samples were obtained in scoop holes or by digging holes within the river bed.

Table 3 shows data for water quality in dry sandy river channels found within Tiva river basin. There were major variations in physico-chemical parameters found in this region. For instance salinity varied from 0.9 to 12.8% with the highest and lowest salinity being measured at Tiva and Ndokole sandy river channels, respectively. TDS concentration varied from 227 to 3,320 mgl^{-1} with the highest and lowest TDS concentrations at Tiva and Ndokole sandy river channels, respectively.

Conductivity ranged from 455 to 6,640 $\mu S.cm^{-1}$with the highest being measured at Ndokole and lowest at Tiva sandy channel. Turbidity was generally low ranging between 2.5 and 13.7 FTU. The relatively high values of salinity, TDS concentrations and conductivity measured in the Tiva sub-basin were attributed to the influence of underlying rocks, evapotranspiration and landuse. The results show that the levels of salinity, TDS concentrations and salinity were much higher in the Tiva river basin as compared to Thua sub-basin. This could be attributed to the fact that most of the measurements in the Tiva sub-basin were undertaken during dry period (July – August 2015) when there was completely no streamflow in the sandy river channels. In the Thua sub-basin, measurements were undertaken in November-December 2015 period which is essentially within the long rainy season. Thus, most of the streams had experienced some dilution to a large degree due to streamflow experienced in the wet season.

Table 3: Water quality of sandy river channels in Kitui Rural within Tiva River Basin

	Ndokole sandy river channel	Kathokoe sandy river channel	Mwitasyano sandy river channel	Kinunu sand river channel	Mamole sandy river channel	Tiva sandy river channel
TDS (mgl^{-1})	3,320	2,850	1,159	861	258	227
Conductivity ($\mu S.cm^{-1}$)	6,640	5,680	2,324	1,725	517	455
Salinity (%)	12.8	10.6	4.3	3.3	1.0	0.9
Temperature (*C)	27.1	26.5	26.4	24.1	25.8	32.2
Turbidity (FTU)	5	2.5	3	6	12	13.7

The Table shows the levels of salinity, conductivity, TDS concentrations, turbidity and temperature beneath the sand bed in various seasonal river channel. The water samples were obtained in scoop holes or by digging holes within the river bed.

3.3 Salinity variations in shallow wells and scoop holes within sandy channels

There are significant variations in the levels of salinity, TDS concentrations and conductivity in shallow wells that are located adjacent seasonal river channels in both Tiva and Thua sub-basins (Table 4). The distance from the shallow wells to the river channel varied from 1m to 10m, with the majority of the wells being located <5m from river channel. For instance, at Ngomano Malatani (S:01^{O}24.375, E 038^{O}12.346) shallow well was located about 5m from the seasonal river channel. The well was about 5m deep cutting thorough the highly foliated gneiss. The water in the well was characterized by high conductivity of 1,829 $\mu S.cm^{-1}$. The TDS concentration and salinity were 913 mgl^{-1} and 3.5%, respectively. These were much higher than the concentrations in the nearby Mui river (Table 4). However, turbidity of the shallow well water was much lower being 3.85 FTU indicative of clear water as compared to the river water that was relatively highly turbidity (30.95 FTU). More than 50% of the TDS observations in sandy river channels were below the value of 1000 mgl^{-1}, which is considered as the limit of palatability (WHO, 2008).

Table 4: The water quality characteristics of shallow wells in Kitui within Thua and Tiva sub-basins

	Parameter	Malatani Shallow Well (Thua basin)	Kinunu Shallow Well (Tiva basin)	Kandokole Shallow Well
1.	TDS ($mg.l^{-1}$)	913	1,022	206
2.	Conductivity ($\mu S.cm^{-1}$)	1,829	2,042	412
3.	Salinity (%)	3.5	3.9	7.9
4.	Temperature (*C)	28.8	21.3	26.9
5.	Turbidity (FTU)	3.85	4.0	206

The above table shows the levels of salinity, conductivity, TDS concentrations, turbidity and temperature beneath the shallow wells dug on the banks of various seasonal river channel. The water samples were obtained either by using a hand pump or drawing to the surface using a rope a bucket.

