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An Assessment of the Spatial and Temporal variations of Groundwater quality in Yatta Plateau in Kitui County, Kenya

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Abstract
The study is primarily focused on the assessment of groundwater quality in the Yatta Plateau of Kitui County. The study focused on the spatial temporal distribution of key chemical parameters namely pH, TDS, Colour, Total hardness, Turbidity, Conductivity, Total alkalinity, Fluoride and Iron. Groundwater samples were collected four times from the six target boreholes found on the plateau in the period between March 2015 and March 2016. The sampling programme covered two dry seasons and two wet seasons. Key physicochemical parameters were analysed using standard laboratory methods. The water samples were analyzed at the Water Resources Management Authority (WARMA) Water Quality Testing Laboratory in Nairobi. The results of the study show that there is no direct relationship between rainfall and variations of groundwater quality in the Yatta plateau. The influence of water abstraction on water quality was also limited. The dominant influence on groundwater quality in the Yatta Plateau was found to be the geological characteristics of the area. It was however found that there was spatial-temporal variability in different groundwater quality parameters that were analysed. The study recommends integrated groundwater resources management including continuous water quality monitoring in the Yatta Plateau in Eastern Kenya.

Key Words: Groundwater quality, physic-chemical parameters, spatial-temporal variability, Yatta Plateau, Kenya

1. Introduction

Groundwater is one of the prime movers of the socio-economic development in many African countries including Kenya (UNEP 2008; Adetundee et al., 2011). Groundwater is recognized as an important resource that supplements surface water resources particularly in Arid and Semi-Arid areas that comprise nearly 80% of the total landmass in Kenya where it is widely utilized for domestic, agricultural and industrial activities (Jones, 2005). Groundwater resources are particularly important in Kenya given that surface water resources in the country are irregularly distributed in space and time, a situation that is exacerbated by considerable climate variability in the country (Mumma et. al., 2011). The importance of groundwater is further illustrated by the fact that about two billion people in the world depend directly on groundwater aquifers for provision of drinking water and 40% of the world's food is produced by irrigated agriculture that relies largely on groundwater (UNEP 2003).

The problem of access to safe water in the developing countries is enormous and therefore to alleviate the problem, governments in these countries have given priorities to implementation of community water projects (Caircross and Feachem, 1983). Most of the community-based water projects are based on groundwater [illegible] worldwide use [illegible]er Supply and Collaboration Council, 2010). Land use has been shown in past studies to influence water quality parameters (Tong and Chem 2011). Surface runoff from different types of land uses can be enriched with different kinds of contaminants (Tong and Chem 2011). Water that percolates deep aquifers and flows as ground water is generally microbially safe and contamination is usually from dissolved minerals derived from underlying rocks. Generally, groundwater is better protected than surface water from the pathogenic contamination. As rainwater infiltrates and percolates through the various geological formations, most of the pathogenic microorganisms are removed through the straining and retaining action. However, according to WHO (2005), groundwater is not always of suitable quality due to various chemical contents influenced by either geology or anthropogenic activities. However, in most cases the chemical composition of groundwater is related to the soluble products of rock weathering and decomposition (Raghunath, 1995; Tavassoli and Khaksar, 2002; Appelo and Postma, 1993; Zhang et al., 2011). The type and concentration of dissolved minerals and groundwater determines the suitability of water for various uses (Mirrabasi et al., 2008).

Volcanic rocks such as the one found in the Yatta Plateau in Eastern Kenya are considerably altered where they are in contact with hydrothermal solutions (Petalas et al., 2006). The volcanic formations such as those in the Yatta Plateau have unique geo-chemistry that influences the water quality characteristics of groundwater derived from them. Some volcanic formations are characterized by high levels of water chemical parameters that limits the extent to which groundwater derived from them can be utilised for various purposes (Mirrabasi et al., 2008). Most chemicals in groundwater are usually of health concern only after extended exposure of years rather than months (WHO 2006). This underscores the importance of groundwater quality assessment to discount the possibility of extended yet unrealized negative effects to the members of the public who uses groundwater (WHO 2006).

Majority of the local community residing in the Yatta plateau depend on groundwater for their domestic water supply. Deterioration of ground water quality in the study area may cause major negative impacts on both health and socio-economic status of the community. It is therefore of utmost importance that the groundwater chemical parameters are established in order to safeguard public health. Groundwater quality assessment in the Yatta Plateau is also important for ensuring sustainable use of water as well as access to safe drinking water. Yatta plateau in Kitui County is water stressed and residents along the Yatta plateau have to walk on average more than 5 Km to access water from the rivers. The availability of and access to water supply strongly influences economic growth and social development patterns (Allan 2000). Based on the Drought Intervention Program report by the GoK (2009), groundwater provision in the Yatta plateau has taken preference to other sources of water and therefore it is important that the groundwater chemical parameters are established and any changes overtime determined. The general objective of this study was therefore to determine the status and the variability of groundwater quality in Yatta plateau and the extent to which the same influence the uses of water. The key focus was boreholes that were drilled through various water development programmes initiated by the Government of Kenya (through Tanathi Water Services Board), including other boreholes drilled by private non-governmental organizations. The study was carried out in two dry and two wet seasons covering chemical water quality parameters particularly pH, TDS, Electrical conductivity, Turbidity, Iron, Total alkalinity, Total hardness and Fluoride. These parameters are some of the most useful and any significant change in them can be used as an early indicator of change in a water system (Langland and Cronin, 2003). The study also covered physical parameters namely color, taste and odor. However, the study did not deal with the biological water quality aspect as this was beyond the objectives of the study. The findings of the study can be used to recommend appropriate management of groundwater resources in Yatta plateau corridor in Kitui County. The study is also intended to provide a better understanding of short and long-term changes in ground water quality in arid and semi arid lands of Kenya. Additionally, the study provides data and information for use in ground water resources management and planning.

2. The Study Area

The Yatta plateau in Kenya traverses parts of Kitui County occupying most parts of Lower Yatta Sub-County (Figure 1). The Yatta Plateau which is situated in the western part of Kitui County occurs within latitudes -1.50^0 S and -1.85^0 S and longitudes 37.75^0 E and 37.95^0E. The area falls within medium potential areas of Kitui County and it experiences poor rainfall distribution which leads to low agricultural production (GOK 2002). The study area within the Yatta Plateau covers a surface area of 1176.8 Km^2. Athi river, the second largest river system in Kenya runs parallel to the Yatta plateau on the western side. The plateau is sandwiched between two rivers (Tiva River and Athi River) which are approximately 15km apart. The thickness of the phonolites that form the geology of the Yatta Plateau from the basement contact to the flow-top ranges from 12 to 25m (Wichura, 2011). The average width of the plateau is estimated to be 3km and along the eroded top of the flow, there is an average gradient of 2.8m/km as shown in Figure 2 (Wichura, 2011). The boreholes that were targeted in this study are located on the plateau (See Figure 3). The Yatta plateau was formed 11-13.6 million years ago by a stream of lava flow through an ancient river valley (webKenya, 2003). The surrounding land was lowered by erosion leaving the lava plateau standing up as a small escarpment of approximately 300km long with an average width of 10km.

