GROUNDWATER LEVEL VARIABILITY IN RUIRU LOCATION, KIAMBU COUNTY, KENYA

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Groundwater Level Variability in Ruiru Location, Kiambu County, Kenya

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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LIST OF ABBREVIATIONS AND ACRONYMNS

BCM	Billion Cubic Meters
CRF	Coffee Research Foundation
EA	Environmental Agency
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
GIS	Geographical Information System
GLI	Groundwater Level Index
GPS	Geographical Positioning System
GWMATE	Ground Water Management Association
IWRMS	Integrated Water Resources Management System
MLD	Million Litre Day
MOWI	Ministry of Water and Irrigation
MP	Measuring Point
NGLA	National Groundwater Level Archive
NIBS	Nairobi Institute of Business Studies
NWSC	Nairobi Water and Sewerage Company
OECD	Organization for Economic Co-operation Development
RUJWASCO	Ruiru-Juja Water and Sewerage Company

SEPA	Scottish Environmental Protection Agency
SIPA	School of International and Public Affairs
SPI	Standard Precipitation Index
UK	United Kingdom
UNEP	United Nations Environmental Programme
USEPA	United States Environmental Protection Agency
WE	Water and Environment
WRMA	Water Resources Management Authority

ABSTRACT

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 exploited, there has been over-exploitation, pollution, wastage and mismanagement. About a third of Kenya's population has no access to potable water. In Ruiru location,rising population and industrial development has led to a high water demand and increased water scarcity. Groundwater from boreholes is a major source of water supply contributing about 70% of the water requirements. Analysis on water supply in the location done by RuiruJuja Water and Sewerage Company (RUJWASCO), shows that even after completion of Jacaranda dam, water demand cannot be met in the location. In addition, declining borehole water levels and drying up of wells during the dry season has become a major concern. The study aimed at determining variability of ground water levels in Ruiru location. A combination of convenience and random sampling were used to sample 384 respondents using a structured questionnaire. A GPS was used to locate sampling points while a dipper measured groundwater levels. Historical monthly rainfall data (1984-2014) for three stations and Monthly rainfall data (2012-2014) for one station was used for analysis. Monthly groundwater levels data for a monitoring borehole in Murera (2012-2014) was obtained from the Water Resources Management Authority (WRMA) Kiambu office. Data was analysed using Microsoft office Excel, trend software, WINKS SDA 7 and wavelet analysis using matlab. Statistical analysis was done using linear regression and Mann-Kendall. Groundwater recharge was estimated using the water-table fluctuation (WTF) method. There was an insignificant increase in trend in the three stations while high power spectrum was observed within the band of 2-5 years. Rainfall variability showed an impact on groundwater levels as groundwater levels were low 37.2m from the ground level during the dry season when rainfall was 20.7mm and high27.3m from the ground level during the wet season when rainfall was 644.4mm. Estimated recharge for 2012-2014 period ranged from an overdraw of 22mm to 9mm. Rainfall variability showed an impact on water supply systems as 75% of respondents experienced low water supply during drought and relatively higher supply during the wet season.75% of the respondents felt that rainfall affected groundwater quantity and supply. It is recommended that more boreholes be monitored to provide sufficient data for proper assessment and management of groundwater resources.

CHAPTER ONE

INTRODUCTION

This chapter contains the background of the research problem which is water scarcity as affected by variability in groundwater level globally, in Africa, Kenya, Nairobi and Ruiru location. The chapter presents the statement of the problem, objectives, research questions, justification, scope of study and limitations.

1.1 Background

Groundwater forms a large portion of fresh water in the world. In semi-arid regions of Asia and the Middle East, which include some of the major breadbaskets of the world, 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 poses a major threat to food security in the coming century (Seckler, 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.

According to the Kenya National Bureau of Statistics 2010, there are about 40 million people living in Kenya (KNBS, 2010). About 17 million of the 40 million people living in Kenya do not have access to clean water (Dobsevage*et al.,* 2006). 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 resources, and a sharp increase in water demand resulting from a high population growth rate and industrial development(Marshall, 2011).

In many areas of Kenya, shortage of water has been amplified by government's lack of investment in water, especially in rural areas. Lack of sufficient rainfall affects ability to acquire food and has led to eruptions of violence in Kenya. Most of the urban poor in Kenya also only have access to polluted water, which causes cholera epidemics and multiple other diseases that affect health and livelihoods. Despite this critical shortage of clean water in Kenya's urban slums, there is also a large rural to urban discrepancy of 30% and 70% in access to clean water which is declining in Kenya (Marshall, 2011).

Slightly less than half of the rural population has access to water, as opposed to urban population where 85 percent have access to safe water including a small 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 per year (World Bank, 2010). Groundwater plays a major role in Kenya's development as it contributes water for irrigation, domestic and industrial use and thus helping in offsetting water supply deficit.

In Ruiru location, groundwatercontribution to total supply is about 70%, Ruiru-Juja Water and Sanitation Company 14%, the remaining percentage being contributed by rainfall, nearby rivers such as Ruiru river and Kamiti river and Nairobi Water and Sewerage Company (Antao, *et al.*, 2007).There is thus pressure to manage available water resources including groundwater which is a major contributor of water supply in Ruiru location. If the state of groundwater in the location is ignored, then there is a high possibility that the location may plunge into a serious water crisis. Groundwater levels variability study plays a big role in assessing sustainability of groundwater resources which is a major source of water supply in the location.

1.2 Statement of the Problem

Water scarcity is a critical problem that causes a challenge to socio-economic development in the world today. Ruiru location is one such area affected by water scarcity due to its high population density as a significant number of people working in Nairobi and Thika towns reside in the location. Recent studies have confirmed that Ruiru location has rapid population growth of about 7.3% without a corresponding increase in water sources (KNBS, 2010).

According to Ruiru-Juja Water and Sewerage Company (RUJWASCO), demand for water in Ruiru location is 33,161m^3 per day while the company can only supply 7000m^3 per day after completion of Jacaranda dam which will be about 21% of the demand as compared to 14% before the completion of Jacaranda dam.The remaining 79% is obtained from other sources such as Community Based Organization's mains, boreholes, dug wells, Nairobi Water and Sewerage Company (NWSC) mains, rain water harvesting from rooftops and directly from nearby rivers such as River Ruiru and Kamiti.

In addition, there has been a rapid increase in the number of boreholes sunk in the area, drying up of wells and decline in borehole water levels during the dry season has become a major issue in recent times(Dobsevage*et al*., 2006). Because borehole water is a major contributor to water supply in Ruiru location, there is need to assess its status to facilitate proper conservation and management. Rainfall is a major contributor of groundwater recharge, but due to climate change there have been prolonged droughts which have greatly impacted recharge. The study looked at variability of groundwater levels within the location and their relationship with rainfall amount and distribution.

1.3 Study Objectives

To determine variability of groundwater levels in Ruiru location.

1.3.2 Specific Objectives

1. To determine rainfall trends and periodicity in Ruiru location.
2. To estimate groundwater recharge in Ruiru location.
3. To determine the impact of rainfall variability on water supply systems in the location.

1.4 Research Questions

1. What are the rainfall trends and periodicity in Ruiru location?
2. What is the level of groundwater recharge in Ruiru location?
3. What is the impact of rainfall variability on water supply systems in the location?

1.5 Justification of the Study

Impacts of climate change have led to extreme conditions in the world such as prolonged drought and flood (Hsu *et al.*, 2007). These changes cause variability in rainfall, a major contributor to groundwater resources. Ruiru location depends on groundwater as a major source of its water supply and any shortcoming in groundwater levels due to prolonged drought is likely to affect water supply in the location. It is, therefore, necessary to assess variability of groundwater levels and the impact of rainfall on groundwater levels for better planning and management of groundwater resources in the location. Provision of safe and clean water to all citizens is one of the objectives of the social pillar of Vision 2030. This study contributes to this objective by providing information on the sustainability of groundwater resources. With the country's new constitution and establishment of devolved governments, many activities have been localized and this is likely to increase dependence on groundwater especially in areas without sufficient surface water sources. This study provides information and data on groundwater resources in the location which is necessary for planning, development and management of ground water resources.

1.6 Scope of the Study

The focus of the study was to determine current groundwater levels of identified abstraction points within Ruiru location. The yield, use of water, economic activities of the surrounding area and spatial distribution of boreholes were determined. The study mapped existing boreholes, determined rainfall trends and periodicity using 31 years of historical data and correlated rainfall with groundwater levels in both wet and dry seasons. Impact of rainfall variability on water supply systems in the location was also assessed.

1.7 Limitations of the Study

It was not possible to access all boreholes desired due to restrictions from owners, protection and lack of enough space to introduce dippers. Although the number of boreholes studied was limited, it was sufficient to provide a good representation of groundwater resources in the location. The study focused on boreholes only and excluded shallow wells since water levels in shallow wells can be influenced by other factors other than rainfall such as surface runoff as they are not well covered. Moreover financial resources and time limitations could not allow coverage of both.

CHAPTER TWO

LITERATURE REVIEW

This chapter looks at the various studies which have been carried out by other people globally which are relevant to groundwater levels variability. It presents the occurrence of groundwater; its movement; reviews literature on rainfall trends and periodicity; estimates groundwater recharge and impact of rainfall variability on water supply systems. It also identifies and gives research gaps and critics of the existing relevant literature.

2.1 Occurrence of ground water

When precipitation falls, it may be evaporated, flow as surface runoff or infiltrate through soil pores into the ground. Once the voids are saturated the water descends under gravity until it is stopped by an impervious layer to form groundwater in an aquifer which is a ground-water reservoir. Occurrence of groundwater may be in the zone of aeration which consists of interstices occupied partially by water and partially by air or saturation zone where all interstices are filled with water, under hydrostatic pressure (Croley, 2003).

The saturated zone extends from the upper surface of saturation down to underlying impermeable rock. In the absence of overlying impermeable strata, the water table, or phreatic surface, forms the upper surface of the zone of saturation. This is defined as the surface of atmospheric pressure and appears as the level at which water stands in a well penetrating the aquifer. Aquifers can be broadly classified into either confined or unconfined. An unconfined aquifer is one in which a water table varies in undulating form and in slope, depending on areas of recharge and discharge, pumpage from wells, and permeability. Rises and falls in the water table correspond to changes in the volume of water in storage within an aquifer. Confined aquifers, also known as artesian or pressure aquifers, occur where groundwater is confined under pressure greater than atmospheric by overlying relatively impermeable strata (Crosbie *et al.*, 2010).

2.2 Ground water movement

When a boundary of an aquifer is pervious, groundwater may enter it. The flow of groundwater is governed by the gradient of the water-table along the boundary (Bear, 2007). It moves from areas of higher elevation or higher pressure/hydraulic head (recharge areas) to areas of lower elevation or pressure. This is where groundwater is released into streams, lakes, wetlands, or springs (discharge areas). Groundwater movement is also influenced by geology of the area. Base flow of streams and rivers, which is the sustained flow between storm events, is provided by groundwater (Bear, 2007).

2.3 Rainfall Trends and Periodicity

Rainfall trend exists if there is a long-term change of rainfall amounts and can increase or decrease. If the rainfall amounts are neither increasing nor decreasing over a long period of time, then there is no trend. Rainfall periodicity is the period of recurrence of a rainfall phenomenon. Rainfall periodicities are used to predict the occurrence of a phenomenon thus helping people to plan well.

Periodic analysis approaches have been based on wavelet analysis (Daubechies, 1992).Wavelet analysis is a tool for analysing non-stationary variance at many different frequencies (Daubechies, 1992) within a geophysical time series (Torrence and Compo, 1998; Smith, *et al*, 1998; Labat, 2005). Wavelets are a set of limited duration waves, also called daughter wavelets, they are used to localise a function on space and scaling thus compressing image data. They are formed by dilations and translations of a single prototype wavelet function$\psi(t)$, where t is real valued, called the basic or mother wavelet. The mother wavelet designed to oscillate like a wave, is required to span an area that sums to zero and die out rapidly to zero as t tends to infinity to satisfy the so-called admissibility condition i.e.

$$\int \Psi(t)dt = 0 \qquad (2.1)$$

.

In this study to compute the wavelet power, the Morlet wavelet $(k = 6)$, was used because its structure resembles that of a rainfall time series, given by

$$\Psi(t) = \pi^{-1/4} e^{6it} e^{-t2/2} \qquad (2.2)$$

Examples of other wavelet functions include the Paul, Mexican hat and derivative of Gaussian (DOG), details are given in Torrence and Compo (1998).

The continuous wavelet transform W_n of a discrete sequence of observations x_n is defined as the convolution of x_n with a scaled and translated wavelet $\psi(\eta)$ that depends on a non-dimensional time parameter η

$$W_n(s) = \sum_{n'=0}^{N-1} x_n \psi^* \left[\frac{(n' - n)\delta t}{s} \right] \qquad (2.3)$$

Where n is the localized time index, s is the wavelet scale, δt is the sampling period, N is the number of points in the time series and the asterisk indicates the complex conjugate. Since complex wavelets lead to complex continuous wavelet transform, the wavelet power spectrum, defined as, $|W_n(s)|^2$ is a convenient description of the fluctuation of the variance at different frequencies. Further, when normalized by σ^{-2} (where σ^{2} is the variance) it gives a measure of the power relative to white noise, since the expectation value for a white noise process is σ^{-2} at all n and s.

To determine significance levels for wavelet spectrum an appropriate background spectrum ischoosen. The many geophysical phenomena, an appropriate background spectrum is either white noise (with a flat Fourier spectrum) or red noise (increasing power with decreasing frequency) (Torrence& Compo, 1998). It has been shown on average that the local wavelet power spectrum is identical to the Fourier power spectrum given by

$$P_k = \frac{1-\alpha^2}{1+\alpha^2 - 2\alpha\cos\left(\frac{2\pi k}{N}\right)} \qquad (2.4)$$

Where $k = 0..........N/2$ is the frequency index. By choosing an appropriate lag-1 autocorrelation equation (2.4) can be used to model a red-noise spectrum. If $\alpha = 0$ in equation (2.4) then it models a white noise spectrum.

If x_n is a normally distributed random variable, then both the real and imaginary parts of $\hat{x}_k$ are normally distributed (Chatfield, 1989). Hence $|\hat{x}_k|^2$ is chi-square distributed with two degrees of freedom, denoted by X_2^2. In order to determine the 95% confidence level, the background spectrum in equation (2.4) is multiplied by the 95th percentile value of X_2^2(Murumkar & Arya, 2013).The confidence interval at each scale can be used to construct confidence contours.

A study on trend and periodicity in India using Seasonal and annual rainfall data of the stations: Akluj, Baramati, Bhor and Malsiras located in Nira Basin, Central India, wasanalyzed using Mann-Kendall (MK), Modified Mann- Kendall (MMK) and Theil and Sen's slope estimator tests. The study described a rising trend at all the stations. The study showed that the trend was statistically significant at Akluj and Bhor stations at 10% significance level. Bhor station showed maximum increase in percentage change i.e. 0.28% in annual rainfall. Monsoon and post-monsoon seasonal rainfall showed a rising trend while summer and winter seasonal rainfall showed a falling trend. Wavelet analysis showed prominent annual rainfall periods ranging from 2 to 8 years at all the stations after 1960s resulting in describing more changes in the rainfall patterns after 1960s. (Murumkar&Arya, 2013).

A study of Trends and periodicities of annual rainfall for 29 sub-divisions of India was done using rainfall series for a period of 124 years (1871–1994). The trends were evaluated using a linear regression technique. To identify climatic changes, the rainfall series were subjected to 11-year moving averages. It was found that in some sub-divisions the trend was in one direction and after some years, the direction was reversed.The significance of the trend values were tested. The periodicity was attributed to the quasi-biennial oscillation. Rainfall series of the most of the sub- divisions and all India indicate a triennial cycle. Significant periods in the range from 3.0 to 8.0 years and 8.0 to 12.0 years were also identified (Naidu *et al.*, 1999).

A study to analyze rainfall time series over a wide time interval was done in Campania region, southern Italy. 211 gauged stations, mainly located within the Campania region, southern Italy, were analyzed for the period 1918–1999. An accurate database was set up through a data quality and time series homogeneity process. Statistical analysis of the database highlighted that the trend appeared predominantly negative, both at the annual and seasonal scale, except for the summer period when it appeared to be positive. The study also showed that over the whole reference period, positive and negative trends were significant respectively for 9% and 27% of total stations and over the last 30 years,a negative trend was significant for 97% of the total stations (Longobardi & Villani, 2009).

Rainfall and temperature trends study at Namulonge parish, in Wakiso district of Uganda used temperature and rainfall records aggregated into monthly means over a period of more than 55 years. These records were analyzed in an effort to identify seasonal trends and shifts in climate. This was achieved by using non-parametric (Mann-Kendall) and parametric (linear regression) techniques. The analysis showed that total rainfall during the March-May season decreased, while maximum temperatures increased during the months between April and September, with both trends statistically significant at 5% confidence level. The Mann-Kendall test revealed that the number of wet days reduced significantly. Temperatures were found to be warmer and rainfall higher in the first climate normal compared to the recent 30 years. Results revealed that April was the only month with a statistically significant rainfall trend (Nsubuga, *et al.*, 2011).

2.4 Estimation of groundwater recharge

Ground water recharge is the process whereby the amount of water present in or flowing through the interstices of the sub-soil increases by natural or artificial means. The amount of water that may be extracted from an aquifer without causing depletion is primarily dependent upon ground water recharge. Rainfall is the principal source for replenishment of moisture in the soil water system and recharge of ground water. Other sources include recharge from rivers, streams, irrigation water etc. Moisture movement in the unsaturated zone is controlled by suction pressure, moisture content and hydraulic conductivity relationships. The amount of moisture that eventually reaches the water table is defined as natural ground water recharge, which depends on the rate and duration of rainfall, subsequent conditions at the upper boundary, antecedent soil moisture conditions, water table depth and soil type (Raghavendra, 2013).

