EFFECT OF RAINFALL VARIABILITY ON GROUNDWATER LEVELS IN NZOIA RIVER BASIN, KENYA.

ABSTRACT

Groundwater is a critical supply of freshwater in Africa, providing safe drinking water near to where it is needed for homes, agricultural, and industrial uses. Due to the high vulnerability of surface water resources to anthropogenic activities and climate change, groundwater consumption has increased dramatically over the last 50 years and is likely to continue rising in future. This study examines the effect of rainfall variability on groundwater levels using rainfall and groundwater level fluctuation data from Nzoia River Basin, Kenya. A cross-sectional survey design was used. Three counties were randomly selected from the basin for study with Busia representing the lower catchment, Kakamega middle catchment and Trans Nzoia upper catchment. Groundwater is the main drinking water resource in the basin supplying 78.8% of the population. Knowledge of long-term rainfall variability and the associated response of the basin's groundwater resources are essential for efficient and sustainable groundwater management. Despite the relatively short period for which water level records are available, these records contain valuable information that can be used beneficially in the development of strategies to assist in the responsible management of our limited groundwater resources. Rainfall and groundwater levels were analysed using the parametric test of linear regression and the non-parametric Mann–Kendall statistical test. Rainfal data for this study was obtained from the Kenya Meteorological Department (KMD) and the Groundwater levels from Kenya Water Resources Management Agency (WRMA). Pearson moment correlation was used to check the relationship between monthly rainfall and monthly groundwater levels. Correlations between groundwater levels and rainfall will help assess aquifer vulnerability to climate change in the basin. Our results indicate that rainfall variability induced by climate change has greatly impacted groundwater levels in the basin. Annual groundwater levels have been steadily falling at the rate between 0.03 ft/year (Kakamega Tande School) and 0.49 ft/year (Kitale Golf Club) in the basin. Annual rainfall over the basin has shown stations recording both decreasing and increasing trends. The falling groundwater level trends indicate a cause for concern and provide a scientific basis for the national and county governments in the basin to strategize on ground water development and management for sustainable water use.

Keywords: Nzoia River Basin, Rainfall variability, Groundwater levels, Trend analysis, Linear regression, Mann Kendall.

1.0 INTRODUCTION

Groundwater is a critical supply of freshwater for a wide range of household, agricultural, and industrial applications. Groundwater storage now faces the danger of depletion across the world in recent decades as a result of unsustainable consumption for rapid developments in agriculture, industry, and urbanization [1]. Groundwater scarcity persists in many nations, jeopardizing the long-term sustainability of the area’s economy and ecosystem services. Precipitation infiltration is one of the most important sources of groundwater recharge. Despite several studies on groundwater recharge, our understanding of the immediate reaction of the local groundwater table to precipitation remains limited. Furthermore, in the context of climate change and high-intensity human activities, it is vital to investigate the spatiotemporal change of the precipitation–groundwater table relationship [2,3,4]. Therefore, the effect of rainfall variability on groundwater levels should be investigated, which will be helpful for groundwater management and its sustainable use in Nzoia River Basin.

Climate change may have a significant impact on ground water levels in the Nzoia River Basin due to rainfall variability. Goyal et al. [5] looked at the variability of ground water levels in a district in Haryana, India, and found a decline in the groundwater levels. Thakur and Thomas [6] found a decrease in ground water level in a Madhya Pradesh district (India). Panda et al. [7] analyzed data from 555 monitoring wells to show a significant drop in ground water levels in Gujarat (India). Patle et al. [8] found a 0.267 m yearly reduction in ground water level in Haryana's Karnal region (India). Nyakundi, et al. [9] studied groundwater level variability in Ruiru, Kiambu county, Kenya, and discovered that rainfall variability had an impact on groundwater levels, with groundwater levels being low during the dry season and high during the rainy season.

Because of its ability to act as a buffer to huge fluctuations in climatic extremes, groundwater is critical for sustainable water management in the face of climate change and variability. Despite the critical need to examine the effects of climate variability and anthropogenic activities on groundwater systems [10], due to a lack of sufficient data sets, relatively little research has been done internationally [11,12]. Because of the interaction of surface and subsurface hydrology, which is governed by the physical properties of the land surface and the permeability of the rock and soil above the aquifer, translating climate into groundwater reactions is a complicated process.

Groundwater systems have a temporal lag in responding to climatic inputs, making it challenging to effectively forecast the effects of climate change and variability [13]. Studies using general circulation models (GCMs) are likewise inaccurate since they do not account for groundwater [14]. Groundwater level time series are the most important source of data on the impact of hydrological and human pressures on groundwater systems [15]. Furthermore, a well-designed monitoring network can provide policymakers with information on how to manage groundwater resources sustainably. Many places of the world have been unable to conduct groundwater evaluations because maintaining an adequate network of monitoring wells is both labor-intensive and costly [16]. There is very little information available on the international level about trends in water-table levels and their possible links to extremes of important climatic variables like rainfall and temperature.

Groundwater levels must be measured and analyzed in order to sustain groundwater supply. Groundwater monitoring systems, as well as strong institutional support, are critical for acquiring, compiling, and analyzing the data required to guarantee that groundwater development occurs in tandem with effective resource evaluation and management [17]. Because groundwater responds much more slowly to changes in meteorological conditions than surface water, it has the greatest potential for coping with and minimizing the implications of climate change on domestic water supply in the Nzoia River Basin. Groundwater, as a result, acts as a natural buffer against the effects of climate change and fluctuation, such as drought [18]. According to Bates et al., [19], the biggest unknown is how climate change will influence groundwater and what resources are now available to support adaptation plans in both developed and developing countries.

Because monitoring networks are often restricted and it is difficult to regionalize point-based measurements, many African nations with significant groundwater depletion problems have minimal knowledge on spatial and temporal variability in groundwater storage [20,17]. Despite the importance and potential of groundwater in the Nzoia River Basin, there have been few direct measurements of groundwater fluctuations over time to guide informed decision-making and planning for the resource's long-term exploitation, until recently when WRMA agreed to commence the process in response to mounting pressure from academia. This study assessed the effect of rainfall variability on groundwater levels to understand the response of groundwater systems to climatic stresses in Nzoia River Basin. Rainfall and groundwater levels were analysed using the parametric test of Iinear regression and the non-parametric Mann–Kendall statistical test. Pearson moment correlation was used to check the relationship between monthly rainfall and monthly groundwater levels. Water demand in Nzoia River Basin is increasing rapidly due to population growth and the associated socioeconomic development. Climate change working through rainfall variability is set to have a wide range of consequences for shallow groundwater resources in the basin. The results of this study provide valuable insights for the national and county governments to make improvements in the management and use of groundwater resources to minimize future risks.

2.0 MATERIALS AND METHODS

2.1 Study area

The Nzoia River Basin is located in the Republic of Kenya, along the Ugandan border, and extends between longitudes 340 E to 350 45' E and latitudes 10 30' N to 00 05' S. (Figure.1). The Nzoia River, which originates in the Cherengani hills and Mount Elgon, is one of Western Kenya's major rivers, draining its waters into Lake Victoria. It has a total length of 334 km and a drainage area of 12,959 km2 [21]. The topography of the Nzoia River basin is diversified, with hilly (Cherangan hills) and mountainous (Mt. Elgon) landscapes at elevations of 4,300 meters above sea level, where the fastest flowing streams of Kuywa, Sioso Ewaso, Rongai, and Koitobos may be found. We arrive to the lower reaches of Lake Victoria at a height of around 1,000 meters, flowing in a north-easterly to south-westerly direction from its upper catchments.

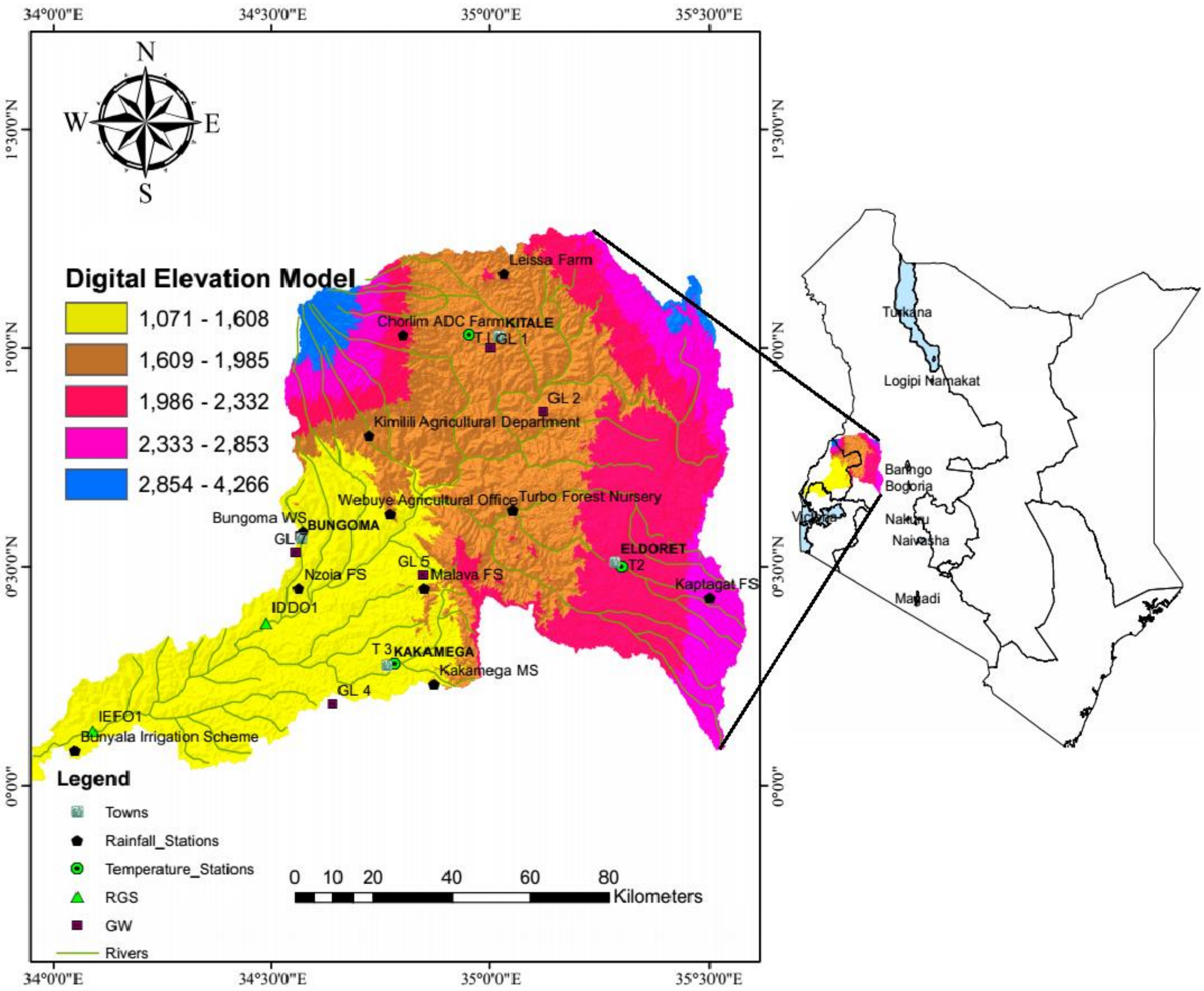


Figure 1: Map of Nzoia River Basin, Kenya

Flooding occurs in this area on a regular basis. The basin has a tropical humid climate. The daytime temperature ranges from 16 degrees Celsius in the highlands to 28 degrees Celsius in the lowlands surrounding Lake Victoria. The annual rainfall ranges from 600 to 2700 mm. Light clays with good drainage and a high moisture retention are the most common soil types. Agriculture is the most common land use [22].

2.2. Data sources

Monthly rainfall data were collected for seven stations; Leissa Farm Kitale, Chorlim ADC Farm, Kaptagat Forest Station, Kakamega Meteorological Station, Bungoma Water Supply, Malava Forest Station and Bunyala Irrigation Scheme with data covering 31 years period from 1970 to 2001 from the Kenya Meteorological Department (KMD), Nairobi, Kenya as shown in Table.1. The rainfall data are expressed in millimetre (mm). Rainfall stations selected were those that are closely located to the groundwater level observation wells. Stations were also examined for data quality, duration and period covered, and whether or not they had simultaneous recordings. Monthly rainfall for each of the stations was calculated by averaging daily data. The annual mean rainfall was calculated by averaging the monthly rainfall totals for each year. Roman et al. [23] provide additional information on measurement uncertainty. Before the data was used, several mandatory data quality control checks were done. All variables were compared to empirical upper and lower limits, as well as systematic errors from other sources (e.g., archiving, transcription and digitalization).

Table: 1. Rainfall Stations with 31 years data covering the period 1970 to 2001 selected for study in Nzoia River Basin, Kenya

Station Wmo Code	**Station name**	**Latitude (^{0}N)**	**Longitude (^{0}E)**	**Altitude (m.a.s.l)**	**Mean Annual Rainfall (mm/year)**
	UPPER CATCHMENT				
8835039	Leissa Farm Kitale	1.17	35.03	1968	995
8834013	Chorlim ADC Farm	1.03	34.80	1951	986
8935010	Kaptagat Forest Station	0.43	35.50	2624	1212
	MIDDLE CATCHMENT				
8934028	Kakamega Meteorological Station	0.23	34.87	1804	1982
8934134	Bungoma Water Supply	0.58	34.57	1509	1515
8934130	Malava Forest Station	0.45	34.85	1636	1834
	LOWER CATCHMENT				
8934139	Bunyala Irrigation Scheme	0.08	34.05	1232	1099

This can contain things like dates that don't exist. El Kenawy et al. [24], Bilbao et al.[25], Miguel et al. [26], and Roman et al. [23] provide more information on these tests. Non-homogeneity and/or discrepancies in meteorological data recorders may result from instrumentation and/or changes in surrounding land cover [27].

