GEOGRAPHICAL INFORMATION SYSTEM BASED HYDROLOGICAL MODELLING OF CLIMATE CHANGE VARIABLES ON HADEJIA RIVER SUB-BASIN, NIGERIA

BY

Mohammed Ismaila SANNI

DEPARTMENT OF WATER RESOURCES AND ENVIRONMENTAL ENGINEERING, AHMADU BELLO UNVERSITY, ZARIA
NIGERIA

AUGUST, 2018

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By

Mohammed Ismaila SANNI
B.Eng. (ABU, 2004), M.Sc (ABU, 2011)
Ph.D/Eng/10016/2011-2012

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT FOR THE AWARD OF A DOCTOR OF PHILOSOPHY DEGREE IN WATER RESOURCES AND ENVIRONMENTAL ENGINEERING

DEPARTMENT OF WATER RESOURCES AND ENVIRONMENTAL ENGINEERING, AHMADU BELLO UNIVERSITY, ZARIA NIGERIA

AUGUST, 2018

DECLARATION

I declare that the work in this dissertation entitled **'**Geographical Information System Based Hydrological Modelling of Climate Change Variables on Hadejia River Sub-basin, Nigeria' has been performed by me in the Department of Water Resources and Environmental Engineering under the supervision of Prof. D.B. Adie, Prof. C.A. Okuofu and Prof. A. Ismail.

The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another higher degree or diploma at another university.

Mohammed Ismaila SANNI _____ _____
Ph.D/Eng/10016/2011-2012 **Signature** **Date**

CERTIFICATION

This dissertation entitled 'Geographical Information System Based Hydrological Modelling of Climate Change Variables on Hadejia River Sub-basin, Nigeria' by SANNI Mohammed Ismaila meets the regulations governing the award of the degree of Doctor of Philosophy (Ph.D) of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

Prof. D.B. Adie Chairman, Supervisory Committee	Date
Prof. C.A. Okuofu Member, Supervisory Committee	Date
Prof. A. Ismail Member, Supervisory Committee	Date
Prof. A. Ismail Head of Department	Date
Dean, Postgraduate School	Date

DEDICATION

This dissertation is dedicated to everyone who wishes me accomplishment in all my exertion.

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In the Name of Allah, the Most Beneficent, the Most Merciful, all the praises and thanks belong to the Almighty Allah who has taught man that which he knew not. I thank Allah for the good health and knowledge He bequeaths on me; He alone makes all things possible in His own time.

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ABSTRACT

Soil and Water Assessment Tool (SWAT) and Geographical Information System (GIS) based hydrological modelling was applied to Hadejia River Sub-basin- an integral of the Chad Basin in the Northern Nigeria- to determine the impacts of land use/cover dynamics on the hydrological regime of the sub-basin under the changing climate factors. The study enhanced solution with dx understanding to the complex problems in the sub-basin, with large quantities of data associated with water systems and distributed nature of hydrological elements. Field data of soil sample, stream flow record from1978 to 2014, rainfall and temperature field data from 1979 to 2015 obtained from NiMET, Spatial and temporal satellite radar hydrometeorology data from 1979 to 2013, satellite imagery of land use/cover digital map for the year 1975, 2000 and 2013, digital soil map of 2013, Digital Elevation Model (DEM) of 30m resolution of the sub-basin were obtained from waterbase.org and used in the modelling. The daily radar weather data of rainfall and temperature was adjusted using the field data of rainfall and temperature, then applied in the modelling. GIS software was used to process, project and characterize the sub-basin physiographical data (Digital Elevation Model-DEM, soil data, and land use/cover and stream network) into WGS 1984 UTM Zone 32N. The point (outlet point) where the field stream flow data was obtained along the river was used to automatically delineate the watershed extent. SWAT was used to simulate and estimate the basin hydrologic parameters that include water yield, ground water recharge, lateral flow, surface runoff, and sediment yield, losses due to potential evapotranspiration and evaporation under the three different land use/cover maps of 1975, 2000 and 2013. In R programming, the trend in the field data of rainfall and temperature time series was determined using the Mann Kendall, Sen.slope and Pettitt change point nonparametric test, as recommended by World Metrologic Organization. The predictive model for the sub-basin field temperature and precipitation time series data was determined by the application of Seasonal Auto Regressive Integrated Moving Average Model (Seasonal ARIMA Model), the data was divided into training dataset (1982 to 2010) for model estimation and testing dataset (2011 to 2014) for model validation. By the application of SWAT Calibration and Uncertainty Procedures (SWATCUP), the observed stream flow data sensitivity parameters were determined, calibrated and validated. Correlation coefficient of one (1) was obtained for the

adjusted radar data of rainfall and temperature with the respective field data. The delineated study area extent was estimated at 15,663.02 km^2; perimeter at 1,323.51km; spot height from 784m to 351m; The longest river (Hadejia River) has total length of 364.461km, a 3rd order stream; principally gentle slope from 0.20-0.92. Based on USDA soil taxonomy, the soil imagery and validated field soil data, the study area has three dominant soils; "sand-sandyloam", "sandyloam" and "sandyloam-sandyclayloam". The characteristics of the land use/cover dynamics from 1975 to 2013 with respect to the area occupied in percentage are; Range Land -60.74, Riparian Forest -4.64%, Wetland -13.58%, Forest Area -4.01%, Bare Area -16.91%, Agricultural Land +8.92%, Urban Area +24.63%, and Water Bodies +79.22% due to more dams construction. Applying the land use/cover data of 1975, 2000 and 2013 respectively, the maximum estimated mean monthly hydrological parameters per year from 1982-2013 are; Potential evapotranspiration (343.9, 343.9, 343.9), evaporation losses (117.6, 122.8, 122.7), Surface runoff (399.0, 405.8, 405.8), Ground water recharge (173.6, 169.4, 169.0), Water yield (482.4, 486.1, 486.1), Sediment yield (88.8, 83.6, 46.7) tonnes/hectare and Lateral flow (0.5, 0.5, 0.3). Using the minimum AIC values, the best ARIMA Model obtained for the seasonal prediction of the sub-basin temperature was ARIMA (3,1,3)(2,0,1)[12] and ARIMA(1,1,1)(1,1,2)[12] for rainfall. Ten (10) parameters were selected for sensitivity analysis: EPCO (plant uptake compensation factor), ESCO (soil evaporation compensation factor), CN2 (moisture condition II curve number), ALPHA_BF (baseflow alpha factor), GW_DELAY (Delay time for aquifer recharge), GWQMN (threshold water level in shallow aquifer for base flow), SPCON (Channel sediment routing parameter), SURLAG (Surface runoff lag coefficient), SEDPST_CONC (sediment deposit concetration), SOL_Z() (Depth from soil surface to bottom layer (mm)).

The sensitivity analysis was followed by observed stream flow calibration and validation statistics determination. The sub-basin land use/cover dynamics shows no significant impacts on the hydrology of the Hadejia River System when compared. There was increase in potential evapotranspiration, decreases in evaporation, surface runoff, ground water recharge, basin water yield, sedimentation and lateral flow under the climate variables. High mean temperature was obtained in the months of March to May, while July to September has low records. Increases temperature was noticed beyond 1998 at the rate of 0.058. Mean monthly rainfall shows that the month of August has high rainfall while November to

March are dry months. The nonparametric test shows fluctuating increases at the rate 0.053 in rainfall that is not significant. The Seasonal ARIMA predictive model overestimate the temperature given by the mean absolute error (MAE)=1.261units, mean error (ME) of -0.559 and root mean square error (RMSE) of 1.501. The filed rainfall was under estimated with MAE=5.458, ME=10.179 and RMSE=14.570. For 500 iterations to obtain the best simulation for observed stream flow data, the most sensitivity parameters are SURLAG (Surface runoff lag coefficient) and CN2 (moisture condition II curve number). The statistics for the SWAT Model performances based on calibration and validation respectively are: p-factor (0.76, 0.28), r-factor (0.71, 1.27), R2 (0.95, 0.62), NS (0.95, 0.32), Mean_sim(Mean_obs) 1.31(1.27) and StdDev_sim(StdDev_obs) 1.16(1.21) for calibration and Mean_sim(obs) 1.25(0.90), StdDev_sim(StdDev_obs) 1.21(1.00) for Validation. The value of R2=0.95 and NS=0.95 in the calibration stage shows a good performances of the SWAT Model, which indicates a very high goodness of fitness between the observed and stimulated stream flow. The study has demonstrated that GIS/SWAT based hydrological modeling of a watershed, can play a very significant role in basin management, by abetting watershed stakeholders to take informed rational decisions with respect to a better watershed management and planning under the impacts of land use/cover dynamics and climate variable.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Globally, water resources are becoming increasingly vulnerable as a result of escalating demand, arising from population growth, expanding industrialization due to rising living standards, pollution, and climate change impacts. This situation is further exacerbated by poor management practices and unsustainable extraction of water for various consumptive uses. Consequently, many regions around the world, particularly urban areas are becoming water stressed and conflicts over access to water are becoming ever more common (Ashantha, & Meththika, 2017).

In Nigeria, Water is widely regarded as the most essential of natural resources, yet freshwater systems are directly threatened by human activities and stand to be further affected by anthropogenic climate change. Water systems are affected by intensive agricultural activities; urban development, industrialization and unplanned engineering infrastructures. Unplanned agricultural practices arising from lack of adequate extension workers and largely un-mechanized procedures leave farmers with the option of bush burning as the only site clearing method. This practice results in deforestation which translated into land degradation and mass wasting events leading to soil-water deficits and sediment loading of surface water. Irrigation practices often affect the wetland hydrology of downstream areas thereby impacting negatively on aquatic ecosystem (Idu, 2015).

The challenges to obtain a balanced sustainable water resources utilization and conversation are being experienced in the Komadugu-Yobe River basin where uncoordinated water

resources developments in upstream areas (Hadeija River Sub-basin) are seriously affecting the middle course and downstream areas. The Hadejia River sub-catchment an integral of the Komadugu-Yobe River basin that stretch across Kano and Jigawa States, has witnessed tremendous exploitation of its surface water resources through the construction of several dams and irrigation schemes, which are large scale in nature without due consideration for water use in downstream areas especially contributions to the Lake Chad which has been reported to have receded out of Nigeria (Sobowale et. al., 2010).

The spatial distribution of rainfall, climate pattern and hydrogeological units from the coastal areas to the Sahel regions of Nigeria provide the evidence that the water resources of the basin are already stretched and, with the potentially large and increasing demands. The amount of rainfall decreasing northwards and the Sahel has annual precipitation of less than 750 mm/year and may be as low as 500 mm/ year in the northeastern region occasionally. Rainfall duration can span for 3-4 months in these northern zones and shallow wells normally dry up during the dry seasons due to insufficient recharge. Proper management of the water resources in the Basin becomes a major area of challenge and a source of concern (Idu, 2015).

Part of northern Nigeria where the Hadeija River sub-basin is located falls within the Sahel or sub-sahelian region characterized by scanty rainfall, vegetation and extreme temperatures. The groundwater systems in the area are such that the aquifers- basement or sedimentary, shallow or deep are all under one form of threat or the other. The Sahel region is populated by farmers who depend on water supply for their livelihood. They need water for their crops and animals. Because of the scanty vegetation, overgrazing has further

depleted the soil cover exposing the soil to denudation and moisture deficit. The farmers often resort to the digging of wells in the shallow basement aquifers to augment surface water resources furnished by various dams in the area. Due to dwindling precipitation, the water levels of these shallow wells are being lowered (Idu, 2015).

One of the hydrological issues of concern in the Hadejia River Basin was the uncoordinated surface water uses. The potential surface water requirement in the Hadejia sub-basin was 2.6 times larger than the mean available surface water resources (IUCN-HNWCP, 1999).

The empirical Thornthwaite model was used to determine the potential evapotranspiration (PE) loss taking into account the land-use dynamics obtained from change detection using Landsat TM of 1986 and 2006. The study concluded that the water balance deficits for the different scenarios reveal a higher demand for soil replenishments. This will be an additional stress on the water resources of the Hadejia –Jama'are River Basin (H-JRB) and, if proper moisture management and adaptation strategies are not put in place, it may lead to serious water crises and probably environmental refugees (Shakirudeen et at., 2011).

SWAT model was applied to H-JRB to determine its water resources potential per capita, it was estimated at 376 m^3 for 2010 and projected to decrease to 232 m^3 by year 2030 (Japan International Cooperation Agency, et al., 2014).

The pressure on the Hadija River catchment water resources is accentuated by climate change and variability. Recent climate patterns show a general decline in average annual rainfall and river discharge, leading to numerous second-order impacts. For example, as a result of a decrease in wet season water flow, silt and weed blockages, and impoundments in Hadeija River watershed, the Komadugu tributary no longer reaches the Yobe River,

which in turn only contributes about 1% of the total water inflow to the Lake Chad (Jibrin, 2007).

One of the major findings of Tanko (2003) was that there is no clear assessment and understanding of the status of water resources availability in the Hadejia-Jama'are-Komadugu-Yobe Basin. On the basis of this finding, a water audit was recommended, and would consist in assessing available water in the basin (both surface water and groundwater) and estimating water demands from the various sectors, and the various spatial units in the basin.

Assessment and understanding of the status of water resources availability in any watershed can be achieved by the application of hydrological models. Hydrologic models are simplified, conceptual representations of a part of the hydrologic cycle. They are primarily used for hydrologic prediction to analyze, understand and estimate the hydrologic processes of a basin (Bhuyan et al. 2003).

A hydrologic model is a simplification of a real-world system (e.g., surface water, soil water, wetland, groundwater, and estuary) that aids in understanding, predicting, and managing water resources. Both the flow and quality of water are commonly studied using hydrologic models (Wikipedia, 2018).

The models that have been typically used are the lumped models and distributed models. The lumped models describe the watershed as a single entity with a single rainfall input (mean rainfall). The discharge at the watershed outlet is described based on a global dynamic of the system. The distributed models (process base model) divide the watershed in smaller units that are more homogenous than the whole watershed and the model is

applied to them. The watershed response is a composite of the responses of the units (Crahi, n.d).

The use of watershed model software to simulate hydrologic processes plays a fundamental role in addressing a range of water resources, environmental and social problems. The development of remote sensing (RS) techniques and ArcGIS Geographic Information System (GIS), Soil and Water Assessment Tool (SWAT), SWAT Calibration and Uncertainty Procedures (SWAT-CUP) and R programming has improved the expanded use of watershed models (Abbaspsor et. al., 2007).

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance from the targeted area. Special cameras collect remotely sensed images of the Earth, which help researchers "sense" things about the Earth (Bhuyan et al. 2003)

ArcGIS is a geographic information system GIS for working with maps and geographic information. It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database.is a suitable tool for the efficient management of large and complex database that provide a digital representation of watershed characteristics used in hydrologic modeling (Bhuyan et al., 2003).

SWAT (Soil & Water Assessment Tool) is a small watershed to river basin-scale model to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used

in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds

SWAT Calibration and Uncertainty Procedures (SWAT-CUP) is a program designed to integrate various calibration/uncertainty analysis programs for SWAT using the same interface. Currently the program can run SUFI2 (Abbaspour et al., 2007), GLUE (Beven and Binley, 1992), and ParaSol (Van Griensven and Meixner, 2006). To create a project, the program guides the user through the input files necessary for running a calibration program. User can save calibration iterations in the iteration history for later use and it is possible to create charts of observed and simulated data and the predicted uncertainty about them.

R programming is a well-developed, simple and effective programming language and an integrated environment for statistical computing, data analysis and processing, and the generation of well-designed publication-quality graphics. It provides a wide variety of statistical techniques (e.g. linear and non-linear modelling, classical statistical tests, time-series analysis, classification, clustering, raster data processing), and can be extended easily by additional packages. Unlike conventional office software, R is a powerful tool to process large data sets, e.g. long-term climate or hydrological time series of daily values.

In response to the challenges pointed out by Tanko (2003) with respect to complex problems associated with the sub-basin, the application of process model approach, GIS based hydrological modelling of Hadeija River hydrological regime under the impact of land use/cover dynamics and climate change was carried out by this study to analyze and understand the hydrological system of the Hadeija River watershed. The study attempt to

estimate spatio-temporal basin parameters that includes the sub-basin water yield, surface runoff, ground water recharge, lateral flow, stream flow, sediment yield, potential evapotranspiration and evaporation losses, rainfall and temperature variation. Predictive model of rainfall and temperature were determined by the application of seasonal ARIMA Model for sustainable water management, in order to support decision makers and operational water managers.

1.2 STATEMENT OF RESEARCH PROBLEM

Proper watershed management requires a painstaking knowledge of the hydrological components that drives the water resources of the watershed. The spatial and temporal knowledge of the basin parameters are required for watershed resources allocation, construction of hydraulic structure, sediment control to enhance the sub-basin productivity. The estimation of the Hadeija Sub-basin watershed parameters that includes water yield, ground water recharge, lateral flow, surface runoff, and sediment yield, loss due to potential evapotranspiration and evaporation losses are paramount to the sustainable utilizations of the watershed resources. The understanding of the watershed hydrological parameters, it characteristics and that of climate variables may subvert the problem of over sizing of the dam's reservoir and poor sedimentation control, as in the case of Tiga and Challawa Gorge Dam whose reservoir capacity were reduced due to their impacts on downstream users. Hence, the need for this research to support environmental planning choices with GIS/SWAT based simulation and prediction models in order to avoid such occurrence of over sizing of hydraulic structure in any watershed with management plan of dam construction and irrigation practices.

1.3 JUSTIFICATION

Geographic information system (GIS) based hydrological modelling of Hadeija River hydrologic system under the impact of climate change enhanced solution to the complex problems, with large quantities of data associated with water systems and distributed nature of hydrological elements with better understanding. The study provides information on the hydrologic responses of the watershed to climate change variables with respect to rainfall and temperature. It makes easier the estimation of the watershed parameters that includes the basin water yield, sedimentation yield, ground water percolation, lateral flow, losses due to evapotranspiration and runoff. The study provide the physiographical information of watershed that include watershed delineated total area, dominant soil texture types, topographic statistics, river networks, and land use distribution pattern. The GIS based study help to surmount the tedious and time consuming conventional approaches to obtain a reliable estimation of hydrological parameters for remote and inaccessible terrain. The results of the study provide a clear assessment and understanding of the status of water availability in the watershed because it is map-related; display information with respect to the watershed estimated parameters using maps.

1.4 AIM

The aim of this research is to apply GIS/SWAT Based Hydrological Modelling to Hadejia River Hydrological System in Northern Nigeria to Assess the Impacts of Land use/cover Dynamics under the Climate Variables on the Hydrology of the Sub-basin.

1.5 OBJECTIVES

1. To calibrate and validate the rainfall and temperature radar weather data with rainfall and temperature ground data obtained from NiMET for the sub-basin using R programming.

2. To characterize the watershed physiographical parameters using Geographical Information System (GIS), Soil and Water Assessment tool (SWAT) software and validate it soil texture properties with field data.

3. To estimate the sub-basin water yield, ground water recharge, lateral flow, surface runoff, sediment yield, loss due to potential evapotranspiration and evaporation losses using SWAT and GIS software.

4. To determine the trend in the field rainfall and temperature time series datasets using the Mann Kendall, Sen slope and Pettitt Nonparametric test in R programming.

5. To determine the predictive model of the sub-basin field temperature and precipitation time series using ARIMA Model in R Programming.

6. To evaluate the GIS/SWAT Model Sensitivity, calibration and validation of the observed stream-flow data using SWATCUP.

1.6 STUDY AREA

The Hadejia River catchment lies between 13^{o}N and 10.50^{o}N, 7.50^{o}E and 10.75^{o}E, as shows in Figure 1.1 The study area was bounded to the west by Katsina State, to the south by Kaduna and Bauchi States, to east by Yobe State and bounded in the north by Niger Republic and part of Katisna State. The total area of the states Kano (20,069.2sqkm) and Jigawa (23,985.6sqkm) was total to be 44,054.8sqkm while the delineated watershed has an area of 15,663.02sqkm with a perimeter of 1,325.51km.

The Hadejia River drainage pattern comprises Challawa, Watari, Jatau and Dudurun Gaya that joined the Jama'are River, which empties into the Lake Chad while Several manmade lakes such as Tiga Dam, Challawa Gorge Dam, Gari, Jakara, Watari, Guzuguzu, Kafin

Chiri, Dudurun Gaya, Bagauda have been constructed to improve portable water supply to towns and villages and to provide water for irrigation along with other uses (Goes, 2001).

1.6.1 Geology

Geologically, more than four-fifth of the sub-basin is underlain by quartzite, undifferentiated meta sediments and basement complex rocks of the Precambrian upper Cambrian origin. Prolonged weathering of the rocks produced deep clay rich regoliths, which have been subjected to laterization. The lateritic outcrops dot the interfluve areas of the upland plain serving as caps for regolith hills e.g. Gwauron Dutse and Dala hills. Well jointed younger granites of Jurassic origin occur in ring complexes in the extreme south. A narrow strip of the Chad Formation occurs to the east (Olofin, 1987).

1.6.2 Soils

In their natural state, the soils divide into four main groups. The ferruginous tropical soils formed on crystalline acid rocks occupy about two fifth of the watershed to the south, southwest and south east; the brown and reddish brown soils and latosols occur in the northern half; the brown and reddish soils are in the northeastern corner; and the juvenile and hydromorphic soils occur along the alluvial channel complexes. The soils largely reflect the influence of parent materials. Intensive use of the soils and addition of manure and chemical fertilizers have altered their character, profile, texture, structure and chemical characteristics (Olofin, 1987).

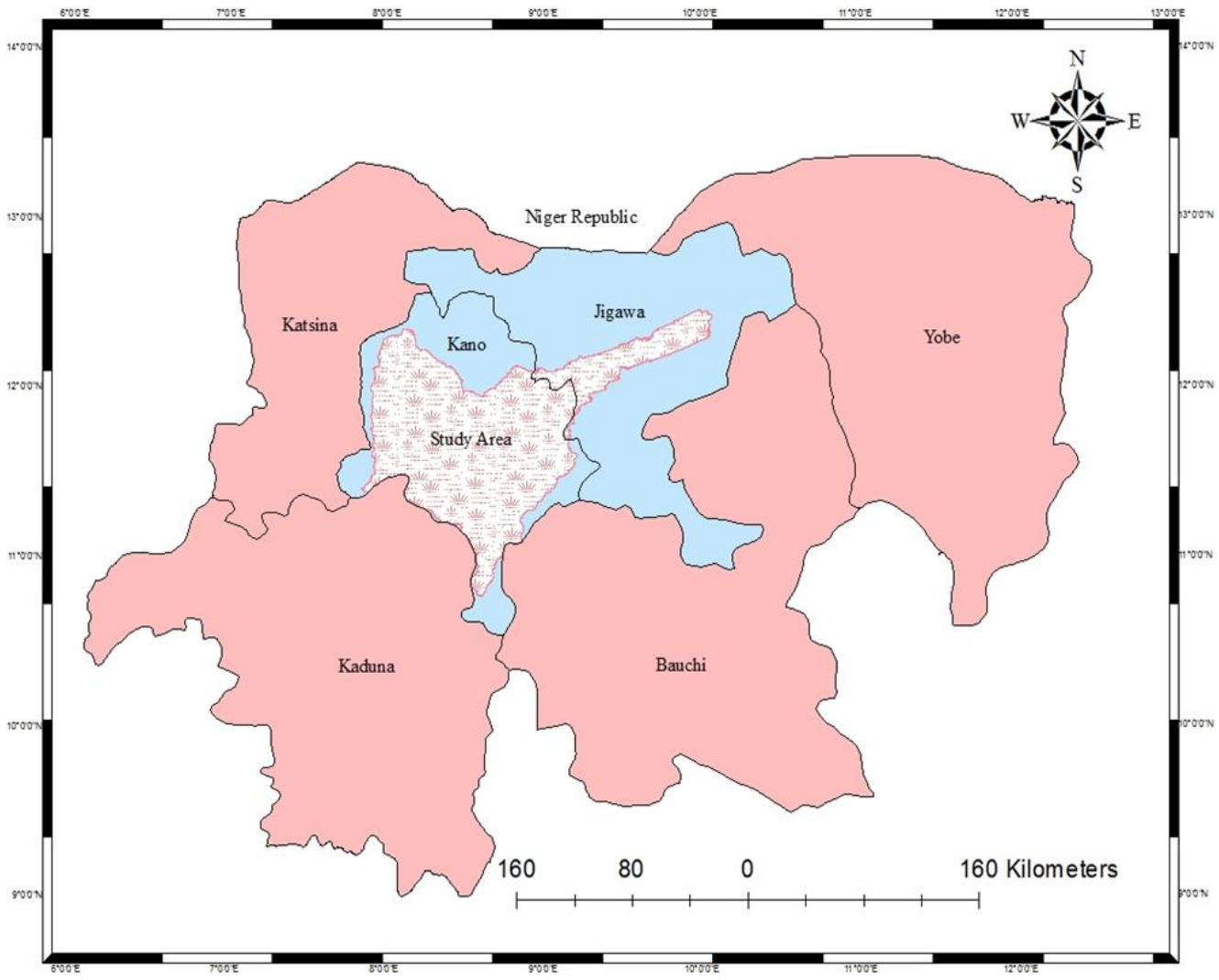


Figure 1.1: Map of the study area

1.6.3 Agriculture

Subsistence and commercial agriculture is mostly practiced in the outlying districts of the basin. Some of the food crops cultivated are millet, cowpeas, sorghum, maize and rice for local consumption while groundnuts and cotton are produced for export and industrial purposes. During the colonial period and several years after the country's independence, the groundnuts produced in the state constituted one of the major sources of revenue of the

country. The basin is a major producer of hides and skins, sesame, soybean, cotton, garlic, gum arabic and chili pepper (Olofin, 1987)

1.6.4 Climate

Mean annual rainfall ranges from over 1,000mm in the extreme south to a little less than 800mm in the extreme north. The rains last for three to five months. Mean temperature ranges from 26°C to 33°C. There are four seasons: a dry and cool season, Kaka (mid - November to February), marked by cool and dry weather plus occasional dusty haze: the dry and hot season, bazara (March midMay) when temperatures climb up to 40°C and which is a transition period between the harmattan and the wet season; the wet and warm season, damina (mid-May to September), is the proper wet season when the lowest diumal temperature is recorded; and a dry warm season, (October to mid-November) marked by high humidity and high temperature next to bazara in hotness (Goes and Bart, 2005).

1.6.5 Vegetation:

The natural vegetation consists of the Sudan and the Guinea Savannah both having been replaced by secondary vegetation. Four-fifth of the basin is now composed of farmed parkland, dotted with patches of shrub savannah. The savannah woodland, which is the second largest zone, is typified by the Falgore Game Reserve. There are few forest plantations of exotic trees (Goes and Bart, 2005).

1.6.6 Ecological Problems:

The watershed experiences great temporal variation in rainfall amount and duration. During the 1970/73 drought, the basin recorded only forty eight percent of the annual mean. This phenomenon and occasional pest infestation pose major dangers to crop and animal lives

and, consequently, human lives. Hydro-agriculture has led to the erosion of top soil, resulting in considerable loss of the fine soil particles which contribute to the high sediment yield of the main rivers. High sediment yield, especially from areas with basement complex rocks, has led to rapid reservoir siltation, thereby reducing the life span of most of the reservoirs (Olofin, 1987).

1.6.7 Hydrology

Hadeija River Basin lies in a region drained by two major river systems, the Kano River and Challawa River that forms the Hadejia River. Much of the catchment is relatively flat with the only significant hills (the Jos Plateau) rising in the south-west from where the headwaters of the Kano River begin. The head water of Challawa Dam rises from the high land of Kano State. This major river system constitutes large wet lands along it channels. From these, many water bodies and lakes have been formed and also intense draw down agriculture is done in these areas (Goes and Bart, 2005).

1.6.8 Population

According to the 1991 population census the Basins have over 19 million people (NPC, 1991); these are made up of 50% males and 50% females. About 80% of the population are said to live in rural areas. The people engage mainly in Agriculture. Poverty and illiteracy level within the Basin is also very high.

1.7 LIMITATION

None availability of data/information: Thus for any meaningful development/management initiative on water resources, there is the need for data. Of course, information is lacking

even on some sensitive water issues which proves very challenging. Even where data is available there is unwillingness to make it easily accessible to researchers by the custodians.

The challenges of data acquisition was surmounted by downloading required daily hydro-meteorological datasets (radar) that includes precipitation, temperature (maximum and minimum), solar radiation, wind speed and relative humidity for free from 1979-2013. Scanty historical stream-flow data was obtained from Hydrological Agency of Nigeria to make informed decisions with respect to the sub-basin.

CHAPTER TWO

LITERATURE REVIEW

Sustainable water management of a river basin is required to ensure a long-term stable and flexible water supply to meet crop water demands as well as growing municipal and industrial water demands. Water resources structures need appropriate planning to ensure the fulfillment of the goals of water management. Water resources management requires a systems approach that includes not only all of the hydrological components, but also the links, relations, interactions, consequences, and implications among these components. Human modifications of the environment, including land cover change, irrigation, and flow regulation, now occur on scales that significantly affect seasonal and yearly hydrologic variations. A thorough knowledge and understanding of the different hydrological phenomena and hydrological cycle as a whole is required in studying the implications of these changes (Janhabi, 2014).

This chapter provides basic background information on the management, characteristic, modelling of watersheds and forecast to help understand watershed processes and function required for basin management plan as related to the research.

2.1 WATERSHED

The term “watershed” describes an area of land in which waters drain downslope, along drainage to a common lowest point. Basin Watersheds can vary in size, and every stream, tributary, or river has an associated watershed. Watershed boundaries can easily be delineated using a topographical map that shows the ridges associated with the various drainages and the mouth of the stream or river where water flows out of the watershed. Watersheds also referred to as catchments, are functional and geographical areas that

integrate a variety of environmental processes and human impacts on the landscape. Integrated assessments recognize the interdependence of resources and components that make up a watershed (Aspinalla & Pearson, 2000).

Due to their complexity, managers and planners have traditionally managed watersheds to optimize only one or a few resources. A more holistic approach is needed that addresses watershed resources and other components while stressing the importance of maintaining the sustainable uses of all the resources within a watershed (Tecle et al., 2003).

Recently there has been a growing recognition that in order to quantify and assess environmental systems it is necessary to conduct an integrated assessment. Integrated assessment accounts for multiple land uses while implementing the concept of sustainability through community based catchment management (Bellamy & Johnson, 2000). Sustainability can be social, environmental, economic or hydrological.

Watersheds, are often subject to multiple land uses, including recreation, agriculture, range management, mining, forestry, and development. Understanding watershed interactions while assessing a watershed requires a thorough understanding of physical, biological, social, and economic components within that watershed (Roni et al., 2002).

Integrated watershed management is recognized as a management process that "promotes coordinated development and management of water, land and related resources, in order to maximize economic and social welfare without compromising the sustainability of vital systems" (Saravanan et al., 2009).

2.1.1 Watershed Management

Management of the environment has been primarily focused on specific issues such as air, land, and water. Most efforts have resulted in decreasing pollutant emissions to air and water, improved landfills, remediation of waste sites and contaminated groundwater, protection of rare and endangered species, design of best management practices to control water and contaminant runoff, and much more. Nonpoint source pollution and habitat degradation continue to be the problem in our watershed. These are the problems that are responsible for most of the water quality use impairments throughout. These are typically complex problems that are difficult to manage. Both nonpoint pollution and habitat degradation generally cross program purviews. To establish a method to tackle these remaining problems managements must come together to better understand the interactions between the environmental components and the actions that can be taken by all towards the goal of ecosystem integrity (Sastry, et al., 2003).

Watershed management is an adaptive, comprehensive, integrated multi-resource management planning process that seeks to balance healthy ecological, economic, and cultural/social conditions within a watershed. Watershed management serves to integrate planning for land and water; it takes into account both ground and surface water flow, recognizing and planning for the interaction of water, plants, animals and human, and land use found within the physical boundaries of a watershed. Watershed management provides a framework to integrate decision-making to help: assess the nature and status of the watershed; identify watershed issues; define and re-evaluate short and long term objectives, actions and goals; assess benefits and costs; and implement and evaluate actions. The study of the relevant characteristics of a watershed aimed at the sustainable distribution of its

resources and the process of creating and implementing plans, programs, and projects to sustain and enhance watershed functions that affect the plant, animal, and human communities within a watershed boundary. Features of a watershed that agencies seek to manage include water supply, water quality, drainage, storm water runoff, water rights, and the overall planning and utilization of watersheds. Landowners, land use agencies, storm water management experts, environmental specialists, water use surveyors and communities all play an integral part in watershed management (Mark et al., 2002).

2.1.2 Objectives of Watershed Management

According to Wagner et al., (2002), the different objectives of watershed management programs are:

- To protect, conserve and improve the watershed land for more efficient and sustained production.
- To protect and enhance the water resource originating in the watershed.
- To check soil erosion and to reduce the effect of sediment yield on the watershed.
- To rehabilitate the deteriorating lands.
- To moderate the floods peaks at downstream areas.
- To increase infiltration of rainwater.
- To improve and increase the production of timbers, fodder and wild life resource.
- To enhance the ground water recharge, wherever applicable.
- To reduce the occurrence of floods and the resultant damage by adopting strategies for flood management.
- To provide standard quality of water by encouraging vegetation and waste disposal facilities

2.1.3 Need for Watershed Management

Watersheds sustain life, in more ways than one, according to Wagner et al, (2002), more than $450 billion in foods; fiber, manufactured goods and tourism depend on clean, healthy watersheds. This is why proper watershed protection is necessary to any community. Watershed protection is a means of protecting a lake, river, or stream by managing the entire watershed that drains into it. Clean, healthy watersheds depend on an informed public to make the right decisions when it comes to the environment and actions made by the community.

Watershed management practices in terms of purpose are as follows

- To increase infiltration
- To increase water holding capacity
- To prevent soil erosion, method and accomplishment

Various control measures for watershed protection are:

- Vegetative measures (Agronomical measures)
- Strip cropping
- Pasture cropping
- Grass land farming
- Wood lands
- Engineering measures (Structural practices)
- Contour trenching
- Terracing
- Construction of earthen embankment
- Construction of check dams

- Construction of farm ponds
- Construction of diversion
- Gully controlling structure
- Rock dam
- Establishment of permanent grass and vegetation
- Providing vegetative and stone barriers

2.1.4 Controlling Pollution

In agricultural systems, common practices include the use of buffer strips, grassed waterways, the reestablishment of wetlands, and forms of sustainable agriculture practices such as conservation tillage, crop rotation and intercropping. After certain practices are installed, it is important to continually monitor these systems to ensure that they are working properly in terms of improving environmental quality. In urban settings, managing areas to prevent soil loss and control storm water flow are a few of the areas that receive attention. A few practices that are used to manage storm water before it reaches a channel are retention ponds, filtering systems and wetlands. It is important that storm water is given an opportunity to infiltrate so that the soil and vegetation can act as a "filter" before the water reaches nearby streams or lakes. In the case of soil erosion prevention, a few common practices include the use of silt fences, landscape fabric with grass seed and hydro-seeding. The main objective in all cases is to slow water movement to prevent soil transport (Wagner et al, 2002).

2.1.5 Governance

The second World Water Forum held in The Hague in March 2000 raised some controversies that exposed the multilateral nature and imbalance in the demand and supply management of freshwater. While donor organizations, private and government institutions backed by the World Bank, believe that freshwater should be governed as an economic good by appropriate pricing, NGOs however, held that freshwater resources should be seen as a social good (Oweyegha et al., 2003). The concept of network governance is where all stakeholders form partnerships and voluntarily share ideas towards forging a common vision that be used to resolve this clash of opinion in freshwater management. Also, the implementation of any common vision presents a new role for NGOs because of their unique capabilities in local community coordination, thus making them a valuable partner in network governance (Evans, 2011).

Watersheds replicate this multilateral terrain with private industries and local communities interconnected by a common watershed. Although these groups share a common ecological space that could transcend state borders, their interests, knowledge and use of resources within the watershed are mostly disproportionate and divergent, resulting to the activities of a specific group adversely impacting on other groups. Examples being the Minamata Bay poisoning that occurred from 1932 to 1968, killing over 1,784 individuals and the Wabigoon River incidence of 1962. Furthermore, while some knowledgeable groups are shifting from efficient water resource exploitation to efficient utilization, net gain for the watershed ecology could be lost when other groups seizes the opportunity to exploit more resources. This gap in cooperative communication among multilateral stakeholders within an interconnected watershed, even with the likely presence of the usually reactive and

political boundary-constraint state regulations, makes it necessary for the institutionalization of an ecological-scale cooperative network of stakeholders (Wagner et al., 2002). This concept supports an integrated management style for interconnected natural resources; resonating strongly with the Integrated Water Resources Management system proposed by Global Water Partnership.

Moreover, the need to create partnerships between donor organizations, private and government institutions and community representatives like NGOs in watersheds is to enhance an "organizational society" among stakeholders (Ewalt, 2001). This posits a type of public-private partnership, commonly referred to as Type II partnership (Emma and Lisa, 2010), which essentially brings together stakeholders that share a common watershed under a voluntary, idea sharing and collectively agreed vision aimed at granting mutual benefits to all stakeholders. Also, it explicates the concept of network governance, which is "the only alternative for collective action" (Milward & Provan, 2000), requiring government to rescale its role in decision making and collaborate with other stakeholders on a level playing field rather than in an administrative or hierarchical manner.

Several riparian states have adopted this concept in managing the increasingly scarce resources of watersheds. These include, the nine Rhine states, with a common vision of pollution control, the Lake Chad and River Nile Basins, whose common vision is to ensure environmental sustainability. As a partner in the commonly shared vision, NGOs has adopted a new role in operationalizing the implementation of regional watershed management policies at the local level. For instance, essential local coordination and

education are areas where the services of NGOs have been effective. This makes NGOs the "nuclei" for successful watershed management (Prabhakar et al, 2010).

2.1.6 Environmental Law

Environmental laws often dictate the planning and actions that agencies take to manage watersheds. Some laws require that planning be done, others can be used to make a plan legally enforceable and others set out the ground rules for what can and cannot be done in development and planning. Most countries and states have their own laws regarding watershed management. Those concerned about aquatic habitat protection have a right to participate in the laws and planning processes that affect aquatic habitats. By having a clear understanding of whom to speak to and how to present the case for keeping our waterways clean, a member of the public can become an effective watershed protection advocate (Prabhakar et al, 2010).

2.1.7 Benefits of a Healthy Watershed

Water is essential for our future. A healthy watershed provides the triple benefits to ecological, economic health and human entities as reported by Wagner et al, (2002). The goal of watershed management is to properly balance and manage this resource

i. Ecological Health

A healthy watershed functions as a complete ecological system promoting the health of all living organisms and landscapes within the watershed. A healthy, intact watershed minimizes the impacts of flooding and erosion and serves to filter sediments and contaminants so they do not reach our streams, lakes, and groundwater

ii. Economic Health

An abundant supply of clean water is essential for a vibrant economy. Homes, farms, municipalities and businesses all need an ample supply of clean water to operate effectively. Clean water allows municipalities, businesses, agricultural producers, and industries to operate more cost effectively, saving money for taxpayers and consumers. Healthy rivers, lakes, wetlands are foundations for recreation and tourism.

Life requires a safe daily supply of water. But water is far more than that: clean surface and ground water is essential to support a high quality of life and the social aspects of our communities. Clean rivers, lakes and streams provide many healthy recreational opportunities including swimming, boating, and fishing.

2.2 WATERSHED CHARACTERIZATION

Watershed characterization and management requires detail information for topography, drainage network and geomorphologic setup of the area for proper watershed management plan for water conservation measures. Watersheds can be classified using any measurable characteristics like- size, shape, location, ground water exploitation, and land use. However, the main classification of watershed is discussed broadly on the basis of size and land use according to Sreedevi et al., (2013) as follow;

2.2.1 Basin Size

The main implication of watershed size appears in terms of spatial heterogeneity of hydrological processes. The spatial variability of watershed characteristics increases with size, therefore, large watersheds are mostly heterogeneous. As the watershed size increases, storage increases. Based on size, watersheds are divided into three classes.

1. Small Watersheds < 250 km^2

2. Medium Watersheds between 250 to 2,500 km^2

3. Large Watersheds > 2,500 km^2

a. Small Watersheds: Small watersheds are those, where the overland flow and land phase are dominant. Channel phase is relatively less conspicuous. The watershed is highly sensitive to high-intensity and short duration rainfalls.

b. Medium Watersheds: Being medium in size, the workability in these watersheds are easy due to accessible approach. Rather than size, shape of the watershed plays a dominant role. Overland flow and land phase are prominent.

c. Large Watersheds: These watersheds are less sensitive to high-intensity-rainfalls of short duration. The channel networks and channel phase are well-developed, and, thus, channel storage is dominant.

2.2.2 Land Use/Land Cover

Land use defines the exploitation (natural and human interactions) characteristics of watersheds which affect the various hydrological processes within the watershed. The watershed classification based on the land-use can be given according to Das (2000) as follows:

a. Agricultural

Agricultural watershed is the watershed in which agricultural activities (crop cultivation) are dominant. It experiences, perhaps the most dynamically significant land-use change. This usually leads to increase infiltration, increased erosion, and/or decreased runoff.

b. Urban

These are the watershed areas having maximum manipulation for the convenience of human being, dominated by buildings, roads, streets, pavements, and parking lots. These features reduce the infiltrating land area and increase imperviousness.

c. Forest

These are the watersheds where natural forest cover dominates other land uses. In these watersheds, interception is significant, and evapotranspiration is a dominant component of the hydrologic cycle. The ground is usually littered with leaves, stems, branches, wood, etc.

d. Mixed

These are the watersheds, where multiple land use/land cover exists either because of natural settings or due to a combination of natural and human interaction activities. In these watersheds, a combination of two or more of the previous classifications occurs and none of the single characteristics dominate the area.

e. Wetland Watershed

Such lands are almost flat and are comprised of swamps, marshes, water courses, etc. They have rich wildlife and plenty of vegetation. As water is no limiting factor to satisfy evaporative demand, evaporation is dominant. Rainfall is normally high and infiltration is minimal (Zavoianu, 2011).

2.2.3 Soil Distribution

Soils can be an important factor in determining the amount of erosion and storm water runoff that occurs in the watershed. Soils have inherent characteristics that control how much water they retain, how stable they are, or how water is transmitted through them.

Understanding the types of soils in the watershed and their characteristics helps to identify areas that are prone to erosion or are more likely to experience runoff (Das, 2000).

2.2.4 Physical and Geomorphologic Characteristics associated with Watersheds

Watershed geomorphology refers to the study of the characteristics, configuration and evolution of land forms and properties; developing physical characteristics of the watershed. It comprises of the characteristics of land surface as well as the characteristics of the channels within the watershed/basin boundary. These properties of watersheds significantly affect the characteristics of runoff and other hydrological processes (Zavoianu, 2011). The principal watershed characteristics considered in this research are:

I. Basin Area

The area of watershed is also known as the drainage area and it is the most important watershed characteristic for hydrologic analysis. It reflects the volume of water that can be generated from a rainfall. Once the watershed has been delineated, its area can be determined by approximate map methods, planimeter or GIS.

II. Basin Length

Length can be defined in more than one way

1. The greatest straight-line distance between any two points on the perimeter
2. The greatest distance between the outlet and any point on the perimeter
3. The length of the main stream from its source (projected to the perimeter) to the outlet

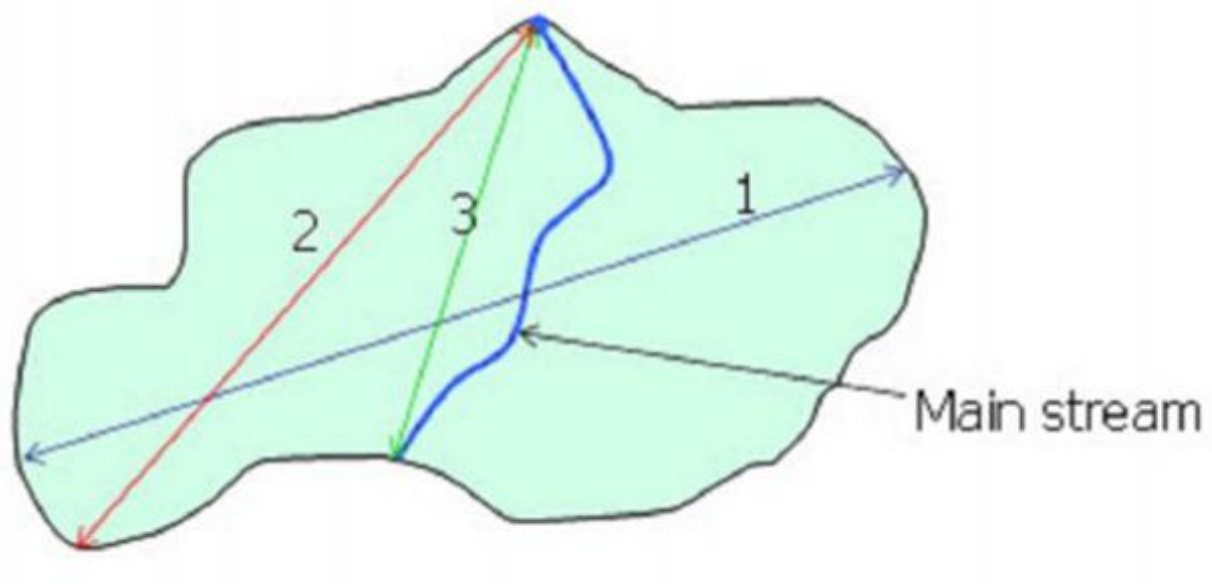


Figure 2.1: Basin length definition (Source: Zavoianu, 2011)

Conceptually the basin length (Lb) is the distance traveled by the surface drainage and sometimes more appropriately labeled as hydrologic length. This length is generally used in computing a time parameter, which is a measure of the travel time of water through a watershed. The watershed length is therefore measured along the principal flow path from the watershed outlet to the basin boundary. The relation between mainstream length and drainage-basin area A in $km^{2,}$ for watershed is given by equation (2.1); where L_b is in km.

$$L_b = 1.312A^{0.568} \quad (2.1)$$

III. Channel Characteristics

The basin geomorphology plays an important role in the transition of water from the overland region to channels (streams) and also from the channel of one order to the other. It is easily determined by contour map and drainage map of the basin. Channel order, channel length, channel slope, channel profile, and drainage density are the most common channel

characteristics, important in estimating the watershed hydrological processes and are discussed as below.

IV. Channel Order

The first-order streams are defined as those channels that have no tributaries. The junctions of two first-order channels form a second-order channel. A third-order channel is formed by the junction of two second-order channels. Thus, a stream of any order has two or more tributaries of the previous lower order. This scheme of stream ordering is referred to as the Horton-Strahler ordering scheme shows in Figure 2.2, while equation (2.2) is used to calculate the stream number.

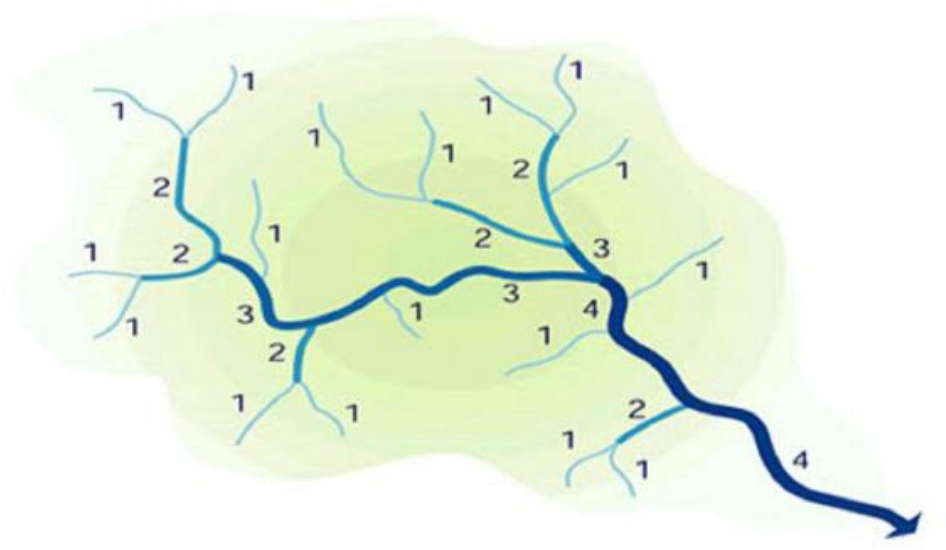


Figure 2.2: The Horton-Strahler ordering scheme (http://www.fgmorph.com/fg_4_8.php)

$$N_w = R_b W - w \qquad (2.2)$$

Where N_w= number of streams of order w; W = order of the watershed; and R_b= Bifurcation Ratio. Bifurcation ratio is defined as the ratio between the numbers of streams of a particular order to the number of streams of one higher order and expressed by equation (2.3)

$$R_b = N_w/(N_w + 1) \quad (2.3)$$

V. Drainage Density

Drainage density (Dd) is defined as the ratio of the total length of streams of all orders within the basin area. It can be thought of as a measure of closeness of drainage spacing. It is the indication of drainage efficiency of overland flow and the length of overland flow as well as the index of relative proportions. It is defined as the total length of drainage per unit area. This term was first introduced by Horton (1932) and is expressed by equation (2.4)

$$D_d = \sum L/A \quad (2.4)$$

where L = Total length of all channels orders in km, A = Area in km^2;

Low drainage density reflects poor drainage conditions in the watershed. Low drainage density is observed where soils are resistant to erosion or very permeable and where slopes are small.