Table 5 shows water quality of shallow wells dug adjacent the river channel at Mwitika (GPS location: 37M 0423188; 9839476). The water in the dry river channel was generally characterized by TDS concentration ranging from 100 to 300 mgl^{-1}. Conductivity and salinity ranged from 200 to 550 $\mu S.cm^{-1}$ and from 0.4 to 1.5%, respectively. The water turbidity was however generally highly variable ranging from 12 to 800FTU. The highly turbidity water was obtained in the river channel that had a relatively high proportion of silt and clay. On the other hand, water obtained from river channel that was dominated with sand was generally characterized by low turbidity.

Table 5: The water quality characteristics in shallow wells and scoop holes in Kitui Rural

Parameter	**Ndokole sandy bed**	**Ndokole shallow well**
TDS (mgl^{-1})	285	206
Conductivity ($\mu S.cm^{-1}$)	568	412
Salinity (%)	10.6	7.9
Temperature (^oC)	26.5	26.9

The table shows the levels of salinity, conductivity, dissolved solids concentrations, turbidity and temperature beneath the sand bed in various seasonal river systems.

The shallow wells in Kitui Rural were characterized by relatively high levels of salinity, TDS concentration and conductivity. For instance, at Kinunu, the salinity, TDS concentrations and conductivity were 3.9%, 1.022 $mg.l^{-1}$ and 2,042 $\mu S.cm^{-1}$, respectively. It can be noted that there is no significant difference in the levels of salinity, TDS concentrations and conductivity in shallow wells located in the Thua sub-basin and those located in Tiva sub-basin. Both tended to exhibit high levels of salinity parameters. This was attributed to the fact that all sub-basins are covered by similar metamorphic rocks associated with the basement complex of Kitui region, although spatial differences are expected in terms of the specific types and nature of underlying metamorphic rocks (also see Nyamai et al., 2003).

The results shows that shallow wells dug adjacent to the river channels have relatively high TDS concentration, conductivity and salinity as compared to the water in hand dug scoop holes located within the seasonal river channel. This is evident in the case of Ndokole river as shown in Table 6. In some of the rivers, the low concentrations of TDS, conductivity and salinity were attributed to the dilution effect of streamflow during the preceding rainy season. The water in a shallow well located about 10m from the Ndokole river had relatively low TDS, salinity and conductivity as compared to that in the river water scoop hole. The river channel consisted of fine to coarse sand and gravels (0.1mm-2mm), gravels and stones that allows rapid infiltration of rainwater.

There is a significant relationship between water salinity parameters in the sandy river channels and the water salinity within the shallow well. The increase in salinity in either leads to a corresponding increase in the other. The salinity, TDS concentration and conductivity were however relatively higher in the shallow well as compared to the water within the sand matrix in the river channel. The relationship was best represented by a linear regression function with coefficient of determination R^2 of 0.99 and correlation coefficient r of 0.99. This implies that the variability of water salinity in the shallow well is related to the variability of the same parameters in the river sandy bed.

There was no significant difference between variations of water salinity in the upstream and downstream of the seasonal river channels. This is best illustrated by data obtained at Kondokole river. This indicates that water within the sand matrix flows slowly downstream and that there is little if any complete trapping of subterranean water. There is therefore interconnectivity between sections of the sandy river bed. There is an increase in the concentrations as the water travels downstream. For instance at Kandokole river, TDS concentration increased from 285 to 332 mgl^{-1} while conductivity increased from 568 to 664 $\mu S.cm^{-1}$. Salinity increased from 10.6 to 12.8% (Table 6). This indicates that water flowing within the sand matrix picks additional salts as it travels downstream through the sand matrix. The rate of flow as computed using Darcy's equation was found to range between 0.0006 to $0.1m^3l^{-1}$ with the hydraulic conductivities ranging from 116 to 300 $m.day^{-1}$. This indicates that the water movement within the sand matrix is slow and this allows water to dissolve rock mineral salts, explaining the progressive increase in salinity as water flows downstream.

