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An Assessment of the Microbiological Water Quality of Sand Dams in Southeastern Kenya

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Received: 7 March 2018; Accepted: 24 May 2018; Published: 31 May 2018

Abstract: Sand-storage dams have proven to be a successful water harvesting method and potential solution to water and food security issues in semi-arid regions such as south east Kenya. This paper examines the microbiological quality of water both contained in the sand dam via test holes and abstracted from it through covered wells and scoop holes. In total, the values of thermotolerant coliform (TTC) concentration, turbidity, and pH are presented for 47 covered wells, 36 scoop holes, and 29 test holes, as well as the conductivity values in conductivity in 39 covered wells and 11 scoop holes. The water from test holes and covered wells was microbiologically of better quality than the scoop holes with median TTC levels of 0/100 mL and 159/100 mL respectively. However, the median values of turbidity for both scoop holes (20–30 NTU) and covered wells (5–10 NTU) exceed the World Health Organisation (WHO) guideline values. In addition the conductivity of water from 23% of scoop holes and 26% of covered wells is above the recommended WHO limit. This study also found that sanitary surveys are not a useful indicator of water quality in sand dams; however, they can identify areas in which sanitation and improvement of water sources are needed.

Keywords: microbiology; faecal contamination; sand dam; sanitary inspection

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1. Introduction

Two major expected impacts of climate change in semi-arid regions such as southeast Kenya are temperature rises and recurrent drought [1]. These changes in climate are predicted to result in shorter more intense periods of precipitation, as opposed to the longer rainy seasons as historically experienced [2]. This will have a detrimental effect on the socioeconomic development of rural areas as they are dependent on rainfall for crop irrigation: agriculture forms the bulk of household income in the region [3,4]. It will also increase the population living in water stressed conditions by 36% by 2050 [5].

One approach to combat these detrimental effects is to increase the storage capacity creating water reserves which can be used during dry periods. To achieve this, small scale local systems, which emphasise local experience in natural methods of water capture, filtration, storage, and release, have been encouraged [6]. Sand dams, which have been successfully implemented in several semi-arid countries, are an example of such a system. A sand dam (Figure 1a) consists of a reinforced wall constructed during the dry season across a seasonal riverbed. During the rainy season, the sand carried by the river is deposited behind the wall (Figure 1b); over a period of years this accumulates until it is level with the top of the dam. Up to 40% of the volume of sand is filled with water from the seasonal river which can then be abstracted by the local community during the dry season. The water is filtered when it passes through the sand, improving water quality in the same manner as a slow sand filter [7].

Figure 1. The sand dams and their water abstraction methods.

By storing water in the sand, evaporation losses are decreased resulting in a greater quantity of potable water than similar sized surface water reservoirs [7]. Another advantage of keeping the water contained is that it eliminates the possibility of creating breeding grounds for insects [7].

Madrell and Neal [8] published a comprehensive set of guidelines for the design of sand dams. Research has focused on their capacity for maintaining vegetation during drought [9], hydrological processes, and water movement around them [10,11], and their impact on a catchment scale [7,12,13]. However, there has been no examination of the quality of water held within them. Good water quality is essential if they are to be used for domestic purposes. Human exposure to water polluted by faecal bacteria can lead to numerous diseases causing fever, diarrhoea, and ultimately death [14]. Therefore, it is necessary to ensure the water contained in these dams is safe to drink.

To date only one study has evaluated the water quality in sand dams. Kitheka [15] examined the variations of salinity and turbidity but not faecal contamination in the naturally forming sand deposits of seasonal rivers and found that turbidities of water abstracted from sand dams could be higher than traditional groundwater sources. This was attributed to the influence of surface runoff during the rainy season depositing clay mud in certain sections of the sand dam.

Water quality may also be affected by the abstraction method with boreholes found to be the safest source in comparison to hand dug wells and open water [16,17].

Faecal contamination is highly variable with higher concentrations found during the wet season [18]. Therefore it is recommended that water quality measurements be combined with sanitary status to obtain an overall picture of the safety of the source [16].

Thus, the aim of this research was to assess both the microbiological safety of water contained in the dam (through test holes) and the safety of water abstracted by the local population (through scoop holes (Figure 1c) and covered wells (Figure 1d)).

As poor construction or maintenance of the source improvements can also lead to unsafe water, the researchers conducted sanitary surveys to examine whether there was a correlation between poor management and maintenance practices and contaminant levels.

2. Materials and Methods

2.1. Field Area

The study location was the Machakos and Makueni counties in south eastern Kenya. This is a semi-arid region subject to erratic rainfall and long periods of water scarcity. The average annual rainfall is 600 mm and rainfall is characterized by small total amounts, strong seasonal, and bimodal distribution [19]. The area experiences erratic rainfall distributed in two rainy seasons, known as the long and short rainy seasons. Long rains occur from March to May and the short rains from November to December, with the short rains being more reliable than the long rains. According to Gichuki [20], 60% of the annual rainfall is received during the short rains while the long rains and the dry season contribute 37% and 3% of the annual rainfall, respectively.