2.3 WATER RESOURCES OF HADEIJA RIVER SUB-BASIN

2.3.1 The Basin Water Resources

Access to water plays a key role in development (it sustains human life, both through direct consumption and use in agriculture for food security and industrial activities), while water availability for drinking purposes is essential, its uses for industrial purposes is important to fuel economic growth (Goes and Bart, 2005).

The most prominent anthropogenic water uses are in the middle and upstream part of the Hadejia River System. These uses are: Kano River Irrigation Project (KRIP), Hadejia Valley Irrigation Project (HVIP) and Kano City Water Supply (KCWS). KRIP, KCWS and HVIP all take their source from Tiga and Challawa dams. Both reservoirs are also used for

fisheries (a secondary benefit). There exist higher demand of water explained by changes in cropping pattern (rice irrigation instead of wheat) and excessive losses in the secondary and tertiary irrigation channels. The total water loss throughout the system was estimated at about 50% (Simon, 1997). Some measures to improve the water use efficiency have been undertaken in recent years that include:

1) desiltation of irrigation canals,

2) farmers in each section have to pay before water is delivered to their section,

3) no water is released into the irrigation sections if it rained the night before,

4) There is less water logging of soils because farmers realize now that it affects the yield of the crops negatively (Water development, 2014).

2.3.2 History of Tiga and Challawa Dams

1. Tiga Dam

The Tiga Dam is a zoned filled earth dam located on River Kano, 70km south of Kano City; it is one of the largest dams in the country and was designed and built between 1970 & 1974. This Dam is the cornerstone of water resources development in the Kano River and Hadejia River Valley in Jigawa State. The Kano River Irrigation Project, which comprises of 62,000 hectares of irrigable land, is planned to be implemented in two phases. The first phase I, covers an area of 22,000 hectares of irrigable land and the second phase, based in the Hadejia Valley and Jama'a projects, cover an area of 40,000 hectares of irrigable land (HJRBDA, 1985).

By releasing water from the dam during both rainy and dry seasons of every year, thousands of farmers along the river course, from Kano to Hadejia and beyond, grow a

variety of crops for both cash and food. The Dam is also another source of drinking water for Kano Metropolis, other towns and villages along the river course in Kano, Jigawa, Yobe and parts of Borno States. Tiga Dam was part of the programme of water resources and agricultural development contemplated in the "Feasibility Study of the Chad Basin" conducted by the United States Bereau For Reclamation in the early 1960's. The programme includes the construction of Challawa Gorge Dam on a tributary of River Kano in Kano State (completed 1992), and the Kafin Zaki Dam on River Jama'are in Bauchi State and the development of irrigation projects such as Kano River Projects I & II and the Hadejia Valley Projects I & II. The Ruwan Kanya Reservoir is a 3.66 km long earth filled dam with storage capacity of 58 million cubic meters of water annexed to the Tiga Dam to serve as a balancing reservoir located at about 5.1km downstream of the Tiga Dam (Water for Development, 2014).

a. Features of Tiga Dam

The Tiga Dam has the following features:

Type of Dam	-	Zoned Earth fill
Crest Length	-	6,000m
Structural Height	-	48m
Hydraulic Height	-	42.68m
Maximum Base Width	-	274.30m
Total Storage Capacity	-	1,974mil.m^3
Active Storage Capacity	-	1,845mil.m^3
Surface Area of Reservoir	-	18,900 hectares
Total Vol. Of fill Material	-	9.18mil.m^3

Spillway Type	-	Free Overflow Concrete Ogee (457m)
Emergency Spillway Width	-	200m

The Dam was equipped with three outlets as follows:

1. The main outlet is a 3.65m conduit supplying a 2.2m Howell Bunger regulating valve.
2. 2Nos. 90cm conduits with 60cm regulating valve.
3. The main Dam outlet, comprising of bulkhead gates, butterfly valve, etc, was installed in the outlet valve chamber, which was submerged 16 meters below the full supply level (Water for Development, 2014).

2. Challawa Gorge Dam

The Challawa Gorge Dam is a large earthfill dam constructed on Challawa River some 90km South-west of Kano City. The dam was designed to create a multipurpose reservoir to serve the water needs of downstream areas in Kano, Jigawa, Yobe and Borno States.

Principal uses of the project's water include:

* To supplement water from Tiga Dam for the irrigation of about 25,000 hectares of the Hadejia Valley Project, 40,000 hectares of Kano River Project Phase II and other farms downstream for the production of rice, wheat, sugarcane, vegetables and other crops.
* Supplementing water supply to Kano metropolis and other communities
* Mandatory minimum flow releases for downstream uses in Jigawa, Yobe and Borno States,
* Flood and erosion control
* Development of fisheries and livestock, and recharge aquifers in the Basin area for successful borehole and Fadama projects.

b. *Features of Challawa Gorge Dam*

*	Length of dam	-	7.804km
*	Dam crest elevation	-	527.45m
*	Maximum height from foundation level	-	42.0m
*	Maximum width at base	-	240.0m
*	Volume of earth fill	-	6.2(mcm)
*	Total reservoir capacity	-	930.0(mcm)
*	Reservoir area at full capacity supply level	-	100km^2
*	Elevation at full supply level	-	523.76m
*	Probable maximum flood (PFM)	-	6,500m^3/sec.
*	Crest length of ungated spillway	-	600m
*	Active Storage	-	904Mm^3
*	Dead Storage	-	26 Mm^3
*	Reservoir losses	-	8.9 Mm^3
*	Annual yield	-	470 Mm^3
*	Catchments area	-	3,857km^2

For the maximum utilization of this supplementary dam it was recommended that Kano River Irrigation Project, Phase II and Hadejia Valley Irrigation Project Phase II be considered for immediate construction (Water for Development, 2014).

2.3.3 The Hadejia Sub-basin River System

The river flow in the Hadejia River is largely (~ 80%) controlled by the upstream Tiga Dam on the Kano River (completed in 1974) and Challawa Dam on the Challawa River (completed in 1992). The dams lack adequate operational information and are (in most

cases) operated based on the ‘rule of thumb’. The third main river in the upstream part of the Hadejia sub-basin is the Watari River, this river has a small dam that does not influence the river flow significantly (Chiroma et al., 2005)..

The three rivers join upstream of Wudil to become the Hadejia River. The average annual flow in the upstream part of the Hadejia River (Wudil) has been reduced by 33% after the completion of Tiga Dam (1979-89). Furthermore, the peak flow is reduced and the river regime has changed from ephemeral to perennial, due to dry season releases for the three large formal users upstream of Hadejia (i.e., KRIP, KCWS and HVP) (Goes, 2002)..

The impact of the peak flow reductions is probably limited in the upstream section of the river due to the relatively high and more reliable rainfall, and the fact that flood rice farming, which depends on peak flows, is not widely practiced in this area. The dry-season river flows at Hadejia increased from 4% of the annual flow in the uncontrolled river to 32% after the completion of the two dams. These dry-season flows:

1) Create favourable circumstances for the development of aquatic macrophyte and silt blockages in the HNW which prevent the Hadejia River from contributing to the Yobe River since at least the early 1990s,

2) Lead to dry-season floods which are disadvantageous for farmers and herders, and

3) Wastewater (Goes, 2002).

2.3.4 The Hadejia Sub-Basin Water Uses Analysis

Tables 2.1 and 2.2 present an overview of the identified major water uses in the sub-basin.

Table 2.1: Overview of major water uses at the sub-basin upstream

Sites	Type of use	References with information
Tiga Dam (1974) and Ruwan Kanya Reservoir on Kano River	live storage 1,845x10^{6}m^3; large scale irrigation (13,300ha, 1997) for Kano River Irrigation Project (KRIP), Kano City Water Supply (KCWS), fishing	HJRBDA; Adams (1991); Adams et al. (1993); Afremedev (1999d); Diyam (1986, 1996); IUCNHNWCP (1999); Oyebande (2003); Oyebande and Nwa (1980); Simon (1997)
Tudun Wada Dam (1977) on Kano River	Live storage 18x10^{6}m^3; irrigation	KSMWR; WRECA (1980)
Bagauda small dam (1970) on a tributary to Kano River	live storage 21x10^{6}m^3; Kadawa Irrigation Scheme; domestic water supply, dam collapsed in 1988	KSMWR; Diyam (1996); Oyebande and Nwa (1980); WRECA (1980)
Marashi Dam (1980) on Challawa River	live storage 6x10^{6}m^3; irrigation	KSMWR; Diyam (1986, 1996); WRECA (1980)
Challawa Dam (1992) on Challawa River	live storage 904x10^{6}m^3; Kano City Water Supply (KCWS), fishing	HJRBDA; Diyam (1996); IUCN-HNWCP (1999); Neville (2005)
Pada Dam (1980) on Challawa River	live storage 10.5x10^{6}m^3; irrigation	KSMWR; Diyam (1986, 1996); WRECA (1980)
Karaye Dam (1971) on a tributary to Challawa River	live storage 16 x10^{6}m^3; urban water supply (Gwarzo, Karaye, Keru and others)	KSMWR; Diyam (1996); Oyebande and Nwa (1980); WRECA (1980
Magaga Dam (1980) on Challawa River	live storage 17 106m^3; irrigation	KSMWR; Diyam (1986, 1996); WRECA (1980)
Gunguzu Dam (1979) on a tributary to Challawa River	live storage 22x 106m^3; small scale irrigation; domestic water	KSMWR; Diyam (1986, 1996); WRECA (1980)

	supply (Garo, Gude)	
Watari Dam (1980) on Watari River (tributary to Challawa River)	live storage 93 $106m^3$; irrigation	KSMWR; Diyam (1986, 1996); WRECA (1980)
Kafin Chiri (1976) small dam near Wudil on tributary to Hadejia Rive	live storage 24.6 $106m^3$; domestic water supply, irrigation, dam partly collapsed in 2001 (HR Wallingford, 2002)	KSMWR; WRECA (1980)
Challawa, Tamburawa and Joda	water treatment works for domestic water supply	
Wudil	domestic water supply Wudil (tubewells in the river bank), Gari irrigation project	KSWB; KSMWR
Hadejia Barrage	Hadejia Valley Irrigation Project (3,000 ha, gross; 2,200 ha net. in 2003), fishing	HJRBDA; Diyam (1996)
floodplains along the Hadejia Rive	small scale irrigation in floodplains using surface and shallow groundwater, groundwater recharge, cattle, domestic uses	ADP and WB Kano and Jigawa states
cities and some villages in the uplands of Kano and Jigawa states	rural and urban water supply, and irrigation. using groundwater from 1st aquifer	WB and Ministries of Agriculture of Kano and Jigawa states

(Source: Goes and Bart, 2005)

Table 2.2: Dams probably not directly draining into the Jama'are or Hadejia rivers

Sites	Type of use	References with information
Dambo small dam on Gari River near Kazaure	Irrigation	MA Jigawa State; Muslim & Umar (1995)
Gari Marke small dam (1980) on Gari River near Kazaure	live storage 203x$10^6$$m^3$; irrigation	MA Jigawa State; KSMWR; Muslim & Umar (1995); WRECA (1980)
Mohammad Ayuba Dam (1975) on Watari River near Kazaure	live storage 4.3x$10^6$$m^3$; irrigation; domestic water supply	MA Jigawa State; WRECA (1980)
Ibrahim Adamu Dam (1974) near Kazaure	live storage 7.4x$10^6$$m^3$; domestic water supply, irrigation	KSMWR; WRECA (1980)
Tomas Dam (1976) on Tomas River near Kunya	live storage 57x $10^6$$m^3$; irrigation	KSMWR; WRECA (1980)
Jakara Dam (1976) on Jakara River near Kano	live storage 54 x$10^6$$m^3$; irrigation	KSMWR; WRECA (1980)
Rimin Gado dam in Gwarzo LGA on Jakara River (on Gwarzo Road)		

(Source: Goes and Bart, 2005)

2.4 PROBLEMS IN THE HADEIJA RIVER SU-BASIN

Continuing population growth, mass movement of internally displaced persons from troubled and water scares areas and urbanization, expanding and intensifying food production and increasing unregulated or illegal usage of the available water and discharge of contaminated water within the basin are all putting pressure on water resources of the basin. There are many causes driving this crisis, but it is clear that freshwaters and

ecosystems in the basin, upon which humanity has depended for millennia, are increasingly threatened (Goes and Bart, 2005).

The KYB project inception document has highlighted some very serious problems facing the basin in recent years. The basin is threatened by escalating and unsustainable pressures from fast-growing populations and cities as well as expanding agricultural and other activities. This is particularly true since the 1970s as the general climate context face chronic variability and deficits in rainfall and surface water resources. In the push for accelerated economic growth, many basin and national water policies show clear limitations in their ability to promote equitable and sustainable resource use. Some of the threats and challenges facing the basin as highlighted include:

i. Fast-growing water demand: Due to the semi-arid conditions, which are prevalent in the basin, scarcity of water has been, and continues to be, the major stimuli of the major development initiatives, which has placed the integrity of the sub-basin at risk.

ii. Reduced river flow due to climate variability and change: The pressure on the basin water resources is accentuated by climate change and variability. Recent climate patterns show a general decline in average annual rainfall and river discharge, leading to numerous second-order impacts. For example, as a result of a decrease in wet season water flow, silt and weed blockages, and impoundments in the upper basin, the Komadugu tributary no longer reaches the Yobe River, which in turn only contributes about 1% of the total water inflow to the Lake Chad.

iii. Fragmented regulatory responsibilities: The acute scarcity of water notwithstanding, water resources development in the basin still remains generally fragmented, with ill-defined and often conflicting responsibilities between government agencies and

stakeholders concerning all aspects of land and water management. The presence of two River Basin Development Authorities (RBDAs) with responsibility for water management in the basin but with little or no coordination illustrates this institutional caveat. The situation is made worse by lack of reliable hydro-meteorological information on the basin, as the monitoring network, which used to be effective up to the late 1970s is no longer in existence.

iv. Uncoordinated development interventions: Consequent to the above, the hydro-agricultural development initiatives in the basin are uncoordinated. This is in terms of the small-scale irrigation activities, which have been stimulated throughout the basin as well as dam construction leading to the progressive expansion of large-scale irrigation schemes.

v. Inequitable access to water resources: Many of these development initiatives have taken place in the upper reaches of the basin and have often penalized inhabitants of lower reaches of the basin, whose productive systems are highly dependent on the river flow. For example, the communities downstream of Hadejia town, in the HNWs, along the river banks, as well as the adjoining shores of Lake Chad, are more dependent for their livelihoods on flood and recession farming than on rain-fed farming. This is because rainfall is too low and unreliable in these areas. Against this background, the Hadejia River system is more than 80% controlled by Tiga and Challawa Gorge dams. These two dams, completed respectively in 1972 and 1992, feed the Kano River Irrigation Project (KRIP), the Hadejia Valley Irrigation Project (HVIP) and the Kano City Water Supply (KCWS). The earlier agreements to guarantee certain amounts of flow from the Hadejia River system for the downstream communities, somehow, are not being actualized.

vi. Growing tensions and risks of conflicts: The lack of co-ordination in management and utilization resulted in higher demand over available water, which leads to a tenuous competition for water between sectors (irrigation, domestic and industrial water use, traditional food production systems, the ecosystem, etc.), and the regions (upstream and downstream states and communities.

vii. At present, delivery infrastructure has been completed to permit 15,000 ha of irrigation to take place from this project. Another 7,000 ha is currently under construction to achieve the full build-out of 22,000 ha of irrigated lands. Notably, the current water demand for the KRIP is 60% higher than expected. In effect, the full amount of the planned irrigation allocation is being utilized on only 60% of the planned irrigation area. According to the IUCN Water Audit Inception Report (2005), "The higher demand is explained by changes in cropping patterns (rice instead of wheat) and excessive losses in the secondary and tertiary irrigation channels (Goes and Bart, 2005).

The possible mechanisms for groundwater recharge in the Hadejia-Jama'are-Yobe River Basin are: (1) direct infiltration of rain into the ground, (2) infiltration through riverbeds, and (3) infiltration through inundated flood plains.

Notably about 14% of the total annual average yield of the reservoirs appears to flow to waste into the Marma channel and Nguru lakes, where it is also causing significant damage to the local environment. Lack of maintenance of mechanical equipment and irrigation channels are some of the man-made contributions to the decreasing basin water yield as shows in plates 2.1 and 2.2



Plate 2.1: Failed control structure and unclear irrigation channel



Plate 2.2: Consequences of poor irrigation channel maintenance

Night reservoir storage are water receiving structures at specific locations to store flow of water during the night and make it readily available for farmers to use during the day time. Night storage reservoirs are also built with the intention of fish farming as part of the original design objectives of KRIP. Plate 2.3 presented one of such silted Night Reservoir located at Kadawa (IUCN Water Audit Inception Report, 2005).



Plate 2.3: Silted Night Reservoir Storage located at Kadawa

2.4.1 Environmental Practices that Affect Water Yield

The contribution of climatic variability to drought and desertification phenomena aggravated by the unsustainable activities of human in the environment, such activities that include deforestation for industrial purpose and fuel wood, urbanization, bush burning, agro-activities on marginal lands has amplified water losses due to evaporation and soil compaction under the heavy weight of the thousands of cattle reduces rate of soil infiltration (FMWR, 2005).

Riverine ecosystems and the myriad species they support are shaped by and dependent on the timing, magnitude, duration, and frequency of flow patterns. Alteration of natural flow patterns and fragmentation of habitat by water storage and diversion projects are the primary reasons that aquatic species are in sharp decline worldwide.

The consequences for the downstream river basin can be profound. In most cases highly dynamic riverine systems are transformed by dams into static water delivery channels, reducing the diversity of habitat and species. Elimination of annual floods deprives riparian forest and wetlands of periodic inundations, effectively disconnecting the river from its productive floodplains. Seasonal natural and cultivated food sources are lost, pastoral use of the floodplain becomes impossible, game species are displaced, groundwater levels decline, and recreational and aesthetic values of a living river basin disappear.

In recent years, increasing attention is being paid to the ecological benefits of re-operating the dams in the basin to store and release water in a pattern that more closely resembles natural flow conditions with their seasonal variability, IUCN-HNWCP has been at the forefront of this work "The Water Management Options". The Water Management Options report from IUCN-HNWCP was not received very well by the FMWR, it was perceived as focused on wetland conservation only (FMWR, 2005).

2.4.2 Flood Plain Practices

It is typical of the southern Sahel, with a strongly seasonal rainfall regime that supports large numbers of people dependent upon seasonal agriculture and pastoralism in the floodplains and wetlands. Around 80% of the rainfall occurs in just three or four months, between June and September, supporting rain-fed agriculture and extensive grasslands for

livestock grazing, with little or no flows occurring during the driest months. Once the rain ends, these resources dry up, and the farmers and pastoralists concentrate in the vast wetlands that have formed where the waters of the Hadejia and Jama'are rivers meet the ancient sand dunes (Goes and Bart, 2005).

2.4.3 Dam Releases and Operation

Tiga and Challawa Gorge dams control 80% of the flows into the Hadejia-Nguru wetlands. There is no coherent, integrated development plan for the entire basin, nor is there much coordination between the agencies responsible for the dams and those for water supply. The groundwater system is recharged mainly from seasonal flooding due to riverbank overtopping and to a lesser extent from concentration of rainfall in depressions. This recharge has been substantially reduced by the flow regulation due to Tiga and Challawa Gorge dams. Virtually all of the rivers lose flow as a result of evaporation, transpiration and, principally, infiltration. The dams have brought changes in river flow, loss of habitat, blocking of channels and changes in silt loading (IUCN, 2005).

Tiga Dam, built on the Kano tributary in the early 1970s, is by far the larger of the two dams. Its primary function is to store water for the Kano River Irrigation Project (KRIP) Scheme. The KRIP was one of the first large-scale irrigation schemes developed in northern Nigeria. At present, delivery infrastructure has been completed to permit 15,000 ha of irrigation to take place from this project. Another 7,000 ha is currently under construction to achieve the full build-out of 22,000 ha of irrigated lands (IUCN, 2005).

Notably, the current water demand for the KRIP is 60% higher than expected. In effect, the full amount of the planned irrigation allocation is being utilized on only 60% of the planned

irrigation area. According to the IUCN Water Audit Inception Report (2005), “The higher demand is explained by changes in cropping patterns (rice instead of wheat) and excessive losses in the secondary and tertiary irrigation channels.”

The Challawa Gorge Dam was completed on the Challawa tributary in 1992. It supplements water deliveries from Tiga dam to the Hadejia Valley Irrigation Project (1000 ha has been developed and 5,000 ha are under construction) and the City of Kano. Challawa Gorge Dam also operates as a flood control facility, and has spilled water for flood management purposes in 3 of the past 10 years of operation. Together, the Kano city water supply, the KRIP and the HVIP consume about half of the estimated long-term annual yield of the reservoirs (IUCN Water Audit Inception Report, 2005).



Plate 2.4: Point of irrigation water release from Tiga Dam



Plate 2.5: Thermometer and hydrometer Cabin at Tiga Dam



Plate 2.6: Rain gauge and solar recorder stand

2.4.4 Flooding in the Sub-basin

By constricting the flows, the irrigation dams reduce the extent of the inundation of the floodplain and wetlands during the wet season and increase it during the dry season. This has desiccated lands that were formerly wetted on a seasonal basis for recessional agriculture, and has waterlogged low lying lands which no longer experience their natural

drying out cycle. Since the dams became operational, the maximum extent of flooding has declined from 300,000 ha in the 1960s to around 70,000 to 100,000 ha more recently (Center for Ecology and Hydrology, 2000). IUCN estimates that the effect of Tiga Dam and the KRIP Phase I Scheme has been to reduce the flood extent by between 200 and 450 km^3.

The effects are particularly acute during the periods of extended drought in the basin. In some years, the flood has failed to arrive completely as a result of the dams, there has not only been a reduction in the magnitude of the floods, but also a decline in their duration, a reduction in the area inundated, a decline in the groundwater tables and a general shortage of water in the lower part of the basin. Since the dam operators do not have inflow monitoring devices nor do they have inflow forecasting tools for the reservoirs, the dam operators tend to create unexpected floods during years of good rains in order to save the dams to the detriment of the downstream communities (IUCN, 2005).

2.5 CLIMATE CHANGE AND THE HYDROLOGICAL CYCLE

Much of the solar energy received by the Earth is used to drive the hydrological cycle, higher levels of solar energy trapped in the atmosphere will lead to an intensification of this cycle, resulting in changes in precipitation patters. These changes will result in increased floods and drought, which will have significant impacts on the availability of freshwater. These impacts on freshwater will be further compounded by rising sea levels, and melting glaciers. Warmer average global temperatures mean greater evaporation, with a warmer atmosphere able to hold more moisture aloft that can fall as precipitation, increasing the potential for flooding. There are a number of factors that contribute to flood risks implied by a warmer climate, including:

• More frequent wet spells in middle/ high latitude winters;

• More intense mid-latitude storms;

• Increased frequency of extreme precipitation events;

• Increased magnitudes of precipitation events of high intensity; and

• Land use changes and surface degradation (for example, deforestation and urbanization)

The combination of more intense and frequent storms with land use changes is already proving to be deadly for the world's vulnerable populations. When less precipitation and higher temperatures occur simultaneously, the availability of water resources is reduced even further while evaporation is increased, leading to a vicious cycle. Further, the poor tend to be more vulnerable to the impacts of climate change. The poor are generally forced to inhabit land (floodplains, steep unstable slopes or exposed coastlines) that increases their exposure to climate risks. Developing countries also tend to be very reliant on climate-sensitive natural resources, such as agriculture, and have limited capacity to withstand and recover from the resulting storms, floods, droughts, disease outbreaks, and disruptions to food and water supplies as a result of climate change (UN, 1992).

As (seasonal) water quantities and quality decrease as a result of intensification of the hydrological cycle, competition for available resources will intensify. Demand for agricultural and domestic water in particular increases significantly at hotter and drier times of the year. Agriculture has always been the dominant end-use of diverted water; this will only intensify with increasing needs for irrigation brought on by higher temperatures and reduced precipitation, coupled with increasing populations. Meanwhile, demands of industry are expected to become a greater issue in the competition for dwindling resources;

in the event of decreasing water tables as a result of climate change, industrial needs will be forced to compete with agricultural and domestic water supply sources, and could lead to conflict (Smith, 2006).

2.5.1 Health Impacts

Clearly, the health implications of changes to water supply are far-reaching. Currently, more than 3 million people die each year from avoidable water-related disease, most of who are in developing countries. The effects of climate change on water will exacerbate the existing implications of water shortages on human health, as follows:

- Water-borne diseases: result from the contamination of water by human/ animal faeces, or by urine infected with pathogenic viruses/ bacteria, both of which are more likely to occur during periods of flood and therefore intensify with the projected increases in natural disasters under climate change. Diseases are transmitted directly when the water is drunk or used in food preparation.
- Water-washed diseases: those resulting from inadequate personal hygiene as a result of scarcity or inaccessibility of water (including many water-borne diseases and typhus).
- Water-based diseases: those caused by parasites that use intermediate hosts living in/ near water (e.g. guinea worm).
- Water-related diseases: borne by insect vectors that has habitats in/near water (such as malaria). For example, malaria has recently appeared in Nairobi and the highlands of Kenya, illustrating the expanding range of mosquitoes due to warmer temperatures.
- Water-dispersed diseases: infections for which the agents proliferate in fresh water and enter the human body through the respiratory tract (e.g. legionella).

Further indirect health challenges include malnutrition arising from agricultural disruption and food insecurity (NNPC, 2009).

2.6 THE IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES

Local climate data are often needed in watershed planning to help understand the local water budget for the region and also for modeling purposes. Hourly or daily precipitation data, as well as temperature, evaporation and wind speed are necessary for simulating rainfall-runoff processes in watershed models. However, if weather data are being used only to generally characterize weather patterns in the watershed, daily or monthly averages are sufficient. Daily and monthly temperature and precipitation data are generally available online in some Meteorological Department website. The data are available by station through the state climate data centers and sometimes with other state departments such as agriculture department, irrigation department. Available data on climate change projections provide ample evidence that water resources are vulnerable and have the potential to be strongly impacted by climate change, with extensive consequences for human societies and ecosystems (Ribeiro et al., 2009).

Numerous internal and external feedback paths occur between anthropogenic impairment of the water cycle and the environmental resources of the atmosphere, soils and the biosphere. Even without the additional stress of climate change, water security already is one of the most pressing issues in developing countries (Gordon et al. 2008).

In many cases, water crisis can be traced back to a failure of state control, and therefore to crisis in governance (Bakker, 2010). According to the IPCC report 2001, the population exposed to water scarcity rapidly augmented with surging temperatures towards the second

half of the century. In the same light, climate model analysis studies by Parry et al., (2001) show that, the impacts of temperature in arid and semi-arid regions are expected to rise above global averages. Thus, in regions already under water stress today, including Africa, climate change will further aggravate the situation. In many water-stressed regions, an increase in global mean temperature above 1.5ºC, can lead to a decrease in water supply and quality (IPCC, 2001).

The international Dialogue on Water and Climate in 2004 noted that water stress will increase significantly in those regions that are already relatively dry (such as sub-Saharan Africa). Further, a region is in a state of high water-related criticality (susceptibility of a region or its population to crises) if water scarcity coincides with a low problem-solving capacity of the population (WBGU, 1998).

Observational records and climate projections provide abundant evidence that water resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems (Bates et al., 2008).

Numerous internal and external feedback paths occur between anthropogenic impairment of the water cycle and the environmental resources of the atmosphere, soils and the biosphere. Even without the additional stress of climate change, water security already is one of the most pressing issues in developing countries (WBGU, 1998).

Bates et al., (2008) reported that warming over several decades has been linked to changes in the large-scale water cycle such as: increasing atmospheric water vapour content; changing precipitation patterns, intensity and extremes; reduced snow cover and widespread melting of ice; and changes in soil moisture and runoff. In other words, the challenges

related to water resources are: having too much of it, having too little of it, and having un-usable resources (e.g. due to pollution or stagnation). Each of these problems may be exacerbated by climate change. Available evidence has proved that looming climate changes are already having serious consequences on the water resources of most African countries, even when the continent of Africa contributes insignificantly to the greenhouse gas emissions responsible for these changes.

According to Smith (2006), the effects of minor levels of climate change are already being felt, with impacts across many economic sectors. While there will clearly be some gains from climate change most of the impacts will be negative, and gains and losses will not be evenly distributed. For example:

i. Water: Rising global temperatures will lead to an intensification of the hydrological cycle, resulting in dryer dry seasons and wetter rainy seasons, and subsequently heightened risks of more extreme and frequent floods and drought. Changing climate will also have significant impacts on the availability of water, as well as the quality and quantity of water that is available and accessible. Melting glaciers will increase flood risk during the rainy season, and strongly reduce dry-season water supplies to one-sixth of the World's population.

ii. Agriculture: Declining crop yields are likely to leave hundreds of millions without the ability to produce or purchase sufficient food supplies, especially in Africa. At mid to high latitudes, crop yields may increase for low levels of change in temperature, but will decline at higher levels of temperature change.

iii. Ecosystems: Changing temperatures will cause ecosystems to shift – forests, land types and plant species will dieback in some areas as temperatures rise, but increase in other

areas. However, in many cases, the pace of change in temperature may be too fast for ecosystems to adjust, resulting in the loss of forests and species.

iv. Health: Higher temperatures expand the range of some dangerous vector-borne diseases, such as malaria, which already kills one million people annually, most of whom are children in the developing world. Further, heat waves associated with climate change, and increases in water borne diseases, will result in increased health problems.

v. Coastlines: Melting ice and thermal expansion of oceans are the key factors driving sea level rise. In addition to exposing coastlines, where the majority of the human population lives, to greater erosion and flooding pressures, rising sea levels will also lead to salt water contamination of groundwater supplies, threatening the quality and quantity of freshwater access to large percentages of the population.

2.7 HYDROLOGICAL MODELLING

A hydrologic model is a simplification of a real-world system (e.g., surface water, soil water, wetland, groundwater and estuary) that aids in understanding, predicting, and managing water resources. Both the flow and quality of water are commonly studied using hydrologic models.

The application and development of hydrological models are key activities of watershed management. It helps to increase our knowledge about hydrological processes, and provide sustainable solutions for integrated water resources management. In general, we develop and apply hydrological models for two main reasons: process understanding and scenario analysis (Betrie et. al., 2011).

2.7.1 Process Descriptions

To understand hydrologic processes, a large amount of detailed quantitative measurements are required at different spatial and temporal scales. The strength of hydrological models is that they can provide output at high temporal and spatial resolutions, and for hydrological processes that are difficult to observe on the large scale that they are generally applied on. Hydrological models therefore enable us to gain insight into hydrologic processes using a limited number of measurements (GIS, 2008).

2.7.2 Scenario Analysis

The most important aspect of applying models is in their use in exploring different scenarios, expressing for example possible effects of changes in population and climate on the water cycle. Models are also applied at the operational level to explore interventions to be used by water managers and policy makers. Examples of this are changes in reservoir operation rules, water allocation between sectors, investment in infrastructure such as water treatment or desalination plants, and agricultural and irrigation practices.

Using hydrological models in scenario analyses we attempt to solve the question "What if…?". Data and statistics are crucial to evaluate the past and present, but models are critical to investigate options for the future (GIS, 2008).

2.7.3 Model Selection

Hydrologic model does not focus on the use of a single hydrological model, but has a variety of models and techniques available. The model that is eventually selected depends on the problem to be addressed and/or the question to be answered. The spatial scale is essential in this context as is the amount of physical detail required for the specific project.

Usually one model does not suffice and a combination of two or three models is required. An overview of models that are frequently used by is listed below:

i. Spatial Processes in HYdrology (SPHY)

The Spatial Processes in HYdrology (SPHY) model is a hydrological modeling tool suitable for a wide range of water resource management applications. SPHY is a state-of-the-art, easy to use, robust tool, that can be applied for operational as well as strategic decision support. The SPHY modeling package is available in the public domain and only uses open source software. SPHY is developed by FutureWater in cooperation with national and international clients and partners..

a. Key Features

- Robust scientific basis
- Combines strength of existing de facto hydrological models
- Modular setup in order to switch on/off irrelevant processes for computation efficiency
- Wide range of applicability in terms of regions, climates, modeling purposes, spatial and temporal scales
- Performs under data scarcity
- Linkable to remote sensing data
- Easy adjustment and application
- Graphical User Interface for QGIS and Open source

b. Application

The SPHY model has been applied and tested in various studies ranging from real-time soil moisture predictions in flat lands, to operational reservoir inflow forecasting applications in

mountainous catchments, irrigation scenarios in the Nile Basin, and detailed climate change impact studies in the snow- and glacier-melt dominated the Himalayan region. Typical examples of SPHY applications are listed in this section along with links to project pages and publications.

- ✓ Climate Change Impact and Adaptation
- ✓ Water and Energy
- ✓ Operational Services
- ✓ Irrigation Management
- ✓ Snow- and glacier fed river basins
- ✓ Model Overview

As input SPHY requires data on state variables as well as dynamic variables. For the state variables the most relevant are: Digital Elevation Model (DEM), land use type, glacier cover, reservoirs and soil characteristics. The main dynamic variables are climate data such as precipitation, temperature, reference evapotranspiration. Since SPHY is grid-based optimal use of remote sensing data and global data sources can be made. For example, the Normalized Difference Vegetation Index (NDVI) can be used to determine the Leaf Area Index (LAI) in order to estimate the growth-stage of land cover. For setting-up the model data on stream-flows are not necessary. However, to undertake a proper calibration and validation procedure flow data are required. The model could also be calibrated using actual evapotranspiration, soil moisture contents, or snow coverage.

The SPHY model provides a wealth of output data that can be selected based on the preference of the user. Spatial output can be presented as maps of all the hydrological processes. Maps often displayed as output include actual evapotranspiration, runoff

generation (separated by its contributors), and groundwater recharge. These maps can be generated on daily base, but most users prefer to get those at monthly or annual aggregated time periods. Time-series can be generated for each location in the study area. Time-series often used are stream flow under current and future conditions, actual evapotranspiration and recharge to the groundwater (FutureWater, n.d).

ii. Soil & Water Assessment Tool (SWAT)

SWAT (Soil & Water Assessment Tool) is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds. SWAT is a public domain software enabled model actively supported by the USDA Agricultural Research Service at the Blackland Research & Extension Center in Temple, Texas, USA. It is a hydrology model with the following components: weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, and water transfer. SWAT can be considered a watershed hydrological transport model. This model is used worldwide and is continuously under development. As of July 2012, more than 1000 peer-reviewed articles have been published that document its various applications.

a. Model operation

SWAT is a continuous time model that operates on a daily time step at basin scale. The objective of such a model is to predict the long-term impacts in large basins of management and also timing of agricultural practices within a year (i.e., crop rotations, planting and harvest dates, irrigation, fertilizer, and pesticide application rates and timing). It can be used to simulate at the basin scale water and nutrients cycle in landscapes whose dominant land

use is agriculture. It can also help in assessing the environmental efficiency of best management practices and alternative management policies. SWAT uses a two-level desegregation scheme; a preliminary sub-basin identification is carried out based on topographic criteria, followed by further discretization using land use and soil type considerations. Areas with the same soil type and land use form a Hydrologic Response Unit (HRU), a basic computational unit assumed to be homogeneous in hydrologic response to land cover change.

iii. Soil Water Atmosphere Plant (SWAP)

SWAP (Soil, Water, Atmosphere and Plant) simulates transport of water, solutes and heat in unsaturated/saturated soils. The model was designed to simulate flow and transport processes at field scale level, during growing seasons and for long term time series. It offers a wide range of possibilities to address both research and practical questions in the field of agriculture, water management and environmental protection (FutureWater, n.d).

a. Model description

SWAP simulates transport of water, solutes and heat in the vadose zone in interaction with vegetation development. The model employs the Richards equation including root water extraction to simulate soil moisture movement in variably saturated soils. Concepts are added to account for macroporous flow and water repellency. SWAP considers for solute transport the basic processes convection, dispersion, adsorption and decomposition. For more extensive studies which for instance include volatilization or nutrient transformations, SWAP generates soil water fluxes for detailed chemical transport models as PEARL for pesticides and ANIMO for nutrients. SWAP simulates soil heat flow taking into account

actual heat capacities and thermal conductivities. The generic crop growth module WOFOST is incorporated to simulate leaf photosynthesis and crop growth. The soil moisture, heat and solute modules exchange status information each time step to account for all kind of interactions. Crop growth is affected by the actual soil moisture and salinity status on a daily basis. An extensive test protocol ensures the numerical code quality of SWAP (FutureWater, n.d).

c. General focus of the model

- ✓ Field scale water and salinity management
- ✓ Irrigation scheduling
- ✓ Transient drainage conditions
- ✓ Plant growth affected by water and salinity
- ✓ Pesticide leaching to ground water and surface water
- ✓ Regional drainage from top soils towards different surface water systems
- ✓ Optimization of surface water management
- ✓ Effects of soil heterogeneity http://www.swap.alterra.nl/summary.

iv. Water Evaluation and Planning (WEAP)

The Water Evaluation and Planning system is a Windows-based decision support system for integrated water resources management and policy analysis. WEAP is a model-building tool, used to create simulations of water demand, supply, runoff, evapotranspiration, infiltration, crop irrigation requirements, in-stream flow requirements, ecosystem services, groundwater and surface storage, reservoir operations, and pollution generation, treatment, discharge and in-stream water quality, all under scenarios of varying policy, hydrology, climate, land use, technology and socio-economic factors. WEAP can dynamically link to the USGS MODFLOW groundwater flow model and the US EPA QUAL2K surface water quality model.

b. WEAP applications generally include several steps.

- ✓ Study definition: The time frame, spatial boundaries, system components, and configuration of the problem are established.
- ✓ Current accounts: A snapshot of actual water demand, pollution loads, resources and supplies for the system are developed. This can be viewed as a calibration step in the development of an application.
- ✓ Scenarios: A set of alternative assumptions about future impacts of policies, costs, and climate, for example, on water demand, supply, hydrology, and pollution can be explored. (Possible scenario opportunities are presented in the next section.)
- ✓ Evaluation: The scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

c. Examples of WEAP Scenario Analyses

Scenario analysis is central to WEAP. Scenarios are used to explore the model with an enormous range of "what if" questions, such as :

- o What if population growth and economic development patterns change?
- o What if reservoir operating rules are altered?
- o What if groundwater is more fully exploited?
- o What if water conservation is introduced?
- o What if ecosystem requirements are tightened?
- o What if a conjunctive use program is established to store excess surface water in underground aquifers?
- o What if a water recycling program is implemented?

- What if a more efficient irrigation technique is implemented?
- What if the mix of agricultural crops changes?
- What if climate change alters demand and supplies?
- How does pollution upstream affect downstream water quality?
- How will land use changes affect runoff? (FutureWater, n.d).

v. AquaCrop

AquaCrop is a crop growth model developed by the Land and Water Division of FAO to address food security and to assess the effect of environment and management on crop production. AquaCrop simulates yield response to water of herbaceous crops, and is particularly suited to address conditions where water is a key limiting factor in crop production. When designing the model, an optimum balance between simplicity, accuracy and robustness was pursued. To be widely applicable AquaCrop uses only a relatively small number of explicit parameters and mostly-intuitive input-variables requiring simple methods for their determination. On the other hand, the calculation procedures are grounded on basic and often complex biophysical processes to guarantee an accurate simulation of the response of the crop in the plant-soil system (FutureWater, n.d).

2.8 COMPUTER PROGRAMME APPLICATION IN HYDROLOGICAL MODELS

Assessment, simulation and prediction of rainfall and corresponding runoff are essential for stakeholders and policy makers to plan or adopt the required policies. There are various techniques available in the literature to assess, simulate and predict hydrological variables. However, the selection of these techniques normally depends on the objectives of

the study, availability of required input data, the quality of available models and some predefined assumptions (Janhabi, 2014).

With limited or no data, the quantitative understanding and prediction of the processes of runoff generation and its transmission to the outlet represent one of the most challenging areas of hydrology. Traditional techniques for design flood estimation include the rational method, empirical methods, flood frequency method, unit hydrograph techniques, and watershed models. The unit hydrograph techniques and watershed models can be used to estimate the design flood hydrograph in addition to the magnitude of the design flood peak (Kalita, 2008).

Hydrological modeling is a commonly used tool to estimate the basin's hydrological response due to precipitation. The selection of the model depends on the basin and the objective of the hydrological prediction in the basin (Hunukumbura *et al*., 2008).

Many computer simulation models have been developed to simulate watershed-scale processes and the hydrologic effects of different management scenarios. Watershed models are effective tools for investigating the complex nature of those processes that affect surface and subsurface hydrology, soil erosion and the transport and fate of chemical constituents in watersheds (Singh *et al*, 2005).

A watershed model can be used to achieve a better understanding of the impact of land use activities and different management practices on these hydrologic processes. Due to the increased spatial data availability, more and more distributed hydrological models are used. For example, with United States of America from 2004 to 2011, as part of the overall Conservation Effects Assessment Project, thirteen projects on agricultural watersheds in the

United States were funded jointly by the U.S. Department of Agriculture USDA, National Institute of Food and Agriculture and the Natural Resources Conservation Services, (Arabi et al., 2012).

Geographic Information System (GIS) is a computer system build to capture, store, manipulate, analyze, manage and display all kinds of spatial or geographical data. GIS application is tools that allow end users to perform spatial query, analysis, edit spatial data and create hard copy maps. In simple way GIS can be define as an image that is referenced to the earth or has x and y coordinate and its attribute values are stored in the table. These x and y coordinates are based on different projection system and there are various types of projection system. To perform the basic task in GIS, layers are combined, edited and designed (GIS, 2008).

GIS can be used to solve the location based question such as "What is located here" or Where to find particular features? GIS User can retrieve the value from the map, such as how much is the forest area on the land use map. This is done using the query builder tool. Next important features of the GIS are the capability to combine different layers to show new information. For example, you can combine elevation data, river data, land use data and many more to show information about the landscape of the area. From map you can tell where high lands are or where is the best place to build house, which has the river view. GIS helps to find new information.

How GIS Works:

- ✓ Visualizing Data: The geographic data that is stored in the databases are displayed in the GIS software
- ✓ Combining Data: Layers are combined to form a map of desire.
- ✓ The Query: To search the value in the layer or making geographic queries.

Data: Data are the fuel for the GIS and the most important and expensive component. Geographic data are the combination of physical features and its information which is stored in the tables. The processes of capturing the geographic data are called digitization which is the most tedious job. It is the process of converting scanned hardcopy maps into the digital format. Digitization is done by tracing the lines along the geographic features for example to capture a building you will trace around the building on image (GIS, 2008).

2.8.1 Types of GIS Data:

Raster Data: Raster data store information of features in cell based manner. Satellite images, photogrammetry and scanned maps are all raster based data. Raster model are used to store data which varies continuously as in aerial photography, a satellite image or elevation values (DEM- Digital Elevation Model).

Vector Data: There are three types of vector data, points, lines and polygons. These data are created by digitizing the base data. They store information in x, y coordinates. Vectors models are used to store data which have discrete boundaries like country borders, land parcels and roads (GIS. 2008).

2.9 SOFTWARE SELECTION

Watershed models simulate natural processes of the flow of water, sediment, chemicals, nutrients, and microbial organisms within watersheds, as well as quantify the impact of human activities on these processes. Simulation of these processes plays a fundamental role in addressing a range of water resources, environmental, and social problems (Vijay and Donald, 2006).

Modeling of water system started during late sixties and some of initial models were physical and prototype in nature. Short-term forecasting of river inflows was conducted by the Water & Power Development Authority (WAPDA) through lumped and semi -distributed models like the University of British Columbia Watershed Model (UBC). The output of this UBC model was taken as input to MODSIM for simulation of irrigation network. The MODSIM simulations were made for hydrological studies and then impact assessment studies for the climate changes on water resources. Another comprehensive model; applied in Indus Basin was; Indus Basin Model Revised (IBMR). This model addressed almost all important parameters; hydrology, cropping, economic, etc. All these models were lumped type's hydrologic simulation models which are unable to represent the spatial variability of hydrologic processes and catchment parameters. Distributed models are now being applied to assess the spatial variability of various watershed parameters. SWAT, based on distributed model has been applied in many researches to predict the effects of land use and climate change impacts on the water resources (Arnold et al., 1998).

In this study, the soil and water assessment tool (SWAT) was applied to the sub-basin because it includes many useful components and functions for simulating the water balance and other watershed processes.

2.10 SIMULATIONS USING SWAT

SWAT is a physically based, continuous time and a public domain hydrologic model. It was developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time (Neitsch et al., 2002). The model has

been tested in different tropical watersheds and reported to have shown better performances when compared with other models (Lenhart et al., 2002).

Borah and Bera (2003), reviewed eleven watershed-scale hydrological models and concluded that Agricultural Non-Point Source (AGNPS), Annualized Agricultural Non-Point Source (AnnAGNPS), Decision Support System for Agro Technology Transfer (DWSM), Hydrological Simulation Program-Fortran (HSPF), MIKE-SHE and SWAT were able to simulate all major components of hydrology, sediments and chemicals applicable to watershed-scale catchments. SWAT was considered a promising model for continuous simulations in predominantly agricultural watersheds.

2.10.1 SWAT Model Description

SWAT operates on a daily time step and is designed to predict the impact of land use, management options in water resources, sediment, and agricultural chemical yields in un-gauged watersheds. The model is process based, computationally efficient, and capable of continuous simulation over long time periods. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. In SWAT, a watershed is divided into multiple sub-watersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, topographical, and soil characteristics. The HRUs are represented as a percentage of the sub-watershed area and may not be contiguous or spatially identified within a SWAT simulation. Alternatively, a watershed can be subdivided into only sub watersheds that are characterized by dominant land use, soil type, and management (Arnold et al., 1998).

Water balance is the driving force behind all the processes in SWAT because it impacts plant growth and the movement of sediments, nutrients, pesticides, and pathogens. Simulation of watershed hydrology is separated into the land phase, which controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel in each sub-basin, and the in-stream or routing phase, which is the movement of water, sediments, etc., through the channel network of the watershed to the outlet. Below is a brief description of the processes simulated by SWAT. Details of these processes are given in the SWAT theoretical documentation that can be downloaded from (http://swatmodel.tamu.edu).

The hydrologic cycle is climate driven and provides moisture and energy inputs, such as daily precipitation, maximum/minimum air temperature, solar radiation, wind speed, and relative humidity, that control the water balance. SWAT can read these observed data directly from files or generate simulated data at runtime from observed monthly statistics. Snow is computed when temperatures are below freezing, and soil temperature is computed because it impacts water movement and the decay rate of residue in the soil. Hydrologic processes simulated by SWAT include canopy storage, surface runoff, infiltration, evapotranspiration, lateral flow, tile drainage, redistribution of water within the soil profile, consumptive use through pumping (if any), return flow, and recharge by seepage from surface water bodies, ponds, and tributary channels.

SWAT uses a single plant growth model to simulate all types of land cover and differentiates between annual and perennial plants. The plant growth model is used to assess removal of water and nutrients from the root zone, transpiration, and biomass/yield production. SWAT uses the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977) to predict sediment yield from the landscape. In addition, SWAT models

the movement and transformation of several forms of nitrogen and phosphorus, pesticides, and sediment in the watershed.

SWAT allows the user to define management practices taking place in every HRU. Once the loadings of water, sediment, nutrients, and pesticides from the land phase to the main channel have been determined, the loadings are routed through the streams and reservoirs within the watershed. The water balance for reservoirs includes inflow, outflow, rainfall on the surface, evaporation, seepage from the reservoir bottom, and diversions. Model equations are given in the SWAT theoretical documentation (http://swatmodel.tamu.edu) and in Arnold et al. (1998), Gassman et al. (2007) presents an overview of:

(1) Climatic inputs and HRU hydrologic balance;

(2) Cropping, management inputs, and HRU-level pollutant losses; and

(3) Flow and pollutant routing.

2.10.2 SWAT Model Inputs Requirement

The watersheds are spatially distributed in nature because of its specially distributed vegetation and topography, soil and precipitation. The calibration of model needs stream flow data in temporal pattern. So in general two types of dataset are required; spatial data sets and temporal datasets discussed in following section according to Arnold, et al., (2010b).

i. Digital Elevation Model (DEM)

Topographical data extracted from DEM involves data on physical/natural features of the watershed, watershed boundaries, floodplains in the watershed, wetlands and water bodies, etc. Depending upon the purpose and the features of watershed planning, the utility of the

topographical data will vary. In many cases, the data on either the spatial variation or the spatio-temporal variation of the topographical data parameters for hydrological characterization, the data on slope, permeability of the ground surface, roughness of the ground surface, obstructions like buildings or other man-made infrastructure or hills or depressions is required.

ii. Utility of Soil data in watershed management

Soil data is an important factor in determining the amount of erosion and storm water runoff that occurs in the watershed of interest. It enables the estimation of water retained within the soil, analyze the slope stability or the flow of groundwater through the soil pores. Data on the types of soils in the watershed and their characteristics helps us to identify the areas that are prone to erosion or sedimentation as well as the areas which are more likely to experience runoff. Digital soil map of the study area was obtained from online and the field soil data was obtained for validation.

iii. Utility of Land Use/ Land Cover (LULC) Data in Watershed Planning

LULC data consists of data on forests, grass/ range lands, cultivated lands, orchards, wildlife reservations, recreation areas, urban/ rural areas, water bodies, eroded areas, etc. Depending upon the purpose and the features of watershed planning the utility of the LULC data in watershed planning varies. In most of the cases, the data on either the spatial variation or the spatio-temporal variation of the LULC data is required to carry out watershed planning.