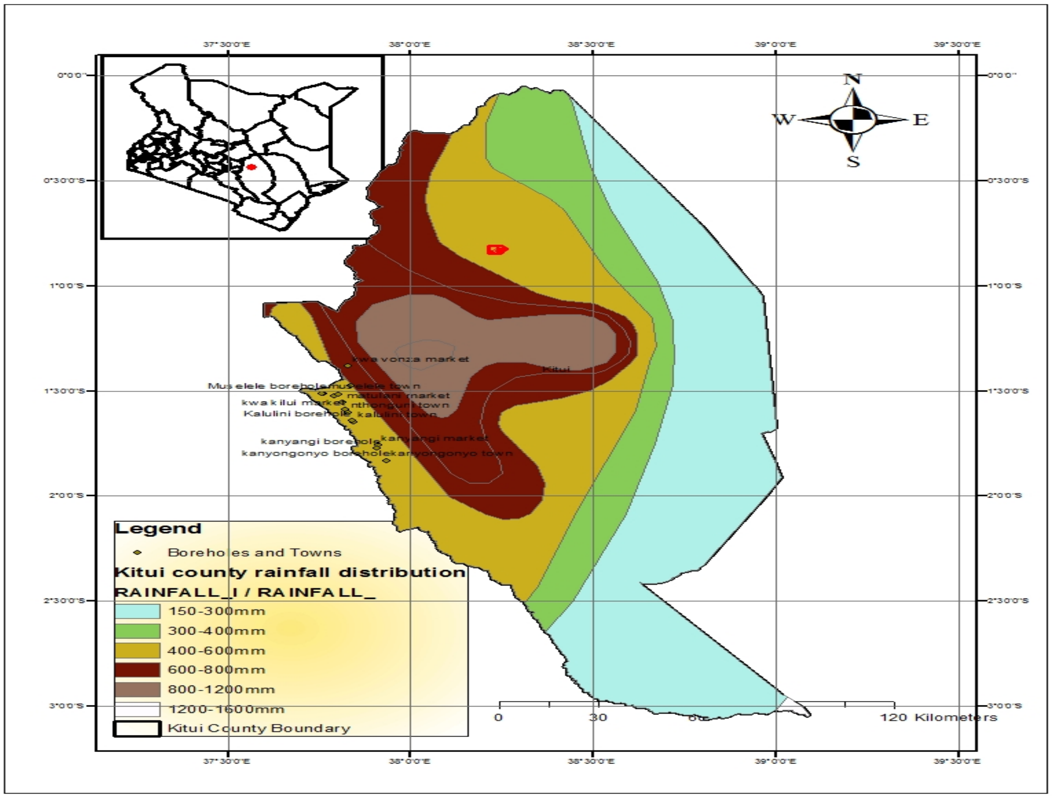

Figure 1: The Location of the Yatta Plateau-the study area in Kenya.

The Yatta lava flow was the most prominent manifestation of the major phonolitic eruption at 13.51 million years ago (Veldkamp et al. 2007). The flow is thought to have originated in a region that now corresponds to the eastern Kenya Rift flank. The lava flowed 300 km through the ancient Athi River valley toward the southeast. The climate of Yatta plateau in Kitui County is hot and dry with unreliable rainfall (Kitui CIDP Report 2014).The plateau experiences temperatures ranging from 14°C to 34°C throughout the year. The hot months are between September and October and from January to February. The maximum mean annual temperature ranges between 26°C and 34°C whereas the minimum mean annual temperature ranges between 14°C and 22°C (Kitui CIDP Report 2014). July is the coldest month with temperatures falling to a low of 14°C while the month of September is normally the hottest with temperature rising to a high of 34°C (Kitui CIDP Report 2014). The climate, therefore, falls under two climatic zones, arid and semi-arid, with most of the plateau being classified as arid. Due to the high temperatures experienced in the Yatta plateau throughout the year, the rate of evaporation is high with a mean annual potential evaporation in the plateau ranging between 1800 to 2400mm per annum. The rainfall pattern is bi-modal with two rainy seasons annually. The long rains fall in the months of March to May. These are usually very erratic and unreliable. The short rains which form the second rainy season fall between October and December and are more reliable (Kitui CIDP Report 2014). The rest of the year is dry and the annual rainfall ranges between 250mm-1050 mm per annum with 40% reliability for the long rains and 66% reliability for the short rains. Rainfall is highly unpredictable from year to year.

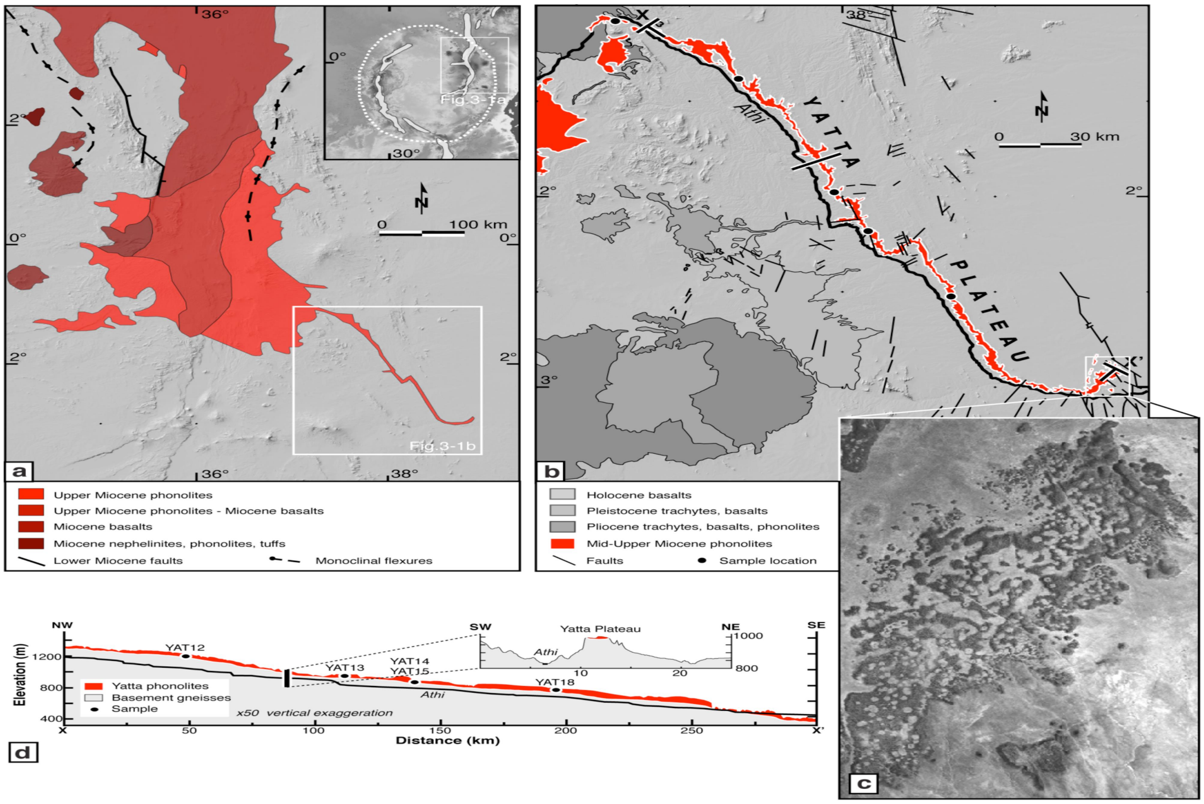

Figure 2: The geology and topography of the Yatta Plateau (Source: Wichura, 2011)

