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Impact of rainfall variability on groundwater levels in Ruiru municipality, Kenya

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Groundwater accounts for the largest fresh water resources in the world. However, there has been limited exploitation of this vital resource in many areas. Where groundwater resources have been utilised, they have been over-exploited, polluted, wasted and mismanaged. In Ruiru municipality, groundwater is a major component of the water supply, contributing about 70% of the water demand. Rising population numbers and industrial development have led to a high water demand, increased water scarcity and more reliance on ground water. Assessing the effect of rainfall variability on groundwater levels of boreholes in Ruiru municipality will help in assessing the sustainability of groundwater resources in the area. Groundwater levels were measured using a dipper and spatial locations of the boreholes were established and mapped using GIS. Rainfall data was collected from the Kenya Meteorological Department and the Water Resources Management Authority. The water table fluctuation method was used to estimate recharge. There was an impact of rainfall variability on groundwater levels. The results showed a decline in groundwater levels during low rainfall periods. The rainfall variability, caused by climate change, brought about prolonged droughts and low recharge in the area. Climate change should be mitigated to cap the decline in groundwater and abstraction controlled to ensure that groundwater resources are managed properly to avoid depletion.

Keywords: climate, groundwater, rainfall, recharge, water-table, water-rest level

JEL classification: Q25, Q54

Introduction

Groundwater forms a large portion of fresh water in the world. In the semi-arid regions of Asia and the Middle East, which are some of the major breadbaskets of the world, the ground water table is falling at an alarming rate. There is an urgent need to focus the attention of professionals and policy makers on the problems of ground water depletion, which is a major threat to food security in the coming century (Seckler, Barker and Amarasinghe 2010). Water use has been growing at more than twice the rate of population increase in the last century and an increasing number of regions are chronically short of water. There are about 40 million people living in Kenya (KNBS 2010), of which about 17 million do not have access to clean water. For decades, water scarcity has been a major issue in Kenya, caused mainly by years of recurrent droughts, poor management of water supply, contamination of the available water, and a sharp increase in water demand resulting from relatively high population growth. Lack of sufficient rainfall affects the ability to acquire food and has led to eruptions of violence in Kenya. (Marshall 2011).

In many areas of Kenya, water shortage has been amplified by the government's lack of investment in water, especially in rural areas. Most of the urban poor in Kenya only have access to polluted water, which has caused cholera epidemics and many other diseases that affect health and livelihoods. Despite the critical shortage of clean water in Kenya's urban slums, there is also a large rural to urban discrepancy in access to clean water (Marshall 2011). Slightly less than half of the rural population has access to water, as opposed to the urban population where 85 percent have access to safe water including a smaller portion of the urban poor in slums. Due to continued population growth, it has been estimated that by the year 2025, Kenya's per capita water availability will be 235 cubic meters per year, about two thirds less than the current 650 cubic meters (World Bank 2010). Groundwater plays a major role in Kenya today as it provides water for irrigation farming, domestic and industrial use thus helping in offsetting the supply deficit.

There is increasing demand for available water resources especially groundwater resources which are the major source of water in Ruiru municipality. It is therefore necessary to study the impact of rainfall variability on groundwater resources in the municipality to help in planning for sustainable management (see Table 1 and Figures 1 and 2).

Table 1: Water sources

Water source	Production capacity m^3/day	Actual yield in m^3/day	Area of coverage
Ruiru water supply	7000	700	25%
Boreholes(RUJWASCO)	360	240	10%
NWSC supply	400	100–150	5%
Community water projects (boreholes)	19890	2000	20%
Total ground water contribution to municipal water supply			70.98%

