Assessment of the Impact of Rainfall Variability on Drinking Water Production at Treatment Plants in Nzoia River Basin, Kenya

Ernest Othieno Odwori[1*]

[1]*Department of Disaster Management and Sustainable Development, School of Disaster Management and Humanitarian Assistance, Masinde Muliro University of Science and Technology, P.O. Box 190-50100, Kakamega, Kenya.*

Original Research Article

ABSTRACT

Increased wet season rainfall is associated with improved water supply at point water sources and improved river flows and water reservoir levels. For piped water supply schemes with surface water intakes, this is supposed to enhance operations since there is adequate raw water unlike in the dry season where operations are interrupted due to insufficient flows. However, this is not the case in Nzoia River Basin as established by this study. As rainfall increases, drinking water production in treatment plants at Moi's Bridge, Lumakanda and Busia water supplies decrease and vice versa. Nzoia River Basin is one of the regions that is highly vulnerable to climate variability in Kenya, hence understanding rainfall variability and trends is important for better water resources management and especially drinking water supply. This study aimed at assessing rainfall variability and trends for 3 rainfall stations in Nzoia River Basin; Leissa Farm Kitale, Webuye Agricultural Office and Bunyala Irrigation Scheme and its impact on drinking water production at Moi's Bridge, Lumakanda and Busia water supplies treatment plants. The rainfall data used in this study covers 31 years period from 1970 to 2001 and was obtained from the Kenya Meteorological Department (KMD), Nairobi, Kenya. Monthly water supply production data for Moi's Bridge, Lumakanda and Busia water supplies covering 15 years period from 2000 to 2014 was obtained from the County governments of Uasin Gishu, Kakamega and Busia. Rainfall variability and trend was analysed

_____

Corresponding author: E-mail: odworiernest@gmail.com;

using the parametric test of Linear regression analysis and the non-parametric Mann Kendall statistical test. Monthly rainfall and monthly drinking water production was analysed using Pearson moment correlation to establish the relationship between monthly rainfall and monthly drinking water supply production at Mois Bridge, Lumakanda and Busia Water supplies treatment plants. The results of variability and trend in annual rainfall shows Webuye Agricultural Office recording declining rainfall at -0.8994 mm/31 years (-0.029 mm/ year); whereas Leissa Farm Kitale shows increasing rainfall at 1.0325 mm/31 years (0.033 mm/ year) and Bunyala Irrigation Scheme's rainfall is increasing at 0.5245 mm/31 years (0.017 mm/ year). Drinking water supply production at Moi's Bridge, Lumakanda and Busia water supplies has been increasing with time between 2000 and 2014. The results of Pearson moment correlation coefficient shows a strong negative relationship between monthly rainfall and monthly drinking water supply production at 0.05 significance level for Moi's Bridge, Lumakanda and Busia water supplies. This shows that as rainfall increases, drinking water supply production in treatment plants at Moi's Bridge, Lumakanda and Busia water supplies decreases. During the rainy season, the cost of water treatment goes up as a result of increased turbidity. Increased rainfall in Nzoia River Basin presents water treatment challenges to the existing water supply treatment plants resulting into reduced production.Water supply managers should improve the capacity of the existing water supply treatment plants to cope with the increased rainfall variability under the changing climatic conditions.

1. INTRODUCTION

In various parts of Africa, rainfall variability has resulted in extensive droughts and floods, posing a significant threat to water availability [1]. Though water supply systems are constantly under strain due to rising water demands, economic development, and population growth, one of the most pressing concerns about the effects of rainfall variability in Nzoia River Basin is the significant impact it has on the production of drinking water at treatment plants. Rainfall variability will become more intense as a result of climate change, resulting in river flow changes and a higher frequency of droughts and floods [2-4]. Increased or decreased annual rainfall influences seasonal runoff, and thus water quality, water supply, and flood threats in various parts of the world [5]. Previous studies have highlighted the connection between rainfall variability and water access, as well as demand and quality. According to Calow et al. (2010) [6], during drought, access to safe drinking water can be a major issue due to water access, availability, limitations and control of water usage. Seasonal variations in rainfall affect water supply availability, and some studies show that contamination varies by season, with a clear pattern of fecal contamination occurring more frequently during the rainy season [7]. Several studies on the impact of rainfall variability on water resources in the African continent have been conducted [8-10], but data on the impact of rainfall variability on drinking water supply production at treatment plants, particularly in

Nzoia River Basin, is still lacking. Rainfall variability is important in a variety of professions. Variability in time and magnitude, for example, influences the design of structures for various purposes such as hydropower, irrigation, and water supply [11]. Water supply refers to the provision of water for drinking, residential use, and irrigation, with universal water distribution ensuring its availability [12].

Water managers must cope with changes in rainfall, lake levels, stream flows, and other aspects of the water cycle on an annual, seasonal, and daily basis [13]. Their ability to adjust to the predictability of climate variability is an important aspect in their success [14]. Rainfall variability will affect water supply production at treatment plants, as higher suspended sediment loads in rivers may render current treatment plants unable to cope without upgrading. Water treatment specialists observe that, "where coagulation is used, doses can be adjusted to cope with higher suspended sediment solids, but a point may be reached where the suspended loads exceed the removal capacity of the treatment plants necessitating closure of the treatment works. Failure to shut down coagulation units in a timely manner will lead to break-through of suspended solids into subsequent filtration units, which is likely to cause clogging, under-performance, and ultimately breakthrough into the final water tanks and distribution system". Treatment plants that are either not regularly staffed or controlled by untrained community members (as most

community-run water supplies in the basin are presently) may struggle to cope with short-term changes, resulting in water quality failures [15]. Chlorination and other disinfection systems will be less effective if suspended solids levels are high [16]. Even short-term treatment failures can result in increased public health concerns [17].

To avoid significant breakthrough, the most common management approach to these risks is to link failures to prompt (often automatic) shutdown. Such arrangements are the norm in high-income industrialized countries, but not in many poorer countries. In low-resource settings, the introduction of automated systems capable of shutting down systems could reduce risks. Increased suspended solid loads may potentially put multistage filtration at risk [18]. This can be regulated through improved controls that shut down water intakes as sediment loads rise, as well as physical measures that force units to cease working, , for instance by having a finer layer close to the inlet of pre-filters that clogs relatively quickly. Reduced flows are expected to result in higher pollution concentrations [19]. Temperature and precipitation changes may alter dissolved organic carbon, resulting in increased precursors of disinfection by-products [20]. Where surface waters utilized as drinking water sources acquire effluent upstream of water supply intakes, they may encounter extra water quality concerns. If river flows drop, the most evident effect will be higher pollution concentrations. However, where combined sewers are employed, the risk of storm water overflows may grow with more heavy rainfall events. In Nzoia River Basin, evaluation of historical trends in rainfall inconsistency at a local scale is essential for managing water supply services. The quantity or availability of water for various purposes is very much dependent on the amount of rain received. The present study analyzes the variability and trends in rainfall in Nzoia River Basin to establish if there have been any significant changes in the patterns during the period 1970 to 2014 and if so, how they have affected water supply production at Moi's Bridge, Lumakanda and Busia water supplies treatment plants.

2. MATERIALS AND METHODS

2.1 Study Area

The study area, Nzoia River Basin lies entirely within Kenya along the border with Uganda in the Lake Victoria Basin. It's situated between latitudes $1^0 30^{'}$ N and $0^0 05^{'}$ S and longitudes 34^0E

and $35^0 45^{'}$ E with an area of 12,959 km^2 and a river length of 334 km up to its outfall into Lake Victoria. This study was carried out in three counties of the basin; Trans Nzoia in the upper catchment, Kakamega in the middle catchment and Busia in the lower catchment. Nzoia River Basin has a population of about 3.7 million people and falls within the Lake Victoria basin of Kenya which is one of the regions in the world with the poorest and fastest growing populations. The basin is made up of nine counties; Elgeyo/Marakwet, West Pokot, Trans Nzoia, Uasin Gishu and Nandi (in former Rift Valley province); Kakamega, Bungoma and Busia (in former Western province) and Siaya (in former Nyanza province).

2.2 Water Resources

Nzoia River originates from Mt. Elgon and Cherengani hills forest. Mt. Elgon forest catchment is located north of Lake Victoria on the border between Kenya and Uganda. The National Park and Forest Reserves protect the forest belt; and Elgon forms the upper catchment area for two major rivers, Nzoia and Turkwel rivers. It also provides water to the Malakisi and Malaba rivers that cross the small farming area south of the mountain before it drains into Lake Kyoga in Uganda.

Nzoia river is one of the largest rivers in Western Kenya which drains into Lake Victoria contributing to the waters that form the source of River Nile. It's catchment area comprises of distinct drainage areas originating from Mt Elgon area; Cheranganyi, Bungoma, Kimilili and Nandi hills including Kakamega area and the Lower Nzoia area up to Lake Victoria. Nzoia River Basin seats astride, between the Lake Victoria and Lake Turkana basins. Streams to the west of the watershed Cheranganyi feed the Nzoia river system, which flows into Lake Victoria, while streams to the east flow into the Kerio river system. Nzoia river and its tributaries provide permanent water supply, but the flows vary by seasons of the year. The main streams of the river flow from the western side of the Elgeyo escarpment (Sergoi, Sosiani and Kipkelion tributaries) and the Cherengani hills (Chepkotet and Kaisungur tributaries) from an elevation of approximately 2,286 m above sea level. It has several tributaries with an average basin elevation of 1,917 m asl. The tributaries which flow from the high slopes of Mt. Elgon attain a maximum elevation in the river basin at 4,300 m above sea level. The tributaries in Mt. Elgon

include Kuywa, Sioso Ewaso, Rongai and Koitobos. The River is from a north-easterly to south-westerly direction with a mean slope of 0.010% from source to discharge into Lake Victoria at about 1,000 m.