The dams were chosen based on the local knowledge of field coordinators who were provided with the following criteria:

1. Dams built by the Africa Sand Dam Federation (ASDF) to facilitate access.
2. Water table within three metres of the dam surface to ensure samples could be gathered.
3. Shallow wells or scoop holes have to be used for domestic purposes.
4. Dam surface not obscured by water to enable excavation when necessary.

All of the sand dams were located in rural areas, adjacent to local settlements and farms. The surrounding areas comprised of vegetation, bare sandy clay soil, and farmland. Various sources of contamination exist in these catchment locations. These include refuse from local markets and settlements, agricultural runoff, and livestock pollution. The banks are comprised of large boulders and rocks or sandy clay and clay sediment was present in the accumulated sand. The accumulated sand has been found to be a coarse mix of fine, medium and coarse sand with layers of silt, clay, and organic material interspersing the layers of sand [21].

The shallow wells were all constructed and designed with similar material under the supervision of ASDF in accordance with their standards. In addition, all the communities received training on good water collection and hygiene practices by ASDF staff members similar to that recommended by RAIN [22].

2.2. Water Quality Indicators

There are many standards used to measure water quality, this study will use the national Kenyan Bureau of Standards (KEBS), East African Standard for Potable Water, and the international World Health Organisations (WHO) guidelines. A comparison of these standards is given in Table 1.

Microbial water quality was assessed based on the thermotolerant coliform (TTC) concentration of the water samples (TTC/100 mL). TTC are widely used as faecal indicator organisms as they can easily be measured in the field using a simple portable kit [23]. Although some TTC are capable of survival in decaying plant material and soils, studies in shallow groundwater in Uganda found that 99% of the TTC detected were in fact *E. coli* [24].

Turbidity was tested as it is closely correlated with bacterial contamination in surface water [25]. High turbidity can also produce harmful by-products when chlorinated, increase chlorine demand, and protect bacteria during disinfection.

Electrical conductivity measurements can be used to estimate the concentration of dissolved solids in water. High conductivity values indicate a “salty” taste which can result in people rejecting microbiologically safe water in favour of unsafe sources [26].

Lastly pH was measured. Both WHO [27] and KEBS [28] recommend a value of between 6.5 and 8.5 to ensure good chlorination efficiency.

Table 1. The Kenyan Bureau of Standards and World Health Organisation Water Quality Guideline Values.

Water Quality Indicator	KEBS [28]	WHO [27]
TTC (TTC/100 mL)	0	0
Turbidity (NTU)	<5	<1
Conductivity (µS)	N/A	1500
pH	6.5–8.5	6.5–8.5

2.3. Descriptions of Water Sources

Scoop holes are simple holes scooped into the sand. To improve water quality, existing water is scooped out and discarded allowing fresh water to seep into the hole.

Test holes were excavated 50 m upstream of the dam wall. A depth of 8 cm of topsoil was removed from an area of 16 m^2 to avoid contamination from animal droppings on the soil surface. Then, a 0.5 m diameter test hole was excavated until the water table was reached. This was performed in order to collect the water stored in the sand dam which had not been in contact with any possible contamination at the surface. The test hole was dug in a stepped manner alternating sides as progress was made so that when water was reached, the researcher would be standing on a sand step avoiding contamination of the sample with shoes. Upon reaching the water table, hands were cleaned and dried. A total of 20 L were abstracted from the test hole with a sterilised bowl.

Covered wells consist of 5 to 10 m deep covered hand dug wells in the adjacent riverbed or in the riverbed itself. The shaft is usually lined with rocks plastered with mortar and most of the time, the well head is composed of a concrete slab, a drainage channel, an apron, and a hand pump. Covered wells visited appeared to be constructed without any sanitary sealing.

2.4. Data Collection

The results presented in this paper are from two distinct field studies. Field study 1 examined the quality of water stored in the sand dam by creating test holes; shallow wells and scoop holes were also examined. Field study 2 aimed to assess and compare the quality of the water abstracted from sand dams through scoop holes and covered wells. The results of both these studies combined address the central aim of this paper to assess both the microbiological safety of water contained in the dam (through test holes) and the safety of water abstracted by the local population (through scoop holes and covered wells). In addition a sanitary survey was carried out. All sampling was taken during the dry season when there were no significant precipitation events and the temperature was approximately constant, so it is not expected that weather had an effect on microbial water quality.

For field study 1, the data were collected from 29 sand dams in Makueni from 3 July–1 August 2014 at locations shown in Figure 2a.

