Vol. 11(6), pp. 91-111, June 2019
DOI: 10.5897/IJWREE2019.0855
Article Number: 03934C661299
ISSN: 2141-6613

http://www.academicjournals.org/IJWREE

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Evaluation of sand-dam water quality and its suitability for domestic use in arid and semi-arid environments: A case study of Kitui-West Sub-County, Kenya

Ndekezi Moïse[1*], James W. Kaluli[2] and Patrick G. Home[2]

[1]Department of Civil Engineering, Pan African University's Institute for Basic Sciences, Technology and Innovation (PAUISTI), hosted at JKUAT, Juja main Campus, Nairobi, Kenya.
[2]Department of Soil, Water and Environmental Engineering (SWEED), Jomo Kenyatta University of Agriculture and Technology (JKUAT), P. O. Box: 62000 – 00200, Nairobi, Kenya.

Received 11 April, 2019; Accepted 6 June, 2019

Sand dams are one of the most successful rainwater harvesting methods, adopted in most of arid and semi-arid lands (ASALs) of Kenya to secure domestic water supply and micro-irrigation. Their ability to maintain acceptable water quality, under extreme climatic conditions of recurrent drought and floods, is therefore of paramount public health concern as various pollutants find easily their way into them. This study assessed the suitability of sand-dam water abstracted via scoop holes (SCHs) and shallow wells (SHWs) in Kitui-West, South-Eastern Kenya. Water quality compliance checks were performed using the specifications of Kenya Bureau of Standards (KEBS) for natural potable water and World Health Organization's (WHO) drinking-water quality guidelines wherever applicable. A total of 48 water samples comprising SCHs (N=33) and SHWs (N=15) were collected during the dry period (February 8 and 28, 2018) and the wet season (March 23, April 20 and May 19, 2018) in three sand dams using well-cleaned plastic bottles, transported in cooler boxes to the laboratory for storage and analysis. They were analyzed for pH, temperature, total dissolved solids (TDS), total hardness (TH), biochemical oxygen demand (BOD), trace metals (Cu, Fe, Mn, Zn, and Cr), *Escherichia coli* (E. coli) and total coliforms (TCs). Results showed that majority of assessed physicochemical parameters and trace metals complied with KEBS limits at the rates of more than 90% except turbidity, Cu and Fe that complied with low overall scores; 44, 56 and 35% respectively. These three parameters behaved differently in both abstraction methods as their mean values (compliance rates) exceeded KEBS limits in SCHs, that is, 297 NTU (18%), 1.7 mg/L (48%) and 2.22 mg/L (9%) and were below limits in SHWs, that is, 3.1 NTU (100%), 0.89 mg/L (73%) and 0.21 mg/L (87%) respectively. E.coli compliance levels were 48% in SCHs and 87% in SHWs with maximum counts as 300 CFU/100 ml, while TCs were detected at high rates of 94 and 47% respectively with maximum counts as 2,500 CFU/100 ml. Therefore, these results demonstrated that water extracted via SCHs is more unsafe than water from SHWs but both provide water that is microbiologically unfit for direct human consumption. Shallow-well water was found to be physicochemically fit and only requires disinfection while scooped water needs first to be purified with homemade water filters and then chlorinated with available disinfection by-products (DBPs) to increase its potability. Continuous monitoring of sand-dam water quality is recommended so that the public awareness should be raised on time when new contaminants emerge or exiting ones become intense so as to avoid possible health risks that can result from unnoticed long-term exposure.

Key words: Sand storage dams, traditional scoop holes, offset shallow wells, drinking water quality compliance; natural potable water; physicochemical properties; organic matter, microbial pollutants, trace metals, climatic seasons.

INTRODUCTION

Food insecurity, chronic water shortages and water quality degradation are the major challenges in the daily life of humankind and wildlife in World's dryland regions occupying 41% of Earth's land. These lands are home to more than a third of the human population (Davies et al., 2016). In Kenya, arid and semi-arid lands (ASALs) occupy approximately 89% of the country's landmass and are home to about 36% of the population, over 70% of the national livestock and about 90% of the wildlife (GoK, 2012; Muthini et al., 2014; Njoka et al., 2016; GoK, 2017). In most of these drylands, the residents are periodically hit by severe water shortages at multiple seasonal recurrences (Huho and Mugalavai, 2010). In their struggle to secure water for domestic use, livestock and food production, they have attempted many rainwater harvesting methods such as sand dams/sub-surface dams, gravity dams, earth dams, water pans/ponds and various roof rainwater harvesting systems (Kimani et al., 2015). Among these methods, sand dams have become one of the most successful and reliable stormwater harvesting methods due to the simplicity in their construction, their ability to store water with minimum evaporation loss and protect it from direct surface contamination and from many water-borne diseases at a local scale and their ability to replenish adjacent shallow wells by raising water table, among others (Maddrell and Neal, 2012; Petersen and de Trincheria, 2015; Maddrell, 2016). They act as slow sand filters, purifying the water through seasonally accumulated sand layers in a natural and uncontrolled process and making it clean for drinking and domestic uses (Ryan and Elsner, 2016). In Makueni County as example, about 81% of the households relied on rivers/streams in which sand dam systems are dominant water harvesting structures (Kimani et al., 2015). They are local-scale technologies consisting of reinforced rubble cement walls built across seasonal sandy rivers to trap both water and sediments behind them during rainy season (Figure 1a), creating aquifer storage for later use in dry season. They are generally implemented in stages and sand-sized sediments are seasonally accumulated (Figure 1b), until sand dam becomes mature. The maturity of sand dams is the status of being full of sand and wall height in relation with river banks has been exhausted. At the maturity stage, sand dams can start supplying clean water to the community. The maturity process can take from 2 to 7 years or many years or decades depending on the geologic and hydrologic conditions, as well as other local conditions such as catchment factors (topography, shape, size, soil type, and land use), sizes and shapes of rivers and anthropogenic activities (Maddrell and Neal, 2013). Mature sand dams can provide on average approximately from 2 to 20 million liters of extractable water, estimated as 25 to 40% of the total volume of accumulated sand (Lasage et al., 2015). Their capacity in capturing and retaining seasonal runoffs depends on the river bed size and its hydrogeological properties, wall design and dimensions, water abstraction method and runoff pattern in the region (Quilis, 2007). Local people access the water stored in sand dams via various water abstraction methods such as scoop holes, riverbank shallow wells, riverbed infiltration galleries and rarely from dug wells. However, water stored in sand dams is also vulnerable to any kind of contaminants as they are made up of self-filled porous materials, uncovered, uncontrolled and unprotected systems. Various detrimental contaminants can easily find their way into sand dams all the time and severely during rainy season. During this season, they receive all kind of contaminants mixed up in surface runoff comprising domestic wastes, animal wastes, and food processing wastes, metallic manufacturing wastes, construction wastes, mining wastes and many others. Despite of these pollutants, water abstracted from sand dams is still used in almost all places without any further purification. This is a situation that may compromise people's health condition as water from sand dams constitute about 35% of main water sources for both human and livestock consumption in the study area (NDMA, 2018).

The quality of stormwater captured and stored sand dams is a major concern, firstly due to its potential great impact on the public health of ASAL inhabitants, as poor microbiological quality is likely to lead to infectious waterborne diseases while poor chemical quality may lead to short or long-term health effects and poor physical quality which may affect its acceptability aspects; and secondly due to the fact it is seasonally triggered by both droughts and floods, the two extreme climate conditions which constitute major challenges for water quantity and quality in the dryland regions. Therefore, ability of sand dams in fulfilling the three interrelated functions; storage, filtration of water through natural process and its protection under uncontrolled open space environments remains controversial among water resources development stakeholders, planners and researchers. In this regard, some studies attempted to understand the nature of this sand-dam water. Most of them led to the conclusion that water abstracted from sand dams via traditional scoop holes is physicochemically and bacteriologically unfit for drinking purposes as it can possibly lead to health risks while water abstracted via shallow wells is physicochemically fit and with minor

*Corresponding author. E-mail: mndekezi@yahoo.com.

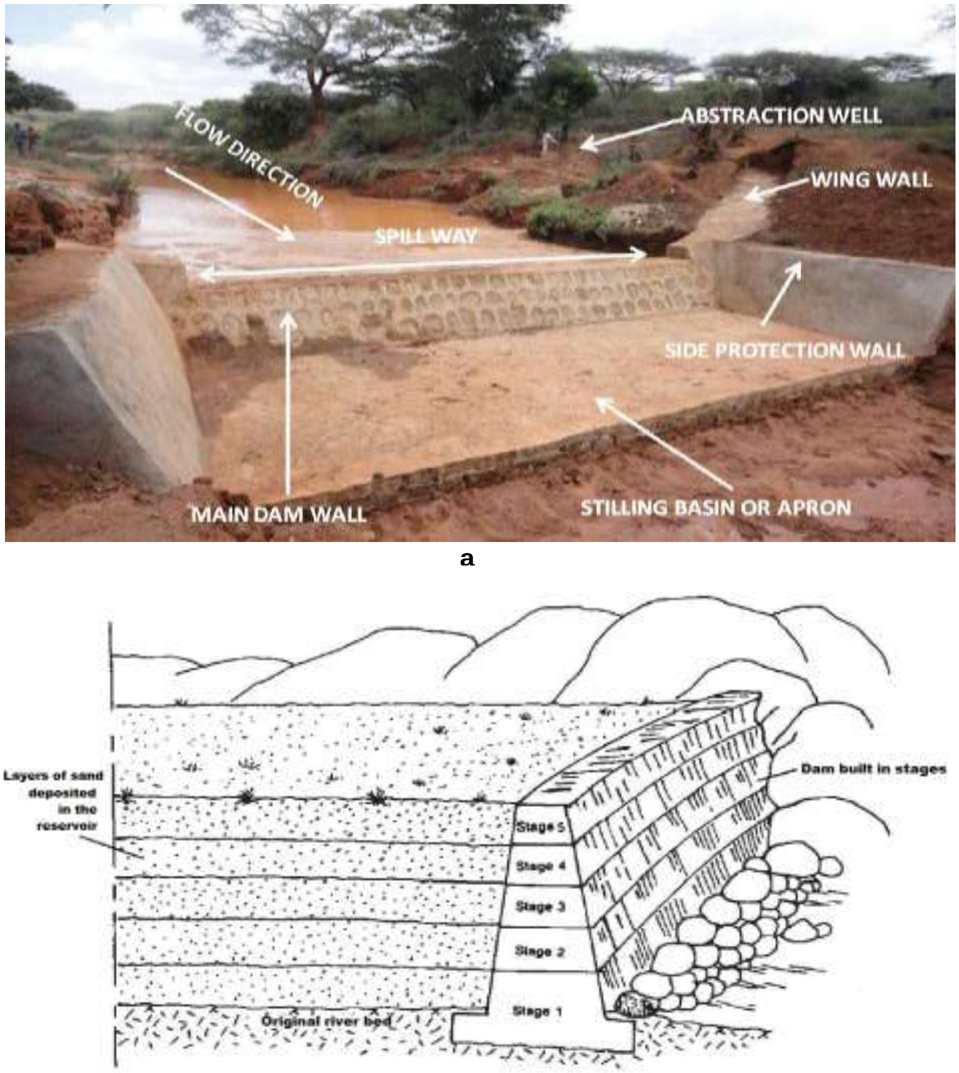

Figure 1. Sand dams: (a) General features (Maddrell and Neal, 2012) and (b) illustration of seasonal accumulation process of sand sediments (Nilsson, 1988).

microbiological risk (Abila et al., 2012; Avis, 2016; Quinn et al., 2018). Most of these studies have explored more bacteriological properties than chemical properties. To date, one study has tackled the assessment of most of the water quality parameters in sand dams (Ndunge et al., 2019) and concluded that water contained in these raw form. In addition, these few studies carried out so far have explored almost the same study area and by considering the same dry season (Avis, 2016; Quinn et al., 2018; Ndunge et al., 2019) except the study of Kitheka (2016) that explored salinity and turbidity levels in both dry and wet seasons. They have also mainly conducted studies during the dry season; however, there is a need to understand seasonal dynamics in both seasons. In addition, most of them compared results with Kenya standard specifications (KS05-459: PARTI: 1996, 1st revision) for drinking water and containerized water (WASREB, 2009) and these specifications were assigning the same guideline limits for both natural potable water and treated water. Current specifications (KS EAS 12: 2014) assigned higher tolerable upper limits for physicochemical properties to the natural potable water, compared to other water types that undergo any form of treatment (KEBS, 2015). Water abstracted from sand dam systems does not undergo any kind of treatment and is directly used by people for all domestic activities. Therefore, the present study has investigated its suitability for domestic use in Kitui-West constituency of Kitui County, South-Eastern Kenya. In this study, two abstraction methods, commonly used by local people to get water from sand dams, that is, scoop holes and shallow wells were assessed and compared in terms of seasonal variations and concentration levels of major physicochemical, organic, microbiological and trace metal

