Rainfall-Runoff Nexus in Mid-block of Yala Catchment

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Abstract

Understanding rainfall- runoff relationship in any watershed is key to proper management of the watershed and mitigating challenges including infrastructural damages, high cost of water treatment and loss of life. This paper establishes the rainfall–runoff relationship by considering discharges in the feeder streams of Zaaba, Edzava, and Garagoli rivers. ArcGiS was used to delineate the watersheds and ANN model used for results analysis. The research derived relationship of rainfall and runoff in the three watersheds with correlation coefficient R, of between 1 and 0.8 for the water sheds showing that the model is suitable and reliable.

Keywords: *ANN; ArcGIS; DEM; Rainfall; Runoff; River Yala watershed.*

I. INTRODUCTION

Planning and management of water systems heavily depends on the ability to understand and predict the hydrological variables such as stream flow and rainfall [1]. This research considered three river watersheds namely Edzava River watershed, Zaaba River Watershed and Garagoli River watershed all located in the mid-block section of Yala catchment. The three rivers are surface water sources for Mbale, Maseno and Kaimosi water treatment plants respectively in western Kenya. Trends of generated runoffs and established rainfall were used for rainfall-runoff model, a standard tool routinely designed for hydrological investigations for many purposes e.g detecting catchment response towards climatic events, estimation of design floods, management of water resources, estimation of the impact of land-use change, flood forecast and stream flow prediction [2]. In Kenya, most of the surface water sources like rivers and streams are key in supplying raw water to the treatment plants. In the recent past, evidence of floods, water related diseases and death, damage of infrastructures and With increasing human activities, none reliable rainfall and pressure on water resources, there is evidence of flood, loss of lives, damage to infrastructure and high cost of treating water for domestic use and drinking. Water quality is as important as its quantity, since it determines its suitability for various use [3]. The Lake Victoria Basin in western Kenya is the most flood-prone region in the country [4] which is caused by runoff generated from the catchment. Western Kenya is characteristically wet throughout the year with no distinctive dry season but with two high rainfall seasons experienced during the year [5]. The mean annual rainfall in western Kenya is above 1600 mm [6]. High runoff generated in Yala river basin are caused by intense storms upstream than the catchment can store or the main Yala river and its tributaries can carry within their normal channel [7], that leads to floods. Floods related fatalities constitute a whopping 60% of disaster victims in Kenya [8]. Catchment generated high runoff occurrence trends increasingly becoming a major concern to the country's socio-economic development due to the substantial economic and financial losses incurred to respond to frequent flood disasters.

Study area

The study area is located within River Yala basin in the Western Region of Kenya, and is within Lake Victoria North Catchment in Kenya (Fig.1). The basin is divided into three zones viz the upper, middle and lower catchment. The upper catchment falls in Nandi County, middle catchment falls in Kakamega and Vihiga counties of Western region and the lower catchment is found in Siaya County in Nyanza region [9]. The catchment is centered about 35º E- 0.1º N, and spreads over an areas of about 3,351 km^2[10]. The Yala River is one of the main Kenyan rivers draining into Lake Victoria, with a monthly average discharge of 27.4 m^3/s [11]. The basin acts as a buffer to Lake Victoria in terms of sediment loading into the lake.

The mid-block of River Yala basin experiences equatorial climate with well distributed rainfall. Long rains are experienced from the months of March to May, while short rains are experienced from the months of September to November with an average annual precipitation of 1900 mm. The rainfall ranges from 1800 to 2000mm, whereas the temperatures ranges from 14ºC to 32ºC, with a mean of 23ºC The driest and hottest months are from December to February. The average humidity experienced is about 41.75%. The feeder streams considered for this study area are Zaaba, Edzava, and Garagoli rivers. These streams serve the Water Supply treatment plants in Western of Kenya i.e Kaimosi, Mbale, and Maseno. . The dry periods in the area of study experiences shortages in drinking water supply, while during the wet months the water supplies experiences challenges with water quality received from the rivers. This calls for more understanding of the effects of weather to surface water.

Map of the research area

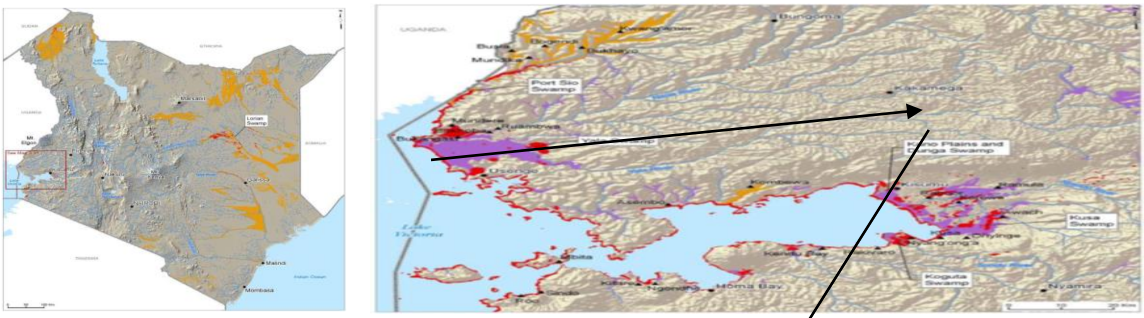

Figure 1: Map of Kenya and Lake Victoria Basin (Source World Resource Institute, 2006)