At all 29 dams a scoop hole was excavated and a sample taken, in addition 25 samples were taken from scoop holes and 8 samples were taken from covered wells. At each source, the TTC, turbidity, and pH were measured.

Water samples were collected in pre-sterilised containers. Samples of 50 mL were taken for the test holes. For both the scoop holes and covered wells, 100 mL samples were filtered for the first three samples after which 10 mL samples were taken for more accurate enumeration of TTC. The collection methods used to obtain samples were as follows:

- For a test hole, 20 L was abstracted before taking water samples.
- For a scoop hole, 20 L was abstracted or until the water became clear.
- For a covered well, the pump nozzle would be flamed with a lighter and water pumped for thirty seconds before sampling

Microbiological analysis of the sample was started on site within 15 min of the sample being taken.

For field study 2, data were collected from 50 sand dams in the Machakos and Makueni area from 22 June–18 July 2016 [29] at locations shown in Figure 2b.

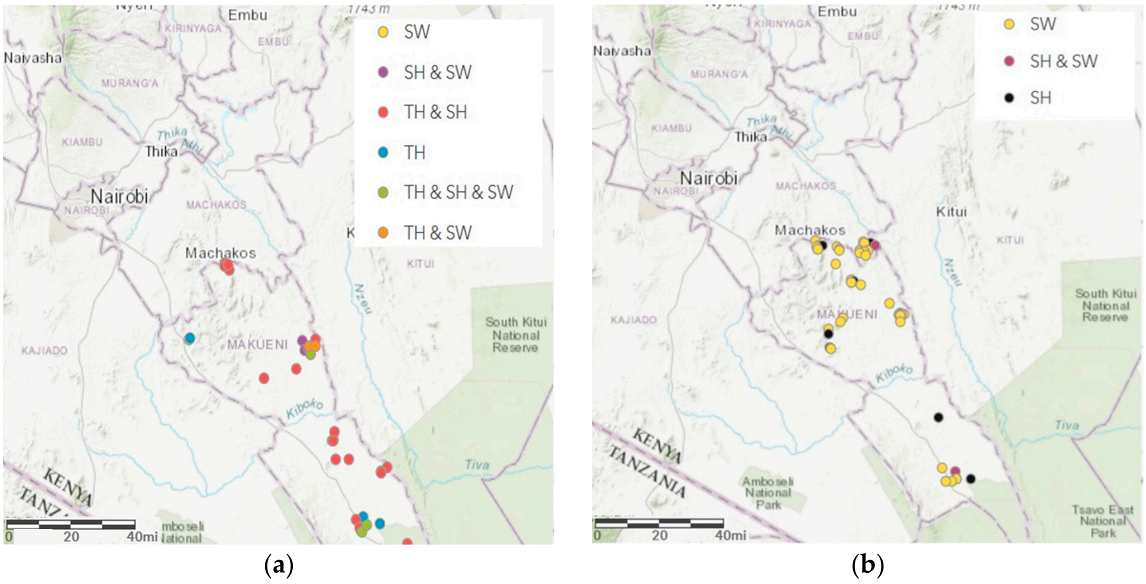

Figure 2. The maps showing the sample sites in (**a**) field study 1 and (**b**) field study 2. SW: shallow well, SH: scoop hole, TH: test hole.

At each sand dam, the population's preferred method of water abstraction was tested. In total, 50 dams were visited, 39 duplicate samples were collected from covered shallow wells, and 11 duplicate samples were collected from scoop holes. At each source, four types of data were collected: turbidty, conductivity, TTC, and pH.

Samples were then collected in pre-sterilised containers. The collection methods used to obtain the samples were as follows:

- For covered wells, water was pumped for thirty seconds before taking water samples.
- In scoop holes, water was first scooped with a sterile cup until the water appeared clear.

Nothing was sterilised at the source, so the sample would be an accurate reflection of the water consumed by the user.

The water samples were stored in dark and cool conditions until they were processed at the last site of the day. The time between sample collection and processing was less than four hours. The research strategy was to collect samples from as many sand dams as possible to get a broad understanding of water quality in sand dams and understand the spatial variations in water quality in sand dams. This meant that sampling only happened at one point in time per dam, and the temporal variations in water quality were not studied.

Because of the unknown degree of contamination, different volumes of water at each sample point were tested. For covered wells, a sample was taken of either 10 or 50 mL and another of 100 mL was taken. For scoop holes, one water sample of 10 mL was taken and another of either 50 or 100 mL.

For both studies, turbidity and pH were measured onsite using a turbidity tube and a pH comparator [23]. In addition, for field study 2, conductivity was measured onsite with hand held probes.

The measurement of TTC for both field studies was performed with portable DelAgua testing kits, which use the membrane filtration method [23]. Firstly, an absorbent pad was placed on a sterilised petri dish and saturated with 2 mL of membrane lauryl sulphate broth (MLSB) liquid growth medium. The sterilised filtration apparatus was assembled with a 0.24 µm cellulose filter membrane in place.