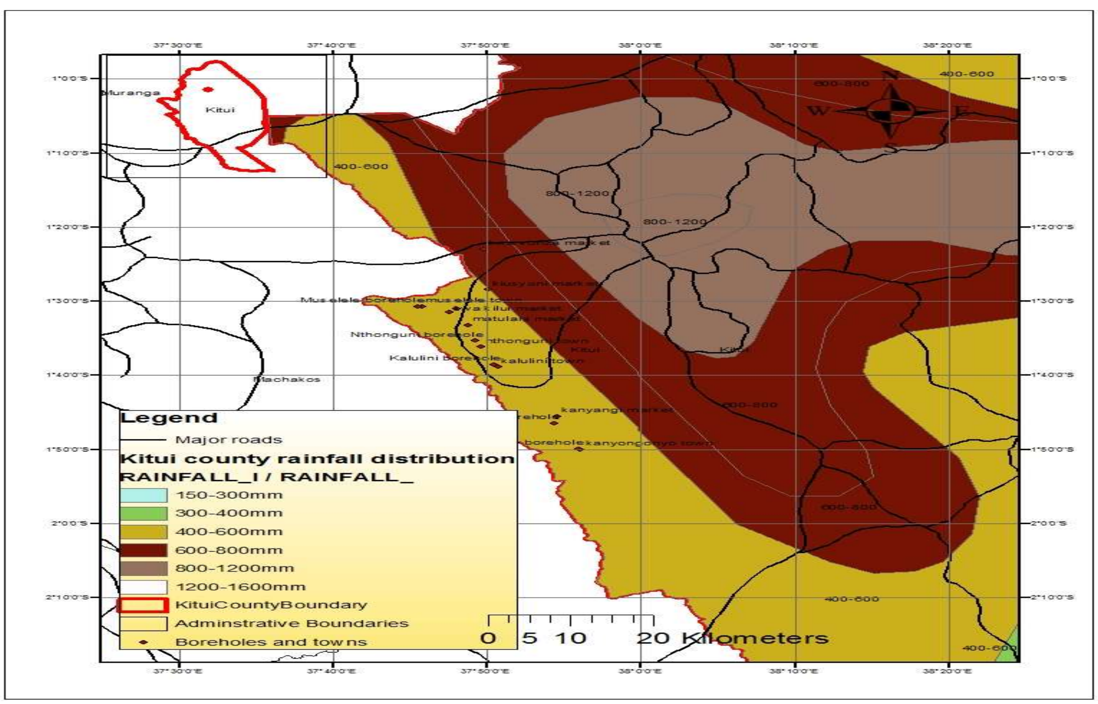

Figure 3: Rainfall distribution and the location of the boreholes in the Yatta Plateau

3. Materials and Methods

3.1 Research Design

The study involved a field survey of water quality in six (6) boreholes located on the Yatta plateau in Kitui County in Eastern Kenya (See Table 1). The groundwater quality parameters of interest included pH, TDS, Colour, Turbidity, Conductivity, Total hardness, Total alkalinity, Fluoride and Iron. These parameters are commonly measured and can be used as indicators of water quality in a water system (Langland and Cronin, 2003). Water samples were collected from each borehole during two dry and two wet seasons. A questionnaire was also administered to respondents in each of the 6 boreholes to establish the extent to which groundwater quality limits water utilisation in the plateau. The respondents were mainly local community who use water from the target boreholes.

Table 1: The Location characteristics of the boreholes that were sampled in the Yatta Plateau

Name of the borehole	GPS Co-ordinates		Date Drilled	Depth (m)	No. of Samples collected	Distance (Km)
	Longitudes	Latitudes				
Muselele	37.75816	-1.51297	31/08/2007	150	4	0
Kwa- Kilui (Paul Makosa)	37.80107	-1.51782	12/08/2013	165	4	4.35
Nthongoni	37.8209	-1.58964	16/05/2014	182	4	13.05
Kalulini (David Mwongela)	37.84097	-1.64295	12/09/2011	230	4	19.34
Kanyangi	37.90672	-1.77496	21/10/1997	133	4	35.67
Kanyongonyo	37.93284	-1.83288	09/07/2007	172	4	42.70
TOTALS					24	

Source: Authors*, 2016*

3.2 Field Surveys and Data Collection

Field Surveys were carried out in the study area paying special attention to the areas where boreholes are located.

Secondary data was obtained from existing records archived by Governmental Institutions such as the Water Resource Management Authority (WARMA). The records of boreholes assisted in establishing the groundwater availability, quality and rock material encountered in the study area. Rainfall Data was obtained from nearby rainfall stations of the Kenya Meteorological Department (KMD).

3.3 Water Sampling and Testing

The ground water samples were collected on monthly basis in the period between February 2015 and February 2016. This sampling period covered two dry seasons and two wet seasons. In the study area, the dry seasons are normally experienced in the period between January and March and between June and September. The wet seasons occur during the long rains of April to May and the short rains of October to December. The samples were collected four times from each of the six target boreholes translating to a total of 24 samples. Each collection comprised of 6 samples which were transported within the same day for testing in WARMA Laboratory in Nairobi. The standard methods that were used in the determination of the concentrations of various physico-chemical parameters were those that have been applied in various previous studies (e.g Thirupathaiah, et al., 2012 and Adetunde et al., 2011). The data analysis involved determination of relationships between various physico-chemical groundwater quality parameters and key drivers such as water table depth, rainfall and water abstraction rates. The statistical methods of data analysis that were applied are regression analysis, correlation analysis and analysis of variable (ANOVA).