LULC influences practically all the processes of hydrologic cycle like interception, infiltration, surface runoff, surface storage, groundwater runoff, groundwater storage, evapotranspiration (ET).

LULC also influences meteorological parameters such as temperature, humidity and wind velocity, which in turn impact the estimation of ET. Therefore, especially the purposes of watershed planning like hydrological characterization, flood management and control, groundwater planning in a watershed get affected significantly. Thus LULC data has a great utility in watershed planning. An improved model performance plays a vital role in achieving the watershed planning objectives. Hence, appropriate values of the lumped and/or distributed model parameters need to be assigned in the model, based on the accurate analysis by experts of the spatiotemporal variations in the watershed LULC data. The land use data for 1975, 2005 and 2013 were downloaded. .

iv. Meteorological Data

Hydro-meteorological data is an important hydrologic data. It includes data on precipitation, temperature, solar radiation or duration of sunshine, wind speed and relative humidity which influence the watershed management. The primary concern of a water management agency is with rainfall, river flow and groundwater, and the focus of their activity will be the measurement and analysis of these variables. Historically the main climate variable collected by a water management agency is rainfall, as this, even in the absence of water management or catchment models will provide an intuitive, subjective or qualitative assessment of the interaction between rainfall, river and groundwater. For the most part, rainfall data are widely available on a daily basis, and can be agglomerated into daily, monthly, or seasonal values, etc.

Rainfall, temperature (maximum), wind speed, relative humidity and solar radiation were obtained for Kano and Jigawa States from the NiMET applied in calibration and validation.

v. Radar weather datasets

Precipitation is the main driving force for hydrological processes in most terrestrial water cycles. From a water resources management perspective, accurate information on the temporal and spatial variation in precipitation plays a critical role in determining the overall water budget at catchment and sub-catchment scale (Younger et al., 2009). The possibility of using precipitation estimated by weather radar for hydrological purposes was initially recognized in the 1970s, when the concept of radar-based quantitative precipitation estimation (QPE) was introduced to practical hydrological operations such as flood forecasting (Wilson and Brandes, 1979). Since then, an increasing number of research activities have explored the potentials of using radar QPE in hydrological applications (He et al., 2011b).

The primary advantage of using radar for rainfall estimation is that it provides higher spatial and temporal resolution products and has larger areal coverage compared to traditional rain gauge measured rainfall. This makes radar-based QPE products very suitable for distributed hydrological modeling ([van de Beek et al., 2010). In principle, radar is able to provide rainfall measurements corresponding to the grid scale of distributed hydrological models whereas rain-gauge-based products are based on geometrical interpolations to each model grid from a limited number of observation points.

Despite the scaling advantages in space and time, stand-alone radar systems may not be able to serve the purpose of quantitative application. This is mainly because radar measures

precipitation remotely and indirectly, and the radar signal is often contaminated with various types of noises and artifacts. As a result, the operational radar QPE is often based on a combination of both radar and rain gauge information (Haberlandt, 2007).

However, it is important to know, first, if the rain gauge network density is sufficient to provide adequate bias correction to the radar data; second, if there are the additional information introduced by using radar data in combination with the existing rain gauge network; and third, if the current rain gauge density can be reduced without sacrificing the quality of the rainfall estimate. It may be expected that the relationship between the qualities of the radar QPE product would be a nonlinear function of the rain gauge density and that the quality at some point would reach a level where additional rainfall information from extra rain gauges would be redundant (Kim et al., 2010). Solving these issues can be beneficial when evaluating the economic aspects of maintaining the rain gauge network and requires that the rainfall products are tested as driving forces to, e.g., in hydrological models.

Radar precipitation has been used in various types of hydrological studies, where the improvement of simulated hydrological dynamics by using high-resolution data is documented. Among them the most common application of radar QPE data is to simulate or predict flash flood events using rainfall-runoff models (Zoccatelli et al., 2011). However, radar-based precipitation products have never been employed in driving a groundwater model. It is acknowledged in groundwater modeling that the spatial and temporal variation of groundwater recharge plays a significant role in obtaining realistic flow paths and changes in storage (Milewski et al., 2009), and that recharge is highly dependent on

precipitation. Therefore, the potential of using radar QPE data in such context may have been overlooked in previous studies. Moreover, the focus of water management at catchment scale has in recent years moved toward using an integrated water resource approach, which requires modeling of the entire water cycle including both the surface and subsurface elements (Benito et al., 2010). Considering the high resolution and large spatial coverage, it is likely that using radar QPE data can provide more realistic forcing at the time scales relevant for ground water recharge.

Dynamic, coupled surface water-groundwater models require years of observation data with relatively high quality to obtain reliable water budgets. However, application of long time series of radar QPE data may cause difficulties, since the non-precipitation echoes as well as other types of errors left on the radar QPE product could accumulate over time and affect the model calibration (Villarini & Krajewski, 2010). Thus, a thorough model performance evaluation using not only the radar but also rain-gauge-based precipitation product for comparison could help to provide an understanding of the physical processes in the hydrological models. Additionally, the coupled hydrological model is also an indirect tool to assess the accuracy of the rainfall input.

- *Radar calibration techniques*

The simple bias adjustment (BA) method, which aims to calibrate the Next Generation Radar Data (NEXRAD) estimated mean to match the rain-gauge observed mean precipitation, has been widely used to calibrate NEXRAD data for distributed hydrologic modeling (Zhang et al., 20 0 4).

Li et al. (2008) exhibited the combination of a linear regression (LR) and a geo-statistical procedure (Ordinary Kriging) for effective calibration of NEXRAD data. Simple Kriging with varying local means (SKlm) (Goovaerts, 2000) and Regression Kriging (RK) (Hengl et al., 2004), have been shown as effective multivariate geo-statistical techniques (Zhang and Srinivasan, 2008), were used to calibrate NEXRAD data.

Several statistics have been computed to evaluate the performance of the radar-gauge merging methods. The result pointed out that mean field bias correction can significantly reduce the error of the radar estimation. Nevertheless, there is a clear benefit of using a spatial correction factor. Based upon this study the best method is the mean field bias correction which makes use of the radar as secondary information to improve the spatial interpolation of gauge values.

Operational radar rainfall estimates rarely match the amounts recorded by rain-gauges, because of spatial mismatches and differences between direct and indirect measurement (NEXRAD estimates precipitation in the air, whereas rain-gauges observe precipitation falling on the ground). Adjusting NEXRAD results using information provided by rain-gauges is common in hydrologic modeling. A simple bias adjustment method is to remove the average difference between the radar estimates at the rain-gauge locations and the corresponding rain-gauge rainfall amounts given in equations 2.5 and 2.6 (Steiner et al., 1999).

$$B = \frac{\sum_{i=1}^{n} Z(x_i)/n}{\sum_{i=1}^{n} R(x_i)/n} \quad (2.5)$$

$$R_{adj} = B.R \quad (2.6)$$

where R_{adj} is the bias adjusted NEXRAD data, R is the NEXRAD data value, B is the bias adjustment factor, $Z(x_i)$ and $R(x_i)$ are, respectively, the rain-gauge observed and NEXRAD estimated precipitation, respectively, at a location x_i, i= 1,2,….n and n is the number of data points sampled using rain-gauges.

2.10.3 Hydrological Response Units (HRUs)

Hydrologic response units are portions of a sub-basin that possess unique land-use/management/soil attributes. The HRU analysis tool in SWAT helped to load land use, soil layers and slope map to the project. The delineated watershed by SWAT and the prepared land use and soil layers were overlapped 100 %. HRU analysis in SWAT includes divisions of HRUs by slope classes in addition to land use and soils type. The multiple slope option (an option which considers different slope classes for HRU definition) was selected (Ahmadzadeh and Delavar, 2015).

The LULC, soil and slope map was reclassified in order to correspond with the parameters in the SWAT database. After reclassifying the land use, soil and slope in SWAT database, all these physical properties were made to be overlaid for HRU definition. For this study a 10 % threshold was selected for land use, soil and slope. The HRU distribution in this study was determined by assigning multiple HRU to each sub-basin (SWAT Theoretical Documentation, 2000).

2.10.4 Reservoir Data

Impoundment structures modify the movement of water in the channel network by lowering the peak flow and volume of flood discharges. Two reservoirs were simulated in the study, which includes Tiga Dam and Challawa Gorge Dams the major reservoirs in the basin.

Monthly outflow values of the reservoirs were collected and prepared into a SWAT acceptable format and input on the main channel network after the watershed delineation.

2.10.5 SWAT Model Outputs

A number of output files are generated in every SWAT simulation. These files are: the summary input file (input.std), the summary output file (output.std), the HRU output file (output.hru), the sub-basin output file (output.sub), and the main channel or reach output file (output.rch).

The detail of the data printed out in each file is controlled by the print codes in the master watershed file. Average daily values are always printed in the HRU, sub-basin and reach files, but the period they are summarized over will vary. Depending on the print code selected, the output files may include all daily values, daily amounts average over the month, daily amounts average over the year, or daily amounts average over the entire simulation period (SWAT Theoretical Documentation, 2000).

In this study the selected output files includes that of catchment total annual water yield, basin sedimentation yield, losses due to evapotranspiration and stream flow.

1) Catchment Water Yield

The water yield is defined as the amount of freshwater derived from unregulated flow (m^3/s) measurements for a given geographic area over a defined period of time. The freshwater flow (yield) is generated from a combination of base flow, interflow and overland flow originating from groundwater, precipitation and/or snowpack. The flow rate encompasses the hydrologic processes (for example, interception, infiltration and evapotranspiration), the state of water storage (for example, lakes, aquifers, snowpack and

soil moisture) within a drainage basin, and is influenced by climatic (for example, temperature) and physiographic (for example, topography) variables of the watershed or basin. This is generated in SWAT using equation (2.7):

$$WYLD = SURQ + LATQ + GWQ - TLOSS - pond\ abstractions \quad (2.7)$$

Where: $WYLD$= *Catchment Water Yield,* $SURQ$=Surface runoff contribution to stream-flow during time step (mm H_2O), $LATQ$= basin lateral flow GWQ=Ground water contribution to streamflow (mm). Water from the shallow aquifer that returns during the time step, $TLOSS$= transmission losses (mmH2O). Water lost from tributary channels in the HRU via transmission through the bed. This water becomes recharge for the shallow aquifer during the time step. Net surface runoff contribute to the main channel stream-flow is calculated by subtracting TLOSS from SURQ (SWAT Theoretical Documentation, 2000).

Benefits of water yield assessment

The benefits of water yield assessment obtained from http://ecoursesonline.iasri.res are listed below

i. The assessment of water yield provides reliable information on availability of water resources (surface and ground water) to plan their extraction and uses.

ii. It integrates the land processes affecting the water movement above and below the ground surface and thus reflects the management of watershed physical properties required to improve the water yield.

iii. It provides information of interactions between head watershed to the tail watershed and thus provides a view on whether to develop conservation measures at head watershed to the tail watershed.

iv. It provides information on water availability at a particular location of watershed as annual, seasonal and at even smaller time scale. This can be well used for planning the water use activities.

v. Provides an idea on surface and ground water interaction in the watershed.

2) Basin Sedimentation Yield

Sediment is a naturally occurring material that is formed by processes of weathering and erosion, and is subsequently transported by the action of wind, water or ice and/or by the force of gravity acting on the particle itself. Sediments are most often transported by water (fluvial processes), wind and glaciers. Beach sands and river channel deposits are examples of fluvial transport and deposition, though sediment also often settles out of slow-moving or standing water in lakes and the ocean. Sand dunes are examples of wind transport and deposition (http://ecoursesonline.iasri.res).

Sediment generation in a landscape is a factor of multiple natural and anthropogenic influences jointly affected by its climatic, hydrologic and geomorphic characteristics, including precipitation, vegetation cover, runoff, land use, topography, drainage density, sediment storage, sediment transport capacity and soil erodibility. Selby (1993) identifies climate and geology as the predominant factors of erosion with a close interdependency of soil type and vegetation. Out of all the sediment generating agents, the role of water in detachment, transportation and deposition is indeed very significant. Since recent past, human activities favoring more to it because of increased land degradation.

In the SWAT Model, Sediment Yield (SYLD) measured in tons/ha, is the sediment from the sub-basin that is generated and transported into the reach during the simulation time step. Sediment yield is estimated for each HRU with the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977) given by equation (2.8) according to (SWAT Theoretical Documentation, 2000).

$$S_{ed} = 11.8(Q_{surf} \,.\, q_{peak} . Area_{hru})^{0.56} K.C.P.L.C_{FRG} \qquad (2.8)$$

Where, S_{ed} =Sediment yield rate (tones/day), Q_{surf} =is the surface runoff volume (mm/day), q_{peak}= peak runoff rate (m^3/s), $Area_{hru}$= area of the HRU (ha), K= soil erodibility factor (0.013 metric ton m^2hr/(m^3-metric ton cm)), C = crop management factor or cover management factor P = support practice factor, L = topographic factor C_{FRG}= is the coarse fragment factor.

3) Evapotranspiration

The combination of two separate processes whereby water is lost from the soil surface by evaporation and from the crop by transpiration is referred to as evapotranspiration. Evaporation and transpiration occur simultaneously and both processes depend on solar radiation, air temperature, relative humidity (i.e., vapor pressure deficit) and wind speed. The FAO Penman-Monteith method to estimate ET_o by SWAT model is as given (2.9):

$$ET_o=\frac{0.408\Delta(R_n-G)+\gamma\frac{900}{T+273}U_2(e_s-e_a)}{\Delta+\gamma(1+0.34U_2)} \quad (2.9)$$

Where, ET_o= reference evapotranspiration rate (mm/day), T= mean air temperature (°C), U_2= wind speed (m/s) at 2 m above the ground, R_n = net radiation at the crop surface in [MJ m^{-2} day^{-1}], G = soil heat flux density [MJ m^{-2} day^{-1}], e_s = saturation vapour pressure [kPa],

e_a = actual vapour pressure [kPa], Δ= slope vapour pressure curve [kPa $°C^{-1}$], γ = psychrometric constant [kPa $°C^{-1}$] (Arnold, et al., 2010b).

4) Stream flow

Arnold *et al*., (2010b) described current research on enhancements to SWAT to route water across discretized landscape units that simulate the impacts of spatial land use changes and

land management on the hill slope-valley continuum. The hydrologic cycle is simulated by SWAT model based on the water balance equation (2.10), which considers the unsaturated zone and shallow aquifer above the impermeable layer as a unit.

$$SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})_i \quad (2.10)$$

Where: SW_t = final soil water content (mm), SW_o = initial soil water content (mm), R_{day}=amount of precipitation on day i (mm), Q_{surf} =amount of surface runoff on day i (mm), E_a =is the amount of evapotranspiration on day i (mm), W_{seep}= amount of water entering the vadose zone from the soil profile on day i (mm) and Q_{gw}= amount of return flow on day i (mm).

The SCS (Soil Conservation Service) curve number procedure (USDA-SCS, 1972) method was used for estimating surface runoff using daily rainfall, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. In this study, the SCS curve number method was used to estimate surface runoff. The SCS curve number equation (2.11) is expressed thus:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8)} \quad (2.11)$$

Where: Q_{surf} = the accumulated runoff or rainfall excess (mm), R_{day}= the rain daily rain depth (mm), S = the retention parameter (mm).

SCS defines three antecedent moisture conditions: I – dry (wilting point), II – average moisture and III – wet (field capacity). The moisture condition I curve number is the lowest value the daily curve number can assume in dry conditions. The curve numbers for moisture conditions I and III are calculated with the equations (2.12) and (2.13), respectively

$$CN_1 = CN_2 - \frac{20\times(100-CN_2)}{(100-CN_2+exp[2.533-0.06361\times(100-CN_2)])} \quad (2.12)$$

$$CN_3 = CN_2 \times \exp[0.00673(100 - CN_2)] \quad (2.13)$$

where; CN_1 = the moisture condition I curve number, CN_2= is the moisture condition II curve number, and CN_3 = is the moisture condition III curve number. The retention parameter is defined by Eq. (2.14)

$$S = 25.4(100/CN - 100) \quad (2.14)$$

2.10.6 SWAT Model Application

SWAT model has undergone extensive validation and due to its versatility, has also been and continues to be used throughout the world in studying a wide range of phenomena. In Japan, the model was used, after successful model calibration and validation, to model stream-flow in the Hii river basin (Somura *et al*. 2003). The study was conducted as their first step to water resources management and to add new studies to a relatively few studies available in Japan that analyses runoff and pollutant loads in their river systems. Meanwhile, SWAT model was used by Benaman *et. al,* (2005), to successfully model stream flow and sediment loading in the Cannonsville Reservoir basin—a New York City water supply watershed in upstate New York.

The model was also utilized by Schoul and Abbaspour (2008a) for freshwater quantification in West Africa by modeling river discharges of Niger, Volta and Senegal rivers. Through the use of the SWAT model, Mishra *et. al.,* (2007) has successfully selected priority sub-watersheds where structure-based control must be built to effectively

control sediment transport to downstream water resources of Banha watershed in Jharkhand, Indi.

The model was also calibrated and validated by Wong (2009) in the Raisin River watershed in Ontario, Canada using five land cover scenarios to study the influence of patterns in terrestrial habitat to water quality and quantity of the watershed. Using SWAT, Duan *et al.* (2009) have generated soil loss class map of a basin in Hebei province, northeast China to identify critical areas for erosion control.

In 2010, Gitau and Chaubey presented work on regionalization of SWAT model parameters for use in ungauged watersheds. Other works were carried out using SWAT application included; Sediment management modelling in the Blue Nile Basin using SWAT model by Betrie, *et al,*. (2011), Amatya *et al*., (2011) evaluated the SWAT model for a low-gradient forested watershed in coastal South Carolina.

In 2012, research was done on the advancing representation of hydrologic processes in the Soil and Water Assessment Tool (SWAT) through the integration of the TOPographic MODEL (TOPMODEL) by Chen and Wu.

Alaba and Madramootoo (2013) carried out a research work titled modeling the impacts of spatial heterogeneity in the Castor Watershed on runoff, sediment, and phosphorus loss using SWAT: Impacts of spatial variability of soil properties. In the same year 2013, Baker and Miller, used the Soil and Water Assessment Tool (SWAT) to assess land use impact on water resources in an East African Watershed.

Estimate of sediment yield in Kaw Lake by Alemayehu *et al*., (2014) was conducted using SWAT. Ahmadzadeh, *et al.,* (2015), researched on assessment of SWAT Model for the Simultaneous Simulation of Streamflow, Actual Evapotranspiration and Crops' Yield: A Case Study in Zarineh Rud Basin. Akhavan *et al*., (2015), worked on Simulation of inflow to Urmia Lake using SWAT model.

The above mentioned application of SWAT in other regions of the world shows how the model can be successfully used for various applications for watershed management and protection.

2.11 TIME SERIES MODELING AND FORECASTING METHODS

Time series modeling is a dynamic research area which has attracted attentions of researchers' community over last few decades. The main aim of time series modeling is to carefully collect and rigorously study the past observations of a time series to develop an appropriate model which describes the inherent structure of the series. This model is then used to generate future values for the series, i.e. to make forecasts. Time series forecasting thus can be termed as the act of predicting the future by understanding the past (Raicharoen *et al*., 2003). Due to the indispensable importance of time series forecasting in numerous practical fields such as business, economics, finance, science and engineering, etc, proper care should be taken to fit an adequate model to the underlying time series.

The appropriate forecasting methods depend largely on what data are available; there exist two types of forecasting methods (Zhang, 2007).

i. Qualitative forecasting:

If there are no data available, or if the data available are not relevant to the forecasts, then qualitative forecasting methods must be used. These methods are not purely guesswork---

there are well-developed structured approaches to obtaining good forecasts without using historical data

ii. Quantitative forecasting:

Quantitative forecasting can be applied when two conditions are satisfied:

1. numerical information about the past is available;
2. it is reasonable to assume that some aspects of the past patterns will continue into the future.

There is a wide range of quantitative forecasting methods, often developed within specific disciplines for specific purposes. Each method has its own properties, accuracies, and costs that must be considered when choosing a specific method. Most quantitative forecasting problems use either time series data (collected at regular intervals over time) or cross-sectional data (collected at a single point in time). The quantitative forecasting is applied to the time series data set analyzed in this study.

2.11.1 Characteristics of Time Series

A time series in general is supposed to be affected by four main components, which can be separated from the observed data. These components are: Trend, Cyclical, Seasonal and Irregular components.

i. Trend component: The general tendency of a time series to increase, decrease or stagnate over a long period of time is termed as Secular Trend or simply Trend. Thus, it can be said that trend is a long term movement in a time series. For example, series relating to population growth, number of houses in a city etc. show upward trend, whereas downward trend can be observed in series relating to mortality rates, epidemics, etc.

ii. Seasonal component: seasonal variations in a time series are fluctuations within a year during the season. The important factors causing seasonal variations are: climate and weather conditions, customs, traditional habits, etc. Seasonal variation is an important factor for businessmen, engineers, shopkeeper and producers for making proper future plans (Scott, 2001)

iii. The cyclical component: the cyclical variation in a time series describes the medium-term changes in the series, caused by circumstances, which repeat in cycles. The duration of a cycle extend s over longer period of time, usually two or more years.

iv. Irregular or random component: The random variations in a time series are caused by unpredictable influences, which are not regular and also do not re peat in a particular pattern. These variations are caused by incidences such as war, strike, earthquake, flood, revolution, etc. There is no defined statistical technique for measuring random fluctuations in a time series. Considering the effects of these four components, two different types of models are generally used for a time series viz. Multiplicative and Additive models.

Multiplicative Model $Y(t) = T(t) \times S(t) \times C(t) \times I(t)$ (2.15)

Additive Model $Y(t) = T(t) + S(t) + C(t) + I(t)$ (2.16)

where $Y(t)$is the observation and $T(t)$, $S(t), C(t), I(t)$ are respectively the trend, seasonal, cyclical and irregular variation at time t

Multiplicative model is based on the assumption that the four components of a time series are not necessarily independent and they can affect one another; whereas in the additive model it is assumed that the four components are independent of each other. Multiplicative model was applied to the time series used in the study (Scott. 2001).

2.11.2 `Time series forecasting

Anything that is observed sequentially over time is a time series and time series data are useful in forecasting something that is changing over time (e.g., stock prices, sales figures, profits, etc.). Examples of time series data include:

- Daily stock prices
- Monthly rainfall
- Quarterly sales results
- Annual profits

Anything that is observed sequentially over time is a time series. Consider time series that are observed at regular intervals of time (e.g., hourly, daily, weekly, monthly, quarterly, annually). Irregularly spaced time series can also occur. When forecasting time series data, the aim is to estimate how the sequence of observations will continue into the future.

Time series forecasting uses only information on the variable to be forecast, and makes no attempt to discover the factors which affect its behavior. Therefore it will extrapolate trend and seasonal patterns, but it ignores all other information such as marketing initiatives, competitor activity, changes in economic conditions, and change in climatic condition ect. Time series models used for forecasting include ARIMA models (non-seasonal and seasonal), exponential smoothing and structural models (Scott. 2001). In this study seasonal ARIMA model and exponential smoothing method (HoltWinters' method) were applied as described below.

2.11.3 Seasonal ARIMA

One of the most popular and frequently used stochastic time series models is the Autoregressive Integrated Moving Average (ARIMA) model. The basic assumption made to implement this model is that the considered time series is linear and follows a particular

known statistical distribution, such as the normal distribution. The popularity of the ARIMA model is mainly due to its flexibility to represent several varieties of time series with simplicity as well as the associated Box-Jenkins methodology for optimal model building process (Hamzacebi, 2008).

A seasonal ARIMA model is formed by including additional seasonal terms in the ARIMA models written as follows:

ARIMA(p,d,q)(P,D,Q)m (2.17)

where the model orders (p,d,q) is non-seasonal part while (P,D,Q) is the seasonal part and m number of periods per season. (p, d, q) and (P,D,Q) are integers greater than or equal to zero, p and P refer to the order of the autoregressive, q and Q moving average part and d and D differencing terms.

2.11.4 Stationarity and differencing

A stationary time series is one whose properties do not depend on the time at which the series is observed. Time series with trends, or with seasonality, are not stationary -the trend and seasonality will affect the value of the time series at different times.

Differencing (d) can help stabilize the mean of a time series by removing changes in the level of a time series, and so eliminating trend and seasonality. On the other hand, a white noise series is stationary -it does not matter when you observe it, it should look much the same at any period of time (Hamzacebi, 2008)..

2.11.5 White Noise

Time series that show no autocorrelation are called "white noise". Figure 2.3 gives an example of a white noise series. For white noise series, we expect each autocorrelation to be close to zero. Of course, they are not exactly equal to zero as there is some random

variation. For a white noise series, we expect 95% of the spikes in the ACF to lie within $\pm 2/T$ where T is the length of the time series. It is common to plot these bounds on a graph of the ACF and PACF. If there are one or more large spikes outside these bounds, or if more than 5% of spikes are outside these bounds, then the series is probably not white noise. All autocorrelation coefficients lie within these limits, confirming that the data are white noise (meaning no any useful information that be taken from the residual). Forecast using ARIMA Model is then applied to time series to obtain values for the future (Scott, 2001).

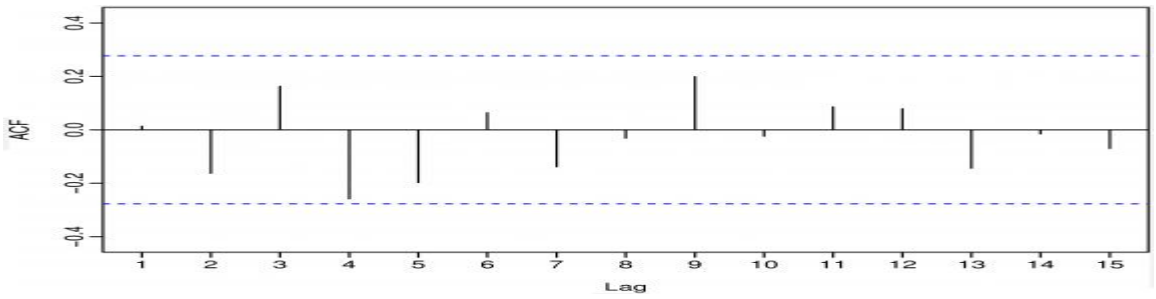


Figure 2.3: White noise

To determine a proper ARIMA model order for a given time series, it is necessary to carry out the Autocorrelation function (ACF) and Partial Autocorrelation Functions (PACF).

2.11.6 Autocorrelation and Partial Autocorrelation Functions (ACF and PACF)

These statistical measures reflect how the observations in a time series are related to each other. For modeling and forecasting purpose it is often useful to plot the ACF and PACF against consecutive time lags, these plots help in determining the ARIMA Model order of terms

.

2.11.7 Box-Jenkins Methodology

After describing various time series models, the next issue is how to select an appropriate model that can produce accurate forecast based on a description of historical pattern in the data and how to determine the optimal model orders. Statisticians Box and Jenkins (1970) developed a practical approach to build ARIMA model, which best fit to a given time series and also satisfy the parsimony principle. Their concept has fundamental importance on the area of time series analysis and forecasting (Zhang, 2003).

The Box-Jenkins methodology does not assume any particular pattern in the historical data of the series to be forecasted. Rather, it uses a three step iterative approach of model identification, parameter estimation and diagnostic checking to determine the best parsimonious model from a general class of ARIMA models (Zhang, 2003). This three-step process is repeated several times until a satisfactory model is finally selected. Then this model can be used for forecasting future values of the time series.

2.11.8 Exponential Smoothing

Exponential smoothing is a procedure for continually revising a forecast in the light of more recent experience. Exponential Smoothing assigns exponentially decreasing weights as the observation get older. In other words, recent observations are given relatively more weight in forecasting than the older observations.

The exponential smoothing method is of three categories:

1. A simple smoothing is used for short-range forecasting, usually just one month into the future

2. The double exponential smoothing method is used when the data show a trend.

3. Triple exponential smoothing method (applied in this study), is used when the data shows the trend and seasonality. To handle seasonality, a third parameter was added called the "HoltWinters" (HW) method after the names of the inventors.

There are two main HW models, depending on the type of seasonality.

- Additive Seasonal Model: This model is used for a time series data whose amplitude of the seasonal pattern exhibits an independent of the average level of the series, i.e. a time series with either increasing or decreasing linear trend.
- Multiplicative Seasonal Model (applied in the study): This model is used when the data exhibit either an increasing or a decreasing fluctuating trend.

The Multiplicative Seasonal Model forecast uses a weighted average of past observations, but it places more weight on more recent observations to make its estimates. The model for exponential smoothing is more complicated than that of moving averages. The equations for exponential smoothing follow the format of equations (2.18).

$$F_{t+1} = \alpha Y_t + (1 - \alpha) F_t \qquad (2.18)$$

where: F_{t+1} = forecast value for period *t+1*, Y_t = Actual value of period *t, the Ft = Forecast value* of period *t,* α = Alpha (a smoothing constant where ($0 \leq \alpha \leq 1$)

From this equation, it was seen that the forecast for the next period will equal the forecast mode for this period plus or minus an adjustment. Alpha (α) will be a value between zero and one and it reflects how much weight is given to distant past values of y when making our forecast. A very low value of α (0.1 to 0.3) Means that more weight is given to past values, whereas a high value of α (0.6 or higher) means that more weight is given to recent values and the forecast reacts more quickly to changes in the series. In this sense α is similar

to the span in a moving average - low values of α are analogous to a higher span. Alpha is required to be chosen when forecasting with exponential smoothing (Chatfield, 1996).

2.12 STATISTICAL TREND ANALYSIS

Trend analysis is a widely used statistical method for analyzing climatic and hydrological data. One of the tests for detecting a monotonic increase or decrease trend in the time series of climate such as temperature and rainfall is the Mann-Kendall test. The test is a non-parametric statistical technique that is based on sign differences and not directly on the values of the random variables and as such the test is less susceptible to the effect of outliers.

The Mann-Kendall trend test is recommended by WMO (World Meteorological Organization) that is often used to test for trend in hydrological time series (Standhill and Cohen, 2009).. It is useful in analyzing data trends over a period of time, also applicable to dataset with uneven sampling and missing values.

The test does not require the assumption of normality for the random variables and is used to show the direction of the significant trends. Due to its superiority Mann-Kendall test has been widely applied to detect trends in climatic studiese hypothesis H_1 that there exist a trend in the time series. Mann-Kendall test . To detect trend using the Mann-Kendall test the null hypothesis H_0 that there is no trend and data are independently and randomly ordered is tested against the alternativ statistics S is given by equation (2.19):

$$S = \sum_{k-1}^{n-1} \sum_{j=k=1}^{n} sgn(xj - xk) \qquad (2.19)$$

Where xj and xk are the annual data values in year j, k and n is the length of the data. S is assumed to be 0 if no trend. An S statistic with a high positive value shows an increasing

trend whereas low negative value represents a decreasing trend in the time series as in equation (2.16):

$$sgn(x_j - x_k) = \begin{cases} 1\ if\ x_j - x_k > 0 \\ 0\ if\ x_j - x_k = 0 \\ -1\ if\ x_j - x_k < 0 \end{cases} \quad (2.20)$$

To indicate the statistical significance of the trend the probability of S and the sample size n needs to be determined. The variance of S is calculated as VAR(S)

$$Var(S) = \lfloor n(n-1)(2n+5) - \sum_t (t-1)(2t-5) \rfloor / 18 \quad (2.21)$$

The calculated values of S and VAR(S) are obtained to calculate the Z test statistic which is given in equation (2.19):

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}\ if\ S > 0 \\ 0 \qquad\quad if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} if\ S < 0 \end{cases} \quad (2.22)$$

To test the statistical significance of Z value at 95% and 99% levels of significance where the critical value of Z at 95% level is $Z_{0.005} = 1.96$ and the critical value of Z at 99% level is $Z_{0.001} = 2.58$. If Z is negative and the absolute value of Z calculated is greater than the critical value, the trend is said to be significantly decreasing but if the value of Z calculated is positive and greater than the critical value the trend is said to be significantly increasing.

If the absolute value of Z is less than the critical value it implies that there is no trend and the alternative hypothesis that the trend is rejected. If the trend is significant it implied that the trend is as a result of a definite cause and not due to chance alone. A significant trend at 99% level showed that the trend is highly significant (Standhill and Cohen, 2009).

2.12.1 Theil-Sen Method of Linear Regression

After estimating the Mann-Kendall statistic which only shows the direction of the trend, the Sen. slope estimator called the Kendall robust line fit is applied to calculate the degree of the trend (Standhill and Cohen, 2009).. Sen slope in time series data occurs where the trend is assumed to be linear. The technique was named after Theil Sen who developed the estimator. It is a non-parametric test that is employed to provide an estimate of the true slope of the Mann-Kendall trend. It shows the measure of the change in the trend per unit time; it is less vulnerable to single data and outlier effect. One of its strength is that it provides a more accurate estimate than linear regression for skewed data. Sen slope estimation is given by equation (2.23)

$$Q = \frac{x_j}{j} - \frac{x_k}{k} \tag{2.23}$$

Where Q = Sen Slope estimator x_j and x_k are data values at time j and k

2.12.2 Forecast Performance Measures

Due to the fundamental importance of time series forecasting in many practical situations, proper care should be taken while selecting a particular model. For this reason, various performance measures are proposed in literature to estimate forecast accuracy and to compare different models. These are also known as performance metrics. Each of these measures is a function of the actual and forecasted values of the time series given as follows (Hamzaçebi, 2008);

i. The Mean Absolute Error (MAE)

The mean absolute error is defined as

$$MAE=\frac{1}{n}\sum_{i=1}^{n} | e_i | \tag{2.24}$$

The properties of MAE are

- It measures the average absolute deviation of forecasted values from original ones.
- It is also termed as the Mean Absolute Deviation (MAD).
- It shows the magnitude of overall error, occurred due to forecasting.
- In MAE, the effects of positive and negative errors do not cancel out.
- MAE does not provide any idea about the direction of errors.
- For a good forecast, the obtained MAE should be as small as possible.
- MAE depends on the scale of measurement and data transformations.
- Extreme forecast errors are not panelized by MAE.

ii. The Mean Absolute Percentage Error (MAPE)

This measure is given by

$$MAPE = \frac{1}{n}\sum_{i=1}^{n} \left|\frac{e_i}{y_i}\right| \times 100 \tag{2.25}$$

- This measure represents the percentage of average absolute error occurred.
- It is independent of the scale of measurement, but affected by data transformation.
- It does not show the direction of error.
- MAPE does not panelize extreme deviations.
- In this measure, opposite signed errors do not offset each other.

iii. The Mean Percentage Error (MPE)

It is defined as

$$MAPE = \frac{1}{n}\sum_{i=1}^{n} \left(\frac{e_i}{y_i}\right) \times 100 \tag{2.26}$$

- MPE represents the percentage of average error occurred, while forecasting.
- It has similar properties as MAPE.

- It shows the direction of error occurred.
- Opposite signed errors affect each other and cancel out.
- Thus like MFE, by obtaining a value of MPE close to zero, we cannot conclude that the corresponding model performed very well.
- It is desirable that for a good forecast the obtained MPE should be small.
- A disadvantage of this measure is that it is undefined whenever a single actual value is zero

2.13.1 SENSITIVITY ANALYSIS

SWAT input parameters are process based and must be held within a realistic uncertainty range. The first step in the calibration and validation process in SWAT is the determination of the most sensitive parameters for a given watershed or sub-watershed. The user determines which variables to adjust based on expert judgment or on sensitivity analysis. Sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model inputs (parameters). It is necessary to identify key parameters and the parameter precision required for calibration (Ma et al., 2000). In a practical sense, this first step helps determine the predominant processes for the component of interest. Two types of sensitivity analysis are generally performed: local, by changing values one at a time, and global, by allowing all parameter values to change. The two analyses, however, may yield different results. Sensitivity of one parameter often depends on the value of other related parameters; hence, the problem with one-at-a-time analysis is that the correct values of other parameters that are fixed are never known. The disadvantage of the global sensitivity analysis is that it needs a large number of simulations. Both procedures,

however, provide insight into the sensitivity of the parameters and are necessary steps in model calibration.

2.13.2 Calibration

The second step is the calibration process. Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions. The final step is validation for the component of interest (stream-flow, sediment yields, etc. (White et al., 2012).

2.13.3 Validation

Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, although "sufficiently accurate" can vary based on project goals (Refsgaard, 1997). Validation involves running a model using parameters that were determined during the calibration process, and comparing the predictions to observed data not used in the calibration. In general, a good model calibration and validation should involve:

(1) Observed data that include wet, average, and dry years (Gan et al., 1997);

(2) Multiple evaluation techniques (ASCE, 1993; Legates and McCabe, 1999; Boyle et al., 2000);

(3) Calibrating all constituents to be evaluated; and

(4) Verification that other important model outputs are reasonable. In general, graphical and statistical methods with some form of objective statistical criteria are used to determine when the model has been calibrated and validated.

Calibration can be accomplished manually or using auto-calibration tools in SWAT (Van Griensven and Bauwens, 2003; Van Liew et al., 2005) or SWAT-CUP (Abbaspour et al., 2007). Ideally, calibration and validation should be process and spatially based, while taking into account input, model, and parameter uncertainties. A good example of process-based calibration involves stream-flow. Stream-flow processes are comprised of the water balance in the land phase of the hydrology, including ET, lateral flow, surface runoff, return flow, channel transmission losses, and deep aquifer recharge. If data are available for each of these processes, they should be calibrated individually.

For sediments, nutrients, pesticides, and bacteria, sources and sinks should be considered. If a longer time period is available for hydrology than water quality data, it is important to use all the hydrology data available for calibration and validation to capture long-term trends. This process-based calibration should be done at the sub-watershed or landscape level to ensure that variability in the predominant processes for each of the sub-watersheds is captured instead of determining global (watershed-wide) processes. There are, however, generally insufficient observed data to enable a full spatial calibration and validation at the watershed scale.

The metrics and methods used to compare observed data to model predictions are also important. Multiple graphical and statistical methods could be used, such as time-series plots, Nash-Sutcliffe Efficiency (NSE); (Nash and Sutcliffe, 1970).

Calibration and validation are typically performed by splitting the available observed data into two datasets: one for calibration, and another for validation. Most data are frequently split by time periods, carefully ensuring that the climate data used for both calibration and validation are not substantially different, i.e., wet, moderate, and dry years occur in both periods (Gan *et al*., 1997).

12.13.4 Model Efficiency

An extensive array of statistical techniques can be used to evaluate SWAT hydrologic and pollutant predictions; for example, Coffey *et al*. (2004) describe nearly 20 potential statistical tests that can be used to judge SWAT predictions, including a coefficient of determination (r^2), NSE (Nash-Sutcliffe Efficiency), root mean square error (RMSE), nonparametric tests, t-test, objective functions, autocorrelation, and cross-correlation. By far, the most widely used statistics reported for calibration and validation are r^2 and NSE. The r^2 statistic can range from 0 to 1, where 0 indicates no correlation and 1 represents perfect correlation, and it provides an estimate of how well the variance of observed values is replicated by the model predictions (Krause *et al*., 2005).

A perfect fit also requires that the regression slope and intercept are equal to 1 and 0, respectively; however, the slope and intercept have typically not been reported in published SWAT studies. If r^2 is the primary statistical measure, it should always be used with slope and intercept to ensure that means are reasonable (slope = 1) and bias is low. NSE values can range between $-\infty$ to 1 and provide a measure how well the simulated output matches the observed data along a 1:1 line (regression line with slope equal to 1).

A perfect fit between the simulated and observed data is indicated by an NSE value of 1. NSE values ≤0 indicate that the observed data mean is a more accurate predictor than the simulated output (Krause *et al*., 2005). An extensive list of r^2 and NSE calibration and/or validation statistics is provided by Gassman *et al*., (2007) for 115 SWAT studies that reported hydrologic results as well as 37 SWAT studies that reported pollutant results. Similar r^2 and NSE statistical compilations for an additional 20 SWAT study are reported by Douglas-Mankin, et *al*., (2010), and 23 SWAT studies are reviewed by Tuppad *et al*., (2011).

These statistics provide valuable insight regarding the hydrologic performance of the model across a wide spectrum of conditions. The input values are usually determined over the course of iterative SWAT simulations, which sometimes number in the thousands. Several optimization schemes have been used in SWAT auto-calibration applications, including generalized likelihood uncertainty estimation (GLUE), shuffled complex evolution (SCE), and the Parameter Estimation (PEST) program (Doherty, 2004).

Govender and Everson (2005) and Wang and Melesse (2005) used PEST to calibrate key hydrology-related parameters for SWAT applications in South Africa and northwest Minnesota, respectively.

Razavi *et al*., (2010) described additional SWAT calibration studies that relied partially on GLUE methodology for watersheds located in Ethiopia and south-central New York.

SWAT-CUP provides a decision-making framework that incorporates a semi-automated approach (SUFI2) using both manual and automated calibration incorporating sensitivity and uncertainty analysis.

CHAPTER THREE

MATERIALS AND METHODS

3.1 GENERAL

Hydrological modelling of Hadeija River Sub-basin was studied, to understand the complex hydrological processes that control the distribution and availability of water resources in the catchment. It was principally undertaken through precipitation apportioning into surface flow, groundwater flows, soil moisture, potential evapotranspiration, runoff being the main components of the hydrologic cycle within a catchment. The overall role of the hydrologic cycle components was influenced by their interaction with soil, vegetation, topography and climate of the watershed and the land use pattern of human interaction on the dry-land being agricultural land, pastures and forestry.

3.2 MATERIALS

The study of watershed hydrology modelling under the impact of land use/cover dynamics climate variables requires the uses of software that includes; GIS, SWAT, SWATCUP, and R programming. The application of the listed software is as described below:

3.2.1 Geographical Information System (GIS)

It is a computer-based tool for mapping and analyzing vector (point, line and polygon) and raster (i.e. Cells) data on existing and occurrence of events on earth. It is used to project the vector (digital elevation model and stream network) and raster (soil digital map and land use/cover digital map) to a common referenced point the WGS 1984 UTM Zone 32N. GIS has the capacities to collect, store, manipulate, analyze and display spatially referenced information and transform data into knowledge and present this knowledge in various

formats for the purpose of supporting decisions (David, 2002). It was used to delineate the study watershed area extent.

3.2.2 Soil and Water Assessment Tool (SWAT)

SWAT is a river basin, or watershed scale model developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large, complex watersheds with varying soils, land use and management conditions over long periods of time. SWAT is a physically based model which requires specific input data that includes weather data, soil properties, and topography (DEM), and land use/land cover characteristics of the watershed. The program allows user to visualize spatial information, document watershed characteristics by estimation of hydrologic parameters (the basin water yield, sediment yield, losses due to evapotranspiration and stream flow values) by providing tables of physical characteristics of streams and sub-basins, perform spatial analysis, delineate sub-basins and streams, construct inputs to hydrologic models, and assist with report preparation (Akhavan and Hameze, 2015).

3.2.3 SWAT-CUP

It is a computer program for calibration, validation, sensitivity and uncertainty analysis of SWAT model output results selected by the user (Abbaspour et. al., 2007

3.2.4 R Programming Package

R is a scripting language for carrying out complicated and simple statistical analyses. It includes routines for data summary and exploration, graphical presentation and data modeling, time series analysis and forecasting.

3.2.5 Physiographical Dataset

The physiographical datasets required were Digital Elevation Model (DEM) that provides information on topography while the land-use/land-cover imagery, soil characteristics imagery and the river/stream network of the basin defines the land system of the basin. These datasets contributed and controls the flow direction, runoff generation, infiltration, stream flow, sediment yield and water yield. Field data of soil sample of the basin was obtained for validation.

3.2.6 Hydro-meteorological Dataset

Hydro-meteorological daily radar weather datasets of thirty five years (1979 to 2013) that include precipitation, temperature (maximum and minimum), solar radiation, relative humidity and wind speed were downloaded from online (waterbase, n.d) in the SWAT acceptable format. The ground data of rainfall and temperature were obtained for Kano and Jigawa States NiMET offices for calibration and validation.

3.3 METHODS

3.3.1 Calibration and Validation of Rainfall and Temperature Dataset

- The radar weather dataset from 1979 to 2013 over the sub-basin was downloaded form the internet using the latitude and longitude of the sub-basin as shows in Figure 3.1.
- The NiMET office in and around the study area was identified
- The ArcGIS clip tool was used to determine the radar points that fell within the sub-basin underlined in blue (Figure 3.2).