The sample was drawn through the membrane using a vacuum pump. The filter membrane was then removed and placed on the absorbent pads in the prepared petri dish. At least one hour was allowed before incubation for bacterial resuscitation. No more than 4 h can elapse between membrane filtration and incubation. The samples then were incubated for 18 h at 44 °C (±0.5 °C).

Samples were removed from the incubator and yellow bacterial colonies were counted. If two valid counts resulted (that is, both Petri dishes were readable, and neither exceeded 100 counts (the number at which counting inaccuracies are likely to be introduced)), the count from the larger volume sample was used. If two equal volumes were taken, the mean was used. Counts above 100 TTC per plate were considered an estimate.

Although all communities received training in good water collection practices when the dam was first constructed, sanitary surveys were also performed during field study 2 to determine whether the lessons learned were being implemented. The questions were adapted from WHO sanitary survey questionnaires and chosen to identify the different factors which could impact water quality [30]. Three risk factors were investigated: hazard factors, pathway factors, and indirect factors. The surveys were carried out using direct observations.

2.5. Statistical Analysis Techniques

The data (TTC, turbidity, conductivity and pH) collected in this field work were not normally distributed; for example, it was found that for TTC results in covered wells there was a large number of zero values and the distribution had a long tail. Consequently parametric tests (e.g., Student's *t*-test) could not be used to compare samples as they are highly influenced by outlying values, Non-parametric tests, which work with ranks rather than absolute numbers, were therefore used. Fisher's exact test examined the relationship between individual sanitary survey questions and poor water quality. The Kruskal-Wallis test was used to compare the different water source types according to the four different indicators measured: TTC, turbidity, conductivity, and pH. Spearman's rank correlation coefficient assessed whether there was a significant correlation between these parameters; these were performed using Matlab's statistics toolbox.

3. Results

3.1. Comparison of Sources

The distribution of the TTC count and turbidity for field studies 1 and 2 are shown in Figures 3 and 4 respectively. The data for field study 2 can also be accessed at doi: 10.17862/cranfield.rd.6394112. Figure 3 shows that while 83% of test holes and 70% of covered wells met both KEBS [28] and WHO [27] standards for TTC, 89% of scoop holes did not. In addition, 59% of covered wells and 92% of scoop holes did not meet KEBS [28] and WHO [27] standards for turbidity. The turbidity tube only allows the identification of a range of Nephelometric Turbidity Unit (NTU) values so they should be treated as ordinal variables. Turbidity tubes do not allow the measurements of values inferior to 5 NTU. Therefore, a turbidity of less than 5 NTU was considered as meeting WHO [27] guidelines.

The percentage of sources with conductivity below 1500 µS/cm (the WHO guideline) and the median values for TTC, turbidity, conductivity, and pH are presented in Table 2. The values for conductivity are limited to covered wells and scoop holes from field study 2 as the conductivity probe malfunctioned during field study 1. Table 2 shows that although the median conductivities for all water sources were within WHO [27] guidelines, 23% of scoop holes and 26% of covered wells exceeded them. All pH values were within the WHO [27] guideline range of 6.5 to 8.5.

Table 2. The water quality information from sand dam abstraction points.

Source	Number of Sources Visited	% with TTC = 0	Percentage with Conductivity <1500 µS/cm	Median Conductivity (µS/cm)	Median TTC	Median Turbidity (NTU)	Median pH
Covered Wells	47	70 (*N* = 33)	74 (*N* = 35)	824 (SD = 421)	0 (SD = 0)	5–10 (SD = 0–5)	7.3 (SD = 0.3)
Scoop Holes	36	11 (*N* = 4)	77 (*N* = 28)	912 (SD = 515)	159 (SD = 148)	20–30 (SD = 5–10)	7.4 (SD = 0.23)
Test Holes	29	83 (*N* = 24)	N/A	N/A	0 (SD = 0)	20–30 (SD = 5–10)	7.3 (SD = 0.21)

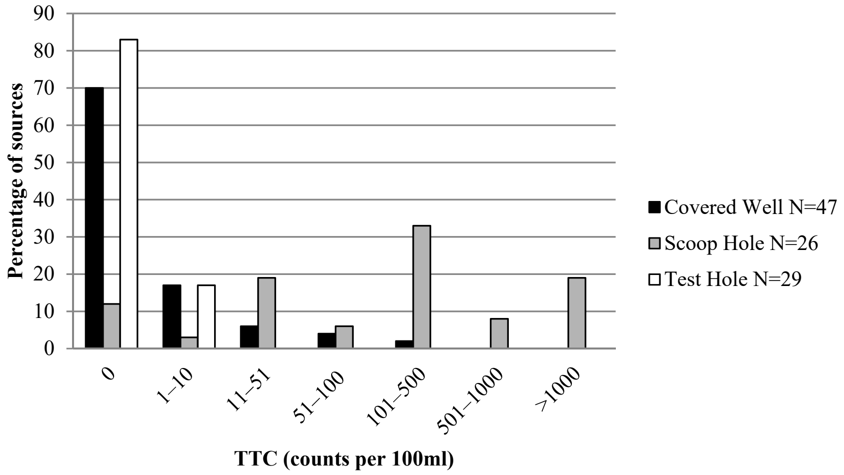

Figure 3. The histogram showing distribution of TTC measurements with different source types. KEBS [28] and WHO [27] guideline value is 0 TTC/100 mL.