Table 6: The latitudinal changes in water quality characteristics in Kandokole river, Kitui Rural

Parameter	Ndokole River (Downstream)	Ndokole River (Upstream)
TDS (mgl^{-1})	332	285
Conductivity ($\mu S.cm^{-1}$)	664	568
Salinity (%)	12.8	10.6
Temperature (^oC)	27.1	26.5
Turbidity (FTU)	-	-

The table shows the levels of salinity, conductivity, dissolved solids concentrations, turbidity and temperature beneath the sand bed in a stretch of a seasonal river system. The water samples were obtained in scoop holes or by digging holes within the river bed.

3.4 Stream-shallow well water quality linkages

There is a relationship between salinity of water in the sand matrix within the river channel and the salinity of water in shallow wells and sand dams. This is best illustrated by the results of measurements undertaken at Kinunu stream (Table 7). These showed that salinity parameters were relatively lower in the sand matrix (scoop holes) within the river channel as compared to those in the shallow wells and sand dams. Within the sand matrix (scoop holes water), the salinity was 3.3% as compared to that in the shallow well and sand dam that were 3.9 and 6.5%, respectively. On the other hand the conductivity within the sand matrix was 1,725 $\mu S.cm^{-1}$ as compared to that in the shallow well and sand dam that were 2,042 and 3,390 $\mu S.cm^{-1}$, respectively. The TDS concentration within the sand matrix in the river channel was 861 mgl^{-1} as compared to that in the shallow well and sand dam that were 1,022 and 1,680 mgl^{-1}, respectively.

Table 7: The water quality characteristics in shallow wells and scoop holes in Kanunu stream in Kitui Rural

Parameter	Kinunu River Scoop hole	Kinunu Shallow Well
TDS (mg/l)	861	1,022
Conductivity ($\mu S.cm^{-1}$)	1,725	2,042
Salinity (%)	3.3	3.9
Temperature (^oC)	24.1	21.3
Turbidity (FTU)		

The table shows the levels of physico-chemical parameters beneath sand bed and the level of the same parameters in a nearby shallow well located < 10m from river channel.

These results shows that during dry season salinity levels within the sand matrix in the river channel is slightly lower than that in the shallow wells and sand dams. There is limited flow of water from the sand matrix in the river channel to the shallow wells located on the banks of the river. Also, there is little flow of water from the sand dams to the river channel. It is also likely that flow of subterranean water from the upstream parts of the catchment leads to high concentrations of salinity parameters in shallow wells. However, it is not clear why water in the sand dam had the highest concentrations of TDS, salinity and conductivity. This could be attributed to the trapping of water emanating from the bank storage and groundwater flow coupled by high evapotranspiration rates. The water flowing in the sand matrix in the river channel could be responsible for relatively lower concentrations of TDS, salinity and conductivity measured there.

Table 8: The levels of physic-chemical parameters in sand dams of Kitui Rural within Tiva sub-basin (Yatta plateau region)

Parameter	Kangutu sand dam	Kwa Kasimu sand dam	Kinunu Sand Dam
TDS (mgl^{-1})	567	396	1,680
Conductivity ($\mu S.cm^{-1}$)	1,135	789	3,390
Salinity (%)	2.2	1.5	6.5
Temperature (^oC)	28	27.1	26.8
Turbidity (FTU)			

The table shows the levels of salinity, conductivity, dissolved solids concentrations, turbidity and temperature beneath three representative sand dams. The concentrations were generally relatively high in sand dams

Table 8 shows the results of measurement of physic-chemical parameters in three representative sand dams constructed in sandy river channels. The results shows that salinity in the sand dams were generally high ranging between 1.5% and 6.5%, while the TDS concentrations ranged between 396 and 1,680 mgl^{-1}. The conductivity varied from 789 to 3390 $\mu S.cm^{-1}$. The high levels of salinity, TDS concentrations and conductivity in sand dams tended to be much higher than those measured in the sand matrix within the river channels, and these are largely above the maximum allowable limit for drinking water and crop irrigation (see WHO, 1993, 2006 and 2008).