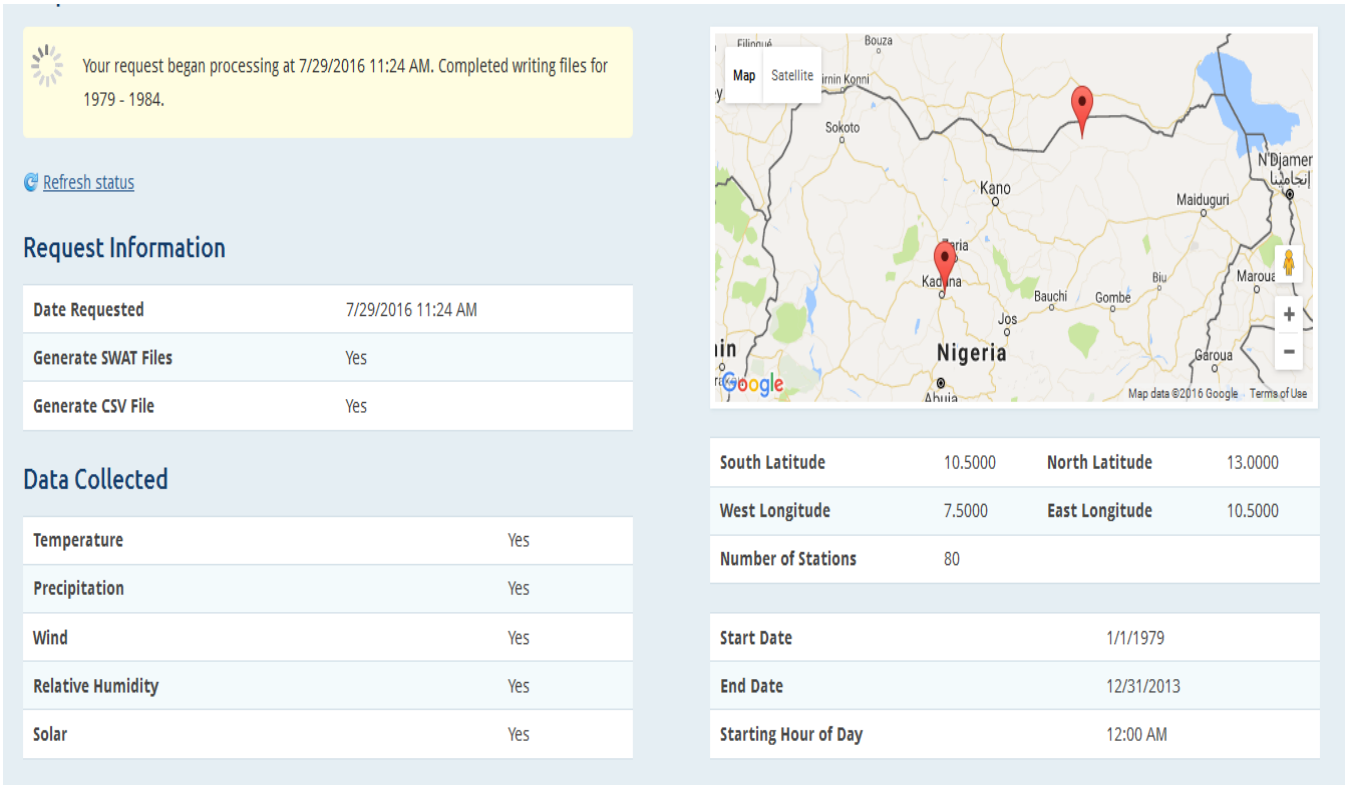


Figure 3.1: Hydrometeorology download interface

- The NiMET office in Kano and Jigawa Airport were selected because other NiMET locations were far from the study area
- Rainfall and temperature dataset from 1979 to 2009 was obtained from the NiMET
- The distance tool in ArcGIS was used to determine the radar Points in the neighborhoods of NiMET office. It was found that p123100 and p12094 were in the neighborhood of Jigawa Airport while other points were within the neighborhood of Kano Airport as shows in Figure 3.2.
- Equations 3.1 and 3.2 were applied to obtain the correction factor for the sub-basin temperature and rainfall.
- $$B = \frac{\sum_{i=1}^{n} Z(x_i)/n}{\sum_{i=1}^{n} R(x_i)/n} \quad 3.1$$
- $$R_{adj} = B.R \quad 3.2$$

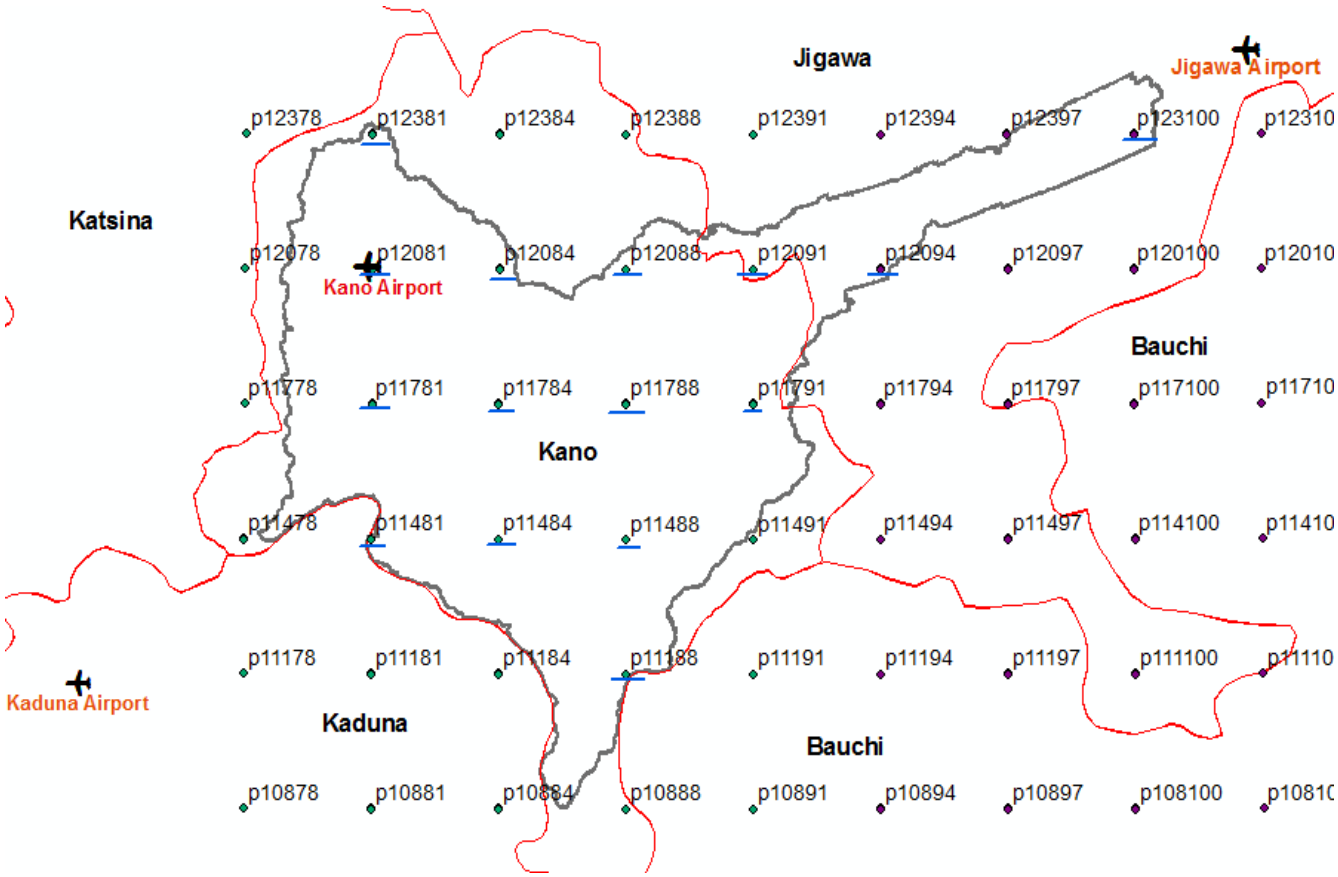


Figure 3.2: NiMET office and radar points global positions in the sub-basin

3.3.2 Algothrim to Calibrate the Radar Weather Data Using Rainfall and Tenperature Field Data in R

- tpctn=read.table(file.choose(),sep=',',header=T)# import rader into R
  attach(tpctn)
  m1=0.9297*(MT123100)# the constant was obtained from equation 3.2
  plot(MT123100,m1,col='red',xlab="",ylab="",las=1,tcl=0.3)
  legend(x=21,y=46,c("regressionline"),cex=0.8,col=c("black"),horiz=T,bty="n")
  mtext("adjusted temperature",side=2,line=2.5,cex=1.1)
  mtext('radar temperature',side=1,line=2,cex=1.1)
  mod=lm(m1~MT123100)
  abline(mod,lwd=2,col="black")#regression line
  lm_coef <- round(coef(mod), 3) # extract coefficients
  text(x=25,y=42,cex=0.8,(bquote(y == .(lm_coef[2])*x + .(lm_coef[1]))))# display equation
  summary(mod)# determine the regression eqution parameters
  text(x=25.5,y=39,bty="n",cex=0.8,bquote(R^2*(adjusted)==.(format(summary(mod)$adj.r.squared))))#print the regression equation on the plot

- The scatter plot and the regression equation between the radar and adjusted radar of rainfall and field rain gauge values are shows in Figure 4.1 and Figure 4.2.
- The same procedure was applied to the radar tempertaure in order to obtain it adjusted values (Figure 4.3 and Figure 4.4).
- The adjusted values for rainfall and temperature were used in the simulation in place of the radar data of rainfall and temperature

3.3.3 Raster and Vector Preparation (GIS and SWAT)

The Nigeria spatial data set that includes the Administrative map of Nigeria, DEM (STRM of 30meter resolution), soil data, the stream network data downloaded from www.waterbase.org and land use/cover map of 1975, 2000 and 2013 downloaded from. The files were retrieved in a zipped format and unzipped for analysis by the application of WinMount software. The steps involved were as described below.

i. The Administrative map of Nigeria : From the Administrative map of Nigeria in Figure 3.3, the states (Kano and Jigawa) shape file where the study site is located were clipped out using the clip tool in ArcGIS10.2 (Figure 3.3 and Figure 3.4)

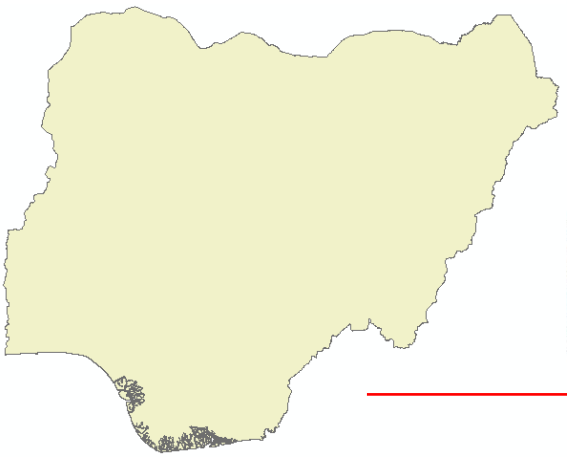


Figure 3.3: Nigeria Map

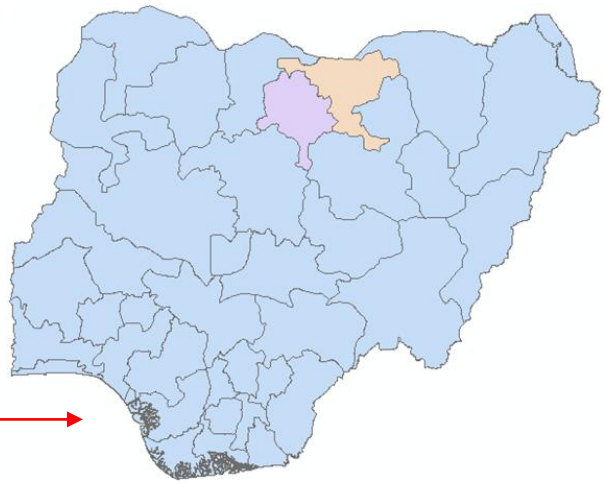


Figure 3.4: States delinaeted Nigeria Map

ii. Figure 3.5 is the clipped out of the study site and it was used to clip other basin maps needed in the analysis that includes the DEM, soil map, stream network and land use/cover cover map.

iii. DEM (Digital Elevation Model): Figures 3.6 to 3.9 shows the stages involved to clip out the study site DEM needed for the calculation of sub-basin parameters such as slope, river profile and contour, etc. The unprocessed dataset (Figure 3.6) was downloaded in tiles and then mosaic into one object (Figure 3.7). The mosaicked object was clipped into Nigeria land extent (Figure 3.8) and then into the study area extent (Figure 3.9).



Figure 3.5: Study site clipped out map

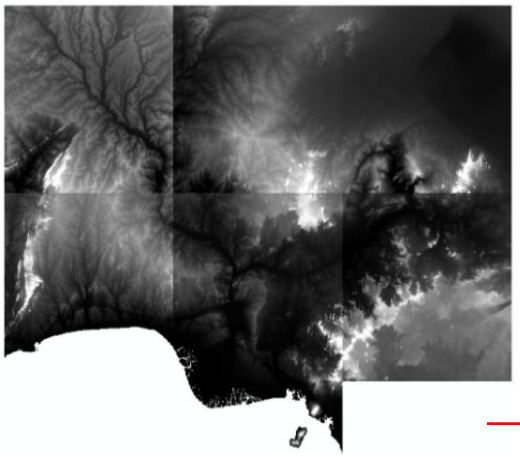


Figure 3.6: Unprocessed DEM datasets

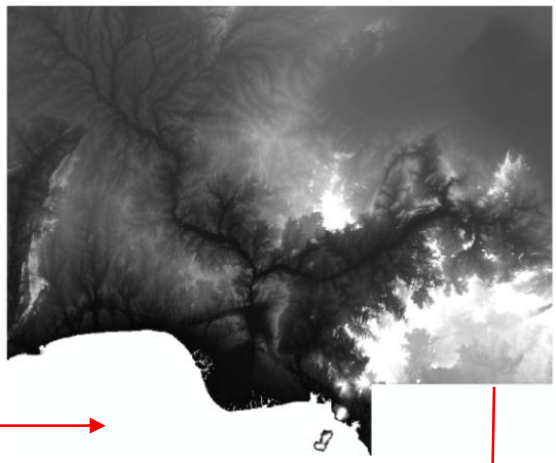


Figure 3.7: Mosaic DEM dataset

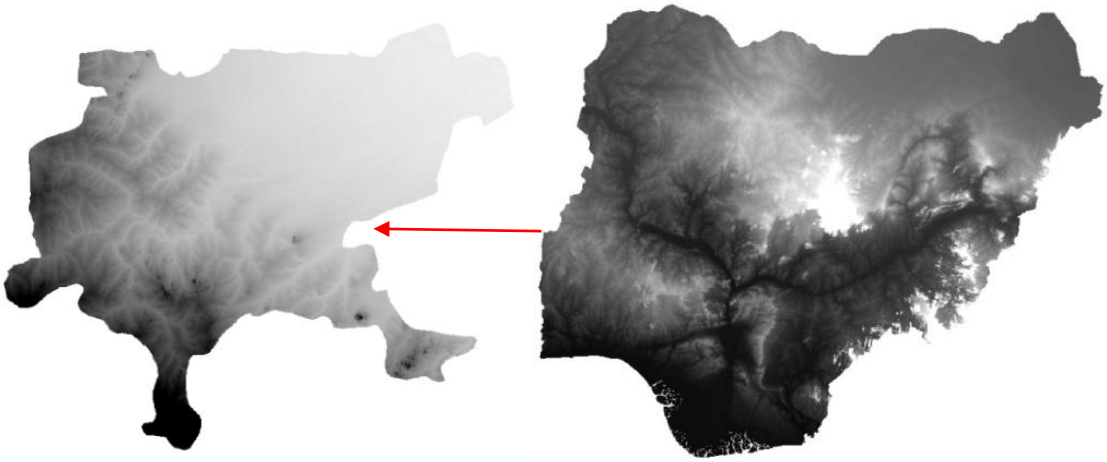


Figure 3.9: Clipped study site DEM Figure 3.8: Clipped Nigeria DEM

iv. River/Stream Network Map: The study site river network data map (Figure 3.11) was clipped from the Nigeria river network map (Figure 3.10). The stream network when placed on the DEM provides information where the relief was so low that the DEM grid was unable to accurately delineate the location of the stream.

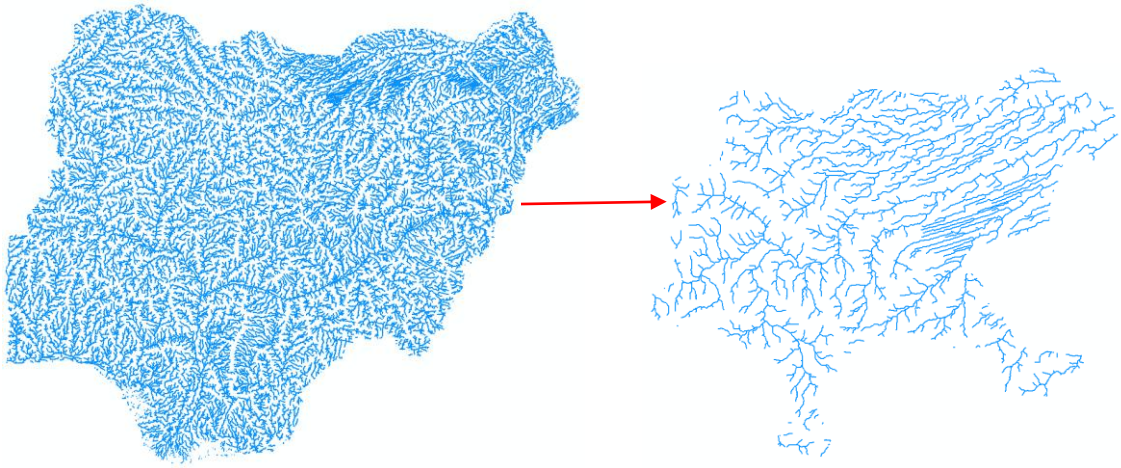


Figure 3.10: Nigeria clipped river network map Figure 3.11: Study site river network map

3.3.4 Watershed Delineation and Characterization (GIS and SWAT)

The watershed delineation uses GIS functions to aid in segmenting watersheds into several hydrologically connected sub-watersheds for use in watershed modeling with SWAT. The

delineation process requires a Digital Elevation Model (DEM) in ESRI grid format clipped to the study site extent. The processes involved in the clipping is explained as followd:

A. Project Setup

1. Start ArcMap and open an empty document
2. On the Tools menu, click Extensions
3. Enable the three extensions list below for ArcSWAT to run:
    - Spatial Analyst
    - SWAT Project Manager
    - SWAT Watershed Delineator
4. From the Customize menu, click Toolbars and select the ArcSWAT Toolbar. The ArcSWAT Toolbar will appear in the ArcMap window.
5. A SWAT project consists of a project directory which contains an ArcMap document, two geodatabases, and a subdirectory structure for storing temporary GIS datasets, and SWAT 2012 input files.
6. Create SWAT project directory using the New SWAT Project button.
7. Save the SWAT project currently working on.

B. The Watershed Delineator

This tool allows the delineation of the watersheds based on an automatic procedure using Digital Elevation Model (DEM) data.

1. Click the Watershed Delineator menu and select the Automatic Watershed Delineation
2. Load the DEM: The DEM of the study area was loaded into the ArcSWAT from the folder where it was saved.
3. The DEM was loaded into the ArcSWAT environment (Figure 3.12)

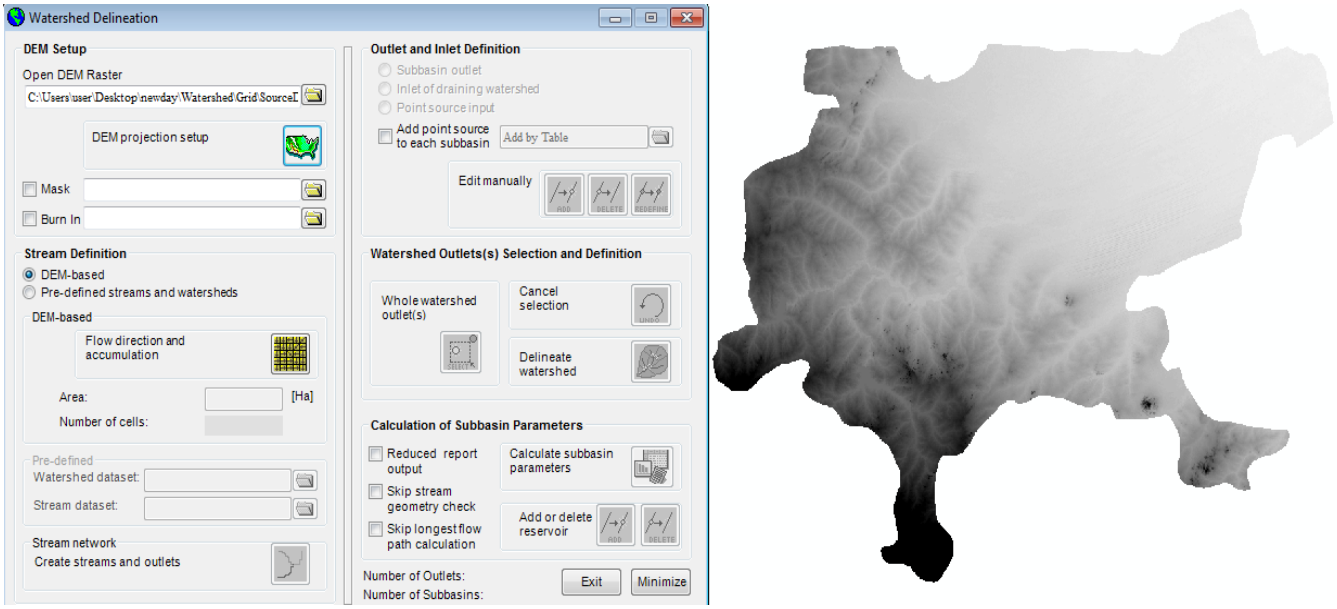


Figure 3.12: loaded DEM of the study area

3. Click the DEM projection setup button to define the properties of the DEM.

4. Load the streams dataset by clicking the check box beside Burn In, then, click on the file browse button next to the Burn In text box. A prompt dialog will open to Select the name of the stream network dataset and click OK (Figure 3.13).

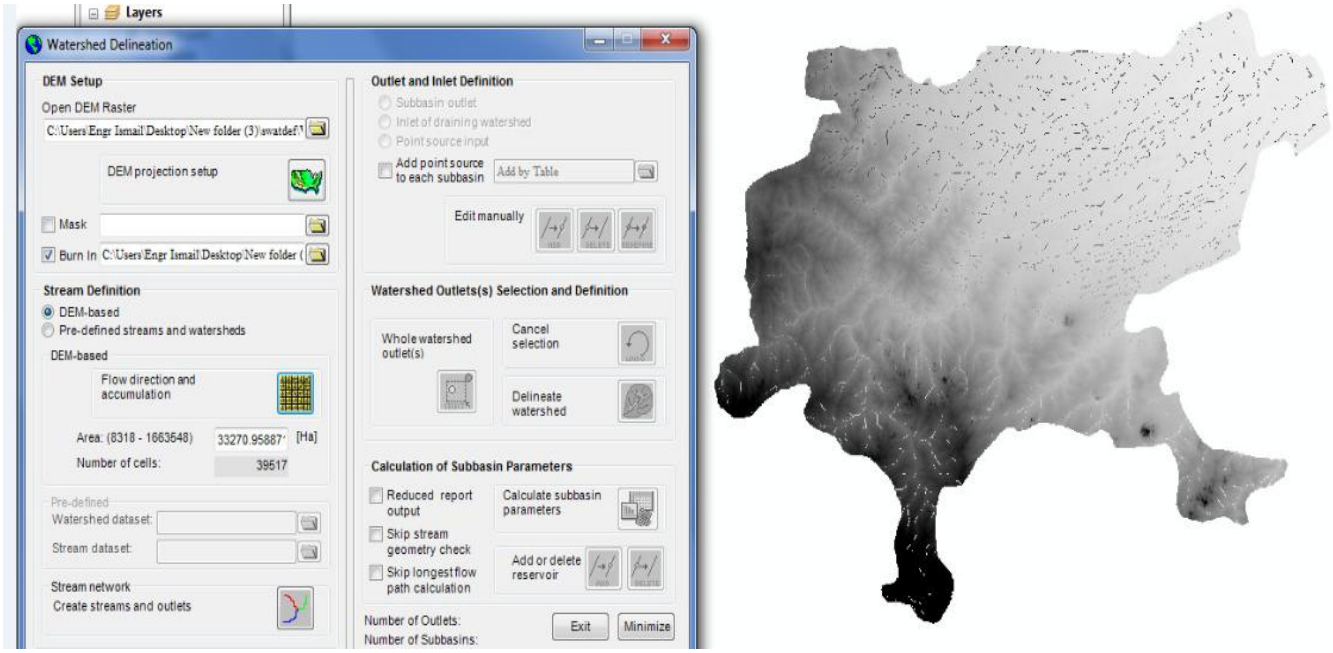


Figure 3.13: Stream network on DEM

5. Click the Flow direction and accumulation button to pre-process the DEM to fill the sinks and calculating the flow direction and flow accumulation grids.

6. Click the create streams and outlets button.

C. Outlet and Inlet Definition

7. Add the outlet configuration by selecting the Add button in edit manually box Outlet is the point where stream networks are connected and the location of stream gauge (Figure 3.14)..

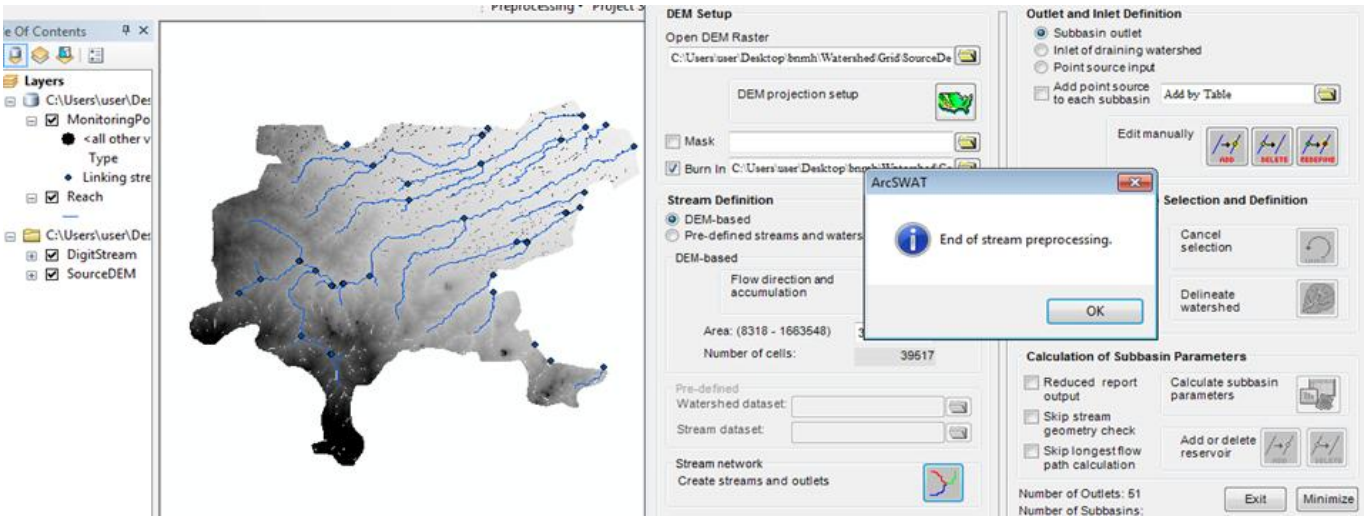


Figure 3.14: Stream outlet point creation

8. Locate the point of stream gauge station and click the left mouse button. An outlet point was snap to the closest stream gauge location in the sub-basin on the stream line and the feature was added to the "Outlets" theme. The stream gauge was located at Hadeija with coordinates of 12.430001^{o}N and 10.069914^{o}E out of the stream centre line (Figure 3.15).

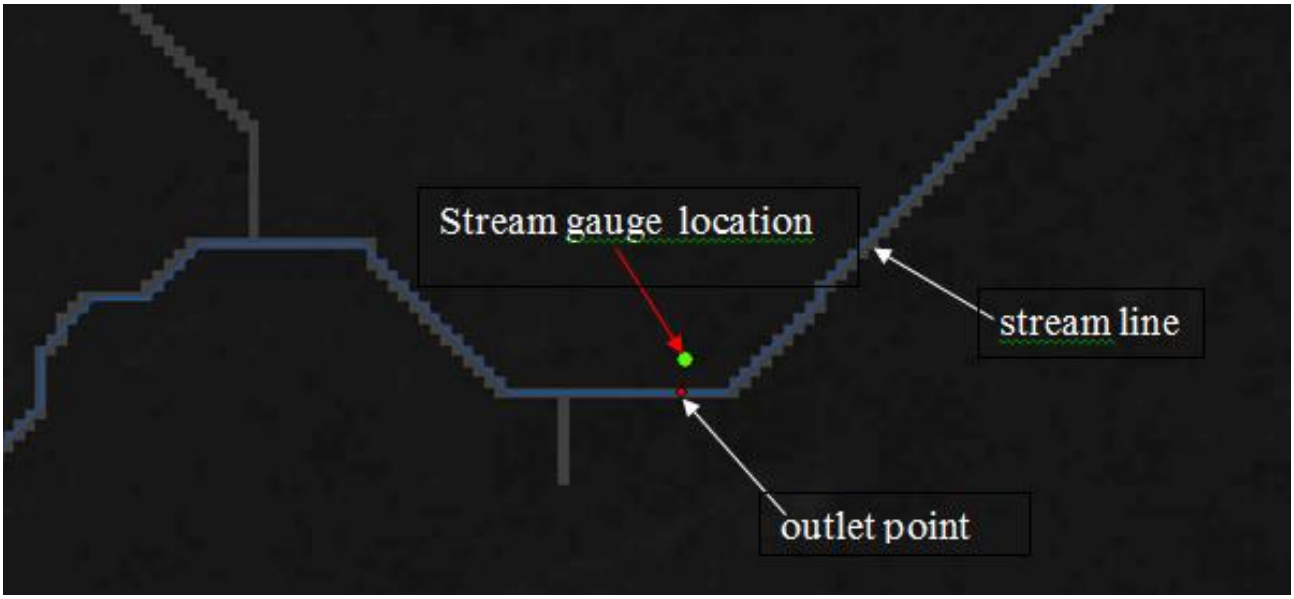


Figure 3.15: outlet point creation

9. When the desired outlet has been added, right click, and choose “Stop Editing”.

10. When prompted to indicate if edits should be saved. Choose “Yes” to save the edit..

11. Click the whole watershed outlet(s) button and select the outlet point created in step 8.

- To select watershed outlets, position the cursor close to the point(s) chosen to be the watershed outlet. Hold down the left mouse button and move the mouse to form a box on the screen around the selected outlet. Release the left mouse button.

12. Click OK to proceed.

13. Click the delineate watershed button to start the watershed delineation,

- The watershed delineation process will run, and when completed a message indicating successful completion appeared.
- The Watershed sub-basins and full watershed boundary layer will be added to the map.

D. Calculation of Sub-basin Parameters: The Calculation of Sub-basin Parameters section contains functions for calculating geomorphic characteristics of the sub-basins and reaches, as well as defining the locations of reservoirs within the watershed

14. Click the Calculation of Sub-basin Parameters button to begin sub-basin parameter calculation. The function calculates geomorphic parameters for each sub-basin and the relative stream reach. The results of the calculations are stored in the table of attributes of the updated Watershed and Reach themes.

15. Adding Reservoir(s): A Reservoir location along the main channel network was added (Figure 3.16).

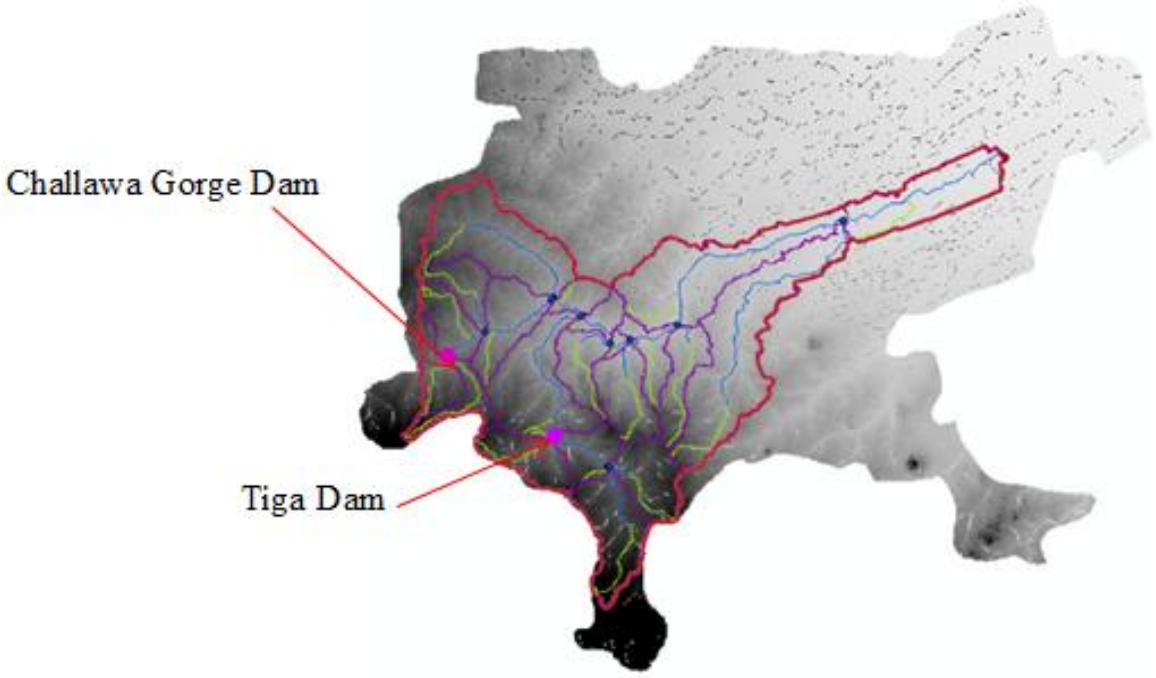


Figure 3.16: Reservoir addition

When watershed delineation was completed and the Exit button was clicked on the Watershed Delineation Menu, the raster datasets generated by the ArcSWAT interface were exported from the SWAT project "Watershed\Grid" folder to the Project Raster Geodatabase. This stage concluded the end of the watershed delineation with the creation of delineated basin extent (Figure 4.5), the longest river profile (Figure 4.6), basin digital elevation model classification (Figure 4.7), basin contour (Figure 4.8), basin 3D elevation map (Figure 4.9), and stream order (Figure 4.10) and basin subdivision map (Figure 4.11).

3.3.5 Hydrological Response Unit (HRU) Analysis

Land use/cover, soil, and slope characterization for the watershed were done using commands from the HRU Analysis menu on the ArcSWAT Toolbar. These tools allow users to load land use and soil layers into the current project, evaluate slope characteristics, and determine the land use/soil/slope class combinations and distributions for the delineated watershed(s) and each respective basin subdivision. The procedures were as follows;

1. Initiate the Land Use/Soil/Slope Definition tool by selecting Land Use/Soil/Slope Definition in the HRU Analysis menu.

2. The Land Use/Soils/Slope Definition dialog opened

3. Load the land use grid by clicking the file browse button in the Land Use Grid section.

4. The raw land use grid will be displayed and clipped to the watershed area (Figure 3.17).

5. Under the Choose Grid Field combo box, choose “value”, then clicked OK.

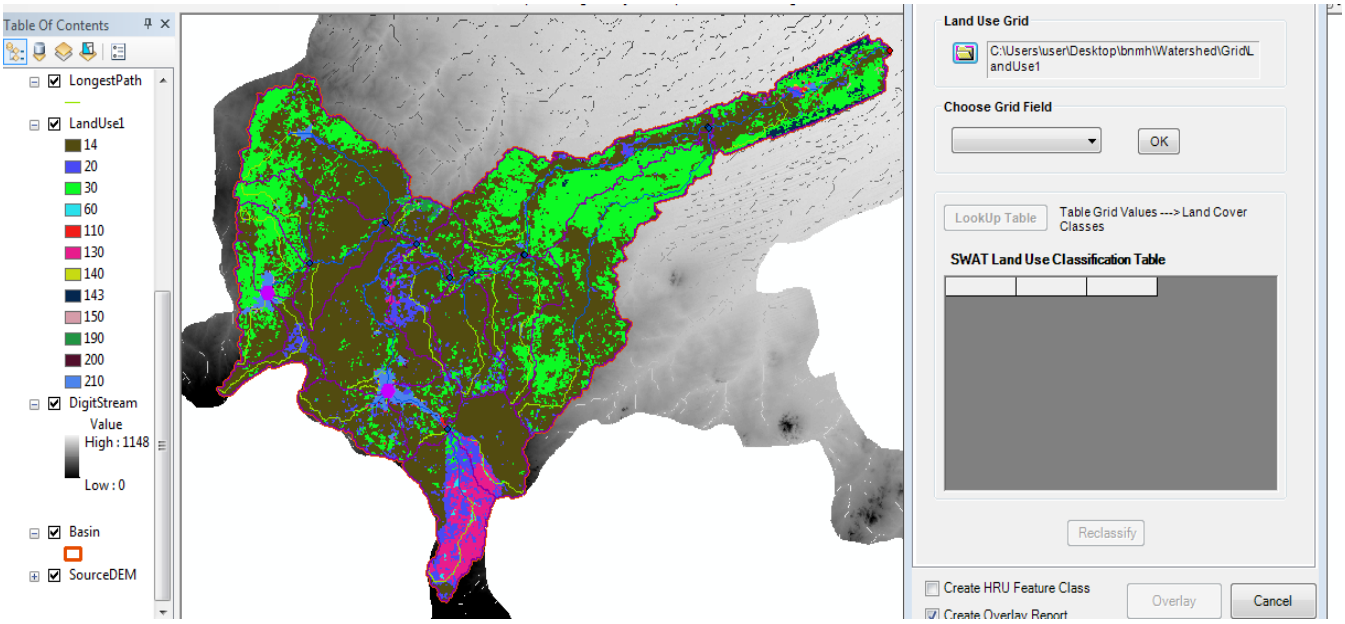


Figure 3.17: Land use/cover data loaded

6. Click the Lookup Table button to load a land use lookup table created in notepad; a custom look up table that define the SWAT land uses codes attached to the land use/cover imagery (Table 3.1)

Table 3.1: Land use/cover lookup

```
"Value","Landuse"
      2,RNGE
      3,WETL
      4,BARR
      6,PLTN
      8,AGRL
      9,WATR
     11,BARR
     12,BARR
     13,URBN
     14,AGRL
     15,FRSE
     23,RFST
     24,AGRL
     25,RFST
     29,RNGE
```

The land use/cover codes are defined as below;

- RNGE: the RNGE was used to represent savanna, sahelian and steppe land
- WETL: it represent wetland
- PLTN: it represent area occupied by Plantation
- AGRL: used for rain-fed and irrigated agricultural land
- WATR: area occupied by water bodies
- BARR: used for area occupied by bare soil and rocky land
- URBN: used for settlement (commercial, industrial, high and low density area)
- FRSE: used for woodland and thicket
- RFST; represents gallery or riparian forest.

7. Select the User Table and load the lookup table

8. After the “LandUseSwat” code has been assigned to all map categories, the Reclassify button will be enabled. Click the Reclassify button, the land use/cover map characteristics of the watershed was created. The created map can be symbolized in different colour (Figure 4.12).

9. Load the soil grid: move to the Soil Data tab on the Land Use/Soils/Slope Definition form and click the file browse button in the Soils Grid section.

10. Fill the prompt box that appeared by selecting the basin soil data location

11. The raw soil grid will be displayed and clipped to the watershed area (Figure 3.18)

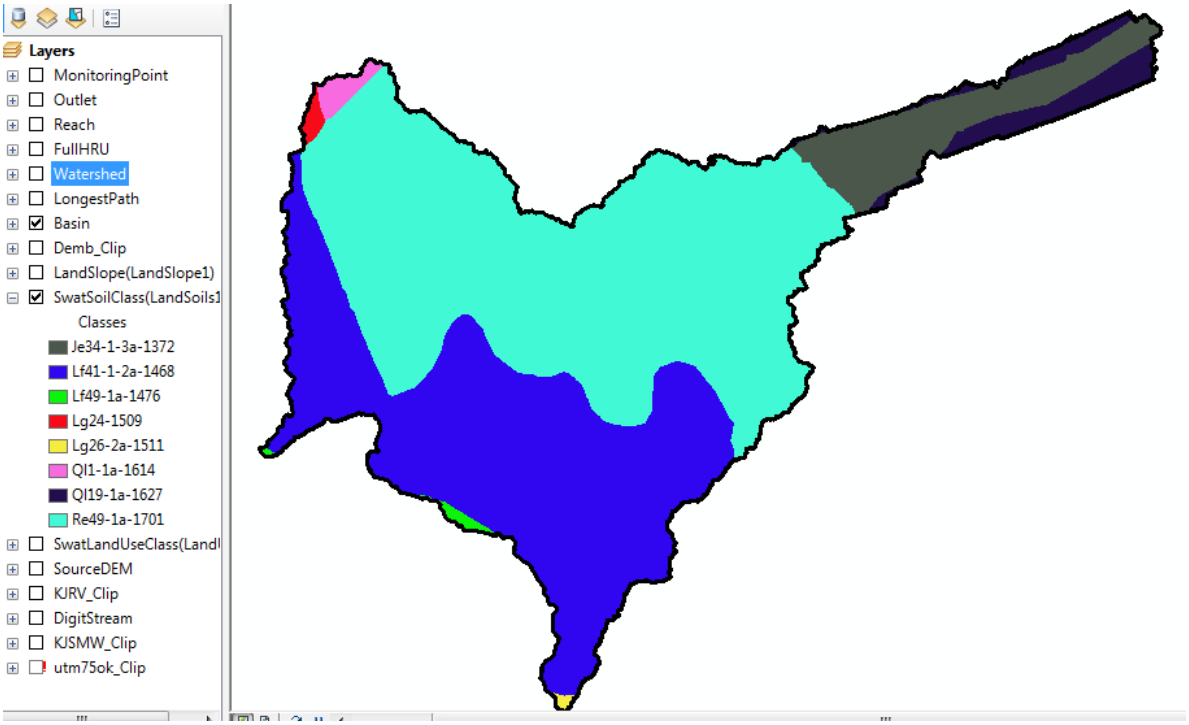


Figure 3.18: Soil map of the sub-basin

12. Under the Choose Grid Field combo box, choose “value”, and then click OK.

13. Click the Lookup Table button to load the soil lookup table (a custom look up table to define the SWAT soil codes was prepared in notepad). In the lookup table each row represents a unique soil texture (Table 3.2) defined after reclassification.

Table 3.2: Soil SWAT codes

"Value"	"Name"
1372	Je34-1-3a-1372
1468	Lf41-1-2a-1468
1476	Lf49-1a-1476
1509	Lg24-1509
1511	Lg26-2a-1511
1614	Ql1-1a-1614
1627	Ql19-1a-1627
1701	Re49-1a-1701

14. After the "SoilSwat" code has been assigned to all map categories, the Reclassify button will be enabled. Click the Reclassify button, the soil map characteristics of the watershed was created. The created map can be symbolized in different colour based on the principal soil (Figure 4.15)
15. To load the slope grid, move to the Slope tab on the LandUse/Soils/Slope Definition form.
16. Click the Multiple Slope option to reclassify the slope grid into multiple slope definition.

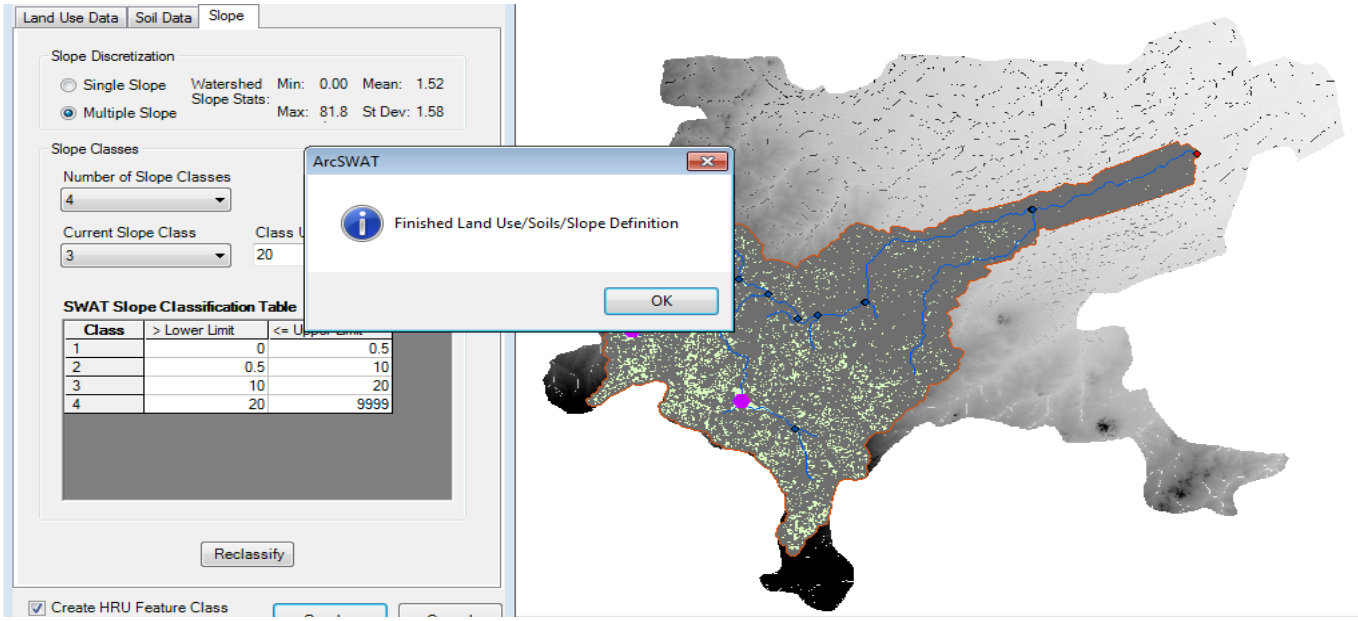


Figure 3.19: Slope grid definition

17. The HRU section end with SWAT reclassification of land use/cover data map, soil data map and slope map of the study area. The cure number (CN) of the entire sub-basin was also regenerated.

3.3.6 Soil Validation

Soil sample was collected from three local governments in the sub-basin in order to validate the soil spatial variation reported using GIS/SWAT, the procedure was as below;

- An unclassified soil map of the study area extent was clipped
- Classified according to the principal soil textural type in SWAT as described above under Hydrological Response Unit (HRU) Analysis through step 8 to 14
- The classified soil map was overlay with delineated study area extent with respect to local government area, in order to locate the where such soil type can be found in the study area (Figure 4.15)
- Soil sample was collected from

Soil sample collection procedure

i. Calibrate the hand auger into 20cm and 50cm using masking tape
ii. Polythene bags were used to transport the collected sample, labeled using permanent marker
iii. The soil was cut down to 20cm marked using the auger and the sample collected within the depth of 0 to 20 cm was thrown away
iv. The auger was returned into the borehole to collect the first sample enough for analysis, which represented sample collection at 20cm
v. step iii and iv was repeated for 50cm

vi. GPS reading at point of soil sample collection was taking; Taura (12.1808N, 9.3135E), Ungogo (12.0545N, 8.4488E), Bunkure (11.7285N, 8.5313E) and Rano (11.5505N, 8.5752E)

vii. The samples were analyzed in Soil Science Department of Ahmadu Bello University Zaria using the Hydrometer Method (the procedure is attached at the appendix)

viii. Compare the experimental result with SWAT reclassified soil data map (Table 4.3)



Plate 3.1: Beginning of soil sampling



Plate 3.2: Less than 20cm thrown away

3.3.7 Import Weather Data

Weather data to be used in a watershed simulation is imported once the HRU distribution has been defined. Weather data is loaded using the first command in the Write Input Tables menu item on the ArcSWAT toolbar**.** For each type of weather data loaded, each sub-watershed is linked to one gage. The Weather Data Definition dialog is divided in six tabs: Weather Generator Data, Rainfall Data, Temperature Data, Solar Radiation Data, Wind Speed Data and Relative Humidity Data. The procedures were as follows;

1. To load the weather data, click Weather Stations under the Write Input Table
2. The Weather Data Definition dialog box will be displayed
3. To load the table containing the locations of the rain gage stations, click Rainfall Data tab of the Weather Data Definition dialog.
4. Click the radio button next to Rain gauges and choose a Precip Timestep of "Daily".
5. Next, click the file browse button next to the Locations Table text box.
6. Select the name of the weather generator stations location table (pcpfprk.txt) from the data folder, and click add.
7. The weather data time series for temperature, relative humidity, solar radiation, and wind speed were added by repeating step 6.
8. Click the OK button at the bottom of the Weather Data Definition dialog

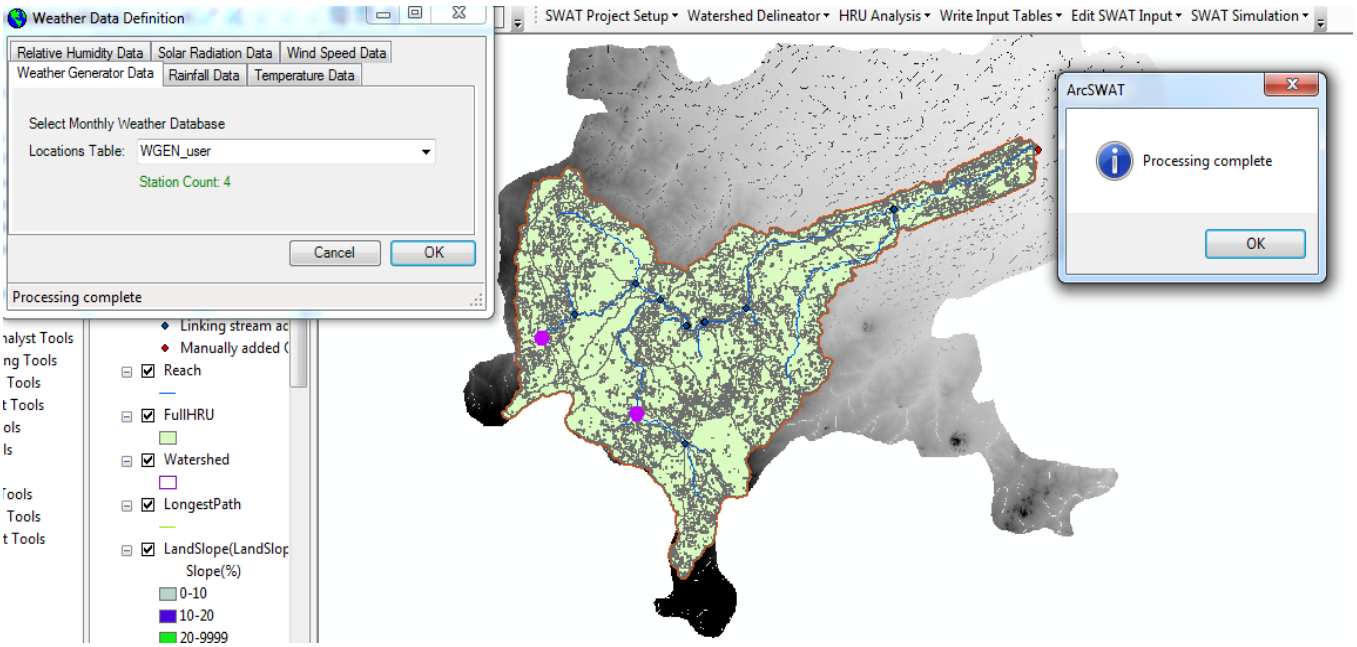


Figure 3.20: Completed weather data definition

3.3.8 Creation of database files

The Write Input Tables menu contains items that allow the user to build database files containing the information needed to generate default input for SWAT. The Write command becomes enabled after weather data is successfully loaded. These commands are enabled in sequence (the next command is enabled only after the steps associated with the previous command are completed) and need to be processed only once for a project.

1. Select the Write SWAT Input Tables from the Write Input Tables menu.
2. The Write SWAT Database Table interface will appear
3. Choosing Select All and clicking Create Tables will launch the process of creating and populating all the SWAT tables with default values.
4. When all databases have been built, a message box will be displayed, click OK to proceed. At this point, the entire Write SWAT Database Tables interface will show the status of which tables have been written in the database (Figure 3.21). A GREEN

Completed label next to the SWAT table name indicates that the table was successfully written.