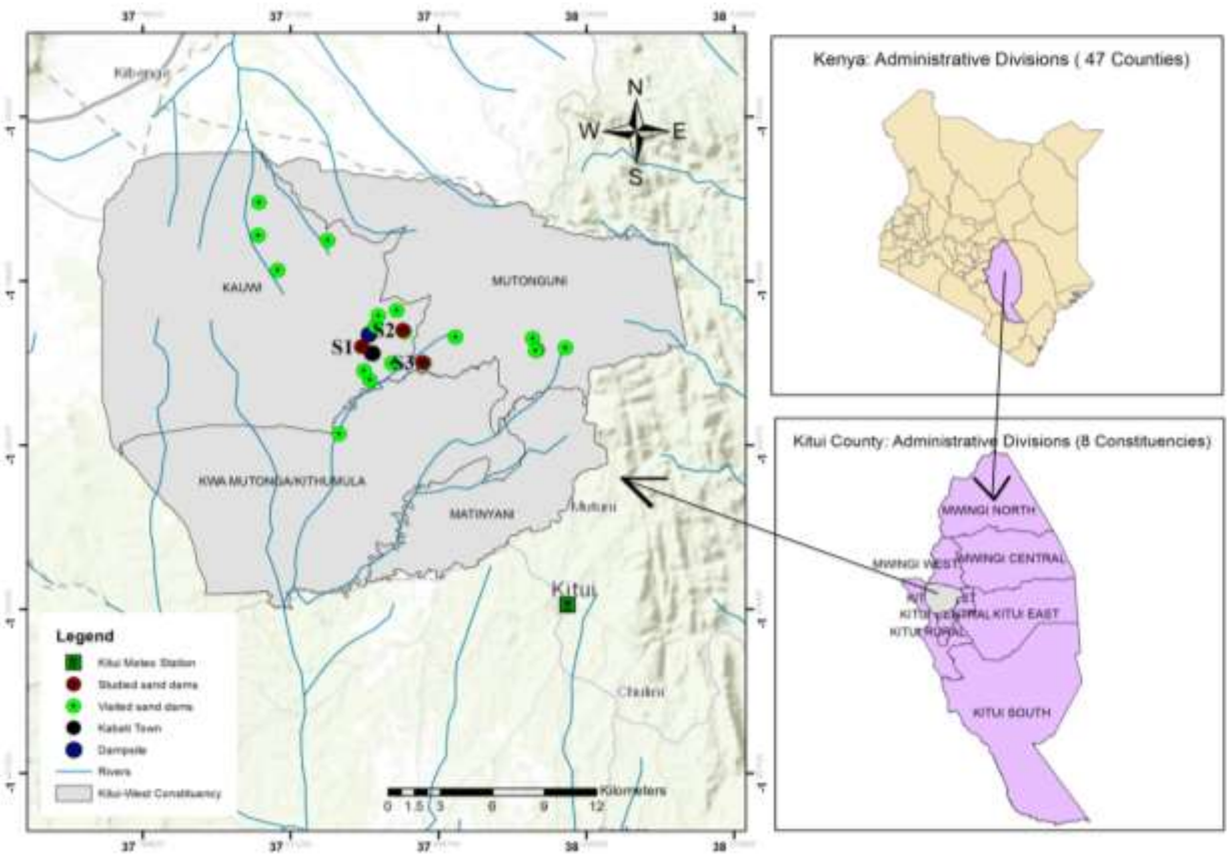

Figure 2. Map showing the study area and sampling sites in Kitui-West, Kitui county.

pollutants.

MATERIALS AND METHODS

Study area

The study was conducted in Kitui-West Constituency, one of eight constituencies making up Kitui County in South-Eastern Kenya. This constituency is subdivided into four administrative wards as indicated in (Figure 2) and is the second most densely populated sub-county with a population density of 161 persons per sq.km over an area of about 667.2 km^2 (CGoK, 2014). It lies between longitude 37° 43' 13.29" to 38° 1' 48.34" E, latitude 1° 6' 33.93" to 1° 22' 13.26" S and between the altitudes of 400 and 1800 m.

The climate of the Kitui County is semi-arid with very erratic and unreliable rainfall. This region is generally hot and dry throughout the year with temperatures ranging from between 14 and 34°C with mean maxima of 28-34°C and mean minima of 14-22°C all over the year (Mwamati et al., 2017). This temperature pattern divides the dry season into two categories: "**short hot dry season**" from mid-December to February and "**long cool dry season**" during months of June to September. Annual rainfall is highly unpredictable from year to year with variations ranging from 500-1050 mm. It is of bi-modal pattern with two rainy seasons; short and long rains. The last fall in months of March-April-May (MAM long-rains season) and are usually very erratic, unreliable (40% reliability) while the former fall in the months of October-November-December (OND short-rains season) and are more reliable (66% reliability) as it is during this season that farmers grow their main food crops (Mutunga et al., 2018).

The annual evaporation rates vary from 1500 and 1600 mm (Kitheka, 2016). These high evaporation losses, in addition to inadequate rains, cause the region to suffer from prolonged water shortages. These problems force local people to use all possible means to maximize rainwater storage using different rainwater harvesting systems in attempt to secure water needs during dry periods. Majority of rural residents spend daily many hours to fetch water entrapped in those systems. In short, water challenges in Kitui can be summarized as follows: A total of 52% of residents in Kitui County use improved water sources, while the rest use unimproved ones (KNBS, 2013), the average distance to the nearest water source is 7 km with 4 km as the shortest distance (in Kitui-Central) and 29.9 km as the longest distance (in Kitui-South). Over 60% of households take approximately an hour to fetch drinking water (CGoK, 2014) and the per capita consumption in the county is about 12 L per day (NDMA, 2018).

Site selection and sampling design

Three sand dams were conveniently and purposively selected after field visits and picked from 36 visited sites on the bases of water availability, ease of accessibility and presence of at least two different abstraction methods like scoop holes with either shallow wells (vertical wells) or riverbed infiltration galleries (horizontal wells). Majority of the visited sand dams were not equipped with

Table 1. Coordinates and characteristics of sampling sites and sampling points.

Characteristic		Site 1	Site 2	Site 3
Name of sand dams		Jua Kali B	Jua Kali A	Kithmula
Name of seasonal river		Kiteti	Wang'ori	Kauwi
Sand accumulation surface (m^2)		736	429	8,134
Coordinates	Latitude	1° 13' 22.06" S	1° 13' 51.97" S	1° 14' 23.41" S
	Longitude	37° 55' 54.3" E	37° 54' 38.02" E	37° 56' 29.77" E
Water usage	Population	125	165	190
	Livestock	N/A	N/A	N/A
	Irrigation	N/A	N/A	N/A
Status of abstraction methods		AB/HP	AB/HP	BS/CU
Sampling points	Scoop holes	Inlet-Middle-Exit	Inlet-Middle-Exit	Inlet-Middle-Exit
	Shallow wells	OP	OP	NOP

N/A: No available data; AB/HP: The use of scoop holes for domestic purpose was abandoned in favor of a hand-pump shallow-well; BS/CU: Both scoop holes and shallow wells are still concurrently used; OP: Water hand pump was operational; NOP: Water hand pump was not operational and samples were taken with help of a 12 Volt battery-powered submersible pump.

shallow wells and none of them was equipped with infiltration gallery outlet pipe.

Therefore, Jua Kali B, Jua Kali B and Kithumula sand dams were selected and indicated as S1, S2 and S3 respectively in Figure 2 and their detailed descriptions were given in Table 1. For scoop holes, the sampling points were fixed at entry, middle and exit of each selected sand dam while shallow wells are permanently fixed in place. In this study, they should be understood as “offset sand wells” to differentiate them from ordinary shallow wells as they are installed into alluvial riverbanks closer to the seasonal river channel where they can draw water seeping through and out of the bottom of sand sediment layers. The latter were treated as stable sampling points while the former were treated as unstable sampling points because the water quality measurements from them are nearly irreproducible during the next scheduled sampling events. Scoop holes dug for the first sampling event were, after few days, destroyed by daily movements of livestock and people during dry season and surface runoffs during rainy season. The next scheduled sampling events were requiring re-digging or refreshing the previous scoop holes.

Samples collection

Sampling was done from dry period (February 8 and 28, 2018) to wet season (March 23, April 20 and May 19, 2018) in sites indicated as red dots in Figure 2. Samples were collected in duplicates (for 1 L bottles) and triplicates (for ½ L bottles) using different plastic bottles (Figure 3e and f), thoroughly cleaned with distilled water and rinsed with water sample prior to collection. In scoop holes, samples were collected by immersing the sampling containers into the dug holes after dirty waters due to digging process have been scooped out and fresh water had freely seeped into them. In shallow wells, water samples were taken by pumping except at the site 3 where the hand-pump was not operating. Here, samples were collected by dipping a 12v battery-powered submersible pump in the sump pit via the manhole cover. It is to be recalled that water flows into the sump pit, the bottom tank of shallow-well pump system, through natural water migration from the bottom of sand dams. During the sampling period, scoop holes depths varied from 0.6 to 1.6 m while during rainy season, they varied from 0.2 to 0.5 m. A total of 48 water samples irrespective of duplicates or triplicates, were collected, comprising of 33 from scoop holes (Figure 3a and b) and 15 from shallow wells (Figure 3c and d). All samples were labeled, codified (see Figure 3f) and packed in ice cooler boxes. After the packing process, they were transported to the laboratories where they were stored in fridges set at 4°C prior to their analyses. Chemical analyses were carried out in JKUAT’s environmental laboratory while BOD, E.coli and Total coliform tests were done at Aqualytic Laboratories Ltd. Physical parameters such pH, temperature, turbidity and total dissolved solids were measured at the field.

Samples analysis

Samples were analyzed following Hach and Palintest manuals (Hach, 2012; Palintest, 2015) as majority of materials and equipment used were from these two companies. Both field and laboratory methods used in this study are listed and described in Table 2. After laboratory analyses, obtained data were analyzed with Spread sheet Software (Excel 2010) to generate results figures, tables and descriptive statistics. The concentration levels of tested parameters were compared to their respective maximum allowable concentrations (MACs) set in KEBS specifications for natural potable water (KEBS, 2015) and in WHO's guidelines for drinking water quality (WHO, 2017a). As the two standards differ mainly in MACs for physic-chemical properties and some chemical parameters, the comparisons were done where applicable. These comparisons were expressed in terms of compliance percentages as ratios of the number of tests meeting guidelines to the total number of tests done for each particular parameter. The general picture of seasonal variations of concentrations for different parameters was visualized by plotting water quality measurements against the rainfall observations from the station nearest to the study area for the study period as presented in Figure 2. There

Table 2. Tested water quality parameters and analytical methods.

	Tested parameters	Techniques and methods	Apparatus/ instrument	Measurement range	Reference standards	
					KEBS[1]	WHO[2]
Field- measured parameters	Temperature, °C	Direct reading	HQ40D Portable Multi Meter	0 - 60°C	NS	NS
	pH, [-]			0-14	5.5-9.5	6.5-8.5
	Total Dissolved Solids, TDS, mg/L	Direct reading	Digital TDS/EC Meter	0-9990	1500	1000
	Turbidity, NTU[3]	Direct reading	Hach 2100Q Turbidimeter	0-1000	25	5
Parameters tested in laboratory	Total hardness as $CaCO_3$, mg/L	Hach method 8213: Titration with EDTA[4]	Digital titrator	10-4000	600	500
	Chromium (Cr), mg/L	Hach Method 8024, Powder pillow (ChromaVer3)	DR 3900 Spectro-photometer	0.01 to 0.70	0.05	0.05
		Hach Method 10219 (TNTplus 854)		0.03 - 1.00		
	Zinc (Zn), mg/L	Hach Method 8009 (ZincoVer5)		0.01-3.00	5.0	3
	Copper (Cu), mg/L	Hach Method 8143		0.001-0.21 (LR[5])	1.0	2
		Hach Method 8506, (CuVer1)		0.04-5.00		
		Hach Method 8026, (CuVer2)				
	Manganese (Mn^{2+}), mg/L	Hach Method 8149		0.006 - 0.70 (LR)	0.1	0.1
		Hach Method 8034		0.1-20.0 (HR)		
		Direct photometric reading (PHOT.20.AUTO)	7100 Palintest photometer	0.001-0.030 (LR)		
	Iron (Fe), mg/L	PHOT.18.AUTO method (Iron LR)		0.01-1.0	0.3	0.3
		PHOT.39.AUTO method (Iron MR[6])		0.02-5.0		
		PHOT.19.AUTO method (Iron HR[7])		0.05-10		
	Biochemical Oxygen Demand (BOD), mg/L	Hach Dilution Method 8043 (Reading with LDO[8] Probe)	Hach HRI3P BOD incubator	0.1 -20.0	NS	NS
	Escherichia coli (E.coli), CFU[10]/100 ml	KS[9] ISO 9308-1:2014 (Colony-counting)	Hach portable Incubator	Nil	Nil	Nil
	Total coliforms (TCs), CFU/100 ml	KS ISO 4832:2006 (Colony-counting)		Nil	Nil	Nil

[1]KEBS's water quality specifications for natural potable water (KS EAS 12: 2014) compiled from (KEBS, 2015). [2]WHO's guidelines for drinking-water quality, compiled from (WHO, 2017a). [3]NTU = Nephelometric Turbidity Units. [4]EDTA Ethylenediaminetetraacetic acid. [5]LR: Low range; [6]MR: Middle Range; [7]HR: High range. [8]LDO: luminescent dissolved oxygen technology probe connectable to Hach HQ40D Portable Multi-meter. [9]KS: Kenyan Standard. [10]CFU: Colony-forming units.

were no correlations established between concentration levels and magnitudes of rainfall depths. Interpretations were limited to observations of seasonal trends of those two variables.