4. Discussion

4.1 The nature of channel bed and bank aquifers

The sand matrix in seasonal river channels in dry season function as alluvial aquifers consisting of silt, sand and gravels. The aquifers are recharged through three ways; (i) by flow of surface runoff in the sandy river channel during rainy season, (ii) by flow of bank storage water and (iii) by flow of groundwater from bordering aquifers. The sand matrix aquifers are recharged throughout the sandy channel by downward percolation of water when the river flows during rainy season.

4.2 Vertical distribution of subterranean water in sandy channels

The occurrence of subsurface water within the sand matrix in river channels and river banks is similar to those observed in typical unconfined aquifers. The sand matrix aquifer can be divided into two zones: aeration zone and saturation zone. The zone of aeration is normally shallow, its depth varying seasonal. This zone contains vadose water. The water table or phreatic surface forms the upper surface of the zone of aeration and this is basically the surface of atmospheric pressure and is the level at which water stands in shallow wells and scoop holes dug in the sandy channels. The zone of aeration is divided into the sand water zone, intermediate vadose zone and the capillary zone. Water in the Sand-Water Zone exists at less than saturation except temporarily when excessive water reaches the sand matrix surface from streamflow during rainy period. The zone extends from the surface of sandy river channels down to 0.1 to 3 m. Its thickness varies with the nature of channel sand material. Amount of water present depends primarily on the exposure of the sand matrix to streamflow during rainy season. Capillary water (water held by surface tension forces) and hygroscopic water (thin film of moisture) are important in this zone. Gravitational water drains through the sand matrix under the influence of gravity.

The Intermediate Vadose Zone extends from the lower edge of the sand-water zone to the upper limit of the capillary zone. The thickness vary from zero, where the bounding zones merge with a high water table approaching surface of the river channel, to more than 3 m under relatively deep water table conditions in the thick sand matrix. The zone serves primarily as a region connecting the zone near the surface of the channel with that near the water table through which water moving vertically downward passes. Nonmoving water is held in place by hygroscopic and capillary forces. Temporary excess water moves downward as gravitational water. The capillary zone extends from the water table up to the limit of capillary rise of water. The thickness of the capillary fringe zone is inversely proportional to the pore size of a sand (also see Todd, 1980; Wilson, 1990; Raghunath, 1990, 2010 and Subramanya, 2008).

The zone of saturation is where all interstices are filled with water under hydrostatic pressure. In a sand matrix aquifer a single zone of saturation underlies a single zone of aeration which extends upwards to the channel surface. In the zone of saturation, water fills all the pore spaces or interstices between sand particles. Hence, the effective porosity provides a direct measure of the water contained per unit volume. Molecular and surface tension forces hold the remainder of the water in place. The saturated zone usually extends from the upper surface of saturation down to underlying impermeable rock in a depth ranging 1 to 5m depending on the thickness of the sand column matrix in the river channel.

The specific yield Sy was computed as the ratio of the volume of water that after saturation, can be drained by gravity to its own volume. This was computed as $S_y = w_y/V$ where Sy = specific yield, w_y = volume of water drained, V = total volume. The values of specific yield depend on grain size, shape and distribution of pores, compaction of the stratum, and time of drainage. Fine–grained materials yield little water, whereas coarse-grained materials permit a substantial release of water. Within the dry river channel, most of the materials were sand with specific yields varying from 23 to 28%. Within the river banks, the materials consisted of loamy soil with high proportion of sand, and hence the specific yield was similar to that in the river channel.

4.3 Variability of salinity within sand bed in seasonal river channels

The levels of salinity, TDS concentration and conductivity within the sand bed of seasonal rivers of semi arid Kitui county are influenced by processes associated with streamflow as well as flux of subterranean water from bank storage and adjacent groundwater aquifers. This means the nature of geological material in terms of chemical composition, grain sizes are ritical in determining the levels of salinity of water held within the sand matrix of seasonal river channels.