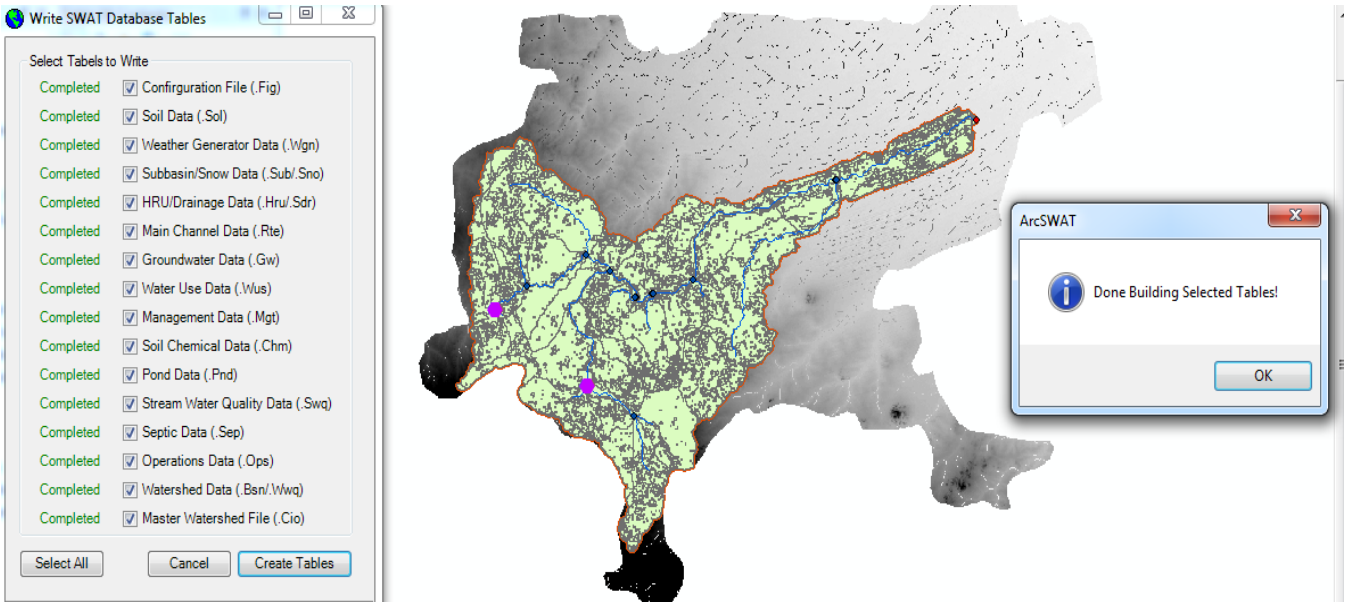


Figure 3.21: Write SWAT Database Tables for weather data

3.3.9 Reservoirs Input Modification

1. Select Reservoirs from the Edit Input menu

2. To edit outlet data for a reservoir, select the number of the sub-basin from the Select Reservoir combo box and input the reservoir outflow data and click OK.

3.3.10 SWAT Simulation

The SWAT Simulation menu finalize the setup of input for the SWAT model and run the SWAT model, perform sensitivity analysis, and perform auto-calibration. Five items are listed on the SWAT Simulation menu.

1. Select Run SWAT from the SWAT Simulation menu, the Set Up and Run SWAT model simulation dialog box is displayed. The dialog box contains several sections in which the user defines the option to be used in the simulation of various processes. The user defined

function includes section for hydrology, water quality, pest control options and management options. In this study the hydrology option was check.

2. SWAT simulation: After the expected output was checked, click the Setup SWAT Run (Figure 3.22).

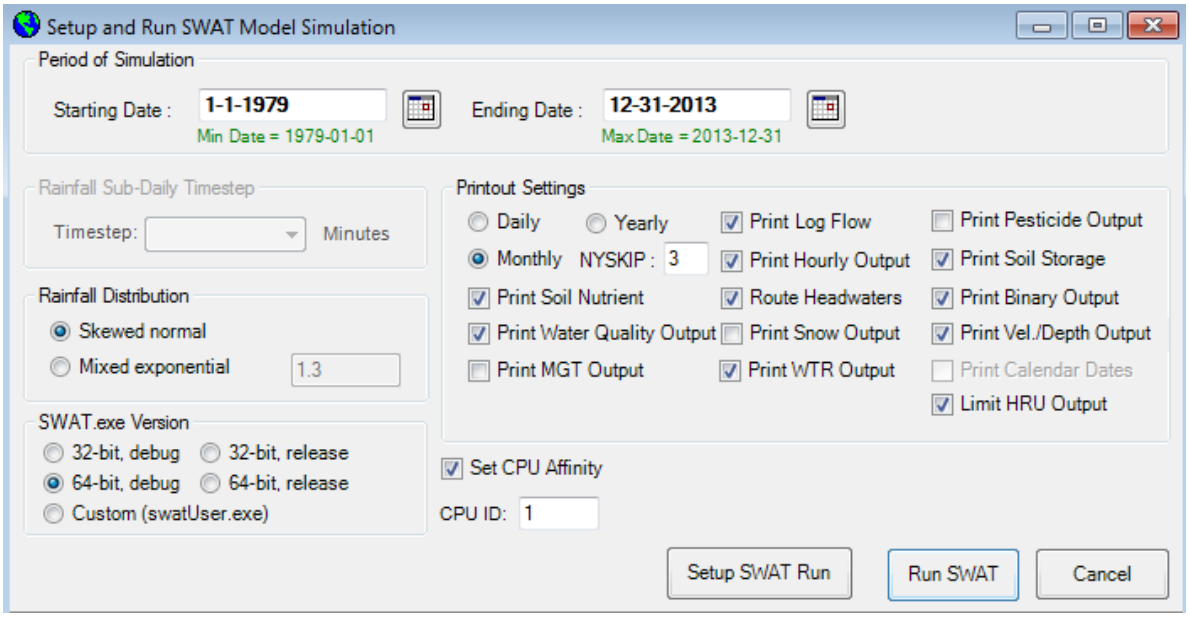


Figure 3.22: setup and run SWAT model simulation interphase

2. Click the Run SWAT button.

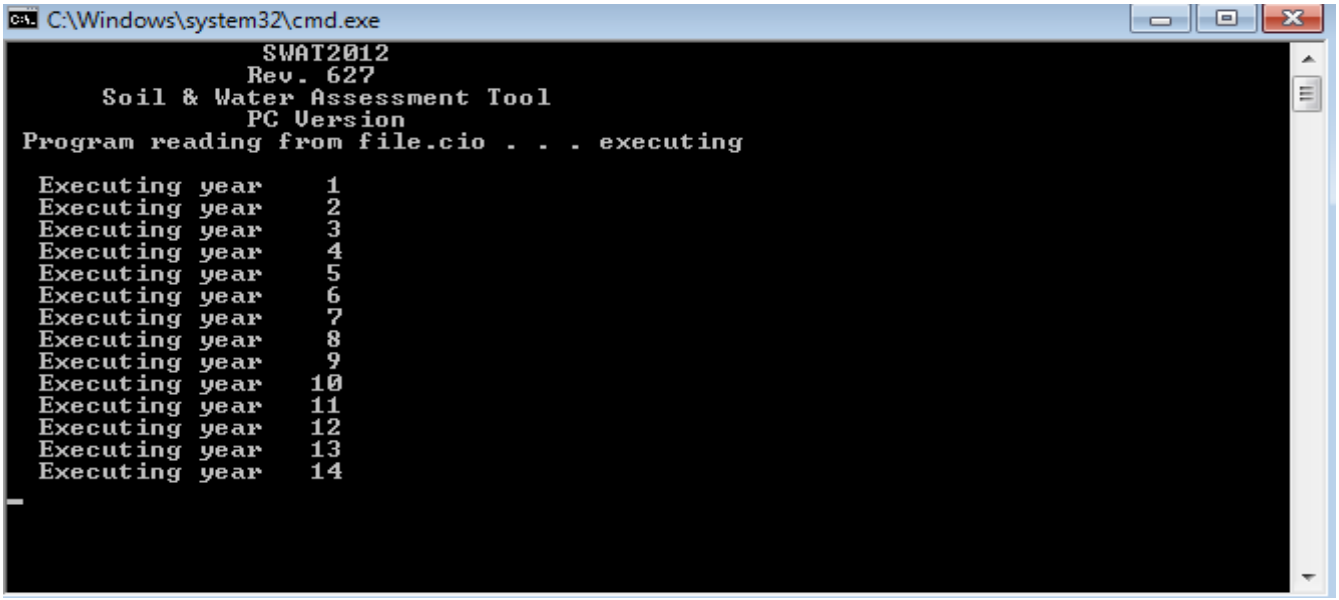


Figure 3.23: Simulation progress window

3.3.11 Read SWAT Output

The second command in the SWAT Simulation menu opens the Read SWAT Output dialog. This dialog provides tools for importing the output text files generated by SWAT into an Access database. Having SWAT output data in a database table format provides a convenient format for extracting output of interest.

1. Select Read SWAT Output from the SWAT Simulation menu (Figure 3.24), the SWAT Output dialog box is displayed.

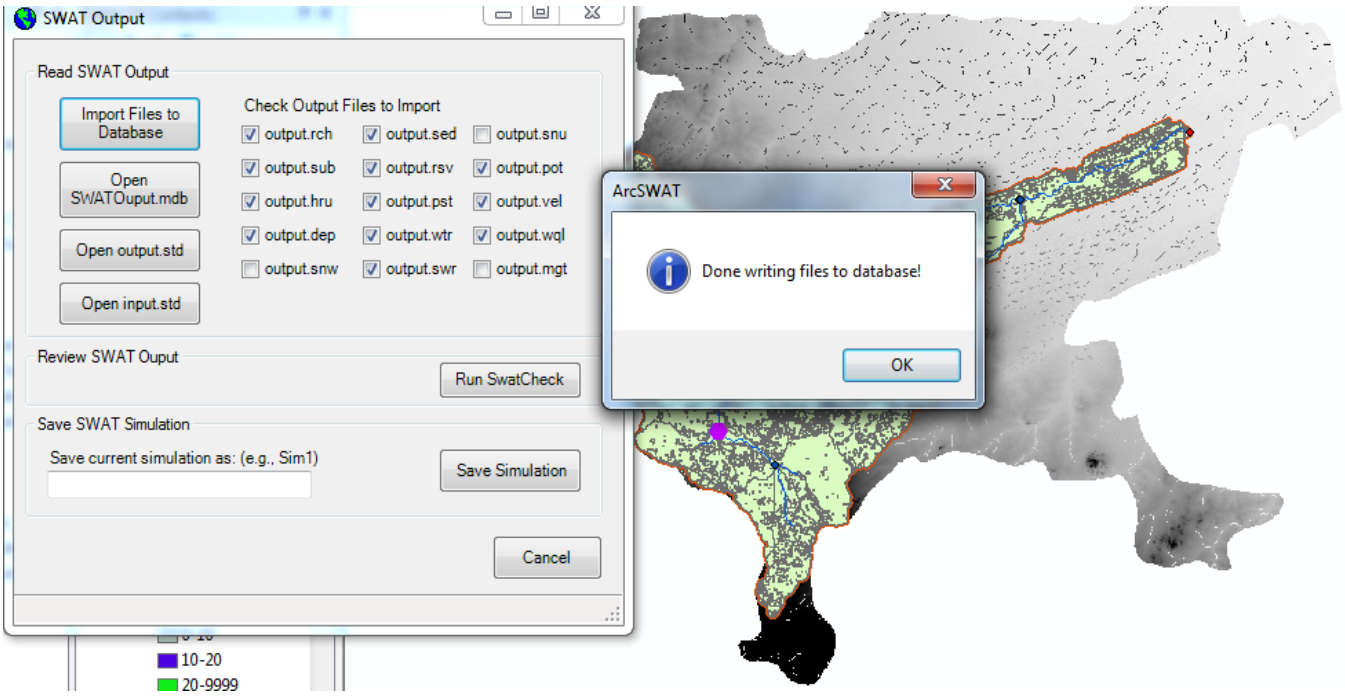


Figure 3.24: Read SWAT Output

2. Run Swat Check

3. Click the save simulation and name the file, this end the whole process of ArcSWAT simulations processes. The procedure was repeated for land use/cover of 2000 and 2013 to determine the impacts of land use/cover dynamics in Hadieja River Sub-basin hydrological parameters.

The simulation output includes the sub-basin water yield, ground water recharge, lateral flow, surface runoff, sediment yield, loss due to potential evapotranspiration and evaporation losses and estimated rainfall over the entire basin.

3.4 DETERMINATION OF TREND IN THE FIELD RAINFALL AND TEMPERATURE TIME SERIES DATA SETS

Plot the annual data

```
pcp<-read.table(file.choose(),sep=",",header=F)# load the data
pcpseries=ts(pcp, start=c(1982,1), frequency=12) #convert the monthly data to time series
attach(pcp)
class(pcp)
ap
pcp.a.ts <- aggregate(pcp.month.ts)/12# convert data to annual data
summary(pcp.a.ts)
plot(pcp.a.ts,xlab="AnnualAveragePrecipitation",ylab="Precipitation",las=1,lwd=2,col="b)
plot(pcp.m.ts,ylab = "Precipitation",las=1,lwd=1.5,col="blue",type="o",pch=16,xlab="Year
title(main="Precipitation Time series:1982-2011")
abline(reg=lm(pcp.m.ts~time(pcp.month.ts)),lwd=2,col="red")
```

Trend Estimation

```
load.packages (Kenndal)
MK(data)
Sens.Slope(data)
```

3.5 PREDICTIVE MODEL OF THE SUB-BASIN FIELD PRECIPITATION AND TEMPERATURE TIME SERIES USING R PROGRAMMING

The predictive model procedure applied to rainfall and temperature field data;

```
tdata=read.table(file.choose(),sep=",",header=F) # import the data into R
View(tdata) # view the data
tdatats=ts(data,frequency = 12,start=c(1979,1)) # convert the data into time series
plot(tdatats)
dim(as.matrix(tdatats))

#Smoothing and cleaning the data
No_outliers = (data)
Data = tsclean (No_outliers)

#Training and Testing dataset #dividing the data into two parts
datatrain=window(tdatats,start=c(1982,1),end=c(2015,12))
plot(datatrain)
dim(as.matrix((datatrain)))
```

```
data.test=window(tdatats,start=c(2012,1))
plot(data.test)
dim(as.matrix(data.test))

#Developing an SARIMA model and analysis
library(forecast)
arima1=auto.arima(datatrain,trace=T,test="kpss",ic="bic")
summary(arima1)
confint(arima1)

#Residual Diagonostic
plot.ts(arima1$residuals)
Box.test(arima1$residuals,lag=20,type="Ljung-Box")
acf(arima1$residuals,lag.max=24)
library(tseries)
Box.test(arima1$residuals^2,lag=20,type="Ljung-Box")
jarque.bera.test(arima1$residuals)
arima1.forecast=forecast(arima1,h=24)
plot(arima1.forecast)
accuracy(arima1.forecast,data.test)
plot,arima(data.test,arima1,xlim=c(2011,2015),range.percent=0.05)
```

This procedure was repeated for both rainfall and temperature predictions

3.6 CALIBRATION, SENSITIVITY AND VALIDATION OF THE STREAM FLOW VALUE ESTIMATED USING SWATCUP

1. Start SWAT-CUP

a. Install the SWAT-CUP in C:\SWAT\SWAT-CUP, the same directory as the SWAT and start the program by pressing the SWAT-CUP icon on the desktop:

2. Open a Project

3. For a new project locate a SWAT "TxtInOut" directory.

4. Choose SWAT and processor versions

5. Select a program from the list provided (SUFI2,GLUE, ParaSol, MCMC, PSO).

6. Give a name to the project and a location where SWAT-CUP project can be saved.

7. Sensitivity analysis: Under the Calibration Inputs edit the following files:- Par_inf.txt, SUFI2_swEdit.def and select the parameters for sensitivity analysis.

8. Observation

Defining the observed data and time period for which we will run the calibration by activating the Rch component of the file, followed by defining the Objective function.

9. Executable: The section on Executable Files plays the role of engine in SWAT-CUP

10. Calibration: Next, after editing all the input files, perform "Save All" and "Close All" tasks. Run the programs in the Calibration window in the order that they appear.

11. Sensitivity analysis: The interphase module of the program performs sensitivity analysis.

12. Validation in SUFI2: To perform validation in SUFI2, edit the files observed_rch.txt, observed_hru.txt, obsrved_sub.txt, and observed.txt as necessary for the validation period.

This end the process of calibration, sensitivity and validation, for details refer to the user manual SWATCUP users' manual

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 GENERAL

The results and discussions presents in this chapter were according to the outlined objectives of the research that included: the calibration and validation of the radar rainfall and temperature data using NiMET data; characterization of the watershed physiographical parameters; estimation of the sub-basin mean monthly water loss due to potential evapotranspiration, evaporation losses, water yield, ground water recharge, lateral flow, surface runoff, and sediment yield; trend in the temperature and field rainfall time series data sets; the predictive model of the sub-basin field temperature and precipitation time series; observed stream flow calibration, validation and sensitivity analysis.

4.2 CALIBRATION AND VALIDATION OF THE RADAR RAINFALL AND TEMPERATURE DATA USING NiMET DATA

Figure 4.1 shows the correlation between the radar rainfalls (unadjusted) and NiMET rainfalls data (field data) at point p11188. The coefficient of correlation (adjusted R^2) between the rainfall radar weather data and field rain gauge dataset was found to be 0.0263, which shows a weak relationship between the two datasets.

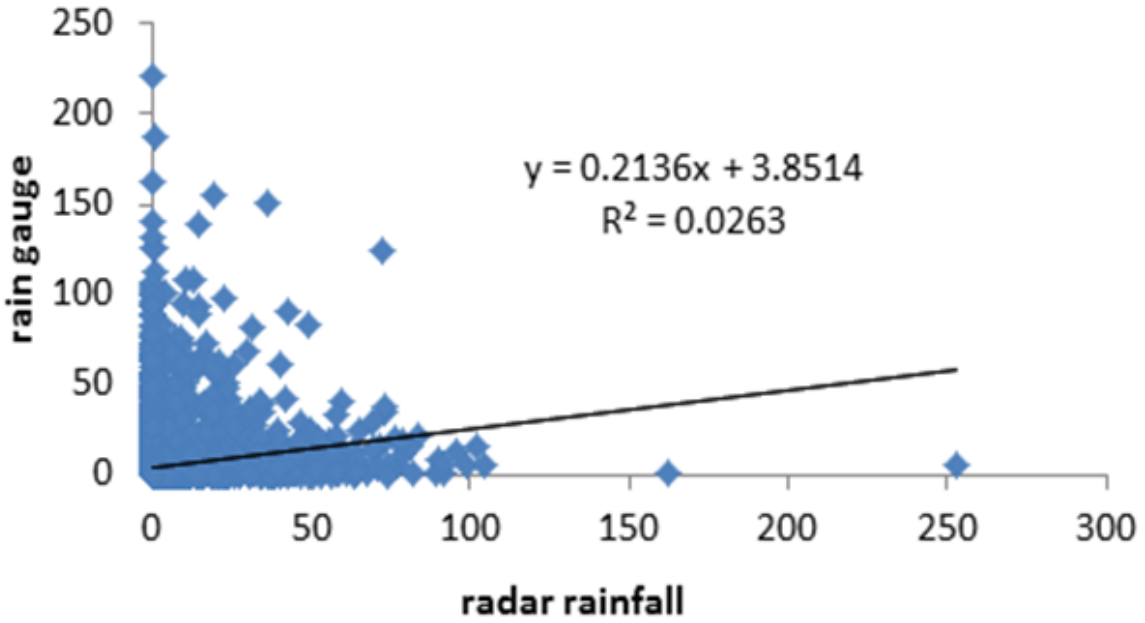


Figure 4.1: Correlation coefficient between radar and rain gauge data

Figure 4.2 shows a perfect coefficient of correlation (adjusted R^2) between the adjusted rainfall radar data and the field data (rain gauge) at point p11188.

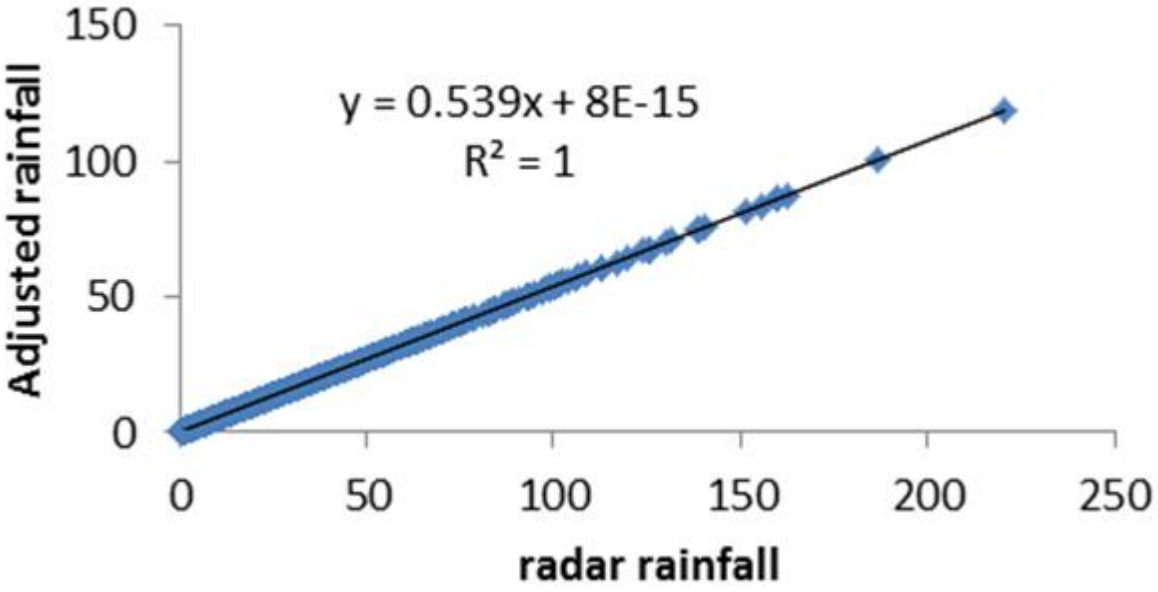


Figure 4.2: Correlation coefficient between adjusted radar and rain gauge data

Figure 4.3 shows a weak correlation coefficient (adjusted R^2) of 0.2737 between the radar temperature (unadjusted) and NiMET temperature data (field data) at point p11188.

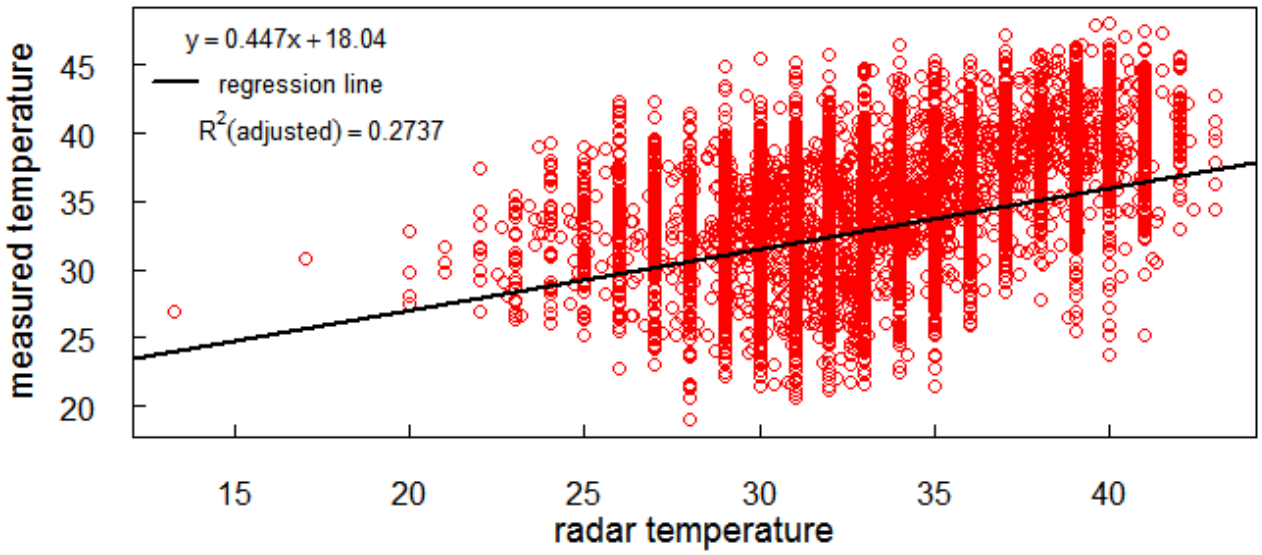


Figure 4.3: Correlation coefficient between radar and temperature gauge

Figure 4.4 shows a perfect coefficient of correlation (adjusted R^2) between the adjusted temperature radar data and the field data (temperature gauge) at point p11188.

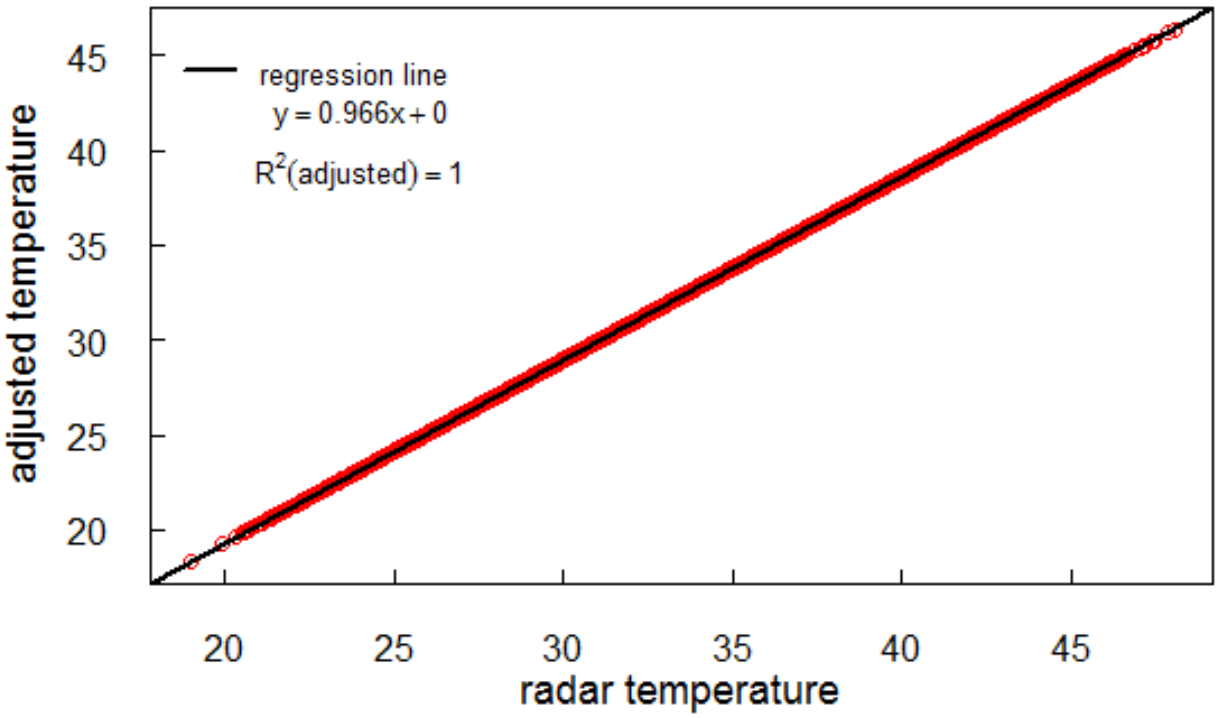


Figure 4.4: Correlation coefficient between radar and adjusted temperature

The Correlation coefficients of other points are at the appendix

4.3 WATERSHED CHARACTERISTICS GENERATED USING GIS/SWAT

i. Figure 4.5 shows the catchment shape, the river network and the two dams in the sub-basin. It was revealed that the sub-basin has a total surface area of 15,663.02 sqkm with a corresponding perimeter of 1,323.51 km.

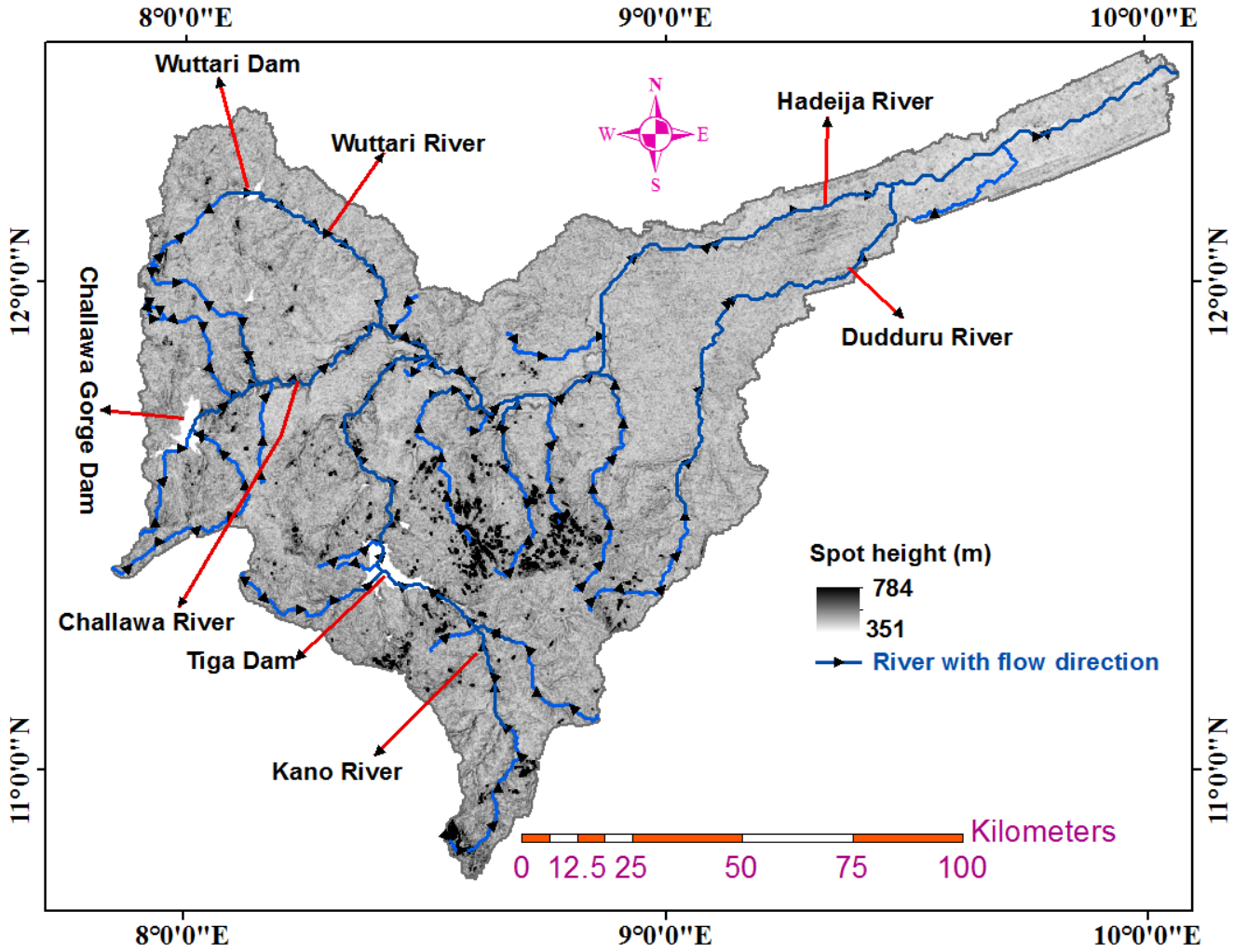


Figure 4.5: Delineated basin extent

ii. Figure 4.6 shows the profile of the longest river (Hadejia River) in the sub-basin with estimated total length of 364.461km; the sudden depression that lies between 60,000m to 80,000m on the distance axis indicated an impoundment (Tiga Reservoir) along the river channel.

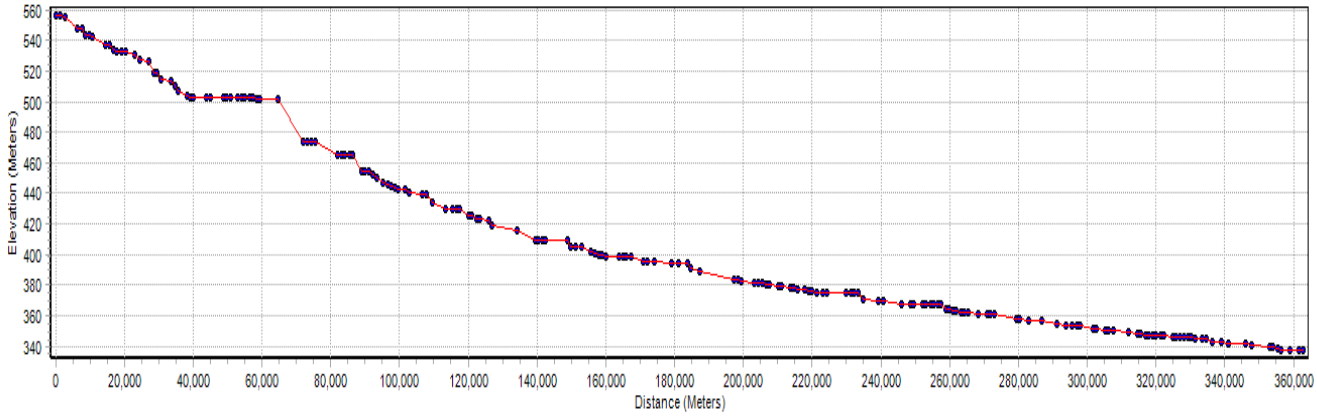


Figure 4.6: Hadejia River profile

iii. The basin Digital Elevation Model (DEM) is as shows in Figure 4.7. It provides a regular grid of elevation points that allows the facsimile of the topographic map in a variety of display formats. It was revealed that the highest elevation in the sub-basin was 784m while the lowest elevation was 351m above sea level.

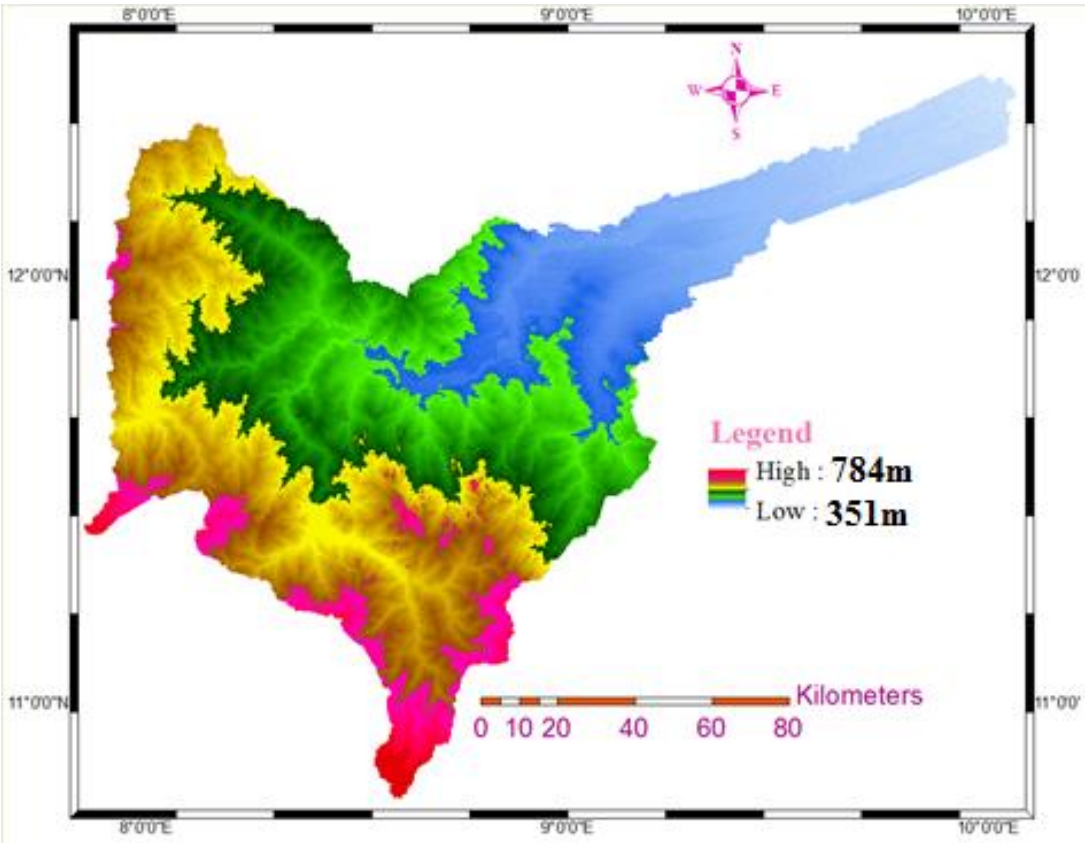


Figure 4.7: Basin Digital Elevation Model classification

iv. The sub-basin contour map (an isoline that connects points on a map that have the same elevation) is as display in Figure 4.8, which provides an effective system for describing the sub-basin configuration that includes the arrangement, spacing, and shape of the basin.

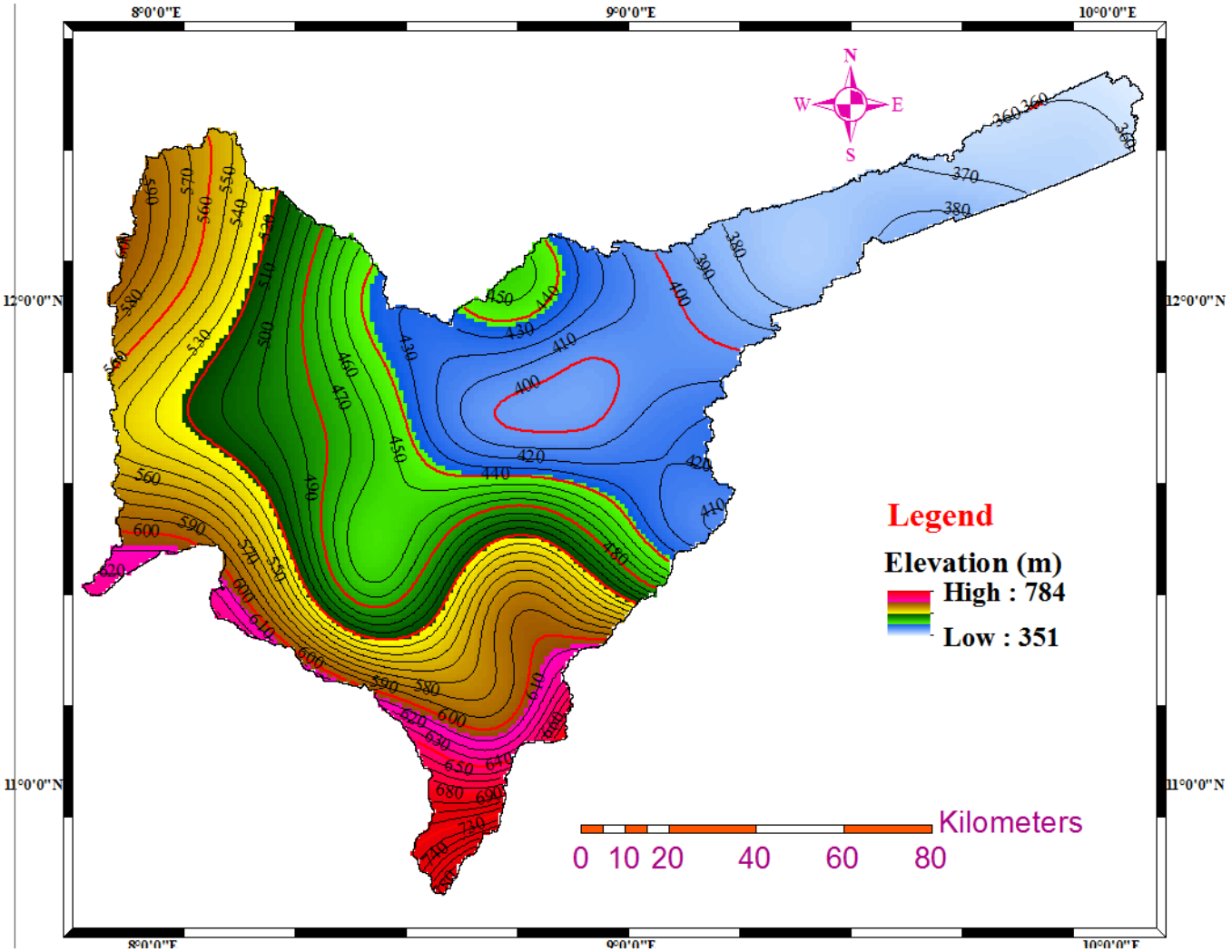


Figure 4.8: Basin contour map

v. Figure 4.9 shows the basin elevation 3D map that unveiled the actual topographic configuration of the land surface.

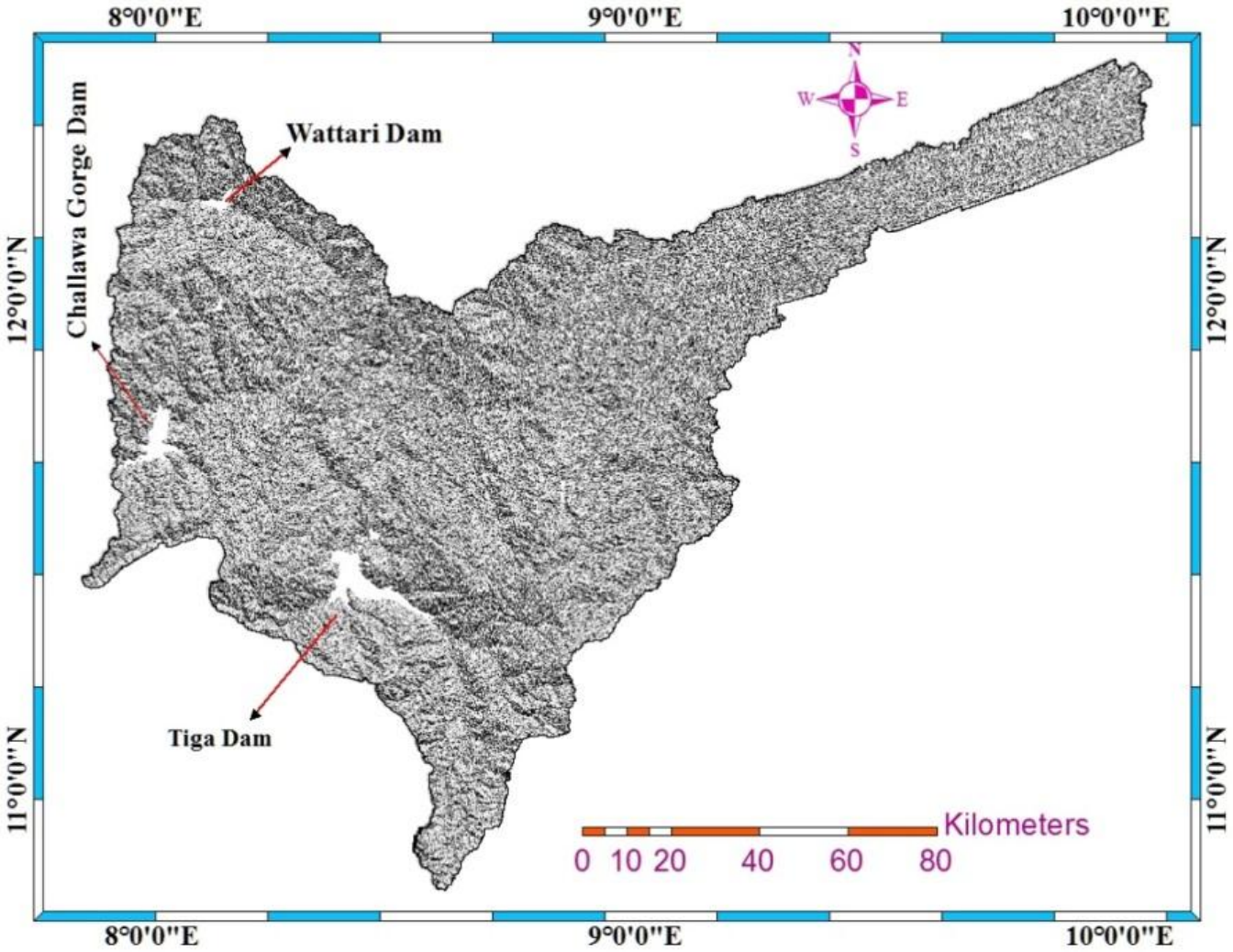


Figure 4.9: Basin 3D elevation map

vi. The first step in the quantitative analysis of the watershed that gives insight into stream network is as shows in Figure 4.10. The information in Table 4.1 and Table 4.2 that described the basin stream network characteristics were extracted from the stream order. The numbers 1(red), 2(green) and 3(blue) represent all 1st order streams, 2nd order streams and 3rd order streams respectively.

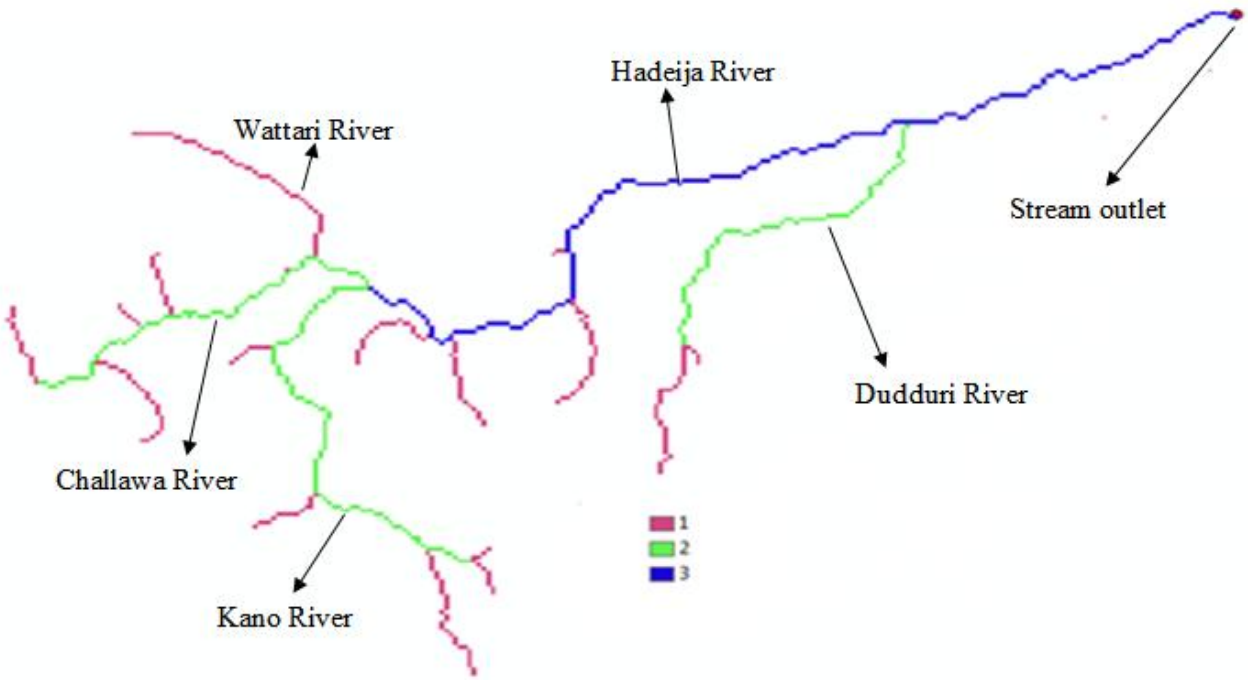


Figure 4.10: Stream order

vii. Table 4.1 and Table 4.2 provides the geomorphology of the basin with respect to the drainage network. Table 4.1 shows that the basin stream network is of third order with a bifurcation ration of 1.47. The bifurcation ratio of a river network show which part of a drainage basin are more likely to flood, comparatively, by looking at the separate ratios. If the bifurcation ration of a river network is low, there is a higher chance of flooding, as the water will be concentrated in one channel rather than spread out. (en.wikipedia.org). From Table 4.1, flood is likely to occur at downstream location with a bifurcation ration of 1.29.

Table 4.1: Linear characteristics of the drainage network of the watershed

River Basin	Stream Order (Su)	Stream Number (Nu)	Stream Length(Lu) (km)	Stream Mean Length(Lum) (km)	Cumulative Stream mean Length (km)	Log Nu	Log Lu
Hadejia	1	17	307.31	18.08	18.08	1.23	2.49
	2	9	278.65	30.96	49.04	0.95	2.45
	3	7	231.48	33.07	82.11	0.85	2.36
Total		43	817.44				
River Bifurcation Ration							
1st order/2nd order			2nd order/3rd order			Bifurcation Ration	
1.89			1.29			1.47	

Table 4.2 shows that the drainage density (the measure of how well or poorly a watershed is drained by stream channels) of the basin was 0.052 km/km^2. The low drainage density indicates a less flood risk and low stream flow velocity in the watershed.