4. Results and discussion

4.1 The influence of rainfall on the variability of groundwater quality

Rainfall is one of the most important factors that may influence ground water quality. The influence may occur through infiltration and subsequent percolation of rain water into the ground water aquifers. During the period of this study there were two wet seasons and two dry seasons. The wet seasons occurred in the period between April and May 2015 and also in the period between October and December 2015. On the other hand, the dry seasons occurred in the period between June and September 2015 and from January to February 2016. During the wet season months of April to May 2015, the Yata Plateau area received a maximum rainfall of 177.9mm while the mean monthly rainfall for the period was 134.45mm. During the wet season of October to November 2015, the area received a maximum rainfall of 313.7mm while the mean monthly rainfall for the period was 119.4mm. During the dry season months from June to September 2015 the maximum rainfall for the period was 6.7mm while the mean monthly rainfall for the period was 3.02mm.

Figure 4a-c shows the variations of key groundwater quality parameters as a function of rainfall for the period between March 2015 and March 2016. The highest concentrations of groundwater pH, TDS and electrical conductivity tended to occur during dry seasons. The concentrations declined during rainy season.

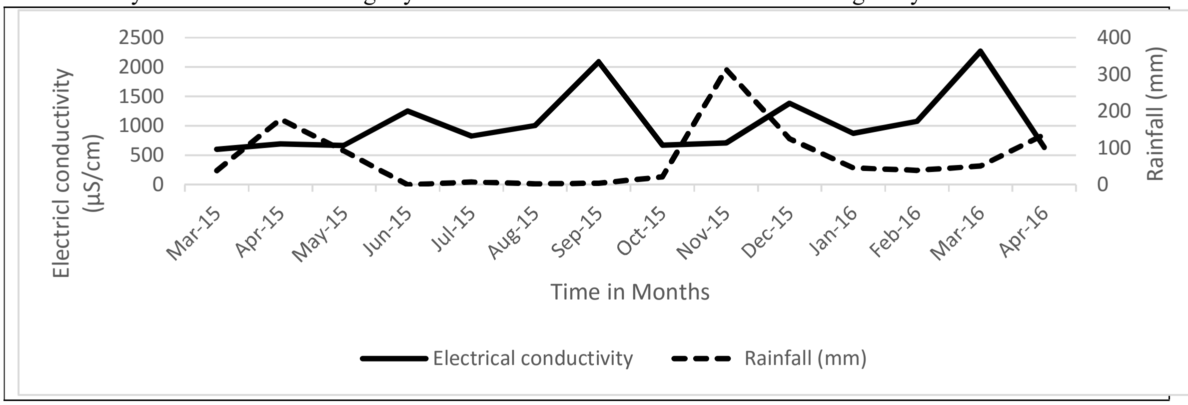

Figure 4(a): The variations of groundwater electrical conductivity as a function of rainfall in the period between March 2015 and March 2016

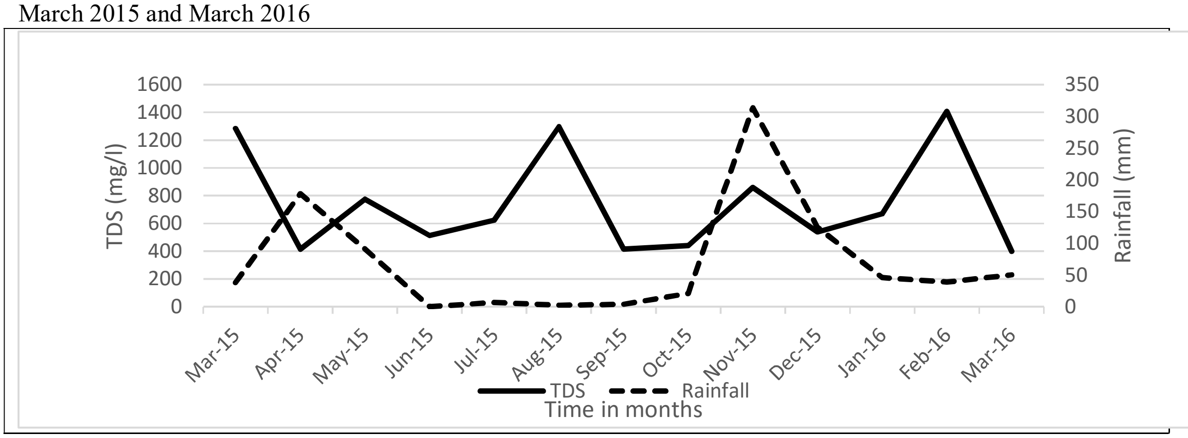

Figure 4(b): The variations of groundwater TDS as a function of rainfall in the period between March 2015 and March 2016

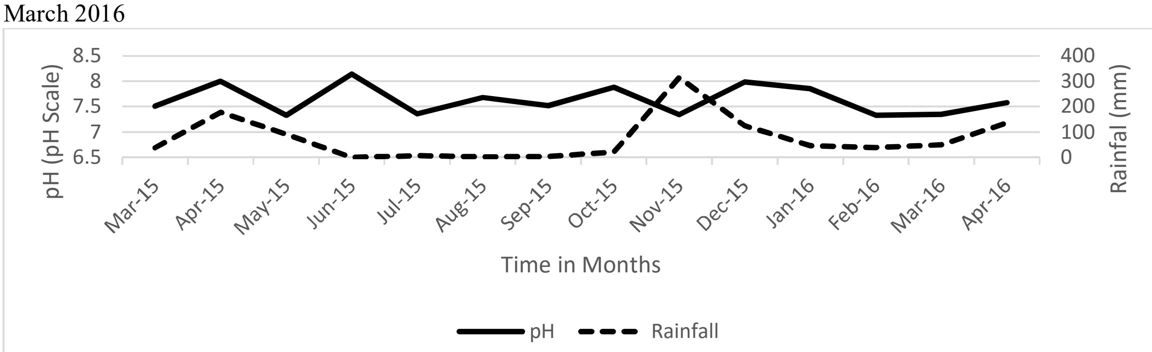

Figure 4(c): The variations of groundwater pH as a function of rainfall in the period between March 2015 and March 2016

Attempt was made to determine whether there is a significant relationship between rainfall variability and variations in groundwater quality parameters. The relationship between groundwater electrical conductivity and rainfall yielded a correlation coefficient r of 0.01. The relationship between groundwater total hardness and rainfall yielded a correlation coefficient r of 0.02. The relationship between groundwater total alkalinity and rainfall yielded a correlation coefficient r of 0.03. The relationship between groundwater TDS and rainfall yielded a correlation coefficient r of 0.06. These results showed that there was no significant relationship between rainfall and groundwater physic-chemical parameters during the sampling period. The absence of a significant relationship between rainfall and the water quality parameters may be due to time taken for surface water to infiltrate and percolate to deep aquifers found in the Yatta Plateau where the depths of boreholes range from 133 to 230m (Table 1). The influence of geology seems to be more important in influencing changes in the level of the groundwater quality parameters in the Yatta Plateau. This finding is consistent with the findings of Tavassoli and Khaksar (2002) who reported that in deep aquifers, in volcanic formations, groundwater quality is not influenced by rainfall.