There is a relationship between the variation of salinity, TDS concentrations and conductivity within the sand bed matrix and the shallow wells located adjacent the river channel. The relationships were found to be strong with high R^2 values > 0.90 indicating that variations of water salinity parameters in the river sand bed are related to the variations of the salinity parameters within the banks of the river channel. This illustrates the inter-connectivity between the water in sandy riverbeds and water within the river banks (bank storage) and adjacent groundwater aquifer. Within the sand bed matrix, the levels of physico-chemical parameters were noted to be mostly above the minimum allowable limit for drinking water. For instance, conductivity in most cases ranged from 156 to 539 $\mu S.cm^{-1}$ which is above the minimum permissible limit of 150 $mS.cm^{-1}$ (WHO, 1993). The levels of conductivity were even higher than those measured in seasonal rivers in Nigeria that ranged from 83 to 204 $\mu S.cm^{-1}$ (Waziri and Ogugbuaja, 2012).

We were unable to establish the extent of seasonal variations of salinity within sand bed matrices, due limited period of measurements. However, it can be noted that most of the measurements in Kitui East were undertaken in dry season and these can be taken to be representative of the levels of salinity in a typical dry period. Likewise, measurements undertaken in Kitui East represent the salinity levels immediately after rainy season. Thus, it can be argued that within the sandbed matrices of seasonal rivers of Kitui, the dry season salinities ranges from 0.9 to 12.8% while the wet season salinities ranges from 0.4 to 1.1%. Also, it can be stated that the wet season TDS concentrations ranges from 78 mgl^{-1} to 272 mgl^{-1} while the dry season TDS concentration ranges from 227 to 3,320 mgl^{-1}. The wet season water conductivity ranged from 156 to 539 $\mu S.cm^{-1}$ while the dry season conductivity were higher ranging from 455 to 6,640 $\mu S.cm^{-1}$. The relatively low salinity, TDS and conductivity levels were experienced in wet season. This could be attributed to the effects of rainfall and streamflow that tends to dilute salinity levels within the sandy river channel. The high levels of salinity and conductivity can be attributed to increased ionic compounds in water (see also Waziri and Ogugbuaja, 2012). The influence of streamflow can be discerned from turbidity data. Low conductivity occurred during periods of low turbidity indicating an inverse relationship between the two parameters (see also Koning and Ross, 1999). The highest conductivity values recorded during the dry season can be attributed to high evapotranspiration rate but not the pollution from the use of manure and fertilizers for irrigation activities as has been reported elsewhere (see Waziri and Ogugbuaja, 2010; 2012). In the case of most of the Kitui seasonal rivers, pollution by fertilizers is of secondary importance in the variability of TDS concentrations, conductivity and salinity within the sandbed matrices of seasonal rivers. The exception is Mwitasyano river channel where there is significant practice of irrigation upstream of the sub-basin. The complex particulate matter consisting of both inorganic and organic chemicals, as well as microbial entities could have important implication on the measured TDS levels and hence salinity and conductivity (cf. Kaufman et al, 2005; Centeno, et al., 2006).

The relatively high salinity, TDS concentrations and conductivity measured during dry season can be explained by increased mineralization of water due to entrapment, groundwater recharge and solubisation of minerals from soils. During this period, it was noted that water obtained from the sandy river channels, shallow wells and sand dams tended to be brackish with salty taste. This was attributed to mineralization of various salts as has also been reported elsewhere (Jain 1998, WHO, 1993). A TDS concentration >2000 $mg.l^{-1}$ has been reported to produce a laxative effect as a result of magnesium sulphate along with some sodium sulphate (Kumaraswamy, 1991, Dembere 1998). High sodium concentrations can cause cardiac problems and toxemia in pregnant women. The maximum permissible limit of TDS in drinking water is 1000 mgl^{-1} (WHO, 1993, 2006 and 2008). The high TDS concentrations measured in sandy channels in dry seasons would limit irrigation activities since water with TDS concentration above the limit of 500 mgl^{-1} has detrimental effect on crops. This explains the continued deterioration of crops irrigated using water drawn from the sandy river channels, particularly Mwitasyano river. Only salinity tolerant crops would do well in such circumstances.