Table 4.2: Aerial Aspects of the Watershed

Morphometric Parameter	**Formula**	**Result**
Basin Area (km^2)	A=LbB	15663.02
Drainage Perimeter (km)	P=2(Lb+B)	1323.51
Drainage Density km/km^2	D=ΣLu/A	0.052
Stream frequency (km^2)$^{-1}$	Fs=ΣNu/A	0.003
Texture ration (km^{-1})	T=ΣN1/P	0.013
Basin length (km)	Lb	364.461
Elongation Ration	Re=2√(A/π)/ Lb	0.387
Circularity ratio	Rc=4πA/P^2	0.112
Form Factor Ration	Rf= A/ Lb^2	0.118

viii. Base on unique land use/cover characteristics, soil type and elevation, the basin was sub divided into twenty-one (21) hydrological respond units shows in Figure 4.11

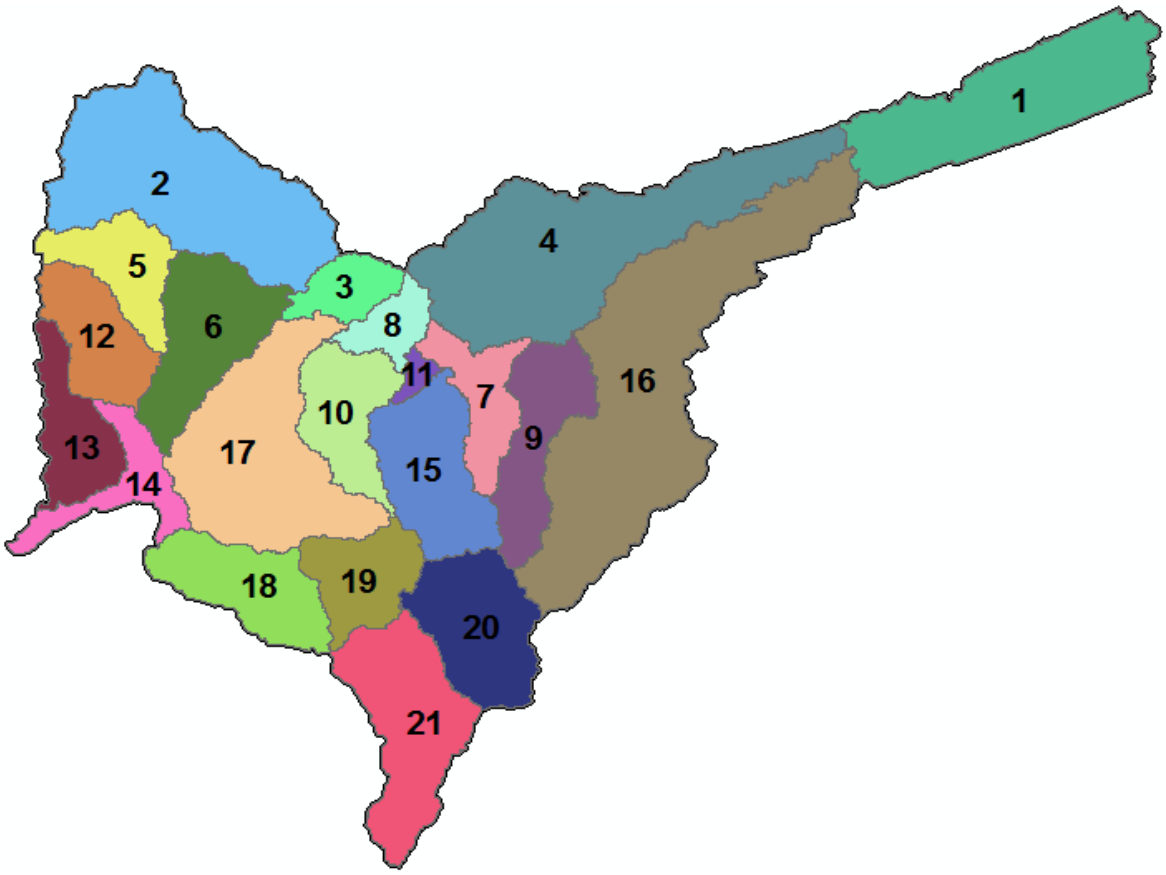


Figure 4.11: Basin subdivision map

ix. The land use/cover of 1975, 2000 and 2013 characteristics with respect to the area occupied in sqkm are as shows in Table 4.3 and discussed as follows;

- It was observed that the range land (RNGE) decreases by 49.74% from 1975 to 2000 with further decreases by 21.88% from 2000 to 2013. The total decreases of 60.74% observed from 1975 to 2013 could be due to increases in irrigated agricultural land, fuel-wood, grazing and urbanization.
- There was a reduction of 18.33% of wetland (WETL) area between 1975 to 2000, increases of 5.81% between year 2000 and 2013 that could be due to increases in rainfall. A reduction of 13.58% was noticed from 1975 to 2013, which implies that despite the increased rainfall insinuated from 2000 to 2013 the sub-basin is yet to recover from declining rainfall.
- There was a continuous reduction in the bare soil and rocky area (BARR) by 14.66% from 1975 to 2000, 2.64% from 2000 to 2013 and 16.91% from 1975 to 2013. The reduction observed could be due to urbanization.
- The sugar plantations noticed in 2000 and 2013 land use/cover change were located in Kura, Madobi, Gabasawa, Wudil, Dawakin-Tofa and Rogo. Others are Kibiya, Sumaila, Rano, Takai and Warawa (Musa, 2009). The extent of the plantation has not really changed over the time considered.
- The agricultural land area continues to increases from 1975 to 2000 by 8.49%, 1.21% from 2000 to 2013 and total increases from 1975 to 2013 by 9.79%. The continuous increases could be due to the quest to survive by the rising population.
- The area occupied by water bodies mainly due rivers, the dams and other hydraulic structures constructed in the sub-basin continue to increases from 1975 to 2000 by

77.85%. Many dams including Tiga and Challawa Gore Dam were completed and active within the 1975 and 2000 land use/cover changes. Water bodies increases in area by 6.17% from year 2000 to 2013 due to some new dam added like

- Continuous increases were observed in the settlement (URBN) land use/cover category due to demand for shelter by the rising population. 11.67% increases from 1975 to 2000, 14.67% from 2000 to 2013 and 24.63% from 1975 to 2013.
- 3.85% decreases was observed in FRSE from 1975 to 2000 and remained constant from 2000 to 2013. The stagnation of the forest resources could be probably some control measures put in place like tree planting etc.
- It was observed that the riparian forest (RFST) along the river bank has 3.07% decreases from 1975 to 2000, 1.61% reduction from 2000 to 2013 and 4.64% reduction from 1975 to 2013. The shrinking of the resources could be to pressure from anthropogenic activities and reduction in river flow and flood plain inundating.

Table 4.3: The area in sqkm of land use/cover dynamics of the year 1975, 2000 and 2013

Year	RNGE	WETL	BARR	PLTN	AGRL	WATR	URBN	FRSE	RFST
1975	14.061	4.087	2.975	0	73.714	0.478	1.922	0.649	2.114
2000	7.067	3.338	2.539	0.05	79.972	2.158	2.176	0.624	2.049
2013	5.521	3.532	2.472	0.05	80.936	2.3	2.55	0.624	2.016

x. Land use/cover map of 1975 (Figure 4.12) shows that agricultural land area was the principal land use category occupying land area of 73.714 sqkm, then range land of 14.061 sqkm in area. There exist no plantations (PLTN) as at 1975 land use/cover type.

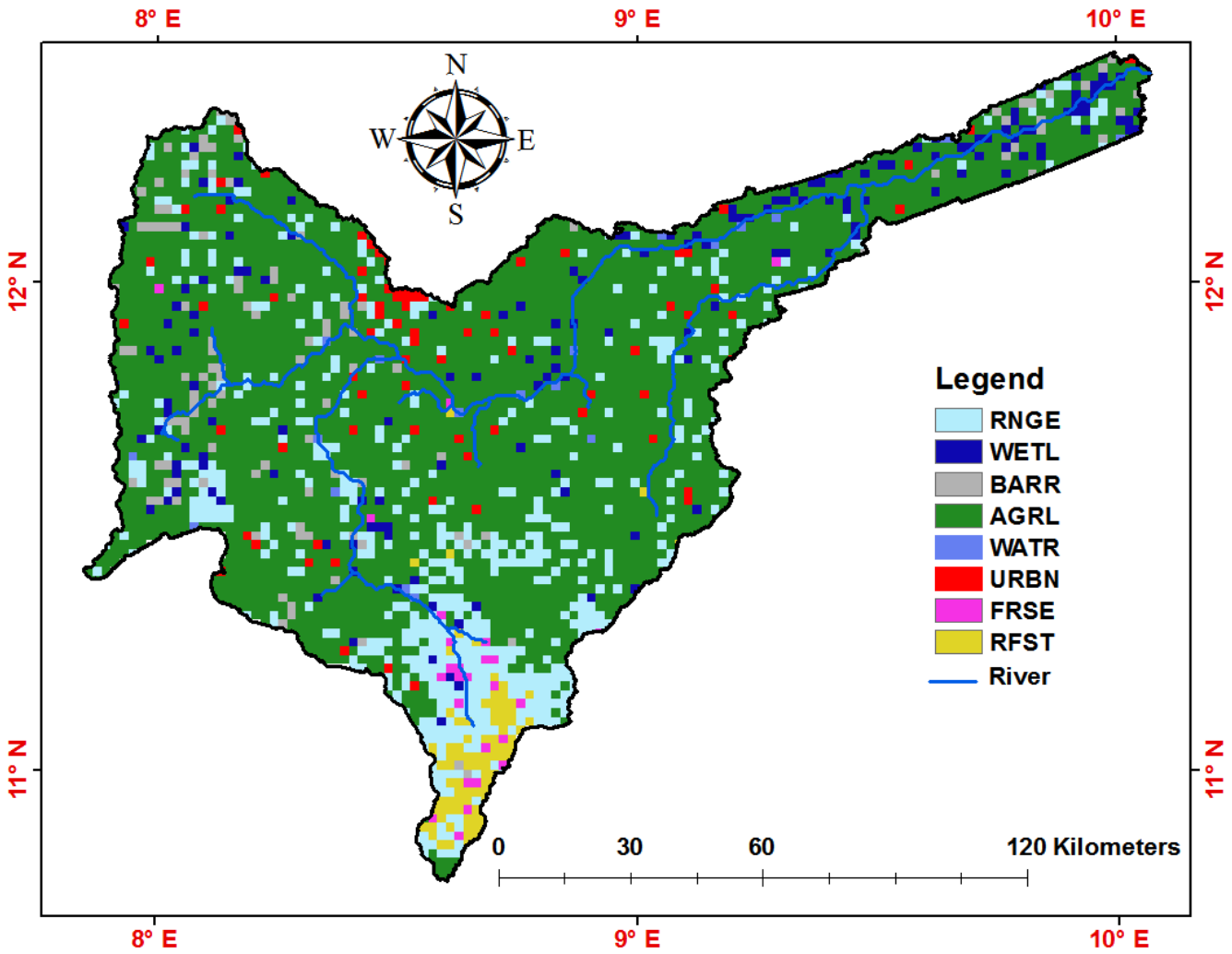


Figure 4.12: 1975 land use/cover characteristics of the basin

xi. Simulation summary (Figure 4.13) using land use/cover of 1975 shows that the mean water losses due to potential evapotranspiration was 2,672.8mm, mean rainfall 799.2mm, mean surface runoff 296.3mm, mean return flow 97.12mm and average Curve Number (CN) of 82.35 in the sub-basin from 1982 to 2013.

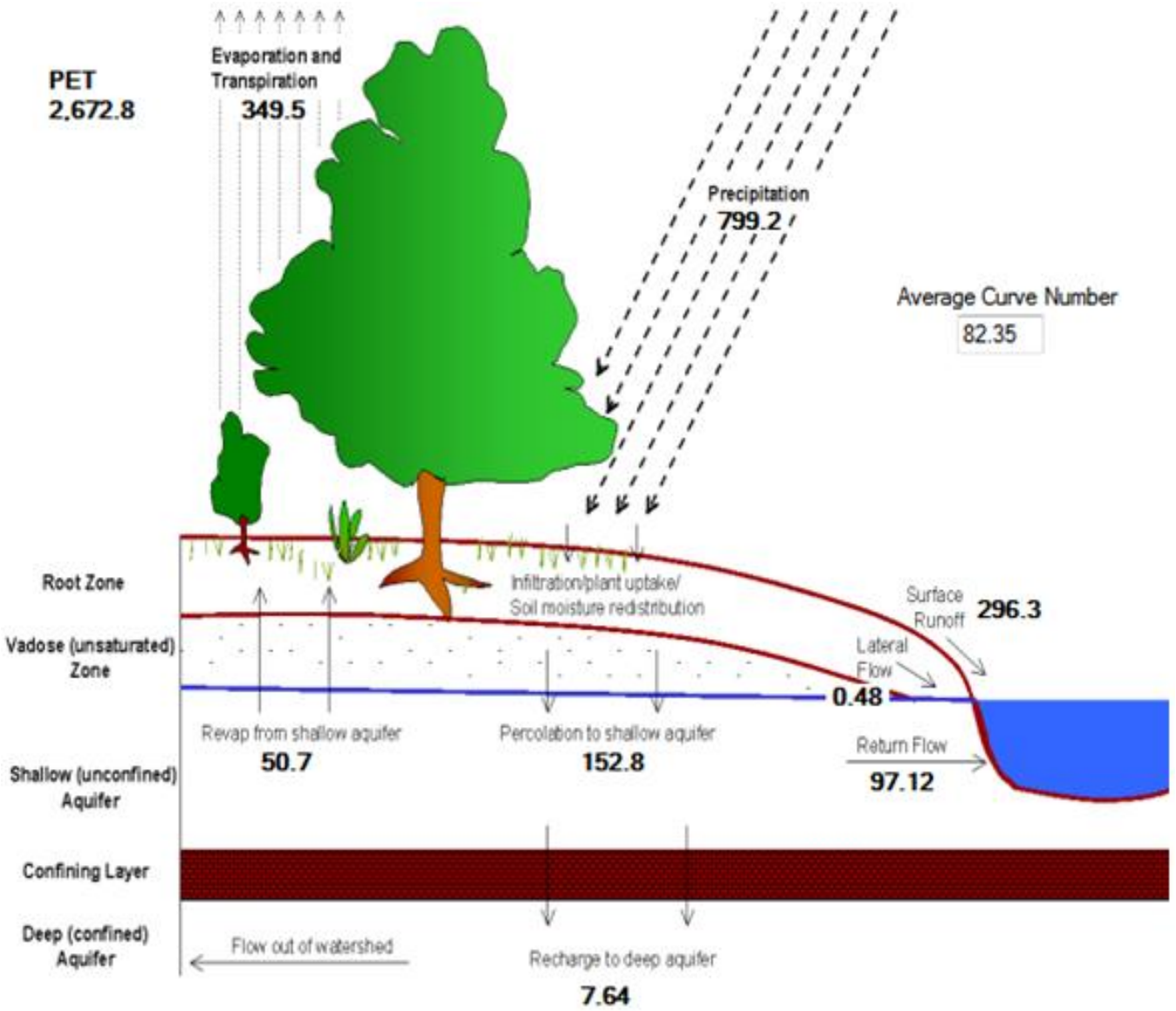


Figure 4.13: Annual total values of hydrological parameters using 1975 land use/cover.

xii. The land use/cover of year 2000 (Figure 4.14) shows the existence of sugar cane plantation, Tiga and Challawa Gorge Dam. Local government areas renowned for mass production of sugar cane includes: Kura, Madobi, Gabasawa, Wudil, Dawakin, Tofa and Rogo. Others are Kibiya, Sumaila, Rano, Takai and Warawa (Musa, H. 2009). Nigeria: Kano's Sweetening Sugar Cane Business daily trust

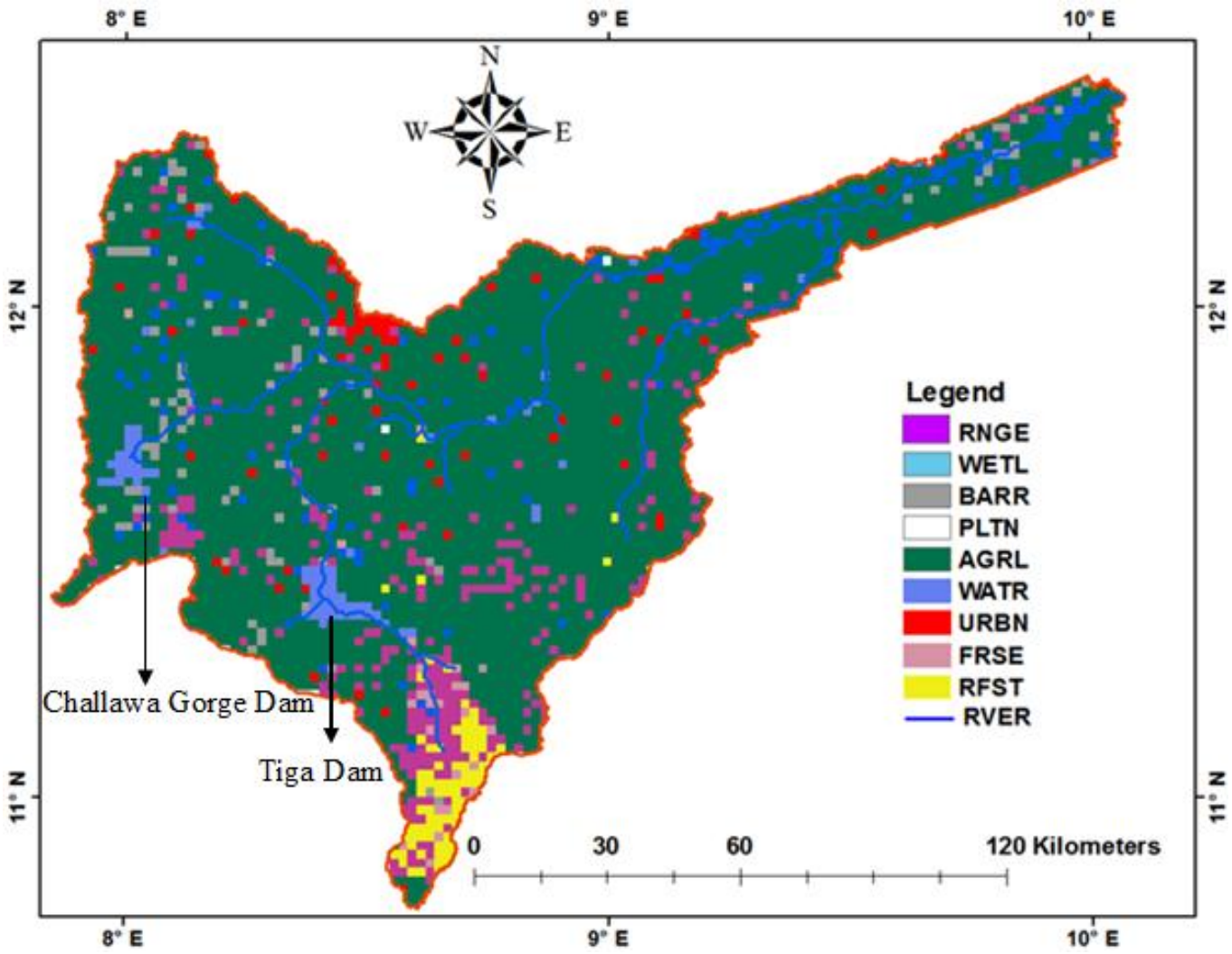


Figure 4.14: 2000 land use/cover characteristics of the basin

xiii. Simulation summary (Figure 4.15) using land use/cover of year 2000 shows that mean water losses due potential evapotranspiration is 2,674.1mm, mean evaporation 362.6mm, mean rainfall 789.1mm, mean surface runoff 291.7mm, mean return flow 90.7mm and average Curve Number (CN) of 82.68 from the year 1982 to 2013 in the sub-basin.

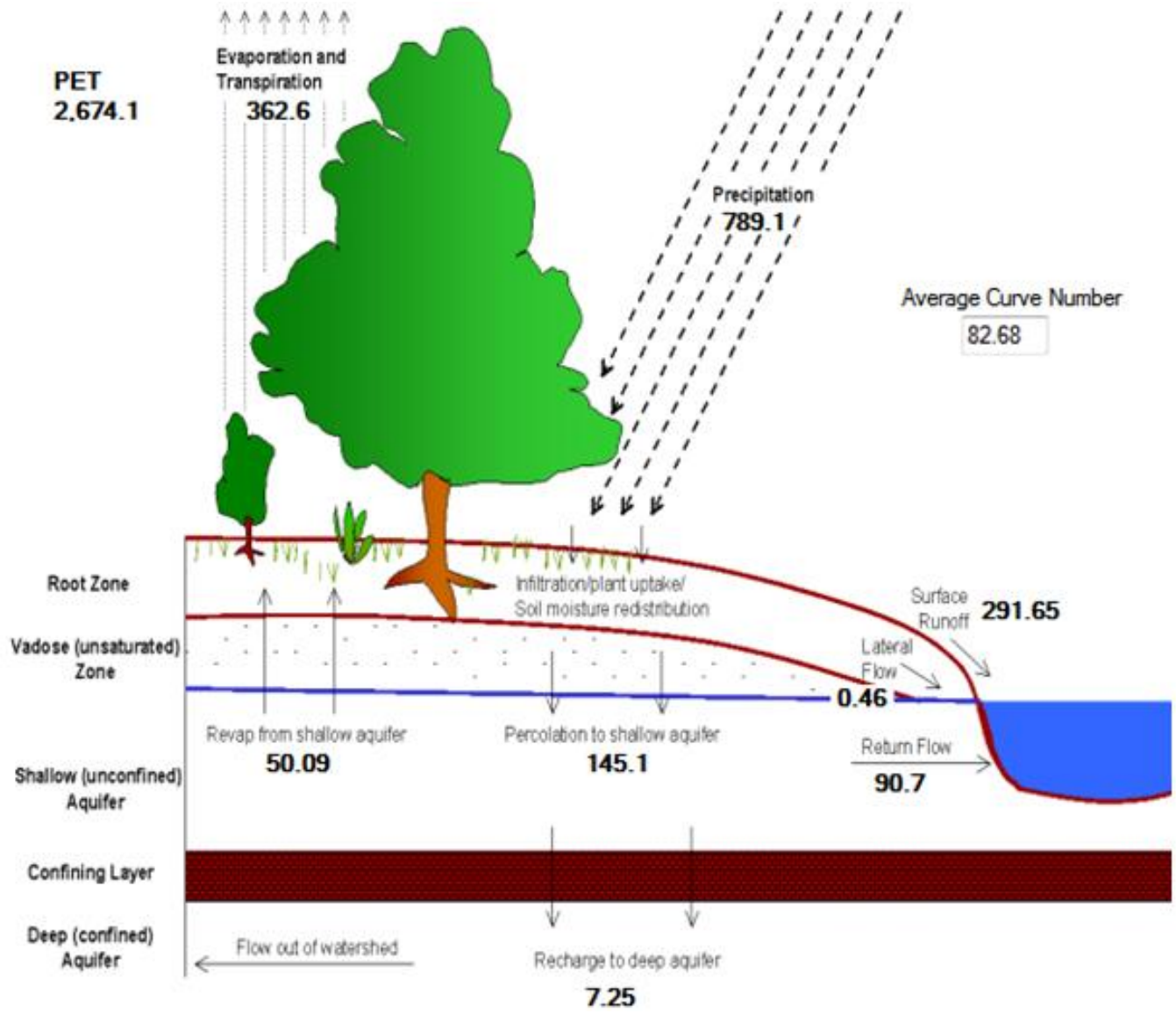


Figure 4.15: Simulation summary using year 2000 land use/cover map

xiv. The land use/cover of year 2013 shows no significant change in the land use classification when compared to the land use/cover of year 2000 (Figure 4.16).

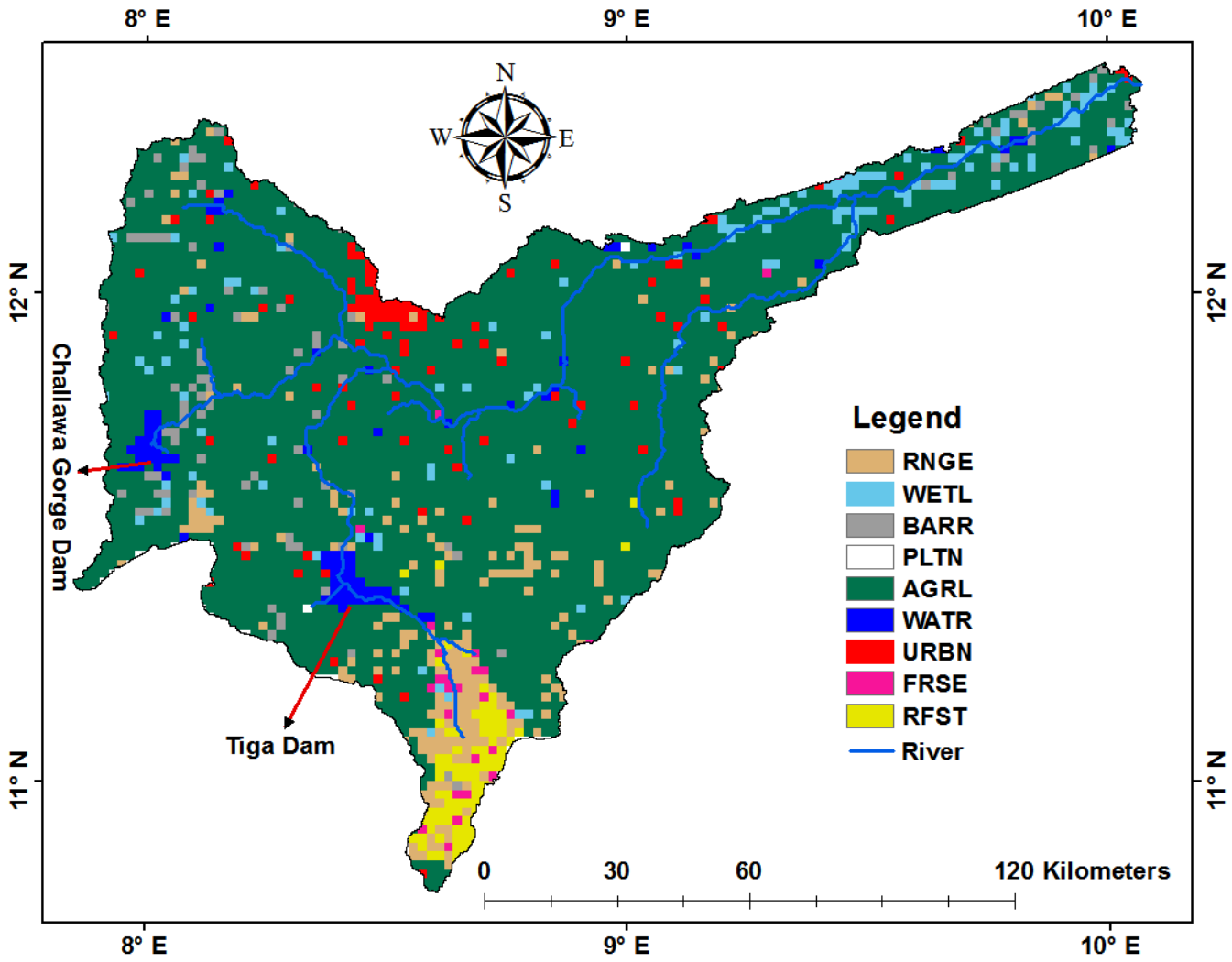


Figure 4.16: 2013 land use/cover characteristics of the basin

xv. Simulation summary (Figure 4.17) using land use/cover of year 2013 shows that mean annual water losses due potential evapotranspiration is 2,674.1mm, mean evaporation 362.2mm, mean rainfall 789.1mm, mean surface runoff 292.1mm, mean return flow 90.62mm and average Curve Number (CN) of 82.69 from the year 1982 to 2013 in the sub-basin.

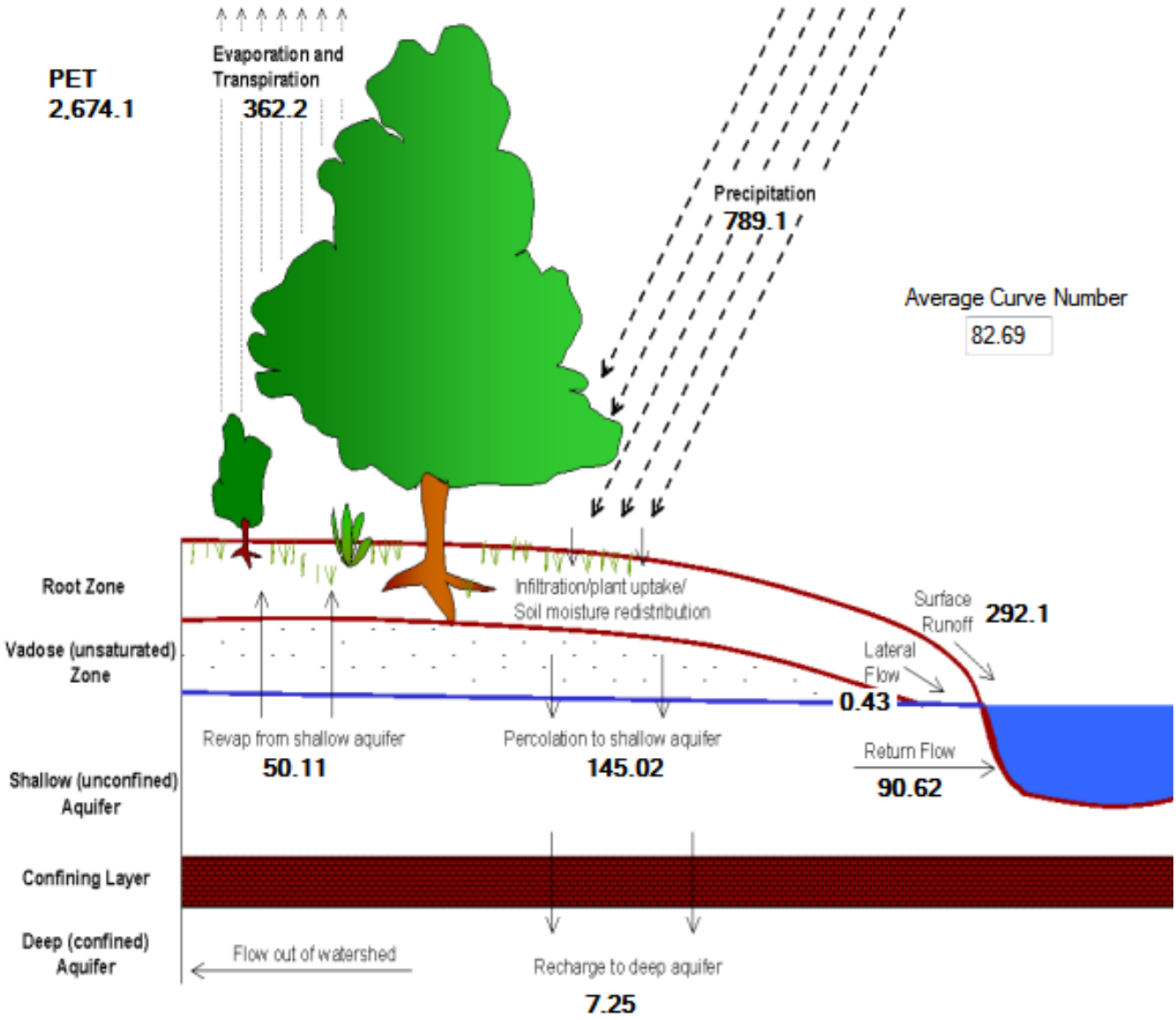


Figure 4.17: Simulation summary using year 2013 land use/cover map

xvi. Figure 4.18 shows the spatial soil characteristics of the sub-basin, obtained from the Harmonized World Digital Soil Data (2009), and processed in SWAT. Based on USDA soil taxonomy and validated with field data, it was revealed that the sub-basin has three principal types of soils; 'sandy to sandyloam' that occupied an area of 1555.3 km^2, sandy to loam with an area of 5163.2 km^2 and 'sandyloam to sandyclayloam' that occupied 8944.5 km^2 with the respective properties as follows:

i. Sandy soils are often dry, nutrient deficient and fast-draining. They have little (or no) ability to transport water from deeper layers through capillary transport. The nutrient and water-holding capacity of sandy soils can be improved through the condition of organic materials.

ii. Sandy loam soils are dominated by sand particles, but contain enough clay and sediment to provide some structure and fertility. Sandy loam soils are made up of approximately 60 percent sand, 10 percent clay and 30 percent silt particles capable of quickly draining excess water but cannot hold significant amounts of water or nutrients for plants use. Plants grown in this type of soil will require more frequent irrigation and fertilization, to support healthy plant growth than soils with a higher concentration of clay and sediment.

iii. Sandy clay loam contains 20 to 35 percent clay, less than 28 percent silt, and more than 45 percent sand. The soil erosion hazard is high in this soil type because of the poor surface soil structure. Poor management of these soils will decrease productivity, poor water and air infiltration and increase waterlogging and surface water run-off on a flat and sloping terrain. Therefore, proper soil management is required particularly for cropping i.e. reduced tillage, stubble retention and good crop husbandry (www.vro.agriculture.vic.gov.au).

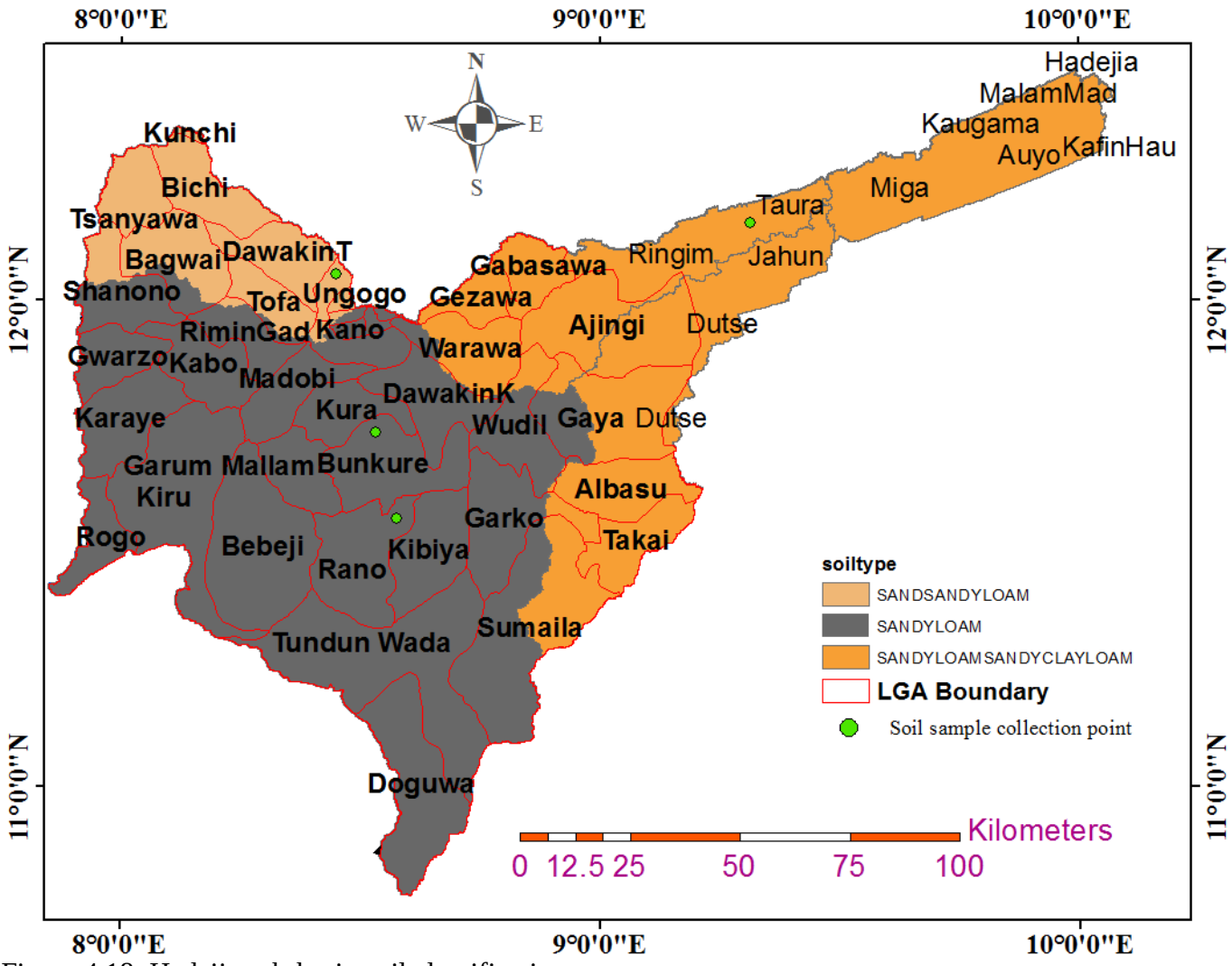


Figure 4.18: Hadeija sub-basin soil classification

xvii. The soil textural types revealed by the application of remote sensing imagery was validate against the field data collected. The point at which the sample was collected is as shows in Figure 4.18. Table 4.4 shows the result of validated and the ArcSWAT sub-basin soil textural reclassification. The field soil characteristics with respect to soil texture generated by the application of remote sensing and ArcGIS can accepted for any field work.

Table 4.4: Soil validation

S/No	LGA Soil sample ID	Particle size analysis corrected to 20°C % Clay	% Silts	% Sand	Field data analysis report	ArcGIS soil Reclassification
1	TAURA (20cm)	22	12	66	Sandy clay loam	'Sandy loam to
2	TAURA (50cm)	24	12	64	Sandy clay loam	Sandy clay loam'
3	Ungogo (20cm)	14	8	78	Sandy loam	'Sandy to Sandy
4	Ungogo (50cm)	14	10	76	Sandy loam	loam'
5	Bunkure (20cm)	12`	16	72	Sandy loam	'Sandy loam'
6	Bunkure (50cm)	12	10	78	Sandy loam	
7	Rano (20cm)	20	30	50	loam	'Sandy loam'
8	Rano (50cm)	20	30	50	loam	

xviii. The basin slope reflects the rate of change of elevation with respect to distance along the principal flow path. Figure 4.19 shows that the basin was mainly characterized by gentle slopes with expected characteristic of longer water residence time..

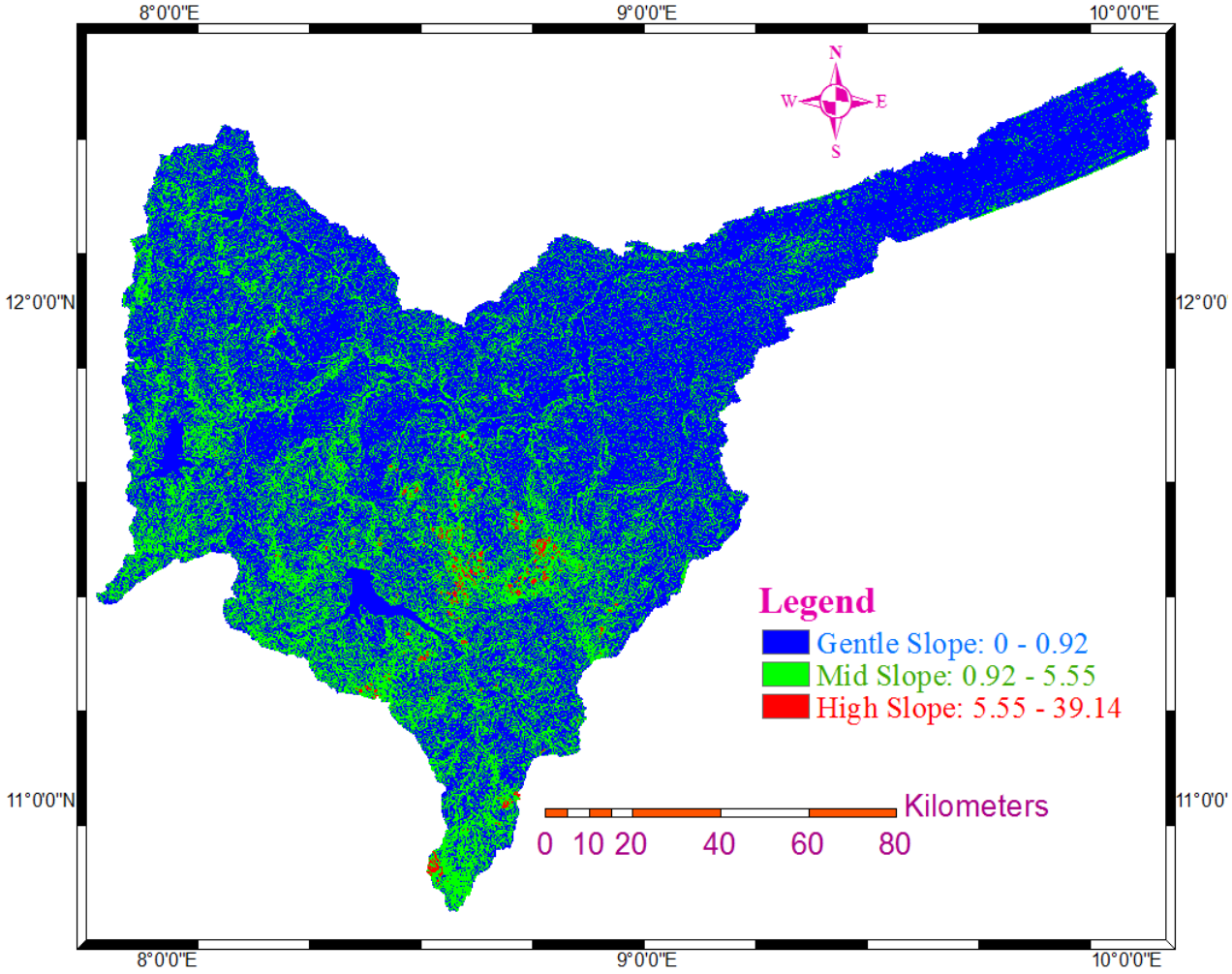


Figure 4.19: Basin slope

4.4 ESTIMATION OF THE SUB-BASIN ANNUAL MEAN OF LOSS DUE TO POTENTIAL EVAPOTRANSPIRATION, EVAPORATION LOSSES, WATER YIELD, GROUND WATER RECHARGE, LATERAL FLOW, SURFACE RUNOFF, AND SEDIMENT YIELD USING SWAT/GIS SOFTWARE.

xix. Water loss due to potential evapotranspiration (annual mean) in the sub-basin by applying the land use/cover maps of 1975, 2000 and 2013 shows no variations in each year (Figure 4.20). It can be deduced that the land use/cover dynamics of the sub- has not altered the losses due to potential evapotranspiration.

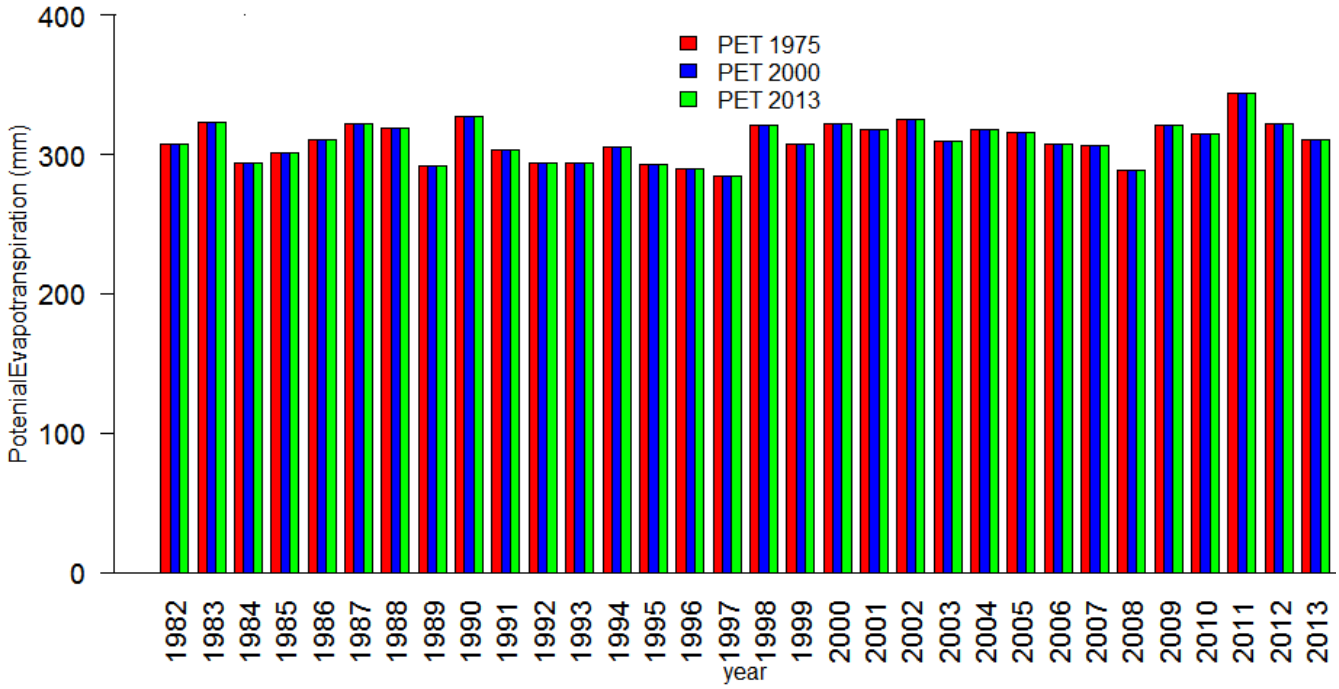


Figure 4.20: Potential evapotranspiration using 1975, 2000 and 2013 land use/cover

xx. Water loss due to potential evapotranspiration estimated using 2013 land use/change map (Figure 4.21), was observed to decreases from 1982 down 1993 then increases beyond 1994 till 2013 as revealed by the trend line. This claim is supported by the research carried out in the sub-basin by the World Bank in 2010; it was reported that the degradation of the sub-basin natural resources, the loss of its biodiversity and the consequent climate change

brought about by increase in temperature and potential evapotranspiration compound the water stress of in the basin.

The empirical Thornthwaite model was used to determine the potential evapotranspiration (PE) loss taking into account the land-use dynamics obtained from change detection using Landsat TM of 1986 and 2006 in the sub-basin. The study concluded that there is increases in potential evapotranspiration that may lead to water balance deficits for the different scenarios reveal a higher demand for soil replenishments. This will be an additional stress on the water resources of the Hadeija –Jama'are River Basin (H-JRB) and, if proper moisture management and adaptation strategies are not put in place, it may lead to serious water crises and probably environmental refugees (Shakirudeen et at., 2011).

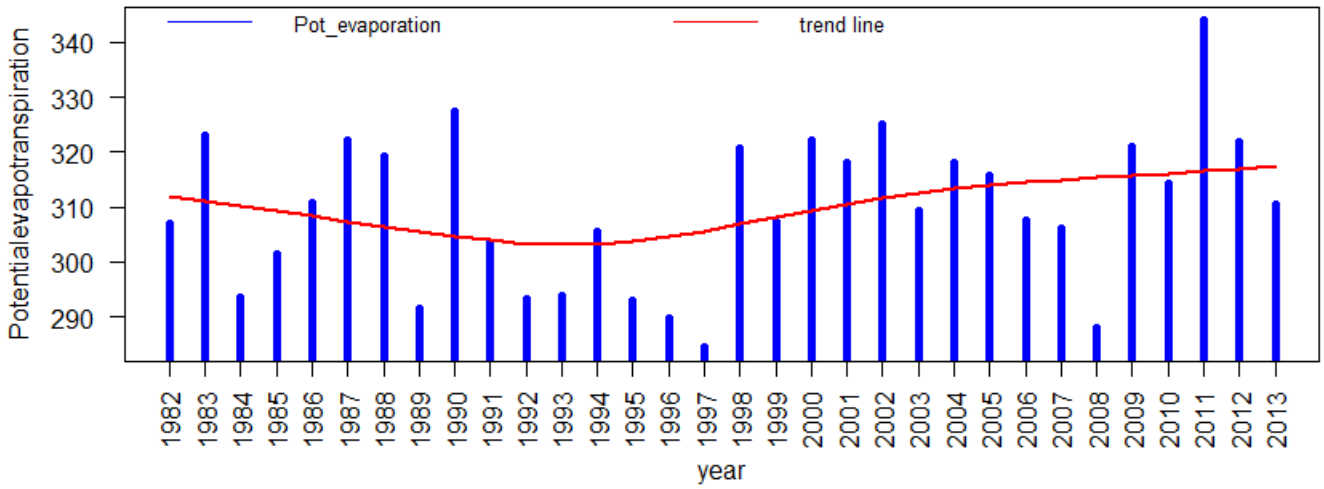


Figure 4.21: Trend in potential evapotranspiration

xxi. The difference in the basin losses due to evaporation estimated using land use/change dynamics was observed to be insignificant, but there seems to consistent trend in all the three land use dynamics (Figure 4.22).