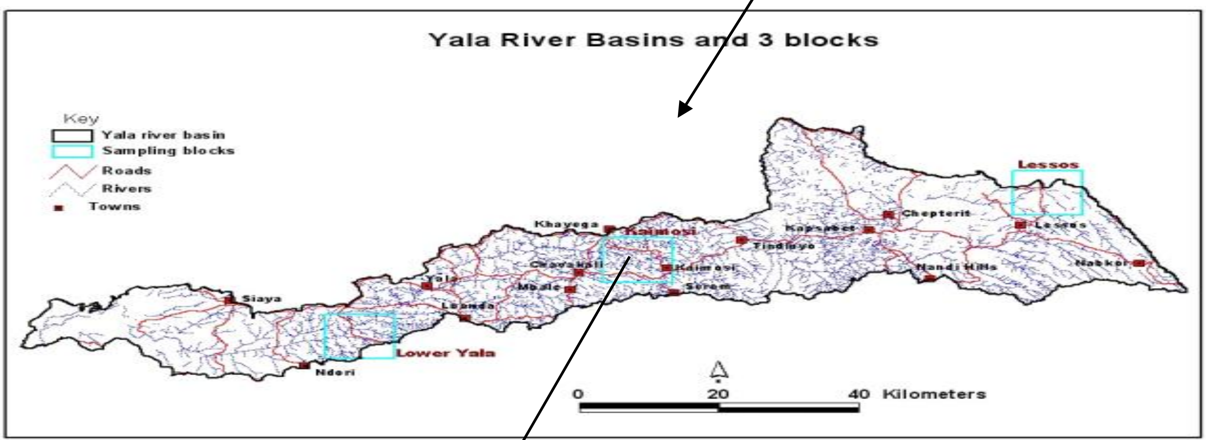

Figure 2: Map of the Yala River Basin,(From Yala & Nzoia river basin report, 2008)

Figure 3: The specific Water treatment plants in Vihiga (From Google earth July 2017)

II. METHODOLOGY

A watershed consists of all points enclosed within an area from which rain falling within these points contribute water which flows towards an outlet. There has been recognition of a catchment, drainage basin or water shed as the most significant surface unit for hydrological studies. Traditionally catchment boundaries have been manually derived from topographical maps and labour intensive activities. This limitation has changed by the introduction of the Digital Elevation Models (DEM) [12].

For this study, the watershed boundary, the length of the river and the areas of the watershed was generated from Yala River catchment shape file maps. The soil map was overlaid on ArcGiS. It was given spatial reference which was the same as the study area (WGS 1984 UTM Zone 37N) and a Digital Elevation Model (DEM) of 30m resolution—reference data set from Vihiga County Survey office (GIS Department) developed for the three river water sheds. The study area was then clipped from the rest of the soil map feature and attribute table of the study area embedded before it was changed to raster file and computation of areas and length of the river done.

The rainfall data and the respective runoff values generated were input into the ANN model and the simulated regression results were used to analyse the relationship whereby rainfall was an input variable while runoff the output parameter. In an ANN model, one of main tasks is to determine the model input variables that significantly affect the output variable(s). In this study, the input variable was rainfall and the output variable was the runoff generated. The records for the past 10 years between 2008 and 2017 was used in simulation of rainfall runoff for the three water sheds in the mid-block of Yala catchment.

The three river water sheds in this study were; Edzava, Garagoli and Zaaba where Mbale, Maseno, Kaimosi towns respectively are located as shown in the DEM map below in fig 4,5 and 6.

A. Input Data

The basic meteorological data requirements are precipitation, potential evapotranspiration and temperature. On this basis, the model produces a catchment runoff, water quality effects of the hydrological cycle. The reliable rainfall data was sourced from the following meteorological station i.e. Shamakhokho station ID-8934200.which is in River Garagoli sub-catchment of Yala, Sabatia station ID-8934150.which helped to cover Edzava river sub catchment and Vihiga D.C's Office station ID-8934213 for the period of 10 years i.e. from 2008 to 2017 was used for the modelling.

B. Secondary data

Secondary information was collected from secondary sources i.e. the demographic reports from Kenya National Bureau of Statics and rainfall from the meteorological department, River discharges from the Water Resources Management Authority.

C. Estimation of Missing Rainfall Data

This study utilized the normal ration method for estimation of the missing data. According to Suhaila, Sayang [13], the normal ratio method the missing precipitation is given as:

$$P_x = \frac{1}{n}\sum_{i=1}^{i=n}\frac{N_x}{N_i}P_i \quad \text{.........................} \quad \text{(Eq.1)}$$

Where Px is the missing precipitation for any storm at the interpolation station 'x', Pi is the precipitation for the same period for the same storm at the "ith" station of a group of index stations, Nx the normal annual precipitation value for the 'x' station and Ni the normal annual precipitation value for 'ith' station.

D. Data analysis

Rainfall-runoff analysis was done for the three river basins in the study area in the mid-block of Yala catchment. The daily rainfall data of four rain-gauge stations Kaimosi, Sabatia, Mbale and Kima/Luanda was used.

E. Run-off generated in the water sheds

Run off quantities were generated using rational method. $Q_p = CiA$ *Where*, *Qp* = peak flow (cfs),*C*= runoff coefficient i= rainfall intensity (mm/hr), *A* = catchment area [14]

The Rational Equation relates peak discharge to the runoff coefficient, rainfall intensity, and drainage area, based on watershed slope, land use, and hydrologic soil type.

The coefficient of runoff for the area of study was taken to range from 0.1 to 0.16 considering the soil properties and catchment characteristics as outlined in Soil Group Coefficient Of runoff [15]

III. RESULTS AND DISCUSSIONS

The respective river watersheds were delineated and their respective maps presented in the figure as discussed.

A. Catchment delineation

From the DEM of Edzava, the watershed covers an approximate area of 152km^{2}and draining two Sub-Counties in Vihiga County namely Hamisi and Sabatia. The river also covers the longest length of 32.344km. Zaaba Water shed covers an approximate area of 79.51km^{2}and draining three Sub-Counties in Vihiga County namely Vihiga, Emuhaya and Luanda and covering a total longest length of 9.423km. Garagoli Water Shed covers an approximate area of 34.04km^{2}and draining the Nandi forest through Hamisi Sub-County to Yala River and covering a total longest length of 17.118km.