In addition to the comparison of concentration levels with rainfall depths and with MAC levels, additional interpretations were done by using descriptive scales going side by side with numerical ratings of acceptability or risk levels of each parameter (Table 3 and Table 4). These descriptive ratings were sequentially defined as follows: Excellent rate was assigned to mean suitable water with no health effects, good for suitable water with minor degree of impairment, fair for suitable water with moderate degree of impairment, marginal for conditionally acceptable water with major degree of impairment, poor for unsuitable water

Figure 3. General overview of sampling points and water samples: (a) and (b) scoop holes, (c) and (d) shallow wells, (e) and (f) water samples during dry and wet season respectively.

Table 3. Classification of water quality based on organic and bacterial pollution levels

BOD Level[1]			Total coliform[2]		E. coli levels[3]	
(1)			(2)		(3)	
Range [mg/L]	**Water quality rating**	**Description**	**Range [CFU/100 ml]**	**Classes (Ratings)**	**Range**	**Level of risk**
<1	Excellent: Very clean	No organic waste is present, no bacteria	0	Excellent	0	No Risk (Excellent)
1-2	Good: Clean	No much organic waste present, no much bacteria	1-20	Good	1	Very low risk (Good)
2-5	Fair: Moderately clean	Few organic waste is present, few bacteria	20-500	Fair	1-10	Low risk (Fair)
5-8	Marginal: Moderately polluted	organic matter is present and enough bacteria load	500-5,000	Poor	11-100	Moderate risk (Marginal)
8-10	Poor: Highly Polluted	Much organic matter /many Bacteria	5,000-10,000	Bad	101-1000	High risk (Poor)
>10	Unacceptable: Severely polluted	Too much organic matter and too many bacteria	>10,000	Unsuitable	>1000	Very high risk (Very poor)

[1]Compiled from ((Radojevic and Bashkin, 1999 [p.197]; (Hocking, 2005 [p.129]; Manivanan, 2008 [p.147]); [2]Compiled from (Janke et al., 2006; UNEP/WHO, 1996 [p.46]); [3]Adapted from (WHO, 1997) p.78; [4]Adapted from (DWAF, 1998), p.22

Table 4. Drinking-water acceptability ratings based on turbidity, TDS and Total hardness levels.

Turbidity level[1]			TDS level[2]		Hardness level[3]	
(1)			(2)		(3)	
Range (NTU)	**Rating**	**Description**	**Range (mg/L)**	**Rating**	**Range (mg/L)**	**Rating**
< 5	Excellent	Very clear	<300	Excellent	0-25	Very soft
510	Good	Clear	300-600	Good	25-50	Soft
1025	Fair	Slightly clear	600-900	Fair	50-100	Moderately soft
2550	Marginal	Moderately cloudy	900-1,2 00	Marginal	100-150	Slightly hard
50 100	Poor	Cloudy	1,200-1,500	Poor	150-200	Moderately hard
100 500		Very cloudy	>1,500	Unacceptable	200-300	Hard
500 1000	Completely unacceptable	Muddy	-	-	300-600	Very hard
>1000		Very muddy	-	-	>600	Extremely hard

[1]Compiled from (DWAF, 1998 [p.63]; Hazelton ans Murphy, 2016 [p.134]; Ahmed et al., 2017); [2]Adapted from (WHO, 2003a); [3]Reproduced from (DWAF, 1998 [p. 81.]),

for use without treatment, very poor or unacceptable for totally unsuitable for drinking and domestic uses. In this context, the degree of impairment should be understood as the frequency of a water parameter to violate its MAC value during period under consideration. Parameters without defined or set permissible levels, were also interpreted is this way. For instance, since there are no guidelines for BOD levels in drinking water, Therefore, the interpretation of water quality based on BOD levels was ascertained using numerical and descriptive ratings described in Table 3 (Col. 1). Parameters whose permissible limits are zeros like E.coli and total coliforms were also interpreted in the same way by rating health risks that can be associated with certain level of their concentration. Water quality levels based on E.coli counts were also ascertained by redistributing sample test results into five risk categories as indicated in Table 3 (Col. 3). Temperature and pH do not pose major health concerns and therefore no much interpretation was made on them. Parameters such as turbidity, total hardness (TH) and total dissolved solids (TDS) were additionally interpreted using acceptability ratings described in Table 4. Finally, the trace metals with low compliance rates were additionally interpreted in terms of histograms describing parameter's MAC violation levels with criteria based on a five-point effect severity scale that is, no health effects, insignificant effects, slight effects, acute or immediate effects and chronic or long-term effects and (DWAF, 1998).

RESULTS AND DISCUSSION

The results presented herein highlight the quality of water sampled from sand dams via scoop holes and shallow wells from the end of DJF short dry season (8 December and 28th February, 2018) and during MAM 2018 long rains from the end of DJF short dry season (8 December and 28th February, 2018). The studied water quality parameters showed that their concentration levels are significantly affected by seasonal variations. Anthropogenic factors also affect water quality of sand dams and these include mainly pastoral activities, agriculture, and use of fertilizers, manures and pesticides, sand harvesting, mining activities, municipal and domestic wastes. In addition, abstraction methods themselves, that is, scoop holes and shallow wells, affect the quality of sand-dam water and the problem is not linked with the nature of the fetching process precautions but with the nature of their design and traditional ways of doing things. Detailed results for analyzed parameters were presented in the following four headings, namely physicochemical, organic, and microbiological and trace metals.

Physicochemical parameters

Field observations of sand-dam water quality

Field observations mainly focused on three parameters (color, odor and taste). They showed that water from shallow wells is quite colorless and odorless across all sites during both dry and rainy seasons but some users talked to during the study period claimed it to have a salt taste. Scoop holes generally exhibited poor physical water quality, which is mainly associated with surface runoffs. From onset, during and up to the recession of rainy season, the color of scoop-hole water became muddy, muddier and moderately cloudy respectively. Scoop holes from two sites (S2 and S3) were not objectionable to odor, but the site 1 showed unpleasant odor and the color was blackish during the recession of the rainy season (mid-May towards June) and the color was blackish. This was perceived to be caused by waste water from households entering at the near end-point of sand dam as the latter is located at about 200 m (the nearest household) and 1 km downstream of municipal solid waste open dumpsite. During rains, some solid wastes that had been dumped are washed away by runoff torrents, contributing to solid loading at sand dam site. The combined effects of household wastewater and dumpsite caused local people around the sand dam to abandon completely the use of scoop holes for domestic use and they rather use them for livestock watering.

Field-measured physicochemical properties

The physicochemical parameters presented under this sub-section are ones considered to detract from the appearance and taste of water, making it unpleasing to drink or use for domestic uses for aesthetic reasons. These include temperature, pH, turbidity, TDS and total hardness (TH). Their concentration analysis results are presented in Figure 4 and showed that almost all physicochemical parameters complied 100% with the KEBS limits except turbidity and TH that complied with 44% (21/48) and 92% (44/48) respectively. The overall averages for temperature, pH, turbidity, TDS and TH were 25.59°C, 7.58, 205 NTU, 501 mg/L and 277.38 mg/L respectively. Additionally, water sample results for turbidity, hardness and salinity were also distributed into different water acceptability levels described in Table 4 (Cols. 1, 2 and 3). The resulting frequency analysis results were presented in Figure 5 in order to draw a detailed picture of the differences between water abstracted from scoop holes and shallow wells.

The Figure 4a showed that the average temperature of all water samples (N=48) generally ranged from 21.2 to 30.6°C (avg. 25.59°C ± 2.40). It shows also that it has decreased slightly during rainy season. Avg. 7.58°C ± 0.26 were within the acceptable range from 7.13 to 8.20 (Figure 4b). Figure 4c shows that turbidity varied significantly in scoop holes during the rain while in shallow wells, it was almost similar across all seasons. Turbidity levels ranged from 18.4 to 974 NTU (avg. 297 NTU) in scoop holes and 1.24 to 6.55 NTU (avg. 3.1 NTU) in shallow wells. Turbidity complied with KEBS limit (≤ 25 NTU) at the rates of 18% (6/33) in scoop holes and 100% (15/15) in shallow wells. The Figure 4d shows that TDS values slightly decreased during rainy season and were higher in shallow wells than in scoop holes. They ranged from 692 to 1132 mg/L (avg. 934 mg/L) in shallow wells and from 64 to 872 mg/L (avg. 304 mg/L) in scoop

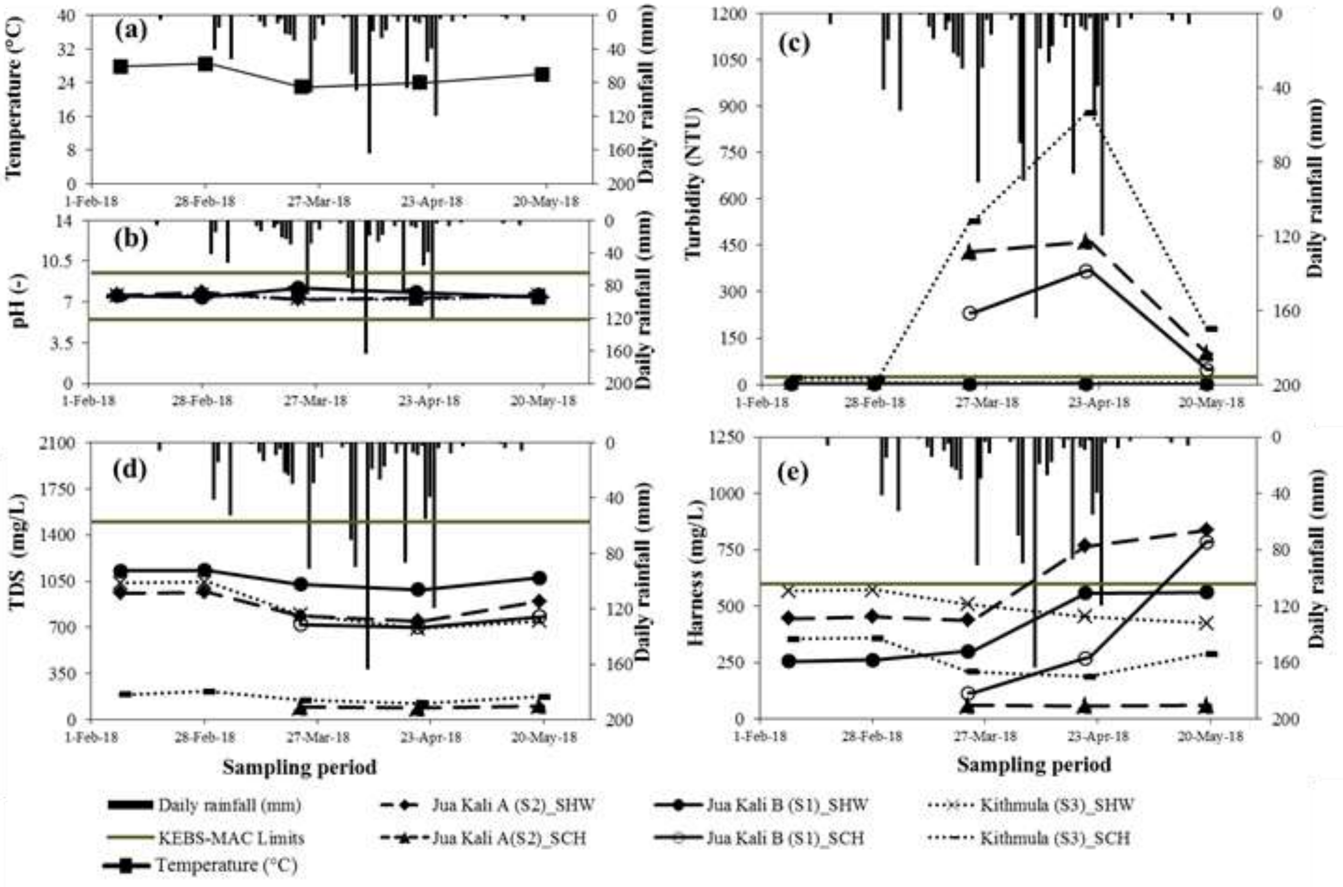

Figure 4. Figure 4. Seasonal variations of physicochemical properties in scoop holes (SCH) and shallow wells (SHW) during MAM 2018 long-rains season (inverted black bars): (a) pH, (b) average temperature of all water samples, (c) turbidity, (d) TDS and (e) total hardness.

holes. Figure 4e shows that the water hardness tended to change slightly towards the end of the rainy season. The values of total hardness were an average of 179 mg/L (ranging from 24 to 1115 mg/L) in scoop holes and an average of 494 mg/L (ranging from 256 to 838 mg/L) in shallow wells. The histograms presented in Figure 5 showed how acceptability of water based turbidity, TDS and total hardness levels varied between scoop holes and shallow wells. The Figure 5a shows that water shallow wells were found to have water with lower turbidity levels (< 10NTU) throughout all the seasons, but with higher TDS levels as indicated in Figure 5b and higher hardness values as indicated in Figure 5c as 67% of them (N= 10/15) fell in *very hard* category as indicated in Table 4 (Col. 3). Scoop holes, on the other hand, were found to have high turbidity levels as 82 % of samples (N= 27/33) violated the recommended limit for natural potable water. They were found to provide fresh water as 73% of them (N=24/33) fell in *fresh taste* category as indicated in Figure 5b. They were also found to have lower hardness levels as 79% of them (N=26/33) ranged from very soft to moderately hard water as indicated in Figure 5c.