Source: Ruiru-Juja Water and Sewerage Company 2008

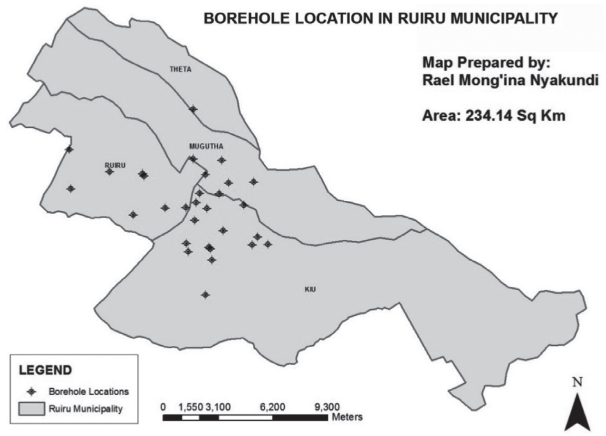

Figure 1: Location map of boreholes studied

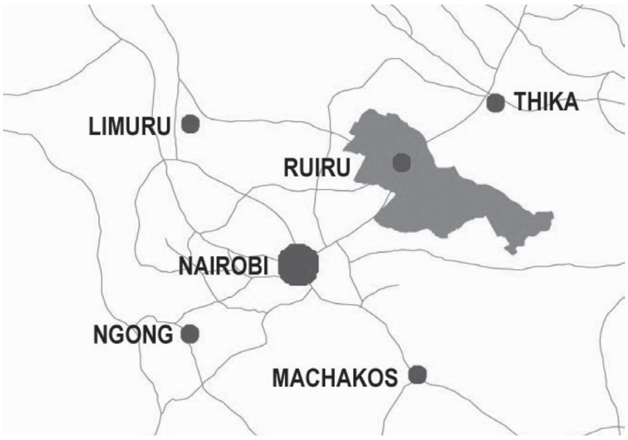

Figure 2: Map of Ruiru Municipality

Methodology

Data on rainfall and groundwater levels of the monitored boreholes was obtained from the Water Resources Management Authority (WRMA) and the Kenya Meteorological Department (KMD). These were modelled using a linear regression model to determine the relationship between them. Water level fluctuation was analysed from the months of February to December. The groundwater and rainfall data as recorded on a monthly basis was analysed and graphically interpreted in order to understand the dynamics of groundwater levels and rainfall. Data which has been graphically analysed based on climate-change scenarios enables changes in future annual groundwater-level minima to be modelled.

The relationship between rainfall and groundwater is explained through linear regression modelling and groundwater recharge. The groundwater recharge is estimated using the water-table fluctuation method, which assumes that a water-table rise in an aquifer is attributable to recharge. Recharge (R) is calculated as

$$R(t_j) = S_y \times \Delta H(t_j) \qquad (1)$$

Where,

$R(t_j)$(cm) = recharge occurring between time t_0 and t_j

S_y = specific yield (dimensionless), and

$\Delta H(t_j)$ = peak water level rise attributed to the recharge period (cm)

Specific yield from recession curve

Specific yield (Sy) is determined by knowing the total drawdown during the dry periods and equating this to the total withdrawal of water from the well during the same period. Hence, Sy is determined from the following equation:

$$Sy - \frac{\alpha t}{d} \qquad (2)$$

Where,

d = total drawdown (m)

t = time period (days)

α = recession constant (m/day)

Establishment of recession equation

Water level below ground level in the open well at any month during the dry period can be predicted by applying the recession model which is of the form:

$$h - h_0 e^{\alpha t} \qquad (3)$$

Where,

h = water level below ground surface at time t (m)

h_0 = initial watrer level (m)

α = recession constant

t = time (days)

The water level rise $\Delta H(t_j)$ will be obtained from the difference between the peak of a water-level rise and the value of the extrapolated antecedent recession curve at the time of the peak (water-table rise).

Key assumptions made in the application of this method include:

1. The observed well hydrograph must only show natural water-table fluctuations caused by groundwater recharge and discharge.
2. Specific yield is constant over the time period of the water-table fluctuations.
3. The pre-recharge water-level recession can be extrapolated to determine $\Delta H(t_j)$, (USGS, 2007).

Results and Discussion

The results (Table 2, Figure 3) show that from 2009 to 2013 there was a steady increase in the number of boreholes (4% to 32%) meaning the rate of groundwater exploitation increased over the same period.

The results of groundwater levels during the dry season and wet season, for example at Borehole Murera (Figure 4), showed that the water levels in the dry season were lower than the water levels during the wet season. The

Table 2: Number of boreholes completed each year from 2009 to 2013

Year	No. of boreholes	Percentage no. of boreholes
2009	1	4%
2010	2	8%
2011	6	24%
2012	8	32%
2013	8	32%