Healy and Cook (2002), present a review of the theory and application of water table fluctuation method for estimating groundwater recharge. It had a limitation of difficulties of estimating specific yield which they overcame through an improved evaluation of specific yield. The new method was presented in a time series framework and can be applied to long-term records of precipitation and water table elevation.

A study on comparing groundwater recharge and base flow in Bukmoongol showed that about 15–31 per cent of annual rainfall might contribute to base flow. The watershed groundwater recharge proportions were computed to be about 10–21 per cent during the wet period and 23–32 per cent for the remainder of the periods (Combalicer *et al.*, 2008).(Scanlon *et al.* 2002),found out that determination of groundwater recharge rates is an inherently difficult task because of uncertainties and assumptions associated with different methods of analysis and because various quantifying methods differ with the type of recharge and the space and time scales represented. Because different methods of quantifying recharge have different limitations, prudent investigators use multiple techniques to constrain recharge estimates and refine their conceptual understanding of recharge.

Multiple methods of estimating recharge have been used in previous studies, including use of environmental tracers and soil physics; use of numerical modeling and soil physics and use of unsaturated-zone monitoring and water-table fluctuations (Jrykama, *et al.,* 2005). In addition, three or more techniques have been used in recent studies (Delin*et al.* 2000; Risser*et al.* 2005).

Rainfall variability in three irrigation areas i.e. Murrumbidgee, Coleambally andMurray irrigation areas were quantified using quartile, decile and the Standard Precipitation Index (SPI) methods. The shallow piezometric level fluctuations in the Murrumbidgee Irrigation Area (MIA) showed a very strong correlation with winter rainfall variation. The shallow piezometric levels in the Coleambally Irrigation Area (CIA) showed a lesser degree of correlation with the SPI due to local and regional groundwater dynamics and changes in rice water use. The piezometric levels in the Murray Valley showed least correlation with the SPI, which was attributed to lower impacts of management practices and the complex nature of groundwater recharge and discharge zones in this area (Khan & Lisa, 2001).

The SPI method provides an excellent opportunity for year to year reporting of seasonal and yearly climatic variability. Its correlation with piezometric levels can be adopted for environmental reporting and used as a method of distinguishing between climatic and management impacts on water tables. Differences in piezometric response in years with similar winter and yearly SPI values may be caused by changes in management practices (Khan & Lisa, 2001).

(Shalini*et al.*, 2012) studied groundwater level variability analysis and its relationship with rainfall for the drought affected Palamu District of Jharkhand State. The sum of least squares method was adopted to analyze the relationship of groundwater level variability with the rainfall trends. The analysis revealed that this region during the post-monsoon season exhibited shallow depth of water level (2-3m) which declines up to 8-10m during pre-monsoon in the month of May. The declining trend of water level was more conspicuous at those places located at relatively lower elevation. Although the south-eastern region exhibited an increase in the rainfall over the years, the average water level was very deep indicating large water losses due to runoff. On the contrary, the southern region showed an increase in the amount of rainfall over the years with concomitant increase in water level indicating a positive relationship between rainfall and depth of water level. The spatial-temporal rainfall trend analysis performed using interpolation in GIS provided conceptual understanding for developing large water harvesting structures in those regions which exhibited an increase in rainfall and the need for developing a number of small water harvesting structures to recharge groundwater in rainfall declining zones.

2. 5 Impact of rainfall variability on water supply systems

A study done on the effect of rainfall variability on water supply in Ikeduru L.G.A., Imo State, showed that there is a strong relationship between rural water supply in the study area and rainfall. Reduction in rainfall amount as revealed by trends and variability patterns, adversely affects rural water supply(Onyenechere *et al*., 2011).The indicated linkagestrong relationship implies that the aquifer; the source of borehole water in the area and source of the various rivers (Mbaa, Oramiriukwa and Okatankwo) found in Ikeduru L.G.A. mainly depend on rainfall for recharge(Onyenechere *et al*., 2011).

(Ma *et al.,* 2005) studied ground-water resources and their changes caused by the impact of human activity in Shiyang River Basin, the arid area of Northwest China. The aquifer was mainly recharged by surface water originating in mountain regions, and there was extensive transfer between rainfall, surface water and ground-water. The deep ground-water was old and was recharged in a colder and wetter climate environment. The shallower water was mainly palaeo water mixed with limited modern recharge. The sources of salinity were from weathering of rock in mountain areas and from higher evaporation leading to higher salinity along the line of ground-water flow. Human activity, in particular large-scale water resources development associated with dramatic population growth in the last 50 years, led to tremendous changes in the ground-water regime.

They found out that recharge has been reduced by 50% and ground-water abstraction exceeded recharge by $0.41\times10^9 m^3 yr^{-1}$. Consequently, the ground-water level had fallen widely by between 3 and 5 m, with a maximum fall of 35 m in several towns. These hydrological changes resulted in a serious degradation of the ecosystem. It was suggested that modernized irrigation technology and new regulation to cover water resources management and allocation within the river basin were urgently needed to achieve sustainable development (Ma *et al*., 2005).

A study on the effect of irrigation methods on recharge in China showed that groundwater recharge intensity became weaker in water-saving irrigation than in flood irrigation. Groundwater discharge was greater for water-saving irrigation than for flood-irrigation, making the reduction in depth more obvious. Furthermore, the reduction in depth of the groundwater level increased with site elevation (Liu *et al.*, 2012).

(Gill, *et al.*, 2014) found out that the current average annual groundwater use in Australia was approximately 3,500gigalitre. Groundwater was used across many industries of the Australian economy. Water used for agricultural irrigation was the largest single user group, comprising on average approximately 60% of Australia's annual groundwater use. Other user groups included mining (12%), manufacturing and other industries (17%), and household water supply (5%), and as an input into potable water supply networks (9%).

Groundwater was also used as drinking water for livestock; however there was no data available showing the quantity used for this purpose. Groundwater supports different environmental values and, by extension, industries that depend upon those environmental values such as tourism and forestry. Another important value of groundwater relates to the use in the future, or its 'insurance' value, which can underpin investment decisions in agriculture and mining and provides value even when the groundwater is not used (Gill, *et al.*, 2014.)

A study on the impact of abstraction on groundwater levels in Bangladesh showed that the mean annual ground- water recharge was higher (300–600mm) in areas where rainfall and potential recharge are greater. Net recharge in many parts increased substantially (5– 15mm/year between 1985 and 2007) in response to increased groundwater abstraction for irrigation and urban water supplies. In contrast, net recharge slightly decreased (−0.5 to −1mm/year) in areas where ground- water-fed irrigation was low (<30% of total irrigation) and where abstraction either decreased or remained unchanged over the period of 1985–2007(Shamsudduha *et al.*, 2011).

Study on the impact of land use and land cover on recharge showed that there is no recharge in natural rangeland ecosystems, moderate-to-high recharge in irrigated agricultural ecosystems and moderate recharge in non-irrigated (dryland) agricultural ecosystems. The study also showed that replacement of rangeland with agriculture changed flow directions from upward (discharge) to downward (recharge). Sustainable land use requires quantitative knowledge of the linkages between ecosystem change, recharge, and groundwater quality (Scanlon *et al.*, 2005).

2.6 Summary, Critique and Research Gaps

Table 2.1: summary of literature review, critique and research gaps

Objective	Related studies	Gap/ critique
Rainfall trends and periodicity	Murumkar and Arya (2013) did rainfall trends and periodicity using wavelet analysis	Recommended further investigation on the impact of climate change on rainfall patterns which is partly handled in this research. The same method was adopted in this research
	Naidu *et al.*(1999) did a study of trends and periodicities in India using linear regression technique	The same technique was adopted for this research
	Longobardi and Villani(2009) did study on time series in Italy.	Compare their annual and seasonal trend gap
	Nsubuga, *et al.*(2011) studied rainfall trends in Uganda	Used linear regression technique
Relationship between rainfall and groundwater levels	Healy and Cook (2002) used the water table fluctuation method to estimate groundwater recharge	The same method was used in this research because it is simple and does not require a lot of data which is not available.
	Combalicer *et al.*(2008) did a research on groundwater recharge and base flow	Rainfall which is a major contributor to recharge was not considered in Combalicer's research but is considered in this research.
	Scanlon *et al.* (2002) estimated recharge rates using different methods	Water table fluctuation method was found to be easier than and so was adopted for this research
Impact of rainfall variability on water supply systems	Khan and Lisa (2001) conducted a research on rainfall variability in irrigation areas.	The research only considered irrigation areas and no other areas like Peri-urban areas. This research considered Peri-urban areas.
	Ma *et al.*(2005) studied human activities and groundwater recharges	The methodology used in his research was adopted in this research.
	Onyenechere *et al.*(2011) studied the impact of rainfall variability on water supply in Nigeria.	Considered only rural areas and not a Peri-urban area and recommended further research and development of groundwater resources which is addressed in this research.
	Shamsudduha (2011) studied impact of irrigation on groundwater levels.	He did not consider industrialization population increase and domestic use which are considered in this research.

CHAPTER THREE

METHODOLOGY

The chapter gives a detailed description of the study area. It also explains the research design; target population; sample size and sampling technique; instruments for the research; data collection procedure, processing and analysis.

3.1 Study Area

3.1.1 Geographical Location

Ruiru location is located in Kiambu County at an altitude of 1564m above mean sea level, latitude of between 1.08^{o} Sand 1.15°S and longitude of between 36.96°E and 37.16^{o}E. Construction of Thika Super Highway and the Northern Bypass has put Ruiru at a strategic location as it now takes less than 30 minutes to reach Nairobi the capital city and about 15 minutes to reach Thika Town. Ruiru location borders Juja location to the north, Machakos County to the East, Githunguri to the West and Nairobi to the South and covers approximately 179.90 square kilometers. Administratively it lies within Ruiru sub-county and is divided into seven administrative wards namelyMwiki, Mwihoko, Kiu, KahawaWendani, Gatongora, Biashara and KahawaSukari.

3.1.2 Climate

The climate of Ruiru location is humid highland sub-tropical in character with seasonal dry and wet periods. Ruiru location receives 1065 mm of rainfall annually which is bi-modal with long rains between March and May and short rains between October and December. A monthly average temperature of 18.9°C, maximum temperature of 24.9°C and a minimum temperature of 13.0°C. Temperatures are highest in the months of January to mid-March before the long rainy season and lowest in the months of July and August.

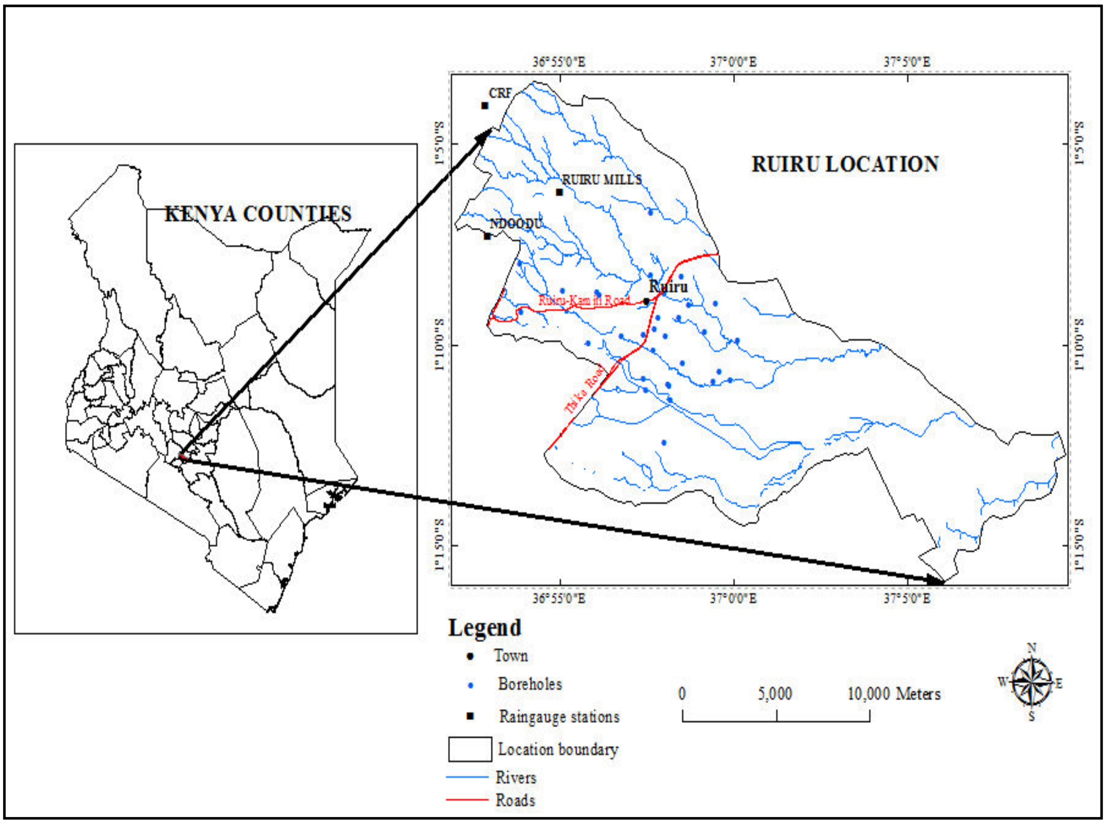

Figure 3.1: Map of Ruiru Location where the study was conducted

Figure 3.1 shows the study area, the boreholes sampled,rainfall stations where the historical rainfall data was obtained from, rivers and roads passing through the study area.

3.1.3 Soils and Geology

Soils in the location are sandy or clay that can support drought resistant crops such as soya beans and sunflower as well as ranching. Most parts of the location are covered by soils from volcanic footbridges that are well drained with moderate fertility. They are red to dark brown friable clays, which are suited for cash crops like coffee, tea and pyrethrum. However, some parts are covered by shallow soils, which are poorly drained, and these areas are characterized by low rainfall, which severely limits agricultural development. The geology of Ruiru location comprises of tertiary volcanic rocks, the most important being what is termed as Nairobi Stone. The Nairobi stone is a tertiary volcanic rock used extensively for building purposes. Soils resulting from tertiary volcanic rocks are dark reddish brown, well drained, friable and very calcareous.

3.1.4 Hydrogeology

The hydrogeology of an area is the interplay of several factors of the site. These include: the nature of the parent rock; structural features of primary and secondary origin; weathering processes and the resultant products; the mechanism of recharge; the recharge medium of water; quantity and its frequency; morphology; disposition and gradient of the subsurface as well as the hydrological and topographical environment. The overall permeability of the subsurface is a result of the grain size, sorting, cementing material and the secondary feature present of joints, faults, fissures and the presence of impending layers such as aquiclude beds, often of clay or consolidated material. The aquifer complex of Nairobi which covers Ruiru reaches about 400m. The poorly defined drainage pattern points to an internal drainage model in a closed basin.

3.1.5 Socio-economic activities in Ruiru Location

Ruiru Location is well-covered with industries and coffee growing farms that provide employment opportunities and contributes to economic growth. These industries have been instrumental in renovation, construction and expansion of schools and general infrastructure development such as roads within the location. The location is served by Ruiru hospital. The industries include Spinners and Spinners Limited, Brookside Dairy Limited, Devki Steel Mills and Bogani Industries. It also houses the following educational institutions; Main and Ruiru Campuses of Kenyatta University and middle-level colleges such as Compuera College, Royal College of Science and Technology, Nairobi Institute of Business Studies and Zetech College.

3.1.6 Water and Sanitation

Ruiru location's water resources comprises of both Surface and Ground water.

There are two rivers that traverse the location; Ruiru River where Ruiru Water and Sewerage Company get its water from and Kamiti River. Parts of the location are also supplied with water by Nairobi City Water and Sewerage Company (NWSC) and areas outside the jurisdiction of these companies either have no water infrastructure or are served by community water projects and boreholes. There are no sewerage infrastructures in the location and majority of the communities including the major trading centres use septic tanks and pit latrines for human waste disposal.

3.1.7 Population.

The population of Ruiru location stood at 109,574people in 2009 (Kenya National Bureau of Statistics, 2010).Based on Kiambu County's growth rate of 7.3%, the current population of the location is estimated to be between 165,000 and 180,000.Within the location population density varies for instance; there is a high population density in Biasharaward while the lower parts are sparsely populated.

3.2 Research Design

The research was conducted using longitudinal type approach. This approach is observational as it entails several observations in order to detect development or changes in the characteristics. It extends beyond a single moment and establishes sequence of events. The approach identifies development of trends by looking at attributes. This design was preferred over other designs since it combines both qualitative and quantitative data and therefore gives an in-depth research. Qualitative data was obtained through questionnaire while quantitative data included groundwater levels, rainfall. Groundwater levels and rainfall amounts were observed over a period of time and were used to develop trends. For this research, the design allowed determination of groundwater and rainfall variability over a period of time (Kothari, 2004).

3.3 Study Population, Sample and Sampling Technique

The study targeted adults of both genders 20-80 years of age, working or residing in Ruiru location as well as borehole owners. A sample is a smaller group or sub-group obtained from the accessible population (Mugenda&Mugenda, 1999). This subgroup is carefully selected so as to be representative of the whole population with the relevant characteristics. Each member or case in the sample is referred to as subject, respondent or interviewees. The sample size was calculated from the equation below obtained from (Mugenda & Mugenda, 1999)

$$n = \frac{Z^2pq}{d^2}$$

Where: $n = the\ desired\ sample\ size$

$$Z = confidence\ level\ at\ 95\%\ (standard\ value\ of\ 1.96)$$

p
$= proportion\ in\ the\ target\ population\ estimated\ to\ have\ characteristics\ being\ measured$

$$q = proportion\ in\ the\ population\ without\ characteristic\ being\ measured$$

$$q = 1 - p$$

$$d = margin\ error\ at\ 5\%, standard\ value\ of\ 0.05$$

The proportion of the population with characteristic being measured is 50% i.e 0.5,

Hence: $p = 0.5$

$$q = 1 - 0.5 = 0.5$$

The sample size was calculated as:

$$n = \frac{(1.96)^2(0.50)(0.50)}{(0.05)^2} = 384$$

In order to assess the variability of groundwater levels in Ruiru location, a combination of convenience and random sampling techniques were employed to select boreholes at different locations within the location. This sampling technique was used because of the difficulty of identifying every borehole and inaccessibility of some boreholes.This was due to restrictions by owners, construction of the boreholes which made them inaccessible and financial and time constraints(Kothari, 2004).

