



Drinking Water Quality in Shallow Wells in Kipsonoi Sub Catchment in Bomet County, Kenya

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Abstract

Water from the shallow wells is at risk of pollution due to agricultural activities through surface runoff carrying faecal matter, herbicides, pesticides and fertilizers. This study looks at the status of the drinking water quality of the shallow wells in Kipsonoi Sub Catchment and its suitability for human consumption. The study objectives are: To determine the basic physical, chemical and biological indicator parameters in shallow wells in the Kipsonoi Sub catchment. Water samples from 31 shallow wells were sampled during the wet season (April) and dry season (January) and analyzed for physical, chemical and biological parameters. Standard methods for the analysis of water samples in the laboratory were used, and the results compared to the guideline values of NEMA, USEPA and WHO. The WQI for the water samples for the sub-catchment was calculated to ascertain whether it is suitable for human consumption. 61.29% of the sampled shallow wells had nitrate contamination, 70.97% had turbidity contamination, and 80.66% had faecal coliform pollution and did not meet the NEMA, USEPA and WHO set standards. Additionally, the student's t-test performed at 95% confidence interval revealed that there was a significant difference ($p \leq 0.05$) between the means of *E. coli* levels for shallow wells in the dry and wet seasons. High levels of faecal coliform were observed in the wet season as compared to the dry season indicating that animal and human wastes were primary contributors to pollution particularly during the wet season. The results of the shallow well sampling indicate significant contamination with nitrates, turbidity and fecal coliform. The water quality in the Kipsonoi Sub Catchment is significantly impacted by agricultural activities, leading to high levels of nitrates and turbidity in the shallow wells, indicating the need for Government partnering together with the community in an effort to reduce this contamination and hence protect the shallow wells.

Subject Areas

Hydrology

Keywords

Drinking Water, Groundwater Quality, Groundwater Pollution, Groundwater, Shallow Wells, Water Quality Parameters, Kipsonoi Sub-Catchment

1. Introduction

Groundwater performs a vital fundamental function in the lives of human beings, both economically and socially regarding domestic, industrial and agricultural utilization [1]. Groundwater is susceptible to pollution caused by human activities as well as other sources for instance, the application of chemical pesticides, agricultural waste, domestic discharge and the effluents from the industries to groundwater and also other water bodies [2]. In response to the growing use of chemicals, pesticides, fertilizers, industrialization and other human factors, the water from various sources is heavily polluted daily [3]. On a global scale, approximately 1.2 billion individuals consume dirty and polluted water which is the root cause of waterborne illnesses [4]. In less developed countries, approximately 1.8 million individuals, predominantly children, die yearly in consequence of ingesting polluted water [5]. In Kenya, most of the health hazards are caused by insecure water quality that emanates from pollutants, the use of chemicals for farming practices and industrial effluents that contaminate the drainage basins and the sources [6]. Bomet County is a tea farming region with approximately 24,868 homesteads relying completely on tea as a major source of income [7]. Farmers in Bomet County have invested heavily in intensive agriculture and fertilizer use to boost food production Bomet County Government [8] [9]. In addition, the available water resources in Kipsonoi Sub-catchment are heavily utilized for social economic activities such as farming, drinking and domestic chores. As a result, shallow wells are vulnerable to human activities, so it is essential to determine their water characteristics. Similar research by Tole and Bomet County Government found that only 11,940 households access piped water, which is equivalent to 8.45% ([8] [10]). Research done by Mutai found that 67% of the households lacked access to clean water for drinking [11]. The insufficient piped water supply makes the populace turn to other water sources like the shallow wells which are easily hand-dug because of the shallow water table that is in the catchment and are inexpensive to construct. Unfortunately, shallow wells are at risk of pollution resulting from heavy agricultural activities, especially tea farming, where chemicals from herbicides, pesticides, fertilizers and disease-causing organisms could easily be carried by runoff during the rainy days. Therefore, this research looks at the shallow wells that are predominantly used, assessing the quality of water and its suitability for

consumption. Lack of safe drinking water in Bomet County immensely contributed to the high cholera prevalence in 2016 [12]. Research done by Tonui found that the contamination of water emanates from effluents from the Kapkoros Tea factory [13]. Cultivation and overapplication of fertilizers and chemicals, for instance, herbicides and pesticides, contributed to the contamination of water in Bomet County. 10.8% of Kapkoros community near Kapkoros factory in Bomet County reported to have been affected by water-related diseases, for instance, typhoid and cholera respectively as a result of polluted drinking water [13]. So, there is a need to look at the current quality of water in the shallow wells and determine if it is suitable for consumption.