Table 3: Water rest level in wet and dry seasons for studies boreholes

B/hole No	10011	10421	10494	10036	10127	10126	10276	10349	10403	10402	10203	10205	10206	10207	10208	10185	10186	10285	10217	10309	10302	10311	10145	10169	10391	10392	10381	10326	10346	195	213
WRL Wet (m)	24.1	17.8	18.1	25.9	22	24.9	25.1	38.2	41.1	30.8	26.8	22.9	21.9	19.3	17.8	18.3	24.7	14.9	13.7	22.9	40.4	28.8	34.8	25.8	29.9	44.9	32.8	35.4	57.9	29.9	42.7
WRL Dry (m)	29.2	20.1	22.2	29.8	26.2	29.8	30.1	43.5	46.3	34.9	30.2	27	28.2	27.2	26.1	23.3	29.2	18.6	18.1	27.3	44.3	32.3	38.1	28.6	33.7	48.8	37.0	39.7	60.8	34.5	46.7
Change in WRL	-5.1	-2.3	-4.1	-3.9	-4.2	-4.9	-5	-5.3	-5.2	-4.1	-3.4	-4.1	-6.3	-7.9	-8.3	-5.0	-4.5	-3.7	-4.4	-4.4	-3.9	-3.5	-3.3	-2.8	-3.8	-3.9	-4.2	-4.3	-2.9	-4.6	-4.0

groundwater level drop ranged between 2.3m and 8.3m. This was attributed to groundwater recharge due to precipitation and high abstraction rates during the dry season (Table 4, Figure 5).

The visual observation hydrograph in the year 2012 indicated high water levels in the months of February, March, April, May, November and December while the months of June, July, August, September and October showed low water levels (Figure 4). This is associated with wet and dry seasons over the year (Figures 6–10, Table 5).

Figures 8, 9, and 10 show two wet seasons when the rainfall amounts are high i.e February to June and September to December. January, July and August have low rainfall amounts.

Figure 11 shows that when when the rainfall amounts are high the water rest level is high due to recharge since it is the distance from the ground level. When the rainfall amounts are low the water levels are deep below the surface of the ground i.e. they decrease.

There was rainfall variability across seasons of the year which can be explained as the impact of climate change in the area that lead to extreme weather conditions such as prolonged droughts and floods. The results indicated a decline in

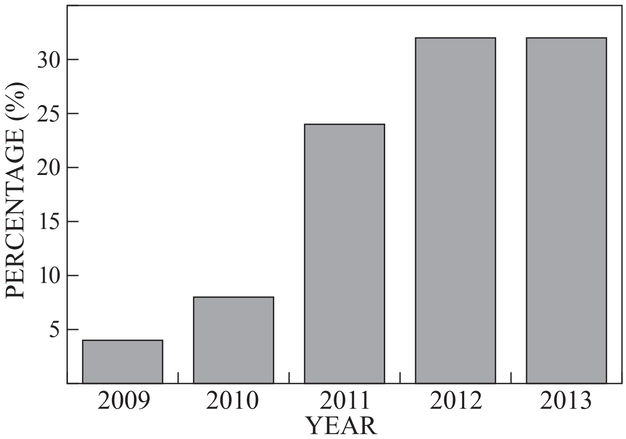

Figure 3: Percentage of boreholes completed per year

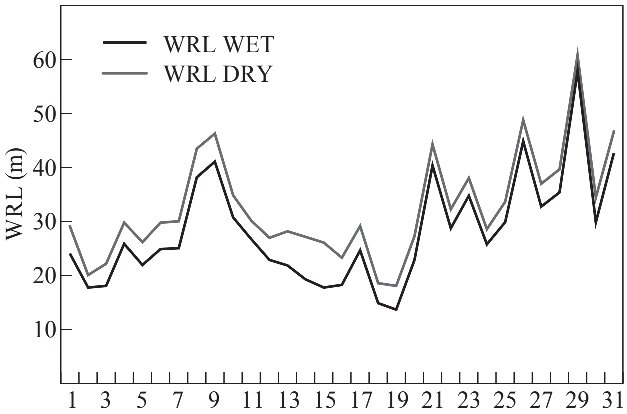

Figure 4: Borehole groundwater level in wet and dry season

Table 4: Groundwater levels for Murera monitoring borehole

2012		2013		2014	
Month	GWL (m)	Month	GWL (m)	Month	GWL (m)
Jan		Jan	26.6	Jan	27.6
Feb	27.4	Feb	27.32	Feb	27.5
Mar	27.4	Mar	27.34	Mar	27.4
Apr	27.3	Apr	27	Apr	27.6
May	28	May	27.1	May	27.5
June	28.2	June	27.18	June	27.55
Jul	37.2	Jul	27.3	Jul	27.6
Aug	32.4	Aug	27.35	Aug	27.75
Sep	37.3	Sep	27.4	Sep	27.65
Oct	36.6	Oct	27.5	Oct	27.75
Nov	27.3	Nov	27.55	Nov	27.8
Dec	27	Dec	27.6	Dec	27.85

GWL = Groundwater level (metres)

groundwater levels during low rainfall as shown in Figures 11, 12 and 13 since groundwater recharge depends mainly on rainfall. Moreover during the dry season there was over-exploitation of the ground water as other sources supplied less water. On the other hand there was a rise in groundwater levels due to infiltration as rainfall amounts increased.