Generally, the physicochemical analysis results showed that the turbidity is the most critical parameter in sand-dam water. It is critical because it makes water appearance unpleasant to drink as indicated in Figure 3f and bacteria, viruses and or other microbial parasites can hide themselves in suspended particles. Unfortunately, turbidity is common problem in almost all sand dams. Due to limited alternative water sources in the region, people fetch it and use simple gravity sedimentation method at a household level. They fill water in containers and let it settle down by gravity. Therefore, sedimentation itself can increase clarity but cannot remove micro-organisms clung on suspended or settled sediments. This situation calls up the use of disinfection by-products (DBPs) even though, on the other hand, turbidity interferes with it as fine particles in turbid water can protect microbial contaminants from disinfectant. The turbidity level above 2 NTU reduces the efficacy of chlorination by increasing chlorine demand and potentially shielding microorganisms from inactivation even though disinfection can be achieved at higher turbidities by increasing chlorine doses and contact time (WHO, 2017b).

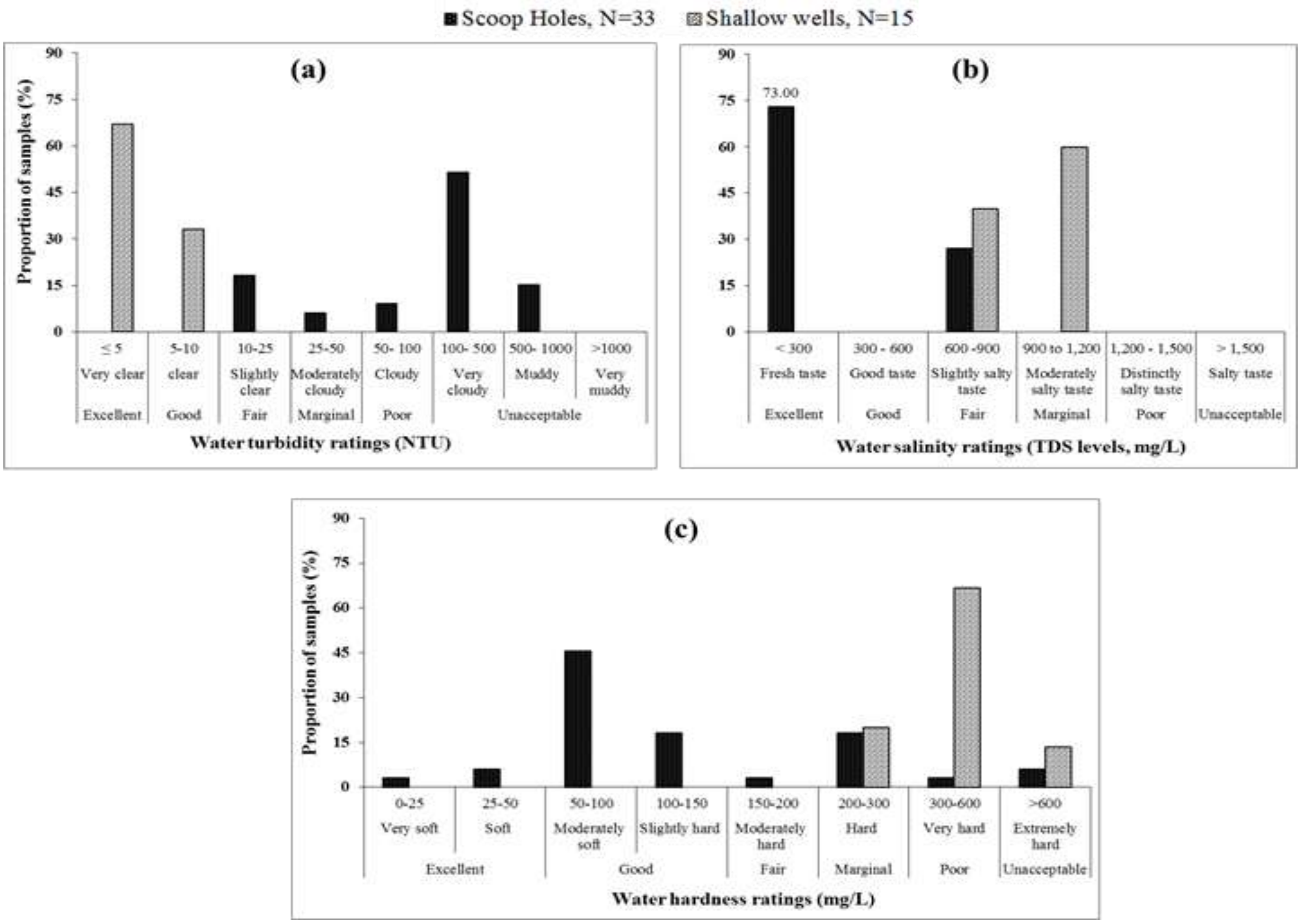

Figure 5. Acceptability ratings of water from scoop holes and shallow wells: (a) Turbidity, (b) Total dissolved solids and (c) Total water hardness.

those found in previous studies on physicochemical properties of water stored in sand dam systems in the region. Avis (2016) found that 75% of shallow wells (N = 8) had considerably lower turbidity levels (< 5 NTU) and maximum value of 10 NTU, comparable to 67% (N=15) ≤ 5 NTU and maximum value of 6.55 NTU, obtained in the present study. He also found that 12% of scoop holes (N=25) had turbidity levels < 5NTU and the maximum value of 100 NTU, compared to 100% of them (N=33) found to be higher than 5 NTU in this study. It should be recalled that he was using WHO limit (≤ 5NTU) which is not a specific guideline. Water from sand dams does not pass through any treatment process. It only occurs by natural filtration process and that is why KEBS recommends MAC value of 25 NTU for natural potable water and ≤ 5 NTU for treated water (KEBS, 2015). Although by considering this limit, scoop holes still score low compliance rates, that is, 18% (N=6/33). Quinn et al. (2018) found that 59% of shallow wells (N=47) and 92% of scoop holes (N=36) didn't meet KEBS/WHO limit for turbidity (≤ 5NTU) but both Avis (2016) and Quinn et al. (2018) used turbidity tubes which can't measure values < 5 NTU and also limited to about 240 NTU, otherwise samples should be diluted. On the other hand, the present turbidity range (18.4-974 NTU) is comparable to the range of 12.28 to 1000 NTU (Kitheka, 2016). The closeness of two study findings is mainly due to the fact that the same turbidimeter (0-1000 NTU) was used, during the same sampling period, in the same region, during the same seasons but in different years.

As regards to hardness levels in sand-dam water, very few studies assessed this parameter. Ndunge et al. (2019) found hardness levels to vary from 37.2 to 356 mg/L in scoop holes, compared to 24 to 1115 and 444 mg/L in shallow wells, compared to the mean value of 494 mg/L presented in this study. Water quality measurements from shallow wells are also comparable to measurements from boreholes as they only differ from depth size. In this regard, Mwamati et al. (2017) found that hardness levels varied from 180-720 mg/L in boreholes, comparable to 256-838 mg/L in shallow wells.

Lastly, Figure 5c shows that TDS values were higher in

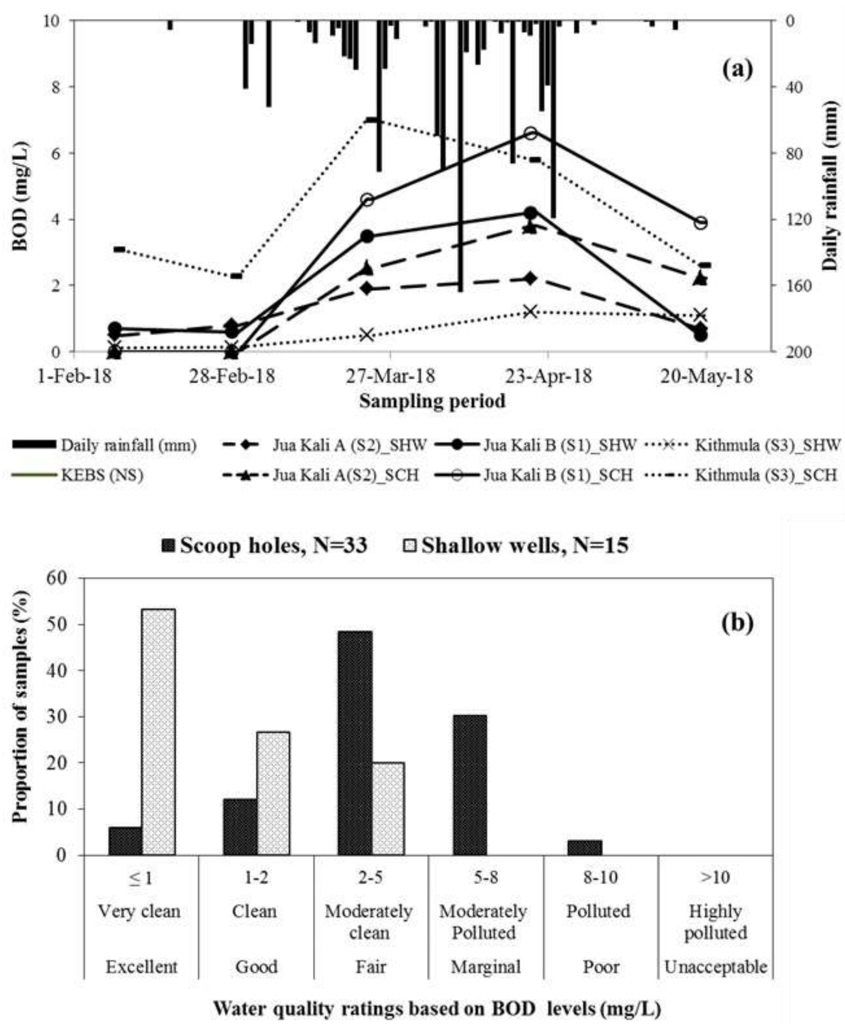

Figure 6. BOD levels in water from shallow wells and scope-holes: (a) seasonal variations and (b) distribution histograms into water quality ratings.

shallow wells (692-1,132 mg/L) than in scoop holes (64-872 mg/L) and this observation was made by Kitheka (2016) who remarked that shallow wells had higher TDS levels (206-1,022 mg/L) than scoop holes (77.8 to 272 mg/L). Mwamati et al. (2017) found also TDS levels to vary from 350 to 1450 mg/L in boreholes, comparable to shallow wells.

Organic and bacterial pollutants in sand-dam water

BOD levels

The 5-day BOD test results are presented in two complementary perspectives; (1) the seasonal variations of BOD levels in both scoop holes and shallow wells as presented in Figure 6a and (2) since there is no guideline value set in both KEBS and WHO drinking-water guidelines, the water quality level based on BOD levels was determined by distributing water sample results into different water quality ratings indicated in Table 3 (col.1). This exercise generated histogram showing number of samples (in %) falling under each category as indicated in Figure 6b.

The Figure 6a shows that BOD levels varied significantly in samples collected during rainy season. They varied from 0.35 to 8.1 mg/L (avg.4.02 mg/L) in scoop holes and from 0.12 to 4.2 mg/L (avg.1.31 mg/L) in shallow wells. BOD levels were found to be high during this season and low at the onset and recession of this season. This is because the rate of BOD reactions depends on the temperature, the population of bacteria, and the amount of organic matter present in the sample (Kunz, 2009). That is to say, high BOD levels indicate the presence of high amount of putrescible organic matter and elevated number of bacteria, mainly aerobic ones. The Figure 6b shows that 80% of water samples (N=12/15) from shallow wells exhibited clean water, free

Table 5. Concentrations and compliance levels of microbiological parameters in sand-dam water extracted via scoop holes and shallow wells.

Sampling detail		Site 1		Site 2		Site 3	
Sampling date	**Sample source**	**E. coli (cfu/100 ml)**	**TCs (cfu/100 ml)**	**E. coli (cfu/100 ml)**	**TCs (cfu/100 ml)**	**E. coli (cfu/100 ml)**	**TCs (cfu/100 ml)**
8-Feb-18		N/A[1]	N/A	N/A	N/A	ND ± ND	19 ± 8
28-Feb-18		N/A	N/A	N/A	N/A	8 ± 8	38 ± 11
23-Mar-18	Scoop holes[2]	60 ± 53	800 ± 265	ND ± ND	600 ± 100	ND ± ND	267 ± 252
20-Apr-18		83 ± 76	1333 ± 153	62 ± 54	733 ± 208	83 ± 76	600 ± 529
19-May-18		170 ± 113	1767 ± 643	90 ± 79	900 ± 361	67 ± 58	1200 ± 200
Compliance (%)	to KEBS/WHO limit	22	0	56	0	60	13
8-Feb-18		ND	ND	ND	ND	ND	ND
28-Feb-18		ND	ND	ND	ND	ND	ND
23-Mar-18	Shallow wells[3]	ND	500	ND	ND	ND	ND
20-Apr-18		ND	1900	150	800	ND	1100
19-May-18		ND[5]	2300	100	700	ND	1700
Compliance (%)	to KEBS/WHO limit	100	40	60	60	100	60

[1]N/A = No data available as the concerned sand dams were dried up during sampling period. [2]Three samples were taken at inlet, middle and exit of every sand dam on the same day of sampling. [3]Every sand dam was equipped with one shallow well, then a single sample was taken as it was treated as stable point. [5]ND = (Not detected).

from organic matter and 20% of them (N=3/15) showed moderately clean water. Scoop holes (N=33) exhibited clean water, moderately clean water, moderately polluted and polluted water at the rates of 18.2, 48.5, 30 and 3% respectively.