2. Research Area Location

The study area is Kipsonoi Sub-Catchment in Bomet County (**Figure 1**). It has a total size of around 564 sq-km. Mau Forest adjoins an extensive part of Bomet County. It lies in the region between longitudes 35°05'E and 35°35'E and latitudes 0°29'S and 1°03'S. It shares boundaries with the counties of Kericho to the north and east, Narok to the south, west, and east, Nyamira to the northwest, and Nakuru to the east. A bigger section of the Kipsonoi Sub catchment is undulating, giving a flatter terrain in the west. The Sub Catchment lies within 1540 and 3000 meters above the sea level [8]. With the exception of the northeastern portion, which rises eastward towards the 3000-meter-high Mau Ridges, the terrain generally slopes to the south. Kipsonoi Sub-catchment receives rainfall which fluctuates between 1000 to 1400 mm [8]. It is characterized by moderate annual temperatures ranging from 16°C to 24°C [8]. Agriculture is the primary economic activity in the Kipsonoi Sub Catchment, with most farmers engaging in mixed farming, with tea farming being the most prominent and the primary economic activity, as stated in the [8]. Most of the parts of the Kipsonoi sub-catchment are composed of tertiary volcanic, but very few parts of the sub-catchment are composed of granitic, bukoban and basement rocks. The hilly topography of the sub-catchment has some effects on lowering soil fertility and therefore necessitating the application of fertilizers. There is no sew-age system in Kipsonoi Sub catchment and most of the residents use latrine for human waste disposal.

3. Research Methodology

The research used the purposive sampling approach. The sub-catchment was divided into administrative units, in this case, 3 sub-counties, and then sampling points were picked from the three sub-counties: 12 from Sotik Sub-county, 14 from Konoin Sub-county and 5 from Bomet Central Sub-county which makes a total of 31 sampled shallow wells. The total shallow wells in Kipsonoi Sub-catchment were identified, then using [14] formula $n = (k/1) + (N/k)$, the minimum sample size was computed based on the total number of shallow wells in the sub-catchment, and then sampling points were picked from the sub-countries depending on the number of wells and the human activities in each sub-county. The

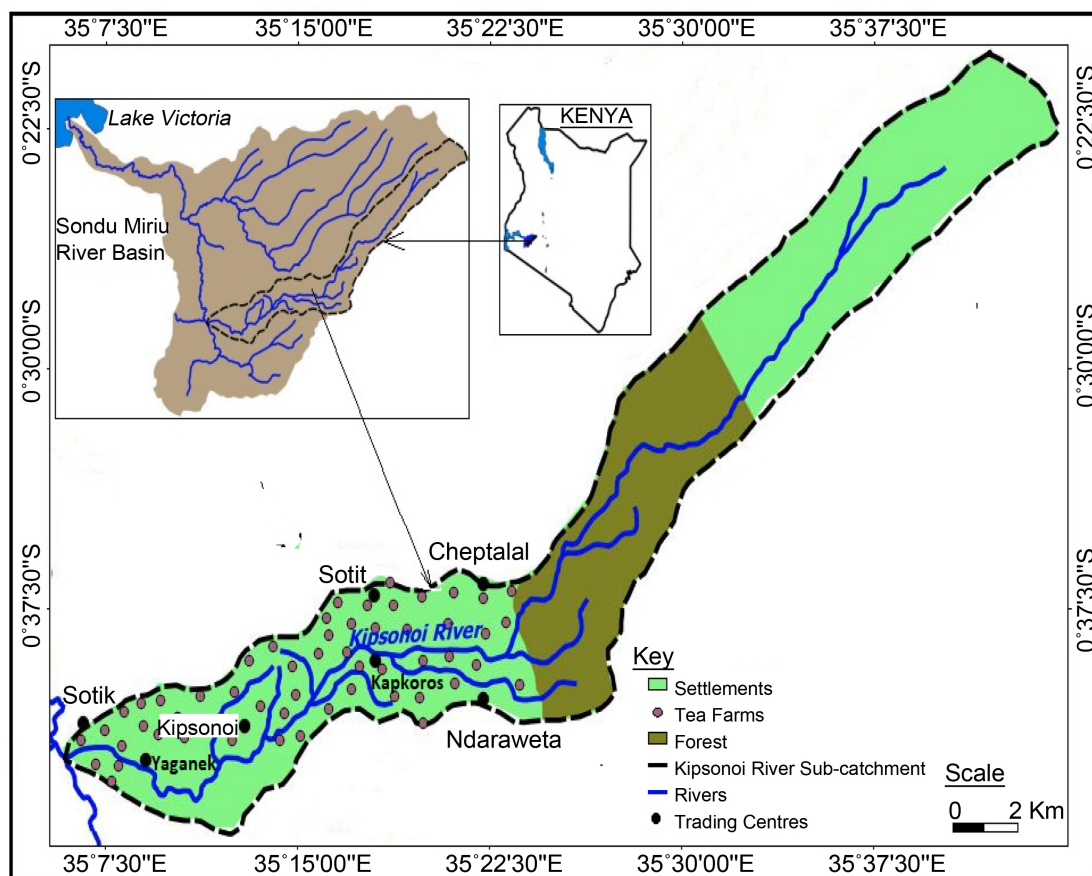


Figure 1. Location of Kipsonoi sub catchment in Bomet county.