Relationship between rainfall and groundwater levels

The study showed that rainfall and groundwater levels were negatively correlated because water rest level was measured from the ground surface. This means that the distance from the ground surface to the surface of water in the borehole was the read figure. Thus as the groundwater level decreased the water rest level increased, hence explaining the negative correlation.

The results showed that rainfall was not the only factor influencing groundwater levels. But rainfall did play a role to a certain extent. Other factors which might have influenced the groundwater levels include the land cover. Ruiru municipality is dominated by pavements as compared to vegetation. This leads to high runoff during the rainfall periods thus infiltration is low. Infiltration rate in the area could also be low because of the geologic

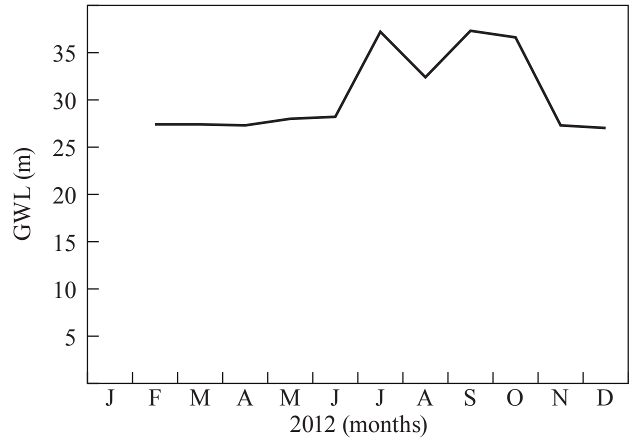

Figure 5: Water rest levels 2011

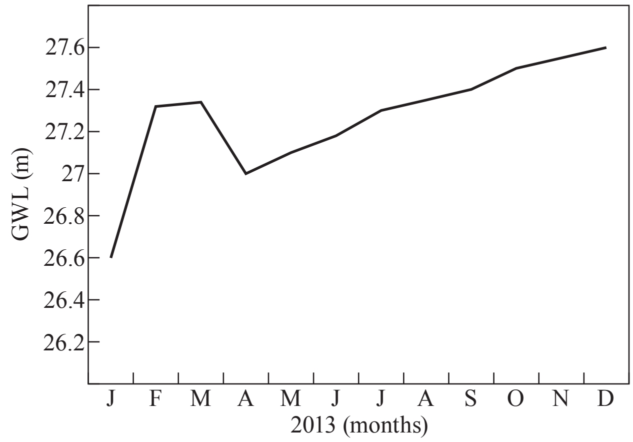

Figure 6: Water rest level 2013

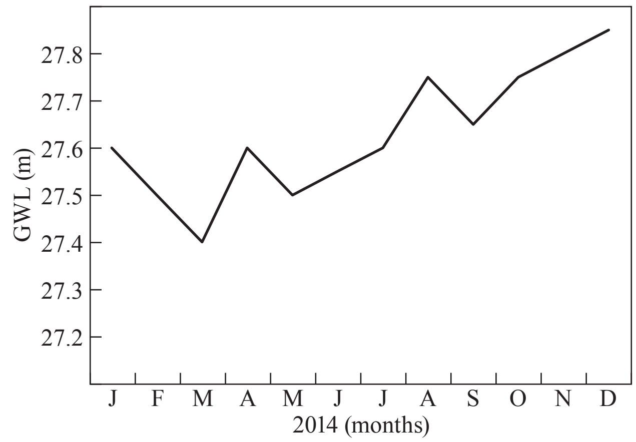

Figure 7: Water rest level 2014

Table 5: Rainfall Data for Ruiru Municipality from 2012 to 2014

2012	2013		2014	
Rainfall (mm)	Month	Rainfall (mm)	Month	Rainfall (mm)
0.0	Jan	71.3	Jan	27.7
35.8	Feb	11.0	Feb	149.9
0.0	Mar	212.4	Mar	131.9
644.4	Apr	161.6	Apr	147.5
503.5	May	112.4	May	99.0
129.0	Jun	41.5	Jun	200.91
20.7	Jul	41.9	Jul	40.4
31.6	Aug	64.8	Aug	66.0
31.5	Sep	56.1	Sep	102.7
334.3	Oct	24.6	Oct	174.1
306.8	Nov	129.8	Nov	199.5
414.1	Dec	212.9	Dec	127.9