B. DEM of the River Water sheds

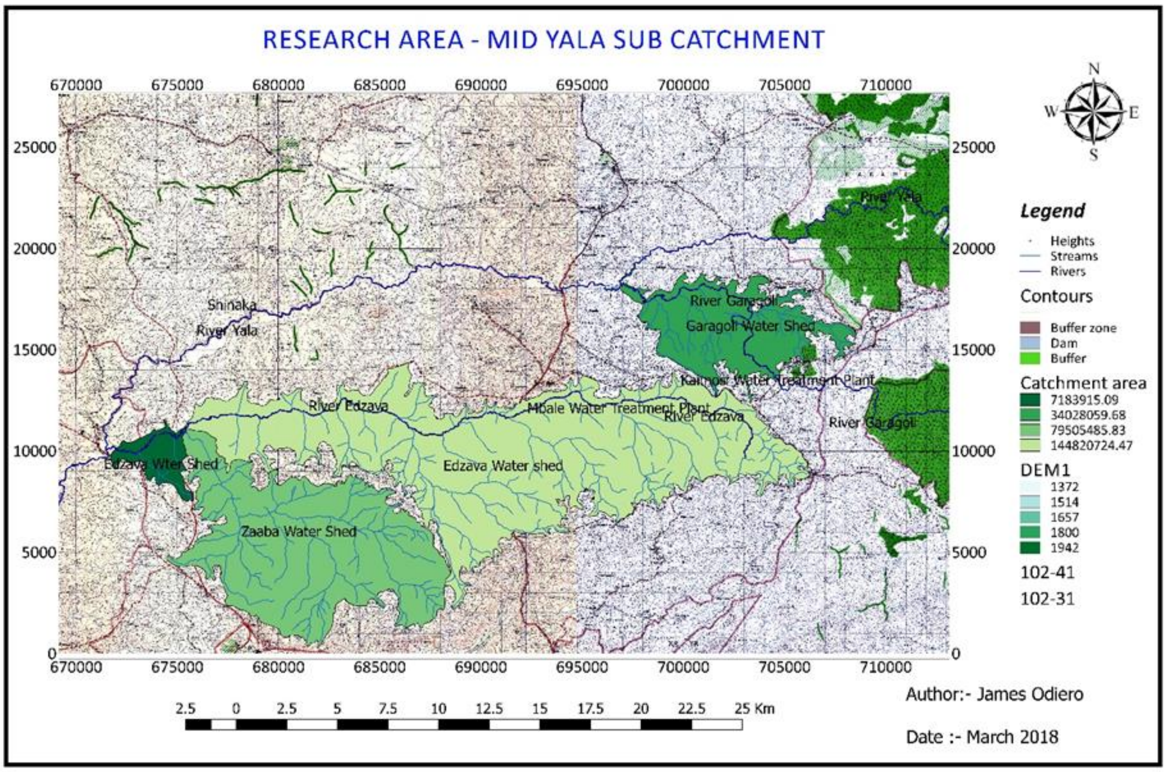

Figure 4: Research area DEM

1. Edzava River Water Shed.

The area is in the middle between Garagoli and Zaaba. It has two urban centers i.e. Mbale and Chavakali. Mbale is the headquarters of Vihiga County and has many Government institutions like the County general Hospital and High schools which have high demand of water. The two centers are separated and drained by river Edzava which also is a source of raw water for Mbale Water supply treatment plant.

The river flows south west and drains to Yala River. It emerges from the areas of Senende, Kalwani and Mago with small tributaries i.e. Digoi and other small streams that feeds Edzava river.

From the DEM of Edzava, the watershed covers an approximate area of 152km^{2}and draining two Sub-Counties in Vihiga County namely Hamisi and Sabatia.

The water quality of the water shed is among the highest priorities as it is a source of water particularly for drinking. Runoff from the agriculture activities, largely tea and maize farming and urban areas of Mudete, Chavakali and Mbale are increasingly affects the water quality. During the period of study the area also lacked proper sewerage facilities to cater for high organic loading from the urban set ups.

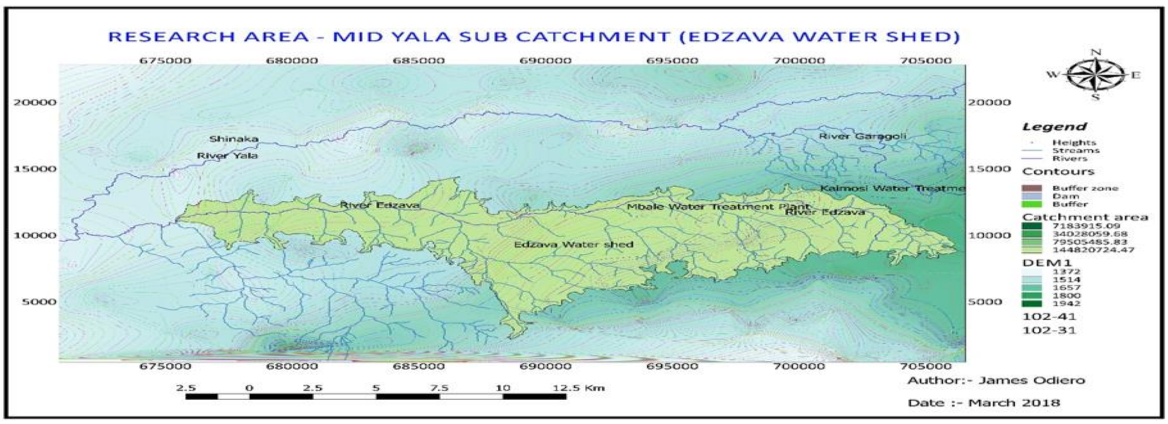

Figure 5: Delineated DEM for Edzava river watershed

2. Zaaba River Water shed

This water shed, is in the lower side towards the end of the mid-block in Vihiga County. The Major urban set up in the area are Kima center, Emuhaya Sub-County offices and Luanda market. The river that drains this area is Zaaba River which as well joins Edzava just before draining to River Yala. The River also is a source of raw water for Maseno treatment plant. The water supply serves the areas of Emuhaya, Luanda and Maseno University.