samples were taken both during the rainy and dry seasons in order to account for seasonal disparities. Shallow wells for sampling were picked considering their proximity to human activities like tea farms and dairy farms. The samples were taken in the early hours of the day. Water samples were gathered early in the morning, before the sun warms up the air and ground, which may warm the water since high water temperatures encourage bacterial development, including potentially dangerous pathogens such as *E. coli*. Samples of water were gathered for physico-chemical analysis and placed in high-density, one-liter linear polyethylene sampling vials sterilized using 10 percent nitric acid. For bacteriological sampling, the samples were gathered in glass vials that had been sterilized at a high temperature of about 170°C for 3 hours. The standard procedures for collecting, preserving, transporting, and analyzing the water samples as outlined in APHA methods were observed. The samples were then labeled, indicating the source's details as well as the date and the time being collected. They were then stored in a cooler box before being taken to a laboratory for testing. After sampling, they were assessed within 24 hours.

The data obtained from analyzing samples in the laboratory was recorded in an Excel spreadsheet and then analyzed using SPSS Version 20 for statistical purposes. The mean and standard deviation were calculated. The physical, chemical,

and biological attributes of the shallow wells in the Kipsonoi Sub Catchment were visually shown and explained using MS Excel line graphs in respect to the drinking water quality requirements stipulated by NEMA, USEPA, and WHO. With a 95% confidence interval, the average differences of the analyzed parameters between samples of water obtained during the dry and wet seasons were compared using the student's t-test. In this statistical study, a significant difference is indicated by a probability (p) value below 0.05, whereas no significant difference between the variables being compared is suggested by a p value greater than 0.05.

4. Results and Discussion

4.1. Levels of Physical, Chemical and Biological Parameters

The mean values of shallow well temperatures ranged from 21.42°C to 22.85°C (**Figure 2**). All of the temperature measurements that were observed in this research were within this range of temperatures of between 20°C and 35°C as stipulated by WHO and NEMA. Temperature is a significant factor in the chemical and biological mechanisms occurring in organisms living in water [15].

For the shallow wells that were sampled, the reported turbidity mean values ranged from 1.12 NTU to 75.5 NTU (**Figure 3**). 70.97% of the sampled shallow wells had their turbidity concentration exceeding the 5 NTU, which is the standard set by WHO and NEMA for drinking water. SW22 had the lowest turbidity, at 1.12 NTU, this is because it had some grass cover, thus reducing the effects of soil erosion by wind and rain that easily carry loose soil particles, especially during the rainy season. High turbidity of 75.5 NTU was recorded in SW7, and this is because the shallow well had poor covering of local wood planks and a drum that could not stop the effects of erosion. Its proximity to the agricultural lands that are sloppy and are constantly tilled could be another factor that contributed to high turbidity. It was observed that about 90% of the sampled shallow wells were covered with timber planks, making them prone to surface runoff pollution and easily carrying debris into these shallow wells. The old tyres and old drums used as shallow well covers also contributed to surface runoff pollution.

The average pH levels in the shallow wells that were sampled ranged from 5.21 to 7.85 (**Figure 4**). The lowest pH level of pH of 5.21 was recorded in SW30. This could result from applying acidic fertilizers excessively, for instance, DAP and NPK fertilizers applied to the maize and tea farms in areas near the shallow well. The highest level of 7.85 was recorded in SW8 and this might be attributed to the weathering of rocks.

The mean values of TDS in water from the shallow wells ranged from 10 mg/l to 100 mg/l (**Figure 5**). All values recorded for TDS were within the acceptable limits for drinking purposes of 1000 mg/l for WHO and NEMA and 500 mg/l for USEPA. TDS of 10 mg/l was recorded in SW22, which had a drum surrounding it and some grass cover around the well, whereas TDS of 100 mg/l was recorded in SW1, which had a timber cover and no vegetation to reduce runoff.

The electrical conductivity values varied between 21 and 200 mg/l (**Figure 6**).