Table 2: Groundwater levels observation wells selected for study in Nzoia River Basin, Kenya

Station name	**Latitude (^{0}N)**	**Longitude (^{0}E)**	**Altitude (m.a.s.l)**
UPPER CATCHMENT			
Kitale Golf Club	1.00141	35.00135	1800
Mois Bridge Quarry	0.85442	35.12129	1850
Kapsabet Boys High School	0.20214	35.12605	1980
MIDDLE CATCHMENT			
Kakamega Mwikalikha School	0.18798	34.64068	1476
Kakamega Tande School	0.48157	34.84678	1574
Bungoma Water Supply	0.57032	34.56210	1420
LOWER CATCHMENT			
Busia Town Prisons	0.44551	34.14391	1224

Monthly groundwater level data were collected for seven monitoring wells; Kitale Golf Club, Mois Bridge Quarry, Kapsabet Boys High School, Kakamega Mwikalikha School, Kakamega Tande School, Bungoma Water Supply and Busia Town Prisons with data covering between 5 and 6 years period from 2011 to 2017 as shown in Table.2. The groundwater level data are expressed in feet (ft). More recently, Water resources management agency (WRMA), Lake Victoria North catchment area, regional office in Kakamega established a network of groundwater monitoring wells in Nzoia River Basin as part of the National network of groundwater monitoring sites in the country.

Table 3: Groundwater levels observation wells and the corresponding Rainfall stations selected for study in Nzoia River Basin, Kenya

Groundwater level observation wells	**Corresponding Rainfall stations**
UPPER CATCHMENT	
Kitale Golf Club	Leissa Farm Kitale
Mois Bridge Quarry	Chorlim ADC Farm
Kapsabet Boys School	Kaptagat Forest Station
MIDDLE CATCHMENT	
Kakamega Mwikalikha School	Kakamega Meteorological Station
Kakamega Tande School	Malava Forest Station
Bungoma Water Supply	Bungoma Water Supply
LOWER CATCHMENT	
Busia Town Prisons	Bunyala Irrigation Scheme

Monitoring wells with short record durations (less than 5 years) and many gaps in their data were removed from the study of the relationship between rainfall and groundwater levels. Seven monitoring wells were selected in hydrogeological environments that commonly supply groundwater to inhabitants of Nzoia River Basin. These monitoring wells are appropriate to examine groundwater levels because: (1) monitored groundwater levels are impacted by neither abstraction nor constructed surfaces; (2) records of groundwater levels are some of the longest available in the basin; and (3) existing rainfall stations are available close to the sites. At each monitoring well, water table levels have been measured manually since 2011 (Figures. 2 – 8). Recordings have been carried out by technicians of Water resources management agency using a dipper. The timestep of the measurements in these records varies from 8 to 22 days on average. Strong seasonality is observed in groundwater-level fluctuations in monitoring wells all over the basin. Table.3 shows the Groundwater levels observation wells and the corresponding Rainfall stations selected for the study on effect of rainfall variability on groundwater levels in Nzoia River Basin, Kenya.

2.3. Methodology

Trend analysis of a time series consists of the magnitude of trend and its statistical significance. For trend detection, different researchers have employed various techniques. Change detection approaches for hydrologic data are described by [28]. In general, the magnitude of a time series' trend is determined using either Regression analysis (parametric test) or Mann–Kendall test and Sen's slope method (non-parametric test).

2.3.1 Linear regression analysis

A parametric model, linear regression analysis is one of the most used methods for detecting a pattern in data series. This model establishes the relationship between two variables by fitting a linear equation to the observed data (dependent and independent). The data is then evaluated to determine whether or not there is a relationship between the interest variables. With the scatter plot, this is achievable. The linear regression model will not be beneficial if there is no association between the two variables. A numerical measure of the correlation between the variables is the correlation coefficient, which runs from -1 to +1. A coefficient value ± 1 for correlation indicates a good match. A value close to zero implies that the two variables have a random, non-linear relation.

The linear regression model is generally described by the following equation:
$Y = m^* X + C$
Where, Y and X are the dependent variable (rainfall, groundwater levels) and the independent variable (time in months or years), respectively, m is the line slope (mm/year) and C is the intercept constant coefficient. The coefficients (m and C) of the model are determined using the Least-Squares method, which is the most commonly used method. Slope sign defines trend variable direction; increases if the sign is positive and decreases if the sign is negative.

2.3.2 Mann- Kendall Test and Sen's Slope Method.

The Mann–Kendall (MK) test was used to examine the trends in rainfall and groundwater levels [29,30]. It's a non-parametric test that doesn't require data to be normally distributed [31]. The MK test is based on the null hypothesis (H0), which states that there is no trend, that the data are independent, and that they are randomly ordered, and that this is verified against the alternative hypothesis (Ha), which states that there is a trend [32]. Sen's slope (SS) estimator, Sen, P.K, [33] predicts the genuine slope (change per unit time).

2.3.3 Pearson’s correlation coefficient

The Pearson correlation coefficient r (also known as the Pearson product-moment correlation coefficient) is a test statistic that determines the statistical relation, or association, between two continuous variables. The test statistics were established by Karl Pearson (1948) based on a related idea proposed by Sir Francis Galton in the late 1800s. Because it is based on the method of covariance, it is known as the best method for quantifying the relationship between variables of interest. It provides information on the magnitude and direction of the relationship. Pearson's Correlation Coefficient assumes that: cases should be independent to each other; two variables should be linearly related to each other; the residuals scatterplot should be roughly rectangular-shaped. The range of coefficient values is +1 to -1, with +1 indicating a perfect positive association, -1 indicating a perfect negative relationship, and 0 indicating no relationship. It is independent of the unit of measurement. For example, if one variable’s unit of measurement is in inches and the second variable is in quintals, even then, Pearson’s correlation coefficient value does not change. Correlation of the coefficient between two variables is symmetric. This means between X and Y or Y and X, the coefficient value of will remain the same [34].

3.0 RESULTS AND DISCUSSION

3.1. Effect of Rainfall variability on Groundwater levels in Nzoia River Basin

3.1.1 Trends in monthly groundwater levels and rainfall

In Nzoia River Basin, low groundwater levels appear persistent during the dry seasons which occur in the months of December, January and February; and also in the June, July, August and September. Shallow aquifers characterize the study area, with groundwater levels responding to rainfall in relatively short periods of time. Although hydrogeologic site uniqueness and spatiotemporal variation in precipitation lead to variance in the amount and timing of reaction, all groundwater levels show rises in response to precipitation. These wells' water levels are measured throughout a same time period, allowing the measurements to represent aquifer storage at a single point in time. The monitoring wells chosen represent the physiographic zones of the Nzoia River Basin effectively. With limited pumping and artificial recharge impacts, each well represents the aquifer's local water table. Water level readings are often similar in wells that are completed in a hydraulically linked aquifer. This network's water management data may be used to quantify the effects of climatic and human-induced pressures on aquifer recharge and discharge, as well as determine the aquifers' hydraulic characteristics. Although the existing monitoring network in the Nzoia River Basin provides a strong framework for collecting ground water level data, the spatial distribution of wells inside specific aquifers is often uneven, with large sections lacking monitoring wells, necessitating a network redesign.

In Nzoia River Basin, a direct correllation between rainfall and groundwater levels is observed, and the spatial and seasonal differences are also well pronounced. This pattern is sometimes distorted by the anthropogenic factors such as groundwater extraction for domestic use. In addition, the rising extreme temperatures influence high domestic water supply requirements, and this is likely to affect groundwater levels in the basin.

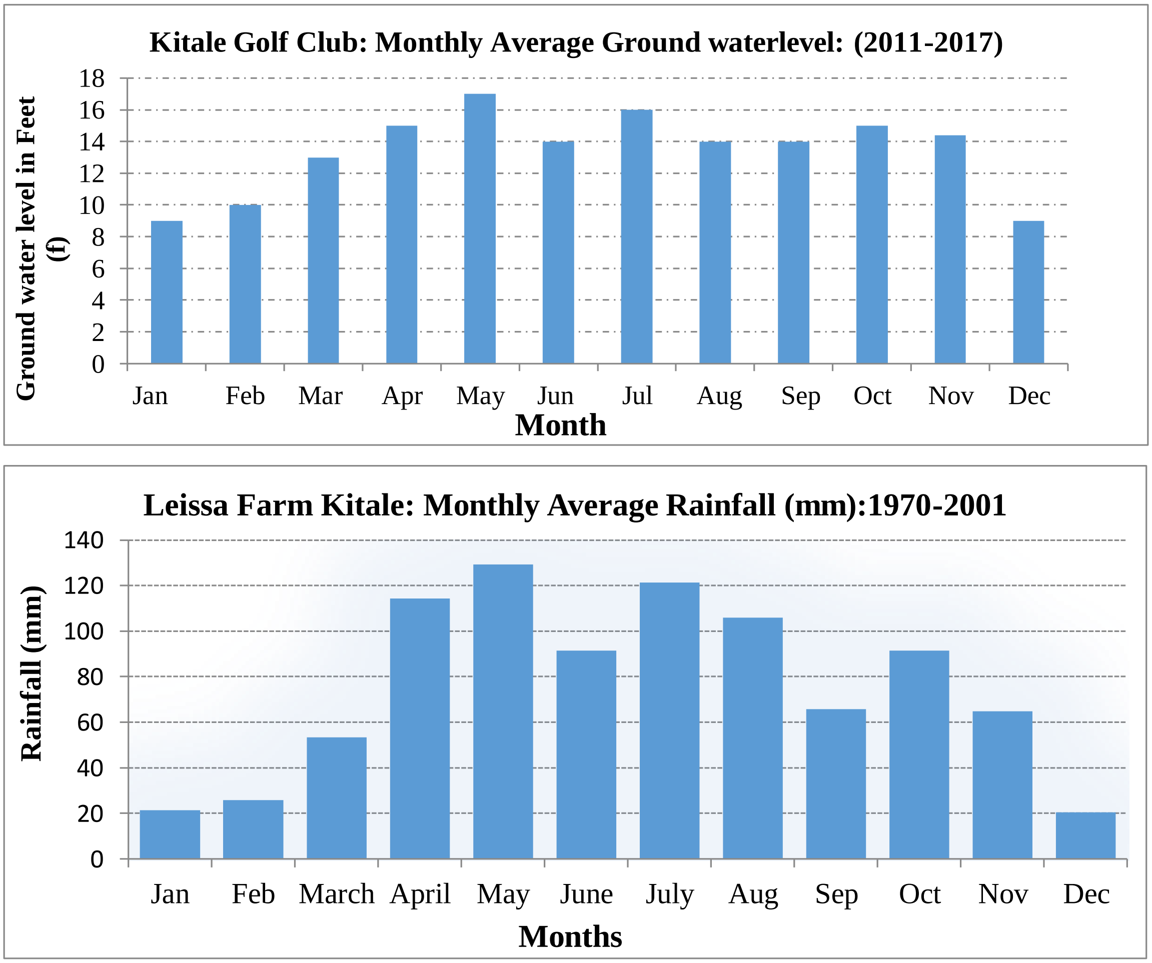


Figure 2: Kitale Golf Club Monthly Average Groundwater levels and Leissa Farm Kitale Monthly Rainfall Bar Graphs

Kitale Golf Club as shown in Figure. 2 recorded a monthly mean groundwater level of 14.16 ft; which corresponds to a monthly mean rainfall of 82.27 mm recorded at Leissa Farm. A major peak was observed in the groundwater levels at 17.2 ft in May which corresponds to the highest rainfall recorded in May (139.92 mm) during the long rains period of March - May (MAM). A minor peak in groundwater levels was seen at 16 ft in July as manifested by the minor rainfall peak occurring in same period.The lowest groundwater level at Kitale Golf Club was recorded at 9 ft in December corresponding to the dry season which occur in the months of December, January and February (DJF).