From the DEM of Zaaba water shed, it covers an approximate area of 79.51km^{2}and draining three Sub-Counties in Vihiga County namely Vihiga, Emuhaya and Luanda.

Because of its position in the lower region, its turbidity is normally high during rainfall periods.

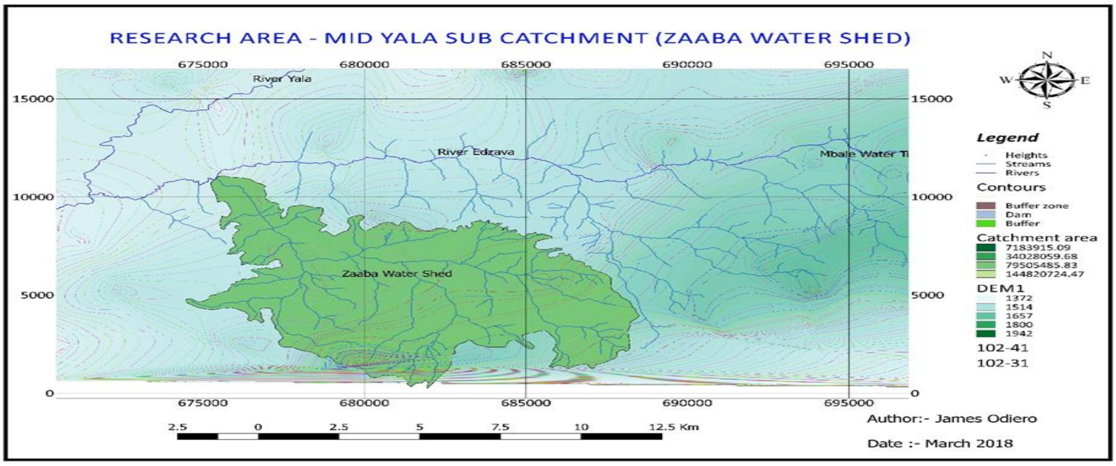

Figure 6: Delineated DEM for Zaaba river watershed

3. Garagoli River Water Shed

This sub-basin is in the upstream of the study area. It is being drained by river Garagoli which flows into a Kaimosi reservoir. The water supply treatment plant derives its water from the reservoir and serves on one side, Kaimosi complex which has major institutions among them being a University, Teachers College, and Polytechnic, High school, Jumuia Hospital and a number of primary schools. On the other side it serves the areas of Shamakhokho urban center and the surrounding. Also there are institutions and schools besides the individual residential customers.

From the DEM of Zaaba water shed, it covers an approximate area of 34.04km^{2}and draining the Nandi forest and through to Yala river.

The sub-basin is characterized by high population and increased urbanization which is exerting pressure on the water resources. In addition, urbanization, deforestation and farming on riparian areas increase volume of runoff to rivers and thus affecting the quality and quantity of water. In addition during the period of study, the reservoir was silted and colonized by marine plants i.e. the reed and other water plants. This phenomenon has reduced the capacity of the reservoir and increasing the organic loading.

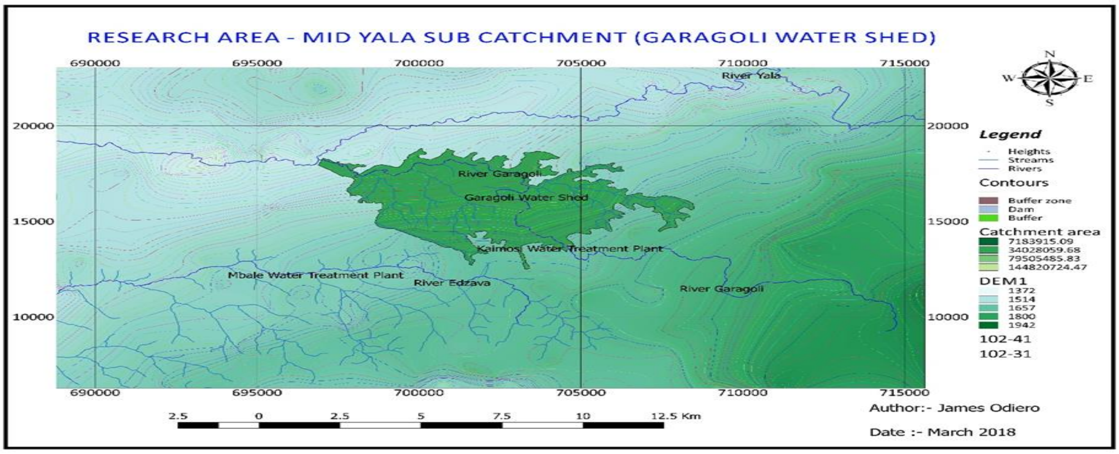

Figure 7: Delineated DEM for Garagoli river watershed

C. *Run-off generated in the water sheds*

The reliable rainfall data was sourced from the following meteorological station i.e. Shamakhokho station ID-8934200.which is in River Garagoli sub-catchment of Yala, Sabatia station ID-8934150.which helped to cover Edzava river sub catchment and Vihiga D.C's Office station ID-8934213 for the period of 10 years i.e. from 2008 to 2017 was used for the modelling. The advantages of using such an existing database are the followings: monthly data from 2008 to 2017, without gaps (gaps fillings are already done through spatialized analysis), the data uncertainty is not necessary higher than the measurements uncertainties of the observed rainfall, _ the data is spatialized.