3.4 Instruments

A structured questionnaire was used. (Appendix 3).Geographical Positioning System (GPS) was used to locate borehole and rainfall stations positions. Dipper was used to measure groundwater levels

3.5 Data Collection Procedure

3.5.1 Measurement of groundwater levels

The procedure below was repeated for 31 boreholes mapped in Figure 3.1 for both dry season (January and February) and wet season (April and May) of 2014.

1. The borehole airspace was opened
2. A 300meters Seba hydrometer (dipper) was used to measure groundwater level.
3. The probe of the dipper was lowered down the borehole until it hit the water causing the buzzer to sound or light.

4. The tape was then pulled back slowly out of the water until the signal stopped.

5. A finger was used to mark the position on the tape against the top of the casing which was taken as the datum level

6. The reading was taken to the nearest centimetre and recorded as the water level.

7. Step 3 to 6 was repeated three times to confirm the reading and average recorded as water level

$$water\ level = \frac{1st\ reading + 2nd\ reading + 3rd\ reading}{3}$$

Figure 3.2: Measurement of groundwater levels

3.5.2 Historical Rainfall Data and Groundwater Levels Data

Historical monthly rainfall data for the past thirty one years was obtained for rainfall stations located within the study area. Data quality analysis was done using the mass curve analysis. Mass curve is a plot of cumulative water supply in this case rainfall versus time. The stations included Coffee Research Foundation, Ruiru Mills and Doondu (mapped in Figure 3.1). Cumulative rainfall amounts for the 31 years for each station were plotted against time. A straight line shows that the data is good and does not require any corrections. Monthly groundwater levels data available for three years (2012 to 2014) for the monitoring borehole in Murera was also obtained from the Water Resources Management Authority (WRMA).

3.5.3 Impacts of rainfall variability on water Supply Systems

Data on impacts of rainfall variability on water supply systems was collected from primary sources using questionnaire, oral interviews and personal observations from 384 persons. Oral interviews were conducted for the aged who have historical insights on the subject matter but who cannot read or write.

3.6 Pilot test (pre-testing the questionnaire)

Sample questionnaire were issued to five respondents who responded to the questions as constructed. Some questions which were not clear were identified in the process and reframed so as to obtain the required information for the study.

3.7 Data Processing and Analysis

3.7.1 Statistical Analyses

The data obtained from field Survey and historical data from Water Resources Management (WRMA) for Murera monitoring borehole and rainfall stations within the location was analysed using Microsoft office Excel and Trend. Summary statistics such as mean and standard deviation were generated. Descriptive statistics such as line graphs and pie charts were used to display and explain trends of groundwater levels and rainfall.

3.7.2 Determination of Rainfall Trend and periodicity

Monthly rainfall for 31 years (1984-2014) was obtained from four stations i.e. Ting'ang'a, Ruiru mills, Ndoondu and Coffee Reseach Foundation located within Ruiru Location. Statistical analysis was done to identify any significant trend using Linear regression model and Mann-Kendal as a check. Graphs were constructed to show any trend in the monthly and annual rainfall.

Linear regression model is explained in the form of $y = a + bx$------------------------3.1

$$y = rainfall$$

$$x = year$$

$$b = slope$$

$$a = intercept$$

The slope explains the trend, if the slope is negative the the trend is decreasing or downward and if the slope is positive then the trend is increasing or upward. The null hypothesis is that the slope of the line is zero i.e. there is no trend in the data. The significance of the data is shown by the p-values with the significance level of 0.05.If the p-value is less than the significance level then the null hypothesis is rejected and if it is more the null hypothesis is not rejected.The R- square is the correlation coefficient which is used to show the strength of the relationship between x and y. R^2 ranges between 0 and 1. 1 means there is a strong correlation while 0 means there is no correlation. If R squared ranges from 0 to 0.3, the the correlation is weak, between 0.3 and 0.7 it is moderate and greater than 0.7 the correlation is strong. A threshhold R^2 value of 0.5 was considered acceptable (Kothari, 2004).

Parametric (linear regression analysis) and nonparametric (Mann-Kendall tests) statistical procedures were applied on historical data. Also, data has been analyzed for trends for the four seasons in order to understand the intra-seasonal change. The procedures involved in Mann-Kendall statistic have been explained in literature (see for example: Piccareta *et al.*, 2004; CRCCH, 2005; Modarres & da Silva, 2007; Kampata *et al.*, 2008; Caloieroe *et al.*, 2009; Kizza *et al.*, 2009; Longobardi & Villani, 2009).

Mann-Kendall(Mk) test was applied by considering the statistic S as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_i - x_k) \qquad (3.2)$$

Where x_i is the data value at time i, n is the length of the data set and sgn (z) is equal to +1,0,-1,if z is greater than, equal to, or less than zero respectively. The null hypothesis is that (Ho = no trend) for a given level of significance. The mean E(S) and variance V(S) of the statistic S are obtained by:

$$E(s)= 0, \qquad (3.3)$$

$$VAR(S) = \frac{1}{18} \lfloor n(n-1)(2n+5) - \sum_{p=1}^{q} t_p \rfloor (t_p - 1)(2t_p + 5) \qquad (3.4)$$

Here q is the number of tied groups (sample data with the same value) and tp is the number of data values in the pth group. The values of S and VAR (S) are used to calculate the test statistic Z as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} \; if \; S > 0 \\ 0 \; if S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} \; if \; S < 0 \end{cases} \qquad (3.5)$$

The presence of a statistically significant trend is evaluated using the Z value. A positive and negative value of Z indicates an upward and downward trend respectively. To test for either an upward or downward trend at p significance, Ho is rejected if the absolute value of Z is greater than Z1-p/2, obtained from the standard normal cumulative distribution table. In this researchsignificance levels of p = 0.05 were applied.

Periodicity test was performed using Wavelet analysis. The approach was preferred because it shows rainfall amounts and their frequency of occurrence. In this study the 95% confidence limit was used to study the periodicity of rainfall in Ruiru location.Grinsted wavelet coherence tool was used for wavelet analysis for this study. The tool comprised of a programme written by Grinsted based on wavelet analysis, data script was feed to the programme, and the programme was run in a matlab platform to give the periodicity spectrum for interpretation.

3.7.3 Relationship between rainfall and groundwater variability

Using Geographical Information System (GIS) software, borehole data was used to map the groundwater abstraction points within the location. The relationship between rainfall and groundwater levels for Murera monitoring borehole was explained through linear regression modeling and groundwater recharge. The groundwater recharge was estimated using water-table fluctuation method which assumes that a water-table rise in an aquifer is attributable to recharge. Recharge (R) is calculated as

$R(t_j) = Sy^* \Delta H(t_j)$..(3.6)

Where,

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

$$s_y = specific\ yield\ (dimensionless), and$$

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

Specific yield was 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, $S_y$was determined from the following equation

$$s_y = \frac{\propto t}{d} \quad (3.7)$$

Where,

$$d = Total\ drawdown(m)$$

$$t = Time\ period(days)$$

$$\propto = Recession\ constant\ (m/day)$$

Water level below ground level in the open well at any month during dry period was predicted by applying recession model. The recession model is of the form,

$$h = h_o e^{\propto t} \quad (3.8)$$

Where,

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

$$h_o = initial\ water\ level\ (m)$$

$$\propto = Recession\ constant$$

$$t = Time\ (days)$$

The required input data was monthly groundwater levels for three years i.e. 2012, 2013 and 2014 obtained from WRMA $h_o = initial\ water\ level\ (m)$ was the groundwater level of the preceding month while $h = water\ level\ below\ ground\ surface\ at\ time\ t\ (m)$was the groundwater level of the following month. $t = Time\ (days)$was the number of days of that particular month i.e. days between initial water level and water level below ground surface at a time t. $d = Total\,drawdown(m)$ was obtained from the difference in groundwater levels between the initial and the final. The water level rise $\Delta H(t_j)$ was obtained from the defference between the peak of a water-level rise and the value of the extrapolated antecedent recession curve at the time of the peak.

$\propto = Recession\,constant$was calculated as shown in equation 3.8. The recession constant obtained from equation 3.8by making it $\propto = Recession\,constant$the subject of the equation was used in equation 3.7 to calculate specific yield. Finally obtained specific yield was used in equation 3.6 to calculate monthly amount of recharge.

3.7.4 Determination of impact of rainfall variability on water supply systems

The responses to the questionairre were entered in an excel software. The question number in the questions were put as the heading of the column and the possible answers were put in the row. Each possible answer was assigned a code.Each questionnaire was evaluated in turn and the codes added in excel software for proportionate analysis. The data obtained was presented in tables of frequencies and percentages and charts.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents research results obtained by following the methods mentioned in chapter 3. The research findings are also followed by discussion. The results include: rainfall trends and periodicity of Ruiru location, groundwater recharge estimate, and the impact of rainfall variability on water supply systems.

4.1 Rainfall Trend and Periodicity

Figure 4.1 shows mass curve for Coffee Research Foundation (CRF) station for the years 1984 to2014

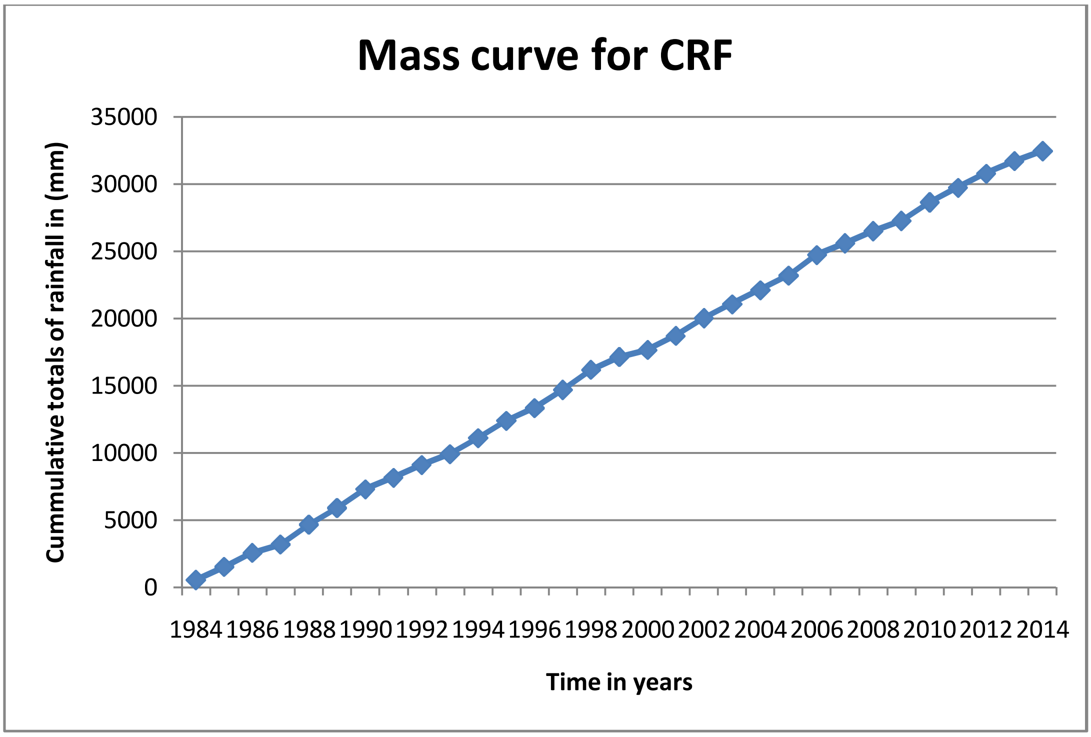

Figure 4.1: Mass curve forCoffee Research Foundation(CRF) station

Figure 4.1 showed no data gaps as the curve was a straight line. Thus the data quality was good and could be used as it was since it required no alterations. The mass curve analysis for the subsequent stations; Ndoondu and Ruiru mills took the same trend as shown in Appendix4 and 5. Rainfall trends and periodicity were determined as follows:

4.1.1 Coffee Research Foundation (CRF) Station

Figure 4.2 shows rainfall trend for Coffee Research Foundation for the years 1984 to 2014

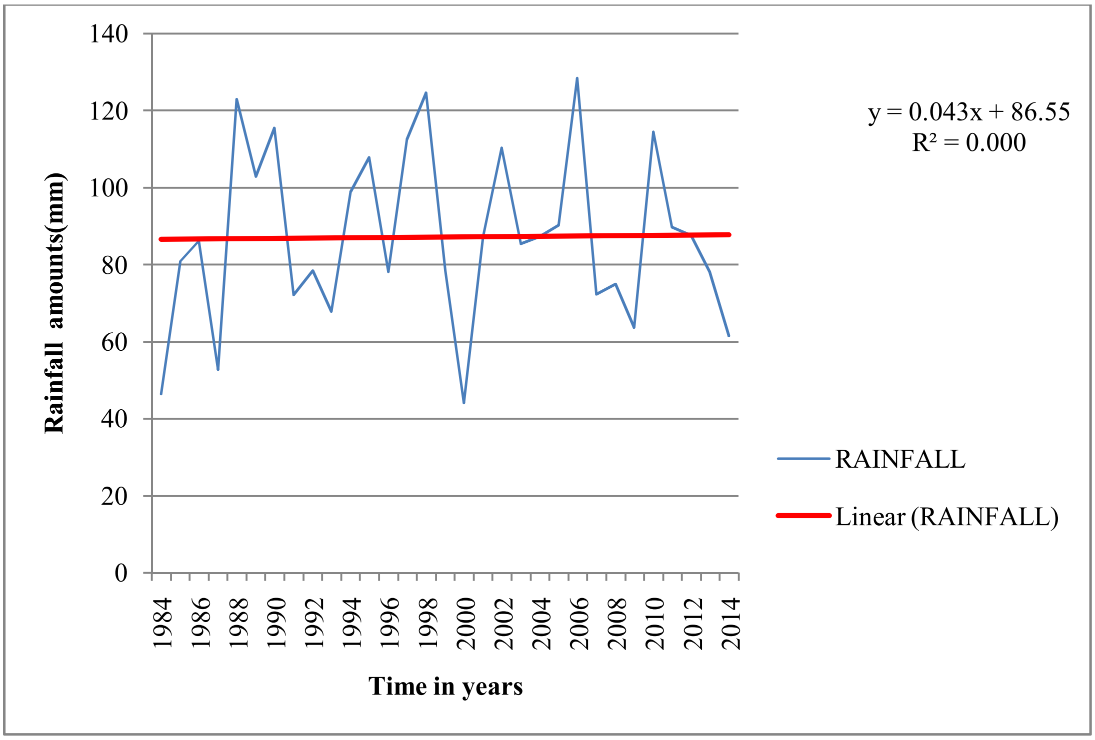

Figure 4.2: Rainfall trends in CRF

In figure 4.2 high mean annual rainfall of 128.50mm was observed in the year 2006 and low of 44.20mm in the year 2000. There was an increasing trend from 1984 to 2014 though not significant.

Figure 4.3 shows mean monthly rainfall for Coffee Research Foundation for the years 1984 to 2014.

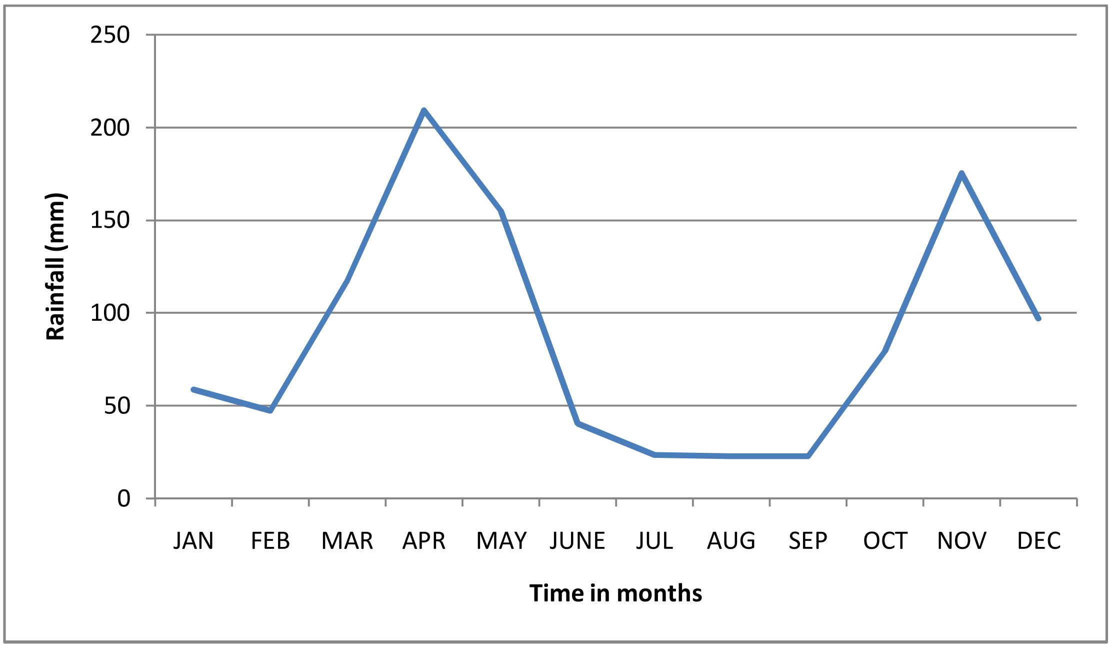

Figure 4.3: Mean monthly rainfall trend in CRF

Figure 4.3 shows high mean monthly rainfall of 209.3mm in the month of April followed by 175.3mm in the month of November was experienced with the monthly mean of 22.5mm in the month of August. There was a double maxima in April and November for CRF station.