Nzoia river enters Lake Victoria a short distance to the north of Yala Swamp and the plains at the downstream reaches of this river are susceptible to floods. The main tributaries of Nzoia river include, Moiben, Kapolet, Koitobos, Rongai, Kimilili, Kipkaren, Lusumu, Isiukhu, and Wuoroya. The mean discharge of Nzoia river basin is about 118 m3/s, the lowest flow is 2.8 m3/s and the maximum probable flood is 1,000 m3/s and the 100 year flood is 930 m3/s. The river average channel width is 40 m and the average gradient is 1 in 240 m.
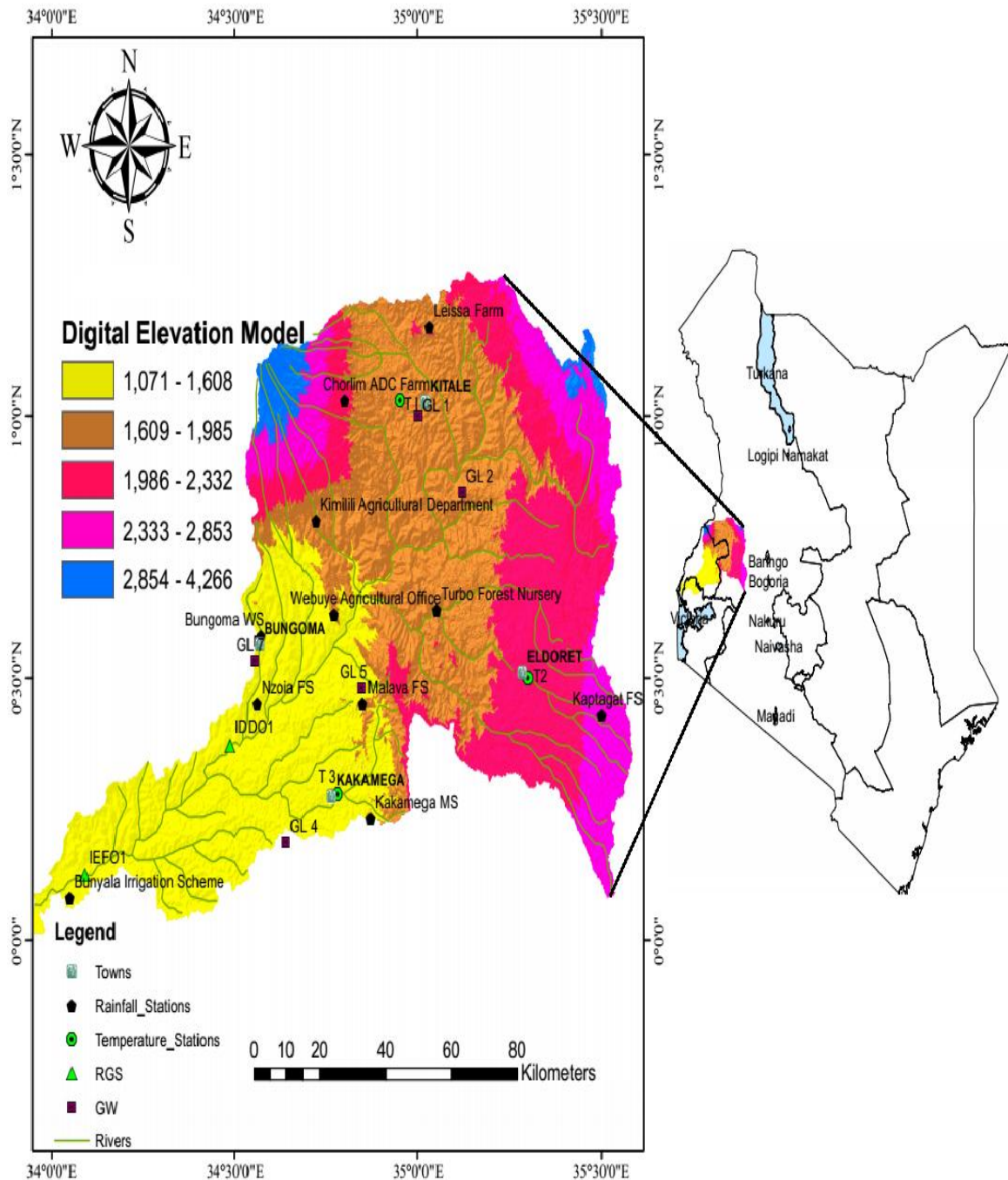

Fig. 1. Map of Nzoia river basin, Kenya

Groundwater is the main drinking water resource, supplying 78.8% of the residents leaving 21.2% for surface water resources. Many of the large piped schemes supplying the towns and rural areas have their intakes built on Nzoia river and its tributaries. On the existing sources of domestic water supply, 62 % of the residents of Nzoia River Basin use improved water sources. Out of these, 3 % use piped water into dwellings, 7 % water piped into compound, yard or plot, 3 % public tap/standpipe, 6% tube well or borehole, 11% protected dug well, 31% protected spring and 1% rainwater collection. Those using non-improved sources are 38%. Out of these, 10 % use unprotected dug well, 19 % unprotected spring, 1% tanker truck/cart with small tank, 8 % surface water (river, dam, lake, pond, stream, canal, irrigation channel) and 0 % bottled water. Individuals frequently have to wait for long periods of time to draw water from point water sources, especially during the dry season. The people of Nzoia River Basin have strong preferences for safe, clean drinking water, and will sometimes walk long distances past alternate sources to get drinking water from sources deemed safe. Women and children collect water for drinking and cooking and transport it home in pretty standard-size 20 liter jerricans for adults and 5-10 liter jerricans for youngsters. Adults and older children in some villages still prefer to bathe in rivers, despite the fact that children under the age of five are routinely bathed at home in basins. Nzoia River Basin water sector still lacks suitable infrastructure as well as the requisite operational and management structures and capacities.

2.3 River Basin Geology

The geology of Nzoia River Basin is quite varied ranging from metamorphic basement rocks, volcanic rocks, to quaternary sedimentary rocks. The areas around Mt. Elgon are characterized by tertiary volcanic rocks mainly phonolites and agglomeratic tuffs. The plateau zones including Uasin Gishu and parts of Nandi are also characterized by Tertiary volcanic rocks which consist of phonolites and agglomeratic tuffs. The middle zone within the catchment is covered by metamorphic basement rocks consisting mainly of the gneissic rocks. These areas include Kitale, parts of Bungoma and West Pokot. The lower parts of the catchment are characterized by volcanic rocks of the Kavirondian system. These consist of meta-sediments, grits and conglomerates. This type of geological formation is noted in such areas like Busia, Butere and

parts of Bungoma and Webuye. The kavirondian system rocks are intruded in some places by granitic rocks (Mumias granite). Certain parts of the lower Nzoia River Basin such as Siaya are characterized by volcanic rocks consisting of the Nyanzian system rocks which are composed of basalts, rhyolites, andesites and rhyolitic tuffs. The volcanic rocks are known to overlie the basement rocks within the larger catchment.

The basin is characterised by three physiographic regions namely; the highlands (characterised by Mt. Elgon and Cherangani hills); the upper plateau (which includes Eldoret and Kitale); and the lowlands (which includes Busia that experiences the majority of flooding in the basin).The dominant topography consists of rolling hills and lowlands in the Eldoret and Kitale plains. The upper Nzoia River Basin has soils that are described as light clay with good drainage and good moisture capacity and are characterized with high fertility. Nzoia River Basin has the soil type textures forming: clay (77%), loamy (9%) and sandy (14%). In the basin, the Ferralsol form well drained soils found mostly on level to undulating land. The Acrisols in the basin form clay-rich soils associated with humid tropical climates and supports forestry; whereas Nitisols compose deep well- drained red tropical soils found mostly in the highlands occupying more than 75% of the catchment.

2.4 Climate and Land use

The Climate of Nzoia river basin is predominantly tropical humid and is characterized by day temperatures that vary from 16 °C in Cheranganyi and Mt. Elgon areas to 28 °C in the lower semi- arid plains of Bunyala. Night temperatures vary from 4 °C in the highlands to 16 °C in semi-arid lowlands. The highest rainfall ranges from 1100 – 2700 mm annually. Lowest rainfall ranges from 600 – 1100 mm annually.

Agriculture is the dominant land use in the region with the main food crops grown as maize, sorghum, millet, bananas, groundnuts, beans, potatoes, and cassava while the cash crops include coffee, sugar cane, tea, wheat, rice, sunflower and horticultural crops. The inhabitants of the basin also practice dairy farming together with traditional livestock keeping.

2.5 Data Sources

Monthly rainfall data were collected for three stations; Leissa Farm Kitale, Kakamega

Meteorological 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 selection was made according to their quality, length and period covered and ensuring they possess simultaneous records of meteorological data. Daily values were averaged in order to obtain monthly rainfall for each of the stations. Mean annual rainfall were obtained by averaging the monthly values for each year. Further information regarding the measurement uncertainty is given in Roman et al. (2014) [21]. Some necessary data quality control tests were performed before data were used. All the variables were checked against empirical upper and lower limits, systematic errors, which resulted from different sources (e.g., archiving, transcription and digitalization). This can include non-existent dates, etc. Further details about these tests can be seen in Roman et al. (2014) [21], El Kenawy et al. (2013) [22], Bilbao et al. (2003) [23], Miguel et al. (2003) [24]. Instrumentation and alteration of surrounding land cover might create non-homogeneity and/or inconsistencies in meteorological data recordings [25].

Monthly water supply production data was collected from three water supplies, Moi's Bridge water supply (close to Leissa Farm Kitale rainfall station), Lumakanda water supply (close to Webuye Agricultural Office rainfall station) and Busia water supply (close to Bunyala Irrigation Scheme rainfall station) covering 15 years period from 2000 to 2014. The water supply production data are expressed in cubic meters per month (m^3/month).

2.6 Methodology

Trend analysis of a time series consists of the magnitude of trend and its statistical significance. Different scholars have used different methodologies for trend detection. Kundzewicz, [26] has discussed the change detection methodologies for hydrologic data. In general, the magnitude of trend in a time series is determined either using regression analysis (parametric test) or using Sen's estimator method (non-parametric method) [27]. Both methods assume a linear trend in the time series. For effective water resource management, trend analysis of rainfall time series data is essential by

Mann-Kendall (MK), Sen's slope estimator, and multiple regression models. Considerable studies have been conducted to detect the regional rainfall trends on annual, seasonal, and monthly bases using the non-parametric Mann-Kendall (MK) test, regression analysis, and Sen's slope estimator test. For example, Caloiero et al. (2001) [28] used the Mann-Kendall (MK) and linear regression method to analyze annual and seasonal rainfall variability in Calabria, Southern Italy and obtained a decreasing trend in annual, autumn, and winter precipitation and an increasing trend in summer. The trends in annual mean precipitation show uniform uncertainty over nearly all of China, except for the northwest by using Mann-Kendall test [29]. Furthermore, significant increasing trends in annual and seasonal precipitation was observed in Northwest China from 1960–2013 using the MK test [30].