The names of the River Water Shed, and the mean annual rainfall, are given in the following table.

Table 1
Watershed characteristics

Station ID	Station Name	Name	Area (KM^2)	Mean Annual Rainfall (mm)	Value at 95% Conf. Level
8934150	Sabatia Div. Office	Edzava	152	1,870	270
8934200	Shamakhokho	Garagoli	34.04	2168	260
8934213	Vihiga D.C. Office	Zaaba	79.51	1,889	280

From the records in the three stations, the rainfall recorded is higher in Garagoli with a mean annual rainfall averaged 10 years to be 2,168mm. Edzava and Zaaba seems to have similar rainfall patterns.

D. *Rainfall Data trends*

As shown in the graph below, the highest registered values were in April, October having over 550mm and 350mm respectively. The three water sheds being in the same and adjacent area in Yala catchment, the trends seems to be the same with Garagoli registering the highest rainfall. This may be attributed to the fact that it lies in the proximity of the Kakamega and Nandi forests.

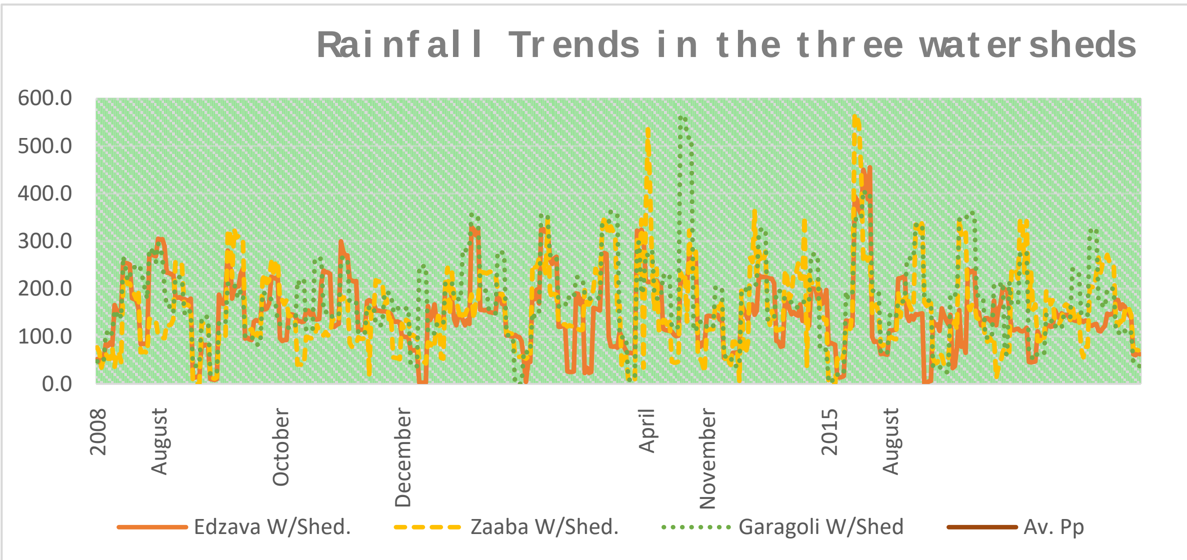

Figure 8: Rainfall trends in three watersheds

The rainfall and runoff peak and low values are as tabulated below

TABLE 2:
Rainfall and Runoff peak values

River water shed	Rainfall (mm)		Runoff (m^3/hr)	
	Peak	Month /Year	Peak	Month /Year
Edzava	455	May 2015	374	March 2013
Zaaba	566	April 2015	358	March 2013
Garagoli	562	August 2015	128	August 2015

Below is a plot of the each water shed cumulative probability at 95% confidence level Edzava watershed at 95% confidence level the value was approximately 270