Table 4.1 shows summary statistic of trend test using Mann-Kendall and linear regression.

Table 4.1: Summary statistic of trend for CRF

Data file : crf tr.csv: RAINFALL					
	Test statistic	Critical values			Result
		(Statistical table)			
		α=0.1	α=0.05	α=0.01	
Mann-Kendall	0.017	1.645	1.96	2.576	NS
Linear regression	0.094	1.699	2.045	2.756	NS

H_{null} : there is no trend in the rainfall trend analysis for 31 years in coffee research foundation

H_{Alter} : there is a trend in the rainfall trend analysis for 31 years in coffee research foundation.

In table 4.1, the results of the p-value according to Linear regression was 0.094 which was less than the critical value of 2.045 for α= 0.05.The check conducted using Mann-kendal also showed the result of 0.017 which is less than the critical value of 1.96 for α= 0.05. Therefore the null hypothesis was not rejected meaning there is no trend in the annual rainfall analysis for 31 years (1984 to 2014) in Coffee research foundation station. Thus there was no significant change in rainfall amounts for the period of 1984 to 2014.

Figure 4.4 shows wavelet power spectrum for March April May (MAM) and October November December (OND) for Coffee Research Foundation for the years 1984 to 2014.

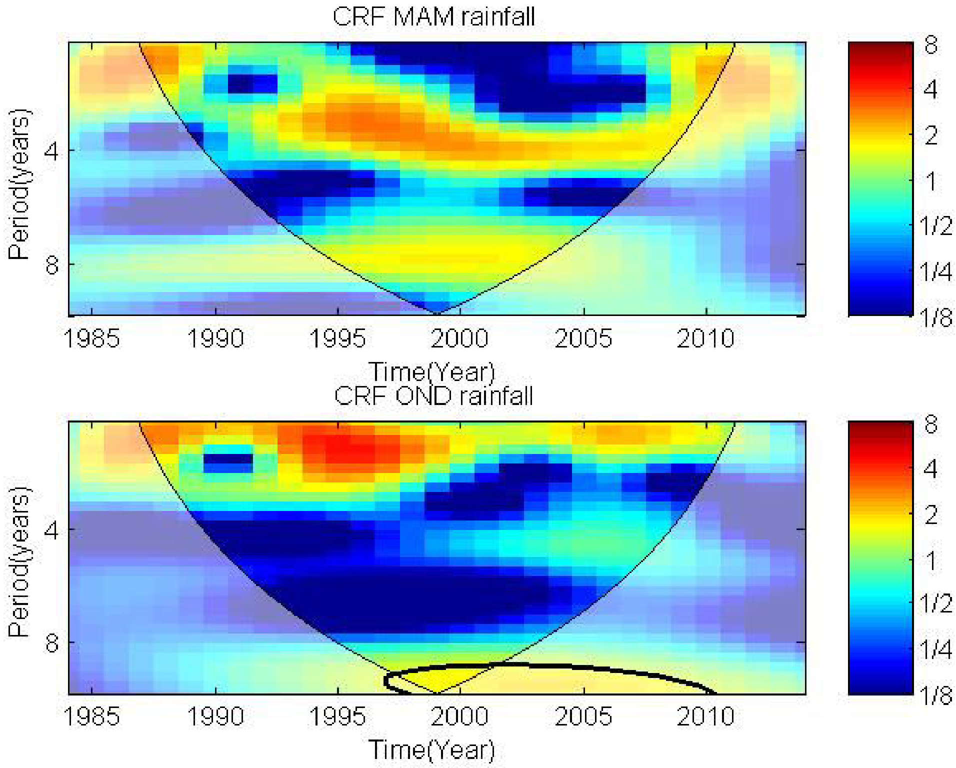

Figure 4.4: Wavelet power spectrum MAM and OND for CRF

In figure 4.4, high power spectrum indicates high intensity of rainfall and its expressed in red colour. The right hand of the figure shows the variation of intensity and how its expressed in colours. The figure showsthat relatively higher power wavelet spectrum (red colour) was observed within the band of approximately 2-5 years between 1993 and 2004 which was significant using the March April and May(MAM) wet season. In the October, November and December (OND) season higher power spectrum was observed within the band of approximately 0-2 years between 1992 and 2000. Hence high intensity of rainfall is likely to occur within the period of 0-5 years

4.1.2 Ndoondu Station

Figure 4.5 shows mean annual rainfall trend for the years 1984 to 2014 for Ndoondu station

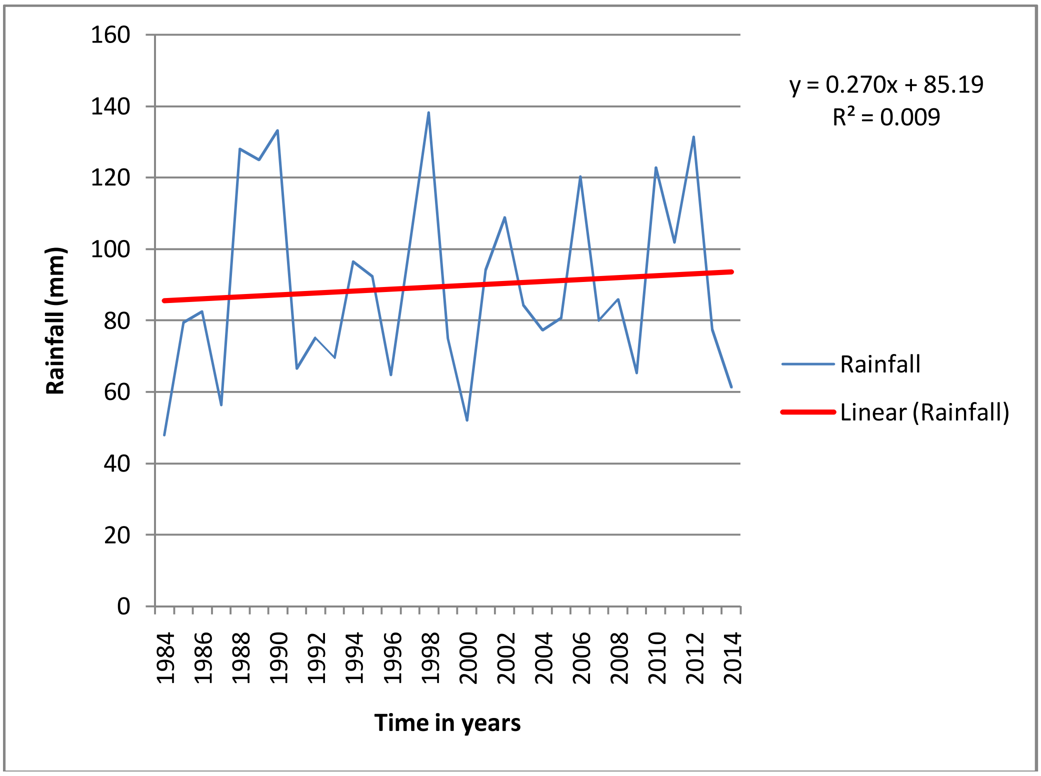

Figure 4.5: rainfall trend in Ndoondu station

High total annual rainfall of 1658.5mm was recorded in the year 1998 and low amounts of 574.7mm in the year 1984 in figure 4.5 above. There was an increasing trend from 1984 to 2014 though not significant.

Figure 4.6 shows mean monthly rainfall for years 1984 to 2014for Ndoondu station

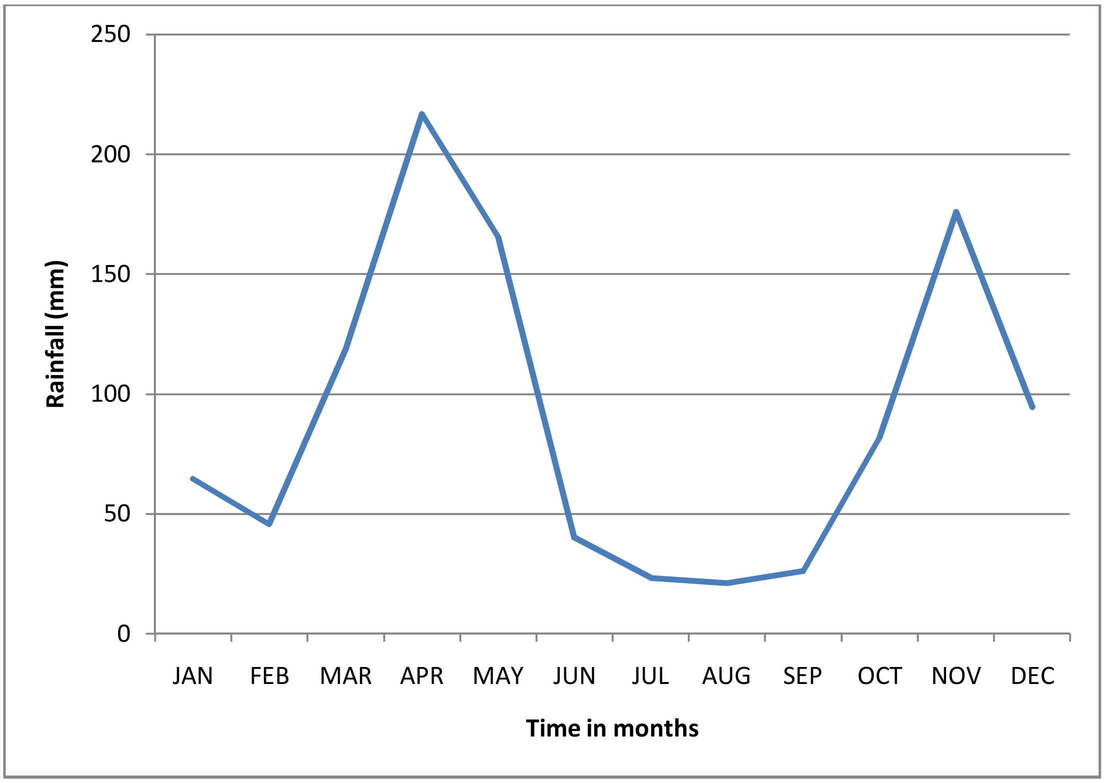

Figure 4.6: Mean monthly rainfall trend in Ndoondu

Figure 4.6 showed high mean monthly rainfall of 216.9mm followed by 175.9mm in the month of April and November, respectively was experienced with the monthly mean of 21.0mm in the month of August. There was an insignificant decreasing trend with double maxima in April and November.The trend was not significant since the R^2 was zero.

Table 4.2 shows summary statistic of trend test using linear regression and Mann-Kendall for the yers 1984 to 2014 for Ndoondu station

Table 4.2: Summary statistic of trend for Ndoondu

Data file : Ndoondu.csv: MEAN ANNUAL RAINFALL					
	Test statistic	Critical values			Result
		(Statistical table)			
		α=0.1	α=0.05	=α=0.01	
Mann-Kendall	0.646	1.645	1.96	2.576	NS
Linear regression	0.518	1.699	2.045	2.756	NS

H_{null} : there is no trend in the rainfall trend analysis for 31 years

H_{Alter} : there is a trend in the rainfall trend analysis for 31 years.

The p-value in the results according to table 4.2 using linear regression was 0.518 which is less than the critical value of 2.045 for α=0.05.Using Mann-Kendall as the check showed a result of 0.646 again less than the critical value of 1.96 forα=0.05 . Thus the null hypothesis was not rejected meaning there is no trend in the annual rainfall analysis for 31 years (1984-2014) in Doondu station. This meant that the rainfall amount was neither decreasing nor increasing during this period.thus there is no pattern of changes of rainfall amounts for 31 years in Ndoondu station.

Figure 4.7 showswavelet power spectrum for March April May (MAM) and October November December (OND) for the years 1984 to 2014 for Ndoondu station.

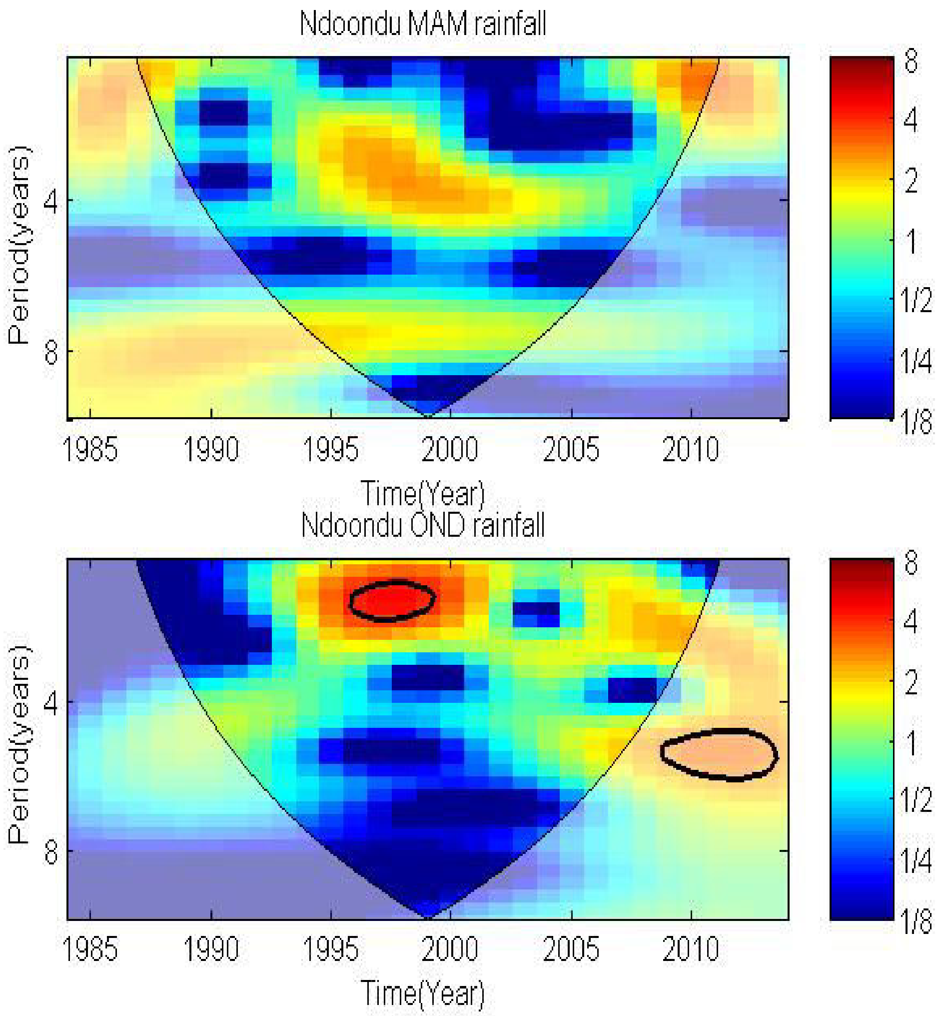

Figure 4.7: wavelet power spectrum OND and MAM for Ndoondu

High power spectrum (red colour) was observed within the band of 0-4 years in the year 1995 and 2000 which was sigfinificant. Relatively higher power spectrum (red colour) was observed within the band of 4-8 years between 2009 and 2014 though it was not significant in the OND season. During the MAM season relatively higher power spectrum was observed within 2- 5 years band in the years of 1994 to 2000 according to figure 4.7. hence for OND high intensity rainfall was likely to occur in the period of 0-4 years while for MAM it will occur in the period of 4-8 years.

4.1.3 Ruiru mills station

Figure 4.8 shows mean annual rainfall trend for the years 1984-2014 for Ruiru mills station

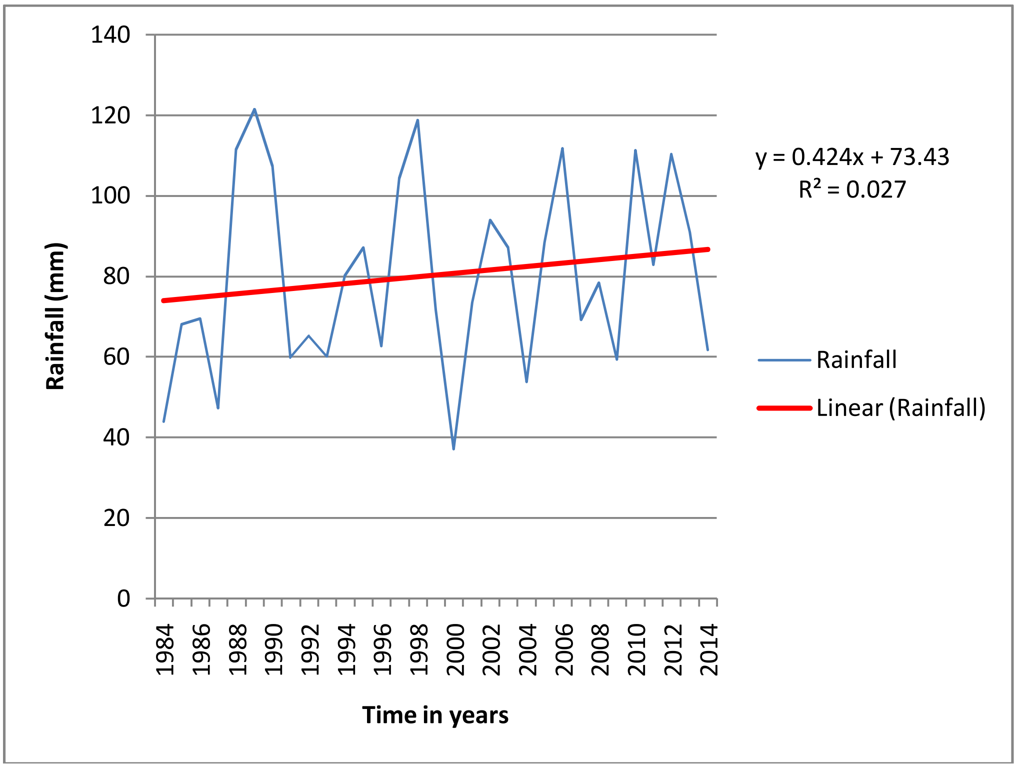

Figure 4.8: Rainfall trend in Ruiru Mills

High total annual rainfall of 1459.95 mm was recorded in the year 1989 and low amounts of 444mm in the year 2000. There was an increasing trend from 1984 to 2014 though not significant as in figure 4.8 above. This shows that over the past 31 years rainfall amounts have been increasing for Ruiru mills station.