2.7 Regression Analysis

Regression analysis is conducted with time as the independent variable and rainfall as the dependent variable. The regression analysis is carried out directly on the time series or on the anomalies (i.e. deviation from mean). A linear equation, y = mt + c, defined by c (the intercept) and trend m (the slope), is fitted by regression. The linear trend value represented by the slope of the simple least-square regression line provides the rate of rise or fall in the rainfall.

2.8 Sen's Slope Estimator Test

The MK test does not provide an estimate of the magnitude of the trend, hence for this purpose, different statistical estimators have been used over the world to study the climatological time series, eg.rainfall. The magnitude of a trend in a time series can be determined using a non-parametric method known as Sen's estimator [27]. To estimate the true slope of an existing trend such as the amount of change per year, Sen's non-parametric method is used. Sen's Slope method involves computing slopes for all the pairs of ordinal time points and then using the median of these slopes as an estimate of the overall slope. The Sen's method assumes that the trend is linear.

This approach provides a more robust slope estimate than the least-squares method because it is insensitive to outliers or extreme values and competes well against simple least squares even for normally distributed data in the time series

[31]. The climate variability study of data series and its analysis requires trends and their statistical significance to be evaluated. Trend evaluations in seasonal and annual rainfall can be performed using the Theil-Sen (TTS) estimator and its 95% (α = 0.05) confidence interval (95CI). This estimator can be calculated following the methods proposed by Sneyers et al. [32] and Gilbert [33]. The results provide the most suitable trend values due to the sensitivity of the method to extreme data [34]. Similar tests have also been used by Roman et al. [21], Gocic et al. [25], Sayemuzzaman et al. [34], and Espadafor et al. [35].

2.8.1 The mann-kendall non-parametric trend test of significance

The Mann Kendall test [36-37] is a statistical test widely used for trend analysis in climatological and hydrological time series [38]. This is a rank based method which is non-parametric and is based on an alternative measure of correlation called Kendall's τ. The Mann-Kendall tests are based on the calculation of Kendall's tau measure of association between two samples, which is itself based on the ranks with the samples. The statistic τ is defined as the difference between the probabilities of concordance and discordance between the two variables. Mann [36] originally used MK test and Kendall [37] subsequently derived the test statistic distribution. The Mann-Kendall statistical test is frequently used to quantify the significance of trends in meteorological time series. The advantage of the method is that normal distribution of data is not expected. The result is seldom influenced by the fewer abnormal values and calculation is simple. There are two advantages of using this test. First, it is a non-parametric test and does not require data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series [34]. Any data reported as non-detects are included by assigning them a common value that is smaller than the smallest measured value in the data set.

A score of +1 is awarded if the value in a time series is larger, or a score of −1 is awarded if it is reduced. The overall score for the time-series data is the Mann–Kendall statistic which is then compared to a critical value to test whether the trend in rainfall is increasing, decreasing or if no trend can be observed. The strength of the trend is proportional to the magnitude of the Mann–Kendall Statistic. Sgn (Xj − Xk) is an indicator

function that results in the values 1, 0, or −1 according to the significance of Xj − Xk where j > k, the function is calculated as follows:

sgn (Xj − Xk) = 1 → if , Xj − Xk > 0
sgn (Xj − Xk) = 0 → if , Xj − Xk = 0
sgn (Xj − Xk) = −1 → if , Xj − Xk < 0

where Xj and Xk are the sequential rainfall values in months J and K (J > k) respectively; whereas, a positive value is an indicator of increasing (upward) trend and a negative value is an indicator of decreasing (downward) trend.

In the equation, X1, X2, X3,…,Xn represents 'n' data points (monthly), where Xj represents the data point at time J. Then the Mann–Kendall statistics (S) is defined as the sum of the number of positive differences minus the number of negative differences, given by:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn} = (\,xj - xk\,)$$

where

sgn (Xj − Xk) = 1 → if , Xj − Xk > 0
sgn (Xj − Xk) = 0 → if , Xj − Xk = 0
sgn (Xj − Xk) = −1 → if , Xj − Xk < 0

Trends considered at the study sites were tested for significance. A normalized test statistic (Z-score) is used to check the statistical significance of the increasing or decreasing trend of mean rainfall values. The trends of rainfall are determined and their statistical significance is tested using Mann–Kendall trend significant test with the level of significance 0.05 ($Z\_\alpha/2$ = ± 1.96).

$$Z = \frac{n-1}{\sqrt{\text{Var}(S)}} \quad \rightarrow \text{if } S > 0$$

$$Z = 0 \rightarrow \text{if, } S = 0$$

$$Z = \frac{n-1}{\sqrt{\text{Var}(S)}} \quad \rightarrow \text{if } S < 0$$

Hypothesis testing Ho = μ = μo (there is no significant trend/stable trend in the data).

Ha = μ_ μo (there is a significant trend/unstable trend in the data) If $-Z_{1-\alpha/2} \leq Z \leq Z_{1-\alpha/2}$ accepts the hypothesis or else reject the null hypothesis. Powerfully increasing or decreasing trends indicate a higher level of statistical significance [39].

2.8.2 Pearson's product moment correlation coefficient

Karl Pearson [40] developed Pearson's product moment correlation coefficient, or Pearson's r, from a related theory proposed by Sir Francis Galton in the late 1800s. It is the most widely used measure of association, as well as the first of the correlational measures to be developed. "All subsequent correlation measures have been developed from Pearson's equation and are adaptations engineered to control for violations of the assumptions that must be met in order to use Pearson's equation" as observed by Burns et al. [41] and Polit et al. [42]. Pearson's r measures the strength, direction and probability of the linear association between two interval or ratio variables.

A Pearson's correlation attempts to draw a line of best fit through the data of two variables, and the Pearson correlation coefficient, r, indicates how far away all these data points are from this line of best fit (i.e., how well the data points fit this model/line of best fit). The Pearson correlation coefficient, r, can take a range of values from +1 to -1. A value of 0 indicates that there is no association between the two variables. A value greater than 0 indicates a positive association; that is, as the value of one variable increases, so does the value of the other variable. A value less than 0 indicates a negative association; that is, as the value of one variable increases, the value of the other variable decreases. The stronger the association of the two variables, the closer the Pearson correlation coefficient, *r*, will be to either +1 or -1 depending on whether the relationship is positive or negative, respectively (Table.2). Achieving a value of +1 or -1 means that all your data points are included on the line of best fit – there are no data points that show any variation away from this line. Values for r between +1 and -1 (for example, r = 0.8 or -0.4) indicate that there is variation around the line of best fit. The closer the value of r to 0 the greater the variation around the line of best fit. Are there guidelines to interpreting Pearson's correlation coefficient? Yes, the following guidelines have been proposed.

Remember that these values are guidelines and whether an association is strong or not will also depend on what you are measuring. The advantage of using Pearson's r is that it is a simple way to assess the association between two variables; whether they share variance (covary), if the relationship is positive or negative, and the degree to which they correlate. The disadvantages of using Pearson's r is that it cannot identify relationships that are not linear, and may show a correlation of zero when the correlation has a relationship other than a linear one. Additionally the types of variable that can be evaluated are limited. In addition to Pearson's r, semipartial and partial correlation can be employed in order to estimate the relationship between an outcome and predictor variable after controlling for the effects of additional predictors in the equation.

3. RESULTS AND DISCUSSION

3.1 Monthly Rainfall and Monthly water Produced at Treatment Plants

Fi.2 shows monthly rainfall distribution for Leissa Farm Kitale, Webuye Agricultural Office and Bunyala Irrigation Scheme with 31 years data covering the period 1970 to 2001. A better understanding of the rainfall pattern is important for formulating effective and efficient water resources management and climate change adaptation policies. Leissa farm recorded a monthly mean rainfall of 82.27 mm in the period 1970 - 2001. The region experienced a major peak in May (139.92 mm) after which monthly rainfall gradually decreased with a minor peak in July and August. From there, the monthly rainfall continued to decrease until a minimum was reached in December (20.90 mm) and January for the next cycle to begin. Webuye Agricultural Office showed from 1970 to 2001 a monthly mean rainfall of 131.91 mm. The station shows a major peak of 236.80 mm in May followed by another minor peak in April, then the rainfalls decrease reaching the lowest levels of 45.18 mm in December for the next cycle to begin. Bunyala Irrigation Scheme showed from 1970 to 2001 a monthly mean rainfall of 92.16 mm. The station showed a major peak of 180.80 mm in April with monthly rainfall reducing to the lowest amount of 40.06 mm in July.

As a result of the inter-tropical convergence zone (ITCZ), Nzoia River Basin has four rainfall seasons each year. There are two rainy seasons and two dry seasons. Long rains come between March and May (MAM), while short rains fall between October and December (OND), both of which are linked to the ITCZ. There is no distinct dry season, although the months of December, January, and February (DJF) and, in some areas, June, July, August, and September (JJAS) are

dry seasons in comparison to the rainy seasons. The local relief and influences of Lake Victoria alter the normal weather pattern, resulting in a third rainfall peak from June to August. The ITCZ has a rather complex structure over the East Africa region that consists of the zonal and meriodional arms. The double passage of the zonal arm is associated with the long and short rainfall season during which a large portion of the annual rainfall total is received. On the other hand, the meriodional arm fluctuates from east to west and vice versa, with the easternmost extent noted in July and August.

This arm is linked to the rainfall that falls in Kenya's western highlands during these months [43]. The ITCZ's migration over the Equator, the southeast and northeast monsoons, Indian Ocean sea-surface temperature, and other meso-scale systems all influence diurnal, seasonal, and annual rainfall patterns [44-45]. There has also been a general upward trend (increase) in rainfall events from September to February, indicating that the short rainy season (October-December) is extending into the basin's usually hot and dry months of January and February. This may be due to more frequent El-Nino events, which are often accompanied by relatively warmer sea surface temperatures over the western Indian Ocean (along the East African coast) and cooler than normal sea surface temperatures to the east of the Indian Ocean. Over much of the country, this sea surface temperature pattern is favorable for increased rainfall. In Nzoia River Basin, it can be concluded that a dry spell seems to set in immediately after the heavy rainfalls. This leaves us to wonder whether there is a relationship between heavy rainfalls and dry spells.