4.2 The influence of water abstraction on groundwater quality

Groundwater is an important resource in the Lower Yatta sub-county of the Kitui County. Ground water is used for various purposes among them domestic water needs and small scale irrigation. Data on groundwater abstraction rates were obtained from records of various water supply projects established in the area. The abstraction of ground water was characterised by significant seasonal variations. The highest abstraction rate of 150m^3/day was recorded during the dry season at Kanyangi borehole. The wet seasons were generally characterised by relatively low abstraction rates ranging from 8 to 65m^3/day. The highest yielding wells were found in the southern and central parts of the plateau while the northern parts yielded relatively lower volumes of groundwater ranging from 2.5 to 2.8m^3/hr. There was evidence of over abstraction of groundwater at Kanyangi, Nthongoni and Kanyongonyo boreholes. The total water demand in the study area is 730m^3/day while the groundwater supply was 413m^3/day which accounts for 57% of the demand. Attempt was made to establish the relationship between groundwater abstraction and variations of some key groundwater quality parameters. The relationship between water abstraction and groundwater turbidity yielded a correlation coefficient r of 0.427 with a coefficient of determination R^2 value of 0.18 (Figure 5). The relationship between water abstraction and groundwater iron concentration yielded a correlation coefficient r of 0.38 with a coefficient of determination R^2 value of 0.14 (Figure 5). The relationship between water abstraction and groundwater pH yielded a correlation coefficient r of -0.56 with a coefficient of determination R^2 value of 0.31 (Figure 5). The groundwater pH tended to be more neutral as water abstraction rate increased. This could be explained by the fact that increased abstraction of groundwater leads to flow of water from the deep aquifers that tended to make the water more neutral. From these results, it can be argued that with the exception of groundwater pH, the abstraction of groundwater does not determine the quality of groundwater in the Yatta Plateau. The results were found to be generally non-linear probably emphasizing the influence of geology (see Figures 5, 6 and 7).

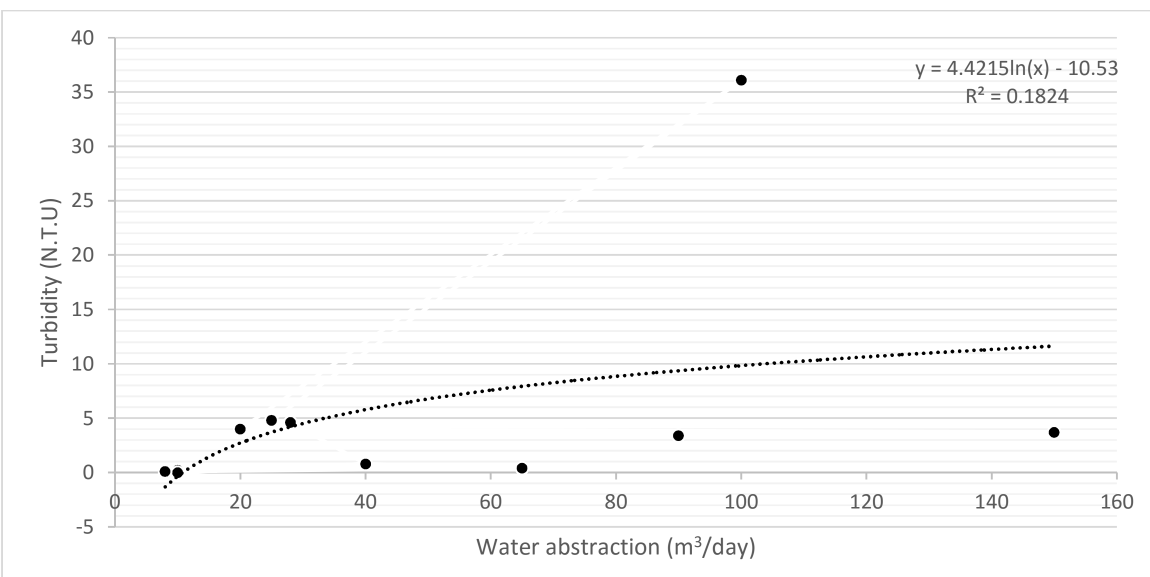

Figure 5: The relationship between groundwater turbidity and groundwater abstraction at the Yatta plateau.

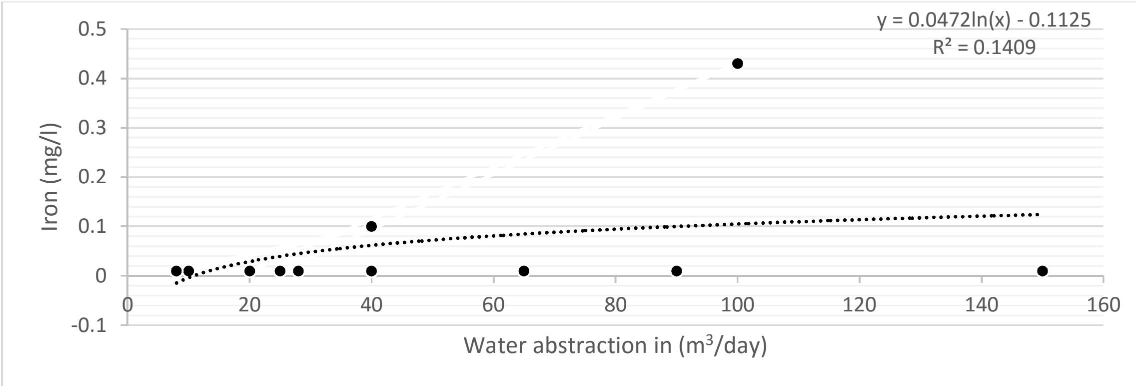

Figure 6: The relationship between groundwater iron concentration and groundwater abstraction at the Yatta Plateau

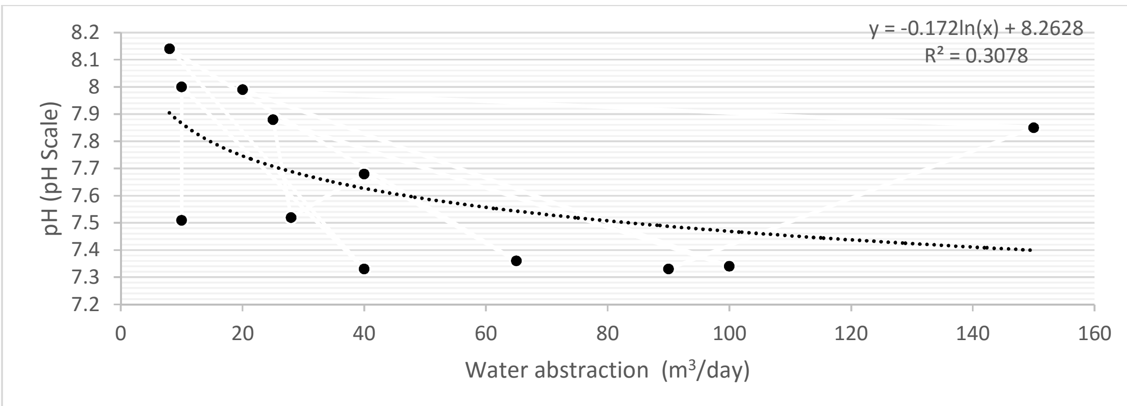

Figure 7: The relationship between pH and groundwater abstraction at the Yatta Plateau

The water demand in the Yatta plateau has been increasing due to increasing population. This is leading to over abstraction of ground water in almost all the boreholes in the Yatta plateau. Although the results shows that currently there is no significant relationship between abstraction rates and water quality parameters (See Figures 5 to 7), this is expected to change in future under the scenario of over-abstraction of groundwater.