All recorded electrical conductivity values were below recommended levels of 1500 and 1200 $\mu\text{S}/\text{cm}$ for potable water as specified by WHO and NEMA, respectively. The lowest level of 21 was recorded in SW22, and this was because the well was protected with grass around it. The highest levels of 200 were recorded in SW1, which correlates with the TDS results and could be attributed to poor well construction. TDS and electrical conductivity levels showed the same trends, indicating that change in total dissolved solids was likely the dominant factor influencing electrical conductivity as shown in **Figure 7**.

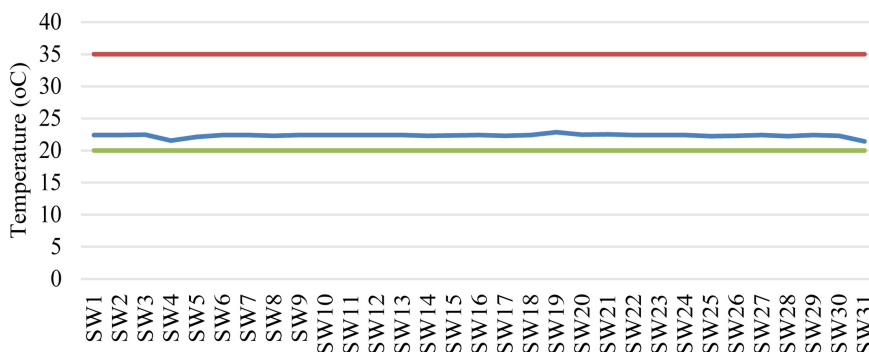


Figure 2. Levels of Temperature of the sampled shallow wells.

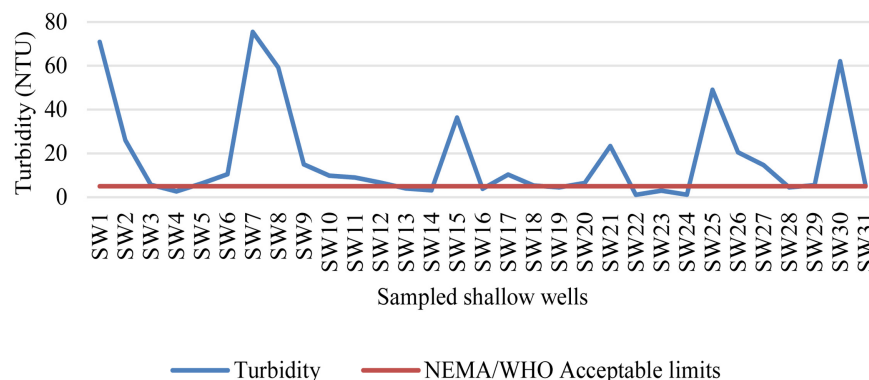


Figure 3. Levels of Turbidity of the sampled shallow wells.

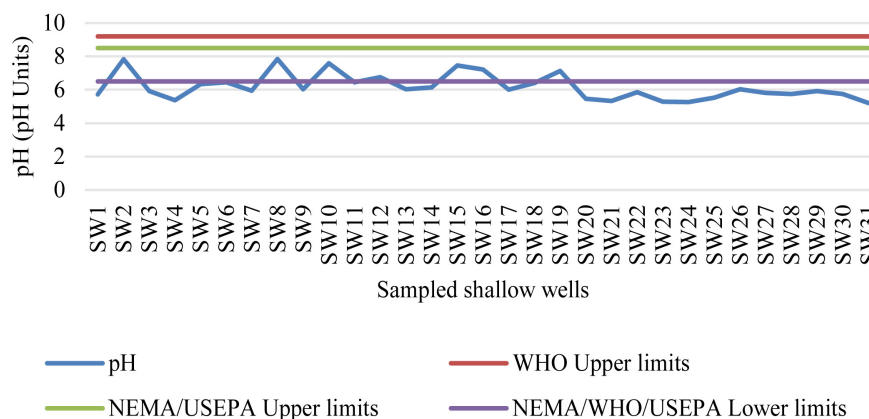


Figure 4. Levels of pH of the sampled shallow wells.

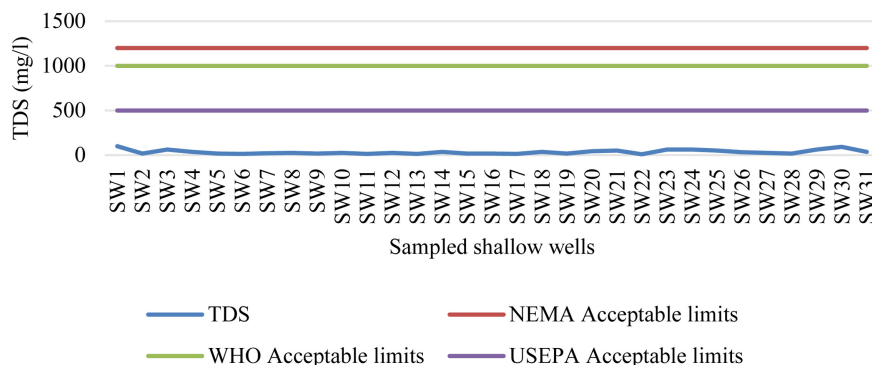


Figure 5. Levels of TDS of the sampled shallow wells.