BOD is a good indicator of both drinking water and wastewater quality but often neglected in drinking water sources. For water sources like sand dams, BOD is the parameter that should not be overlooked. Sand dams behave ambivalently: (1) They are surface waters during rainy season and (2) they act as unconfined aquifer storage during dry period. This nature subjects them to the vulnerability of organic matter loads as thousands of livestock and wild animals spend much time and long distances, grazing riparian areas reinvigorated by sand dam storages over dry seasons.

Though BOD levels do not have direct health implications (Sengupta, 2018) but water with BOD > 5 mg/L can lead to long-term effects and affect lives of people (Wen et al., 2017). Apparently, few studies assessed BOD levels in quasi-similar water sources in the region and they showed the same trends as in this study. Two studies Kosgey (2013) and Kwamboka (2018) measured BOD levels measured in Athi River, along the reaches of Machakos County and found them to vary from 6 to 15 mg/L and from 2 to 32 mg/L respectively.

Microbiological pollutants

The MAC value for both E. coli and total coliform bacteria in both KEBS and WHO drinking water quality guidelines is Zero CFU/100 ml. Both their concentration and compliance levels in water from scoop holes and shallow wells are presented in Table 5 and Figure 7.

E. coli levels

Seasonal variations of E. coli levels and distribution of sample results into E. coli risk levels are presented in Figure 7a and Figure 7b respectively. The E. coli levels ranged from < 1 to 150 CFU/100 ml in shallow wells and from < 1 to 300 CFU/100 ml in scoop holes. Figure 7c shows that 87% of samples from shallow wells (N=13/15) and 48% from scoop holes (N=16/33) complied with KEBS/WHO guideline value. E. coli bacteria are reliable indicators of recent faecal contamination in drinking water sources (Verhille, 2013). Therefore, 13% of samples (2/15) from shallow wells and 52% of samples (17/33) from scoop holes indicated that they were contaminated with faecal wastes. Based on distribution of sample results into E. coli risk levels as indicated in Figure 7c, it can be concluded that shallow wells can pose minor risks to the users while it is very risky to use directly water from scoop holes. Water from shallow wells complied with high rate because normally, water reaches the pump suction tank after having passed through different sand layers in sand dams and riverbank soil layers.

Total coliforms

Total coliforms generally varied from < 1 to 2,500 CFU/100 ml and 53% of shallow wells (N=8/15) and 6% of scoop holes (N=2/33) complied with KEBS/WHO guidelines as indicated in Figure 7d. This indicates that

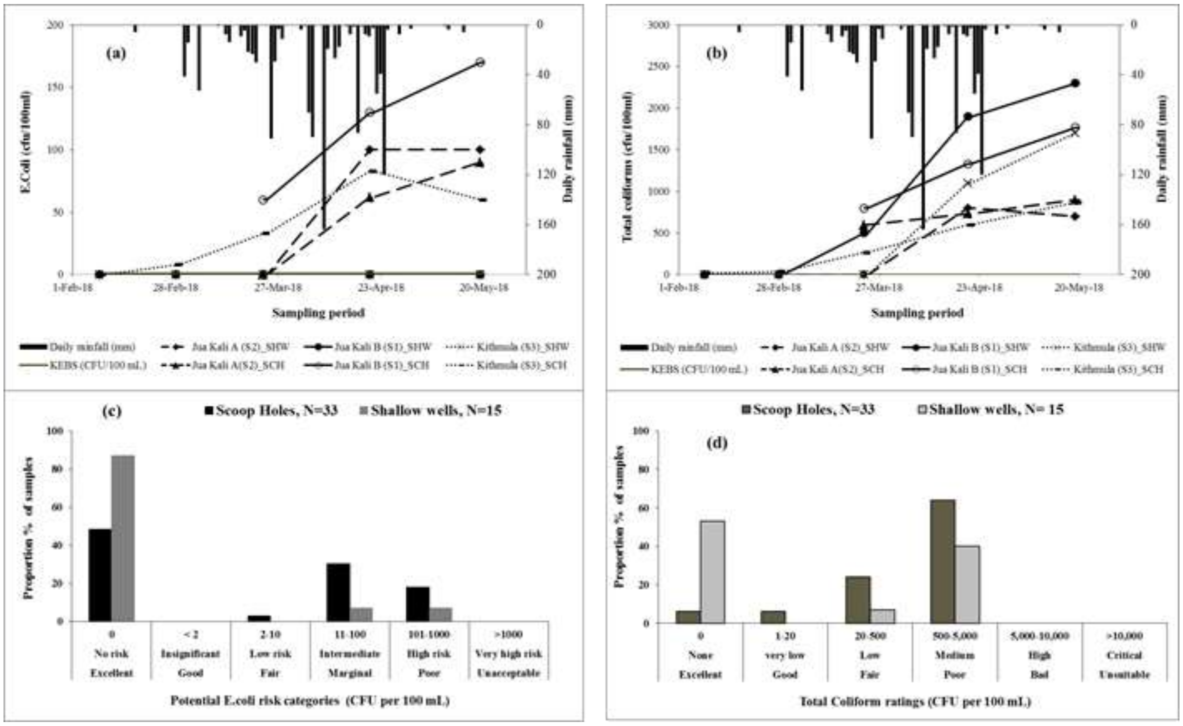

Figure 7. Comparison of microbial contamination levels in water from sand dams via shallow wells (SHW) and scoop holes (SCH): (a) and (b) seasonal variations of E.*coli* and Total coliforms; (c) and (d) their respective guideline value violation levels.

47 and 94% didn't comply with recommended limit respectively. Following the same order of arguments, distribution of sample results into total coliform ratings showed that 40% and 64% of them fell in the marginal range from 500 to 5,000 CFU/100 ml as indicated in Table 3 (Col. 2).

Total coliforms are generally harmless and if only one is detected in water source, the contamination is more probably of environmental source than faecal one. Normally, many researchers ignored or tend to ignore the coliforms as indicator of water contamination as they are generally harmless. The recent advances in taxonomic studies showed that they are not specific to the intestine of humans or warm-blooded mammals as they can also be found in the environment such as in soil, in surface waters and in various plants (Verhille, 2013). In this study, their analysis was added for three reasons:

i. To get overall picture of the microbial quality status of water in sand dams as they are supposed not to be present in water intended for domestic use.

ii. Their presence in water source indicates also that pathogens could be present there too and or can also access it.

iii. They indicate whether water necessitates disinfection, that is, chlorination or boiling to improve its quality for drinking.

From Figure 7a and b, seasonal variations of both E. coli and total coliforms showed low trends in dry season and high trends towards the recession of rainy season. These lower trends can be explained by the fact that during dry period, samples were taken in scoop holes deeply dug (0.6 to 1.6 m). Those samples have little chance of being accessed by faecal pollutants. In addition to this argument, studies had also showed that there is a dependence of E. coli occurrence on the depths in sediment profile (Pachepsky and Shelton, 2011). The latter demonstrated that E. coli bacteria were higher at shallow depths and getting lower at deep depths. The higher trends on the other hand, can be explained by the fact that the ability of E. coli bacteria or total coliforms to multiply in the soil is a function of soil moisture content and their ability to outcompete predators is in function with soil dryness (Solo-Gabriele et al., 2000).

By observing scrutinously rainfall variations from both Figures 7a and b, much rain fell in March and April. During this period, water levels in sand dams often increase greatly up to overtopping dam wall and stormwater continues flowing in the natural riverbed channel. In this situation, bacteria were not favoured to multiply. From the beginning of May, rains started decreasing remarkably and the sediment dryness was increasing in the same way. Bacteria brought from far way by runoff began to gain a favourable environment enabling them to grow and multiply. No correlations were established between sample depth or soil dryness or between rainfall amounts and concentration levels of E.coli and total coliforms, but stormwater obviously enhances the transport of different bacteria from their generation points towards sand dams. Even though the philosophy behind the sand dams is to protect stored water from surface contamination and water loss through evaporation (Maddrell, 2016), they can’t fulfil these two critical functions as they are made up of loose self-deposited porous sediments which are also repeatedly destabilized by seasonal runoffs, sand harvesting and scooping processes. They can just minimize contamination and evaporation losses compared to air-open storage systems.

Different previous studies showed that scoop holes are unsafe methods for abstracting water from sand dams for drinking purposes. Nevertheless, Abila et al. (2012) evidenced that shallow wells can also be contaminated with E. coli bacteria as he found them in the range of 20 to 110 CFU/100 ml. They added that the possibility of shallow wells to be contaminated depends on the distance that separates them from the residential areas as those located within dense residential areas are the most vulnerable. They tested total coliforms and found them to vary from 370 to 2,352 CFU/100 ml, comparable to the range of 0 to 2, 500 CFU/100 ml in this study. Onyango-Ouma and Gerba (2011) tested also E. coli levels in shallow wells (N=4) and found that their counts were in the range of 4 to >2,420 (too numerous to count). Avis (2016) found that shallow wells are vulnerable to faecal contamination as he found that 62.5 % of shallow wells (N=8) contained E. coli bacteria in the range of 0 to 76 CFU/100 ml. Avis (2016) also found that 83% of scoop holes (N=29) were free from E. coli bacteria. Quinn et al. (2018) who tested E. coli in shallow wells (N=47) and 36 scoop holes (N=36) found that 70% of shallow wells (33/47) and 11% of scoop holes (4/36) complied with the recommended guideline while 30% (14/47) and 89% (32/36) didn’t comply with it respectively. Finally, Ndunge et al. (2019) found that 67% of scoop holes (N=32) contained E. coli bacteria in the range of 8 to > 180 CFU/100 ml. The present findings are consistent with previous findings and therefore, it can be concluded that water from sand dams is categorically unfit for direct human consumption. It needs further treatments at household level, which can mainly be physical methods such as household sand filters, cloth filtration, ceramic filters, biosand filters, solar disinfection (SODIS) and chemical disinfection methods such as water purification tablets (Aquatabs), water purification powders and chlorine solutions such as water guards, PUR and P and G water purifiers).

Possible sources of organic and bacterial pollutants in sand dam water

Sand dams systems have been adopted in most of Kenya’s arid and semi-areas to secure water supplies for domestic, micro-irrigation and livestock watering purposes. High aridity of the region and a big number of livestock (about 70% of the national livestock) make pastoralists travel long distances in search of pasture. In the study area, we observed that cows, goats, sheep and donkeys spend many hours a day grazing on banks of seasonal rivers which accommodate sand dam systems. The latter create a favorable environment that attracts both livestock and wild animals (about 90% of national wildlife) coming to graze on greenish riparian vegetation reinvigorated by sand dam storages during dry seasons. As they move all along seasonal rivers, grazing grasses and drinking water in scoop holes left behind by people, they leave droppings scattered on sand dam surfaces, continually spread over and over due to daily to-and-fro movements of people and animals.

In addition to animals’ droppings, other organic wastes including dead plants, leaves, and grass clippings, washed-off manure, sewage, and food waste from households, were observed in surrounding areas of sand dams. Therefore, organic matter and microbiological pollutants in sand dams are substantially linked with animals’ droppings. Sand dams are freely accessible by whatever and whoever. Thus, it may not be easy to protect them from contamination. In addition, the contribution of the use of bushes and trees for privacy can’t be ignored as it was observed that there are no sanitation facilities provided for cattle keepers and passers-by. When it rains, everything is washed away by surface runoffs into stormwater drains towards sand dams.

Metal concentrations in sand-dam water

Trace metal elements

The trace elements assessed in this study include copper (Cu), iron (Fe), manganese (Mn), zinc (Zn) and chromium (Cr). Except Cu and Fe, the remaining have the same guideline limits in both KEBS and WHO water quality standards. The KEBS MAC limits for Cu and Zn are 1 and 5 mg/L (KEBS, 2015) while in WHO guidelines, they are 2 and 3 mg/L (WHO, 2017a) respectively. Therefore, WHO compliance levels for these two elements were indicated in brackets wherever applicable. The results including mean values, standard deviations and compliance levels are presented in Table 6 while seasonal variations of trace metals in sand-dam water are indicated in Figure 8. Combined results, from both shallow wells and scoop holes, showed that Mn, Zn and Cr complied with KEBS/WHO guideline limits at the rates of 98, 100 and 94% respectively as indicated in Table 6. Only two parameters Cu and Fe complied with low rates of 56 (73) and 35% respectively. Scoop holes contributed heavily to these low rates as they scored 48% (N=16/33) and 9% (N=3/33) respectively. Water from shallow wells complied with KEBS/WHO limits at the rates of 73 (80 for Cu) and 87% for

Table 6. Concentrations and compliance rates of trace metals in sand-dam water extracted via shallow wells and scoop holes.