The mean monthly water supply production at Moi's Bridge, Lumakanda and Busia water supplies was 11,840, 7,406 and 62,003 m³/month respectively. The lowest monthly production was observed in the long rains period occuring between March and May (MAM). The lowest monthly water supply production at Moi's Bridge, Lumakanda and Busia water supplies was 5,016 in April, 4,926 in May and 50,811 in April respectively. The highest monthly production was observed in the short rains period of October to December (OND) and the dry seasons which occur in the months of December, January and February (DJF) and in some parts of the basin, June, July, August and September (JJAS). The highest monthly water supply production at Moi's Bridge, Lumakanda and

Busia water supplies was 20,533 in December, 11,064 in January and 85,387 in February respectively. The total annual water supply production at Moi's Bridge, Lumakanda and Busia water supplies between 2000 and 2014 was 142,075; 88,875 and 744,042 m³/year respectively. Fig. 2 shows mean monthly rainfall distribution at Leissa Farm Kitale, Webuye Agricultural Office and Bunyala Irrigation Scheme whereas Table. 3 shows monthly water supply production (m³/month) at Moi's Bridge, Lumakanda and Busia water supplies. Moi's Bridge water supply is in close proximity of Leissa Farm Kitale rainfall station, Lumakanda water supply, Webuye Agricultural Office rainfall station and Busia water supply, Bunyala Irrigation Scheme rainfall station. Table 1 shows monthly rainfall variability at Leissa Farm Kitale, Webuye Agricultural Office and Bunyala Irrigation Scheme rainfall stations against drinking water supply production at Mois Bridge, Lumakanda and Busia water supplies treatment plants. From Fig. 2, Fig. 3 and Table.3; the relationship between monthly rainfall and monthly drinking water supply produced at the treatment plants is very clear. When monthly rainfalls increase, the monthly drinking water supply produced at the treatment plants decline; and vice versa. The relationship between monthly rainfalls and monthly drinking water supply production is negative.

The relationship between monthly rainfall and monthly drinking water supply production at Mois Bridge, Lumakanda and Busia Water supplies treatment plants was checked using Pearson Moment Correlation analysis. The results of Pearson moment correlation coefficient shows a strong negative relationship between monthly rainfall and monthly water supply production at 0.05 significance level for Moi's Bridge, Lumakanda and Busia water supplies. This shows that as rainfall increases, water supply production in treatment plants at Moi's Bridge, Lumakanda and Busia water supplies decreases and vice versa. There are a number of reasons as to why increased rainfalls in Nzoia River Basin result into reduced water supply production at water supply treatment plants. Increased amount of rainfalls may result into increased frequency of flooding leading to increase in sediment loads of streams which makes water treatment complicated and expensive. Increased intensity of rainfall leads to more run-off resulting in more

erosion and greater transport of contaminants to surface waters, flash flooding and consequently deterioration of water quality entering treatment plants.
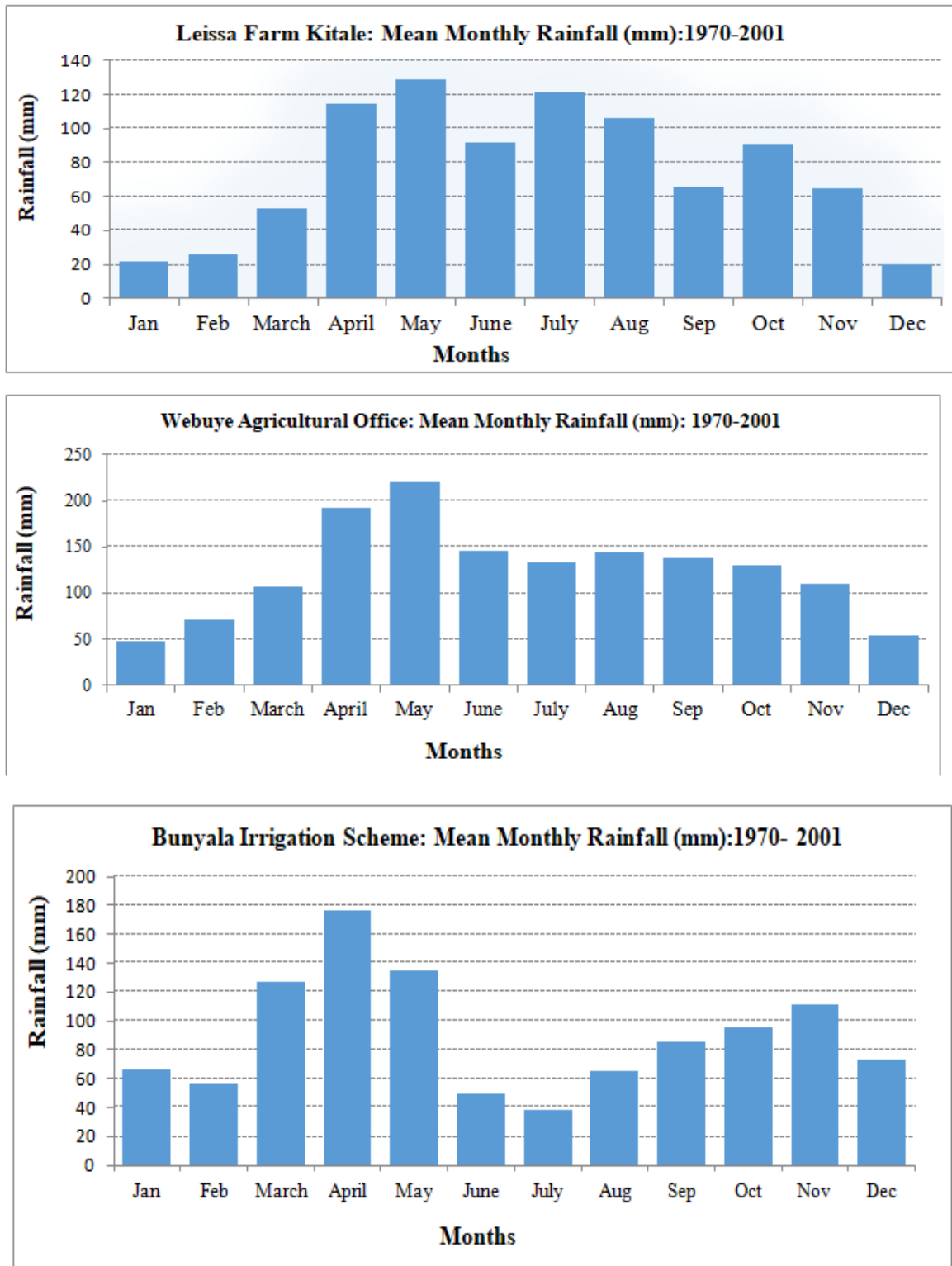

Fig. 2. Mean Monthly rainfall distribution for selected rainfall stations within Nzoia River Basin, Kenya
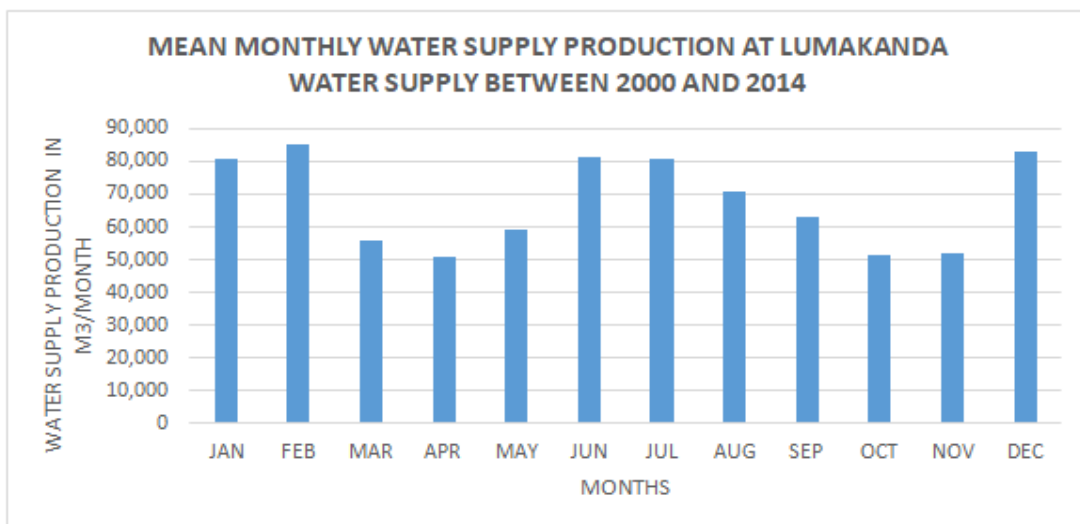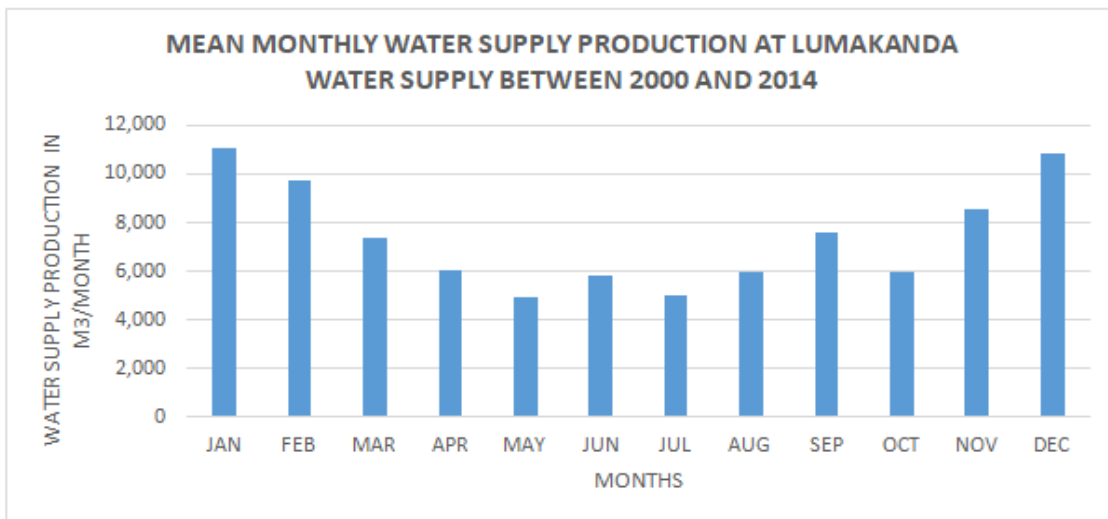
MEAN MONTHLY WATER SUPPLY PRODUCTION AT MOI'S BRIDGE WATER SUPPLY BETWEEN 2000 AND 2014