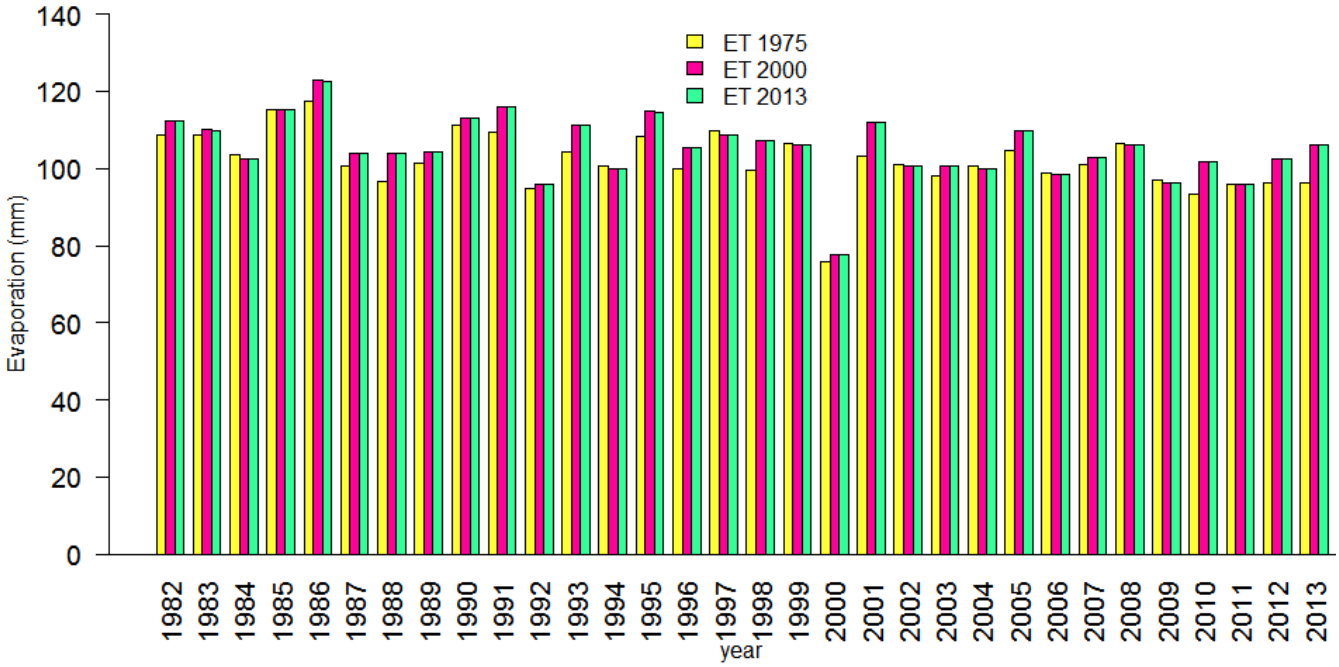


Figure 4.22: Evaporation obtained using 1975, 2000 and 2013 land use/cover

xxii. The trend line in Figure 4.23 shows that evaporation in the sub-basin is declining, probably due to shrinkage in the wetland noticed in the land use/change dynamics.

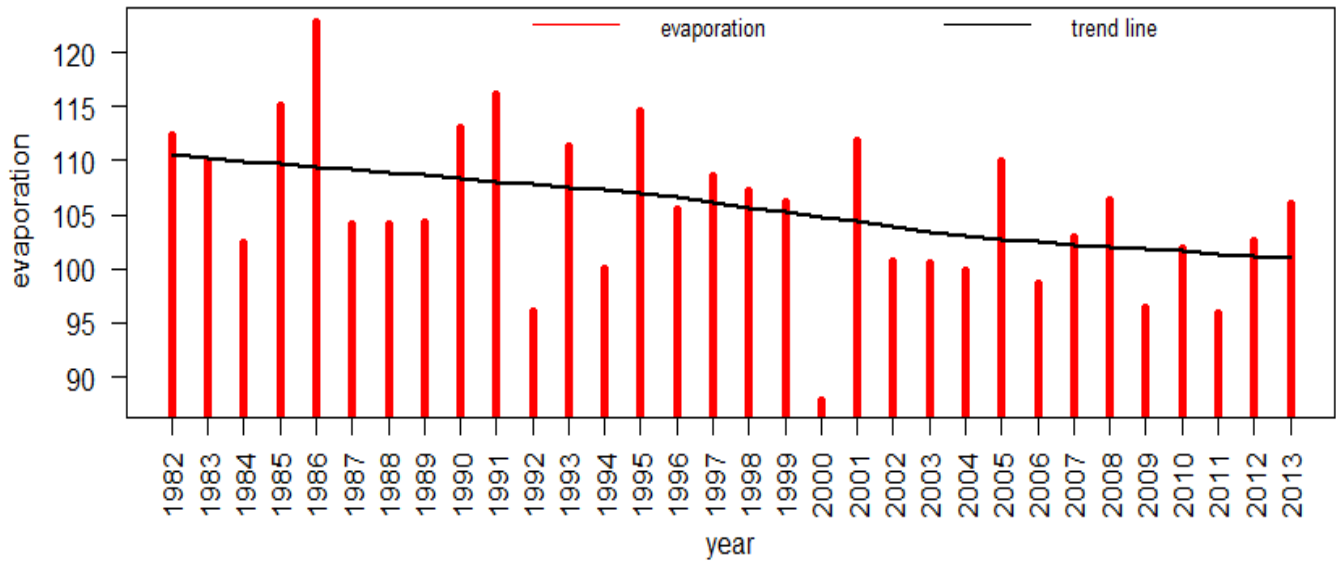


Figure 4.23: Trend in evaporation

Figure 4.24 shows the hot spots of evaporation in the sub-basin. Major losses were experienced around Tiga Dam followed by Challawa Gorge Dam. It revealed that

evaporation depend on the availability of water body location, like rainfall and temperature that shows a progressive increases (decreases) across the sub-basin.

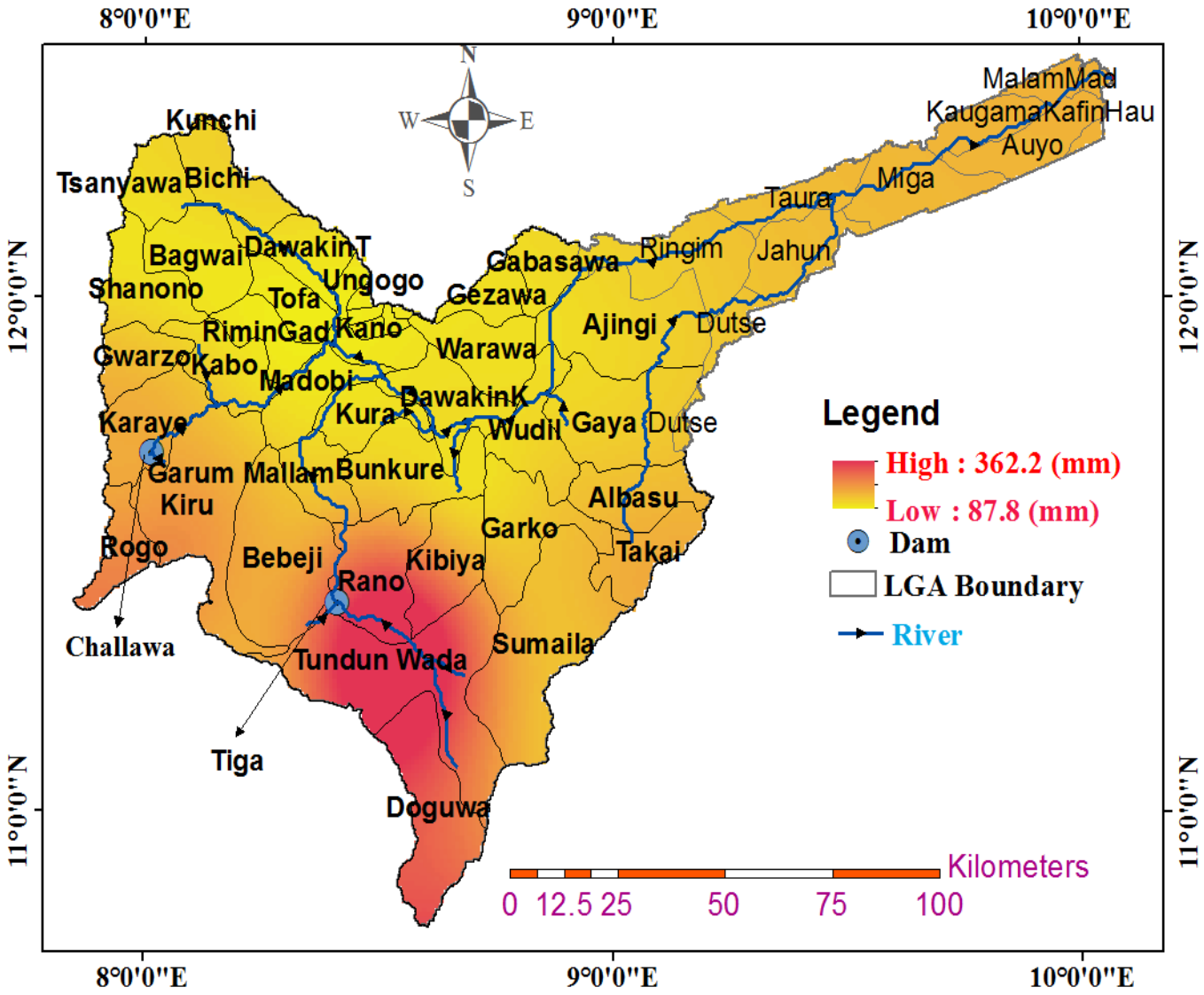


Figure 4.24: Spatial variation of losses due to evaporation

xxiii. There is no significant change in the land use/cover dynamics impacts on the Surface runoff estimated. Relatively low surface runoff was noticed in the year 1984, 2000 and 2004 (Figure 4.25).

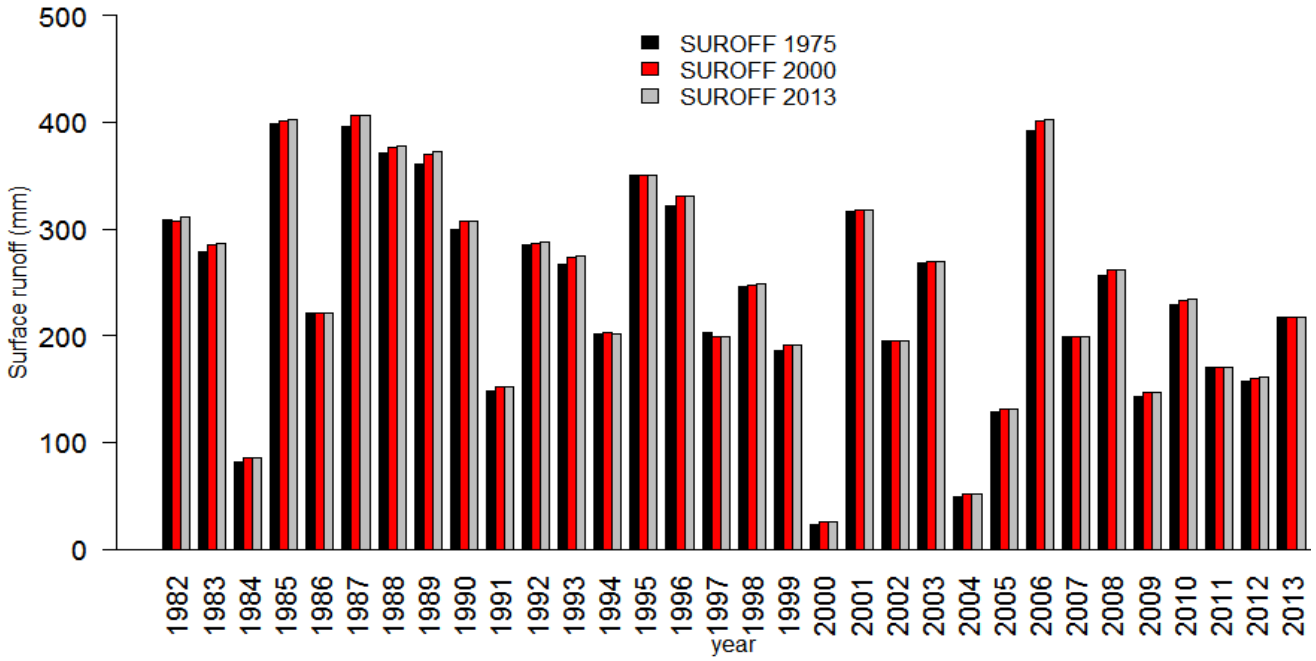


Figure 4.25: Surface runoff estimation using 1975, 2000 and 2013 land use/cover map

xxiv. The trend line (Figure 4.26) shows that the sub-basin surface runoff is decreasing.

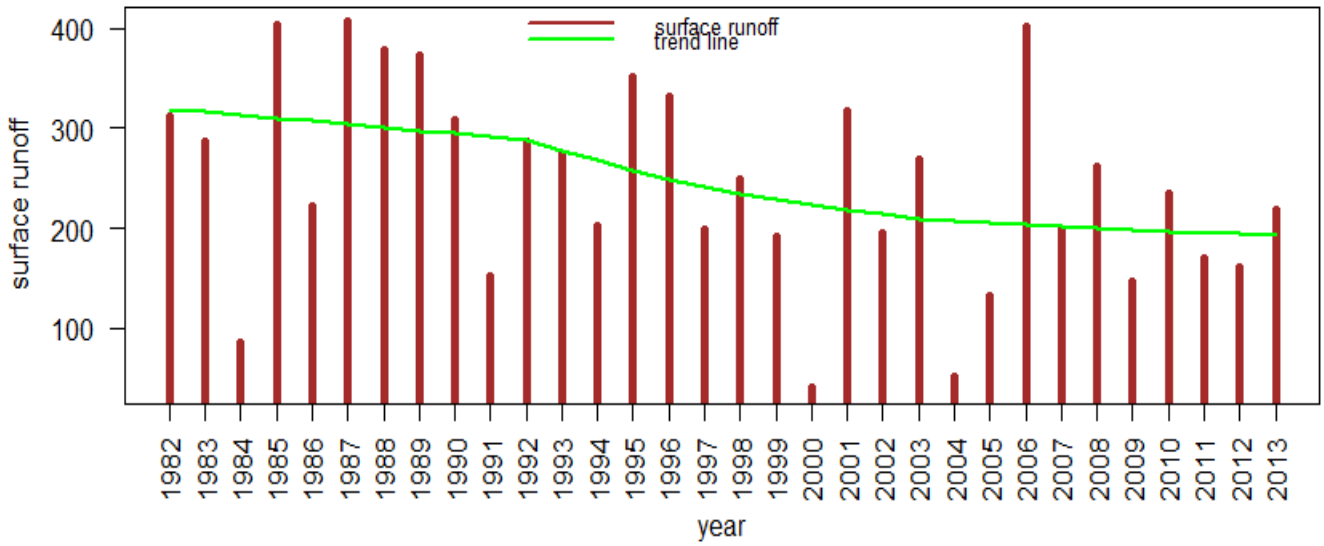


Figure 4.26: Trend in the sub-basin surface runoff

xxv. The rate of ground water recharge estimated using the land use/cover of 1975 was higher than the 2000 and 2013 land use/cover map (Figure 4.27). This could be attributed to less build up area captured by the land use/cover map of 1975.

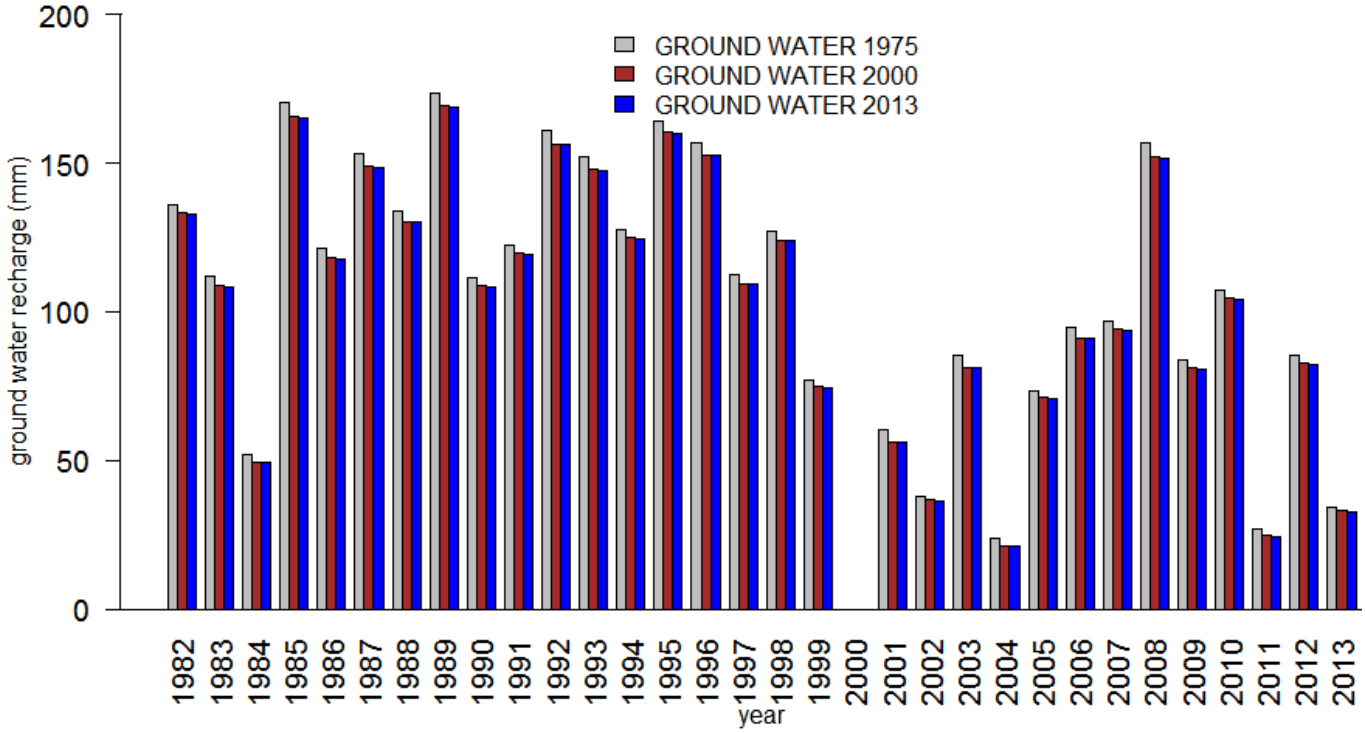


Figure 4.27: Ground water estimation using 1975, 2000 and 2013 land use/cover map

xxvi. The trend in the sub-basin ground water recharge shows decreases in the amount of recharge over the period analyzed (Figure 4.28). This agrees with findings of IUCN and HNWCP, (1999) that there is a reduction in the area inundated, a decline in the groundwater tables and a general shortage of water in Hadeija sub-basin.

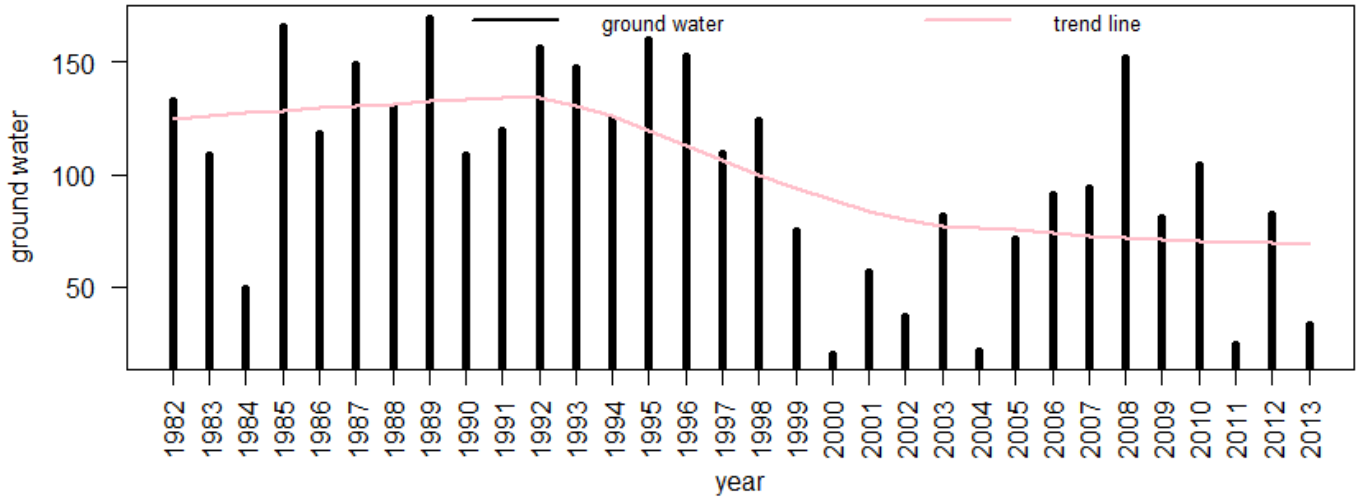


Figure 4.28: The trend in the sub-basin ground water recharges

xxvii. The amount of basin water yield using the three land use/cover maps show no changes in terms of water balance of the sub-basin. Land use/cover dynamics has no much significant impacts on the available water balance of the sub-basin (Figure 4.29)

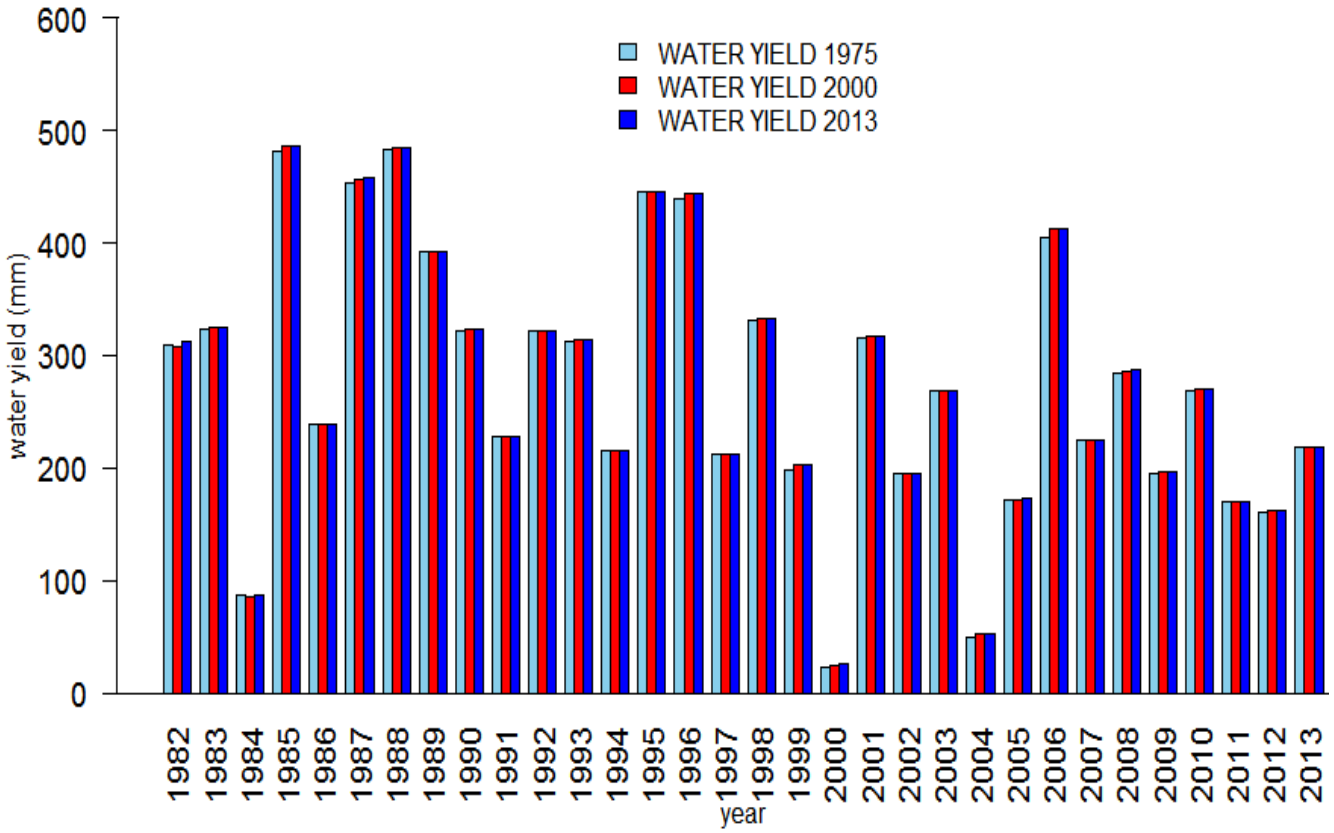


Figure 4.29: Water yield estimation using 1975, 2000 and 2013 land use/cover map

xxviii. The trend line shows that the basin water yield is declining as shows in Figure 4.30. SWAT model was applied to H-JRB (Hadeija-Jama'are River Basin) to determine its water resources potential per capita, it was estimated at 376 m^3 for 2010 and projected to decrease to 232 m^3 by year 2030 (Japan International Cooperation Agency, et al., 2014).

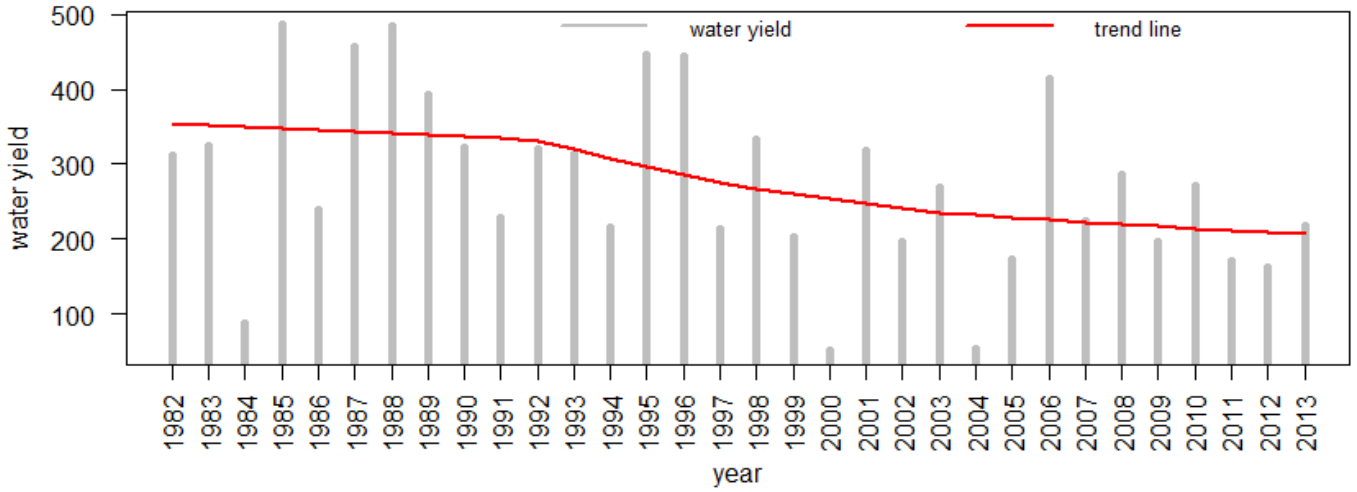


Figure 4.30: Water yield estimation trend

xxix. The sediment yield estimated using land use/cover of 2013 was significantly lower than the estimation obtained for 1975 and 2000 land use/cover (Figure 4.31).

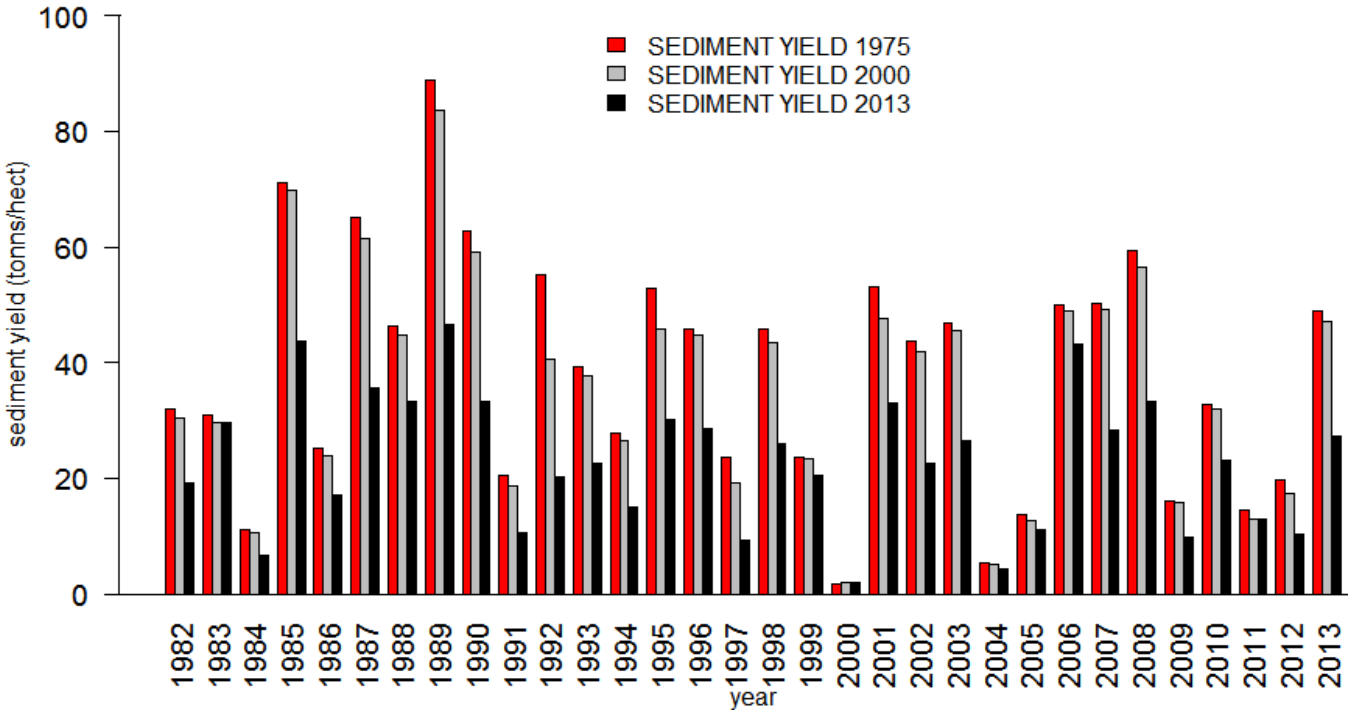


Figure 4.31: Sediment yield estimation using 1975, 2000 and 2013 land use/cover map

xxx. Though agricultural land has increased, sediment production in the basin is declining as revealed by the trend line as shows in Figure 4.32

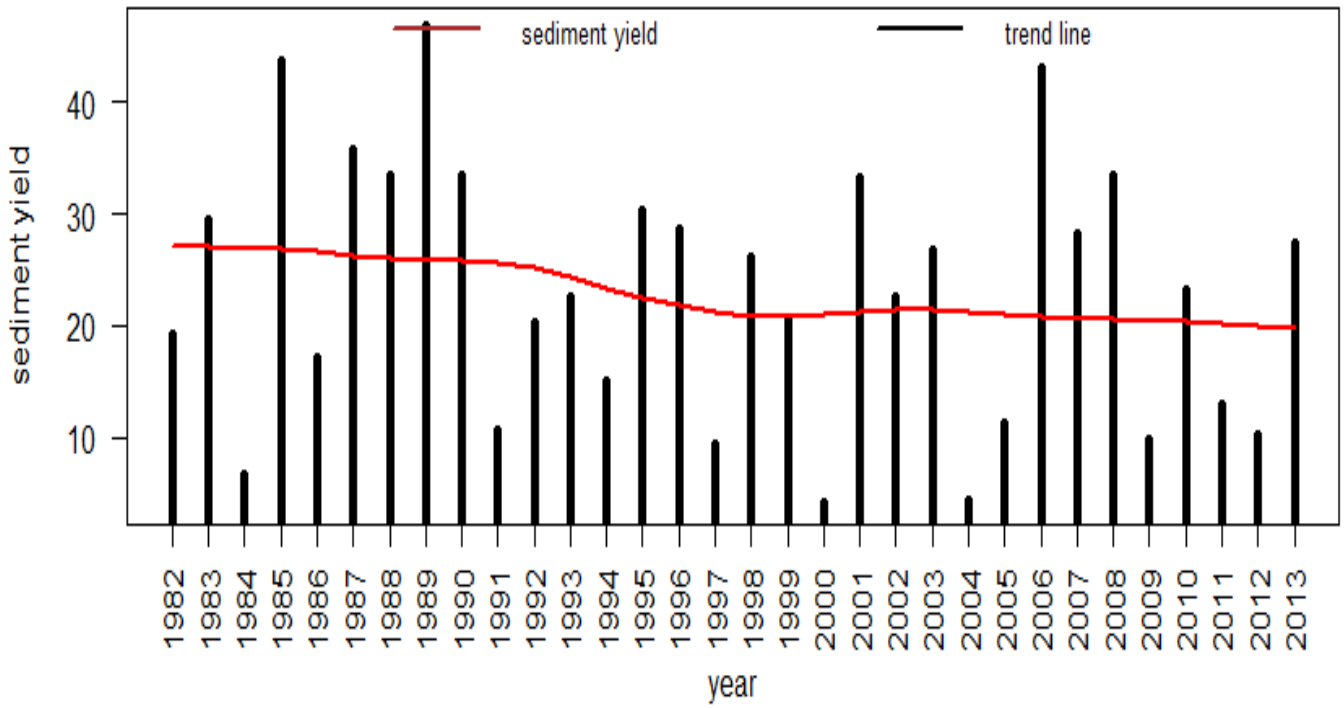


Figure 4.32: trend in sediment production

Figure (4.33) revealed the hot spot where sedimentation is likely to be produced in basin delineated with respect to local government area. The spatial variation provides a means of on-site protection of the basin from sedimentation threat. It can be seen that Dawakin, Ungogo, Garko, Kibiya and Karaye Local Government Area are highly prone to sedimentation yield.

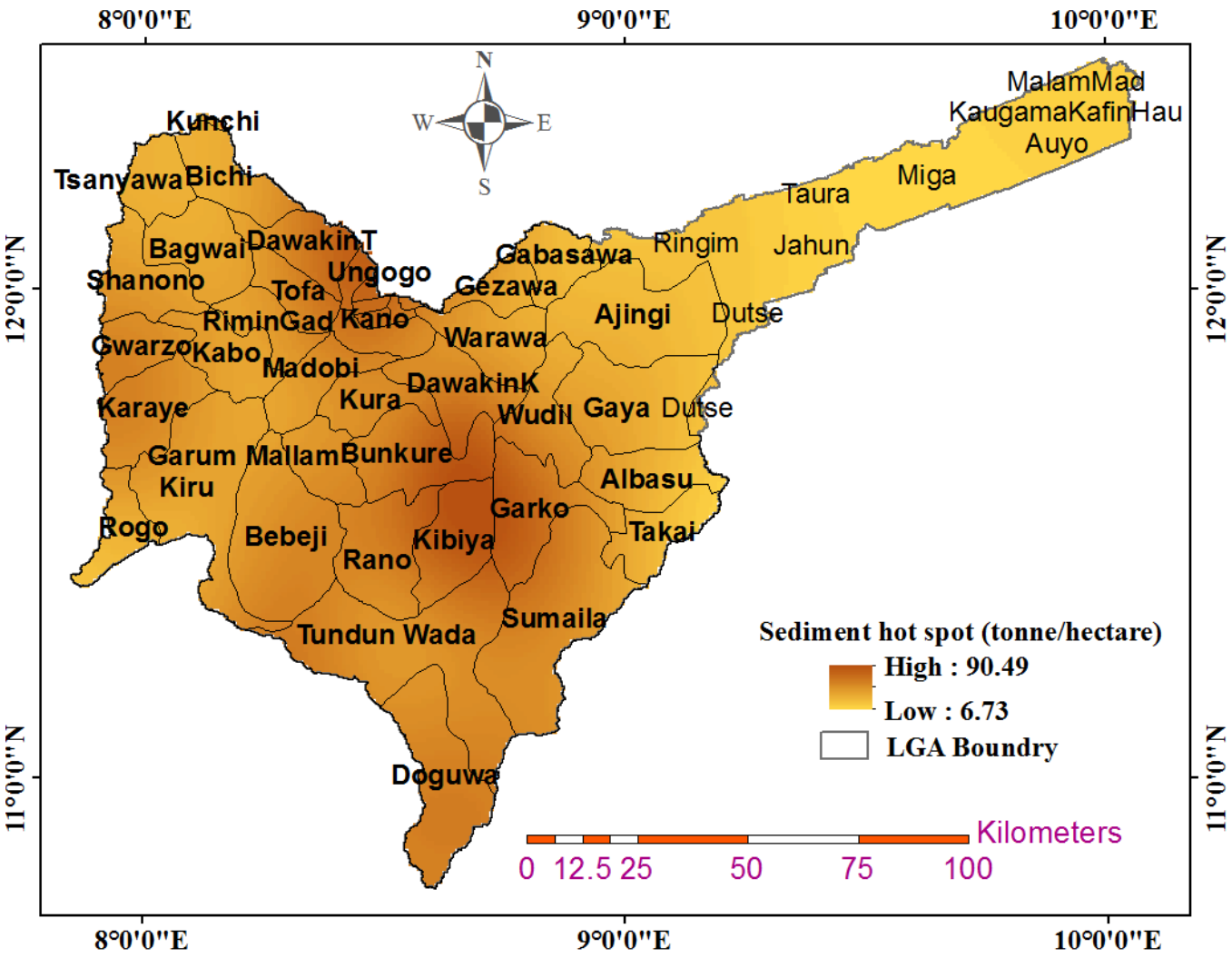


Figure 4.33: Spatial variation of the sub-basin sedimentation

xxxi. Figure 4.34 shows that the estimated lateral flows was highest in 1975, followed by 2000 then 2013 land use/cover map. Though, in some years they were estimated to be equal.

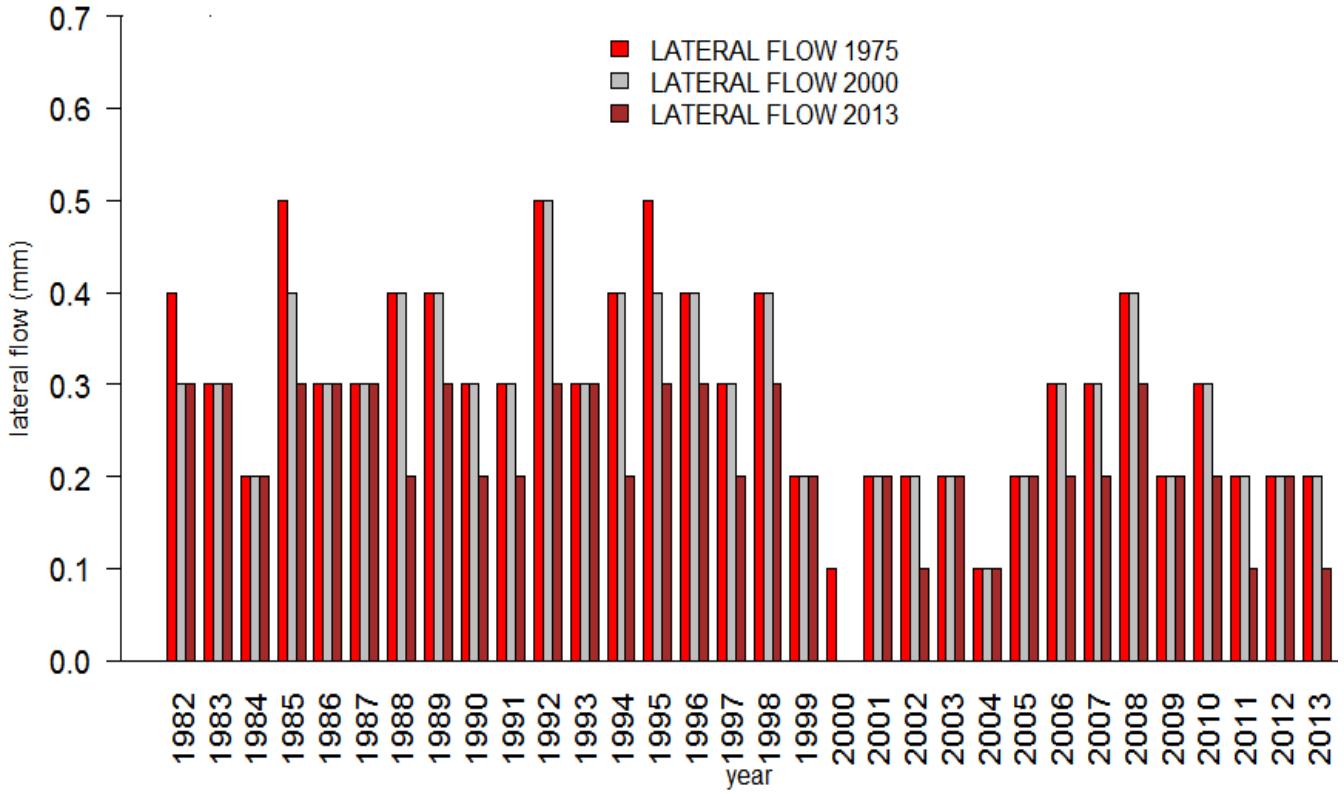


Figure 4.34: Lateral flow estimation using 1975, 2000 and 2013 land use/cover map

xxxii. There was a continuous decrease in the basin lateral flow as shows in Figure 4.35

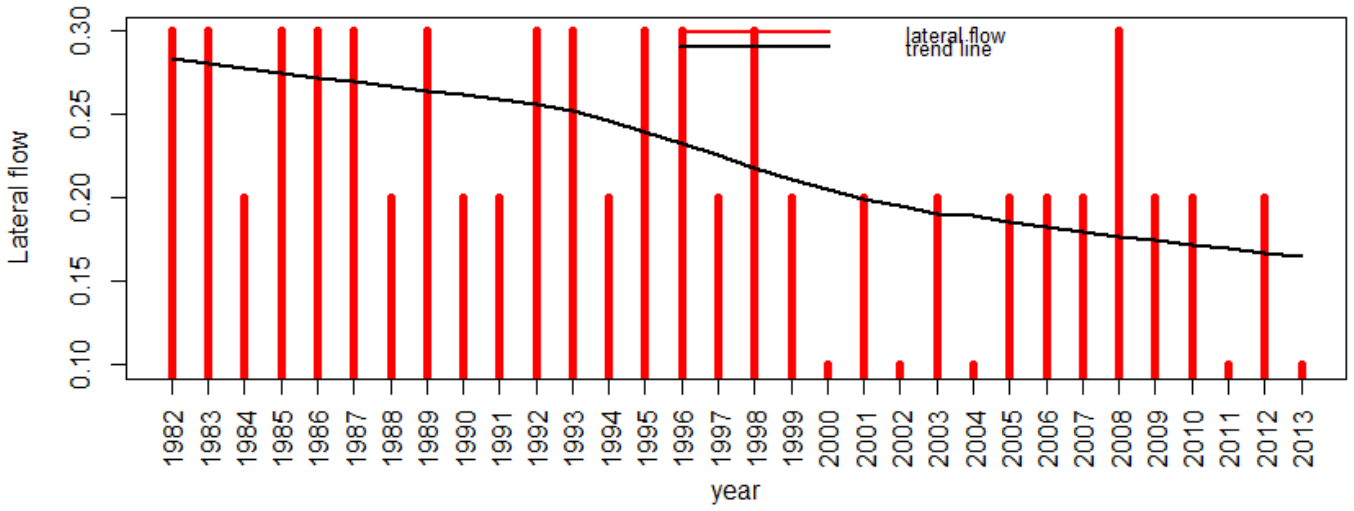


Figure 4.35: Trend in lateral flow estimation

Figure 4.36 shows the water balance in each year, it revealed the mean annual rainfall in sub-basin was around 800mm. According to Murtala et al., (2015), he reported that the mean annual rainfall of the Hadeija Sub-basin is 897.7 mm, and maximum and minimum values are 1,872 mm and 419.6 mm respectively.

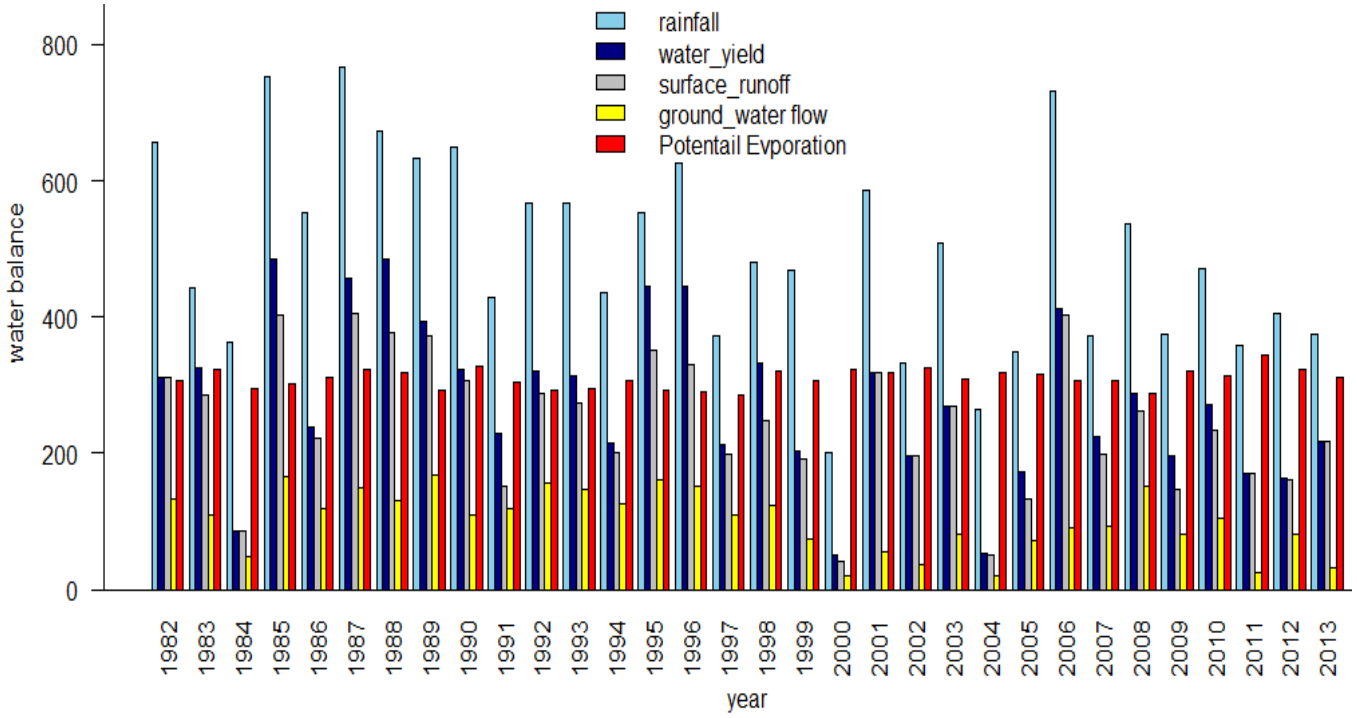


Figure 4.36: Water balance

Table 4.5 shows the estimated hydrologic parameters using the three land use/cover maps of the sub-basin. It can deduce that the land use/cover dynamics of the sub-basin has not significantly impacted on the hydrologic parameters of the basin.

Table 4.5: The estimated hydrologic parameters land use/cover dynamics.

S/No	Variable (mm)	1975	2000	2013
1	Potential evapotranspiration	343.9	343.9	343.9
2	evaporation	117.6	122.8	122.7
3	Surface runoff	399.0	405.8	405.8
4	Ground water recharge	173.6	169.4	169.0
5	Water yield	482.4	486.1	486.1
6	Sediment yield	88.8	83.6	76.7
7	Lateral flow	0.5	0.5	0.3

4.5 DETERMINATION OF THE TREND IN THE FIELD TEMPERATURE AND RAINFALL TIME SERIES DATA SETS

4.5.1 Temperature Monthly Distribution

Figure 4.37 emphasizes the seasonal patterns in the maximum monthly temperature time series, the horizontal short lines indicate the mean for each month. The plot reveals the changes in seasonality over time. It was revealed that the peak temperature in the sub-basin is in the month of April with it trough in the month of August.

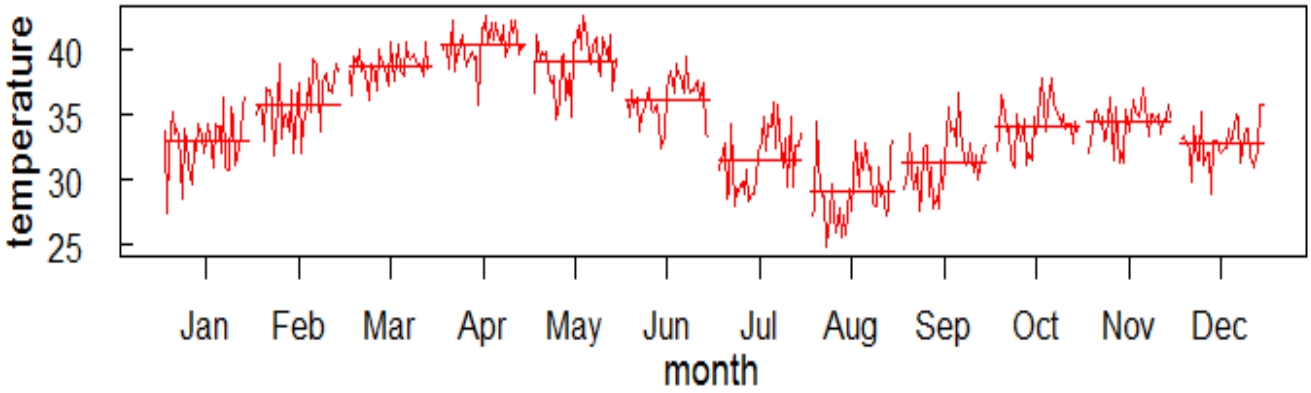


Figure 4.37: Monthly temperature seasonal pattern

4.5.2 Annual Mean Temperature from 1982 to 2015

Figure 4.38 shows the sub-basin responses to 34 years annual mean temperature; it was revealed by the trend line that there have been increases in the sub-basin temperature. This agree with the findings of Murtala et al., (2015), that all temperature indices are pointing a general warming trend since 1960 from the analysis of the century meteorological records (1914 to 2013) obtained from Malam Aminu Kano International Airport (MAKIA) Meteorological Station.