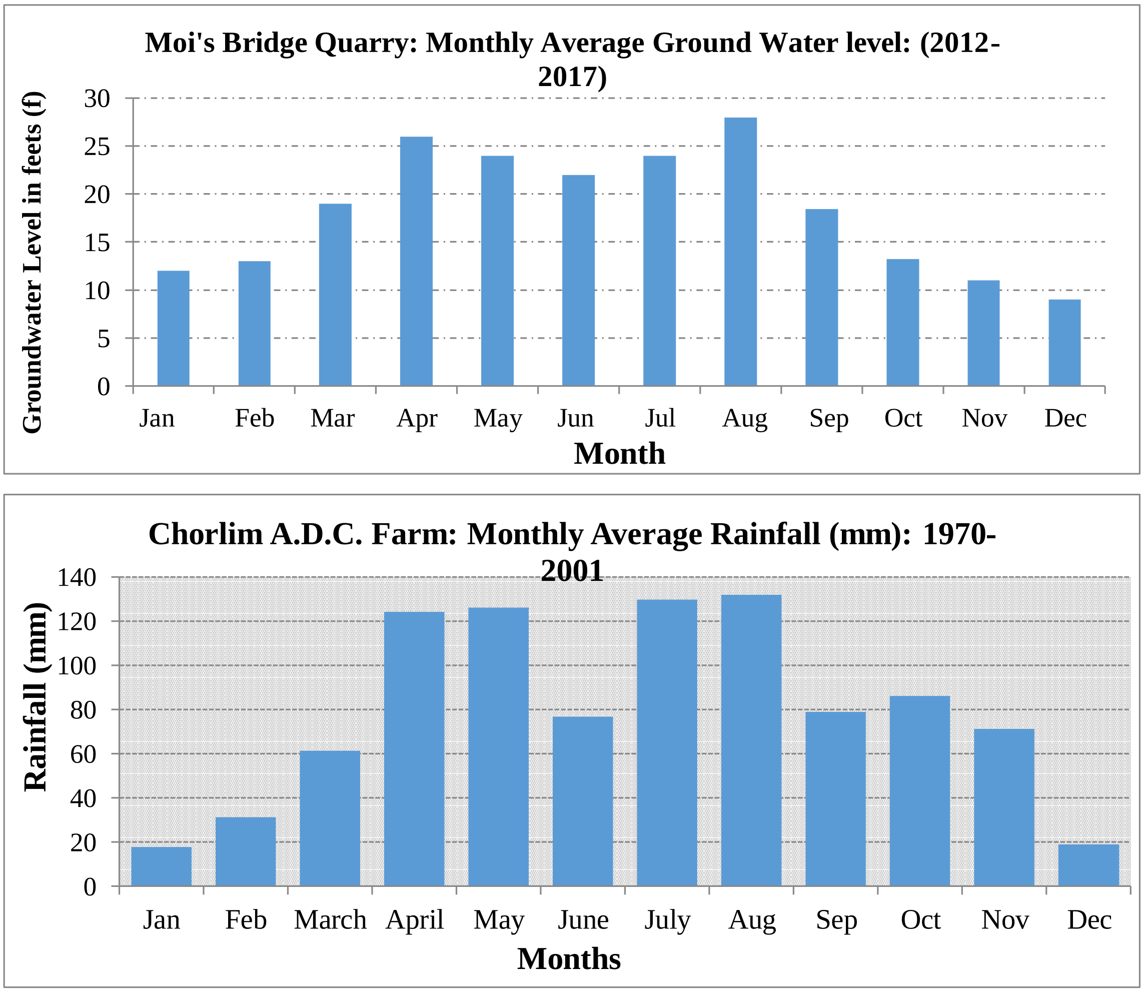


Figure 3: Mois Bridge Quary Monthly Average Groundwater levels and Chorlim ADC Farm Rainfall Bar Graphs

In Figure.3 at Mois Bridge Quary, the monthly mean groundwater level recorded was 15.9 ft; which corresponds to a monthly mean rainfall of 86.37 mm recorded at Chorlim ADC Farm. A minor peak was observed in the groundwater levels at 25.3 ft in April which corresponds to the high rainfall recorded in April - May during the long rains period of March - May (MAM). A major peak in groundwater levels was seen at 26 ft in August as manifested by the third rainfall peak occuring in the months of June to August due to the modification of the regular weather pattern by the local relief and influences of Lake Victoria. The lowest groundwater level at Mois Bridge Quarry was recorded at 9 ft in December corresponding to the dry season which occur in the months of December, January and February (DJF).

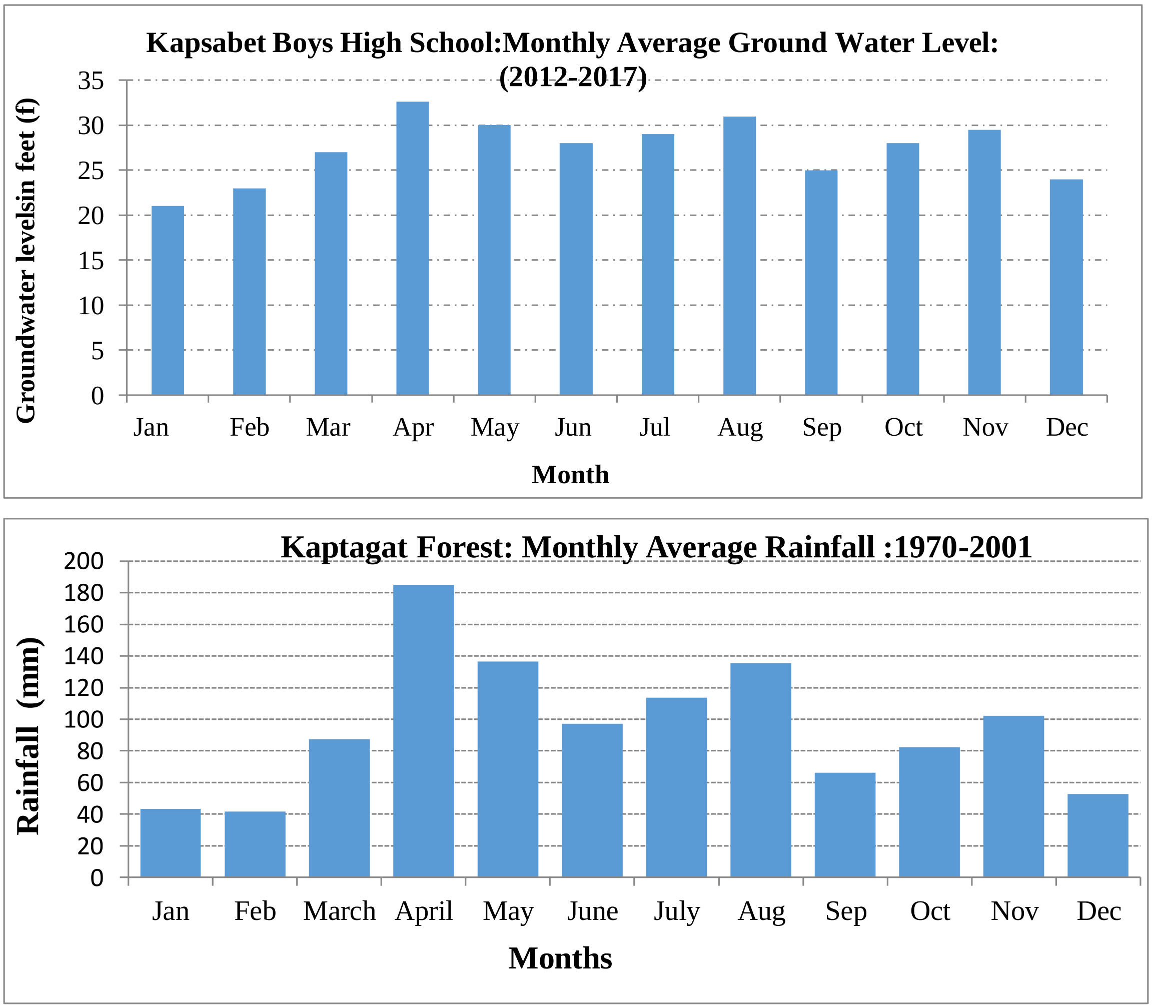
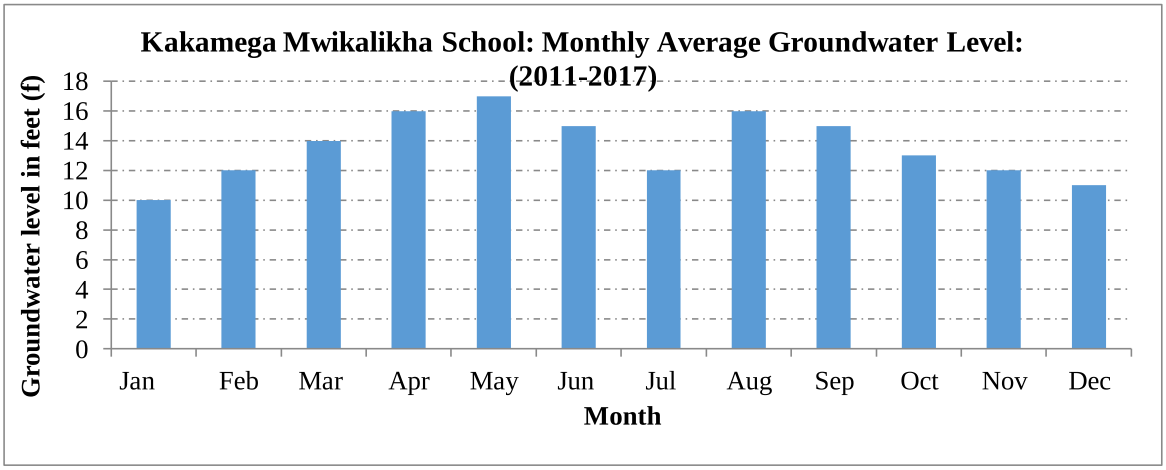


Figure 4: Kapsabet Boys High School Monthly Average Groundwater levels and Kaptagat Forest Rainfall Bar Graphs

Figure.4 shows the monthly mean groundwater level recorded at Kapsabet Boys High School as 28.4 ft; which corresponds to a monthly mean rainfall of 103.04 mm recorded at Kaptagat Forest station. A major peak was observed in the groundwater levels at 32 ft in April which corresponds to the highest rainfall recorded in April (195.61 mm) during the long rains period of March - May (MAM). Minor peaks in groundwater levels were seen in May (30 ft), as a result of the long rains period; August (31 ft) as manifested by the third rainfall peak occuring in the months of June to August due to the modification of the regular weather pattern by the local relief and influences of Lake Victoria; and November (29 ft) due to the short rains that come in October to December (OND). The lowest groundwater level at Kapsabet Boys High School was recorded at 21 ft in January corresponding to the dry season which occur in the months of December, January and February (DJF).



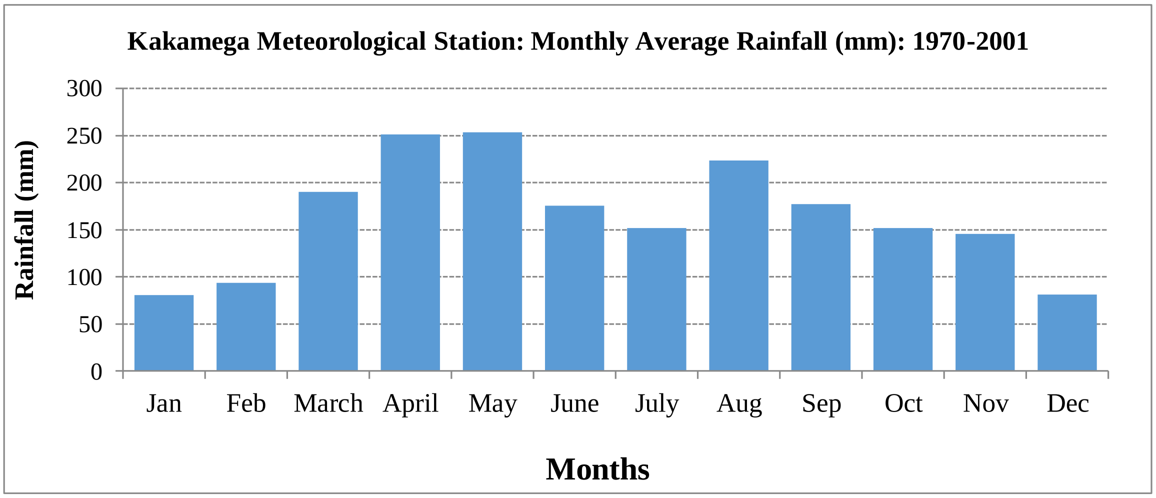
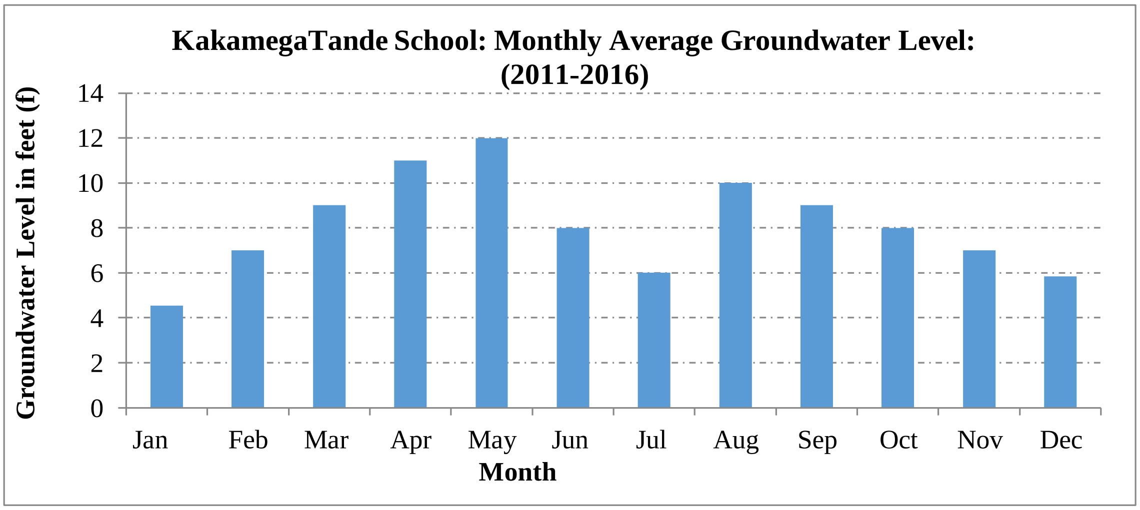


Figure 5: **Kakamega Mwikalikha School Monthly Average Groundwater levels and Kakamega meteorological station Rainfall Bar Graphs**

Similarly, Figure.5 shows the monthly mean groundwater level recorded at Kakamega Mwikalikha School as 7.9 ft; which corresponds to a monthly mean rainfall of 164.48 mm recorded at Kakamega meteorological station. A major peak was observed in the groundwater levels at 17 ft in May which corresponds to the highest rainfall recorded of 251.47 mm in May and 248.00 in April during the long rains period of March - May (MAM). Minor peaks in groundwater levels were seen in April (16 ft), as a result of the long rains period; June (15 ft) and August (16 ft) as manifested by the third rainfall peak occuring in the months of June to August due to the modification of the regular weather pattern by the local relief and influences of Lake Victoria. The moderately high groundwater levels observed between October and December are as a result of the short rains that come in October to December (OND). The lowest groundwater level at Kakamega Mwikalikha School was recorded at 10 ft in January corresponding to the dry season which occurs in the months of December, January and February (DJF).