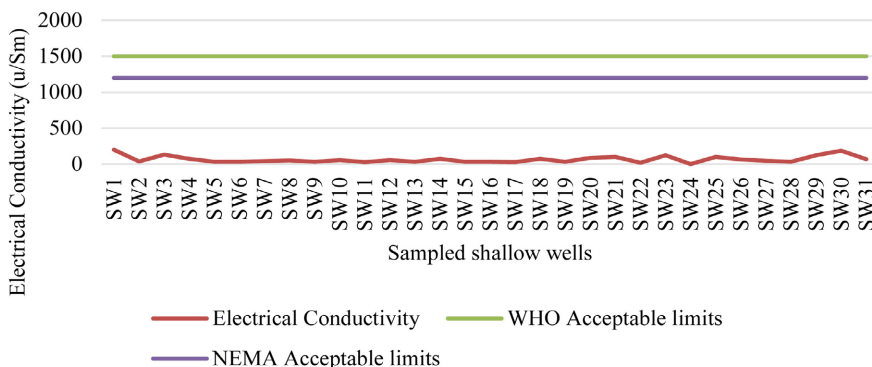


Figure 6. Levels of electrical conductivity of the sampled shallow wells.

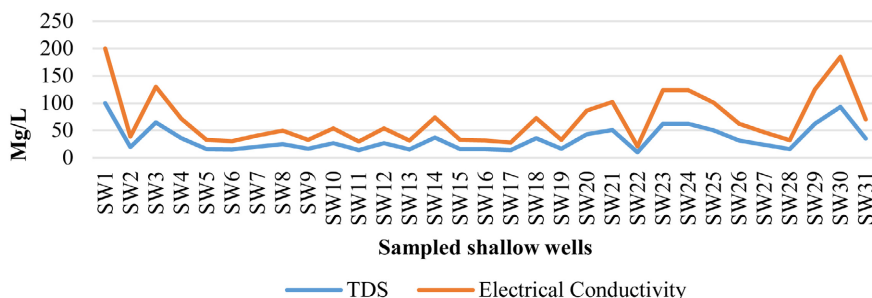


Figure 7. Levels of electrical conductivity and TDS of the sampled shallow wells.

The levels of total hardness in Kipsonoi Sub Catchment ranged from 2 mg/l - 19 mg/l (Figure 8). It was discovered that every single total hardness level in the shallow wells that were analyzed fell within the stipulated range of less than 500 mg/L for water used for drinking as specified by both the WHO and NEMA. The lowest levels were recorded in SW22 because the well was located near a shopping centre and therefore is generally less likely to impact groundwater hardness directly, while the highest levels were recorded in SW1 and this is because the well was located near intensive agricultural fields and animal waste disposal systems.

The alkalinity levels in the sampled shallow wells varied, ranging from 2 mg/L at sampling site SW 24 to 15 mg/L at sampling site SW 8 (Figure 9). All the collected samples in this study indicate that the recorded alkalinity levels were below

the 500 mg/l set standards by WHO for water meant for consumption. Generally, low levels of alkalinity in the Kipsonoi sub-catchment could be attributed to the dilution from the surface runoff that is slightly acidic from the acidic fertilizers like NPK fertilizers that are applied to the tea farms in the Kipsonoi sub-catchment, which can dissolve these minerals, removing them from the system and reducing their impact on alkalinity [16].

Levels of phosphates varied between 0 mg/l and 4.9 mg/l (**Figure 10**). The lowest level of 0 was recorded in 0.1% shallow wells, while the highest level of 4.9 mg/l was observed in SW1. All the recorded phosphate values were below the recommended standards of 30 mg/l for the water meant for consumption as specified by WHO and NEMA. High levels of phosphates in SW1 could be attributed to the fact that the well was covered with timber planks and old tyres which do not protect the well from storm runoff, allowing it to be washed into the well through the wet seasons, in addition to the absence of vegetation cover around it to prevent runoff. Proximity to the maize farms and animal waste disposal systems could be another factor.

Nitrate levels varied from 0 mg/l to 66.3 mg/l (**Figure 11**). Levels of nitrate in most of the samples of water obtained from the shallow wells were above the acceptable limits of 10 mg/l as prescribed by NEMA, USEPA, and WHO for drinking purposes. The lowest levels of 0 were recorded in SW5 and SW6, whereas the highest levels of 66.3 mg/l were recorded in SW8. High levels of nitrates in SW8 could be attributed to the animal deposits from the cattle kraal and tea farms, which are the likely cause of nitrate pollution in groundwater through runoff. The close proximity of latrines, farms, and cattle kraals to these shallow wells is among the reasons for high nitrate levels recorded in these wells.