MEAN MONTHLY WATER SUPPLY PRODUCTION AT LUMAKANDA WATER SUPPLY BETWEEN 2000 AND 2014

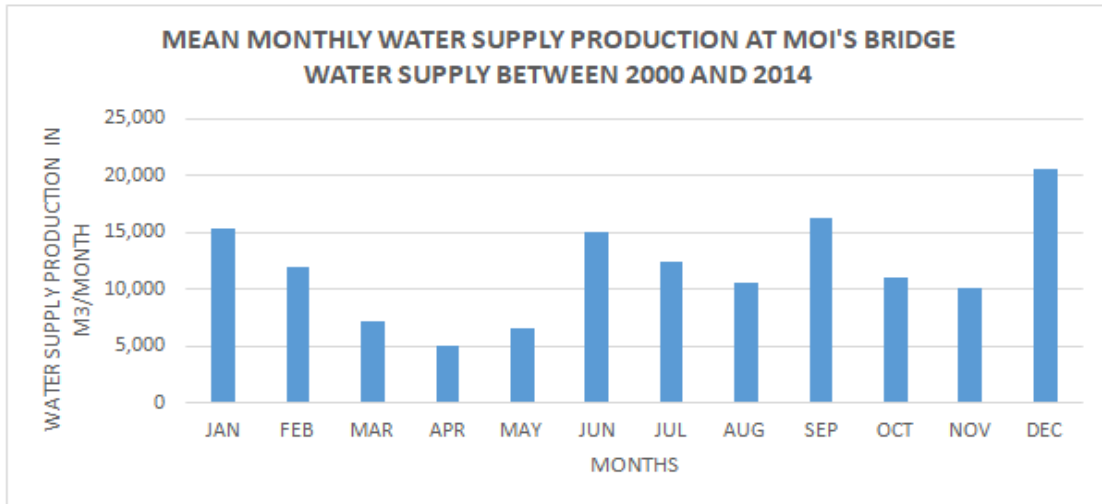**MEAN MONTHLY WATER SUPPLY PRODUCTION AT LUMAKANDA WATER SUPPLY BETWEEN 2000 AND 2014**

Fig. 3. Monthly water supply production (m³/month) at Moi's Bridge, Lumakanda and Busia water supplies in Nzoia River Basin, Kenya

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

Station ID(in Fig.1)	Station Wmo Code	Station name	Latitude (^{0}N)	Longitude (^{0}E)	Altitude (m.a.s.l)	Mean Annual Rainfall (mm/year)
R 1	8835039	Leissa Farm Kitale	1.17	35.03	1968	995
R 2	8934028	Kakamega Meteorological station	0.23	34.87	1804	1982
R 3	8934139	Bunyala Irrigation Scheme	0.08	34.05	1232	1099

Table 2. Pearson correlation coefficient range of values

	Coefficient, r	
Strength of Association	Positive	Negative
Small	1 to 3	-0.1 to -0.3
Medium	3 to 5	-0.3 to -0.5
Large	5 to 10	-0.5 to -1.0

Table 3. Monthly rainfall variability and drinking water supply production at Mois Bridge, Lumakanda and Busia Water supplies treatment plants in Nzoia River Basin, Kenya

Month	Upper catchment		Middle catchment		Lower catchment	
	Monthly mean rainfall (mm) at Leissa Farm Kitale Rainfall station	Monthly mean water production (m3/month) at Mois Bridge Water Supply	Monthly mean rainfall (mm) at Webuye Agricultural Office Rainfall station	Monthly mean water production (m3/month) at Lumakanda Water Supply	Monthly mean rainfall (mm) at Bunyala Irrigation Scheme Rainfall station	Monthly mean water production (m3/month) at Busia Water Supply
January	23.6	15,328	51.9	11,064	69.0	80,916
February	23.9	11,947	74.4	9,753	58.5	85,387
March	65.7	7,184	116.0	7,385	130.7	56,004
April	114.3	5,016	203.6	6,017	180.8	50,811
May	139.9	6,538	236.8	4,926	135.3	59,433
June	102.5	15,077	158.6	5,827	49.7	81,062
July	137.4	12,445	151.7	5,005	40.1	80,762
August	112.6	10,635	157.1	5,937	66.7	70.800
September	74.4	16,225	141.5	7,594	86.7	62,996
October	102.4	10,988	130.3	6,003	99.2	51,500
November	69.6	10,139	116.0	8,528	110.8	51,900
December	20.9	20,553	45.2	10,836	78.3	83,200

Increased rainfalls may also result into power outages as a result of destruction to power lines by rainstorms, pipe burst due to erosion exposing water pipelines, siltation of intake works, clogging of intake structures on rivers, damage to flooded treatment plants and pumping equipment. All these factors could lead to reduced production of water supply at treatment plants in Nzoia River Basin during the rainy season. During the rainy season, abundant drinking water supply is also available from other alternative sources like boreholes, protected dug wells, protected springs, rainwater harvesting, unprotected dug wells, unprotected springs and surface water (river, dam, lake, pond, stream, canal, irrigation channel); and this could reduce dependence on piped water supply leading to reduced production at treatment plants. In Nzoia River Basin, 78.8% of the residents depend on groundwater for domestic water supply. Increased amount of rainfall leads to increased groundwater recharge and rising groundwater levels at boreholes, wells and springs enabling residents to meet their domestic water supply requirements without turning to piped water supplies where the commodity is highly priced compared to these communal sources. This brings down demand for piped water supplies resulting into reduced production at treatment plants [46].

Some of the risks of climate change (rainfall) mentioned above in relation to flooding have identified adaptation measures in the basin. To reduce the severity of flooding in the basin, we need to protect water supply installations against flooding and the direct impact of increased flows. This should be done by protecting the water intake facilities, pumping stations, treatment plants and other inatallations exposed to flooding and landslides. Installation of water treatment plants of state of the art which can deal with decreased water quality due to climate change impact may also be required. Upgrading of existing treatment plants e.g. aeration facilities for ammonium oxidation; installation of pre-sedimentation ponds or river bank filters (water extraction from underground at river bank) for pre-treatment before releasing to the treatment plant is a measure worthy considering. In order to provide continuous and reliable power supply to our water supply installations, underground cables may have to be used in some areas. Identification and use of overhead transmission line routes less exposed to storm risks will also be considered. Installation of back-up power supply to water supply installations is recommended. Implementing some of these

measures will require a reliable knowledge base which is still a big problem in most county governments of the basin.

Looking at Fig. 2, Fig. 3 and Table.3; the other side of the relationship between monthly rainfall and monthly drinking water supply production is that reduced monthly rainfall results into increased monthly water supply production at treatment plants in Moi's Bridge, Lumakanda and Busia water supplies. This can be explained by a number of reasons as identified by this study. Reduced rainfall comes with reduced sediment loads in streams making raw water treatment less complicated and with use of less chemicals. There will be few hazards and disasters that may affect power supply to water supply installations as well as damage to water infrastructure. Reduced rainfalls come with drought conditions and there will be reduced water flows at the alternative water supply sources. Groundwater recharge is reduced with low rainfall. These factors compel the inhabitants of Nzoia River Basin to use more piped water supply resulting into increased production at the treatment plants during the low rains period. Reduced rainfall may lead to decreased river flows which has to be managed in terms of lower water tables that leaves the intake facilities hanging and not being able to collect water for the pumping stations or gravitation to the treatment plants due to the reduced pressure head.

3.1.1 Annual rainfall and annual water produced at treatment plants

Fig.4 shows the average annual rainfall trends for Leissa Farm Kitale, Webuye Agricultural Office and Bunyala Irrigation Scheme with 31 years data covering the period 1970 to 2001. The parametric test of linear regression has been applied to the stations to show the trend, intercepts, slopes and regression lines and the results are as follows; Leissa Farm Kitale annual mean rainfall from 1970 to 2001 was found to be 82.23 mm. The lowest and highest recorded rainfall in the period was 48.60 (1976) and 114.03 (1998) mm per year, respectively. Rainfall at Leissa Farm Kitale has been increasing over the years at the rate of 1.0325 mm/31 years (0.033 mm/ year). The increase in rainfall shows a statistically insignificant trend. Webuye Agricultural Office annual mean rainfall from 1970 to 2001 was found to be 131.91 mm. The lowest and highest recorded rainfall in the period was 62.42 (1988) and 190.32 (1977) mm per year, respectively. Rainfall at Webuye Agricultural