4.3 Temporal Variability in water quality

The groundwater quality for boreholes located on the Yatta plateau showed significant temporal variations. Figure 8 shows the temporal variation in groundwater electrical conductivity. The electrical conductivity for each of the boreholes was plotted against time in seasons and the WHO standard for the electrical conductivity (2500 µS/cm). The lowest value for electrical conductivity was 184µS/cm which was found at Muselele borehole during the drilling period. The highest was 2270µS/cm which was found at Kanyongonyo borehole during the wet season of May 2015. The results showed that in most of the boreholes, the electrical conductivity was well below the WHO Standard of 2500 µS/cm. This was the case in both wet and dry seasons.

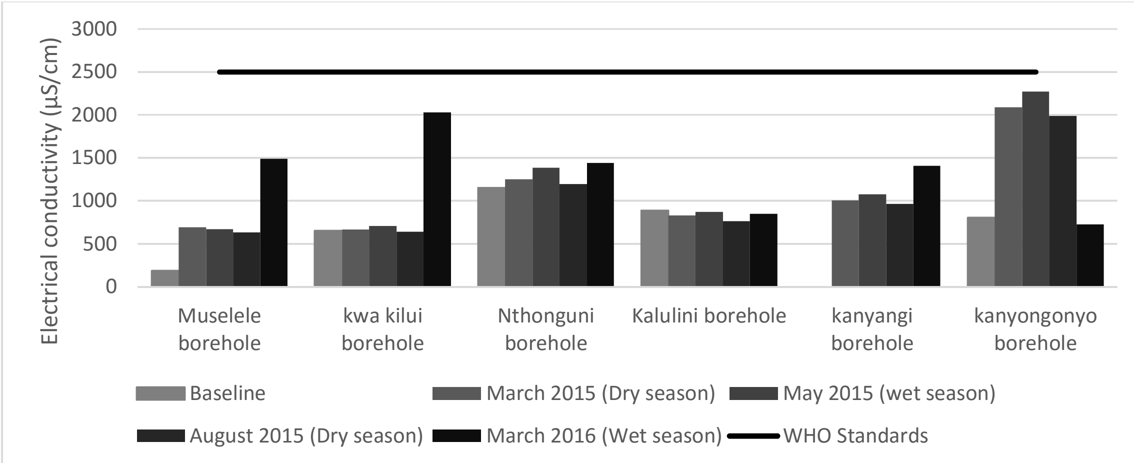

Figure 8: The temporal variations of groundwater electrical conductivity for boreholes located in the Yatta Plateau

Temporal variations of iron in groundwater within the Lower Yatta plateau are shown in Figure 9. The groundwater iron concentration was plotted against time in seasons. The highest value for groundwater iron concentration was 1.63 mg/l that was measured at KwaKilui borehole during the drilling period. The lowest concentration was 0.01 mg/l that was measured in all boreholes in the Yatta Plateau in both dry and wet seasons. In most boreholes with the exception of KwaKilui, Nthongoni and Kalulini boreholes, the iron concentrations were below the Kenya Bureau of Standards (KEBS) and WHO standards for Iron of 0.3 mg/l. The drilling periods when the baseline data was measured is shown in Table 1.

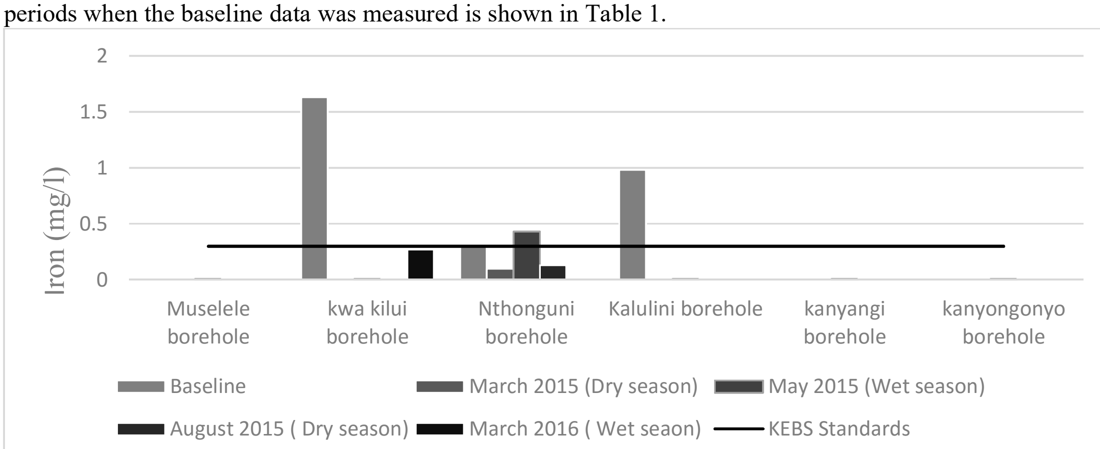

Figure 9: The temporal variations of groundwater iron concentration for boreholes located in the Yatta Plateau

Figure 10 presents the concentrations of TDS in groundwater for boreholes found in the Yatta Plateau. The KEBS drinking water standard for TDS is 1000 mg/l while that of WHO is 1500 mg/l. With the exception of Muselele, KwaKilui and Kanyongonyo boreholes, most of the boreholes had TDS concentrations that were below KEBS drinking water standards. The highest TDS value of 1407 mg/l was measured at Kanyongonyo borehole during the wet season of May 2015 while the lowest TDS concentration of 114 mg/l was measured at Muselele borehole during the drilling period shown (see Table 1).