Sampling detail		Scoop hole[1]					Shallow well[2]				
Site	date	Cu	Fe	Mn^{2+}	Zn	Cr	Cu	Fe	Mn^{2+}	Zn	Cr
	8-Feb-18	N/A	N/A	N/A	N/A	N/A	0.48	0.09	0.04	0.11	0.042
	28-Feb-18	N/A	N/A	N/A	N/A	N/A	0.52	0.06	0.05	0.09	0.034
Site 1	23-Mar-18	0.63 ± 0.57	0.57 ± 0.031	0.01 ± 0.001	0.05 ± 0.002	0.03 ± 0.004	0.7	0.05	0.024	0.08	0.05
	20-Apr-18	0.97 ± 0.42	0.73 ± 0.131	0.03 ± 0.006	0.05 ± 0.01	0.05 ± 0.008	1.1	0.03	0.05	0.09	0.04
	19-May-18	2.37 ± 1.03	0.06 ± 0.032	0.07 ± 0.026	0.04 ± 0.02	0.03 ± 0.01	0.9	Bdl[3]	0.07	0.08	0.03
	8-Feb-18	N/A	N/A	N/A	N/A	N/A	0.34	0.06	0.026	0.04	0.032
	28-Feb-18	N/A	N/A	N/A	N/A	N/A	0.28	0.08	0.014	0.07	0.035
Site 2	23-Mar-18	0.1 ± 0.092	1.47 ± 0.068	0.02 ± 0.016	0.06 ± 0.01	0.045 ± 0.006	2.1	bdl	bdl	0.12	0.04
	20-Apr-18	0.28 ± 0.298	1.84 ± 0.501	0.03 ± 0.022	0.06 ± 0.018	0.047 ± 0.011	2.30	0.02	0.08	0.3	0.03
	19-May-18	0.31 ± 0.2	1.7 ± 0.577	0.03 ± 0.023	0.06 ± 0.017	0.032 ± 0.004	2.40	0.01	0.07	0.2	0.04
	8-Feb-18	0.95 ± 0.15	2.33 ± 0.15	0.08 ± 0.01	0.03 ± 0.01	0.04 ± 0.01	0.60	1.20	0.007	0.037	0.041
	28-Feb-18	1 ± 0.1	2.4 ± 0.26	0.06 ± 0.05	0.04 ± 0.01	0.04 ± 0.01	0.50	1.10	0.008	0.042	0.046
Site 3	23-Mar-18	3.2 ± 0.95	5.37 ± 2.01	0.08 ± 0.01	0.03 ± 0.01	0.03 ± 0.01	0.60	0.25	0.006	0.033	0.036
	20-Apr-18	4.5 ± 1.4	4.85 ± 2.25	0.07 ± 0.03	0.03 ± 0	0.04 ± 0.01	0.50	0.22	0.090	0.034	0.038
	19-May-18	4.33 ± 3.16	3.07 ± 2.74	0.15 ± 0.13	0.04 ± 0.01	0.03 ± 0	0.01	0.03	0.080	0.030	0.032
KEBS/WHO MACs		1/2	0.3	0.1	5/3	0.05	1/2	0.3	0.1	5/3	0.05
Compliance (%)		48/73	9	97	100/100	85	73/80	87	93	100/100	100

[1]Three samples were taken at inlet, middle and exit of every sand dam on the same day of sampling. [2]Only one sample was taken from shallow well of each sand dam on the same day of sampling. [3]bdl =below detection limit.

Fe respectively. The concentrations of Cu and Fe in scoop holes varied from 0-7.9 mg/L (avg.1.63 mg/L > KBS limit (≤ 1 mg/L) but < WHO limit (≤ 2 mg/L) and from 0.02-7.45 mg/L (avg. 2.22 mg/L > both KEBS/WHO limits (≤ 0.3 mg/L) respectively.

In shallow wells, the concentrations of the two parameters ranged from 0.01 to 2.4 mg/L (avg.0.89 mg/L < both WHO/KBS limits) and from 0-1.2 mg/L (avg. 0.21 mg/L < both WHO/KBS limits) respectively. From these two viewpoints, high levels of Cu and Fe were measured in samples taken from scoop holes during rainy period. Though Cu and Fe concentrations are within normal ranges of occurrence in drinking water (≤ 0.005 to > 30 mg/L (WHO, 2004) and ≤ 0.01 to > 50 mg/L (WHO, 2003b) respectively, they showed that their presence in sand dams is more linked to surface contamination than being associated with their natural abundance in Earth's crust. If the Cu and Fe concentrations were from geological formations, higher values should have been detected in shallow wells. Therefore, sources of these two parameters are presumably linked to runoff contamination and shallow wells are less vulnerable to it because runoff water entrapped by sand dam systems, takes time to reach shallow well sump pits and is also filtered all along the journey through different sand layers. From Figure 8a, Cu concentrations changed abruptly in scoop holes of site S3 and slightly in the shallow well of site S2. Their trends showed that there is high probability to return to lower values after rainy season in June, July and August. The Figure 8b shows that Fe concentrations were very high compared to recommended limit (≤ 0.3 mg/L) in scoop holes of the site S3 and in scoop holes of the site S1. Figure 8c, d and e showed that Cr, Mn and Zn were below the recommend limits in both KEBS/WHO guidelines.

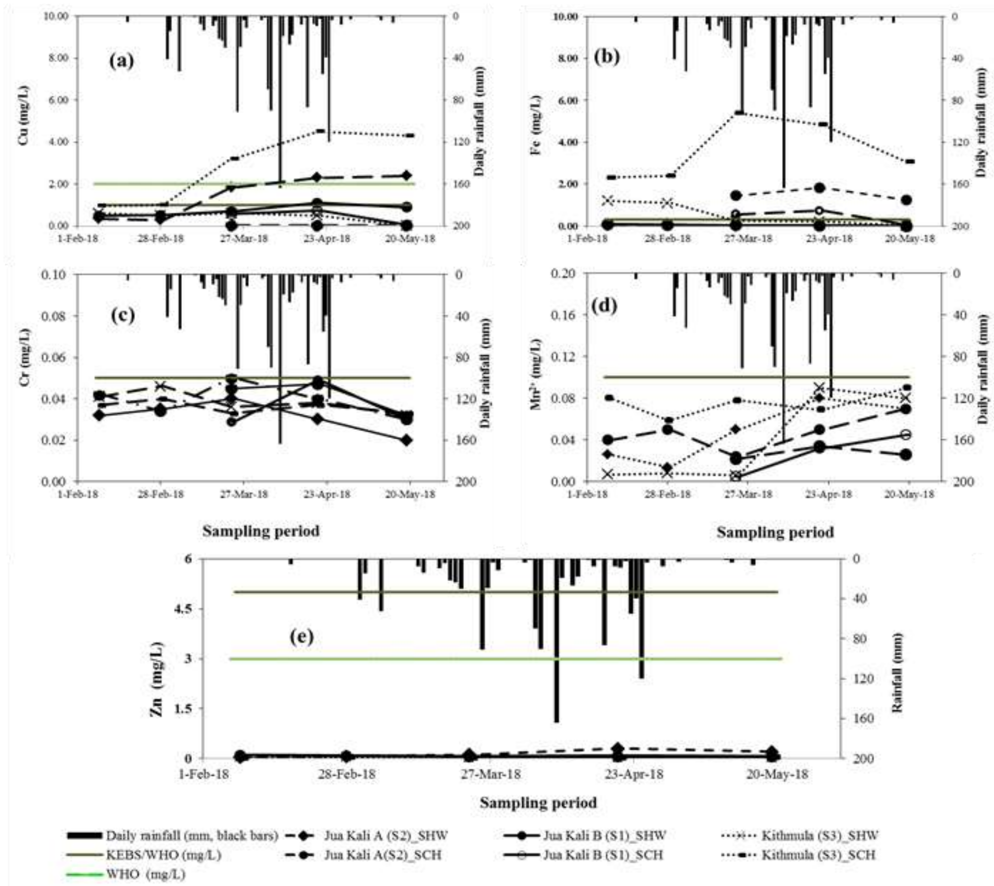

Figure 8. Seasonal variations and compliance levels of trace metal concentrations in water from shallow wells (SHW) and scoop holes (SCH) during MAM 2018 long-rains (inverted black bars): (a) Cu, (b) Fe, (c) Cr, (d) Mn and (e) Zn.

Possible health effects that can be associated with high Fe and Cu in sand-dam water

From Figure 8a and b, Cu and Fe were found to be higher compared to the remaining trace metals tested (Mn, Zn and Cr). In order to get a general picture of what should be the effects on human health if people routinely continue to drink sand-dam water containing high Fe and Cu levels, all water sample results for these two elements were distributed into concentration-effect ratings (DWAF, 1998). These are five-point rating scale categories in increasing order of severity, i.e. no effects, insignificant effects, slight effects, chronic effects (that can occur after long-term exposure to a pollutant present only in small amounts) and acute effects (instant health effects that can occur within hours or days of consumption like vomiting, nausea, headaches, stomach cramps, or diarrhoea). The resulted frequency distributions of Fe and Cu measurements into concentration-effect ratings are presented in Figure 9 (a) and (b) respectively. In this figure, shallow wells were found to have Cu levels with no possible effects at the rate of 87% and with insignificant effects at the rate of 13%. They were also found to have Fe levels with no effects at the rate of 86.7% and slight effects at the rate of 13.3% (Figure 9 b). Scoop holes were also found with Cu and Fe levels that cannot present health effects at the rate of 48.5% and 12% respectively while 27% and 15% of samples fell in category of chronic effects as indicated in (Figure 9 a and b) respectively.

Normally, copper and iron are very essential to human health. Too little is unhealthy and too much can lead to poisoning. They are not hazardous to health, but can cause taste, odor, appearance and staining problems in water. Particularly, normal levels of iron found in drinking water cannot lead to major health problems as Iron is unknown to cause cancer in people (WHO, 2003b; FDH, 2015). On the other hand, Cu concentrations greater than 2 mg/L (guideline set to prevent health-related problems) have not been proven to cause cancer in humans (ATSDR, 2004) but .can cause acute damage to the liver, kidneys and chronic effects in sensitive individuals like persons with Wilson's disease (a genetic disorder causing copper to accumulate in the liver, brain and other vital organs immediately after birth) and children with various cirrhosis syndromes (DWAF, 1998; National Research Council, 2000; WQA, 2013).

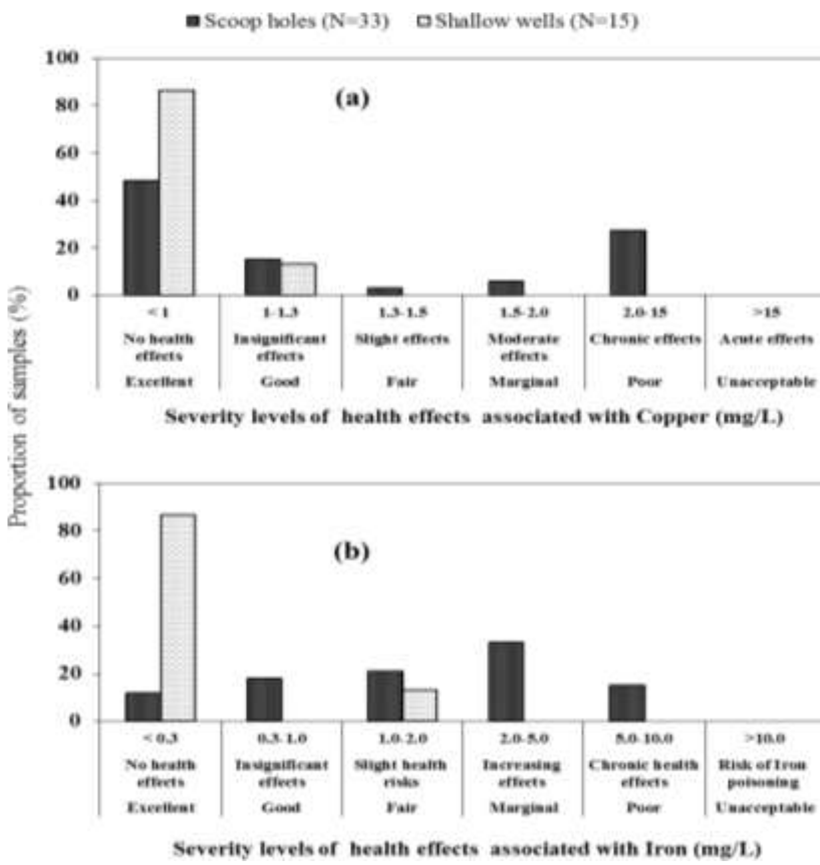

Figure 9. Histograms showing the distribution of Cu (a) and Fe (b) measurements from scoop holes and shallow wells into severity categories of potential health effects.

Few previous studies tackled the assessment of metals in sand-water water. On this particular point, comparisons for water quality measurements in sand dam systems via scoop holes of sand dams were extended on studies conducted on rivers as the latter form the major inflows into the former while measurements in shallow wells were also compared to previous studies conducted on boreholes in the region as the two only differ from depth sizes. Shallow wells are normally less than 20 m deep and rarely up to 30 m while boreholes can be greater than 50 m and can reach 300 m (Danert, 2015). Therefore, the single study, up to date, that specifically assessed metals in sand-dam water, showed that the levels of Fe, Mn, Zn and Cu were in the ranges of 0.074 to 4.22 mg/L, 0.91 to 4.55 mg/L, <0.01 to 0.71 mg/L and <0.01 mg/L respectively (Ndunge et al., 2019). On the contrary, however, their results showed higher concentrations of Mn compared to 0 to 0.3 mg/L and almost undetectable Cu in scoop holes and shallow wells, compared to mean values of 1.63 (0-7.9 mg/L) in scoop holes and 0.89 (0.01-2.4 mg/L) in shallow wells. Wambu et al. (2015) evaluated Cu levels in various sources in Siaya County (Kenya) and found that 20% of borehole samples (N=5) exceeded WHO limit (≤ 2 mg/L) in the range from 0.72 to 2.63 mg/L (avg. 1.59 mg/L); 38% of dams and open pans (N= 26) didn't comply with it in the range from from 0.15 to 3.34 mg/L (avg. 1.58 mg/L). Ombaka and Gichumbi (2012) measured some trace metals in Ruguti river in Meru South (Kenya) and concentrations were found to be 2.51 mg/L (Fe), 0.29 mg/L (Mn), 0.23 mg/L (Zn), undetected Cr and Cu.