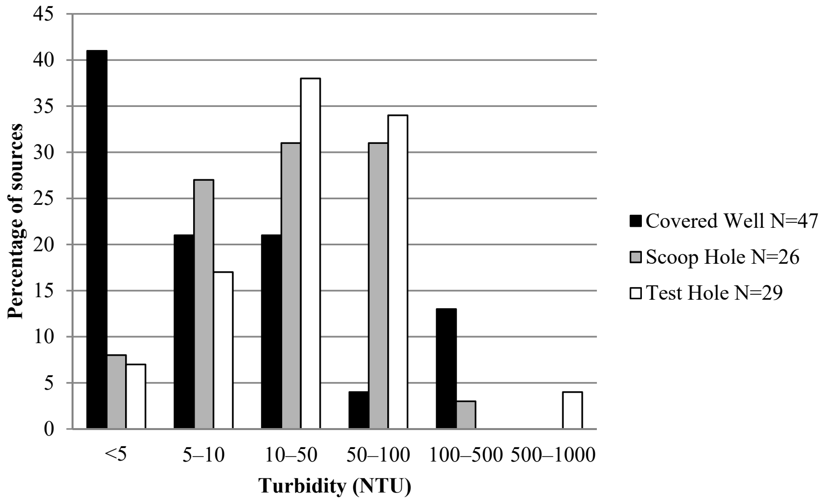

Figure 4. The histogram showing the distribution of turbidity measurements with different source types. KEBS [26] and WHO [27] guideline values are <5 NTU and <1 NTU respectively.

The Kruskal-Wallis test was used to compare the different water source types according to the four different indicators measured: TTC, turbidity, conductivity, and pH. There was no statistically significant difference between the conductivity and pH values of the different sources ($p = 0.94$ and 0.68 respectively). For the TTC count per 100 mL and the turbidity, the results were statistically significant ($p < 0.04$ and <0.01 respectively). This is due to the method the Kruskal-Wallis test uses of ranking the sources by median.

For the TTC count per 100 mL (medians shown in brackets below), it was found that the covered wells (median 0) and test holes (0) are significantly better than scoop holes (159).

In terms of turbidity measured in NTU, the median of covered wells (5–10) was lower than the value for scoop holes and test holes (20–30).

3.2. Comparison between Variables

In order to assess whether there was a significant correlation between the different parameters measured in field study 2 (TTC, turbidity, conductivity, and pH), Spearman's rank correlation was calculated for the test holes scoop holes and covered wells. The age of the dam was also included as it has been suggested that high conductivity is linked to the build-up of dissolved solids in the dam over a number of years [15]. The data regarding the age of the dam were restricted to a smaller sample ($N = 31$) of covered wells as accurate construction data was only available for a limited number of sites. The dams ranged in age between two and 6 years. It was found that there was no significant correlation between any of the water quality parameters (TTC, turbidity, conductivity, pH) and the age of the dams.

3.3. Correlation between TTC and Sanitary Score

The results of the sanitary survey for both covered wells and scoop holes for field study 2 are shown in Tables 3 and 4 respectively.

Table 3. The results of sanitary survey and Fisher's exact test results for association between risk factors identified and presence of TTC for covered wells for field study 2.

Question	Percentage of "yes" Answers ($N = 39$)	Frequency of "yes" Answers ($N = 39$)	*p*-Value for Association between Risk Factors Identified and Presence of TTC
Is there a latrine within 10 m of the well?	0	0	n/a
Is there a latrine on higher ground than the well within 100 m of the well?	10	4	0.56
Is the fencing around the well inadequate to keep animals away?	100	39	n/a
Is the hand-pump loose at point of attachment to the well head?	100	39	n/a
Is the drainage channel around the well cracked, dirty, or broken?	62	24	0.27
Is the concrete apron less than one meter wide all around the well?	54	21	1
Is there poor drainage, allowing stagnant water within two meters of the well?	100	39	n/a
Is the concrete apron around the well cracked?	36	14	0.70
Are the walls of the well inadequately sealed?	15	6	0.31
Is there any other source of contamination within 10 m of the well?	100	39	n/a
Is there any farming activity within 15 m of the well?	41	16	0.44

Fisher's exact test was used to examine whether there was any correlation between individual survey questions and poor water quality. Some of the survey questions had exclusively "yes" or "no" answers for all of the wells and scoop holes visited. For example none of the wells or scoop holes had a latrine within 10 m. These questions were omitted from the statistical analysis, the results of which are shown for wells and scoop holes in Tables 3 and 4 respectively. It is clear for both wells and scoop holes there was no significant association between any of the potential risk factors and the presence of TTC in the water.