The potassium levels varied from 1.35 mg/L at sampling site SW22 to 7.3 mg/L at sampling site SW1 (**Figure 12**) for the shallow wells that were sampled. All values of phosphates recorded in the water from the shallow wells were below the recommended limits of 200 mg/l stipulated by WHO. High levels of potassium in SW1 could be attributed to fertilizer application to tea farms. Conversely, low potassium levels in SW22 could be because the well is protected from runoff by a drum around it coupled with proper grass cover that reduces runoff contamination.

Sodium (Na^+) levels in the sampled shallow wells varied, with the lowest level of 0.55 mg/L at sampling station SW28 and the highest level of 27.5 mg/L at sampling site SW5 (**Figure 13**). All the sodium values gotten from the shallow wells were within the set standards of 200 mg/L recommended by WHO. The highest level of 27.5 mg/L at sampling station SW5 could be because it is influenced by the underlying geology near the well. The well was located in an area where sodium-containing minerals like granitic rocks were predominant, increasing the sodium concentration in the well. The sodium concentrations in sampled wells were lower during the rainy season due to dilution by rainwater during the rainy season.

The fluorides in the shallow wells varied from 0.00 mg/L to 1.215 mg/L at sampling site SW20 (Figure 14). All the fluoride values gotten from the shallow wells were within the set standards of 1.5 mg/L as stipulated by WHO and NEMA and 2 mg/L recommended by USEPA. The existence of fluorine in the natural waters is determined by the geological composition of the region.

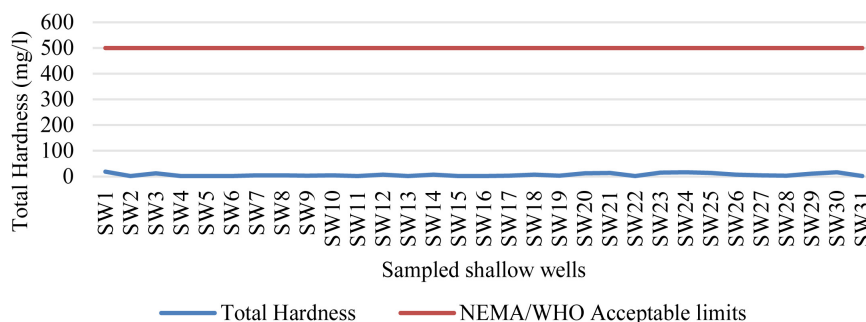


Figure 8. Levels of total hardness of the sampled shallow wells.

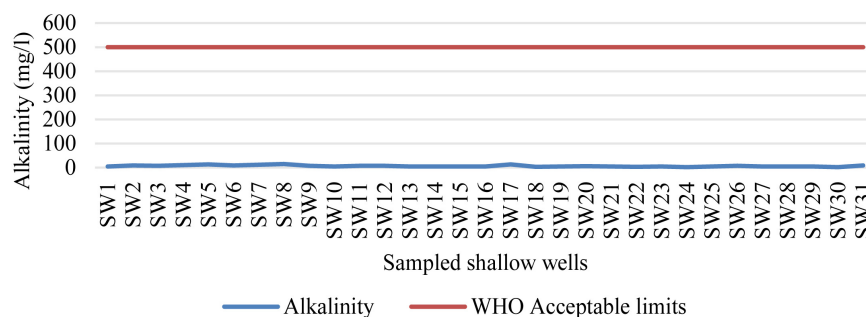


Figure 9. Levels of alkalinity of the sampled shallow wells.

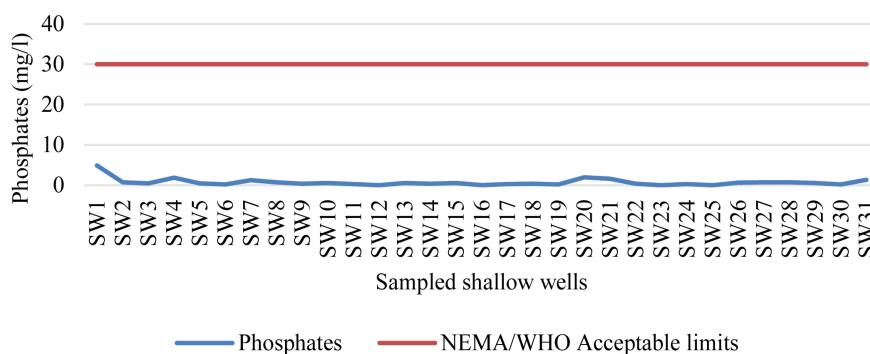


Figure 10. Levels of phosphates of the sampled shallow wells.