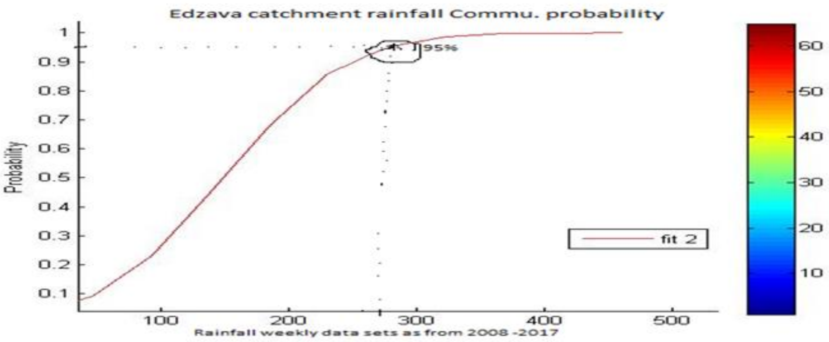

Figure 9: Edzava watershed Confidence level

Zaaba watershed at 95% confidence level the value was approximately 280

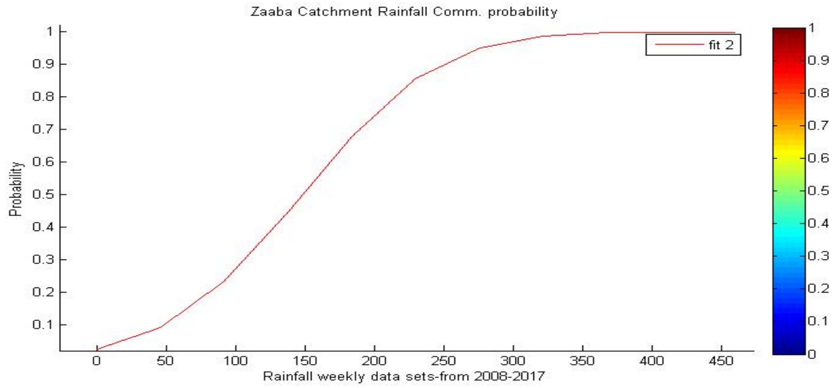

Figure 10: Zaaba watershed Confidence level

Garagoli watershed at 95% confidence level the value was approximately 260

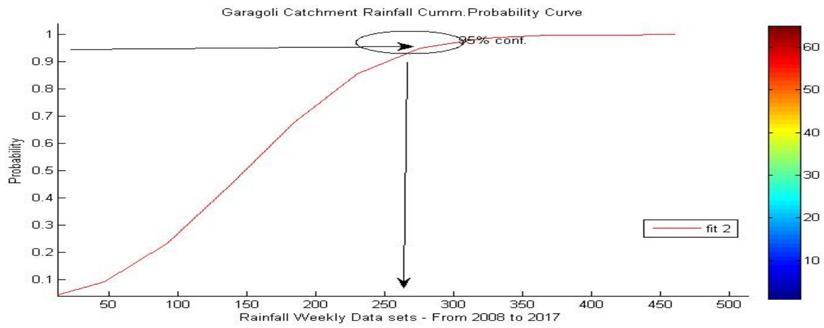

Figure 11: Garagoli watershed Confidence level

E. *Runoff generated*

The Rational Equation relates peak discharge to the runoff coefficient, rainfall intensity, and drainage area, based on watershed slope, land use, and hydrologic soil type.

The runoff peak months were April –June and August –October in each year as observed from the analysis. It is observed that Garagoli water shed has the highest runoff with over a total of 250m3 in April and September of every year.

The runoff trends are as follows:

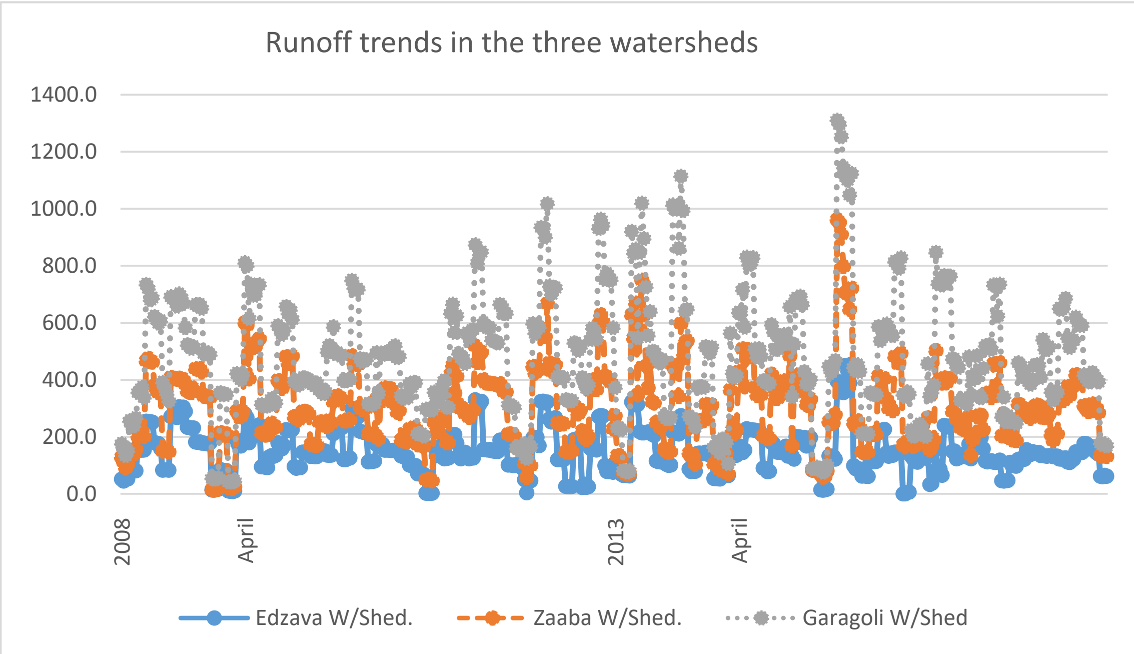

Figure 12: Runoff trends in the three watersheds

F. *ANN model simulation results*

1. *Edzava water shed simulation results*

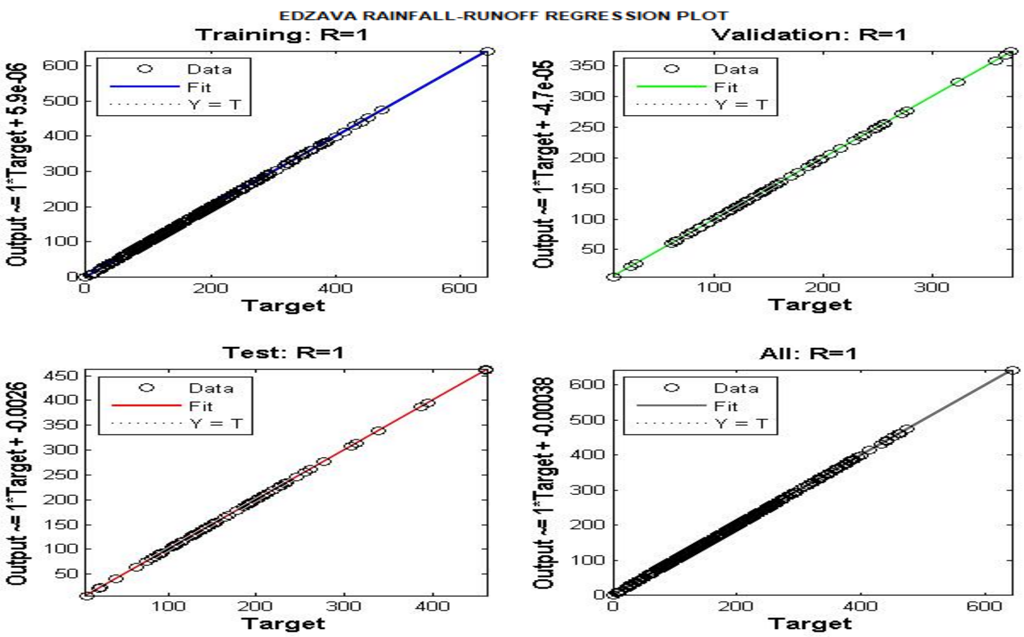

Figure 13: Edzava water shed regression plot

After simulation the rainfall and runoff produced a best fit regression with a coefficient of correlation, R of 1 for training, validation and testing.

In Edzava Watershed, the equation of relationship established in the model was therefore:

$P_E = R_E + 0.00038$ ……………………………(2)

Where,

P= Precipitation (Rainfall in mm) for Edzava

R_E =Runoff (in m^3/h) for Edzava

The value of $c = 0.00038$ is the relationship constant.

2. Zaaba water shed simulation results

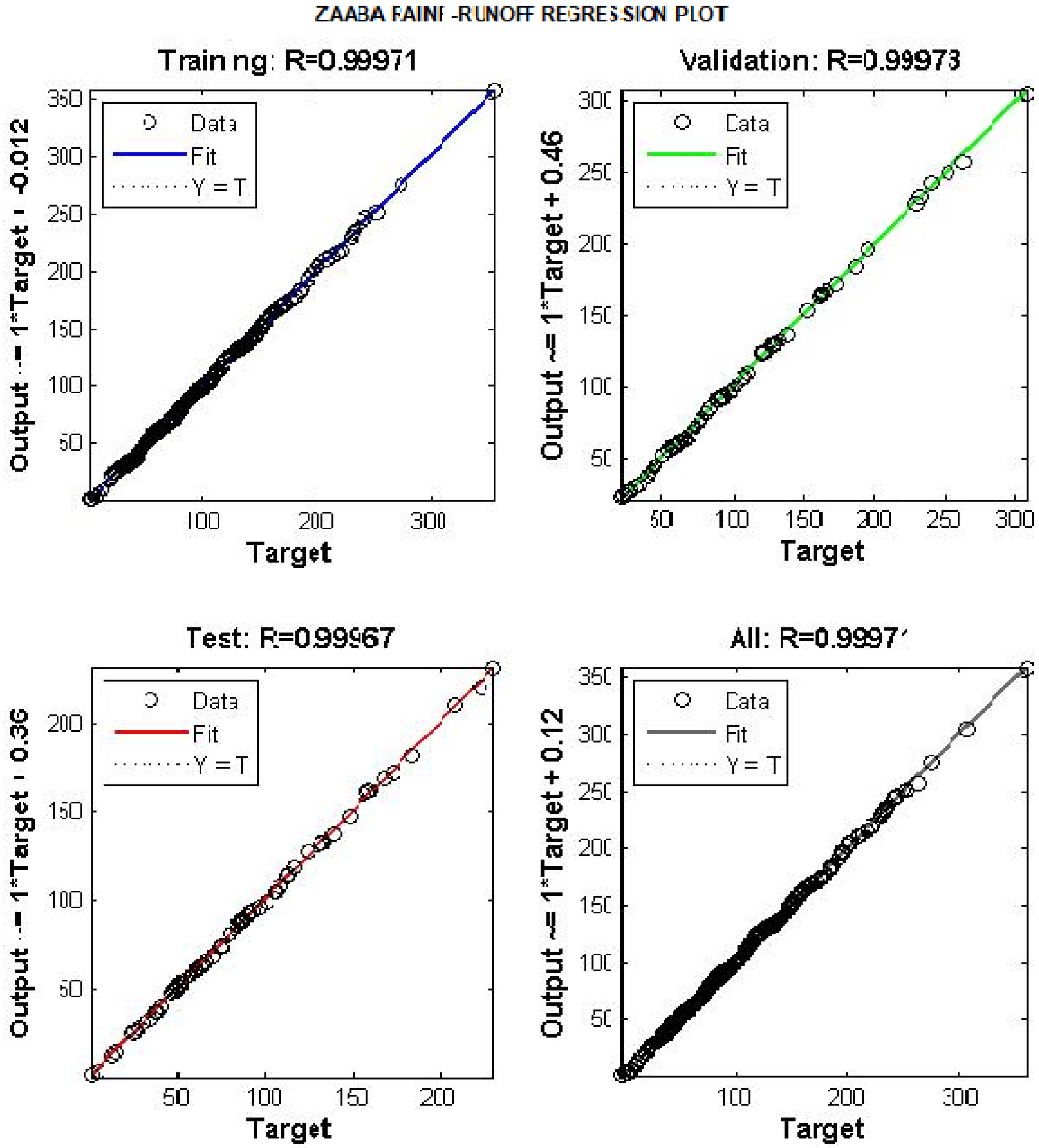

Figure 14: Zaaba Water Shed regression plot

Zaaba Rainfall- Runoff regression plot after simulation gave a best fir of R=0.999. This model was reliable for rainfall runoff simulation and more so it can be reliable for watershed managers in decision making and planning.