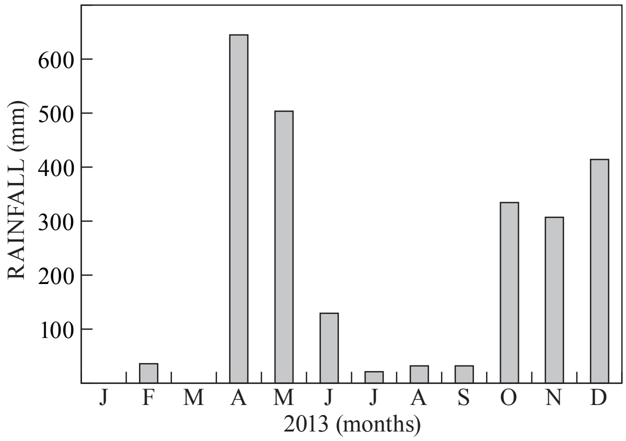

Figure 8: Rainfall in Riuru Municipality 2012

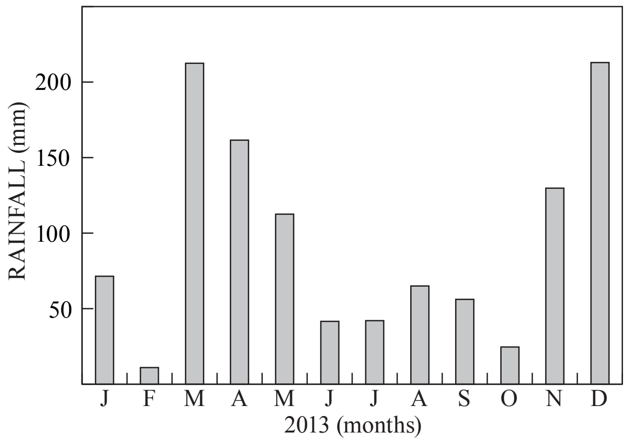

Figure 9: Rainfall in Riuru Municipality 2013

formation, thus it took a lot of time for the rainfall to be reflected on the groundwater levels. Abstraction of water from the boreholes also influenced the groundwater levels as it is a major source complementing other water supply sources in the municipality.

The recharge was calculated using the water table fluctuation method for every month from January to December for the years 2012, 2013 and 2014 as shown in Table 6 above, and the total recharge for the whole year calculated by summing the recharge for every month.

In the year 2012 the recharge rate ranged from no recharge to a maximum recharge of about 120 mm (Figure 14). In the same year summing the total monthly recharge gives -5.59mm which implies that there was no recharge instead there was overdraw of groundwater.

In the year 2013 the recharge ranged from no recharge i.e. –6.48mm to a maximum of 11.599mm (Figure 15). The total annual recharge in the same year was 1.588mm.

In the year 2014 the amount of recharge ranged from no recharge of –0.79mm to a maximum of 3.159mm (Figure 16). The total annual recharge in the same year was 3.916mm.

The total annual recharge increased from no recharge in the year 2012 to a recharge of 1.588mm recharge in the year 2013. There was also an increase of recharge from 1.588mm in the year 2013 to 3.916mm in the year 2014, an increase of 2.328mm (Figures 17, 18 and 19). Figures 17,18 and 19 show that when the rainfall amounts are high the recharge is high.

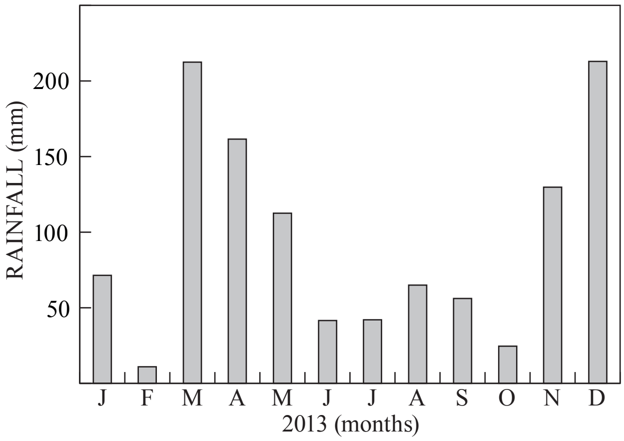

Figure 10: Rainfall in Riuru Municipality 2014

Table 6: Calculation of recharge in Riuru Municipality for the years 2012, 2013 and 2014