Njuguna et al. (2017) assessed Nairobi river water quality and some of the trace metals were found to be 11.9 mg/L (Fe), 9.89 μg/L (Cu), 2.915 mg/L (Mn), 2.568 mg/L (Zn) and 0.05 mg/L (Cr). Mwamati et al. (2017) measured Fe levels in boreholes in Yatta Plateau in Kitui County, Kenya and were found to be in the range of 0.01-1.63 mg/L. Based on the present findings and previous findings, it is remarked that concentration levels of Cu and Fe vary from region to region and from one water source to another.

Potential sources of trace metals in sand-dam water

In this section, much emphasis was put on Fe and Cu elements as they were ones found to exceed the set guideline values. Firstly, possible sources of Cu, Fe, Mn, Zn and Cr contamination in sand-dam water are presumably associated with contaminants brought by surface runoffs from different places, especially metal works such as welding and metal fabrication workshops, iron ore mining areas, oil stations and garages, slaughterhouses, demolitions, dumped metallic items, rusting of metallic structures like bridges, iron bars in faulty sand dam walls, Cu pipes and so on. Secondly, in addition to aforementioned possible sources, the contribution of natural metal abundance in Earth's crust cannot be neglected. Fe is the 4th most abundant element (about 5% by weight) and the 2nd abundant metal after aluminium (Krebs, 2006; Al-Fartusie and Mohssan, 2017). Mn is the 12th most abundant element (about 0.1% by weight) and the 5th most abundant metal (Nordberg et al., 2015). Cr is the 17th most abundant element (about 0.02% by weight) occurring in water in the +3 and +6 oxidation states (Izbicki et al., 2008; Chirilă and Drăghici, 2008). Zn is the 24th most abundant element (about 0.013% by weight) occurring in low concentrations in water as Zn ores are slightly soluble (Chirilă and Drăghici, 2008; ul Hassan et al., 2017). Lastly, Cu is the 26th abundant element (about 0.007% by weight), a reddish metal naturally occurring metal that is found in rock, soil, water and sediment and in air at low levels (ATSDR, 2004; Krebs, 2006; Chirilă and Drăghici, 2008). Generally, copper occurs in nature in one of four oxidation states; copper (0), copper (I), copper (II), and copper (III) rarely occurring copper in water (Georgopoulos et al., 2001) while Cu occurs in two oxidation states, the divalent or ferrous form (II) and the trivalent or ferric form (III) and it is also tested in water samples as total Fe after sample oxidation (Kaasalainen et al., 2016).

The third and final possibility of presence of higher Cu and Fe concentrations measured in scoop holes than in shallow wells may be associated with hydrometeorological factors such as floods, droughts, landslides or mudslides and anthropogenic activities. Top soil appearance in the study area was perceived to sandy red soil which is normally consisting of kaolinite, iron and copper oxides. Heavy metals in soils can also originate from mineralization and weathering of rocks found within the region area (Mulwa, Maina, & Patel, 2012) and then, can reach water sources through stormwater runoffs. Nzeve, et al. (2014) showed that sediments in some water reservoirs in nearby regions contain trace metals. In their study on sediments from Masinga reservoir, trace metal concentrations were measured and found to be in the ranges of 5.2- 34.64 mg/Kg (Cu), 138.75-937 mg/Kg (Mn), 5.2-100.35 mg/Kg (Zn) and 7.5-77.6 mg/Kg (Cr). In short, there are many possible sources that can accelerate the presence of metals in sand dam systems, operating in open environment. Anything from anywhere can easily reach made up of self-packed riverbed sediments.

LIMITATIONS

In this study, the selection of sites was done on the basis of convenience and with a specific goal. Therefore, there may have been a selection bias as we wanted to select sand dam systems with at least two water abstraction methods, able to generate samples and easily accessible to facilitate the transport of samples, sampling equipment and water testing kits. It was limited to sampling from scoop holes and shallow wells adjacent to sand dams. In order to get a comprehensive picture of physicochemical and bacteriological qualities of water within the entire sand-dam system, piezometers should have been installed at various points to provide supplementary water samples as they can reproduce quasi-comparable measurements compared to scoop holes, which are very unstable. The study didn't also establish any association between the detection of E. coli bacteria in sand-dam water and the occurrence of water-borne diseases in the community under study area and no deep investigation into the relationship between concentration levels and contamination sources. Therefore, there are needs to conduct further studies aiming at identifying specific sources of pollution, studying completely annual and seasonal changes in water quality, isolating occurrences of bacterial contamination and correlating them to waterborne diseases in the region. There are also needs to discern impacts and contributions of hydrogeochemical processes in the hydrologic cycle, geological formations and municipal sewerage systems to sand-dam water quality dynamics in the region. As arid and semi-arid areas supports nomadic pastoralism with two major challenges i.e. limited availability of pasture and water; future studies should also seek to better understand the impact of open-range ranching pastoralism and strategic siting of sand dams within catchments on water quality integrity as sand dams operate in unprotected environments and also create environment attracting both wild and domestic animals due to revitalized riverbanks. All above studies may lead to discern point and non-point sources of pollution or other events occurring within catchments that lead to degradation of water quality. This can help to prevent potential contamination or to undertake operational strategies to restore its integrity once it is deteriorated. All of these aforementioned limitations constitute the potential focal points for future investigations.

Conclusions

The present study investigated the quality and suitability of water from rainwater harvesting systems commonly known as "sand dams", adopted in many arid and semi-arid regions, especially in developing countries as sources of domestic water supply. Kenya, a country with 89% of its land mass classified as drylands, was selected as a typical arid and semi-arid case study and is the region where the use of sand dam technologies has gained full development, especially in rural areas. These sand dams are simply impermeable concrete walls constructed across and along seasonal rivers to store water during rainy season for later use in dry season. The stored water gets filtered in uncontrolled manner through natural seepage processes within sandy sediment layers. Local people access it by digging scoop holes into sediments or pumping it via shallow wells constructed adjacent to sand dam riverbanks and or riverbed infiltration galleries and many others. Among these methods, our study assessed the two commonly used methods i.e. scoop holes and shallow wells. The results showed that each method has its own efficiency level in protecting from water from being contaminated in the storage and during fetching process at the sites. The water quality results for these two methods, coupled with previous findings, allowed us to conclude that sand dams provide unsafe water for direct human consumption in its raw form. This type of water needs first to be purified so that it can be used for domestic purposes. Shallow wells provide water that is physicochemically fit but microbiologically unfit with minimal health risks while water abstracted via scoop holes is both physicochemically and microbiologically unfit with high potential health risks. Therefore, the use of scoop holes as sand-dam water abstraction method for domestic purposes should be discouraged. With this method, major parameters mainly pertaining to the colour of water unsatisfactorily adhered to KEBS limits with low compliance rates, i.e. turbidity (18%); copper (48%) and iron (9%) of samples taken in scoop holes compared to 100%, 73% and 87% of samples taken from shallow wells respectively. Microbiological parameters i.e. E.coli bacteria and total coliforms also scored low rates as 48% and 6% in scoop holes and 87% and 53% in shallow wells respectively. Shallow wells were also found with very low BOD level while scoop holes were somewhat polluted. In regard to the trace metal toxicity and health risk, both water sources met considerably the allowable limits set for manganese, chromium and zinc but scoop holes exhibited higher iron and copper concentrations in samples taken during rainy season than in shallow wells. This is an indication that their presence is linked with surface runoff pollution. These results for these two methods, coupled with previous findings, allowed us to conclude that sand dams provide unsafe water for direct human consumption in its raw form. This is the type of natural water that needs first to be purified so that it can be used for domestic purposes. Thus, with the observed high dependence on sand dams via traditional scoop holes and limited alternative water sources in the region, it calls for utilization of disinfectant by-products (DBPs) and household-level water purification strategies to increase its potability.

RECOMMENDATIONS

Based on field observations and the results of this research, the following recommendations are proposed with regard to preserving water quality and improving the health and well-being of people:

- It is recommended that sand-dam water should continuously be monitored so that public awareness is raised when new contaminants emerge or existing ones become intense.
- Though the use of DBPs is recommended for both water from shallow wells and scoop holes, water intended for drinking apart from other domestic uses should be boiled as some studies showed that some microorganisms survive after treatment with DBPs such as water guard (Tersagh et al., 2015). And also, water chlorination with DBPs should be controlled and used with caution as their reaction with water and other chemical compounds may generate chemical compounds such as halogenated organic by-products like trihalomethanes (THMs), which are potential carcinogens (Mishra et al., 2014).
- The comparison of the two abstraction methods showed that scoop holes are less suitable for domestic water supply source than shallow wells. Scoop holes can only be left for livestock watering and irrigation practices and for domestic water supply; they can be replaced by other improved abstraction methods like riverbed infiltration galleries wherever the shallow wells are impractical.
- The construction of sanitation facilities, septic tanks, public sewages and dumpsites should consider the locations of sand dams to avoid incidental contamination as abandonment of some sand dams due to upstream dumpsites was observed.
- It is also recommended that local people should avoid sharing water access points with livestock and wild animals because they use scoop holes left behind and people reuse them after animals have left.
- The use of scoop holes in the vicinity of shallow wells should be avoided because field observations showed that they contribute, to some extent, to their contamination as shallow wells are normally sited in unconsolidated sediments near riverbanks to allow water seeping from sand dam sediments reach them.
- Finally, if not no appropriate measures are taken, the continuous use of sand-dam water via the traditional scoop holes may lead, in an unnoticed way, to prolonged exposure of intakes of chemical, microbial and metal contaminants that, in their turn, can lead to chronic health effects in the future.

CONFLICTS OF INTEREST

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

This research was supported by African union research grant through Pan African University‘s Institute for basic Sciences, Technology and Innovation (PAUSTI). The

Jomo Kenyatta University of Agriculture and Technology (JKUAT) is sincerely acknowledged for having provided different equipment and facilities including but not limited to lab facilities, free access to electronic sources, equipment such as GPS units, field water testing kits and technical guidance. Our sincere thanks are extended to all unmentioned people who were involved in this research work in one way or another and to the anonymous reviewers for their constructive comments and suggestions that helped to improve this manuscript.

REFERENCES

Abila R, Mutemi M, Mutuku E, Mutati K, Mutinda M, Musyoka CM (2012). Physico-chemical and bacteriological quality assessment of shallow wells in Kitui town, Kenya. Journal of Environmental Science and Water Resources 1(2):27-33.

Ahmed KM, Haroun MA, Mahyoub JA, Al-Solami HM, Ghramh HA (2017). Environmental Impacts of the liquid waste from Assalaya Sugar Factory in Rabek Locality, White Nile State, Sudan. International Journal of Environment, Agriculture and Biotechnology 2(4):1493-1504.

Al-Fartusie FS, Mohssan SN (2017). Essential Trace Elements and Their Vital Roles in Human Body. Indian Journal of Advances in Chemical Science 5(3):127-136.

Avis O (2016). A Microbial Analysis of Water in Sand Dams and Associated Abstraction Methods. 7th Rural Water Supply Network (RWSN) forum "Water for everyone" from 29th November – 2nd December, 2016 (pp. 1-19). Abidjan, Côte d'Ivoire: Rural Water supply network (RWSN). pp. 1-19.

ATSDR (2004). Toxicological profile for Copper. Atlanta, Georgia: U.S. Department of Health and Human Services, Public Health Service Agency for Toxic Substances and Disease Registry (ATSDR). Retrieved March 20, 2018, from: https://www.atsdr.cdc.gov/ToxProfiles/tp132.pdf.

Chirilă E, Drăghici C (2008). Contamination of Soils by Waste Deposits. In: V. Sargsyan & L. Simeonov, eds. Soil Chemical Pollution, Risk Assessment, Remediation and Security. Dordrecht: Springer Netherlands pp. 13-26.

CGoK (County Government of Kitui) (2014). Kitui County Integrated Development Plan 2013- 2017. Kitui: County Government of Kitui (CGoK), Republic of Kenya. Retrieved August 20, 2017, from https://cog.go.ke/downloads/category/82-county-integrated-development-plans-2013-2017?download=134:kitui-county-integrated-development-plan-2013-2017.

Danert K (2015). Manual Drilling Compendium. St Gallen, Switzerland: Skat Foundation, Rural Water Supply Network Publication 2. Retrieved March 2018, from: https://www.ircwash.org/sites/default/files/1-653-3-1423242064.pdf.