The sanitary scores for covered wells and scoop holes were significantly different ($p < 10^{-4}$) with covered wells having a median of 5 potential risk factor out of a possible 11 and scoop holes 6 out of a possible 10. TTC and sanitary score for both sources are plotted against each another in Figure 5 to test how well they compare; Spearman's rank correlation coefficient was calculated for all sources combined ($\varrho = 0.22$ and $p = 0.1$). The results suggest that whilst there was a correlation between TTC and sanitary score, this correlation was weak and only 22% of the variation in TTC was explained by variation in sanitary score. So in the case of this study, the sanitary surveys cannot be used to predict water quality. This may be due to the limited number of surveys completed and a larger data set should be used in the future to examine the potential of sanitary surveys for the prediction of contamination. In addition the Kruskal-Wallis test was used to compare the sanitary score in different areas. It was found that there was a statistically significant difference between the areas of $p = 0.016$.

Table 4. Results of sanitary survey and Fisher's exact test results for association between risk factors identified and presence of TTC for scoop holes for field study 2.

Question	Percentage of "yes" Answers (*N* = 11)	Frequency of "yes" Answers (*N* = 11)	*p*-Value for Association between Risk Factors Identified and Presence of TTC
Is there a latrine within 10 m of the well?	0	0	n/a
Is there a latrine on higher ground than the well within 100 m of the well?	18	2	0.48
Is there any other source of contamination within 10 m of the well?	100	11	n/a
Is the fencing around the well inadequate to keep animals away?	100	11	n/a
Is the riverbed used as a road for cattle?	100	11	n/a
Is there a scoop hole for animal consumption upstream to the scoop hole for human consumption?	64	8	0.49
Has it rained within five days?	0	0	n/a
Do users have direct contact with water during the collection?	100	11	n/a
Is the scoop hole without any protection against runoff?	100	11	n/a
Is there any tree around the scoop hole which could lead to contamination?	46	5	0.52

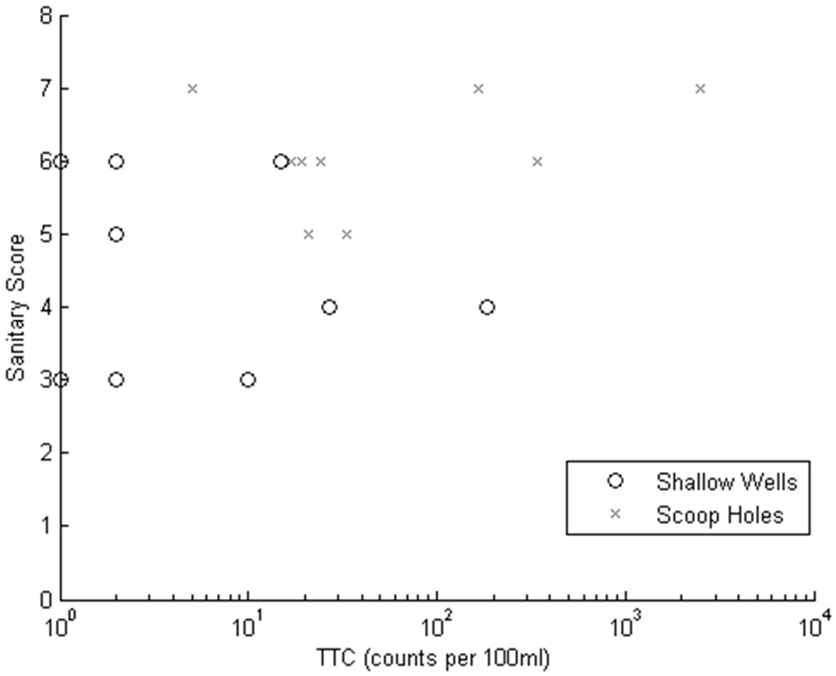

Figure 5. The plot of TTC against the sanitary score for field study 2.