2012	Final (h)	Initial (Ho)	Time(t)	A	h/ho	ln (h/ho)	Δh(d)	Sy	Recharge
Feb	27.4	27.3	28	5.67113E-05	1.003663	0.001588	0.1	0.015879	0.001588
Mar	27.35	27.4	31	-2.55881E-05	0.998175	-0.00079	-0.05	0.015865	-0.00079
Apr	27.3	27.35	30	-5.29305E-05	0.99635	-0.00159	-0.1	0.015879	-0.00159
May	28	27.3	31	0.00035469	1.025641	0.010995	0.7	0.015708	0.010995
Jun	28.2	28	30	0.000103036	1.007143	0.003091	0.2	0.015455	0.003091
Jul	37.2	28.2	31	0.003880446	1.319149	0.120294	9	0.013366	0.120294
Aug	32.4	37.2	31	-0.001935417	0.870968	-0.06	-4.8	0.0125	-0.06
Sep	37.3	32.4	30	0.002038794	1.151235	0.061164	4.9	0.012482	0.061164
Oct	36.6	37.3	31	-0.000265411	0.981233	-0.00823	-0.7	0.011754	-0.00823
Nov	27.3	36.6	30	-0.004243948	0.745902	-0.12732	-9.3	0.01369	-0.12732
Dec	27	27.3	31	-0.000154803	0.989011	-0.0048	-0.3	0.015996	-0.0048
Total annual recharge									-0.00559
2013									
Jan	26.6	27	31	-0.000209101	0.985185	-0.00648	-0.4	0.016205	-0.00648
Feb	27.32	26.6	28	0.000414252	1.027068	0.011599	0.72	0.01611	0.011599
Mar	27.34	27.32	31	1.02521E-05	1.000732	0.000318	0.02	0.015891	0.000318
Apr	27	27.34	30	-0.000181158	0.987564	-0.00543	-0.34	0.015985	-0.00543
May	27.1	27	31	5.17912E-05	1.003704	0.001606	0.1	0.016055	0.001606
June	27.18	27.1	30	4.26721E-05	1.002952	0.00128	0.08	0.016002	0.00128
Jul	27.3	27.18	31	6.1716E-05	1.004415	0.001913	0.12	0.015943	0.001913
Aug	27.35	27.3	31	2.5635E-05	1.001832	0.000795	0.05	0.015894	0.000795
Sep	27.4	27.35	30	2.64411E-05	1.001828	0.000793	0.05	0.015865	0.000793
Oct	27.5	27.4	31	5.10365E-05	1.00365	0.001582	0.1	0.015821	0.001582
Nov	27.55	27.5	30	2.6297E-05	1.001818	0.000789	0.05	0.015778	0.000789
Dec	27.6	27.55	31	2.54025E-05	1.001815	0.000787	0.05	0.01575	0.000787
Total annual recharge									0.009545
2014									
Jan	27.55	27.6	31	-2.54025E-05	0.998188	-0.00079	-0.05	0.01575	-0.00079
Feb	27.5	27.55	28	-2.81753E-05	0.998185	-0.00079	-0.05	0.015778	-0.00079
Mar	27.4	27.5	31	-5.10365E-05	0.996364	-0.00158	-0.1	0.015821	-0.00158
Apr	27.6	27.4	30	0.000105284	1.007299	0.003159	0.2	0.015793	0.003159
May	27.5	27.6	31	-5.08512E-05	0.996377	-0.00158	-0.1	0.015764	-0.00158
Jun	27.55	27.5	30	2.6297E-05	1.001818	0.000789	0.05	0.015778	0.000789
Jul	27.6	27.55	31	2.54025E-05	1.001815	0.000787	0.05	0.01575	0.000787
Aug	27.75	27.6	31	7.59324E-05	1.005435	0.002354	0.15	0.015693	0.002354
Sep	27.65	27.75	30	-5.22617E-05	0.996396	-0.00157	-0.1	0.015679	-0.00157
Oct	27.75	27.65	31	5.05759E-05	1.003617	0.001568	0.1	0.015679	0.001568
Nov	27.8	27.75	30	2.60603E-05	1.001802	0.000782	0.05	0.015636	0.000782
Dec	27.85	27.8	31	2.51743E-05	1.001799	0.00078	0.05	0.015608	0.00078
Total annual recharge									0.003916

Through the application of the WTF method, estimated recharge rates were calculated for the boreholes established in unconfined aquifer settings. In the year 2012 there was no recharge as the groundwater was overdrawn by 5.59mm. In 2013 a recharge of 1.588mm was realized while a recharge of 3.159mm was achieved in 2014.