The levels of faecal coliform MNP/100 mL observed from the research varied from 0 mL/100 mL at a number of sampling stations to 1750 mL/100 mL at sampling stations SW2, SW7 and SW31 (Figure 15). However, the study found that 80.65% of the sampled shallow wells exceeded the recommended standards of 0 MNP/100 mL set by WHO, NEMA and USEPA. The high presence of faecal coliform could be attributed to the closeness of the shallow wells to the cattle kraals,

pit latrines and areas where solid waste is disposed of. Lack of proper standard covering also contributed to the contamination. The pollution is caused by more water seeping into the ground during the rainy season, which creates favorable conditions for organisms to spread and reproduce, particularly from runoff, sewage, and waste material [17] [18]. 80.65% of the shallow wells had contamination levels ranging from 4 to over 2400, indicating that they are polluted and therefore require treatment before being used for consumption since they pose a potential risk of water contamination by disease-causing bacteria or viruses [19]. Most people generally just sieve the water and use it for drinking purposes. Iyer found that all slum and 80% of housing society households directly collected water for drinking after simple sieving [20].

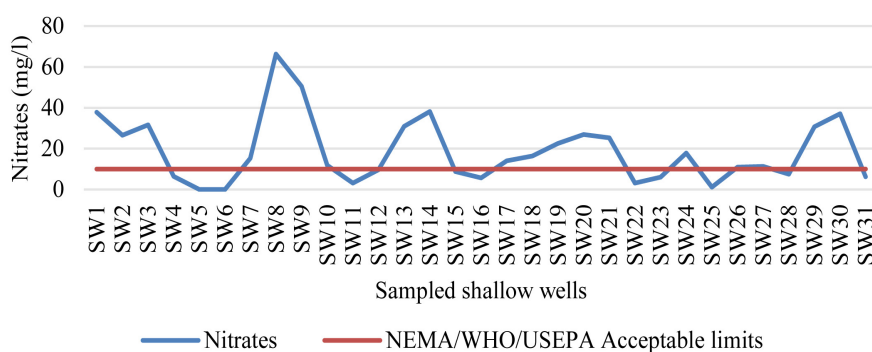


Figure 11. Levels of nitrates of the sampled shallow wells.

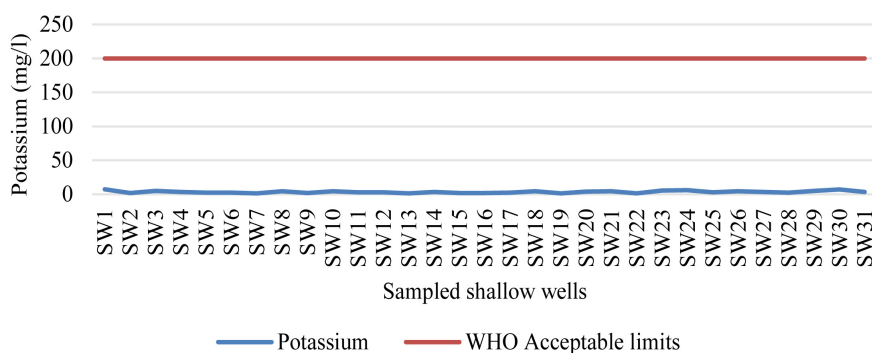


Figure 12. Levels of potassium of the sampled shallow wells.

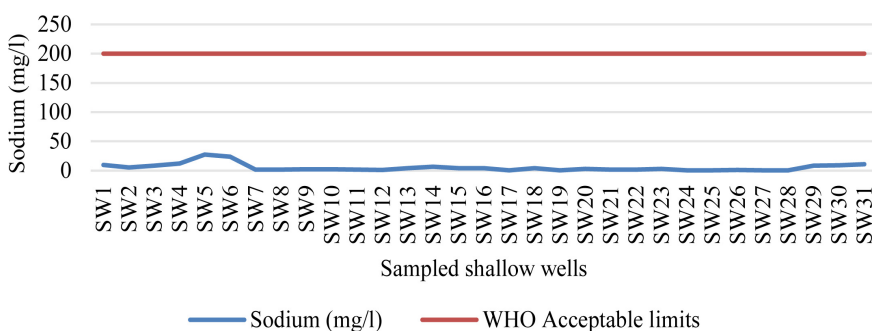


Figure 13. Levels of sodium of the sampled shallow wells.