4. Discussion

4.1. Source Comparison

The findings of this research indicate that the water in sand dams adheres to WHO [27] guidelines for maximum TTC concentration. A total of 83% of test holes contained no TTC and 100% had less than 10 TTC per 100 mL indicating a low risk (<10 TTC count per 100 mL). The low concentrations of TTC actually present were attributed to contamination introduced while excavating the holes [31]. This is confirmed by the fact that of the 5 test holes that tested positive for TTC, four were dug in the first three days of sampling. TTC were not seen in later holes as the technique Avis [31] used improved with practice. It is also possible that the contamination was caused by clay or other organic matter present in the accumulated sand. In line with previous research, it was found that covered wells were microbiologically safer than scoop holes [16]. This was expected as the water in covered wells had greater protection from sources of contamination such as animals and human touch. Only covered wells had a median TTC count that met WHO [27] guidelines (zero TTC count per 100 mL), with 70% of covered wells meeting the standard and 87% found to have a low microbiological risk. Only 11% of scoop holes had zero TTC contamination with 14% having a low risk factor. This is contrary to the finding of Sutton [32] who found that open scoop holes could be analogous to fully protected wells if the aquifer is not polluted as they have low storage and, thus, are often replenished through scooping existing water away. This process was observed during field study 2. However, in this study it was found through sanitary surveys that scoop holes exhibited significantly more contamination than covered wells with a median value of 6/11 compared to 5/10. This indicates that in the case of sand dams, contamination is predominantly introduced during abstraction rather than being already present in the sand. From Figure 1, it is clear that some samples from scoop holes resulted in very high values of TTC (>1000 TTC/mL). This could be due to factors such as animals accessing the water or depositing faeces near the scoop hole. This will be examined further in Section 4.3.

The median turbidities for both covered wells and scoop holes exceed KEBS [26] and WHO [25] guidelines. However both values are comparable to other research findings [16,33,34]. Kitheka [15] found that 16% ($N = 6$) of covered wells by naturally deposited sand reservoirs in seasonal rivers experienced turbidity in excess of 100 NTU. The cause of these increased values is unclear. However, 5 out of 6 of these sources are located within 10 km of one another in the Kalawa region of Machakos. This suggests that there may be issues with local construction methods or that material or the sediment deposited by seasonal rivers in this area contains large amounts of clay. Excess turbidity in shallow wells has also been attributed to sand harvesting, which has been found to occur in the region [35,36]. Sand harvesting has become commonplace on some riverbeds [37]. Erosion and movement of sand from the dams could also cause turbidity as this would have a similar effect to sand harvesting. This movement can be caused by leakage underneath or around the dam. This leakage creates holes through which accumulated sand can be moved by flowing water [38]. The turbidity in scoop holes may be attributed to clay present in the sediment trapped behind the dams.

Water conductivity is also of concern with regards to the longevity of sand dams. It has been suggested that evapotranspiration leads to concentration of deposited mineral salts in the dam resulting in water with a high saline content [15]. The results of this field study do not support that hypothesis, however, with no significant correlation between the age of the dam and the conductivity of the water ($p = 0.285$). Conductivity seems to be more strongly linked to area with the Kanthuni, Kibwezi and Kako regions of Makueni, all showing excessive levels. This indicates that it may be geology and rock types which predominately affect conductivity readings as found by Kitheka [15]. Further research is required to determine the origin and composition of the sediment in saline sand dams to determine whether the sediment or the water inflow is the cause of the increased conductivity. The findings of this field study indicate that more comprehensive geological and water sampling surveys should be completed before a dam is constructed to ensure it is not rendered unusable by saline water.

Increased conductivity in semi-arid regions has also been attributed to water logging and inadequate drainage [39]. This is usually combatted by improving drainage or flushing the soil system. In sand dams flushing usually occurs in the rainy season where seasonal rivers displace stagnant water in the sediment. It was found that the region with the highest average conductivity (Kibwezi) experiences on average 155.1 mm less annual rainfall in March to May than the area (Tawa) with the lowest average conductivity [40]. Low rainfall could cause inadequate flushing of salt through the system resulting in higher salinity water.

Kitheka [15] also observed that covered wells located 10 m away from the sand dam had lower conductivity than scoop holes positioned on the dam. This research did not find any significant differences between the conductivities of water from the two types of source tested. However, concurrent measurements of wells and scoop holes were not taken at individual dams. Further research is needed to examine whether, in higher conductivity dams, it may be advantageous to have site wells on the banks of dams as opposed to directly on them.

4.2. Sanitary Survey

Scoop holes had a higher chance of being contaminated than covered wells and this was reflected in higher median TTC concentrations, although there was no significant statistical correlation between the two elements. This is in contrast to previous research which has found a close correlation between high scores (>5) in the sanitary survey and bacteriological contamination revealed by water-quality tests [41].

The results show that there is a statistically significant difference in sanitary survey scores of water sources located in different regions. This did not result in a difference in TTC concentrations between regions, for the reasons listed above. However it is of concern that contamination tends to increase during the rainy season [24]. It is, therefore, recommended to target high scoring areas for further hygiene training and maintenance of water sources.