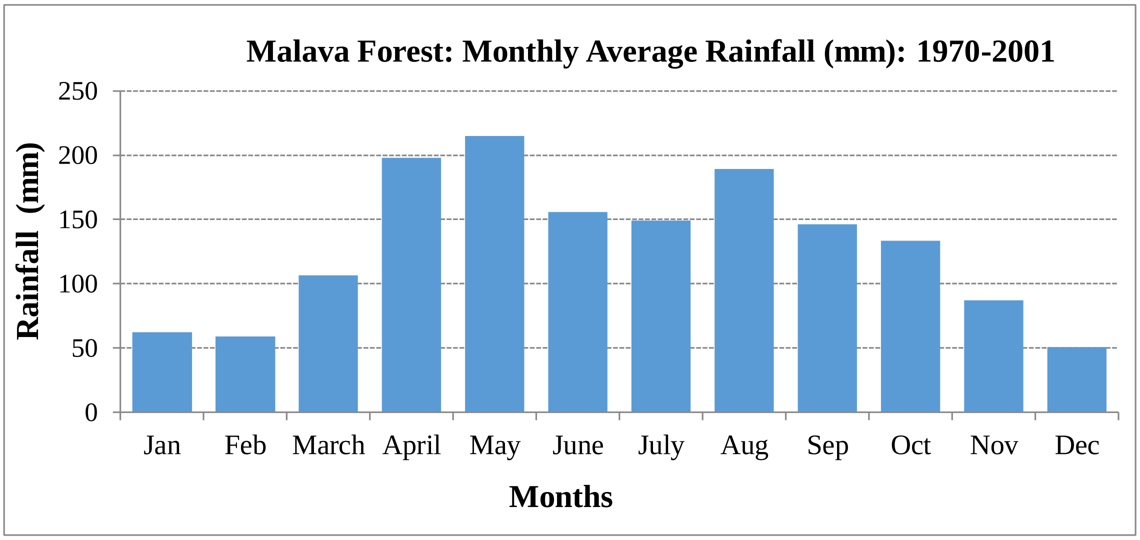
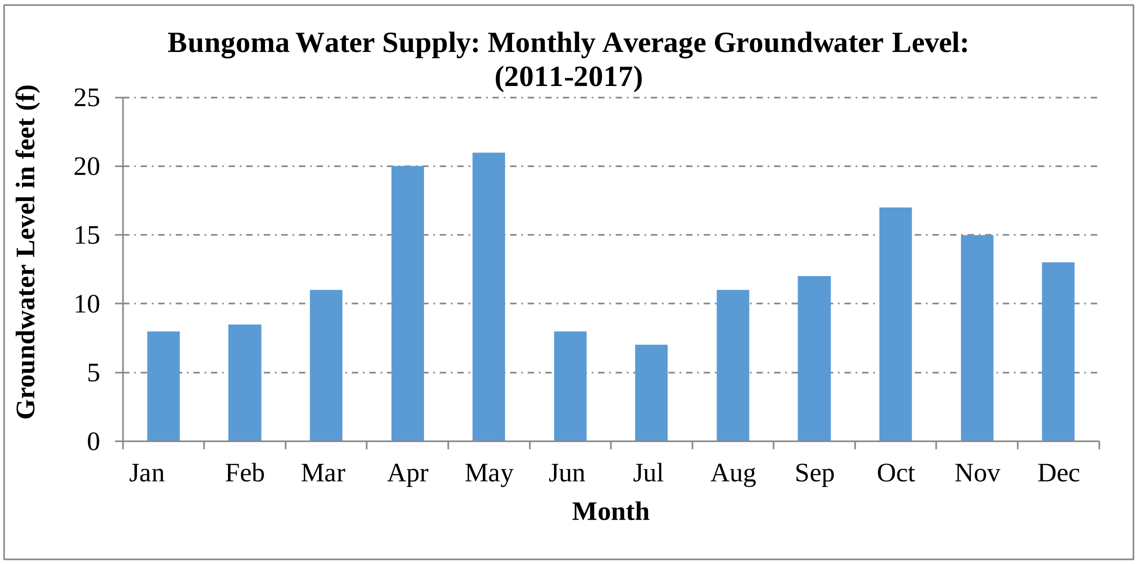


Figure 6: **Kakamega Tande School Monthly Average Groundwater levels and Malava Forest Rainfall Bar Graphs**

As shown in Figure. 6, the monthly mean groundwater level recorded at Kakamega Tande School was 4.5 ft; which corresponds to a monthly mean rainfall of 158.01 mm recorded at Malava Forest. A major peak was observed in the groundwater levels at 12 ft in May which corresponds to the highest rainfall recorded of 251.37 mm in May during the long rains period of March - May (MAM). Minor peaks in groundwater levels were seen in March (9 ft) and April (11 ft) as a result of the long rains period; June (8 ft) and August (10 ft) as manifested by the third rainfall peak occuring in the months of June to August due to the modification of the regular weather pattern by the local relief and influences of Lake Victoria. The moderately high groundwater levels observed between September and December are as a result of the short rains that come in October to December (OND). The lowest groundwater level at Kakamega Tande School was recorded at 4.5 ft in January corresponding to the dry season which occurs in the months of December, January and February (DJF).



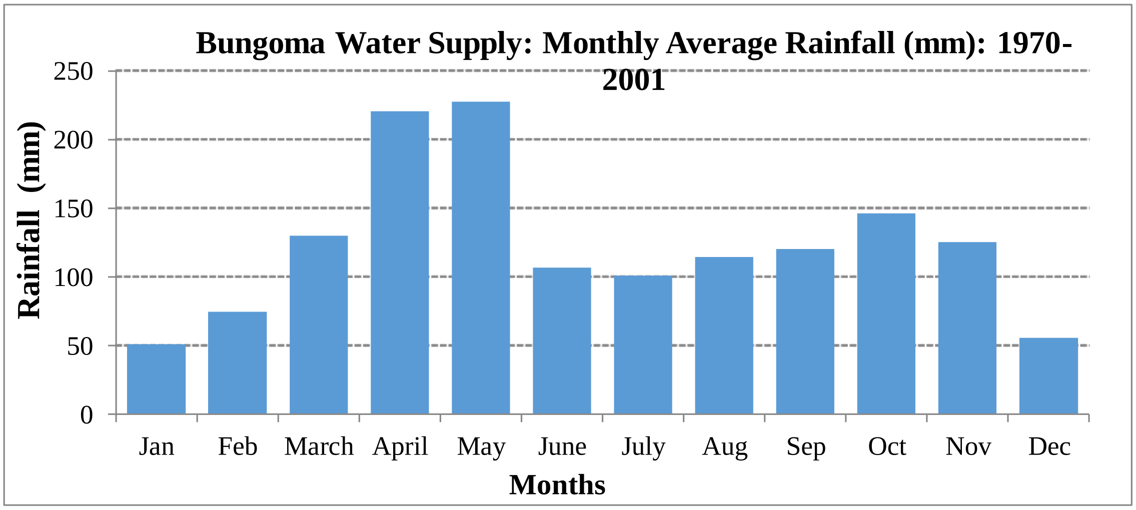


Figure 7: Bungoma Water Supply Monthly Average Groundwater levels and Bungoma Water Supply Rainfall Bar Graphs

Bungoma water supply as shown in Figure.7 recorded a monthly mean groundwater level of 10 ft; which corresponds to a monthly mean rainfall of 126.58 mm recorded at Bungoma water supply. A major peak was observed in the groundwater levels at 21 ft in May which corresponds to the highest rainfall recorded in May (237.81 mm) during the long rains period of March - May (MAM). A minor peak in groundwater levels was seen at 17 ft in October as a result of the short rains that come in October to December (OND). The lowest groundwater level at Bungoma water supply was recorded at 7 ft in July due to the dry seasons which occur in the months of December, January and February (DJF) and in some parts, June, July, August and September (JJAS).

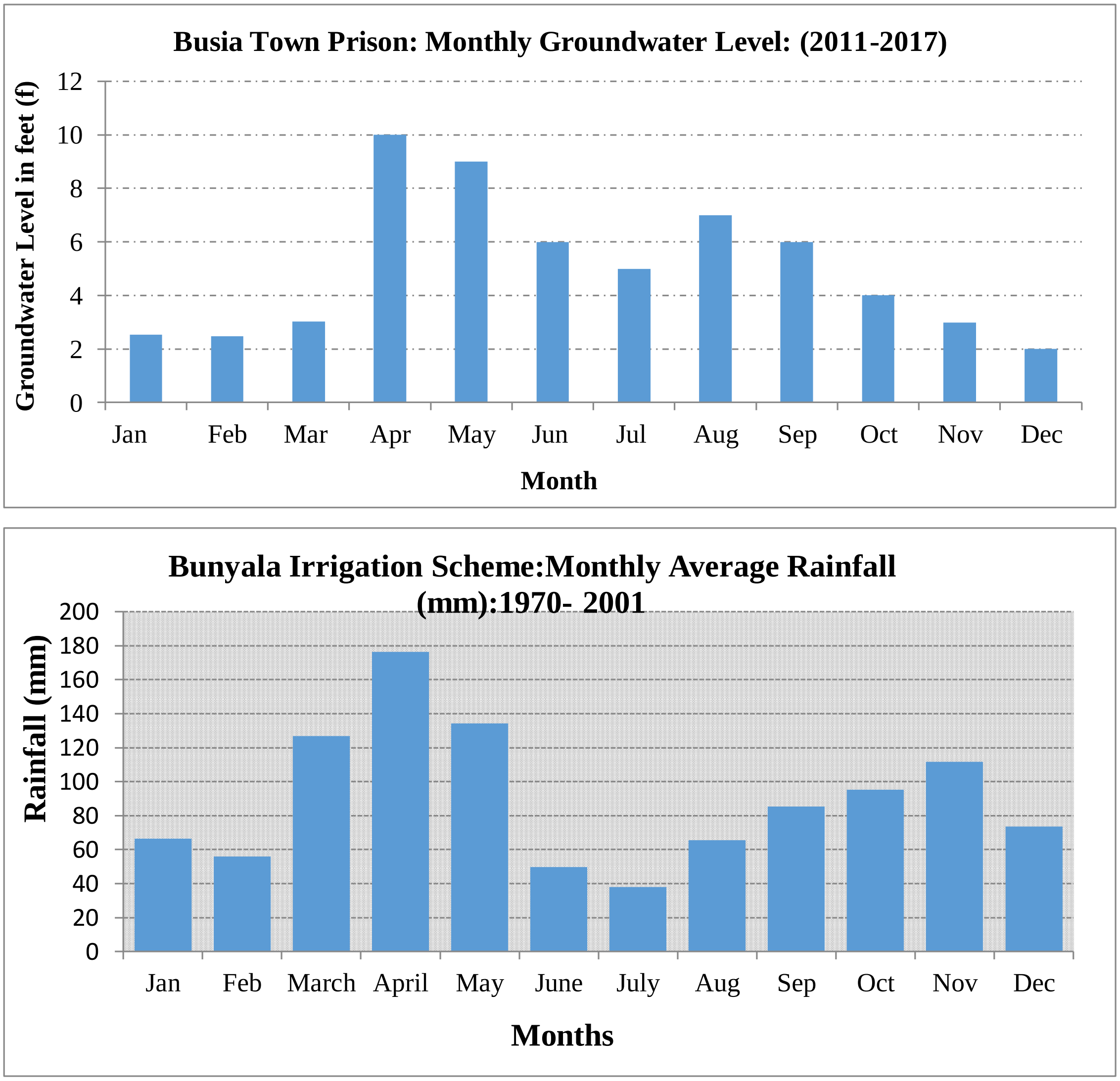


Figure 8: Busia Town Prison Monthly Average Groundwater levels and Bunyala Irrigation Scheme Rainfall Bar Graphs

Busia Town Prison as shown in Figure. 8 recorded a monthly mean groundwater level of 3 ft; which corresponds to a monthly mean rainfall of 92.16 mm recorded at Bunyala Irrigation Scheme. A major peak was observed in the groundwater levels at 10 ft in April which corresponds to the highest rainfall recorded in April (180.80 mm) during the long rains period of March - May (MAM). The moderately high groundwater levels observed between August, September and October are as a result of the modification of the regular weather pattern by the local relief and influences of Lake Victoria coupled with the short rains that come in October to December (OND). The lowest groundwater level at Busia Town Prison was recorded at 2 ft in December corresponding to the dry season which occurs in the months of December, January and February (DJF).

Groundwater level and precipitation correlations can be used to estimate aquifer vulnerability to climate change [35]. Deep groundwater production wells will exhibit considerable water level variations over time, with a varied lag in climate reaction times ranging from seconds to millions of years [36]. Aquifer groundwater levels and climate relationships have been studied by several Researchers. Because of the relatively long recharge and aquifer response period, long-term climate cycles have the greatest visible effects on groundwater levels. The El Nino Southern Oscillation (ENSO) has been demonstrated to generate the biggest changes in groundwater levels in the Nzoia River Basin. Local geology [37], land use and land cover [38], and other factors impacting infiltration and recharge rates all influence groundwater response to climate. Over the study period of 2011 to 2017, all wells in the study area showed a decrease in groundwater levels. The complex and regionally varied relationship between groundwater pumping/withdrawal, climate change, and groundwater levels is complicated. Groundwater depletion is associated with dry seasons in the climate record, while groundwater recovery is associated with wet seasons.