The high levels of salinity and the related parameters of TDS and conductivity were explained by the nature of flow within sand matrix. The hydraulic conductivity (K) were low ranging between 117 and 320 $cm.day^{-1}$ with the implication that water flowing slowly within the sand matrix would cover a distance of between 0.1 and 0.3 km on daily basin. The water flux rates computed according to Darcy's equation were also generally low ranging from 0.0005 to 0.01 m^3s^{-1}. This could be attributed to the low channel gradient (0.01 to 0.05) and nature of sand particles including the compaction of sand matrix. There was relatively high proportion of silt and clay > 5% in some instances and this was observed to limit the fluxes of water through the sand matrix. This would also limit the exchange of water between the river channel and the bank storage.

The dry season salinity levels in Kitui sandy river channels are comparable to those reported elsewhere. For instance, in the Colorado River Basin, before initiation of salinity control programme, the salinity of spring runoff ranged from < 200 mgl^{-1} to >1,000 mgl^{-1} during the low flow months (U.S. Department of the Interior, 2011). The use of water with high salinity levels is associated with problems such as reduced agricultural crop yields, corrosion, and plugging of pipes and water fixtures in housing and industry (U.S. Department of the Interior, 2011).

4.4 Exchange of water between the bank and river channel

During wet season seasonal rivers flows with water derived from land drainage. The increase in water level leads to flow of water from the river channel to the banks resulting in what is termed as bank storage. The replenishment of bank storage takes place during periods of high flows (Figure 2). The water flowing into the banks is usually derived from surface runoff and is therefore characterized by relatively low concentrations of TDS, conductivity and salinity. However, the water subsequently acquires high salinity, TDS and Conductivity due to dissolution of minerals in the bank zone and also within the river channel.

During dry season, the water level reduction in the river channel results into subsequent flow of water from bank storage due to favourable hydraulic gradient. The water flowing back into the river channel has greater concentration of minerals hence leads to high salinity, conductivity and TDS concentration. This water subsequently tends to raise the level of dissolved solids in the river channel.

4.5 Exchange of water between sand dam and river channel

The level of physico-chemical parameters in sand dams were much higher than those measured within the river channel bed sand matrix. The salinity level in sand dams during dry season ranged between 1.5% and 6.5%, while the TDS concentrations varied from 396 to 1,680 mgl^{-1} and conductivity varied from 789 to 3390 $\mu S.cm^{-1}$. These results show that water in sand dams does not meet the permissible levels for drinking water (WHO, 1993, 2006, 2008). The trapping of water within the sand dams seems to lead to an increase in the concentration of dissolved solids and hence salinity and conductivity. This could be due to evapotranspiration and a result of the influx of water from bank storage and bordering groundwater aquifers. The influence of the later seems to be important in view of the saline nature of basement complex rocks. The saline Kankur limestone was observed along most of the banks of river channels in Yatta Kitui rural region (draining the volcanic Yatta plateau) through which sand dams have been constructed. The results therefore emphasize the importance of geology among other considerations such as site location with respect to the drainage from nearby streams, and the interchange between the river channel and the bank storage.