Office has been decreasing over the years at the rate of - 0.8994 mm/31 years (-0.029 mm/ year). The decrease in rainfall shows a statistically insignificant trend. Bunyala Irrigation Scheme annual mean rainfall from 1970 to 2001 was found to be 92.16 mm. The lowest and highest recorded rainfall in the period was 69.48 (1987) and 121.33 (1999) mm per year, respectively. Rainfall at Bunyala Irrigation Scheme has been increasing over the years at the rate of 0.5245 mm/31 years (0.017 mm/ year). The increase in rainfall shows a statistically insignificant trend.
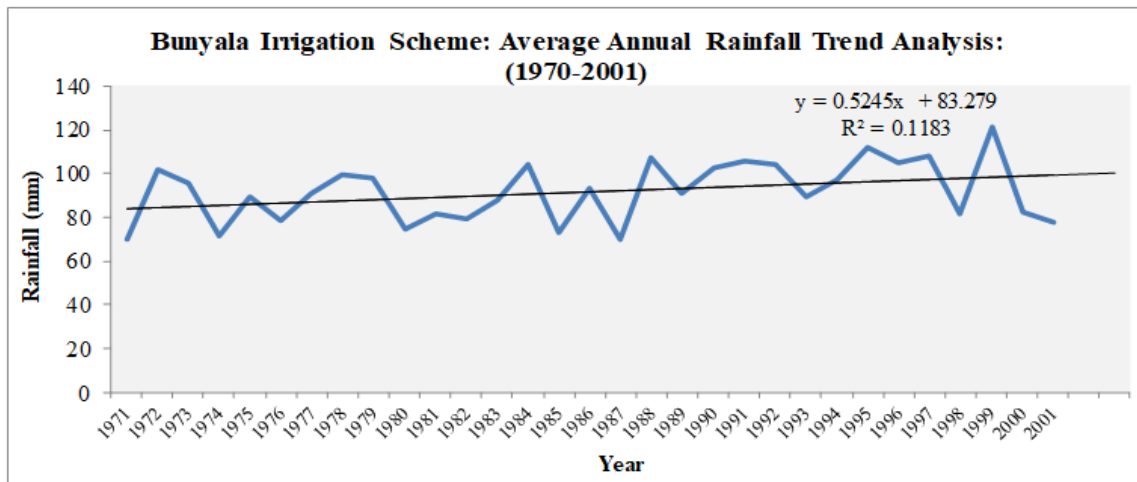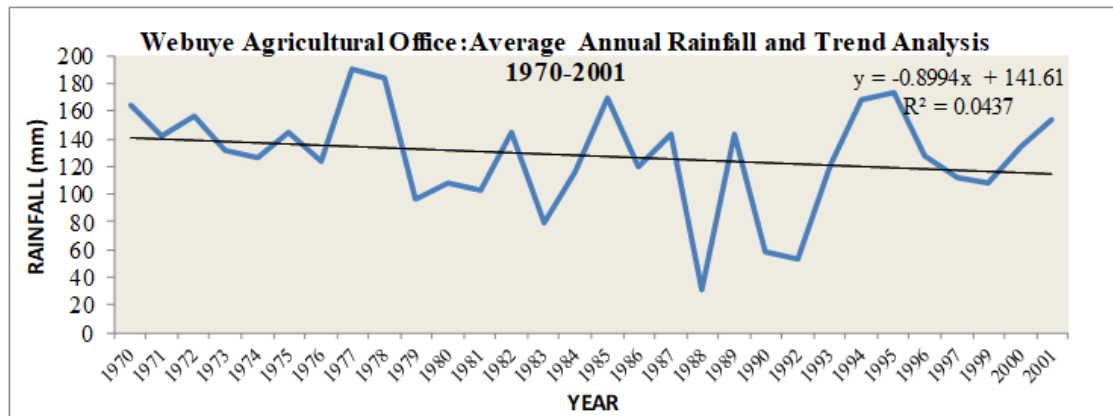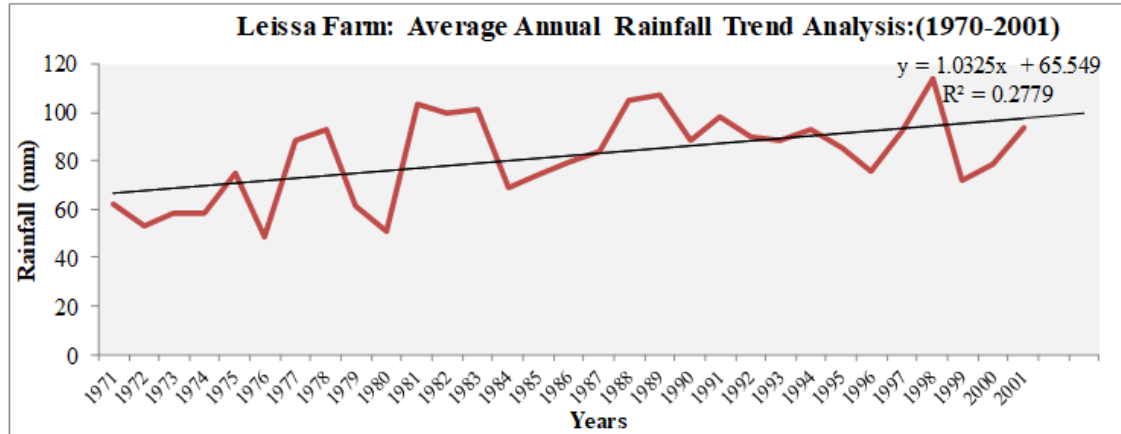

Fig 4. Average annual rainfall trends for selected rainfall stations within Nzoia River Basin, Kenya

There is variation in annual rainfalls within the three rainfall stations with some recording declining and others increasing rainfall trends (Table. 4). Using the parametric test of Linear regression analysis on annual rainfall; one station; Webuye Agricultural Office showed declining rainfall at 0.8994 mm/31 years (-0.029 mm/ year). The remaining two stations; Leissa Farm Kitale 1.0325 mm/31 years (0.033 mm/ year) and Bunyala Irrigation Scheme 0.5245 mm/31 years (0.017 mm/ year) had increasing rainfalls.The implication of increasing and decreasing trends in rainfall is a signal of climate change and could pose future challenges in water resources availability and access in the basin. 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. Accurately predicting rainfall trends is vital in the economic development of the basin. The results here highlighted a mix of positive (increasing) and negative (decreasing) trends in annual rainfall. Rahman and Begum [47] noted that ''predicting trends using precipitation time series data is more difficult than predicting temperature trends''.

Throughout the latter half of the century, the Fourth Intergovernmental Panel on Climate Change (IPCC) recorded temporal and spatial variation in precipitation patterns across Asia [48]. Rainfall is the most important factor influencing stream flow changes and human activities in the Nzoia River Basin; therefore, studying the spatial-temporal distribution features of rainfall is critical in understanding drought-climate changes, as well as providing a climatic foundation for drought-flood monitoring and estimation of the basin's hydrological conditions. When the change of sequence trend becomes more obvious, tendency can be intuitively judged by using the change curves. But, when there is no obvious trend change, this intuitive judgment is not reliable, so we need to use statistical methods such as Mann-Kendall test to solve the problem.

3.1.2 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 3 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. 5. 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. The Mann Kendall test Statistic (S) indicates that there is an increasing rainfall trend for Leissa Farm Kitale and Bunyala Irrigation Scheme; and reducing rainfall trends for Webuye Agricultural Office. 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., [49] used Mann Kendall method and regression analysis to examine the long-term variation of annual rainfall in Shapotou area. When running the Mann-Kendall statistical test, if the p value is less than the significance level $\alpha = 0.05$, Ho, (there is no trend), hence, the hypothesis is not accepted. Rejecting Ho indicates that there is a trend in the time series, while accepting Ho indicates no trend is detected. Rejecting the null hypothesis implies that the result is said to be statistically significant at $\alpha = 0.05$ level of significance.

For this test result, the null hypothesis is accepted for Leissa Farm Kitale, Webuye Agricultural Office and Bunyala Irrigation Scheme. In these stations, annual rainfall has shown no trend as the computed p-value is greater than the significance level $\alpha = 0.05$ (Table 5) and the result is statistically insignificant. Of the three stations, none showed a statistically significant trend through the MK test at 5% level of significance. All the three stations showed statistically insignificant trends.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 6. Table.6 shows a comparison of the results of Linear regression analysis and the Mann-Kendall test statistic (S) applied to the selected three rainfall stations with 31 years data covering the period 1970 to 2001 in Nzoia River Basin. Leissa Farm Kitale and Bunyala Irrigation Scheme recorded increasing rainfalls under both Linear regression analysis and the Mann-Kendall test statistic (S). Webuye Agricultural Office recorded decreasing rainfalls under both Linear regression analysis and the Mann-Kendall test statistic (S). By analyzing the temporal-spatial variation of rainfall, the prediction of rainfall change in Nzoia River Basin will be more accurate in future and this will provide a reliable basis for anchoring rational development and utilization of water resources for various purposes such as domestic water supply, agricultural, industrial, etc, uses. Based on the above results, it is of immense importance to discuss the ecological, economic, and social impacts affecting household domestic water supply that could result if the observed increasing and decreasing rainfall trends continue in various parts of Nzoia River Basin.

This study results follow the same statistical trends and are consistent with what has been reported by Githui, [50] for Nzoia River Basin where she found that most of the rainfall stations with increasing rainfall were in the upstream part of Nzoia River. These changes in rainfall patterns could lead to further water-related disasters in Nzoia River Basin in the near future, such as droughts and floods. Global climate shifts, forest loss, land use changes and practices (e.g., irrigated agriculture), and increased aerosols from anthropogenic activities are all potential causes of changing rainfall trends. The wide range of negative and positive trends observed at different rainfall stations in the basin highlights the need for more comprehensive climate change research in Nzoia River Basin.

The mean annual water supply production at Moi's Bridge, Lumakanda and Busia water supplies between 2000 and 2014 was 142,075, 88,875 and 744,042 m^3/year respectively. The lowest annual production at Moi's Bridge was 120,129 m^3/year (2000); Lumakanda, 42,292 m^3/year (2010); and Busia, 455,171 m^3/year (2000). The highest annual production at Moi's Bridge was 161,130 m^3/year (2012); Lumakanda, 129,519 m^3/year (2005); and Busia, 1,072,506 m^3/year (2011). Total water supply production at Moi's Bridge, Lumakanda and Busia water supplies between 2000 and 2014 was 2,131,130 m^3/15 years 1,333,125 m^3/15 years and 11,160,630 m^3/15 years respectively (Table7).

Fig.5 shows mean annual drinking water supply production trend at Mois Bridge, Lumakanda and Busia water supplies treatment plants between 2000 and 2014, a graph with a positive trend line was also obtained, showing that water supply increased with time from 2000 to 2014. The World Bank water and sanitation programme has rehabilitated most of the urban water supplies in the basin.

Mois Bridge and Busia water supplies have had their intake works, treatment works and distribution networks rehabilitated and expanded. Lumakanda has had a new water supply system constructed with the intake works on Kipkaren river to boost production. These World Bank water and sanitation programme works are responsible for the observed increasing trend in water supply production between 2000 and 2014. Within the same period, the population in these urban centres has also increased rapidly and this has lead to increased water demand. With the changing climate, temperatures in the basin are becoming warmer and this also increases the consumption of water by people, animals, and plants to maintain their health. Kenya's new Constitution (Constitution of Kenya 2010) went into effect in 2013, proclaiming water supply and sanitation services to be a fundamental right and delegating essential water and sanitation tasks to counties. The constitution's Fourth Schedule lays forth the division of powers between the national government and the county governments. Water and sanitation services, storm water management in "built-up regions," and solid waste management are among the tasks and powers of county governments, according to

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

Rainfall station	Rainfall trend	Slope (Rate of change)		R^2
Leissa Farm Kitale	Increasing	1.0325 mm/31 years	0.033 mm/ year	0.2779
Webuye Agricultural Office	Decreasing	- 0.8994 mm/31 years	-0.029 mm/ year	0.0437
Bunyala Irrigation Scheme	Increasing	0.5245 mm/31 years	0.017mm/ year	0.1183

Table 5. Results of the Mann-Kendall test for 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**
Leissa Farm Kitale	20.000	0.022	9120.667	0.8423	0.05	Accept Ho Statistically insignificant trend
Webuye Agricultural Office	-63.000	-0.127	3801.667	0.315	0.05	Accept Ho Statistically insignificant trend
Bunyala Irrigation Scheme	113.000	0.243	3461.667	0.057	0.05	Accept Ho Statistically insignificant trend