Davies J, Barchiesi S, Ogali CJ, Welling R, Dalton J, Laban P (2016). W Water in drylands: Adapting to scarcity through integrated management. Gland, Switzerland. International Union for Conservation of Nature (IUCN), DOI: http://dx.doi.org/10.2305/IUCN.CH.2016.06.en

Department of water affairs and forestry (DWAF) (1998). Quality of Domestic Water Supplies – Vol. 1 Assessment Guide. Department of Water Affairs and Forestry, Pretoria.

FDH (2015). Chemicals in Private Drinking Water Wells. Fact Sheet for iron. Tallahassee, Florida: Florida Department of Health (FDH). Retrieved March 20, 2018 from: http://www.floridahealth.gov/environmental-health/drinking-water/_documents/iron-fs.pdf

Georgopoulos PG, Roy A, Yonone-Lioy MJ, Opiekun RE, Lioy PJ (2001). Environmental copper: its dynamics and human exposure issues. Journal of Toxicology and Environmental Health Part B: Critical Reviews 4(4):341-394.

Government of the Republic of Kenya (GoK) (2012). Development Strategy for Northern Kenya and Other Arid Lands, Nairobi: "Retrieved January 20, 2018, from https://www.medbox.org/vision-2030-development-strategy-for-northern-kenya-and-other-arid-lands/download.pdf"

Government of the Republic of Kenya (GoK) (2017). National Policy for the Sustainable Development of Arid and Semi-Arid Lands, Nairobi, Kenya. Retrieved August 31, 2018, from: http://devolutionasals.go.ke/wp-content/uploads/2018/03/ASAL-POLICY-August-2017-.pdf

Hach (2012). Water Analysis Handbook (7th ed.). Loveland, Colorado, U.S.A.: Hach Company, PDF Book. Retrieved August 16, 2018, from http://www.prosess-styring.no/nedlasting/prosman/dr6000/WAH_2012/DOC086.52.01000.pdf

Hazelton P, Murphy B (2016). Interpreting Soil Test Results: What Do All the Numbers Mean? (3rd ed.). Collingwood, Australia: CSIRO publishing.

Hocking MB (2005). Water quality measurement. In M. B. Hocking, Handbook of Chemical Technology and Pollution Control (3rd ed., pp. 105-135). San Diego, California, USD: Elsevier Inc.

Huho JM, Mugalavai EM (2010). The Effects of Droughts on Food Security in Kenya. The International Journal of Climate Change: Impacts and Responses 2(2):61-72.

Izbicki JA, Ball JW, Bullen TD, Sutley SJ (2008). Chromium, chromium isotopes and selected trace elements, western Mojave Desert, USA. Applied Geochemistry 23(5):1325-1352.

Janke R, Moscou R, Powell M (2006). Citizen Science Water Quality Testing Series. PK-13 W-6 Total Coliform and *E. coli* Bacteria, Kansas State University.

Kaasalainen H, Stefánsson A, Druschel GK (2016). Determination of Fe (II), Fe (III) and Fetotal in thermal water by ion chromatography spectrophotometry (IC-Vis). International Journal of Environmental Analytical Chemistry 96(11):1074-1090.

KEBS (2015). Kenya Standard (KS EAS 12: 2014, First Edition) Specifications for potable water, Nairobi, Kenya: Kenya Bureau of Standards.

Kimani MW, Gitau AN, Ndunge D (2015). Rainwater Harvesting Technologies in Makueni County, Kenya. Research Inventy: International Journal of Engineering and Science 5(2):39-49.

Kitheka JU (2016). Seasonal river channel water exchange and implications on salinity levels in sand dams: Case of semi-arid Kitui Region, Kenya. Journal of Environment and Earth Science 6(12):66-85.

KNBS (2013). Exploring Kenya's Inequality: Kitui County. Nairobi: Kenya National Bureau of Statistics (KNBS) and Society for International Development (SID). Retrieved from http://inequalities.sidint.net/kenya/wp-content/uploads/sites/2/2013/09/Kitui.pdf

Kosgey J (2013). Determination of selected heavy metals pollutants and physico-chemical parameters in sediments and water: a case study of River Athi, Machakos County, Eldoret, Kenya: s.n.

Krebs RE (2006). The History and Use of Our Earth's Chemical Elements: A Reference Guide. 2nd ed. Connecticut: Greenwood Press.

Kunz RG (2009). Appendix D. What Is BOD and How Is It Measured?. In: Environmental Calculations: A Multimedia Approach. Hoboken (New Jersey): John Wiley and Sons, Inc., DOI: 10.1002/9780470925386.app4, pp. 543-558.

Kwamboka RM (2018). Impact of Anthropogenic Activities on Water Quality: the Case of Athi River in Machakos County, Kenya. Journal of Environmental Science, Toxicology and Food Technology 12(4):1-29.

Lasage R, Aerts JC, Verburg P, Sileshi AS (2015). The role of small scale sand dams in securing water supply under climate change in Ethiopia. Mitigation and Adaptation Strategies for Global Change 20(2):317-339.

Maddrell S (2016). Securing water supplies with sand dams. *Ingenia,* March, Issue 66:26-32.

Maddrell S, Neal I (2012). Sand dams: A Practical Guide. London, UK: Excellent Development Ltd., Retrieved from: https://www.samsamwater.com/library/Maddrell_and_Neal_2012_Sand_Dams_a_Practical_Guide_LR.pdf.

Maddrell S, Neal I (2013). Building sand dams: A practical guide, London, UK: Excellent Development, Retrieved on May 16, 2018 from:

http://www.rainfoundation.org/wp-content/uploads/2017/10/Sand-Dam-Manual-Version-2-review-copy-1.pdf.

Manivanan R (2008). Water Quality Modeling: Rivers, Streams and Estuaries. New Dheli, India: New India Publishing Agency.

Mishra BK, Gupta SK, Sinha A (2014). Human health risk analysis from disinfection by-products (DBPs) in drinking and bathing water of some Indian cities. Journal of Environmental Health Science and Engineering 12(1):73.

Mulwa BM, Maina DM, Patel JP (2012). Multielemental Analysis of Limestone and Soil Samples of Kitui South (Kenya) Limestone Deposits. International Journal of Fundamental Physical Sciences 2(4):48-51.

Muthini AD, Munguti KK, Appleford G, Odero V, Wendy E, Swai A (2014). Tapping Water Resources and their Potential in the Arid and Semi Arid Lands: The Case of Marsabit County, Kenya. Nairobi: Concern Worldwide.

Mutunga E, Ndungu C, Muendo P (2018). Factors Influencing Smallholder Farmers' Adaptation to Climate Variability in Kitui County, Kenya. International Journal of Environmental Sciences and Natural Resources 8(5).

Mwamati FT, Kitheka JU, Njuru GP (2017). An Assessment of the Spatial and Temporal variations of Groundwater quality in Yatta Plateau in Kitui County, Kenya. Journal of Environment and Earth Science 7(1):90-104.

NDMA (2018). Kitui County: Drought Situation and Early Warning Phase Classification. Drought Early Warning Bulletin, p. 9. Nairobi, Kenya: National Drought Management Authority (NDMA). Retrieved March 16, 2019, from https://reliefweb.int/sites/reliefweb.int/files/resources/Kitui-December-2018.

Ndunge D, Mbuge DO, Omuto CT (2019). Protocol for Evaluating Sand Dam Water Quality in Semi-Arid Areas: A Case Study of Makueni County. IOSR Journal of Engineering 09(1):1-14.

Nilsson A (1988). Groundwater Dams for Small-Scale Water Supply. London, UK: Intermediate Technology Publications, DOI: https://doi.org/10.3362/9781780442297.001.

Njoka JT, Yanda P, Maganga F, Liwenga E, Kateka A, Henku A, Mabhuye E, Malik N, Bavo C, Schubert C (2016). Kenya: Country situation assessment. Nairobi: Pathways to Resilience in Semi-arid Economies (PRISE), PDF document accessible from:http://prise.odi.org/wp-content/uploads/2016/01/Low-Res_Kenya-CSA.pdf.

Njuguna SM, Yan X, Gituru RW, Wang Q, Wang J (2017). Assessment of macrophyte, heavy metal, and nutrient concentrations in the water of the Nairobi River, Kenya. Environmental monitoring and assessment. Environmental monitoring and assessment 189(9):454 (1-14).

Nordberg GF, Fowler BA, Nordberg M (2015). Handbook on the Toxicology of Metals. 4th ed. s.l.: Academic Press, DOI: https://doi.org/10.1016/C2011-0-07884-5.

Nzeve JK, Kitur EC, Njuguna SG (2014). Determination of Heavy Metals in Sediments of Masinga Reservoir, Kenya. Journal of Environment and Earth Science 4(20):125-132.

Ombaka O, Gichumbi JM (2012). Water quality assessment of Ruguti River in Meru South, Kenya. International Journal of Water Resources and Environmental Engineering 4(12):404-414.

Onyango-Ouma W, Gerba CP (2011). Away-from-home drinking water consumption practices and the microbiological quality of water consumed in rural western Kenya. Journal of Water and Health 9(4):628-636.

Pachepsky YA, Shelton DR (2011). Escherichia coli and fecal coliforms in freshwater and estuarine sediments. Critical reviews in environmental science and technology 41(12):1067-1110.

Palintest. (2015). Methods for water and environmental analysis: Palintest Spectrophotometer and Direct-Reading Photometers. Gateshead, Tyne and Wear, England, UK: Palintest Ltd. Retrieved May 18, 2018, from https://www.palintest.com/application/files/4614/8465/2880/Photometer_Test_Methods.zip

Petersen EN, de Trincheria J (2015). How to get more water from sand dams – for half the cost. International Symposium on RWH. Dire Dawa, Ethiopia.

Quinn R, Avis O, Decker M, Parker A, Cairncross, S (2018). An Assessment of the Microbiological Water Quality of Sand Dams in Southeastern Kenya. Water 10(6):708.

Radojevic M, Bashkin VN (1999). Practical Environmental Analysis. Cambridge, England, UK: The Royal Society of Chemistry. DOI: https://doi.org/10.1039/9781847551740.

Ryan C, Elsner P (2016). The potential for sand dams to increase the adaptive capacity of East African drylands to climate change. Regional Environmental Change pp. 1-10.

Sengupta PK (2018). Industrial Water Resource Management: Challenges and Opportunities for Corporate Water Stewardship. s.l.:John Wiley and Sons Ltd.

Solo-Gabriele HM, Wolfert MA, Desmarais TR, Palmer CJ (2000). Sources of Escherichia coli in a coastal subtropical environment. Applied and Environmental Microbiology 66(1):230-237.

Tersagh I, Dooshima N, Onaji JP (2015). Efficacy of Water Guard Disinfectant as a Domestic Stored Water Treatment Method in Makurdi Metropolis. Research Journal of Environmental Sciences 9(8):364-369.

ul Hassan Z, Ali S, Rizwan M, Hussain A, Akbar Z, Rasool N, Abbas F (2017). Role of zinc in alleviating heavy metal stress. In Essential Plant Nutrients (pp. 351-366): Springer, Cham.

UNEP/WHO. (1996). Assessment of the state of microbiological pollution of the Mediterranean Sea. Athens: United Nations Environment Programme (UNEP). Retrieved April 4, 2019, from https://wedocs.unep.org/bitstream/handle/20.500.11822/546/mts108.pdf?sequence=2&isAllowed=y

Verhille S (2013). Understanding microbial indicators for drinking water assessment: interpretation of test results and public health significance, Vancouver, British Columbia, Canada: s.n.

Wambu EW, Omwoyo WN, Akenga T (2015). Excessive Copper(II) and Zinc(II) Levels in Drinkable Water Sources in Areas Along the Lake Victoria Shorelines in Siaya County, Kenya. Bulletin of environmental contamination and toxicology 96(1):96-101.

WASREB (2009). Drinking water quality and effluent monitoring guidelines. Nairobi, Kenya: Water Services Regulatory Board (WASREB) in support of GTZ. Retrieved February 3, 2018, from: http://www.waterfund.go.ke/toolkit/Downloads/2.%20Drinking%20Water%20Guidelines.pdf

Wen Y, Schoups G, Van de Giesen N (2017). Organic pollution of rivers: Combined threats of urbanization, livestock farming and global climate change. Scientific Reports 7:43289.

World Health Organization (WHO) (1997). Guidelines for Drinking water Quality (2nd ed., Vol. II). Geneva, Switzerland: World Health Organization. Retrieved May 9, 2019 from: http://www.who.int/water_sanitation_health/dwq/gdwqvol32ed.pdf

World Health Organization (WHO) (2003a). Total dissolved solids in Drinking water, Geneva, Switzerland: World Health Organization, Publication No.WHO/SDE/WSH/03.04/16.

World Health Organization (WHO) (2003b). Iron in Drinking-water, Geneva, Switzerland: World Health Organization, accessible from: https://www.who.int/water_sanitation_health/dwq/chemicals/iron.pdf.

World Health Organization (WHO) (2004). Copper in Drinking-water, Geneva, Switzerland: World Health Organization.

World Health Organization (WHO) (2017a). Guidelines for drinking-water quality: Fourth edition incorporating the first addendum, Geneva, Switzerland: World Health Organization.

World Health Organization (WHO) (2017b). Water quality and health - Review of turbidity Information for regulators and water suppliers. [Online]
Available at: http://apps.who.int/iris/bitstream/10665/254631/1/WHO-FWC-WSH-17.01-eng.pdf [Accessed 25 December 2018].