Groundwater pumping/withdrawal may decrease during a wet season, while aquifer recharge increases, alleviating stress on groundwater supplies. During a dry season, the opposite conditions and outcomes occur. Wells with varying tendencies in groundwater level reduction have been discovered in close proximity, however this is due to the fact that the depths of these wells may reach different aquifers. Based on their own physical features, extraction rates, and recharge rates, these layered aquifers have different head level trends. Changes in rainfall and temperature extremes, evapotranspiration, and anthropogenic groundwater extraction all have an impact on aquifer recharging and outflow/discharge [15]. Groundwater levels have been declining in the Nzoia River Basin, as they have in many other countries, posing a threat to drinking water supplies. Aquifers are over-exploited in groundwater-dependent dry and semi-arid regions, when natural replenishments are insufficient to balance groundwater withdrawals [39].

3.1.1.1 Relationship between monthly groundwater levels and monthly rainfall using Pearson’s product moment correlation coefficient in Nzoia River Basin

In quantifying the relationship between monthly groundwater levels and monthly rainfall, a correlation analysis among the groundwater levels at individual monitoring wells and rainfall in the associated meteorological stations as shown in Table.3 was conducted. The results show a strong positive relationship between groundwater levels and rainfall at 0.05 significance level for Kitale Golf Club monitoring well and Leissa Farm Kitale rainfall station; Mois Bridge Quarry monitoring well and Chorlim ADC Farm rainfall station; Kapsabet Boys School monitoring well and Kaptagat Forest rainfall station; Kakamega Mwikalikha School monitoring well and Kakamega Meteorological station; Kakamega Tande School monitoring well and Malava Forest rainfall station; Bungoma Water Supply monitoring well and Bungoma Water Supply rainfall station; and Busia Town Prisons monitoring well and Bunyala Irrigation Scheme rainfall station. This shows that as rainfall increases, groundwater levels at the seven monitoring wells increase and vice versa. Linear relationships between rainfall and groundwater levels at monitoring wells are strong as the coefficient of correlation range from 0.81 to 0.98. The monitored wells in the study area are shallow; however, when it comes to deeper wells, the linearity in the relationships between monthly rainfall and monthly groundwater levels is lower due, in part, to time lags between input (rainfall) and response (groundwater-level rise). For deeper wells time lags will occur in the transmission of water through unsaturated zones. The findings of this study are in line with a growing body of evidence from Sub-Saharan Africa that suggests that increased rainfall due to global warming may boost groundwater recharging. The representivity of the monitoring wells and the frequency of groundwater level readings limit the robustness of this study's findings.

3.1.2 Trends in annual groundwater levels and rainfall in Nzoia River Basin

Rainfall stations showed both increasing and decreasing annual rainfalls whereas all groundwater level monitoring wells showed declining levels in the basin.

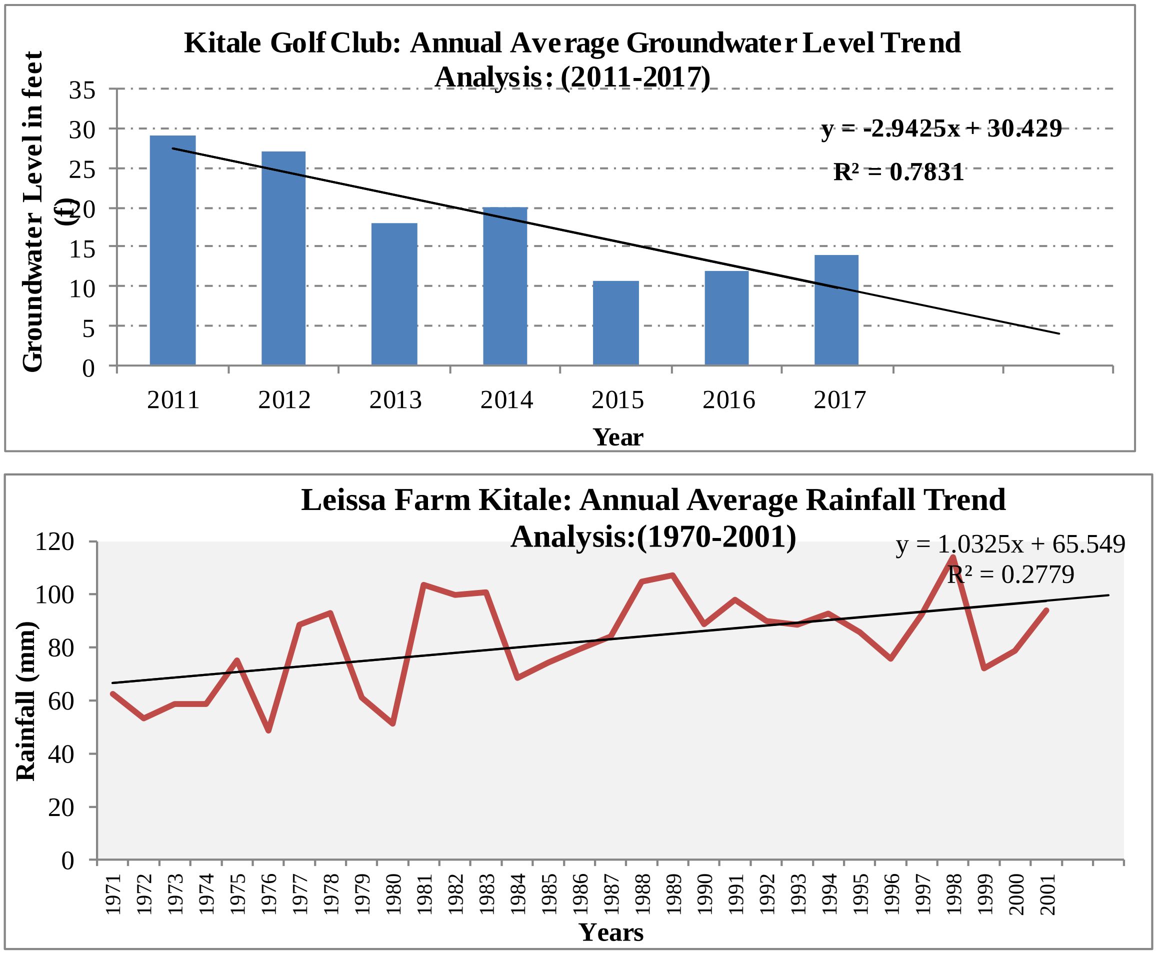


Figure 9: Kitale Golf Club Annual Average Groundwater levels and Leissa Farm Kitale Rainfall Bar Graphs

The results are consistent with the observations made in other parts of Kenya, Eastern Africa, Africa and many other regions of the world. Kitale Golf Club had average annual groundwater levels decreasing at 2.9425 ft/6years (0.49 ft/year) whereas average annual rainfall at the neighboring Leissa Farm Kitale station was increasing at 1.0325/31 years (0.03 mm/year). The decrease in annual groundwater levels and the increase in annual rainfalls both exhibit statistically significant trends. Kitale Golf Club borehole is in the centre of Kitale town and the rate at which water is being drawn exceeds the recharge rate by far.

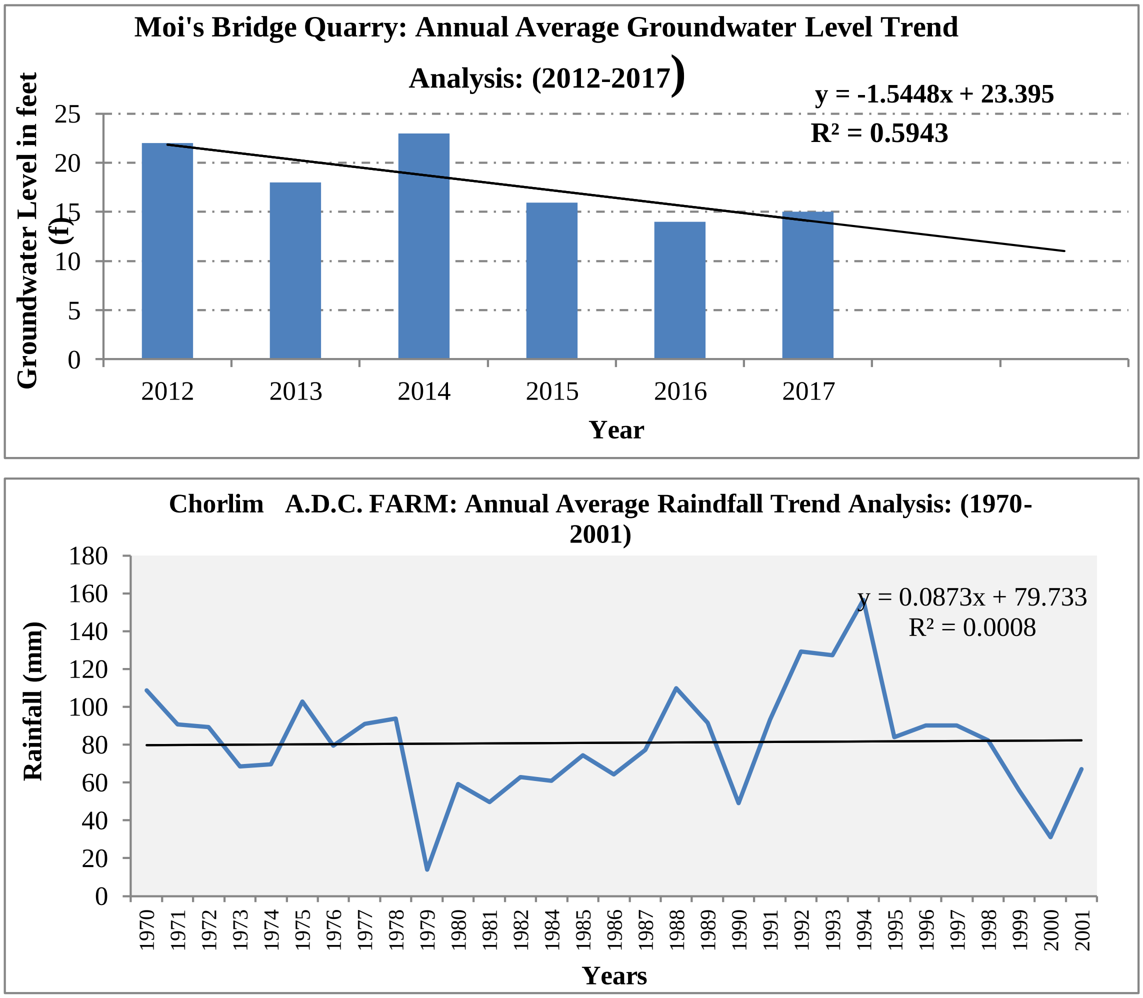
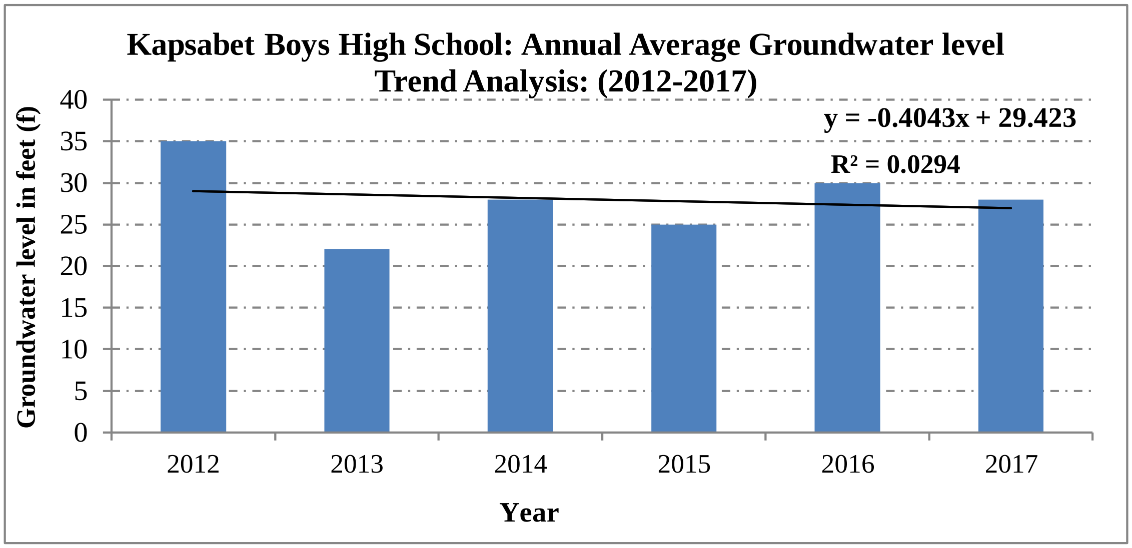


Figure 10: Mois Bridge Quary Annual Average Groundwater levels and Chorlim ADC Farm Rainfall Bar Graphs

Average annual groundwater levels at Mois Bridge Quarrry are decreasing at 1.5448 ft/5 years (0.31 ft/year) whereas average annual rainfall at the neighboring Chorlim ADC Farm station was increasing at 0.0873 mm/31 years (0.003 mm/year). The decrease in annual groundwater levels is statistically significant whereas the increase in annual rainfalls is statistically insignificant. Groundwater levels at Mois Bridge Quarrry are falling at a faster rate than recharge.