It is postulated that salinity level in sand dams exhibits a seasonal cycle reminiscent of wet and dry periods. During early stages of rainy season, the TDS concentration and salinity will be generally low and similar to that in the river channel. However, once streamflow ceases, water trapped in the sand matrix progressively becomes more loaded with mineral salts. The high residence time of water in the sand dam allows more dissolution of rock mineral salts and therefore salinity tends to progressively increase with time. Later in the drought period, there is tendency for water in the sand dam to acquire more dissolved solids partly thorough dissolution of mineral salts and also through flow of effluent from the bank storage and bordering groundwater aquifers. This considerably raises TDS concentrations and salinity levels in sand dams. Thus, while sand dams allows for the flow of water into river banks and bordering aquifers, such water has less concentration of dissolved solids and salinity since it is derived from surface runoff. However, during periods of extended drought, water flowing back into the sand dam has high dissolved solids content leading to relatively high salinity and conductivity. It is thus expected that better water quality (with low salinity) will be experience in sand dams and river channels immediately after rainy season, and relatively poor water quality will be experienced in extended drought periods. The poor dry season water quality was noted to be further complicated by pollution caused by livestock within the river channels. This is a common occurrence particularly during watering of livestock in scoop holes dug within the dry river sand bed. The defaecation and urination by the animals within the river channel subsequently leads to build up of dissolved solids, nutrients and possibly faecal coliform bacteria. Water obtained from shallow scoop holes dug within the river channels and sand dams tended to be characterized by pungent smell and was generally unpalatable.

4.6 Implications on water resources development in ASALS

This study has provided data and information on the levels of salinity, TDS and conductivity within sand beds of selected seasonal rivers, including the levels in shallow wells and sand dams constructed within the sandy river channels in Kitui county. The results showed that during dry seasons, the levels of salinity, TDS concentrations and conductivity are generally high and is some cases the levels are above the permissible levels for crop irrigation and drinking water. The conditions in all seasonal rivers are much better in wet seasons, although the levels of turbidity are much higher. However, it is important to note that it is during the extended drought periods when water in sand beds of river channels is critical to the local communities. During this period, it is water that is obtained from sand beds, sand dams and shallow wells that sustains the local communities and their livestock. Thus selection of optimal sites for construction of sand dams and shallow wells is of great importance as this determines if good quality water will be prevalent in drought periods, when the use of water from the river channel is the most critical. Thus, good understanding of the dynamics of water exchange between the river channel and the banks and bordering groundwater aquifer, including the nature of rocks, is important.

It must be emphasized that construction of sand dams in sandy river channels in arid and semi arid lands is seen has one of the approaches of sustainably providing water to communities that would otherwise face major difficulties in accessing water, particularly in remote areas of Africa (see Lasage et al., 2008) Thus, development of shallow wells and sand dams is been integrated into the conventional integrated water resources management approaches involving community participation. Investigations focused on water quality of seasonal rivers to establish their potentiality in terms of sand dam development should be one of the major water resources development programme in Kitui county including all countries in the Sahelian region of Africa. This is important since it is unlikely that the conventional piped water supply will in the near future reach the remotest semi arid and arid regions of Ssahelian Africa where nomadic pastoralist are found.

5. *Conclusions*

This study aimed at establishing the salinity levels (including the associated physico-chemical parameters) in sandbeds of seasonal rivers and the interaction between water in seasonal river channel and that in the bank storage and or groundwater aquifers. This study has established that water salinity in Kitui dryland river systems is subject of complex interrelationships. There are significant spatial temporary variations that are attributed to the nature of underlying geological system as well as the nature of drainage from the congruent river basin. The water quality in dry sandbeds of seasonal river channel improves considerably immediately after rainy season due to dilution effect of increased river runoff and also due to flushing of dissolved solids from the river. However, the levels of dissolved solids increase considerably once streamflow ceases since the resulting hydraulic gradient favours the influx of water with high TDS concentrations (and hence high salinity) from the bordering aquifer and bank storage. The dry season level of dissolved solids and salinity in sand dams and shallow wells tends to be even much greater than that in the river channel sand matrix due to increased residence time that leads to entrapment and more dissolution of rock minerals. Evapotranspiration leads to concentration of dissolved mineral salts by removing freshwater from the river channel. The study emphasizes the need for water resources management in arid and semi arid lands of Kitui County and Sahelian region of Africa to take cognizance of the role that can be played by hydrological investigations in ensuring that sand dams and shallow wells are constructed in locations with optimal conditions in order to provide good quality water to the increasing human and livestock populations. The study also provides an impetus for further research on the hydrology of seasonal rivers of Africa that are still little studied as compared to other regions of the world.

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