Figure 4.9 shows mean monthly rainfall for the years 1984 to 2014 for Ruiru mills station.

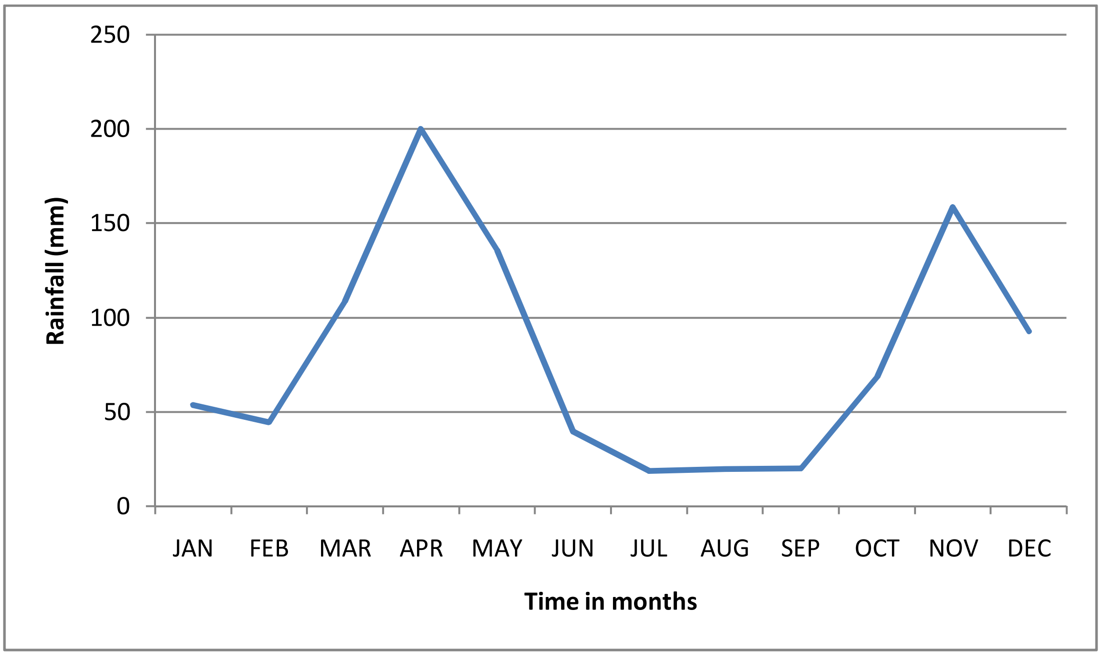

Figure 4.9: Mean monthly rainfall trend in Ruiru mills

In figure 4.9there was high mean monthly rainfall of 199.9mm followed by 158.6mm in the month of April and November, respectively was experienced with the monthly mean of 18.6mm in the month of July. There was an insignificant decreasing trend with double maxima in April and November.

Table 4.3 shows summary statisticof trend test using linera regression and Man-Kendall for the years 1984 to 2014 for Ruiru mills station

Table 4.3: Summary statistic of trend for RuiruMills station

Data file : Ruiru mills.csv: MEAN ANNUAL RAINFALL					
	Test statistic	Critical values			Result
		(Statistical table)			
		α=0.1	α=0.05	α=0.01	
Mann-Kendall	0.986	1.645	1.96	2.576	NS
Linear regression	0.9	1.699	2.045	2.756	NS

H_{null} : there is no trend in the rainfall trend analysis for 31 years in Ruiru Mills

H_{Alter} : there is a trend in the rainfall trend analysis for 31 years in Ruiru Mills.

In table 4.3 the p-value calculated using trend software was 0.9 which is less than the critical value of 2.045 for α=0.05 in linear regression. The check statistic according to Mann-kendall showed a result of 0.986 which is less than the critical value of 1.96 for α=0.05. Thus the null hypothesis was not rejected meaning there is no trend in the annual rainfall analysis for 31 years (1984-2014) in Ruiru Mills station.

Figure 4.10 shows wavelet power spectrum for March April May (MAM) and October November December (OND) for the years 1984 to 2014 for Ruiru mills station.

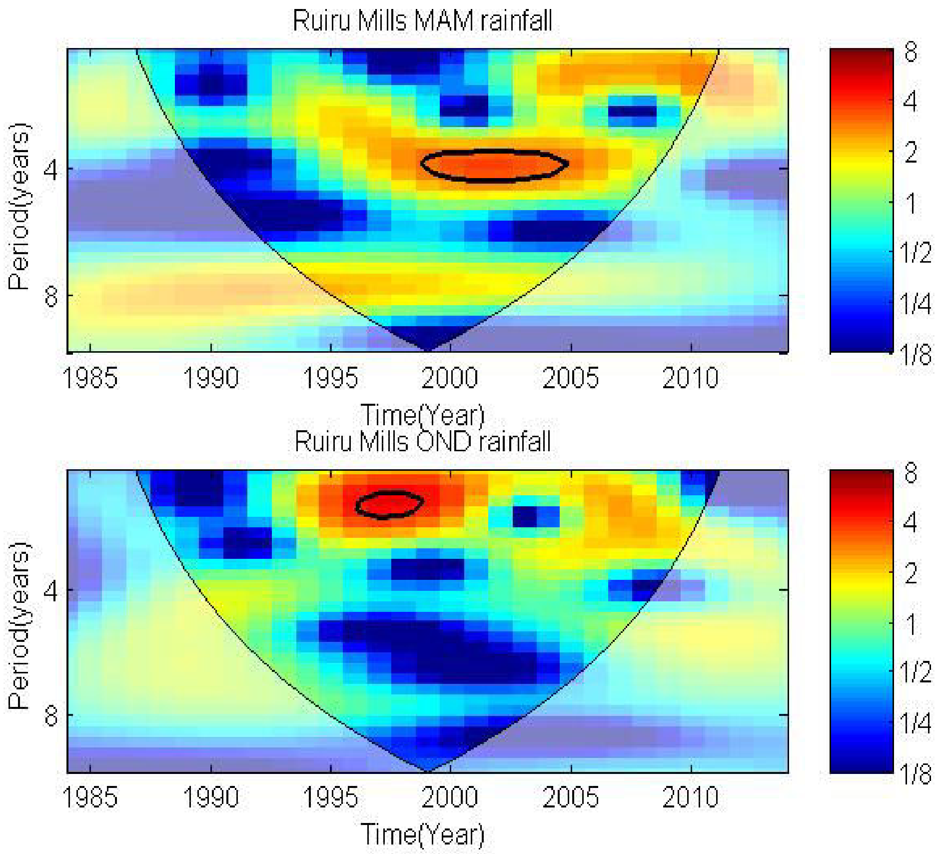

Figure 4.10: Wavelet power spectrum MAM and OND for Ruiru Mills

During the MAM wet season high power spectrum (red colour) was observed within the band of 3-5 years in the year of 1999 to 2005 which is significant. In the OND season, high power spectrum (red colour) was observed within the band of 0-3 years between the year 1995 and 2001 and its signicant as showed in figure 4.1. this means that high intensity rainfall occurred in the period of 3-5 years in MAM and a period of 0-3 in OND.

4.1.4 Rainfall Trends for the Three Stations

Comparing significant difference in mean annual rainfall among stations using Winks Software, the calculated p-value was 0.006 which was less that 0.05.Thus the null hypothesis which stated no significance deference in the mean annual rainfall among stations, was not rejected. Therefore there was no significant difference between the stations.

4.2 Estimation of groundwater recharge

Figure 4.11 shows number of boreholes completed each year for 31 boreholes studied between 2009 and 2013.

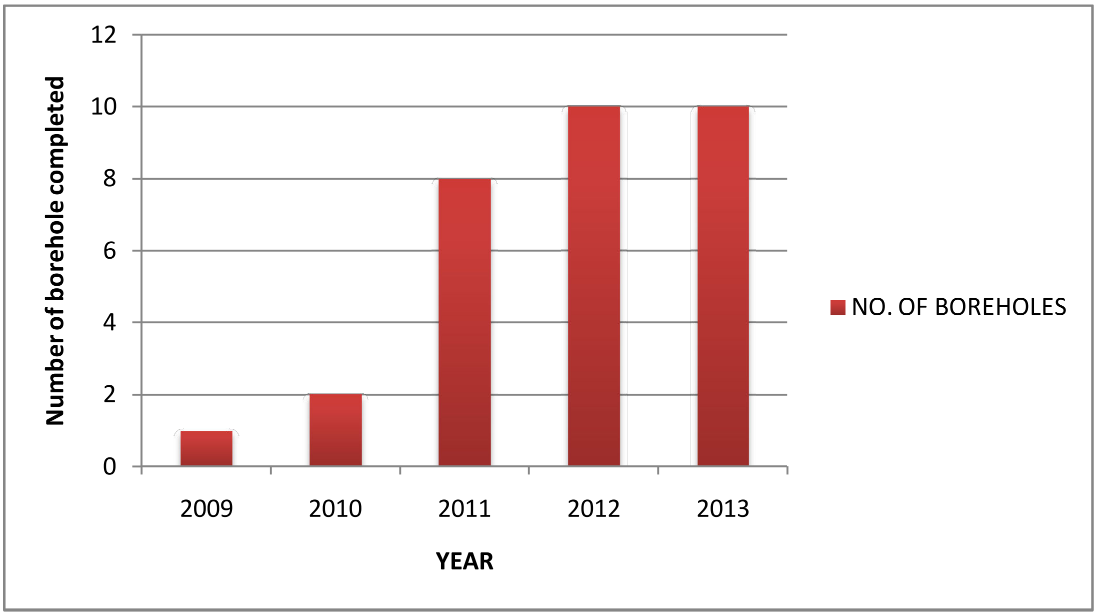

Figure 4.11: Number of boreholes and completion year

Figure 4.11 shows that between the years2009 and 2013 there was a steady increase in the number of boreholes (1 to 10) meaning the rate of groundwater exploitation increased over theperiod.

Figure 4.12 shows groundwater levels below ground level of 31 boreholesstudied during the wet and dry season

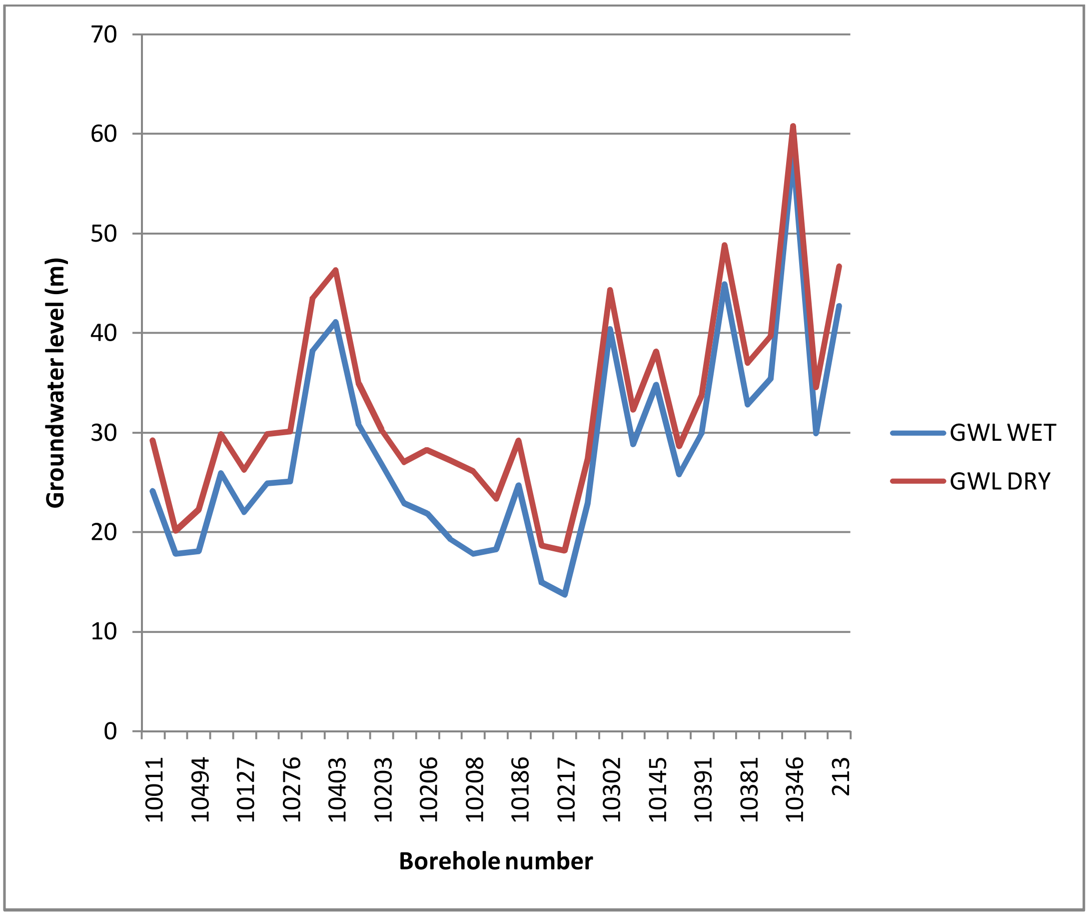

Figure 4.12: Groundwater levels during dry and wet season

The results of groundwater levels during the dry and wet seasons showed that water levels in the dry season were lower than water levels during the wet season (Figure 4.12). The groundwater level drop ranged from 2.3m to8.3m. This was attributed to groundwater recharge from precipitation and high abstraction rates during the dry season.

There was a decrease in groundwater levels in the dry season across all boreholes. This was explained that during the wet season the rainfall amounts were high which percolated to the ground causing rise in the water table. The increase in levels can also be attributed to decreased dependence on groundwater, because with the increased rainfall amounts more people access pipe water from water companies. This is because water companies have enough water in their dams from surface water sources such as rivers and hence there is no rationing. Those who used borehole water for irrigation had enough rainfall and their crops needed no irrigation.

Table 4.4 shows mean monthly groundwater levels for Murera Monitoring borehole in 2012, 2013 and 2014

Table 4.4: Groundwater levels for Murera monitoring borehole

2012		2013		2014	
MONTH	**WRL(m)**	**MONTH**	**WRL(m)**	**MONTH**	**WRL(m)**
JAN	27.60	JAN	26.60	JAN	27.60
FEB	27.40	FEB	27.32	FEB	27.50
MAR	27.40	MAR	27.34	MAR	27.40
APR	27.30	APR	27.00	APR	27.60
MAY	28.00	MAY	27.10	MAY	27.50
JUNE	28.20	JUNE	27.18	JUNE	27.55
JUL	37.20	JUL	27.30	JUL	27.60
AUG	32.40	AUG	27.35	AUG	27.75
SEP	37.30	SEP	27.40	SEP	27.65
OCT	36.60	OCT	27.50	OCT	27.75
NOV	27.30	NOV	27.55	NOV	27.80
DEC	27.00	DEC	27.60	DEC	27.85

Figure 4.13 shows groundwater levels for Murera monitoring borehole in 2012, 2013 and 2014

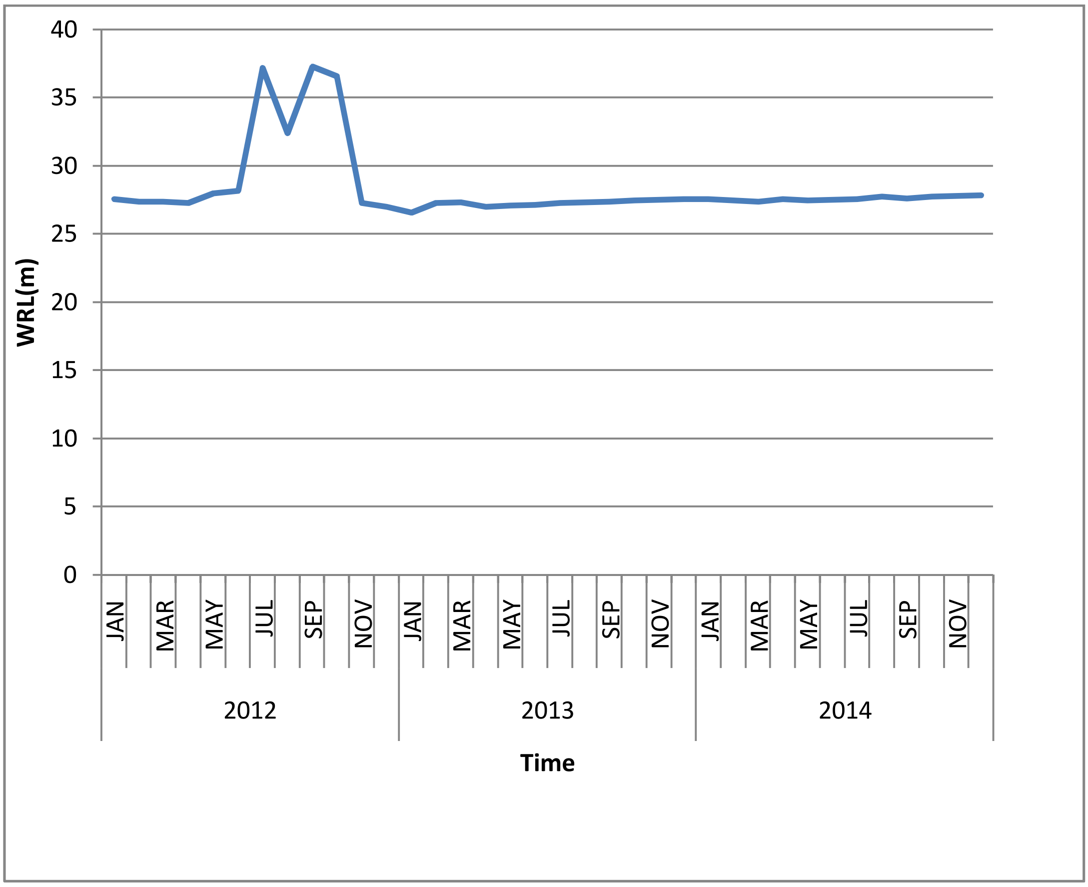

Figure 4.13: Groundwater levels in the year 2012-2014

Figure 4.13 showed that groundwater levels were low i.e 37.30m from the ground level in the year 2012 September, and high i.e 26.60m from the ground surface in January 2013. This can be due to low amount of rainfall which affect recharge in the month of January

Table 4.5 shows monthly rainfall amounts in 2012, 2013 and 2014.