Table 6. Comparing Linear regression analysis and Mann-Kendall test statistic (S) results for Annual Rainfall for 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	
Leissa Farm Kitale	20.000	Increasing	1.0325	Increasing	Accept Ho Statistically insignificant trend
Webuye Agricultural Office	-63.000	Decreasing	- 0.8994	Decreasing	Accept Ho Statistically insignificant trend
Bunyala Irrigation Scheme	113.000	Increasing	0.5245	Increasing	Accept Ho Statistically insignificant trend

Table 7. Mean annual drinking water supply production at Mois Bridge, Lumakanda and Busia water supplies treatment plants in Nzoia River Basin, Kenya

| Year	Upper Catchment	Middle Catchment	Lower Catchment
	Mean annual drinking water supply production at Mois Bridge Water Supply (m3/Year)	Mean annual drinking water supply production at Lumakanda Water Supply (m3/Year)	Mean annual drinking water supply production at Busia Water Supply (m3/Year)
2000	120,129	57,151	455,171
2001	121,023	59,699	533,953
2002	123,015	57,813	557,420
2003	121,137	53,935	550,672
2004	144,010	59,457	502,034
2005	132,142	42,292	613,841
2006	140,056	93,848	637,320
2007	142,087	87,904	827,155
2008	147,129	89,941	766,632
2009	150,023	128,116	921,240
2010	155,141	129,519	1,011,360
2011	160,001	122,935	1,072,506
2012	161,130	124,755	807,554
2013	153,022	125,396	940,812
2014	161,085	100,364	962,960
Total Production from 2000 to 2014	2,131,130	1,333,125	11,160,630
Mean Annual	142,075	88,875	744,042
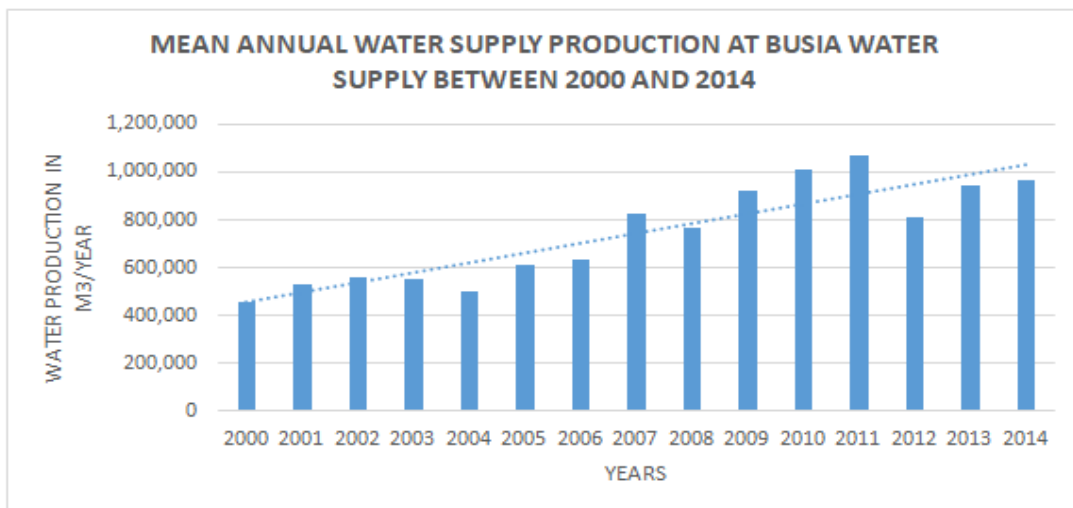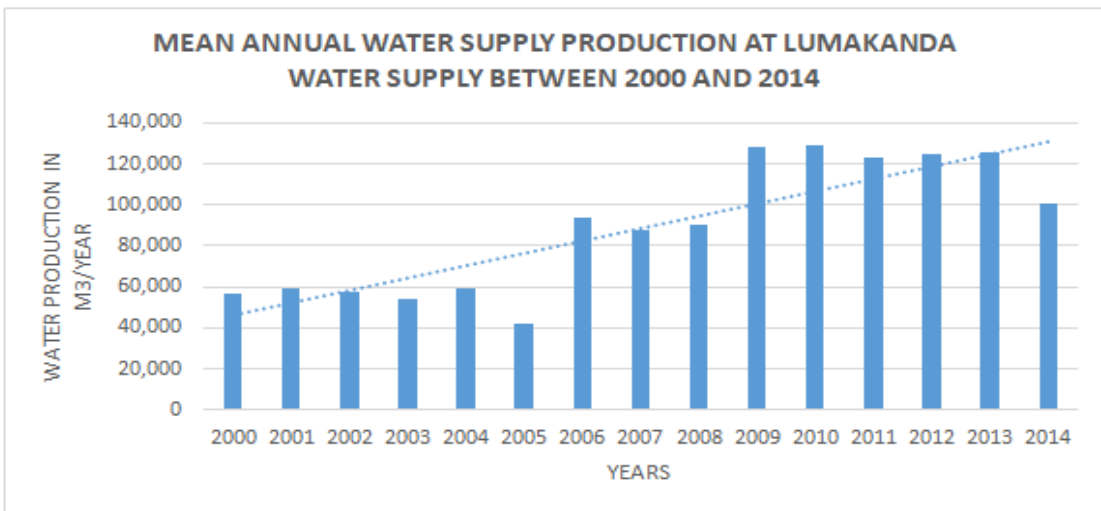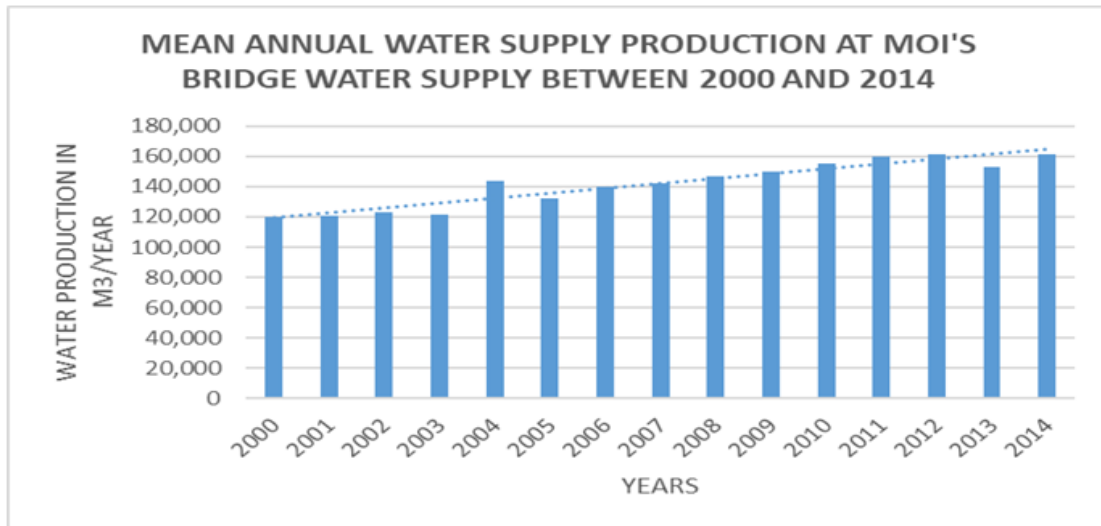
Fig. 5. Mean annual drinking water supply production trend at Mois Bridge, Lumakanda and Busia water supplies treatment plants in Nzoia River Basin, Kenya

Sections 2 and 11 of Kenya's 2010 Constitution's Fourth Schedule [51]. The national government is responsible for formulating policy and regulation for water resource management, while counties are responsible for implementing these policies, according to Section 22 of the Fourth Schedule. Under this new dispensation, the county governments have put exerted efforts in supplying water to their residents and these efforts can be manifested in the graphs between 2013 and 2014.

4. CONCLUSION

In this study, we have investigated rainfall variability and trends for 3 rainfall stations in Nzoia River Basin; Leissa Farm Kitale, Webuye Agricultural Office and Bunyala Irrigation Scheme and its impact on water supply production at Moi's Bridge, Lumakanda and Busia water supplies treatment plants. Trend in annual rainfall shows Webuye Agricultural Office recording declining rainfall at -0.8994 mm/31 years (-0.029 mm/ year); whereas Leissa Farm Kitale shows increasing rainfall at 1.0325 mm/31 years (0.033 mm/ year) and Bunyala Irrigation Scheme's rainfall is increasing at 0.5245 mm/31 years (0.017 mm/ year). Water supply production at Moi's Bridge, Lumakanda and Busia water supplies has been increasing with time between 2000 and 2014, but the results of Pearson moment correlation coefficient shows a strong negative relationship between monthly rainfall and monthly water supply production for Moi's Bridge, Lumakanda and Busia water supplies. This shows that as rainfall increases, water supply production in treatment plants at Moi's Bridge, Lumakanda and Busia water supplies decreases and vice versa. Increased rainfalls come with operational problems that result into reduced water supply production at treatment plants. Water supply production at Moi's Bridge, Lumakanda and Busia water supplies treatment plants is not only determined by rainfall variability, but by a number of other factors that work alongside rainfall variability such as water treatment challenges resulting from increased turbidity, changed environmental conditions facilitating damage to water infrastructure and other related operational logistics. The County governments in Nzoia River Basin should put in place proper mitigation and adaptation strategies for the observed rainfall variability and trends to minimize its impacts on water supply production at treatment plants, hence, the results of this study provide a useful basis on which the management of water supplies in the basin can be anchored.