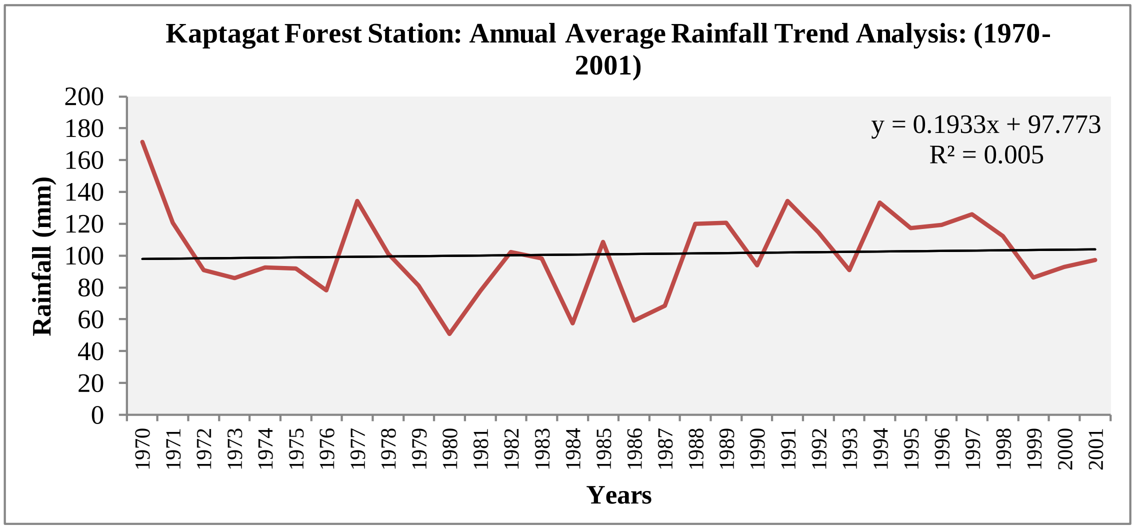


Figure 11: Kapsabet Boys High School Annual Average Groundwater levels and Kaptagat Forest Rainfall Bar Graphs

Average annual groundwater levels at Kapsabet Boys High School are decreasing at 0.4043 ft/5 years (0.08 ft/year) whereas average annual rainfall at the neighboring Kaptagat Forest station was increasing at 0.1933 mm/31 years (0.006 mm/year). The decrease in annual groundwater levels is statistically insignificant whereas the increase in annual rainfalls is statistically significant. Groundwater levels at Kapsabet Boys High School are falling slowly.

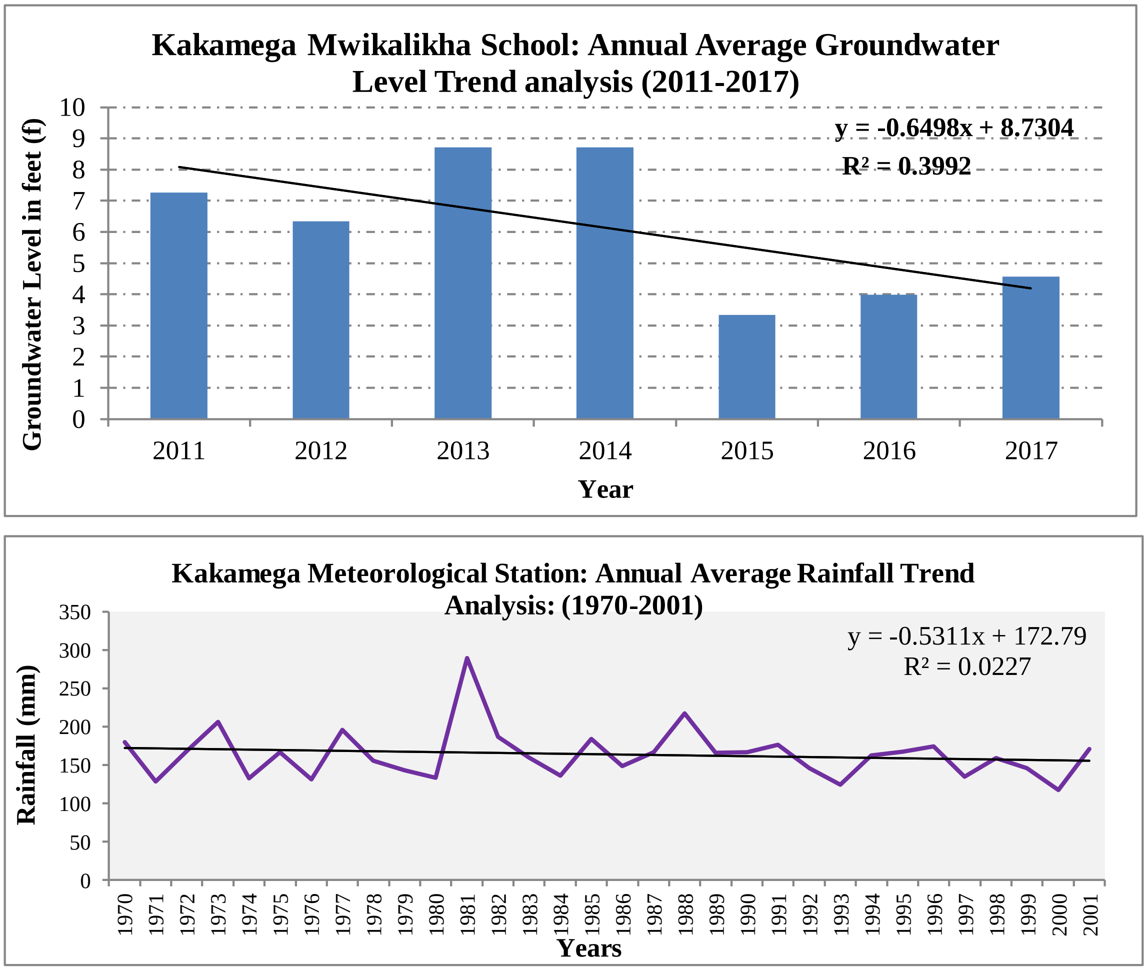
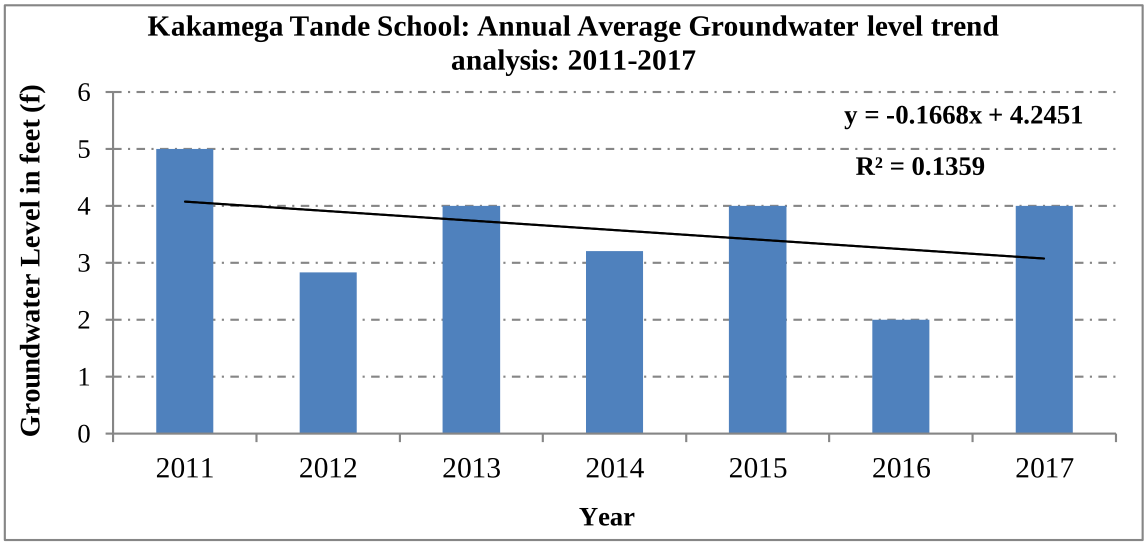


Figure 12: Kakamega Mwikalikha School Annual Average Groundwater levels and Kakamega meteorological station Rainfall Bar Graphs

Average annual groundwater levels at Kakamega Mwikalikha School are decreasing at 0.6498 ft/ 6 years (0.11 ft/year) whereas average annual rainfall at the neighboring Kakamega meteorological station was also decreasing at 0.5311 mm/31 years (0.017 mm/ year) The decrease in annual groundwater levels is statistically insignificant whereas the decrease in annual rainfalls is statistically significant. Groundwater levels at Kakamega Mwikalikha School are falling faster.



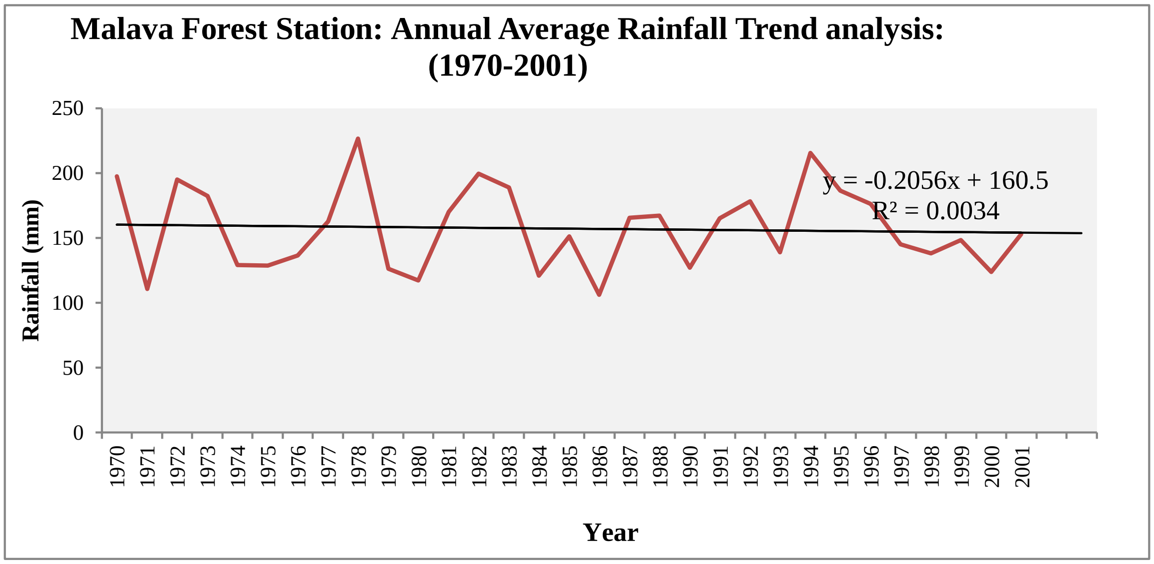
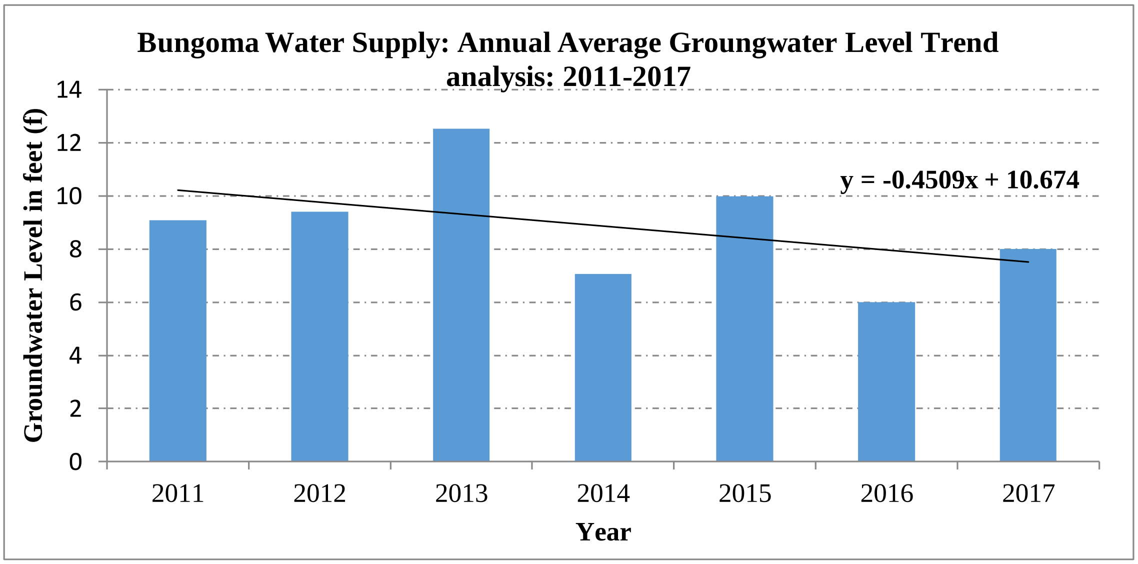


Figure 13: Kakamega Tande School Annual Average Groundwater levels and Malava Forest Rainfall Bar Graphs

Average annual groundwater levels at Kakamega Tande School are decreasing at 0.1668 ft/ 6 years (0.03 ft/year) whereas average annual rainfall at the neighboring Malava Forest station was decreasing at 0.2056 mm/31 years (0.021 mm/ year). The decrease in annual groundwater levels is statistically insignificant whereas the decrease in annual rainfalls is statistically insignificant. Groundwater levels at Kakamega Tande School are falling faster.