Table 4.5: Rainfall data for 2012, 2013 and 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	200.9
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 4.14 shows monthly rainfall amounts in 2012, 2013 and 2014.

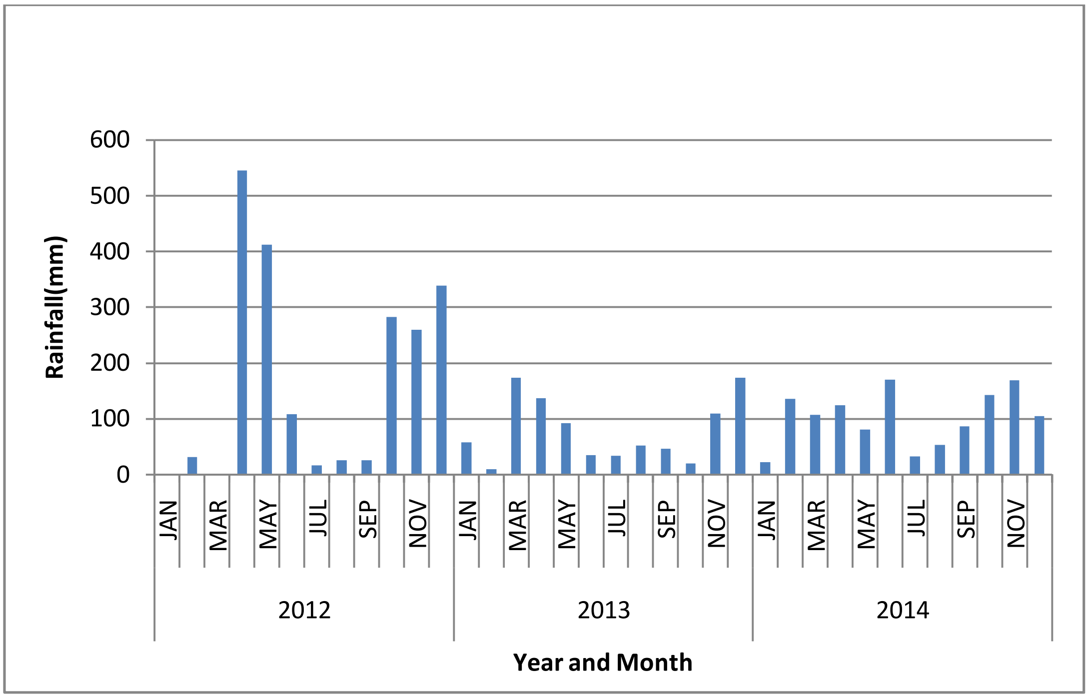

Figure 4.14: Rainfall amounts for the years 2012-2014

Figure 4.14 shows that high amount of rainfall (644.4 mm) was recorded in April 2012 and lowest amount (0 mm) in January 2012. Relatively higher amounts were recorded in the months of March, April and May and October November and December. On the other hand, months of January, June, July August and September showed low amounts of rainfall. This showed that rainfall amounts had two maxima in a year.

Figure 4.15 shows monthly rainfall amounts and groundwater levels of Murera monitoring boreholes in 2012, 2013 and 2014.

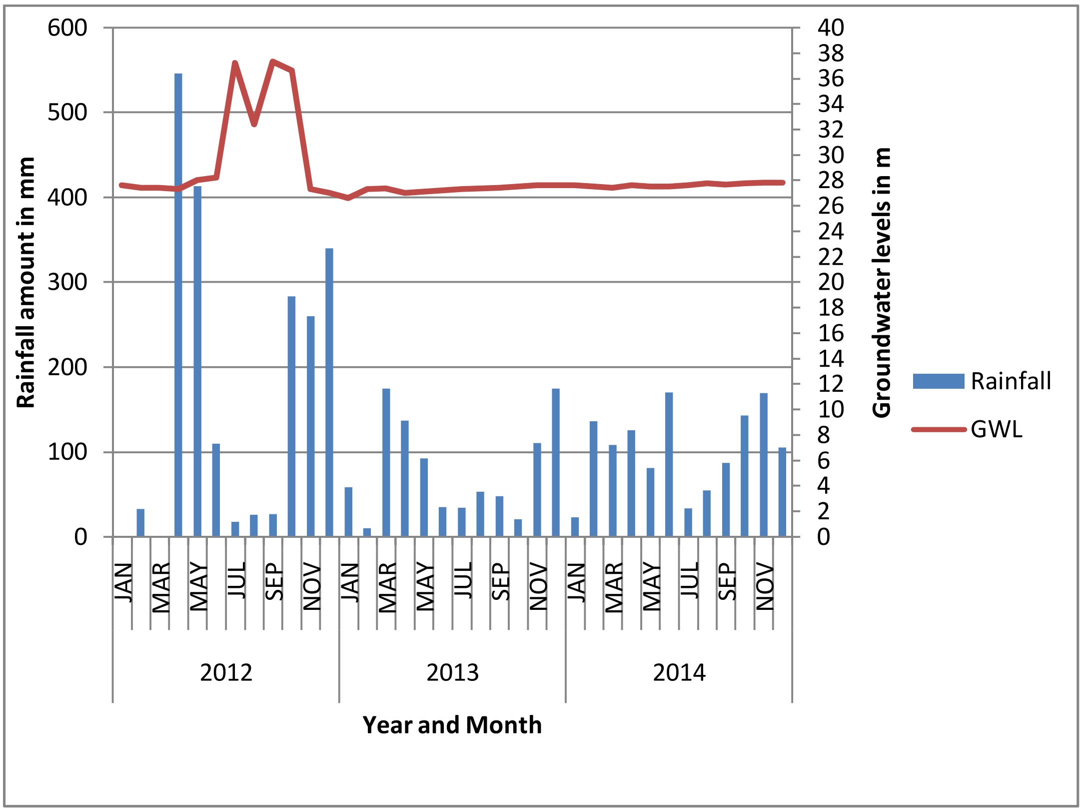

Figure 4.15: Rainfall amounts and groundwater levels for Murera monitoring borehole (2012-2014)

Figure4.15 shows that when the rainfall amounts are high groundwater level is high due to recharge. This is because when the rainfall amounts are low the water levels are deep i.e decreases. In December 2012 despite the rainfall amounts being low the groundwater level is shallower implicating low abstraction or an erroneous reading. The results indicated a decline in groundwater levels during low rainfall in figure 4.15 since groundwater recharge depends mainly on rainfall. Moreover during dry season there was over exploitation of the ground water as other sources supplied less water. On the other hand there was rise in groundwater levels due to infiltration as rainfall amounts increased.

Figure 4. 16 show correlation of rainfall amounts and groundwater levels for 2012 to 2014 for Murera monitoring borehole.

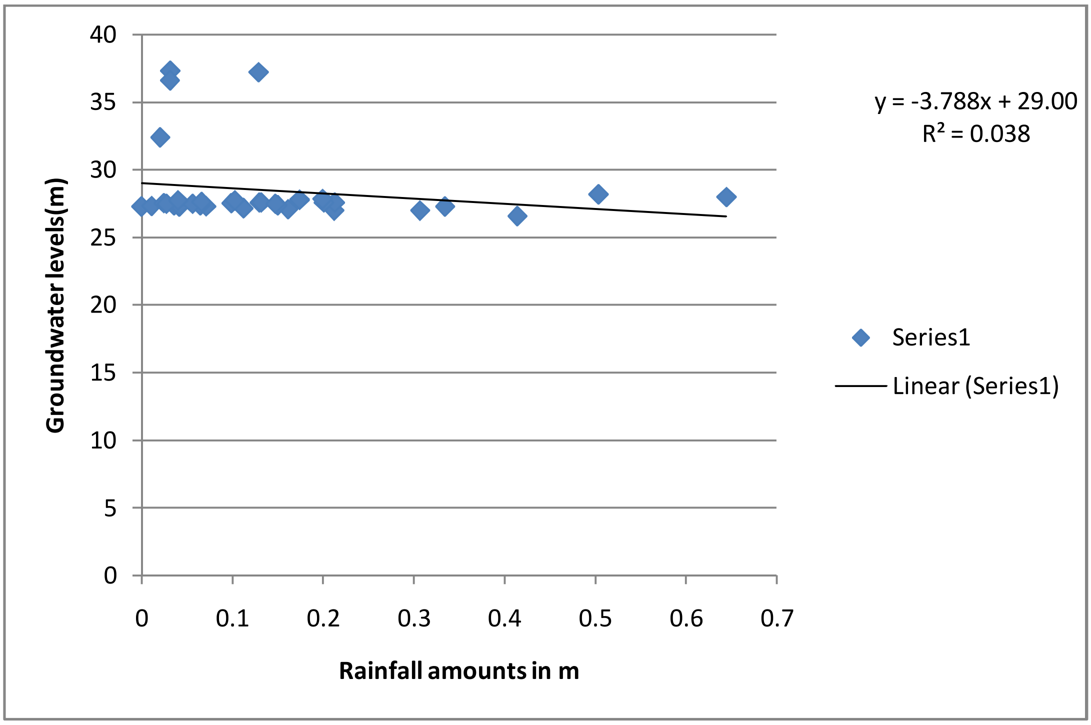

Figure 4.16: Scatter diagram showing correlation of rainfall and groundwater levels for 2012-2014

Figure 4.16 showed that rainfall and groundwater levels were negatively correlated with correlation coefficient of 0.038. The slope was negativeshowing a declining pattern.Thus as rainfall amounts increased, groundwater level decreased. The results showed that rainfall was not the only factor influencing groundwater levels because there was a weak correlation of -0.038. But rainfall did play a role to a certain extent. Other factors which might have influenced the groundwater levels include the land cover, Ruiru location being dominated by pavements as compared to vegetation there is high runoff during the rain periods thus infiltration is low. Infiltration rate in the area could also be low because of the geologic formation, thus it takes a lot of time for rainfall to be reflected on the groundwater levels. Abstraction of water from the borehole could also influence the groundwater levels as 75% of the population relied on borehole as a source of water supply.

Figure 4.17 shows estimated recharge for the year 2012, 2013 and 2014

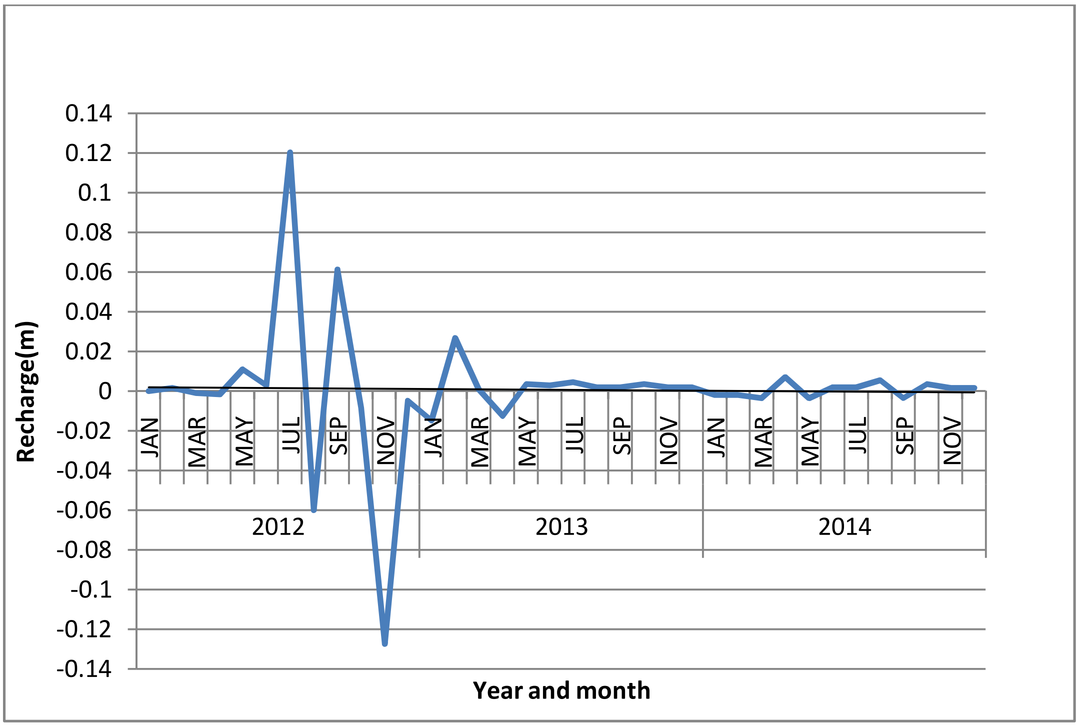

Figure 4.17: Recharge for the year 2012-2014

The recharge was calculated using the water table fluctuation method for every month January to December for the year 2012, 2013 and 2014 as shown in appendix 3 and the total recharge for the whole year calculated by summing the recharge for every month. In the year 2012 the recharge ranged from no recharge to a maximum recharge of about 293 mm. The total annual recharge for the same year was -13mm implying an over draw of groundwater.

In the year 2013 the recharge ranged from no recharge i.e. -15mm to a maximum of 26mm. The total annual recharge in the same year was 22mm. In the year 2014 the amount of recharge ranged from no recharge of -4mm to a maximum of 7mm. The total annual recharge in the same year was 9mm.The total annual recharge increased from no recharge in the year 2012 to a recharge of 22mm recharge in the year 2013. There was also a decrease of recharge from 22mm in the year 2013 to 9mm in the year 2014, a decrease of 13mm.

Figure 4.18 shows recharge and rainfall for the year 2012, 2013 and 2014.

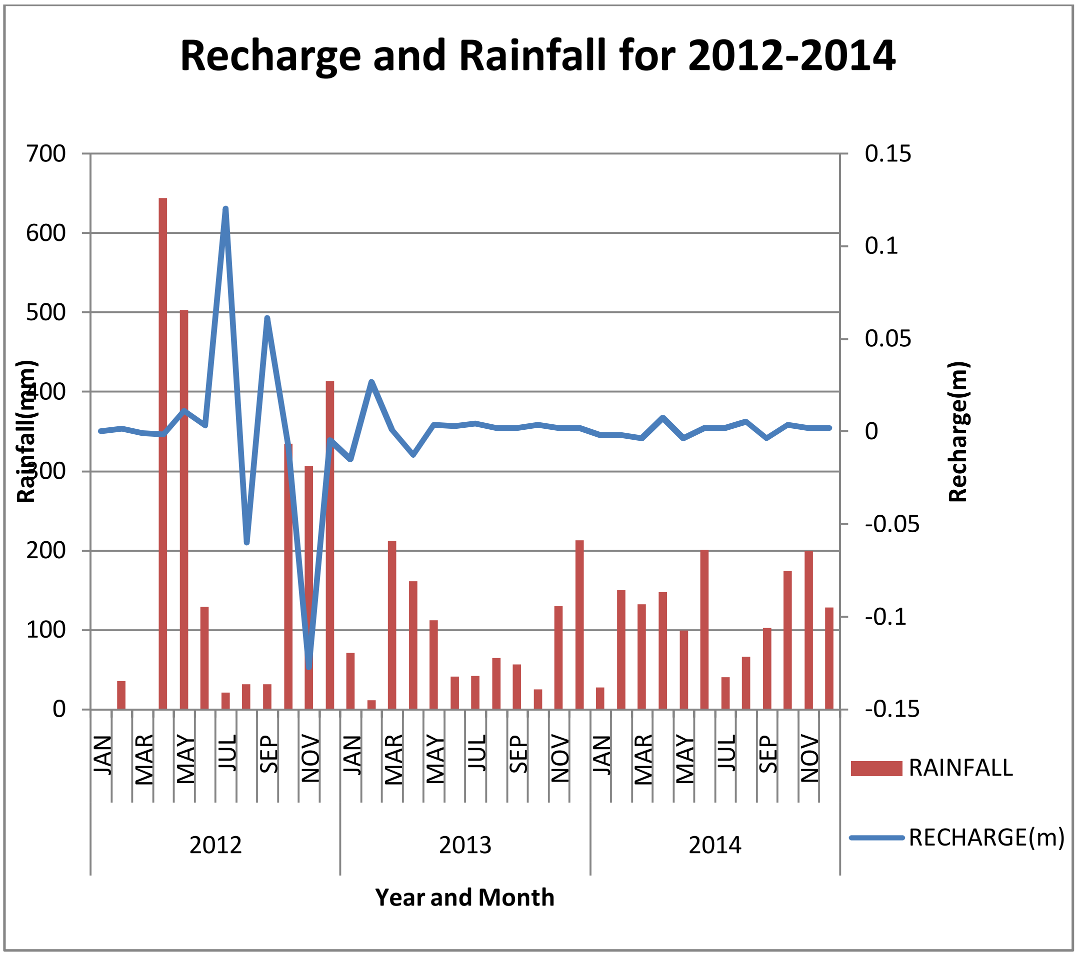

Figure 4.18: Relationship between Recharge and rainfall amounts (2012-2014)

The results showed that when the rainfall amounts are high the recharge is high. This is because rainfall is a major contributor to groundwater recharge. However in the month of November 2012 despite the rainfall amount being high about 300mm the amount of recharge was low about -293mm and that could be an error.