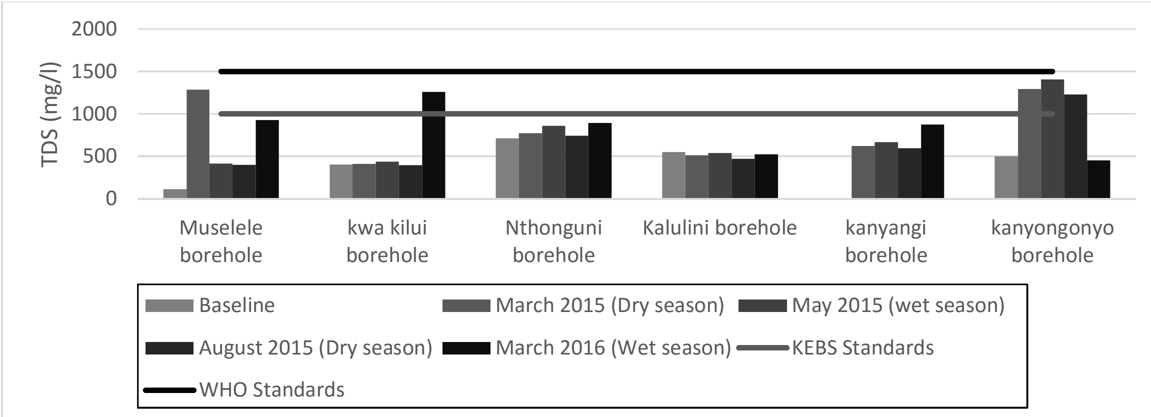

Figure 10: The temporal variations of the total dissolved solids for boreholes located in the Yatta Plateau

Figure 11 presents the temporal variation in fluoride concentration in boreholes found in the Lower Yatta plateau. Groundwater fluoride concentrations were plotted against time for each of the boreholes. The results showed that fluoride concentrations at Muselele and Kanyongonyo boreholes were above the WHO and KEBS drinking water standards of 1.5 mg/l . In some boreholes such as the Kalulini borehole, the fluoride concentrations was found to equal the WHO and KEBS drinking water standards during the drilling periods. The highest fluoride concentration of 2.4 mg/l was measured during the drilling period at Kanyongonyo borehole. The highest fluoride concentration of 0.3 mg/l was measured at KwaKilui borehole during the drilling period (see Table 1).

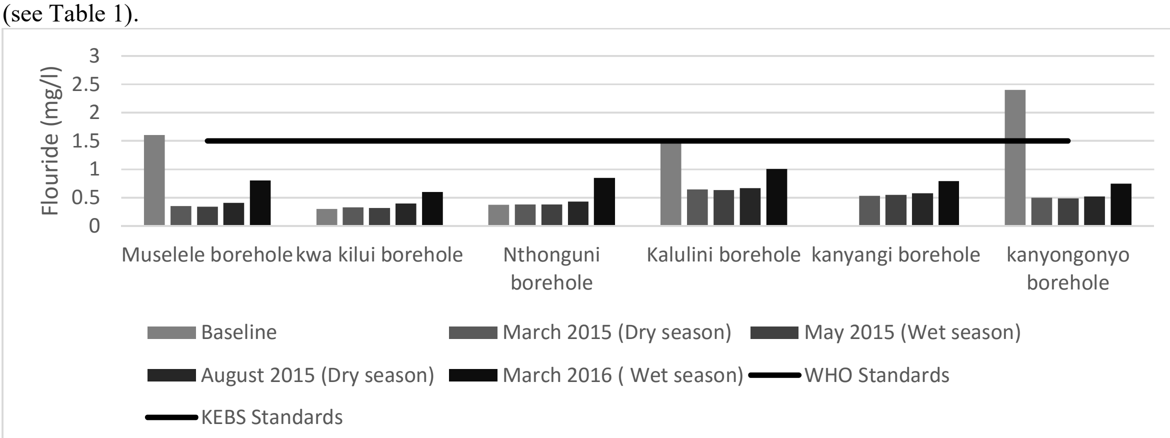

Figure 11: The temporal variations of fluoride concentration for boreholes located in the Yatta Plateau

4.5 Spatial variability of groundwater quality
4.5.1 Groundwater pH

The variations of pH showed significant spatial variations. For instance, the pH for Nthongoni and Kanyongonyo boreholes was lower as compared to the other boreholes while that of Kalulini and KwaKilui boreholes was relatively higher. The groundwater tended to be alkaline/neutral/acidic due to the volcanic rocks that make up the geology of the area (Petalas et al., 2006). The pH levels were relatively to the south as compared to the north of the plateau. Kalulini and KwaKilui boreholes tend to appear to be approaching high alkalinity levels while Nthongoni and Kanyongonyo boreholes tend to be approaching neutral pH levels. The pH levels for all the boreholes in the Yatta plateau was however within the KEBS and WHO drinking water standards.

4.5.1.2 Groundwater electrical conductivity

The groundwater electrical conductivity showed significant spatial variations. Kanyongonyo boreholes to the south of the plateau had the highest electrical conductivity levels. The differences in the electrical conductivity were attributed to the underlying geology. The weathering of rock formations in individual borehole aquifers leads to the dissolution of anions and cations which in turn affects the groundwater quality in the Yatta Plateau.

The concentration rates of different materials in groundwater are dependent on rocks which are in conduct with the water (see also Tavassoli and Khaksar, 2002). The electrical conductivity levels in boreholes in the Yatta plateau were however within the WHO and KEBS standards for drinking water of maximum 2500 uS/cm.

4.5.1.3 Groundwater iron concentrations

The concentrations of iron in groundwater in the Yatta plateau showed significant spatial variations. Nthongoni boreholes had the highest concentration of iron. The concentrations of iron reduced southwards towards Kanyongonyo borehole. The spatial variations of pH followed the same trend as that of the pH in the specific boreholes although boreholes with low pH levels (acidic water) were characterized by high concentrations of iron. High iron concentrations in groundwater aquifers are usually related to low pH levels (Petalas et al., 2006). The iron concentration in groundwater in the Yatta Plateau was however within the WHO and KEBS drinking water standards where the maximum is 0.2 mg/l.

4.5.1.4 Groundwater total alkalinity

The total alkalinity in groundwater in the Yatta plateau also showed significant spatial variations. Kanyongonyo and Kanyangi in the south of the plateau had the highest total alkalinity concentrations. The concentrations of total alkalinity reduced northwards towards KwaKilui borehole. The high alkalinity in the boreholes was attributed to the geo-chemistry of the Yatta plateau which causes rock minerals to dissolve into the aquifers (see also Petalas et al., 2006). The total alkalinity in most boreholes in the plateau was however within the WHO and KEBS drinking water standards (500 mg $CaCO_3$/l).

4.5.1.5 Total Dissolved Solids (TDS)

The TDS reduced northwards from Kanyongonyo Borehole towards Muselele borehole regardless of the seasons. The TDS witnessed in the boreholes was attributed to the underlying geology of the Yatta plateau (cf. Alberta, 2009; Tavassoli and Khaksar, 2002). The TDS concentrations were also within the WHO and KEBS drinking water standard where the maximum is between 1500 and 1000 mg/l.