4.3. Potential Risk Factors

Several factors unique to sand dams were observed during the sanitary surveys. With regards to shallow wells, no sources had adequate fencing to limit contamination from animals within 10 m from the water sources. In this study, donkeys' faeces were frequently found within the fenced area next to the shallow wells as they were permitted to come close to the water source to facilitate loading. Howard et al. [24] demonstrated a correlation between animal faeces and increased concentration of coliforms and faecal streptococci.

Sand dams also generate significant farming activity within the vicinity of the water source. To improve productivity, manure is commonly used. From previous research, a distance of 15 m is advocated between manure application and water sources to avoid water contamination [42]. At 16 of the 39 shallow wells visited (41%) agricultural activities were observed within 15 meters of the well. Sometimes, farming is performed on the riverbanks so when a runoff event occurs, manure which has not been absorbed by the soil is carried and accumulates close to the shallow well due to the lack of drainage channels.

Shallow wells are located on top of the sand dams. This results in the upper part of the well wall, which is above the ground, being exposed to water during the rainy season. This necessitates the adequate sealing of the well to prevent pathogen entry. The sanitary survey results (Table 2) show that 15% of the wells have inadequate sealing, these wells were all found to be surrounded by stagnant water and damage attributed to prolonged water contact observed.

Seasonal flooding makes it technically and economically difficult to construct a concrete apron one meter wide around the hand pump as recommended by WHO [30] guidelines. In this study only 46% of wells had an adequate apron. The concrete apron is important as it prevents any water stagnation close to the well and, consequently, the infiltration of the dirty water back into the aquifer.

Cracks were observed in 62% of the drainage channels and 36% of the aprons respectively. All the shallow wells were built within the last five years and the majority of the cracks were minor. However, the communities have not planned to maintain these sources, which could lead to an increase in the likelihood of water contamination in the future.

As scoop holes are open to the surface, they are highly prone to contamination through seepage and surface runoff contaminated with faecal matter. Nevertheless protection measures can still reduce the risk of contamination. Donkey faeces were found within 10 m of every scoop hole for the reasons listed above. There were attempts at fencing in some areas but this was inadequate for keeping animals away.

One of the advantages of sand dams is that they create a river crossing for the population and animals [8]. Consequently, all rivers were reported to be a crossing point constituting a hazard as fencing was inadequate.

Although all scoop holes visited were used only for human consumption and not for animals, little care was taken to avoid the presence of scoop holes for animals upstream of those used for drinking water. A total of 63% of scoop holes were found downstream of an animal scoop hole.

4.4. Limitations

This study was limited to sampling from test pits, shallow wells, and scoop holes. Additional data points could be gathered by sampling the water contained in the dam at various locations using piezometers. This would give a better understanding of the spatial variability of microbiological contamination within a sand dam. This is important as the greatest changes in microbial community and structure has been detected in zones proximal to wells. These changes have been associated with the deterioration of quality in well water [43].

Although *E. coli* (indicated by TTC) is considered the best option to assess microbiological water quality, it has limitations [44]. In experimental bacterial inoculation of underground waters and fine-grain sands, it has been established that E. coli is viable for three months [45]. Therefore, to ensure accuracy, repeated measurements should be completed across both the rainy and dry seasons.

It is acknowledged that sanitary surveys are of limited use in scoop holes as protection measures may be hard to implement, but it is currently the only method for the assessment and improvement available for this water source.

5. Conclusions

It was found that the median values of TTC for both the water contained in the dam (abstracted from uncontaminated test holes) and from covered wells were 0 TTC per 100 mL. This indicates that sand dams are safe for the abstraction of water in conjunction with properly constructed and sited wells. However, the positive effects on water safety are compromised when scoop holes are used as an access point.

Turbidity exceeded WHO [27] limits in 59% of covered wells. This is an area of concern as highly turbid water is difficult to chlorinate if required. Further research is needed in this area to determine the cause of this turbidity whether it is sediment composition, construction, sand harvesting, erosion, or inadequate flushing. This may impact the guidance with regards to the location of sand dams and the position and design of their wells.

The conductivity of water in sand dams is also an issue with 23% of scoop holes and 26% of covered wells exceeding the WHO [27] limits of 1500 μS/cm. Further research is needed to quantify the source of the salinity to ensure sand dams are not located in highly saline areas.

Author Contributions: S.C. and A.P. conceived and designed the field study; O.A. and M.D. collected the data; R.Q. analyzed the data and wrote the paper.

Funding: This research was funded by EPSRC grant number: EP/N009711/1.

Acknowledgments: Excellent Development and the Africa Sand Dam Foundation are thanked for their support of the fieldwork. Maria Biskupska is thanked for her assistance in preparing for the fieldwork. Justus Nyangoka is thanked for his assistance in hosting and assisting one of the field researchers.

Conflicts of Interest: The authors declare no conflict of interest. The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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