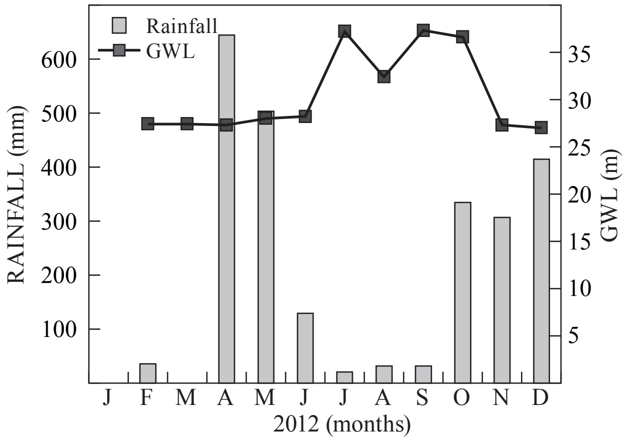

Figure 11: Rainfall and water rest level in Riuru Municipality 2012

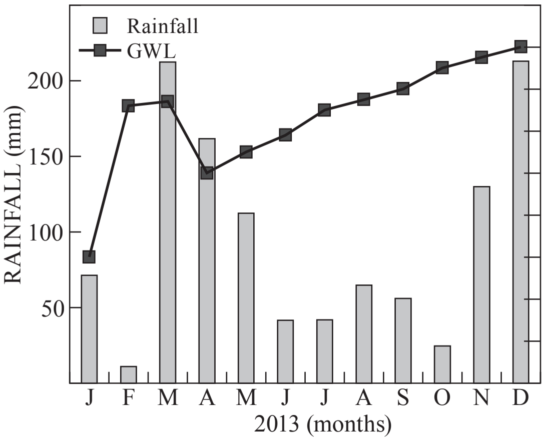

Figure 12: Rainfall and water rest level in Riuru Municipality 2013

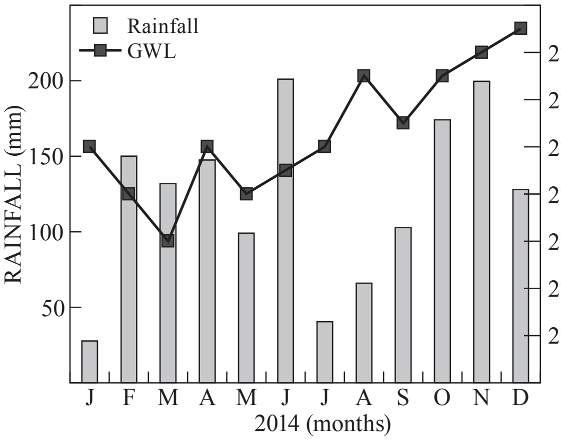

Figure 13: Rainfall and water rest level in Riuru Municipality 2014

Conclusion

There was an impact of rainfall variability on groundwater levels. The rainfall variability, caused by climate change, brought about extreme weather conditions such as prolonged droughts and flood in the area. Thus climate change should be mitigated to cap decline in groundwater especially during low rainfall periods. In Ruiru municipality, being dominated with pavement land cover, abstraction should be controlled to ensure that groundwater resources are managed properly to avoid depletion**.**