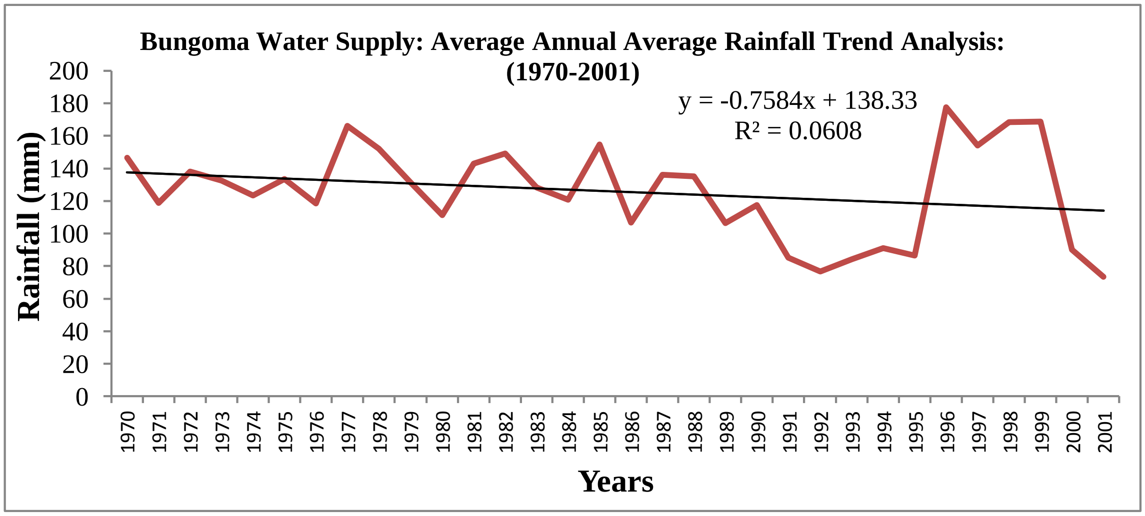
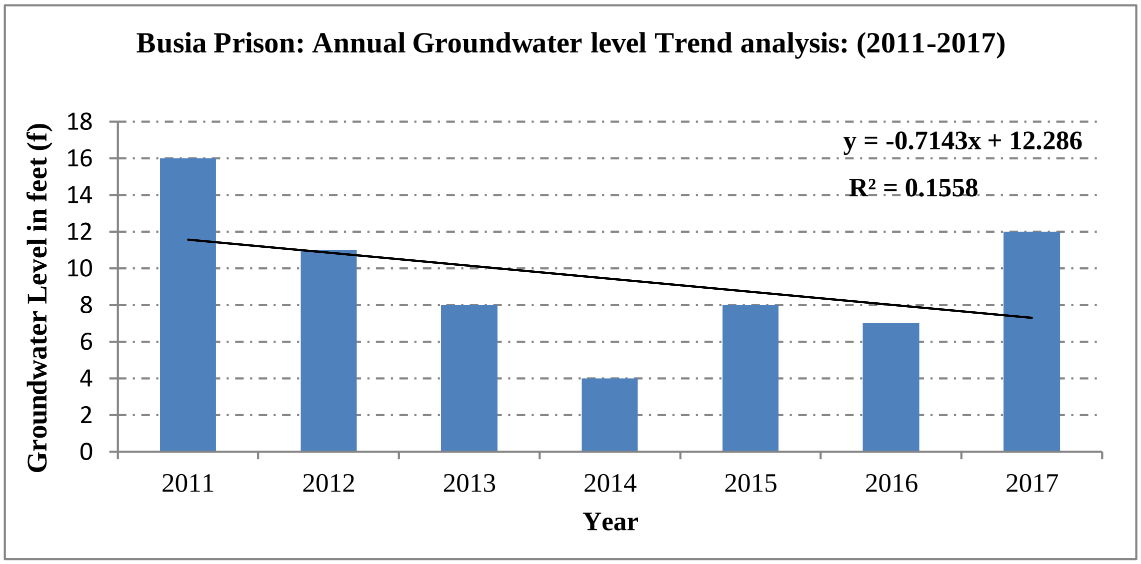


Figure 14: Bungoma Water Supply Annual Average Groundwater levels and Bungoma Water Supply Rainfall Bar Graphs

Average annual groundwater levels at Bungoma water supply are decreasing at 0.4509 ft/ 6 years (0.08 ft/year) whereas average annual rainfall at Bungoma water supply was decreasing at 0.7584 mm/31 years (0.025 mm/ year). The decrease in annual groundwater levels is statistically insignificant whereas the decrease in annual rainfalls is statistically insignificant. Groundwater levels at Bungoma water supply are falling faster.



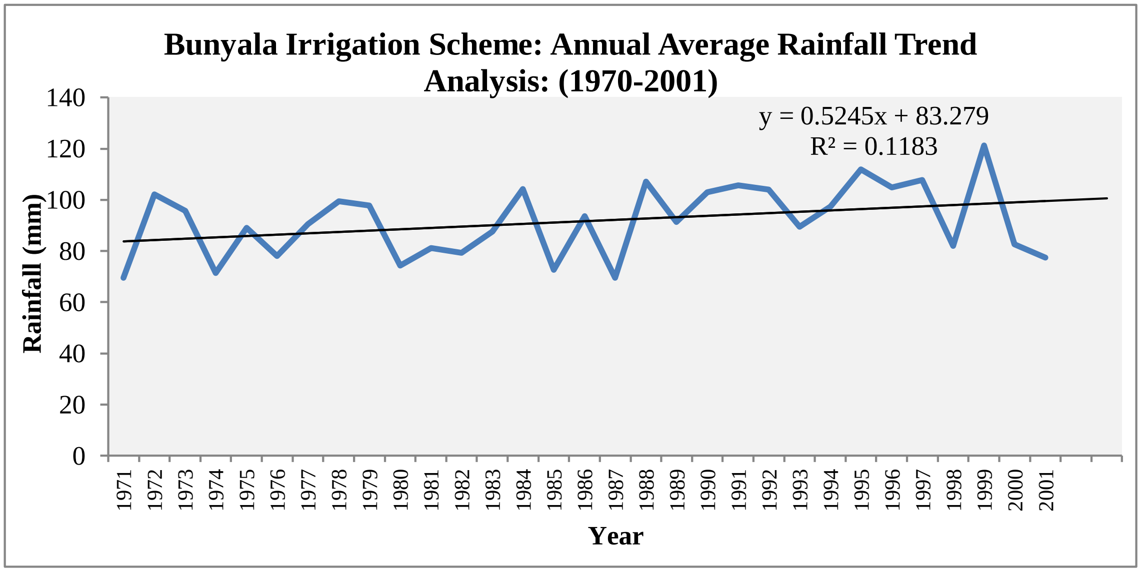


Figure 15: Busia Town Prison Annual Average Groundwater levels and Bunyala Irrigation Scheme Rainfall Bar Graphs

Average annual groundwater levels at Busia Town Prison are decreasing at 0.7143 ft/ 6 years (0.12 ft/year) whereas average annual rainfall at the neighboring Bunyala Irrigation Scheme was increasing at 0.5245 mm/31 years (0.017 mm/ year). The decrease in annual groundwater levels is statistically insignificant whereas the increase in annual rainfalls is statistically insignificant. Groundwater levels at Busia Town Prison are falling much faster.

Using the parametric test of linear regression analysis on annual rainfalls, there is variation within the seven rainfall stations with some recording declining and others increasing rainfall trends. Three stations; Kakamega Meteorological Station, Bungoma Water and Malava Forest Station showed declining rainfalls. The remaining four stations; Leissa Farm

Kitale, Chorlim ADC Farm, Kaptagat Forest Station and Bunyala Irrigation Scheme had increasing rainfalls. The rainfall stations recording increasing rainfalls were in the upper and lower cartchments whereas those recording declining rainfalls were in the middle catchment as shown in Table.4.

Table. 4: Annual rainfall trend results from Linear regression analysis in Nzoia River Basin, Kenya

Rainfall station	**Slope (Rate of change)**		**R^2**	**Trend**
UPPER CATCHMENT				
Leissa Farm Kitale	1.0325 mm/31 years	0.033 mm/ year	0.2779	Increasing
Chorlim ADC Farm	0.0873 mm/31 years	0.003 mm/ year	0.0008	Increasing
Kaptagat Forest Station	0.1933 mm/31 years	0.006 mm/ year	0.0050	Increasing
MIDDLE CATCHMENT				
Kakamega Meteorological Station	- 0.5311 mm/31 years	-0.017 mm/ year	0.0227	Decreasing
Bungoma Water Supply	- 0.7584 mm/31 years	-0.025 mm/ year	0.0608	Decreasing
Malava Forest Station	- 0.2056 mm/31 years	-0.021 mm/ year	0.0034	Decreasing
LOWER CATCHMENT				
Bunyala Irrigation Scheme	0.5245 mm/31 years	0.017 mm/ year	0.1183	Increasing

The impact of rising and falling rainfall trends is a symptom of climate change, and it could cause future issues in the basin's groundwater availability and access. Increasing rainfall trends will bring the challenge of flooding and landslides to domestic water supply infrastructure. Decreasing rainfall trends will bring the challenge of water scarcity and droughts. The slopes for all stations are more than -1, indicating that the annual rainfall variation trend in these areas is generally small. The difference of these changes is mainly due to the impact of climate change in different regions of Nzoia River Basin during the decades, and the intensity of human activities. There is a general trend towards increased rainfall in the upper carchment, (where the two high ground areas of Mt. Elgon and Cherengani hills occur) and reduced rainfalls in the middle and lower catchments. Rainfall is also strongly influenced by elevation with greater amounts occurring in the high ground areas.

When the parametric test of Linear regression analysis was applied on annual groundwater levels for Kitale Golf Club, Mois Bridge Quarry, Kapsabet Boys High School, Kakamega Mwikalikha School, Kakamega Tande School, Bungoma water supply and Busia Town Prisons observation wells. All the wells recorded declining water levels as shown in Table.5.

Table 5: Annual Groundwater level trend results from Linear regression analysis in Nzoia River Basin, Kenya

Groundwater level observation wells	**Slope (Rate of change)**		**R^2**	**Trend**
UPPER CATCHMENT				
Kitale Golf Club	-2.9425 ft/ 6 years	-0.49 ft/year	0.7831	Decreasing
Mois Bridge Quarry	-1.5448 ft/ 5 years	-0.31 ft/year	0.5943	Decreasing
Kapsabet Boys High School	-0.4043 ft/ 5 years	-0.08 ft/year	0.0294	Decreasing
MIDDLE CATCHMENT				
Kakamega Mwikalikha School	-0.6498 ft/ 6 years	-0.11 ft/year	0.3992	Decreasing
Kakamega Tande School	-0.1668 ft/ 6 years	-0.03 ft/year	0.1359	Decreasing
Bungoma Water Supply	-0.4509 ft/ 6 years	-0.08 ft/year	0.2875	Decreasing
LOWER CATCHMENT				
Busia Town Prisons	-0.7143 ft/ 6 years	-0.12 ft/year	0.1558	Decreasing

The aquifers are hydraulically linked, and the trends are interdependent, according to the various spatial patterns of the trends. The volume and duration of effective rainfall, which enables groundwater recharging in a given topography and hydrogeological context, are believed to have reduced principally due to rainfall extremes in the basin, as observed in terms of drought and flood years. This is evident, as the basin's groundwater levels have continued to decline year after year. Groundwater storage has been declining in the Nzoia River Basin due to an over-reliance on groundwater for domestic water supply and other requirements, with little or no replenishment from recharge. This scenario is aggravated when the drawdowns accumulate as a result of multiple drought events, as is currently common in the basin. Furthermore, due to increased crop water demands and domestic water supply requirements, the rapidly rising temperature is believed to have negatively impacted groundwater resources.

Annual groundwater levels have dropped across the basin, while extreme weather occurrences (rainfall and temperature extremes) have risen. If current climate patterns persist over the next few decades, there will certainly be a shortage of groundwater due to the projected increase in human demands. Future research is needed in the basin to accurately characterize the trends in groundwater level and the climatic extremes. The primary elements explaining the observed groundwater level trends in the Nzoia River Basin are geological formations and rainfall totals. The upland recharge zones frequently experience high groundwater level reductions. The reduction in groundwater levels immediately after the long rains season shows that most catchments in the Nzoia River Basin are quick at releasing groundwater. The geology and geomorphology of catchments play a major role in groundwater depletion. The higher and steeper the slope of a watershed, the faster it loses water to the low-lying land.

3.1.3 Mann-Kendall test on Annual groundwater levels

Annual groundwater levels data for selected stations within Nzoia River Basin under Table.2 were analyzed for trend using Mann-Kenall test and the results are shown in Table.6. When the Mann Kendall test statistics are less than 0, it indicates that groundwater level is decreasing; and when the values are higher than 0, groundwater level is increasing.