4.5.1.6 Groundwater turbidity

The turbidity levels in groundwater found in the Yatta plateau were relatively higher in Nthongoni in the east of the plateau. The concentrations reduced southwards and northwards towards Kanyangi and Muselele boreholes. The high turbidity witnessed in Nthongoni borehole was attributed to the high level of electrical conductivity and the geology of the area (cf. Tavassoli and Khaksar, 2002), Petalas et al.,(2006; Tong and Chem, 2011; Raghunath, 2006). The highest turbidity values noted at Nthongoni borehole were above WHO standards for drinking water of maximum of 5 N.T.U.

4.5.1.7 Groundwater fluoride concentrations

Fluoride concentrations in groundwater showed significant spatial variations. Kalulini borehole in the south of the plateau was found to have relatively higher fluoride levels compared to other boreholes in the plateau. The concentration of fluoride reduced to the south, east and north of the area from the area of maximum concentration at Kalulini. However, the levels of fluoride were within the WHO and KEBS drinking water standards which may be related to the chemical desolution of volcanic rocks (cf. Raghunath, 2006. Therefore differences witnessed in fluoride concentrations in the Yatta plateau boreholes may be due to variations in the geology of the Yatta plateau (cf. Tavassoli and Khaksar, 2002; Petalas et al., 2006).

4.5.1.8 Groundwater total hardness

The total hardness of groundwater showed significant spatial variations. Kanyongonyo had a relatively higher concentration of total hardness while Kalulini had the lowest concentration compared to the other boreholes. The total hardness for Kanyongonyo borehole was above both WHO and KEBS drinking water standards. This was attributed to the high levels of TDS noted within the borehole during the sampling period (see also Thirupathaiah et al., 2012). Total hardness has been attributed to high levels of magnesium and calcium salts in the water (cf. Thirupathaiah et al., 2012). The high levels of total hardness may be also due to the dissolution of minerals present within the aquifer (cf. Tavassoli and Khaksar, 2002).

4.5.2 Temporal variability in groundwater quality

The variability of water quality parameters in the Yatta plateau showed different trends (Figures 8 to 11). The groundwater electrical conductivity was above the baseline values for all the boreholes except for Kalulini borehole. There is therefore an increase in the level of groundwater electrical conductivity since the boreholes were drilled. All the values for the parameter were however found to be within the WHO drinking water standards. This implies that the water was safe for human consumption. Due to the similarity witnessed in the electrical conductivity trend, it is most likely that the increase could be as a result of dissolution of rock material within the aquifers leading to increase of ions in the water (Tavassoli and Khaksar, 2002; Thirupathaiah et al., 2012).

The results showed that iron concentrations in groundwater have decreased in three boreholes namely KwaKilui, Nthongoni and Kalulini boreholes. However, there is no change in the remaining three boreholes. The decrease in iron concentration could be due to an increase in pH level within the water column above pH of 6.5 (cf. Environmental Fact Sheet (http://www.idph.state.il.us). This could also be due to differences in the composition of the geologic formations (cf. Tavassoli and Khaksar, 2002; Petalas et al., 2006).

Significant temporal variation for groundwater TDS was found to exist in the Yatta plateau. The TDS concentrations were however below the WHO drinking water standards. However some values for Muselele, KwaKilui and Kanyongonyo boreholes were found to surpass the KEBS standards. Generally, the groundwater from the studied boreholes is safe for drinking purpose. The differences in concentration could be due to differences in the geological formations and factors such as weathering or rocks (cf. Tavassoli and Khaksar, 2002; Tong and Chem, 2011; Alberta Environment, 2009).

Although the fluoride values for the boreholes during the sampling period were found to be lower than those of the baseline data, there was an increasing trend. The current levels of fluoride are much higher as compared to the levels during the drilling period. This increase was attributed to the dissolution of volcanic rocks (cf. Tavassoliand Khaksar, 2002; Petalas et al., 2006). The increasing trend in fluoride levels may in future be a threat to public health if the levels are above the WHO Drinking water standards (WHO 2006).

4.6 The effects of groundwater quality in water utilization

The concerns of the local community in the Yatta plateau with regard to the suitability of groundwater for various purposes, was determined through questionnaire survey. The groundwater in the Lower Yatta plateau is used for various purposes among them domestic, livestock and small scale irrigation uses. The demand for water has been rising due to increase in population. The results of questionnaire survey shows that the local community in the Yatta plateau is almost entirely dependent on groundwater for their domestic water needs. The main water quality concern for the majority of water users (90%) was taste of water. The local community (80%) noted that salinity of groundwater was a major issue. The taste in the water could be attributed to the influence of the underlying rocks through desolution of rock minerals (e.g those from Kankur limestone). Previous studies elsewhere have shown that taste in water may be due to the presence of high levels of total hardness and electrical conductivity within the boreholes. The local community noted that the taste in water changed seasonally. The taste was better during the wet season as compared to dry season when salinity levels are high. These results agree with those of Adetunde et al., (2011) and Yan, et al., (2015). Other water quality concerns that were raised by the local community were color and odor of water. Most of the people noted that there was odor in the borehole water. However, only a small proportion of the local community complained of odor in the borehole water for Kanyangi, Kalulini, Kanyongonyo and Nthongoni boreholes. The local community was however unable to indicate with certainty whether there was seasonal variations in groundwater odor. The odor in the groundwater was attributed to presence of iron in the groundwater (see also Adetunde et al., 2011).

More than 95% of the local community indicated that color of groundwater was a key concern. The small group that complained of water color further suggested that the color varied with different seasons and that major changes occurred mostly during the wet season. The presence of color could be attributed to dissolved minerals in the water (cf. Tavassoli and Khaksar, 2002). The presence of color affected the water users such that some of them found the water being unfit for drinking purposes. However, water color should not be a major issue in a rural community without alternative water source. Study done by WHO (2006) established the main issue of concern is high levels of dissolved minerals that induces tatse in groundwater.

Conclusions

This study showed that there were significant spatial variations in the groundwater quality parameters in the Yatta plateau. The spatial variations do not seem to be interconnected. The causes of the spatial variations were mainly attributed to the nature of geological formations in Yatta plateau. Both short term and long term changes in the groundwater chemical parameters were found to exist. The influence of hydrogeology on the ground water quality was found to play a key role in the variations since other factors including rainfall were found not to play a role in the water quality changes. There was no significant influence of the water abstraction on the groundwater quality. Most of the ground water quality parameters except for turbidity were found to be within the WHO and KEBS drinking water standards. However, it was also found that some of the parameters notably

Electrical conductivity, TDS and fluoride were increasing when compared to baseline levels and are likely to surpass the WHO and KEBS standards in the future. The study recommended that regular and enhanced groundwater quality monitoring be undertaken in order to establish with certainty groundwater quality trends in the Yatta plateau. It is also recommended that a detailed geologic investigation be conducted for the boreholes in the region so as to ascertain the causes of significant spatial variations of groundwater quality parameters in the Yatta Plateau.

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