4.3 The impact of rainfall variability on water supply systems.

4.3.1 Climate change awareness

The characteristics of the sample population constituted of 54% male and 46% female. 17% of the population ranged 20 to 30 years of age, 25% 31 to40, 25% 41 to 50, 18% 51 to 60, 8% 61to70 and 7% 71 to 80 years of age. 50% of the respondents were from agricultural sector, 30% domestic and 20% industrial sector. 87% of the population agreed that they have noticed changes in rainfall patterns over the years. They explained that they have experienced long rains in March and April but over the years the pattern changed to May and June. 100% of the population has experienced changes in temperature attributing it to extremes i.e. very hot at times and very cold especially at nights.100% of the population has heard of climate change.

Figure 4 19 show response on flood frequency

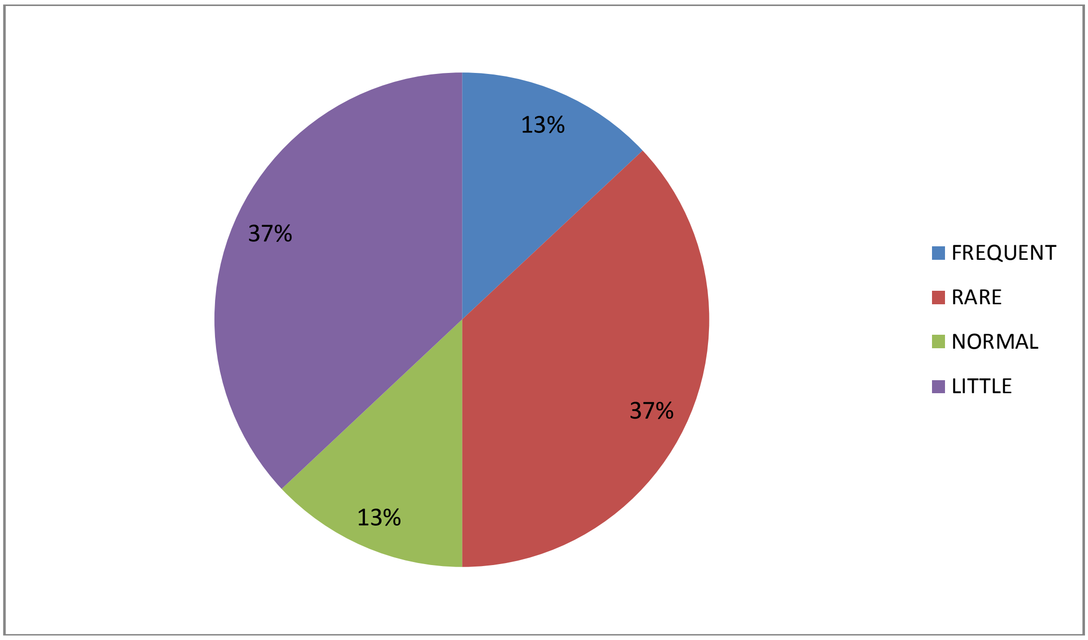

Figure 4.19: Response on flood frequency in the area

Figure 4.19 shows that 37% of the population experienced little flood frequency, 37% experienced rare, 13% experience frequent and 13% experienced normal flood frequency. For those who experienced floods, they experienced in the months of April, May, early June, November and December. 13% of the population harvest floodwaters while 87% don't. 87% of the population experienced changes in drought frequency while 13% did not. The respondents experienced drought in the months of Januaryand February. During this period they got water from the boreholes and Nairobi Water and Sewerage Company. The population spent between 7 to 10% of their income on water. Therefore majority of respondents did not experience flood. The population that experienced flood, did not harvest water for use during the dry season. This led to increase in expenditure for buying water.

4.3.2 Rainfall Variability and Water Supply

Figure 4.20 shows response on sources of water for daily uses in the area.

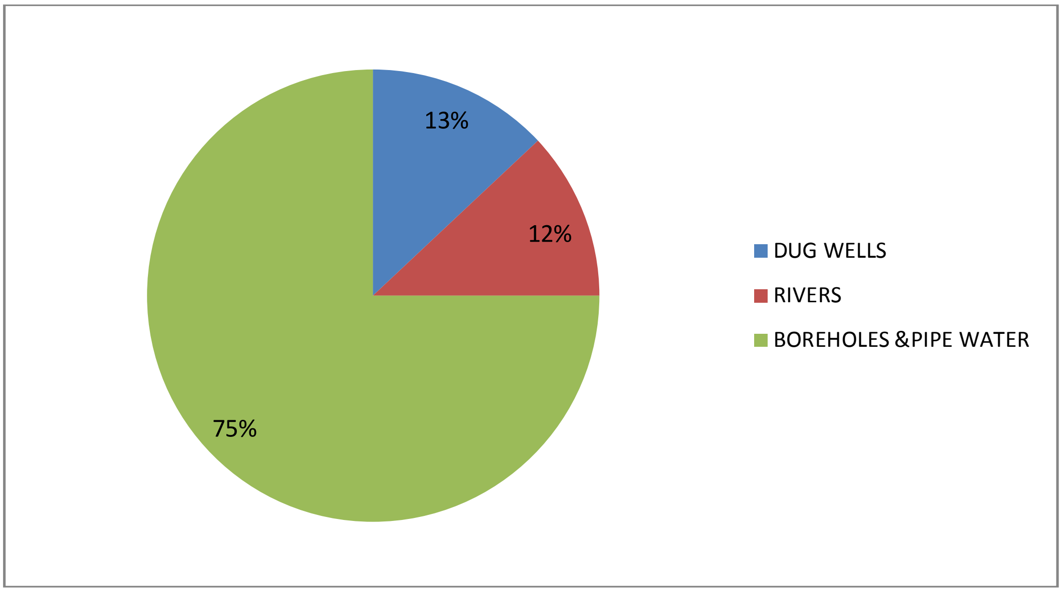

Figure 4.20: Sources of water for daily uses

Figure 4.20 shows that 13% of the population use dug wells as their major source of water, 12% used rivers, 75% of population used boreholes and pipe water according to respondents. The data showed that most people using piped water also use borehole water as a back up indicating unreliability of the two water sources and the population experienced irregular supply of water especially during dry periods.

Figure 4.21 shows responses on the effect of rainfall variability on groundwater quantity.

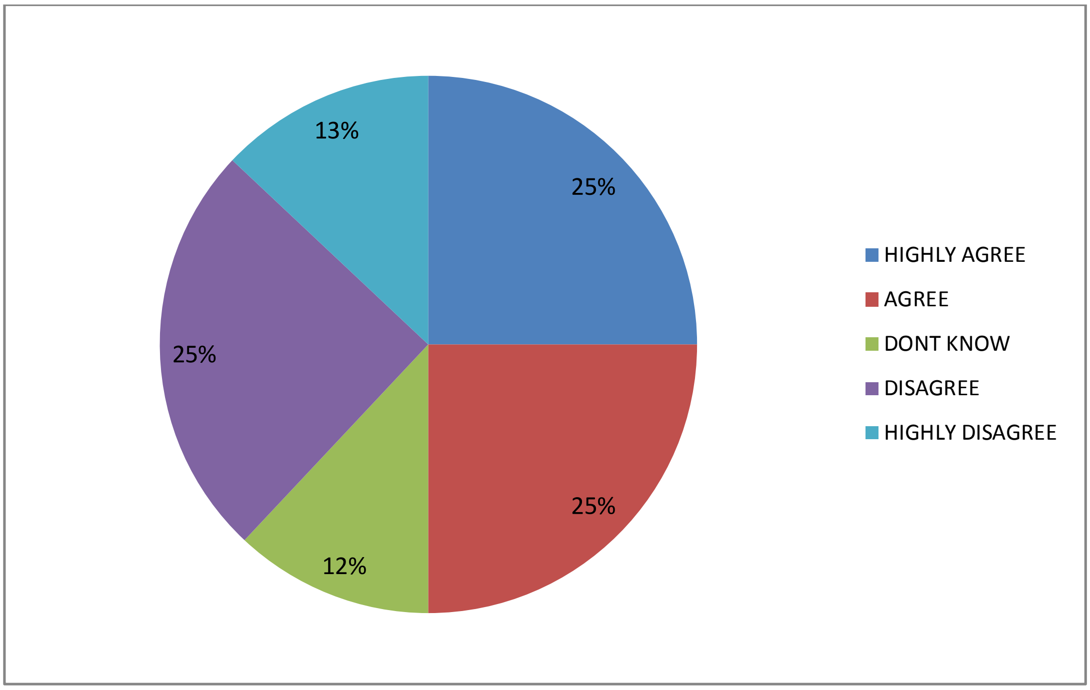

Figure 4.21: Effect of rainfall variability on groundwater quantity

In Figure 4.21, 25% of the population highly agreed that rainfall variability has affected groundwater quantity, 25% agreed, 12% don't know, 25% disagreed while 13% highly disagreed. Thus majority of respondents agreed that rainfall variability had an impact on groundwater quantity.

Figure 4.22 shows responses on the existence of rainfall variability over years.

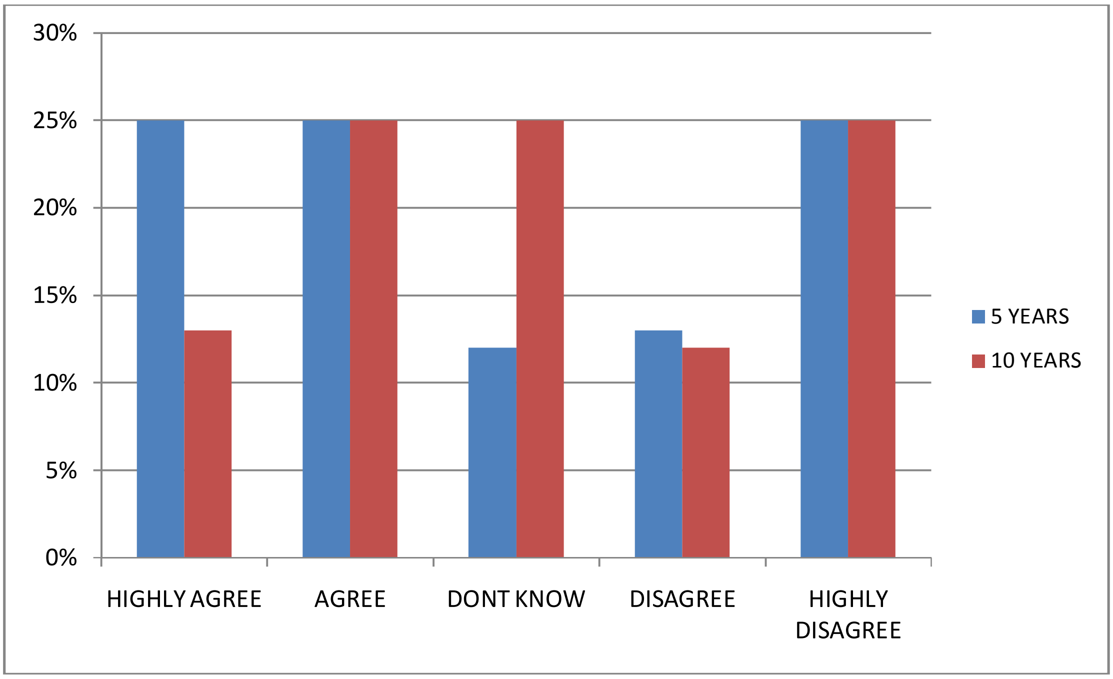

Figure 4.22: Existence of rainfall variability over the years

In Figure 4.22, 13% of the population highly agreed that rainfall variability has been there in the last ten years, 25 % agreed, 25% don't know, 12% disagreed while 25% highly disagreed. 25% of the population highly agreed that rainfall variability has been there in the last five years, 25% agreed, 12 % don't know, 13 % disagreed while25% highly disagreed.Therefore, majority of respondents have experienced rainfall variability in the past years.

Figure 4.23 shows response on the effect of rainfall variability on water supply

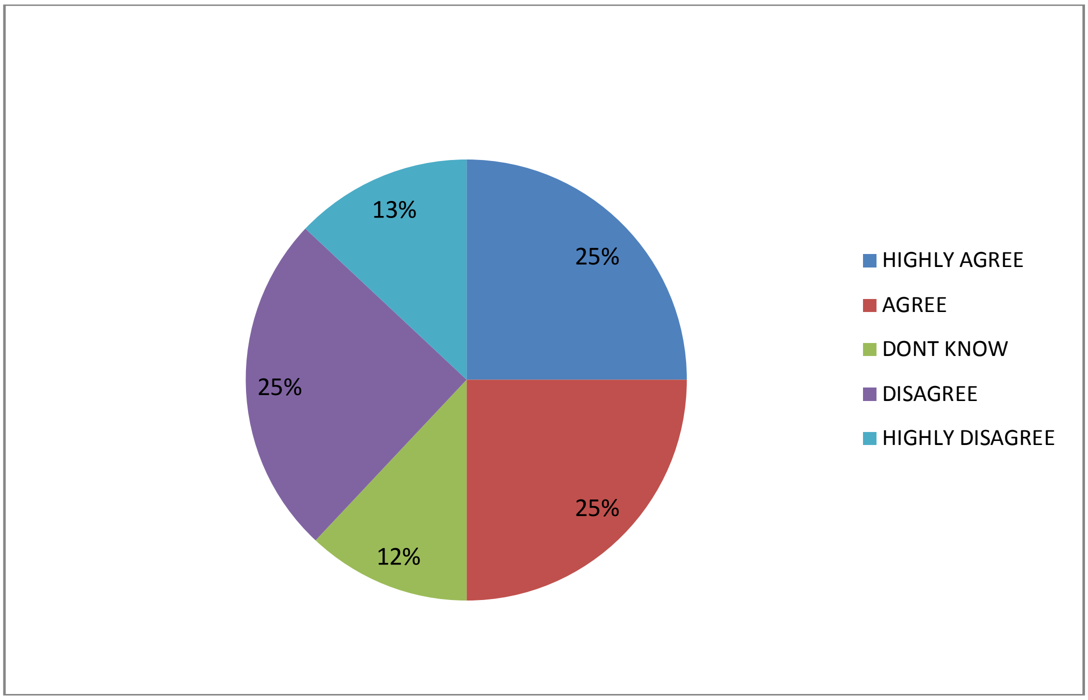

Figure 4.23: Effect of rainfall variability on water supply

Figure 4.23 shows that 25% of the population highly agree that rainfall variability has affected water supply in the area, 25% agree, 12% don't know,25% disagreed while 13% highly disagreed. Therefore majority of respondents agree that rainfall variability affects water supply in the area.

4.3.3 Consequences and impacts of rainfall related changes

Figure 4.24 shows the response on consequences and impacts of rainfall related changes.

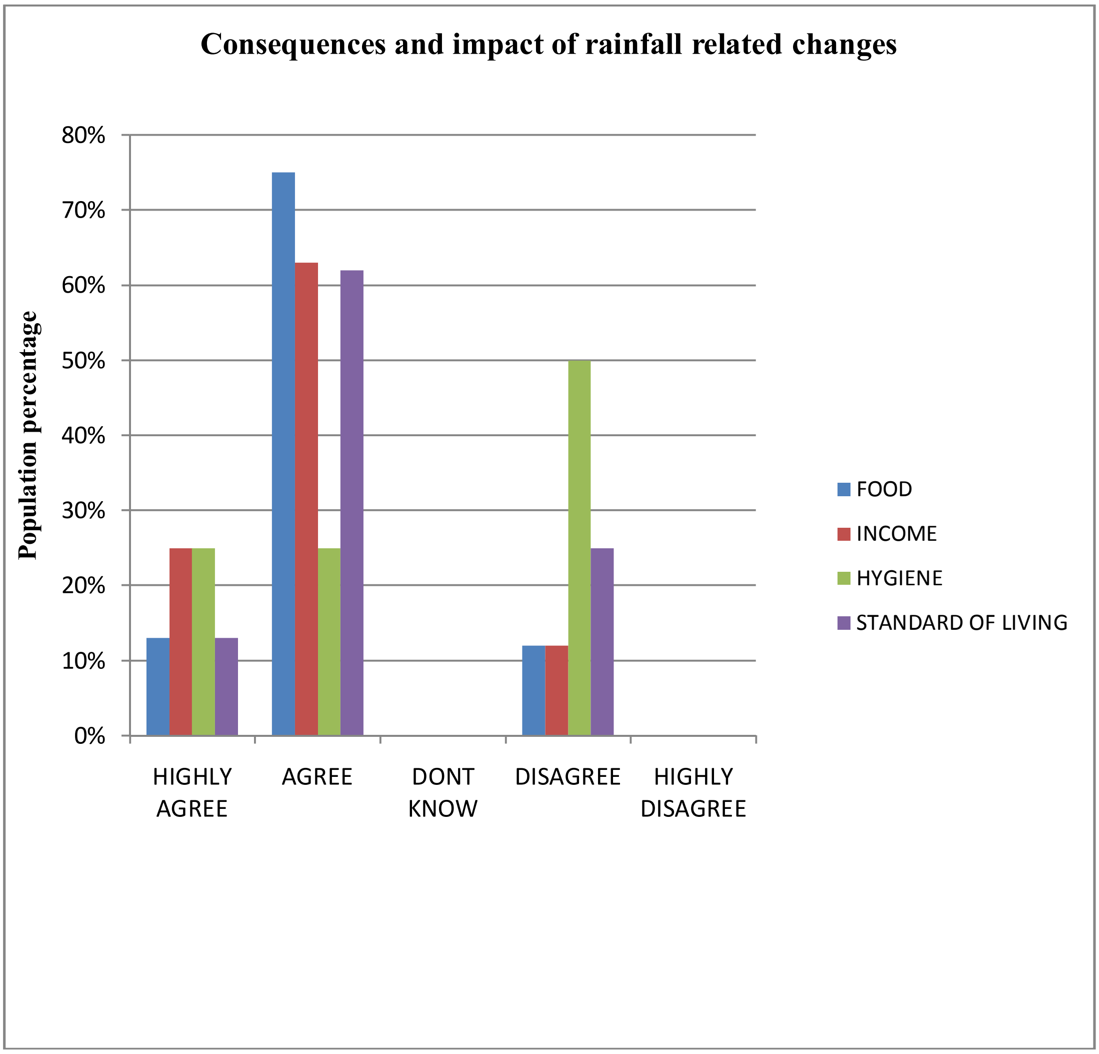

Figure 4.24: Consequences and impacts of rainfall related changes

From Figure 4.24, 13% of the population highly agreed that rainfall variability has affected food sufficiency for households, 75% agreed while 12% disagreed. This shows that fluctuation of rainfall amounts in the area can lead to food insecurity. 25% of the population highly agreed that rainfall variability has affected income in their households, 63% agreed while 12% disagreed. This implies that rainfall variability can also affect householdincomes as some businesss which generate income need water for them to run. 25% of the population highly agreed that rainfall variability has affected the health of their households, 25% agreed while 50% disagreed. 13% of the population highly agreed that rainfall variability has affected the standard of living of their household, 62 % agreed while 25% disagreed. The standard of living of majority of respondents isaffected by rainfall variability. 75% of the population have experienced water shortage from boreholes during abstration especially during dry season. This can be attributed to low groundwater recharge and over-abstraction.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

There was an increasing rainfall trend across the three rainfall stations i.e. Ndoondu, Ruiru mills and Coffee Research Foundation for the years 1984 to 2014. However, the trend was not significant as the p-value was greater than 0.05 and hence the null hypothesis was not rejected. The null hypothesis was adopted meaning there was no significant trend.