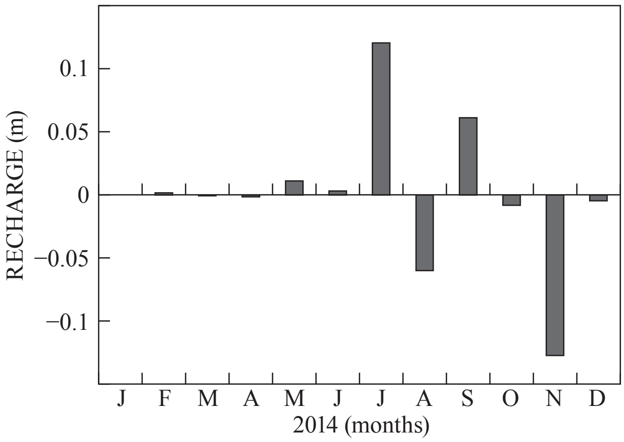

Figure 14: Recharge in Riuru Municipality 2012

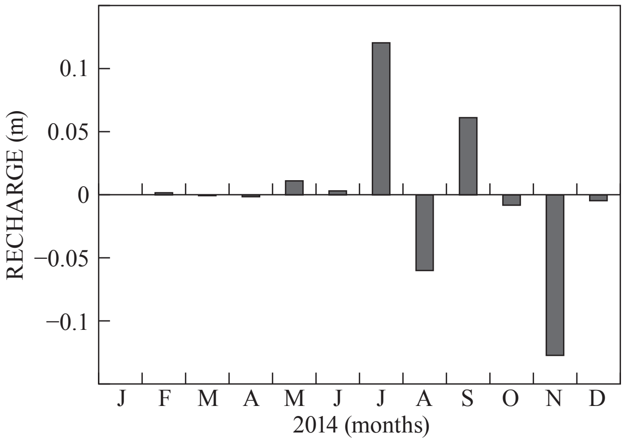

Figure 15: Recharge in Riuru Municipality 2013

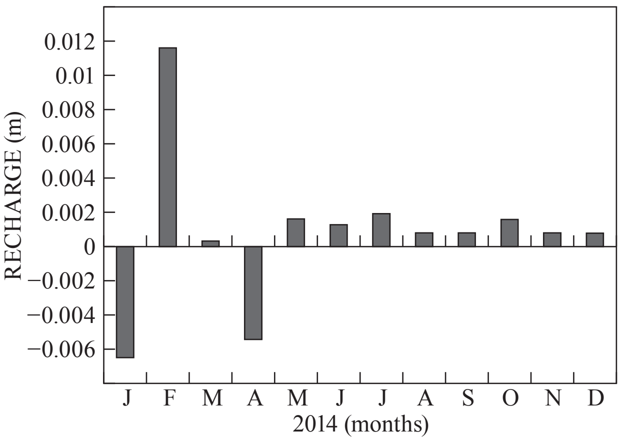

Figure 16: Recharge in Riuru Municipality 2014

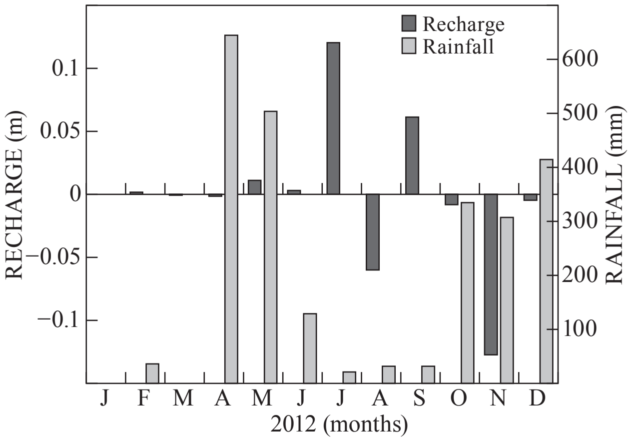

Figure 17: Recharge and rainfall in Riuru Municipality 2012

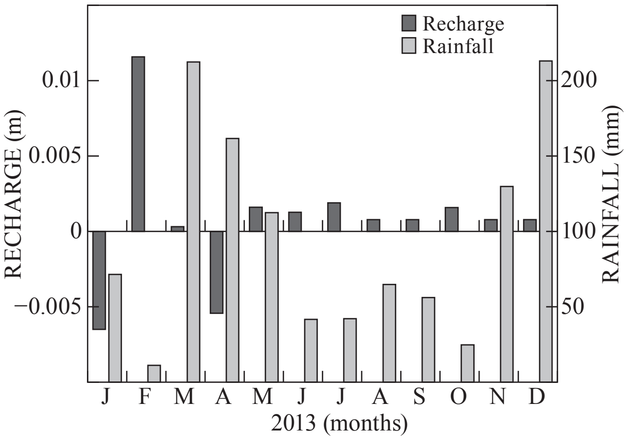

Figure 18: Recharge and rainfall in Riuru Municipality 2013

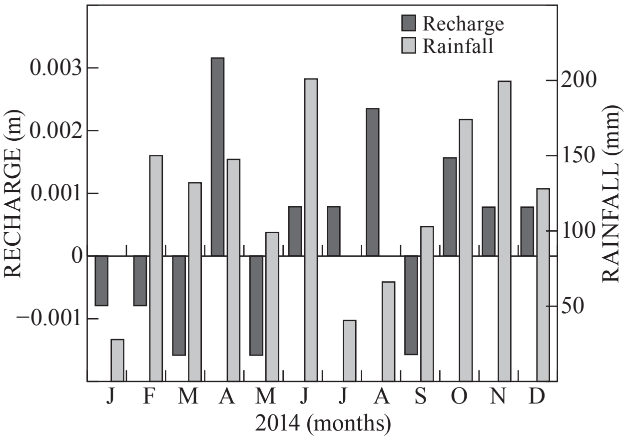

Figure 19: Recharge and rainfall in Riuru Municipality 2014

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