In Zaaba Watershed, the equation of relationship established in the model was therefore:

$P_z = R_z + 0.12$ ……..(3)

Where, P_Z= Precipitation (Rainfall in mm) for Zaaba

R_Z=Runoff (in m^3/h) for Zaaba

The value of $c = 0.12$ is the relationship constant.

3. *Garagoli water shed simulation results*

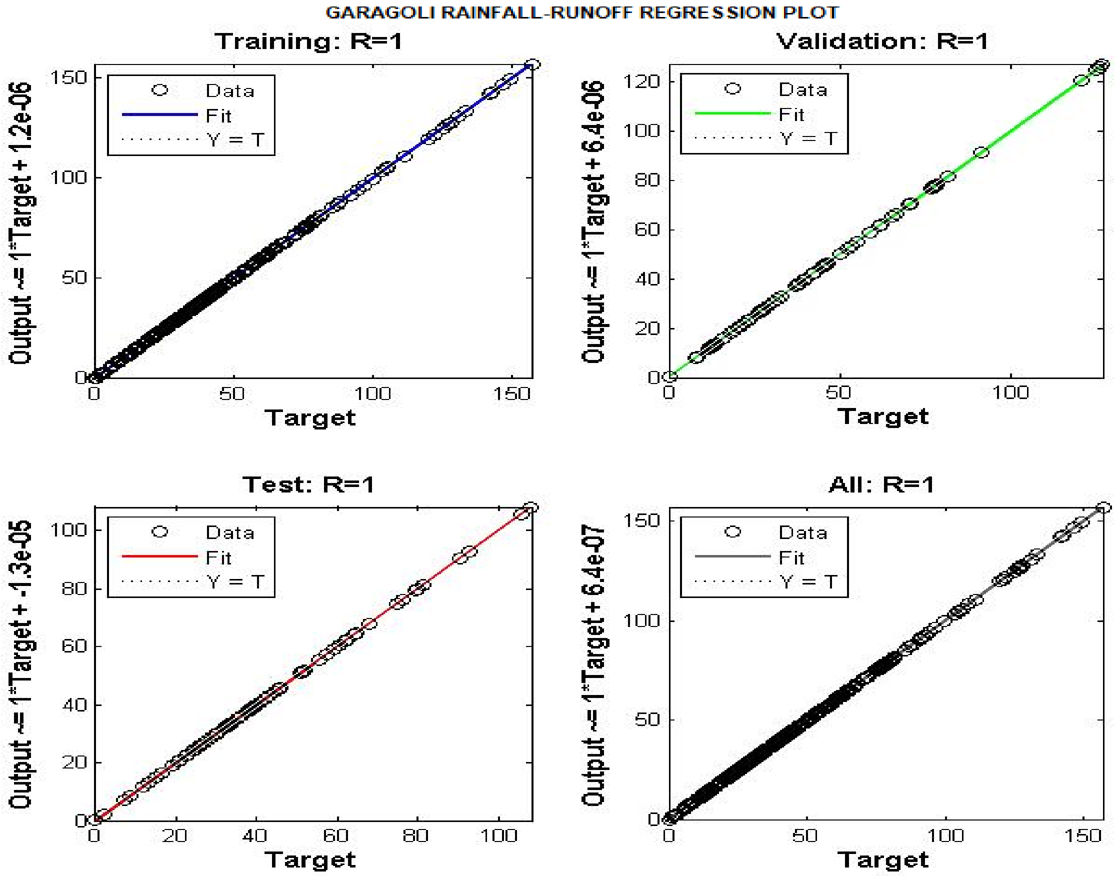

Figure 15: Garagoli Water Shed regression plot

The regression plot for Garagoli after simulation gave a best fit of R=1. This model showed that the runoff is directly proportional to rainfall. With this results, the model is good and reliable.

In Garagoli Watershed, the equation of relationship established in the model was therefore:

$$P_G = R_G + 6.4^{-0.07} \quad \text{..........................(4)}$$

Where,

P_G= Precipitation (Rainfall in mm)

R_G=Runoff (in m^3/h)

The value of $c = 6.4^{-0.07}$ is the relationship constant.

In summary, the ANN simulation results for Edzava, Zaaba and Garagoli watersheds gave $R^2$of 1, 0.999 and 1 respectively. This results above therefore shows that the model is suitable and reliable for prediction and can be used for water shed managers in the research are for decision making and planning of water shed interventions.

IV. CONCLUSION AND RECOMMENDATIONS

A. *Conclusion*

The research considered rainfall measurements for a period of 10 years and the average duration. The information collected shows that the rainfall has a direct relationship with runoff. The higher the rainfall that higher the runoff when all other factors (Land use/cover, soil) are kept constant.

The runoff in the three river water shed was generated and analysed. All the three water shed had high values in April-May and September- October the period which coincided with the peak rainfall values This peak values highest peak values were registered in in all the Water shed in the month of March - April and August – September which are the peak rainfall periods. The sub peak values in each month alternated between the short and the long rainfall periods in each year. High runoff events takes place in the month of March which is normally a planting season in the catchment and fields were normally prepared.

The research observed that there was a direct relationship of rainfall and runoff in the three watersheds. The relationship is as provided in the mathematical model derived from every watershed regression analysis.

Recommendations

The rainfall –runoff relationship is a direct proportional relationship and therefore the watershed managers can rely on the results of this research in predicting future possible scenarios in the water shed.

This trends will guide the water supply managers to understand the maximum values expected in the water shed and more so in their water supplies.

The asset developers i.e. for dams, river intakes, roads, bridges and irrigation schemes in this watershed will have to consider this trends carefully for sound design and management of the facilities. A comprehensive study is to be done to establish the response of both the surface and ground water to different seasons of rainfall.

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