Through the application of the Water Table Fluctuation (WTF) method, estimated recharge rates were calculated for the boreholes completed in unconfined aquifer. In the year 2012 there was no recharge as the groundwater was overdrawn by 13mm. In 2013, 22mm recharge was realized while a recharge of 9mm was achieved in 2014.There was an impact of rainfall variability on groundwater levels as the groundwater levels were low during the dry seasondue to low recharge and high abstraction;and high during wet season because of high recharge and low abstraction. The rainfall variability could be caused by climate change, brought about by extreme weather conditions such as prolonged droughts and floods in the area. Thus climate change should be mitigated to cap decline in groundwater especially during low rainfall periods. Ruiru town which is within the location is dominated by pavement land cover, abstraction should be controlled to ensure that groundwater resources are managed properly to avoid depletion**.**

Rainfall variability had an impact on water supply systems as majority of respondents experienced droughts and floods which were attributed to climate change. Majority of respondents expressed shortage of water during drought periods including drying and decline of borehole water levels. Rainfall variability also affected food sufficiency, income, health and standard of living. This is because during dry seasons the agricultural production is low and the prices of food in the market are high hence people spent more. Nevertheless during dry period water supply is low and people may have to buy water at an extra cost as compared to wet seasons. There is poor sanitation as particularly the town setup relies on water to flash their toilets and general hygiene, this lead to outbreak of diseases. Some industries may lower their production as most of them cannot run their operations without water.

5.2 Conclusion

- There was no rainfall trend in Ruiru location for the years 1984 to 2014
- Recharge for the years 2012,2013 and 2014 was estimated to be 18mm
- Rainfall variability had an impact on water supply systems in Ruiru location
- There was groundwater level variability in Ruiru location

5.3 Recommendations

- More boreholes should be monitored in the area to provide sufficient data for groundwater resources management
- More research on the impact of climate change on water resources and determination of net recharge should be done
- Groundwater recharge should be enhanced by controlling abstraction or adopting storm water soak pits
- Water conservation measures should be adopted to avoid wastage

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APPENDICES

Appendix 1: Questionnaire

Questionnaire - A study of the Effect of Rainfall Variability on groundwater levels in Ruiru location

A. Identification and Characterization

Name of respondent; ……………………………………………………………………….

Address; ………………………………………………………………………………

Date; ……………………………………..……………………………………….

Hour……………………………………………………………………………………….

Area/region/ward; ……………………………………………………………………..

Sex……………………………………………………………………………………..

Age interval…………………..……………………………………………………….

Occupation; …………………………………………………………………………….

B. Climate Change Awareness

1. How has water supply for your daily uses changed during the years? Dry season, Wet season, Cold season, hot season?

Explain………………………………………………………………………………

……………………………………………………………………………………………….

2. Have you noticed any changes in the rainfall patterns over the year? No /Yes Explain?

…………………………………………………………………………………………………
…………………………………………………………………………………………………

3. Have you noticed any changes in temperature? Yes/ No. Explain

…………………………………………………………………………………………………

4. Have you ever heard of the term “climate change? Yes/ No………………….

5. What does climate change mean?

………………………………………………………………………………………..

6. Is the area affected by floods? Yes/No…………………………………..

7. Flooding; have you noticed any change in floods frequency in the area? No/ Yes

If yes, response 1-Frequent 2-Rare 3-Normal 4-Little

………………………………………………………………………………………………

i. In which months of the year do you experience flooding? ....

ii. Do you harvest flood waters?

....

8. Drought; Have you noticed any change in drought frequency in the area? No/ Yes

If Yes,: response1-Frequent 2- Rare 3-Normal 4-severe

……………………………………………………………………………………
…………

i. In which months of the year do you experience drought?

ii. How do you get your water during theDrought period?

………………………………………………………………………

iii. How much of your income do you spend on water during dry and wet season?

……………………………………………………………………..

C. Rainfall variability and water supply

i. What do you understand by the term rainfall variability?…………………………..

………………………………………………………………………………

ii. Have you experienced rainfall variability? Yes/ No…………….

iii What is your major source of water for your daily uses? 1. Piped water 2. Dug wells 3. Boreholes 4.River 5. Water tanks

…………………………………………………………………………………

iv. How much water do you use daily for the household/workstation? ……………

v. Do you use the amount of water during the dry and Wet Seasons? Yes/ no

…………………………………………….

vi. What problems do you face in sourcing water for your use? Are these problems different in the wet and dry seasons? Yes/No, Does it vary over the year? Yes/No …………………………

Note; for this research Groundwater sources only considers boreholes.

Provide your view on the following:

SN	Issues	Highly agree	Agree	Don't know	Disagree	Highly disagree
1	Rainfall variability has affected the groundwater quantity					
2	Rainfall variability has been there in the last 5 years					
3	Rainfall variability has been there in the last 10 years					
4	Rainfall variability has affected the water supply in the area					

vii. How has rainfall variability affected your source of water supply in terms of?

Water source;	At present	5 years ago	10 years ago	Any Particular Observations
Number				
Abundance of supply				
Quality of water				

Response: 1-Good 2-Bad 3-Fewer 4-Numerous 5-No change

D. Consequences and Impacts of Rainfall Related Changes

i. Apart from using water for domestic purposes, what else do you use your water for? …………………………………………………

ii. Have you had any challenges in water supply/ availability in the past years Yes/No ………..

iii. If yes what are the challenges and how do you cope? ……………………….............

iv. If one of the coping strategies mentioned is buying water, then how much does it cost you to buy water to meet your daily demands and what is the quantity that you normally buy?

v. How has this affected your economy in terms of:

a. Food stock

Diminishing		Any particular observation
Unchanged		
Increasing		

b. Income generating activities

Income Activity	At present	5 years ago	10 years ago	Any Particular observations

c. Health

Sickness (water related)	Frequencies

d. Are there any other impacts you would like to specify

e. How do you perceive your future developments with this rainfall variability? (Food sufficiency, Income, health, standards of living etc)

f. Provide your view on the following

SN	Issues	Highly agree	Agree	Don't know	Disagree	Highly disagree
1	Rainfall variability has affected food sufficiency for household					
2	Rainfall variability has affected income for my household					
3	Rainfall variability affected the health of my household					
4	Rainfall variability has affected the standard of living of my household					
5	Rainfall variability has affected (Any other)					

g. Which of these climate changes affect you directly in your daily life and why?

E. Rainfall Variability adaptation Strategies and water supply enhancement

i. How do you use and manage your water to ensure sustainable supply?

……………………………………………………………………………………….

ii. Have you taken any proactive measures to consider rainfall variability adaptation?

Yes/No …………………….

iii. If yes, briefly explain the initiative you have taken …………………………………

…………………………………………………………………………………………

iv. Are there any other methods of rainfall variability adaptation that could be implemented in your household to effectively manage the water resources………………………………………

v. What may be the constraints to implementation of these strategies?

....

vi. What do you think should be done by the whole society to protect the water resources from the effects of rainfall variability?

vii.If the source is borehole? How much do you use per day…………….

viii.What is the size of your household?...................

ix. What do you use borehole water for? Domestic use, drinking, cleaning, industrial processes, irrigation…………………………………………………………

x.Have you ever experienced water shortages from the borehole ? If yes, when do you experience the shortage?

…………………………………………………………………………………………………

xi.Is there a time when you do not use borehole water? If yes, when?

………………………………………………………………………………………..

THANK YOU FOR YOUR TIME.

Appendix 2: Field Data Sheet Template

Table 1: Field sheet Template

BHNo	OWNER	LOCALITY	USE TYPE	DLONG	DLAT	ALT	COMP. DATE	T_DEPTH	WSL	WRL	YIELD	GEOLOGY

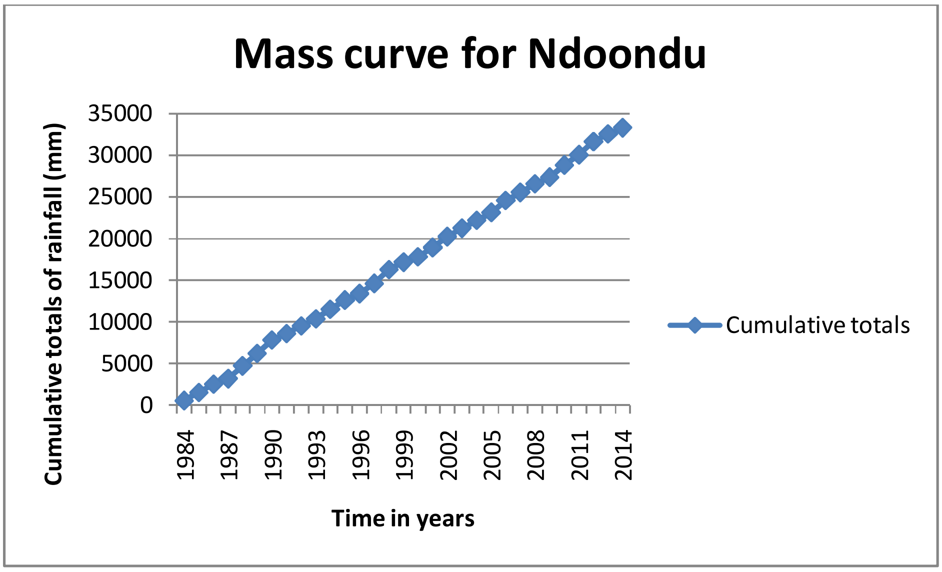
Appendix 3: Calculation of Recharge for the Year 2012, 2013 and 2014

2012									
MONTH	**FINAL(h)**	**INITIAL(ho)**	**TIME(t)**	**α**	**h/ho**	**ln (h/ho)**	**Δh(d)**	**sy**	**R(m)**
FEB	27.4	27.3	28	0.000130583	1.003663	0.003656	0.1	0.036563	0.003656
MAR	27.35	27.4	31	-5.89189E-05	0.998175	-0.00183	-0.05	0.03653	-0.00183
APR	27.3	27.4	30	-0.000121877	0.99635	-0.00366	-0.1	0.036563	-0.00366
MAY	28	27.3	31	0.000816703	1.025641	0.025318	0.7	0.036168	0.025318
JUN	28.2	28	30	0.000237249	1.007143	0.007117	0.2	0.035587	0.007117
JUL	37.2	28.2	31	0.008935058	1.319149	0.276987	9	0.030776	0.276987
AUG	32.4	37.2	31	-0.004456463	0.870968	-0.13815	-4.8	0.028781	-0.13815
SEP	37.3	32.4	30	0.004694497	1.151235	0.140835	4.9	0.028742	0.140835
OCT	36.6	37.3	31	-0.000611132	0.981233	-0.01895	-0.7	0.027064	-0.01895
NOV	27.3	36.6	30	-0.009772051	0.745902	-0.29316	-9.3	0.031523	-0.29316
DEC	27	27.3	31	-0.000356446	0.989011	-0.01105	-0.3	0.036833	-0.01105
TOTAL RECHARGE									-0.01288

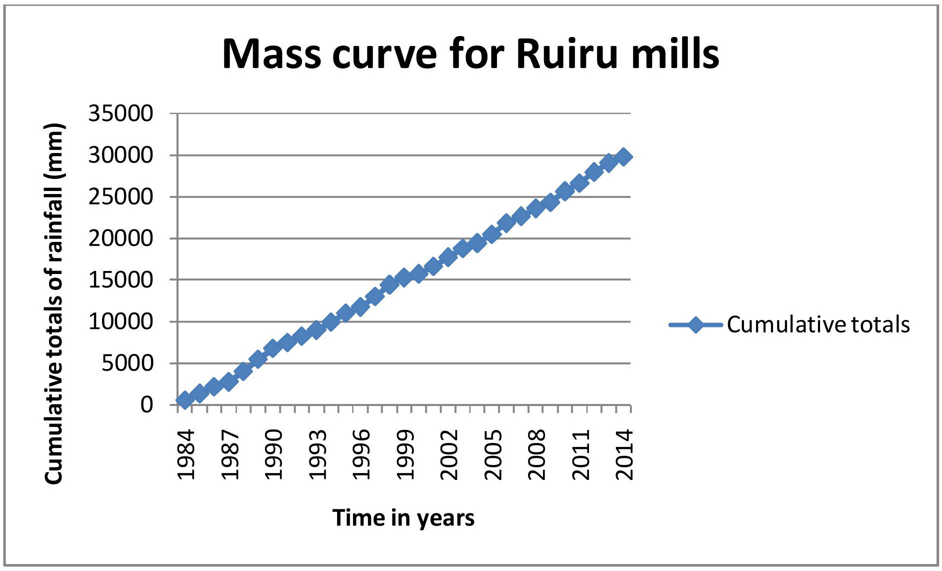
2013									
MONTH	**FINAL(h)**	**INITIAL(ho)**	**TIME(t) Days**	**α**	**h/ho**	**ln (h/ho)**	**Δh(d)**	**sy**	**R**
JAN	26.6	27	31	-0.000481473	0.985185	-0.01493	-0.4	0.037314	-0.01493
FEB	27.32	26.6	28	0.000953851	1.027068	0.026708	0.72	0.037094	0.026708
MAR	27.34	27.32	31	2.36063E-05	1.000732	0.000732	0.02	0.03659	0.000732
APR	27	27.34	30	-0.000417132	0.987564	-0.01251	-0.34	0.036806	-0.01251
MAY	27.1	27	31	0.000119254	1.003704	0.003697	0.1	0.036969	0.003697
JUNE	27.18	27.1	30	9.8256E-05	1.002952	0.002948	0.08	0.036846	0.002948
JUL	27.3	27.18	31	0.000142106	1.004415	0.004405	0.12	0.036711	0.004405
AUG	27.35	27.3	31	5.90267E-05	1.001832	0.00183	0.05	0.036597	0.00183
SEP	27.4	27.35	30	6.08828E-05	1.001828	0.001826	0.05	0.03653	0.001826
OCT	27.5	27.4	31	0.000117516	1.00365	0.003643	0.1	0.03643	0.003643
NOV	27.55	27.5	30	6.0551E-05	1.001818	0.001817	0.05	0.036331	0.001817
DEC	27.6	27.55	31	5.84915E-05	1.001815	0.001813	0.05	0.036265	0.001813
TOTAL RECHARGE									0.021979

2014									
MONTH	**FINAL(h)**	**INITIAL(ho)**	**TIME(t) Days**	**α**	**h/ho**	**ln (h/ho)**	**Δh(d)**	**sy**	**R(m)**
JAN	27.55	27.6	31	-5.84915E-05	0.998188	-0.00181	-0.05	0.036265	-0.00181
FEB	27.5	27.55	28	-6.48761E-05	0.998185	-0.00182	-0.05	0.036331	-0.00182
MAR	27.4	27.5	31	-0.000117516	0.996364	-0.00364	-0.1	0.03643	-0.00364
APR	27.6	27.4	30	0.000242425	1.007299	0.007273	0.2	0.036364	0.007273
MAY	27.5	27.6	31	-0.000117089	0.996377	-0.00363	-0.1	0.036298	-0.00363
JUN	27.55	27.5	30	6.0551E-05	1.001818	0.001817	0.05	0.036331	0.001817
JUL	27.6	27.55	31	5.84915E-05	1.001815	0.001813	0.05	0.036265	0.001813
AUG	27.75	27.6	31	0.000174841	1.005435	0.00542	0.15	0.036134	0.00542
SEP	27.65	27.75	30	-0.000120337	0.996396	-0.00361	-0.1	0.036101	-0.00361
OCT	27.75	27.65	31	0.000116455	1.003617	0.00361	0.1	0.036101	0.00361
NOV	27.8	27.75	30	6.0006E-05	1.001802	0.0018	0.05	0.036004	0.0018
DEC	27.85	27.8	31	5.7966E-05	1.001799	0.001797	0.05	0.035939	0.001797
TOTAL RECHARGE									0.009017

Appendix 4: Mass curve for Ndoondu station



Appendix 5: Mass curve for Ruiru mills station



Appendix 6: Groundwater levels in wet and dry season

BH No	10011	10421	10494	10036	10127	10126	10276	10349	10403	10402	10203	10205	10206	10207	10208	10185
WRL WET	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
WRL DRY	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
DIFF (m)	-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

BH No.	10186	10285	10217	10309	10302	10311	10145	10169	10391	10392	10381	10326	10346	195	213
GWL(m)DRY	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
GWL(m) DRY	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
DIFF(m)	-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