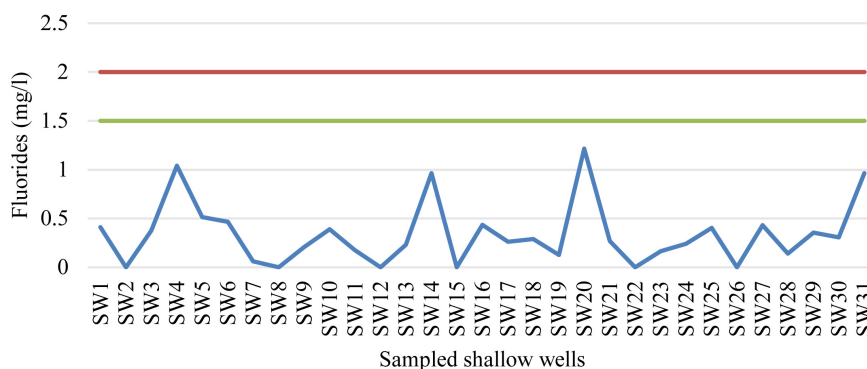


Figure 14. Levels of fluoride of the sampled shallow wells.

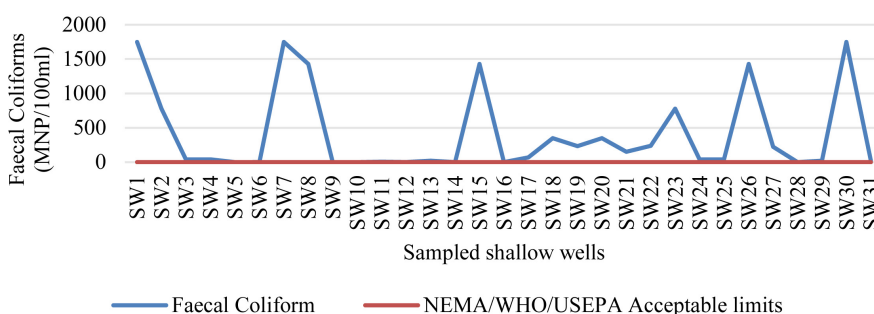


Figure 15. Levels of faecal coliforms of the sampled shallow wells.

4.2. Mean Differences for Biological, Physical and Chemical Characteristics

The means for any of the chemical and physical attributes of the shallow well waters in the two seasons did not significantly vary ($p > 0.05$) according to the findings according to the independent t-test analysis carried out at a 95% confidence interval, whereas there was a statistically significant variation ($p < 0.05$) for the mean of *E. coli* levels for shallow wells during the dry and the rainy seasons (Table 1).

Table 1. Mean differences during the dry and the rainy seasons.

Water Quality Parameter	WET SEASON	DRY SEASON	P values
	Mean ± Std. Error	Mean ± Std. Error	
pH	6.23 ± 0.138	6.16 ± 0.135	0.706
Temperature	22.30 ± 0.043	22.36 ± 0.054	0.373
Turbidity	23.62 ± 5.431	17.21 ± 3.382	0.321
Conductivity	71.71 ± 8.500	66.77 ± 8.294	0.679
Sodium	5.24 ± 1.125	5.58 ± 1.181	0.884
Potassium	3.59 ± 0.301	3.24 ± 0.288	0.410
Total hardness	7.61 ± 1.067	6.06 ± 0.920	0.276

Continued

Phosphates	0.97 ± 0.233	0.79 ± 0.214	0.577
Fluoride	0.32 ± 0.058	0.35 ± 0.058	0.766
Nitrates	19.15 ± 2.891	18.28 ± 2.846	0.830
Alkalinity	7.03 ± 0.662	5.81 ± 0.582	0.169
Total Dissolved Solids	35.77 ± 4.256	33.29 ± 4.157	0.678
Faecal coliforms (<i>E. coli</i>)	615.03 ± 167.424	220.45 ± 60.597	0.033*

*Significant at 95% confidence interval level.

5. Conclusion and Recommendations

The predominant chemical, microbial, and physical characteristics were nitrates, turbidity and faecal coliform. *P* values were significant at 0.05 for the faecal coliform, indicating that animal and human wastes were primary contributors to contamination, especially during the rainy season. The wells in Kipsonoi Sub Catchment should be constructed with proper sealing to prevent contamination from surface runoff and debris. The water should also be treated before consumption in order to lower the elevated concentrations of turbidity, nitrates and faecal coliform to meet regulations. Filtration to remove turbidity, boiling or chlorination to kill bacteria and ion exchange or distillation to remove nitrates are some examples of these treatments (See **Figures 16-18**).



Figure 16. Filtration treatment process of removing turbidity drinking water.



Figure 17. Chlorination treatment process of removing bacteria in drinking water.



Figure 18. Ion exchange treatment process of removing nitrates in drinking water.

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points.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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