Table: 6: Results of the Mann-Kendall test on Annual Groundwater levels data for Nzoia River Basin, Kenya

Station name	Mann-Kendall test					
	Mann Kendall Statistic (S)	Kendall's Tau	**Var (S)**	p-value (two tailed test)	alpha	Test Interpretation
UPPER CATCHMENT						
Kitale Golf Club	-39.000	-0.709	165.000	0.003	0.05	Reject Ho Statistically significant trend
Mois Bridge Quarry	-27.000	-0.491	165.000	0.043	0.05	Reject Ho Statistically significant trend
Kapsabet Boys High School	-10.000	-0.183	164.000	0.482	0.05	Accept Ho Statistically insignificant trend
MIDDLE CATCHMENT						
Kakamega Mwikalikha School	-25.000	-0.455	165.000	0.062	0.05	Accept Ho Statistically insignificant trend
Kakamega Tande School	1.000	0.018	165.000	1.000	0.05	Accept Ho Statistically insignificant trend
Bungoma Water Supply	-3.000	-0.055	165.000	0.876	0.05	Accept Ho Statistically insignificant trend
LOWER CATCHMENT						
Busia Town Prisons	7.000	0.127	165.000	0.640	0.05	Accept Ho Statistically insignificant trend

The Mann Kendall test Statistic (S) indicates decreasing groundwater levels trend for Kitale Golf Club, Mois Bridge Quarry, Kapsabet Boys High School, Kakamega Mwikalikha School and Bungoma water supply observation wells whereas Kakamega Tande School and Busia Town Prison showed increasing groundwater levels trends. The results for Kitale Golf Club and Mois Bridge Quarry were statistically significant, whereas those for Kapsabet Boys High School, Kakamega Mwikalikha School, Kakamega Tande School and Busia Town Prison were statistically insignificant at 5% significance level.

Comparing Fitted Linear regression trend line and Mann-Kendall test statistic (S) results for annual groundwater levels data; Mann Kendall test statistic (S) showed two stations recording increasing groundwater levels (Kakamega Tande School and Busia Town Prison) and five stations recording decreasing groundwater levels (Kitale Golf Club, Mois Bridge Quarry, Kapsabet Boys High School, Kakamega Mwikalikha School and Bungoma water supply). On the other hand, the fitted linear regression line showed all stations recording declining ground water levels as shown in Table.7.

Table: 7: Comparing Fitted Linear trend line and Mann-Kendall test statistic (S) results for Annual groundwater levels data in Nzoia River Basin, Kenya

Station name	Mann-Kendall test		Fitted Linear trend line		Mann Kendall Test Statistical Interpretation
	Mann Kendall Statistic (S)	Groundwater levels trend	Fitted Linear trend line slope	Groundwater levels trend	
UPPER CATCHMENT					
Kitale Golf Club	-39.000	Decreasing	-2.9425	Decreasing	Reject Ho Statistically significant trend
Mois Bridge Quarry	-27.000	Decreasing	-1.5448	Decreasing	Reject Ho Statistically significant trend
Kapsabet Boys School	-10.000	Decreasing	-0.4043	Decreasing	Accept Ho Statistically insignificant trend
MIDDLE CATCHMENT					
Kakamega Khwisero Mwikalikha School	-25.000	Decreasing	-0.6498	Decreasing	Accept Ho Statistically insignificant trend
Kakamega Malava Tande School	1.000	Increasing	-0.1668	Decreasing	Accept Ho Statistically insignificant trend
Bungoma Water Supply	-3.000	Decreasing	-0.4509	Decreasing	Accept Ho Statistically insignificant trend
LOWER CATCHMENT					
Busia Town Prisons	7.000	Increasing	-0.7143	Decreasing	Accept Ho Statistically insignificant trend

Ground water is likely to become more valuable in the next decades as temporal variations in precipitation, soil moisture, and surface water are expected to rise as a result of more frequent and severe climate extremes caused by climate change [40]. The expected implications of climate change on diffuse groundwater recharge are still a source of considerable skepticism, which is linked to the inherent uncertainties in climate forecasts and terrestrial reactions to changing rainfall and land cover. Increases in groundwater abstraction, both in absolute terms and as a percentage of total water withdrawals, are more certain, posing a danger to overexploitation of groundwater resources. This risk is expected to be particularly critical in Busia county's Samia and

Bunyala sub-counties, where projected increases in the frequency and intensity of droughts, combined with rising populations and living standards, as well as the projected expansion of irrigated land, will exacerbate groundwater demand. Conjunctive uses of ground and surface water, such as using surface water for irrigation and domestic requirements during wet seasons and ground water during droughts, are anticipated to become increasingly important. Managed aquifer recharge, which stores extra surface water and treated waste water in depleted aquifers, could also be used to enhance groundwater storage during droughts. Indeed, using aquifers as natural storage reservoirs avoids many of the issues associated with big, manmade surface water reservoirs, such as evaporative losses and environmental impacts. Our ability to adequately analyze the reactions of groundwater to climate variability and change, to estimate directly groundwater replenishment, and to constrain models and satellite observations is significantly hampered due to a lack of groundwater data (for example, groundwater levels and withdrawals).

With the projected annual rainfall generally showing a tendency to increase slightly over the region, the annual groundwater levels are expected to rise, but due to the increased temperatures increasing evapotranspiration coupled with increased water demand arising from the rapidly growing populations for agricultural activities, domestic use, industry and other emerging uses, groundwater levels are set to show a declining trend. Groundwater levels in each area of the basin will respond differently to changes in climate. The higher mountain (Elgon and Cherengani) areas are expected to receive more rainfall (which could sustain high groundwater levels) than the middle catchment areas and the lower basin bordering Lake Victoria will receive the lowest rainfalls (which could result into falling groundwater levels). With the temperatures getting warmer as projected in the coming years, groundwater levels are expected to decline in most areas of the basin as a result of increases in evapotranspiration and reduced groundwater recharge.

3.1.4 Mann- Kendall test on annual rainfall

The non-parametric test, Mann Kendall method was used to analyze if there is a monotonic upward or downward trend in rainfall over time. Rainfall has crucial impact on the water cycle in the study area. Annual rainfall data for 7 stations under study in Nzoia River Basin were analyzed for trend using the non-parametric Mann-Kenall test and the results are shown in Table. 8. The Mann-Kendall test gives interesting insight about annual rainfall for Nzoia River Basin. When the Mann Kendall test statistics (S) are less than 0, it indicates that rainfall is decreasing; and when the values are higher than 0, the rainfall is increasing.

Table: 8: Results of the Mann-Kendall test on Annual Rainfall from selected Rainfall Stations in Nzoia River Basin, Kenya

Station name	Mann-Kendall test					
	Mann Kendall Statistic (S)	**Kendall's Tau**	**Var (S)**	**p-value (two tailed test)**	**alpha**	**Test Interpretation**
UPPER CATCHMENT						
Leissa Farm Kitale	20.000	0.022	9120.667	0.8423	0.05	Accept Ho Statistically insignificant trend
Chorlim ADC Farm	-58.000	-0.061	9775.333	0.564	0.05	Accept Ho Statistically insignificant trend
Kaptagat Forest Station	741.000	1	6833.667	< 0.0001	0.05	Reject Ho Statistically significant trend
MIDDLE CATCHMENT						
Kakamega Meteorological Station	1035.000	1	11155.000	< 0.0001	0.05	Reject Ho Statistically significant trend
Bungoma Water Supply	-140.000	-0.171	7929.667	0.118	0.05	Accept Ho Statistically insignificant trend
Malava Forest Station	-129.000	-0.143	9130.333	0.180	0.05	Accept Ho Statistically insignificant trend
LOWER CATCHMENT						
Bunyala Irrigation Scheme	113.000	0.243	3461.667	0.057	0.05	Accept Ho Statistically insignificant trend

The Mann Kendall test Statistic (S) indicates that there is an increasing rainfall trend for Leissa Farm Kitale, Kaptagat Forest Station, Kakamega Meteorological Station and Bunyala Irrigation Scheme; and reducing rainfall trends for Chorlim ADC Farm, Bungoma water supply and Malava Forest Station. In recent years, many scholars have done a lot of research on the analysis of the hydrological and meteorological trends using Mann Kendall test; eg. Wang et al., [41] used Mann Kendall method and regression analysis to examine the long-term variation of annual rainfall in Shapotou area.

Table: 9: Comparing Linear regression analysis and Mann-Kendall test statistic (S) results for Annual Rainfall from selected Rainfall Stations in Nzoia River Basin, Kenya

Station name	Mann-Kendall test		Linear regression analysis		Mann Kendall Test Statistical Interpretation
	Mann Kendall Statistic (S)	Rainfall trend	Linear regression trend slope	Rainfall trend	
UPPER CATCHMENT					
Leissa Farm Kitale	20.000	Increasing	1.0325	Increasing	Accept Ho Statistically insignificant trend
Chorlim ADC Farm	-58.000	Decreasing	0.0873	Increasing	Accept Ho Statistically insignificant trend
Kaptagat Forest Station	741.000	Increasing	0.1933	Increasing	Reject Ho Statistically significant trend
MIDDLE CATCHMENT					
Kakamega Meteorological Station	1035.000	Increasing	- 0.5311	Decreasing	Reject Ho Statistically significant trend
Bungoma Water Supply	-140.000	Decreasing	- 0.7584	Decreasing	Accept Ho Statistically insignificant trend
Malava Forest Station	-129.000	Decreasing	- 0.2056	Decreasing	Accept Ho Statistically insignificant trend
LOWER CATCHMENT					
Bunyala Irrigation Scheme	113.000	Increasing	0.5245	Increasing	Accept Ho Statistically insignificant trend

Of the 7 stations, only 2 showed a statistically significant trend through the MK test at 5% level of significance; and the trend for the remaining 5 stations is statistically insignificant. Mann-Kendall test and linear regression test have been used to evaluate annual rainfall over Nzoia River Basin. Apart from this, the linear trend fitted to the data has also been tested with the Student t-test to verify results obtained by the Mann-Kendall test and the results are presented in Table 9. Table.9 shows a comparison of the results of Linear regression analysis and the Mann-Kendall test statistic (S) applied to the selected 7 Rainfall Stations. Leissa Farm Kitale, Kaptagat Forest Station and Bunyala Irrigation Scheme recorded increasing rainfalls under both Linear regression analysis and the Mann-Kendall test statistic (S). Bungoma Water Supply and Malava Forest Station recorded decreasing rainfalls under both Linear regression analysis and the Mann-Kendall test statistic (S). Chorlim ADC Farm recorded decreasing rainfall under Mann-Kendall test statistic (S) and increasing rainfall under Linear regression analysis; whereas Kakamega meteorological station recorded increasing rainfall under Mann-Kendall test statistic (S) and decreasing rainfall under Linear regression analysis. These study results follow the same statistical trends and are consistent with what has been reported by Githui [42] for Nzoia River Basin where she found that most of the rainfall stations with increasing rainfall were in the upstream part of Nzoia River.

3.1.5 Factors influencing the relationship between groundwater

levels and rainfall

(i) Human activities

Changes in land use and land cover, as well as increasing groundwater pumping and withdrawal for domestic, industrial, and agricultural purposes, have an impact on the natural balance of groundwater resources, resulting in altered dynamics. If the amount of groundwater withdrawn equals the amount of groundwater recharged, and the groundwater level is lower than the original average water level, bigger changes will occur, but the groundwater level will not continue to decrease [43]. If the amount is too big and outweighs groundwater recharge, the groundwater level will continue to fall, resulting in an increase in the thickness of the unsaturated zone, which has resulted in an increase in the time it takes for the groundwater level to respond to precipitation. The response time of the groundwater level to precipitation will increase further if overexploration remains constant or increases. Previous research has looked into the relationship between the lag time of two parameters and the thickness of the unsaturated zone [44,45]. For example, Zhang et al [45] demonstrated in his works that when the unsaturated zone thickness exceeds the diving evaporation limit, the infiltration rate drops as the unsaturated zone thickness increases, and the temporal delays rise.

(ii) Lithology of the aquifer

Apart from the impact of human activities, the lithology of the aquifer is another key component influencing the groundwater-precipitation interaction [46,37]. Various lithologies of the aquifer have different hydrogeological properties, such as hydraulic conductivity, precipitation infiltration recharge coefficient, specific yield, and so on. Precipitation can easily recharge groundwater, while subterranean runoff in bedrock fissure aquifers swiftly discharges water into rivers. As a result, groundwater responds to precipitation more quickly, although there is no visible change in water level.

(iii) Intensity of precipitation

One of the most important sources of groundwater is precipitation. The magnitude of precipitation will have a significant impact on groundwater dynamics [47]. Because of the influence of the elements stated above, the spatiotemporal relationship between groundwater level and precipitation is distinct. Furthermore, the groundwater level dynamics in the Nzoia River Basin are extremely vulnerable to heavy rains. Figures 2–8 show how this association was demonstrated in the current study. Groundwater levels in the Nzoia River Basin are extremely vulnerable to high rainfall, hence, maximizing the use of heavy rainfall and flood resources could be an effective approach of recharging groundwater resources.

4.0 CONCLUSION

Analysis of historical groundwater level records in Nzoia River Basin indicates that groundwater levels declined between 2011 and 2017 throughout the basin. Groundwater level declines are uniformly spread over the basin but highest in the upland recharge areas (upper Nzoia catchment). The findings show significant negative trends in water storage over multiple decades, but without understanding aquifer storativity, rates of groundwater depletion cannot be deduced from groundwater level variations. Increased energy consumption for pumping, the need for deeper wells, and irreversible repercussions such as permanent aquifer compaction and land subsidence may all occur as groundwater levels continue falling. Groundwater level changes are caused by a variety of factors that vary in time and space across the basin. In this study we found correlations between monthly rainfall and monthly groundwater levels. Groundwater levels are clearly influenced by climate change. Groundwater is becoming a more important resource for fulfilling daily water demands and balancing variations in surface water supplies. Groundwater is being withdrawn at unsustainable rates across the Nzoia River Basin, resulting in long-term groundwater level decreases and groundwater storage loss. Across the basin, the dynamics of extraction, recharge, and changes in the surface water–groundwater balance are complex and vary. This study's findings can be utilized to pinpoint areas of the basin where a more extensive aquifer or sub-aquifer scale analysis is needed to better groundwater management.

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