CONSENT AND ETHICAL APPROVAL

Concerning ethical considerations, this study ensured that ethical values are not violated by closely adhering to ethical guidelines for conducting research. After the approval of the research proposal, the researcher sought for written permission from Masinde Muliro University of Science and Technology, Directorate of postgraduate studies. The researcher also through the Directorate of postgraduate studies applied to National Council for Science, Technology and Innovation (NACOSTI) for research permit and authorization to collect data in Trans Nzoia, Kakamega and Busia counties. The researcher also requested and was granted permission by the County Commissioners of Trans Nzoia, Kakamega and Busia counties; and the County Directors of Education, Trans Nzoia, Kakamega and Busia counties, for further permission to conduct research in their areas of jurisdiction. Ethics pertaining to identification, disclosure understanding, deception, informed consent, confidentiality, right to privacy and anonymity were pertinent to the study and therefore upheld. The researcher ensured that participants had informed consent at individual level and the respondent participation in the study was made without coercion. They were given adequate information about the study which included: the main objectives of the study; expected duration of participation and procedures to be followed and the benefits of the study to them. The purpose of the study was explained by the researcher as purely academic. This information formed the basis on which the selected respondents made an informed decision to participate in the study. They were also informed of their right to withdraw from the study at any stage if they felt they would no longer continue with the interview. The respondents were assured of confidentiality and complete freedom in answering the questions. The participants were informed that the study findings would be published and this published report will keep the participants' identities confidential. Other values that were adhered to by the researcher during the study were avoidance of psychological harm to respondents by not asking demeaning questions. Finally the researcher remained objective and assured that findings, conclusions and recommendations were based solely on data rather than personal feelings and prejudices.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERANCES

1. Gautam M. Managing drought in sub-Saharan Africa: Policy perspectives. In Proceedings of the 2006 Drought: Economic Consequences and Policies for Mitigation at the IAAE Conference, Queensland, Australia; 2006.
2. Lenderink G, Buishand A, Van Deursen W. Estimates of future discharges of the river Rhine using two scenario methodologies: Direct versus delta approach. Hydrology. Earth Syst. Sci. 2007;11:1145–1159.
3. May W. Potential future changes in the characteristics of daily precipitation inEurope simulated by the HIRHAM regional climate model. Climatol. Dyn. 2008;30:581–603.
4. Vrochidou AEK, Tsanis IK, Grillakis MG, Koutroulis AG. The impact of climate change on hydrometeorological droughts at a basin scale. J. Hydrol. 2013;476:290–301.
5. Georgakakos A, Fleming P, Dettinger M, Peters-Lidard C, Terese TC, Richmond K, Reckhow K, White D. Ch. 3: Water Resources. In Climate Change Impacts in the United States: The Third National Climate Assessment; Melilo JM, Richmond T, and Yohe GW, Eds. U.S. Global Change Research Program: Washington, DC, USA. 2014;69–112.
6. Calow R, MacDonald C, Nicol M, Robins NS. Groundwater security and drought in Africa: Linking availability access and demand. J. Ground Water. 2010;48;246–256.
7. Kostyla C, Bain R, Cronk R, Bartram J. Seasonal variation of faecal contamination in drinking water sources in developing countries: A systematic review. Sci. Total Environ. 2015;514:333–343.
8. Conway D, Aurelia P, Sandra A, Hamisai H, Claudine D, Gil M. Rainfall and water resources variability in Sub Saharan Africa during the 20th century. J. Hydrometeorol. 2008;10:41–59.
9. Onyenechere EC, Azuwike DO, Enwereuzor AI. Effect of rainfall variability on water supply in Ikeduru, L.G.A of Imo State, Nigeria. Int. Multidiscip. J. 2011;5:223–241.
10. Nyakundi RM, Makokha M, Mwangi JK, Obiero C. Impact of Rainfall Variability on Groundwater Levels in Ruiru Municipality. Afr. J. Sci. Technol. Innov. Dev. 2014, 7, 329–335.
11. Kwon HH, Casey B, Kaiqin X, Upmanu L. Seasonal and annual maximum streamflow forcasting using climate information: Application to the Three Gorges Dam in Yangtze River basin, China. Hydrol. Sci. J. 2009;54:582–595.
12. Oteze GE, Fayose SA. Regional development in the Hydrogeology of the Chad basin. Water Resour. 1998;1:9–29.
13. McDonald AT, Kay D. Water resources: Issues and strategies; Longman Scientific & Technical, Wiley: Harlow, UK;1988.
14. Kabat P, Van Schaik H. Climate Change the Water Rules: How Water Managers Can Cope with Today's Climate Variability and Tomorrow Climate Change.World Water Assessment Programme. In World Water Development Report; World Water Assessment Programme; UNESCO: Paris, France;2003.
15. Jimenez Cisneros BE, Oki T, Arnell NW, Benito G, Cogley JG, et al. Freshwater resources. In ´Climate Change 2014: Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects (Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change), ed. CB Field, VR Barros, DJ Dokken, KJ Mach, MD Mastrandrea, et al., 2014;229–69. Cambridge, UK: Cambridge Univ. Press.
16. WHO. Guidelines for Drinking Water Quality. Geneva, Switz.: WHO. 4th ed;2011.
17. Hunter PR, Zmirou-Navier D, Hartemann P. Estimating the impact on health of poor reliability of drinking water interventions in developing countries. Sci. Total Environ. 2009;407:2621–24
18. Howard G, Charles K, Pond K, Brookshaw A, Hossian R, Bartram J. Securing 2020 vision for 2030: climate change and ensuring resilience in water and sanitation services. J. Water Climate. 2010;1(1):2–16
19. Vorosmarty VJ, McIntyre PB, Gessner MO, Dudgeon D, Prusevich A, et al. Global threats to ¨ human water security and river biodiversity. Nature. 2010;467:555–61
20. Delpla I, Jones TG, Monteith DT, Hughes DD, Baures E, et al. Heavy rainfall impacts on ` trihalomethane formation in

contrasting northwestern European potable waters. J. Environ. Qual. 2015;44(4):1241–51.

21. Roman R, Bilbao J, De Miguel A. Reconstruction of six decades of daily total solar shortwave irradiation in the Iberian Peninsula using sunshine duration records. Atmos. Environ. 2014;99:41–50.

22. El Kenawy A, Lopez-Moreno JI, Stepanekc P, Vicente-Serrano SM. An assessment of the role of homogenization protocol in the performance of daily temperature series and trends: Application to northeastern Spain. Int. J. Climatol;2013.

23. Bilbao J, De Miguel A, Ayuso A, Franco JA. Iso-radiation maps for tilted surfaces in the Castile and Leon region, Spain. Energy Convers. Manag. 2003;44:1575–1588.

24. Miguel A, Bilbao J, Román R, Mateos D. Measurements and attenuation of erythemal radiation in Central Spain. Int. J. Climatol. 2003;32:929–940.

25. Gocic M, Trajkovic S. Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. Glob. Planet. Chang. 2013;100:172–182.

26. Kundzewicz ZW. Change detection in hydrological records – a review of the methodology. Hydrol. Sci., J., 2004;49(1):7–19.

27. Sen PK. Estimates of the regression coefficient based on Kendall's tau. J. Am. Stat. Assoc., 1968;63:1379–1389.

28. Caloiero T, Coscarelli R, Mancini M. Trend detection of annual and seasonal rainfall in Calabria (Southern Italy). Int. J. Climatol. 2011;31:44–56.

29. Li J, Zhu Z, Dong W. Assessing the uncertainty of CESM-LE in simulating the trends of mean and extreme temperature and precipitation over China. Int. J. Climatol. 2017;37:2101–2110.

30. Yang P, Xia J, Zhang Y, Hong S. Temporal and spatial variations of precipitation in Northwest China during 1960–2013. Atmos. Res. 2017;183:283–295.

31. Fan JQ, Yao QW. Nonlinear Time Series: Nonparametric and Parametric Methods (Springer Series in Statistics). Springer-Verlag, New York;2003.

32. Sneyers R. On the Statistical Analysis of Series of Observations; WMO Technical Note 143, WMO No. 415, TP-103; World Meteorological Organization: Geneva, Switzerland, 1990;192.

33. Gilbert RO. Statistical Methods for Environmental Pollution Monitoring; Van Nostrand Company: Hoboken, NJ, USA, 1987;320.

34. Sayemuzzaman M, Mekonnena A, Jha MK. Diurnal temperature range trend over North Carolina and the associated mechanisms. Atmos. Res. 2015;160:99–108.

35. Espadafor M, Lorite IJ, Gavilán P, Berengena J. An analysis of the tendency of reference evapotranspiration estimates and other climate variables during the last 45 years in Southern Spain. Agric. Water Manag. 2011;98:1045–1061.

36. Mann HB. Non-Parametric Tests against Trend. Econometrica, 1945;13:245-259

37. Kendall MG. Rank Correlation Measures. Charles Griffin, London;1975.

38. Del Rio S, Cano-Ortiz A, Herrero L, Penas A. Recent trends in mean maximum and minimum air temperatures over Spain (1961–2006). Theor. Appl. Climatol. 2012;109:605–626.

39. Keredin TS, Annisa M, Surendra B, Solomon A. Long years comparative climate change trend analysis in terms of temperature, coastal Andhra Pradesh, India. Refer J Res Sci Technol 2013;2(7). ISSN 2277-1174

40. Pearson K. Early Statistical Papers. Cambridge, England: University Press; 1948.

41. Burns N, Grove S. The Practice of Nursing Research: Conduct, Critique, and Utilization (5 ed.). St. Louis: Elsevier Saunders;2005.

42. Polit D Beck C. Essentials of Nursing Research: Methods, Appraisal, and Utilization (6 ed.). Philadelphia: Lippincott Williams & Wilkins;2006.

43. Okoola RE. Space – Time characteristics of the ITCZ over equatorial East Africa during anomalous rainfall years. PhD. Thesis, 1996. Department of Meteorology, University of Nairobi, Kenya.

44. Mistry VV, Conway D. Remote forcing of East African rainfall and relationship with fluctuations in levels of Lake Victoria. Int J Clim 2003;23:67–89

45. Nicholson SE. A review of climate dynamics and climate variability in Eastern Africa. In: TC Johnson, EO Odada (eds) The limnology, climatology and palaeoclimatology of East African Lakes. Gordon and Breach, Melbourne, Australia. 1996;25–56.

46. Odwori EO. Climate change and Domestic water supply in Nzoia River Basin, Kenya. PhD. Thesis. Department of Disaster Management and Sustainable Development, Masinde Muliro University of Science and Technology, Kakamega, Kenya;2021.

47. Rahman MD, Begum M. "Application of non parametric test for trend detection of rainfall in the largest Island of Bangladesh," ARPN Journal of Earth Sciences. 2013;2(2):40–44.

48. IPCC. "Synthesis Report. Contribution of Working Group I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on climate change Core writing team. In: Pachauri RK, Reisinger A (eds).," Cambridge Univ. Press 32 Ave. Am. New York, NY 10013-2473, USA. 2007;996.

49. Wang S, Wei H, Zheng X. Trend of runoff and mutation analysis in Weihe River basin [J].Water Resources Reserch, 2008;03:1-2.

50. Githui FW. Assessing the impacts of environmental change on the hydrology of the Nzoia catchment, in the Lake Victoria Basin. PhD Thesis. Department of Hydrology and Hydraulic Engineering, Faculty of Engineering, Vrije Universiteit Brussel Pleinlaan 2 1050 Brussels;2008. Available:http://www.mendeley.com.

51. GOK. Constitution of Kenya, Government printers, Nairobi, Kenya;2010.