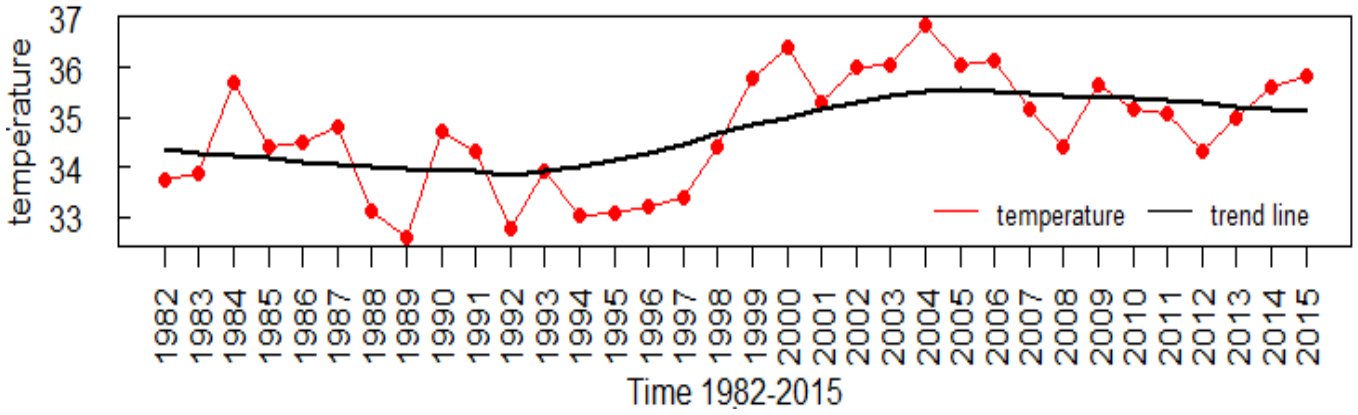


Figure 4.38: Annual average temperature: 1982-2015

The Mann Kendall and Sen's Slope Z value of 2.609 above the Z critical value of 2.5 at 95 percent confidence interval between 0.0180 and 0.099 (Table 4.5), obtained for the sub-basin mean temperature nonparametric test, suggest that the increases in basin temperature revealed by the trend line is significant. The P value of 0.009 that is less than 0.05 shows that the trend in mean temperature is monotonic and the positive value of τ (3.016) show that the increases in the trend is strong.

The Sen's slope of 0.058 is the rate of the increases in the temperature trend across the years.

The Pettitt test of p value 0.0002 less than 0.05 suggested that there was a change point in mean temperature data set denoted by K value of 17, which shows that from the mean annual temperature of 34 data points (1982 to 2015), the probable change point is at the 17th data point that correspond to 1998.

Table 4.6: Temperature nonparametric regression test statistic

S/No	Nonparametric test	Z	p_value	S	variance	tau (τ)	K	Sen's slope
1	Mann Kendall	2.609	0.009	177	4550	0.316	-	-
2	Sen's Slope	2.609	0.009	-	-	-	-	0.058
3	Pettitt test	-	0.0002	-	-	-	17	-

4.5.3 Temperature Line Plot

Figure 4.39 shows the annual variation in temperature plot with respect to the mean annaual temperature indicated by the dotted line. It was revealed that the sub-basin temperature has been rising since 1998 as already shows by the Pettitt test in Table 4.6 above.

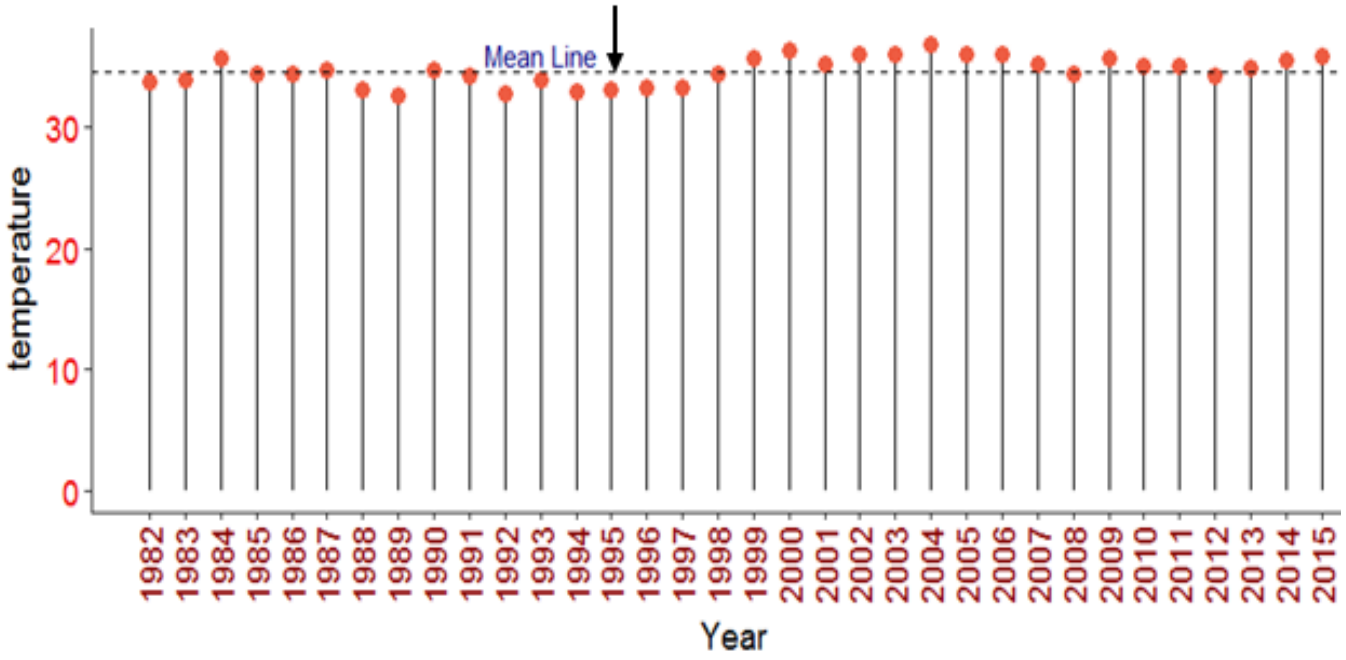


Figure 4.39: Mean temperature line plot

4.5.4 Mean Temperature Matrix Plot

The mean temperature variation with respect to month and year can be deduces from the matrix plot at easy. Figure 4.40 shows that high temperature is always observed in the months of March, April and May while July, August and September have relatively low temperature. August 1988 was when the sub-basin witnesses a very low average temperature shows by the dark green colour.

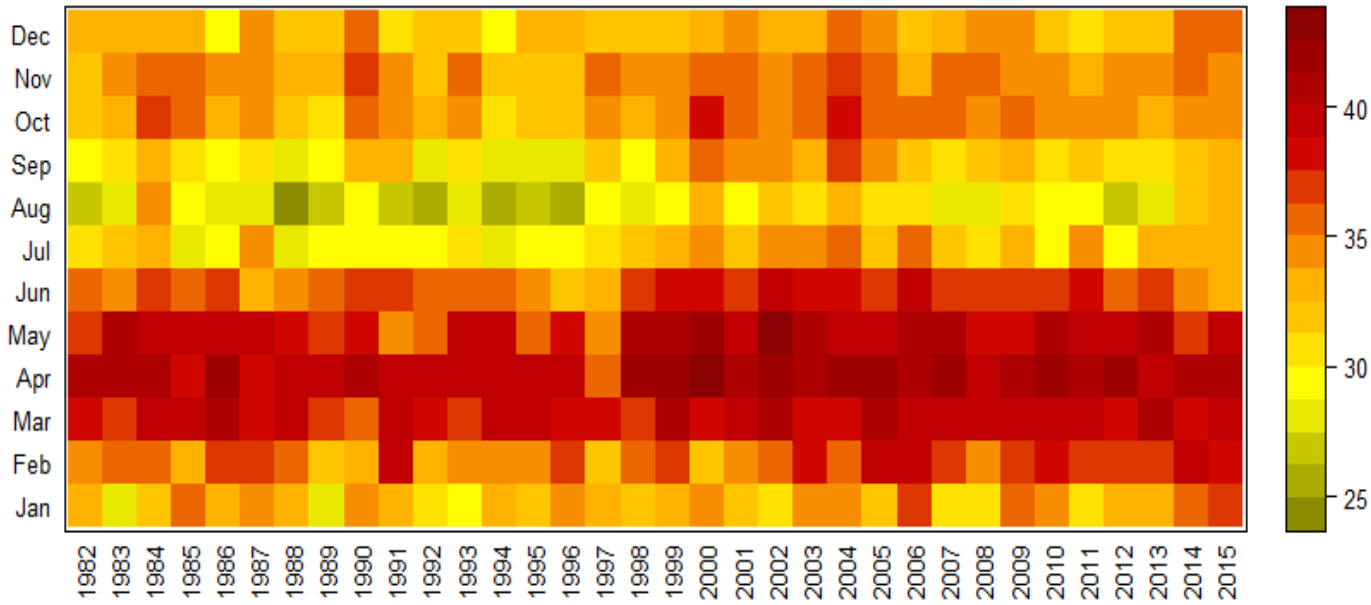


Figure 4.40: Temperature matrix plot

4.5.5 Spatial Variation of Temperature over the Hadejia Sub-basin

Figure 4.41 shows the spatial temperature increases in the range of 33.7°C to 38.5°C from south to the north and increases form western to eastern parts of the sub-basin.

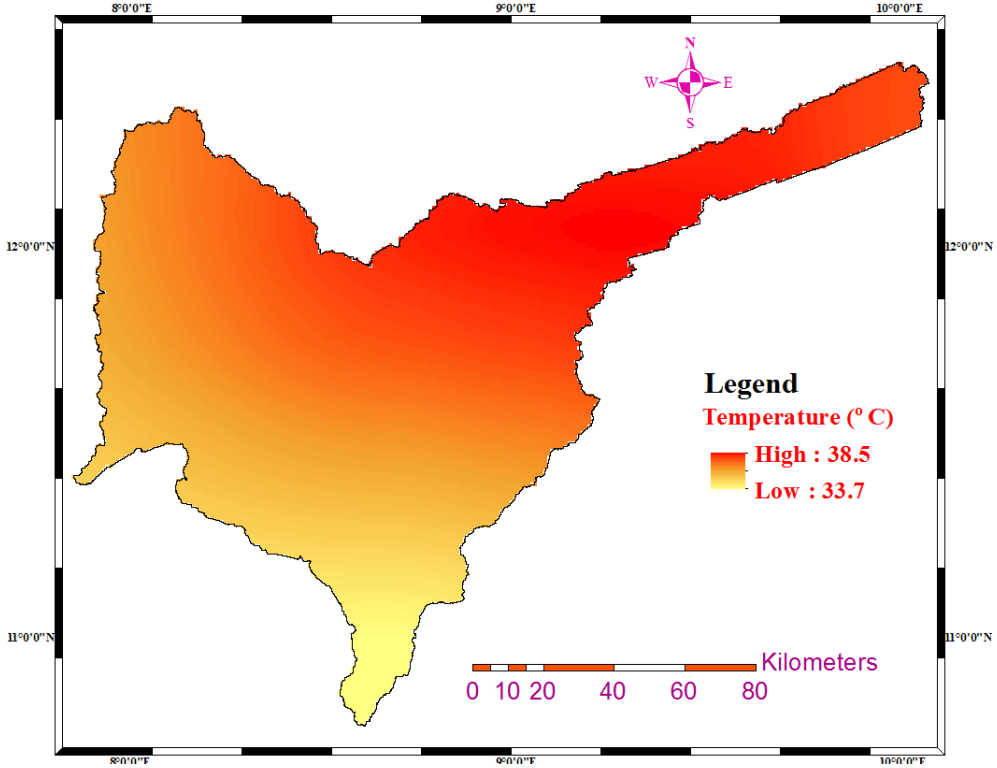


Figure 4.41: Temperature spatial variation

4.5.6 Rainfall Monthly Mean Distribution

The plot in Figure 4.42 reveals the underlying seasonal pattern in the sub-basin total monthly rainfall distribution from 1982 to 2015; the horizontal short lines indicate the mean for each month. It shows that the peak of the rainfall is in the month of August, while the months of November, December, January, February and March usually witness dryness and rainfall picks in April. This agrees with the findings of Murtala, et.al. (2015) from a century rainfall records (1914 to 2013) obtained from Malam Aminu Kano International Airport (MAKIA) Meteorological Station. The data contained monthly rainfall records, which were used in calculating the mean monthly and annual rainfall for the station. He found out that that the wettest month of the year is August that have the least variability while the November, December, January, February and March form the dry periods.

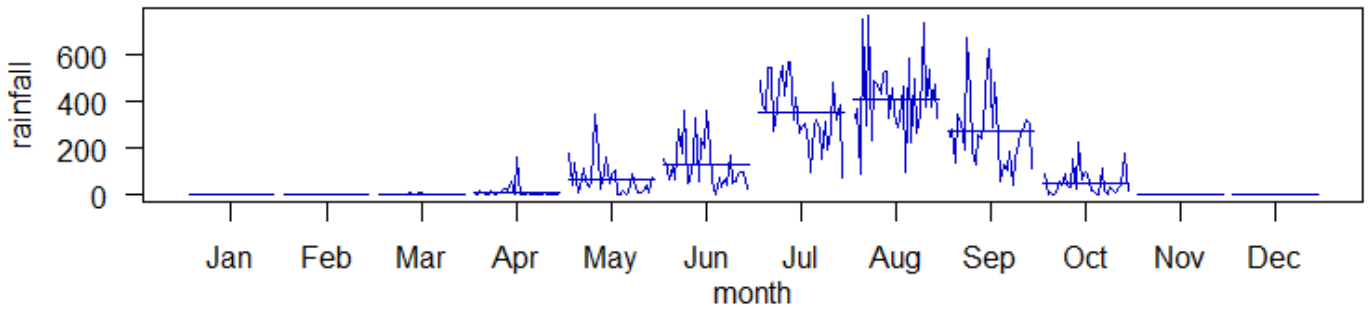


Figure 4.42: Monthly seasonal rainfall pattern

The maximum of the mean monthly rainfall for each year show increases trend as revealed by Figure 4.43. The nonparametric statistics inherent in the maximum of the mean monthly distribution is given in Table 4.7 below. The trend line show improvement in rainfall on average in the study area.

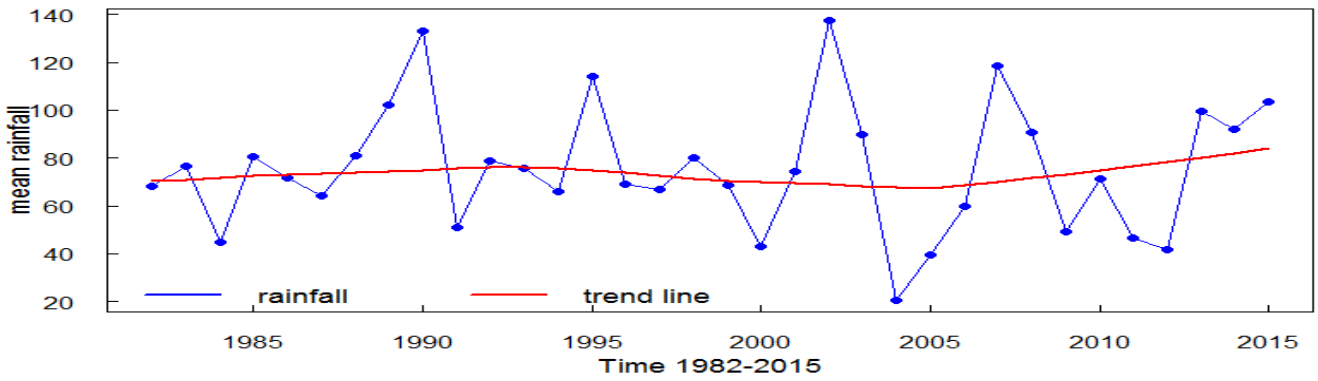


Figure 4.43: Maximum of the mean monthly seasonal rainfall pattern

The Z value of 0.0296 below the Z critical value of 2.5 at 95 percent in the Mann Kendall and Sen's Slope nonparametric test suggested that the increases in the sub-basin mean monthly rainfall is not significant (Table 4.7). The P value of 0.976 that is greater than 0.05 shows that the trend in mean rainfall is not monotonic and the positive value of τ (0.005) show that the increases in the trend is weak type. The Sen's slope of 0.0538 is the rate of the increases in the rainfall trend across the years.

The Pettitt test of p value of 1.069 greater than 0.05 suggested that there was a change point in mean rainfall data set and it occurred towards end of the data points. The K value of 31 shows that from the mean rainfall of 34 data points (1982 to 2015), the probable change point is at the 31st data point that correspond to 2012 present in Figure 4.36 above.

Table 4.7: Rainfall nonparametric regression test statistic

S/No	Nonparametric test	Z	p_value	S	variance	tau (τ)	K	Sen's slope
1	Mann Kendall	0.0296	0.976	3	4550.333	0.005	-	-
2	Sen's Slope	0,0296	0.976	-	-	-	-	0.0538
3	Pettitt test	-	1.069	-	-	-	31	-

4.5.7 Rainfall Area Plot

The area plot in Figure 4.44 was used to represent the maximum of the mean monthly rainfall from 1982 to 2015 over the sub-basin. It clearly revealed the fluctuations in mean monthly rainfall across the year in the sub-basin.

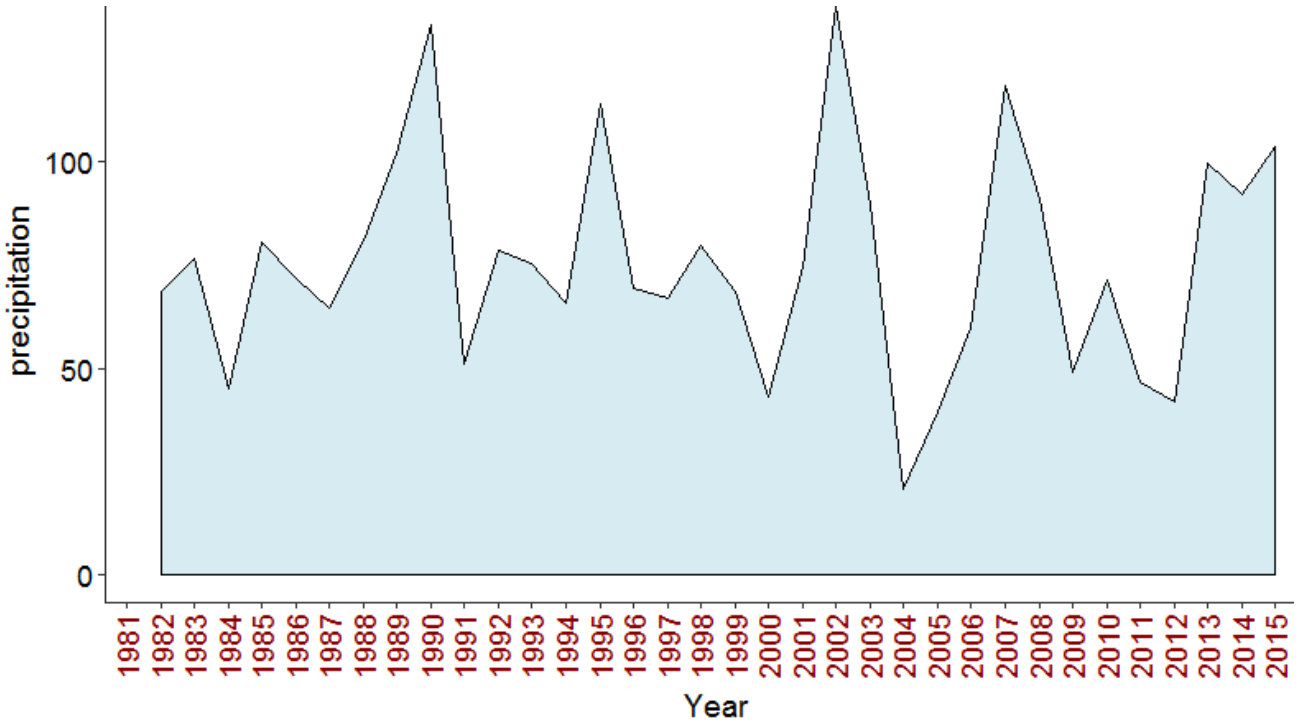


Figure 4.44: Rainfall area plot (1982-2015)

4.5.8 Rainfall Matrix Plot

Figure 4.45 shows the matrix time series plot that summarizes the relationships between the monthly and yearly mean rainfall from 1982 to 2015 pinpointing specific months and year that might have similar correlations.

The plot shows that the month of July in 1990 and 2002, August 1989, 2003 and 2007 had good rainfall. 1984 and 2004 were dried year all though the months. It was also revealed that the months of November, December, January and February are always dried months while there may be little rainfall in months of March and April.

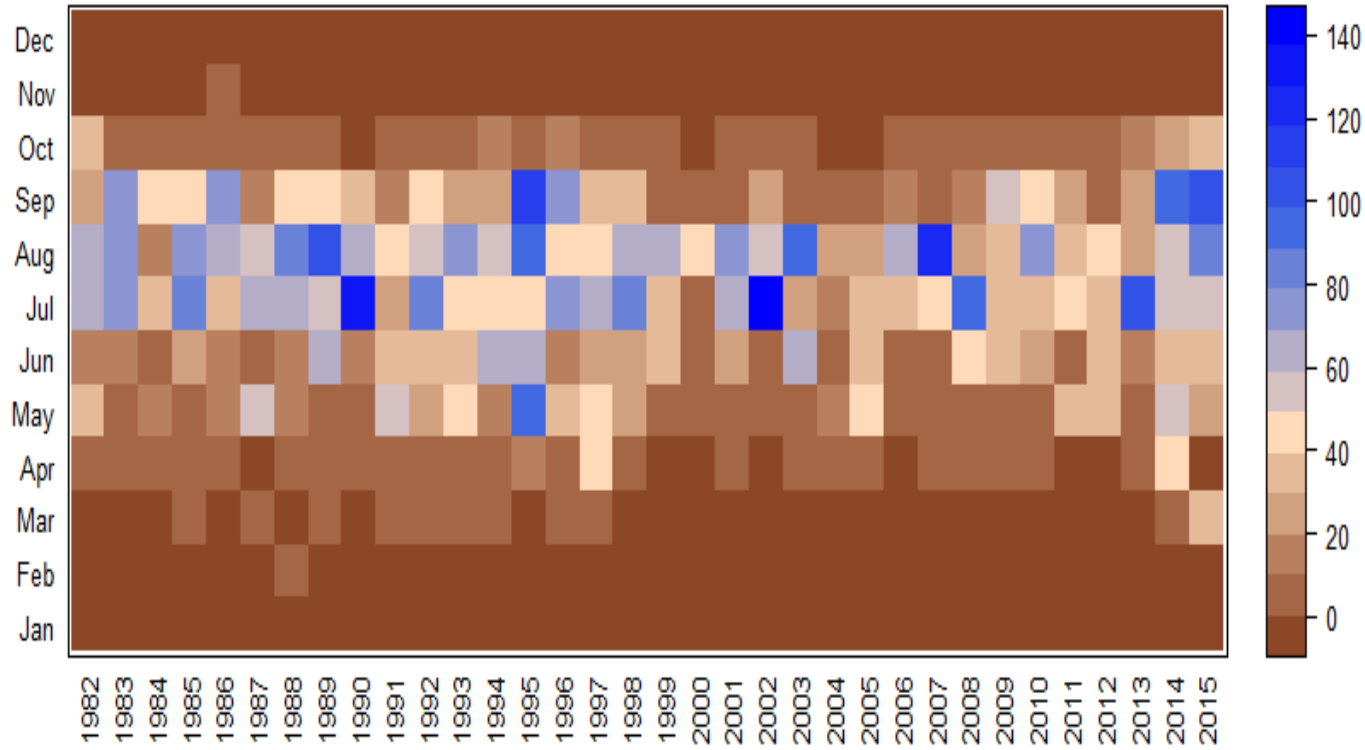


Figure 4.45: Rainfall Matrix plot

4.5.9 Spatial Variation of Precipitation over the Sub-basin

Figure 4.46 presents the spatial variation of rainfall across the sub-basin; it was revealed that the total annual rainfall decreases in the range of 1,633.4mm to 657.0mm from southern to the northern and reduces form western to eastern part of the sub-basin. The spatial reduction of rainfall across the sub-basin agrees with the previous studies carried out by Adefolalu, (1986); Bello, (1998); and Oguntunde *et al*, (2011) that there exist spatial variation of rainfall across the sub-basin form southern to northern and from western to eastern part of the sub-basin in increasing order.

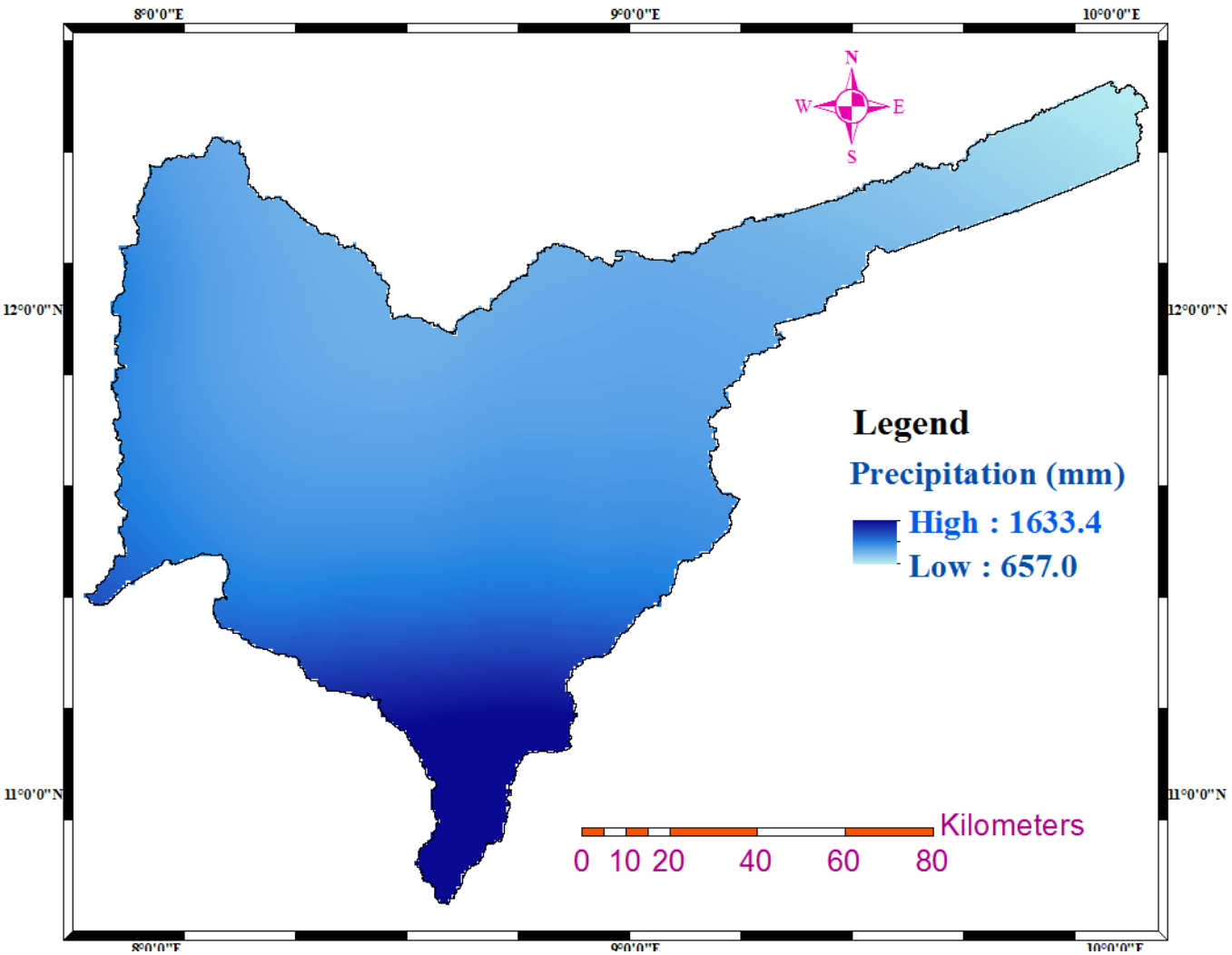


Figure 4.46: Precipitation spatial variation

4.6 DETERMINATION OF THE PREDICTIVE MODEL OF THE SUB-BASIN FIELD TEMPERATURE AND PRECIPITATION TIME SERIES

4.6.1 Predictive Model of the Sub-Basin Field Temperature Data

By the application of auto.arima with respect to the minimum AIC, the best arima model obtained for the seasonal prediction of the sub-basin temperature was ARIMA (3,1,3)(2,0,1)[12], below are the several arima model generated with it corresponding AICs.

```
>arima1=auto.arima(data.train,trace=TRUE,test="kpss",ic="aic")
 Fitting models using approximations to speed things up...

ARIMA Model Selection                    AIC
 ARIMA(2,1,2)(1,0,1)[12] with drift      : Inf
 ARIMA(0,1,0)          with drift        : 1971.858
 ARIMA(1,1,0)(1,0,0)[12] with drift      : 1675.973
 ARIMA(0,1,1)(0,0,1)[12] with drift      : 1864.95
 ARIMA(0,1,0)                            : 1965.911
 ARIMA(1,1,0)          with drift        : 1959.005
 ARIMA(1,1,0)(2,0,0)[12] with drift      : Inf
 ARIMA(1,1,0)(1,0,1)[12] with drift      : Inf
 ARIMA(1,1,0)(2,0,1)[12] with drift      : Inf
 ARIMA(0,1,0)(1,0,0)[12] with drift      : 1737.009
 ARIMA(2,1,0)(1,0,0)[12] with drift      : 1677.081
 ARIMA(1,1,1)(1,0,0)[12] with drift      : Inf
 ARIMA(2,1,1)(1,0,0)[12] with drift      : 1631.047
 ARIMA(2,1,1)(1,0,0)[12]                 : 1625.602
 ARIMA(2,1,1)                            : 1834.236
 ARIMA(2,1,1)(2,0,0)[12]                 : Inf
 ARIMA(2,1,1)(1,0,1)[12]                 : Inf
 ARIMA(2,1,1)(2,0,1)[12]                 : Inf
 ARIMA(1,1,1)(1,0,0)[12]                 : 1624.951
 ARIMA(1,1,0)(1,0,0)[12]                 : 1670.031
 ARIMA(1,1,2)(1,0,0)[12]                 : 1624.49
 ARIMA(0,1,1)(1,0,0)[12]                 : 1651.659
 ARIMA(2,1,3)(1,0,0)[12]                 : 1619.856
 ARIMA(2,1,3)(1,0,0)[12] with drift      : 1625.503
 ARIMA(2,1,3)                            : 1818.897
 ARIMA(2,1,3)(2,0,0)[12]                 : Inf
 ARIMA(2,1,3)(1,0,1)[12]                 : Inf
 ARIMA(2,1,3)(2,0,1)[12]                 : Inf
 ARIMA(1,1,3)(1,0,0)[12]                 : Inf
 ARIMA(3,1,3)(1,0,0)[12]                 : 1609.367
 ARIMA(3,1,2)(1,0,0)[12]                 : Inf
```

ARIMA(3,1,4)(1,0,0)[12] : Inf
ARIMA(2,1,2)(1,0,0)[12] : 1630.266
ARIMA(4,1,4)(1,0,0)[12] : Inf
ARIMA(3,1,3)(1,0,0)[12] with drift : 1614.874
ARIMA(3,1,3) : 1821.341
ARIMA(3,1,3)(2,0,0)[12 : Inf
ARIMA(3,1,3)(1,0,1)[12] : Inf
ARIMA(3,1,3)(2,0,1)[12] : 1601.001
ARIMA(4,1,3)(1,0,0)[12] : 1615.103

Best model: ARIMA(3,1,3)(2,0,1)[12], aic=1601.001

The arima forecast plot in Figure 4.47 shows the training data in black and the forecast in blue. It shows that the forecast exhibits seasonal characteristic inherent in the training data.

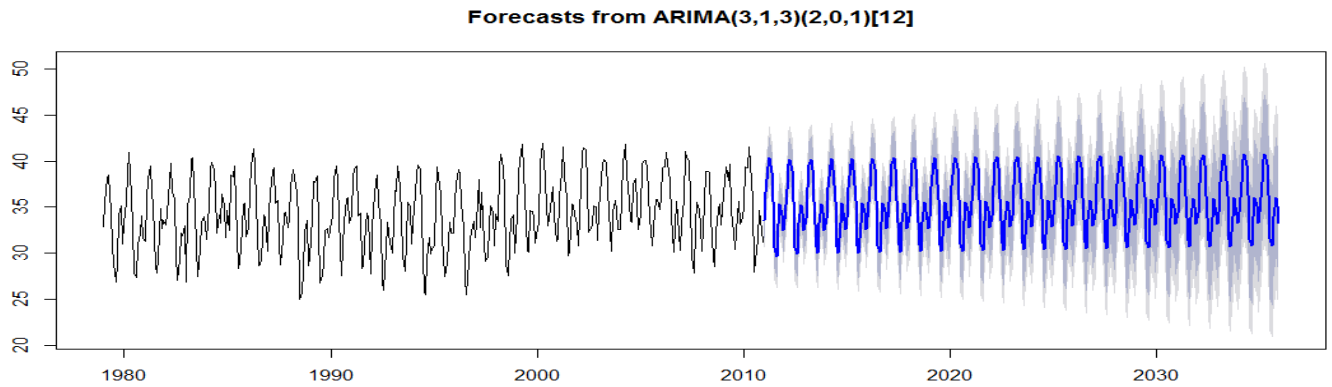


Figure 4.47: The ARIMA temperature forecast plot

The plot of the training data residual Figure 4.48 obtained by subtracting the predicted values from the actual value provides the means of testing the arima.model selection by the use of ACF and PACF.

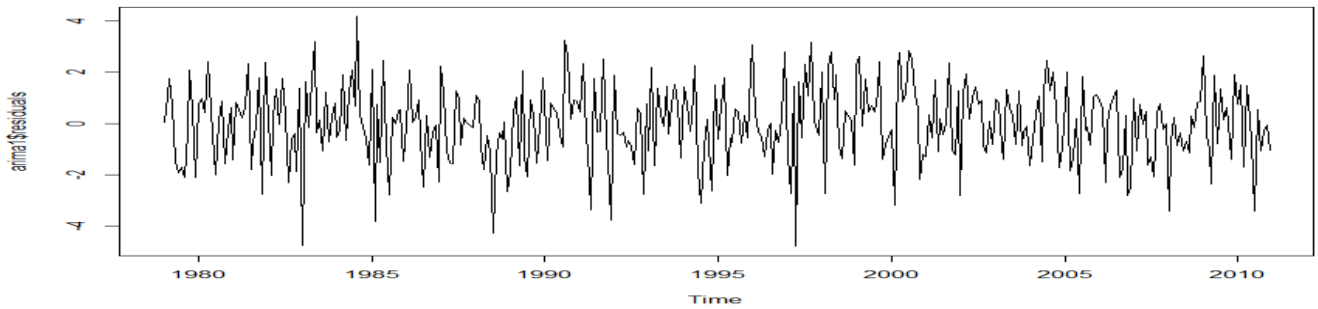


Figure 4.48: The temperature residual plot

The ACF Figure 4.49 show that the ARIMA Model selected can be used in the temperature prediction because all the spikes except the self-autocorrelation spike at one (1) as required were within the ACF boundary (dotted blue line).

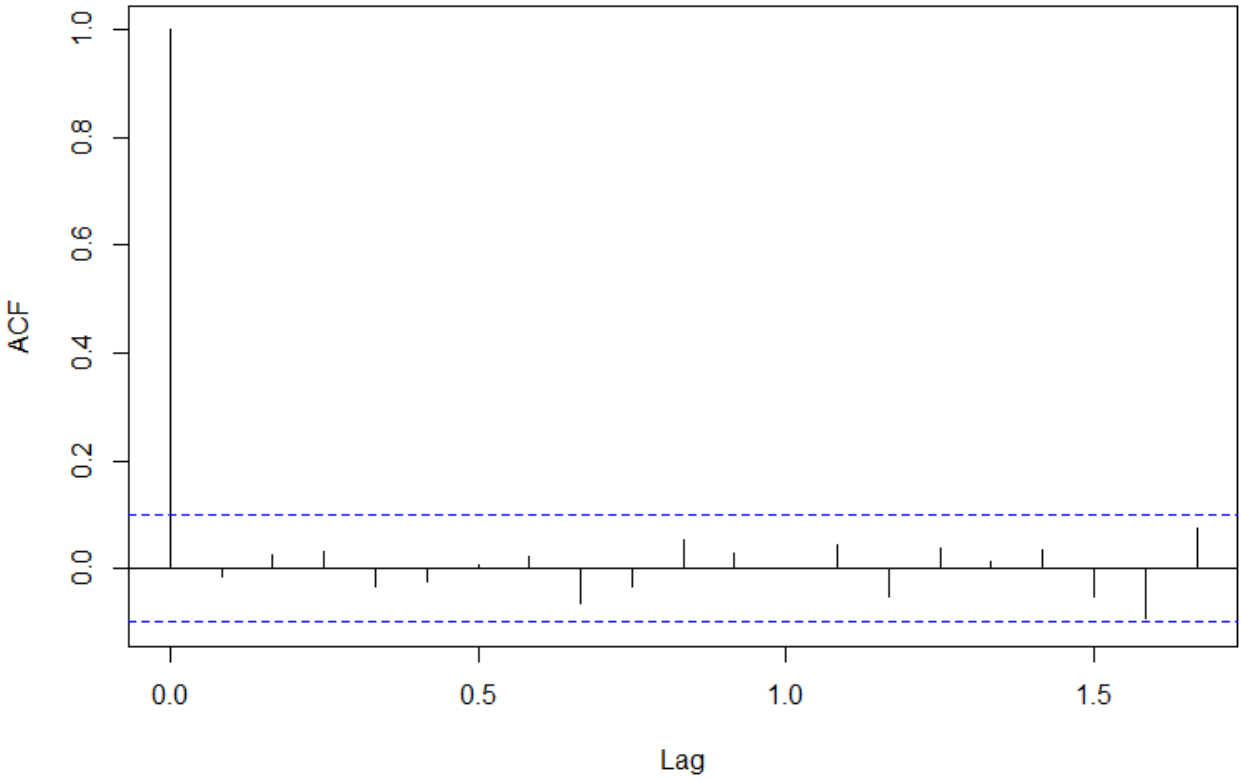


Figure 4.49: Temperature ARIMA ACF plot

PACF also shows that the ARIMA Model selected can be used in prediction because all spikes were within the significant limit (Figure 4.50)

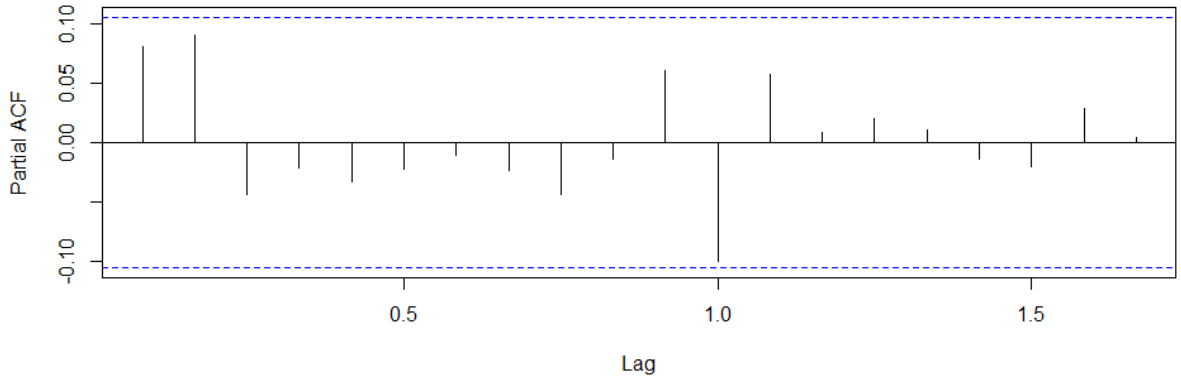


Figure 4.50: Temperature ARIMA PACF plot

The forecast was done after confirming the ARIMA Model selection alright and the output generated is given below by the command arima1.forecast$mean in R programming.

```
> arima1.forecast$mean
      Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec
2011 33.5 36.6 39.4 40.4 38.8 35.6 30.6 29.7 33.2 35.3 34.2 32.5
2012 33.7 36.9 39.7 40.2 39.0 35.7 30.6 29.9 33.2 35.3 34.4 32.5
2013 33.7 37.1 39.6 40.2 39.1 35.6 30.7 30.0 33.2 35.3 34.4 32.5
2014 33.8 37.1 39.6 40.2 39.1 35.7 30.8 30.0 33.3 35.4 34.5 32.6
2015 33.8 37.1 39.7 40.3 39.1 35.7 30.8 30.1 33.3 35.4 34.5 32.6
2016 33.9 37.2 39.7 40.3 39.2 35.7 30.8 30.1 33.3 35.5 34.5 32.6
2017 33.9 37.2 39.7 40.3 39.2 35.8 30.9 30.1 33.4 35.5 34.6 32.7
2018 33.9 37.2 39.7 40.4 39.2 35.8 30.9 30.2 33.4 35.5 34.6 32.7
2019 34.0 37.3 39.8 40.4 39.2 35.8 30.9 30.2 33.4 35.6 34.6 32.7
2020 34.0 37.3 39.8 40.4 39.3 35.9 31.0 30.3 33.5 35.6 34.7 32.8
2021 34.0 37.3 39.8 40.4 39.3 35.9 31.0 30.3 33.5 35.6 34.7 32.8
2022 34.1 37.3 39.8 40.4 39.3 35.9 31.1 30.3 33.5 35.6 34.7 32.8
2023 34.1 37.4 39.9 40.5 39.3 35.9 31.1 30.4 33.6 35.7 34.8 32.9
2024 34.1 37.4 39.9 40.5 39.4 36.0 31.1 30.4 33.6 35.7 34.8 32.9
2025 34.2 37.4 39.9 40.5 39.4 36.0 31.2 30.5 33.6 35.7 34.8 33.0
2026 34.2 37.5 39.9 40.5 39.4 36.0 31.2 30.5 33.7 35.8 34.9 33.0
2027 34.2 37.5 40.0 40.6 39.4 36.1 31.3 30.5 33.7 35.8 34.9 33.0
2028 34.3 37.5 40.0 40.6 39.5 36.1 31.3 30.6 33.7 35.8 34.9 33.1
2029 34.3 37.5 40.0 40.6 39.5 36.1 31.3 30.6 33.8 35.9 34.9 33.1
2030 34.3 37.6 40.0 40.6 39.5 36.2 31.4 30.6 33.8 35.9 35.0 33.1
2031 34.4 37.6 40.1 40.7 39.6 36.2 31.4 30.7 33.9 35.9 35.0 33.2
2032 34.4 37.6 40.1 40.7 39.6 36.2 31.4 30.7 33.9 36.0 35.0 33.2
2033 34.4 37.7 40.1 40.7 39.6 36.3 31.5 30.8 33.9 36.0 35.1 33.2
2034 34.5 37.7 40.1 40.7 39.6 36.3 31.5 30.8 34.0 36.0 35.1 33.3
2035 34.5 37.7 40.2 40.8 39.7 36.3 31.6 30.8 34.0 36.1 35.1 33.3
```

Figure 4.51 is the plot of the training data (the continuous black line from 1982 to 2010), the test data (the broken black line from 2011 to 2014) and the blue line (the forecast data). This was done to visualize the accuracy of the forecast.

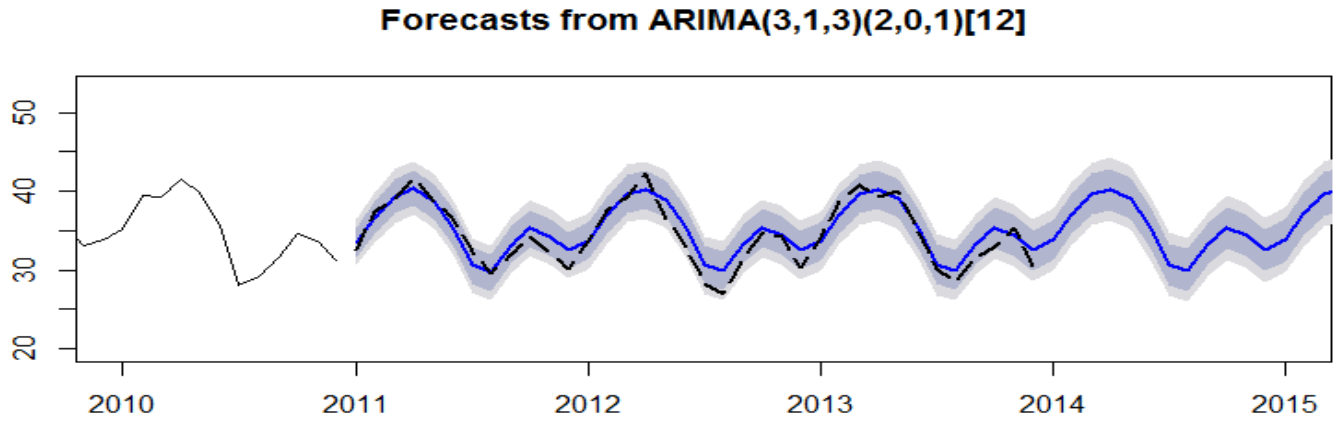


Figure 4.51: Temperature Forecast accuracy plot

Accuracy test gives information on the performances of the predictive model by the interpretation of the test set statistical parameters. It is the portion of the blue line on the broken line shown in Figure 4.51 above. The two most commonly used scale-dependent measures are based on the absolute errors MAE or squared errors RMSE (Hyndman & Hyndman, 2006). Training and test data statistics when compared gives information on how fit the predictive model is with respect to over or under fitting.

The ME(mean error) of -0.56 suggested that the actual values is over predicted by mean error of 0.56, which means that every element of the predicted values need to adjusted by -0.56. Ideal value ME = 0; ME > 0 implies that the model tends to under-forecast while ME < 0, implies that model tends to over-forecast.

The RMSE (root means standard error) is the standard deviations of the error (1.5) from the mean of 0.

The MAE (Mean Absolute Error) show that the model tends to slightly over-forecast with an average absolute error of 1.26 units.

```
> accuracy(arima1.forecast,data.test)
                     ME     RMSE      MAE         MPE     MAPE      MASE         ACF1
Training set -0.0139326 1.479669 1.175924 -0.2374181 3.510667 0.6783125 -0.01480437
Test set     -0.5589577 1.500638 1.261838 -1.9699609 3.816740 0.7278705  0.28884125
```

4.6.2 Predictive Model of the Sub-Basin Field Rainfall data

The best ARIMA Model obtained for the seasonal prediction of the sub-basin rainfall was ARIMA (1,1,1)(1,1,2)[12], below are the several ARIMA Model generated with it corresponding AICs.

```
>arima1=auto.arima(data.train,trace=TRUE,test="kpss",ic="aic")
Fitting models using approximations to speed things up...

Arima model selection                                    AICs
 ARIMA(2,0,2)(1,0,1)[12] with non-zero mean        : Inf
 ARIMA(0,0,0)          with non-zero mean          : 3600
 ARIMA(1,0,0)(1,0,0)[12] with non-zero mean        : 3344
 ARIMA(0,0,1)(0,0,1)[12] with non-zero mean        : 3442
 ARIMA(0,0,0)              with zero mean          : 3730
 ARIMA(1,0,0)              with non-zero mean      : 3474
 ARIMA(1,0,0)(2,0,0)[12] with non-zero mean        : 3277
 ARIMA(1,0,0)(2,0,1)[12] with non-zero mean        : Inf
 ARIMA(0,0,0)(2,0,0)[12] with non-zero mean        : 3272
 ARIMA(0,0,1)(2,0,0)[12] with non-zero mean        : 3276
 ARIMA(1,1,1)(1,1,2)[12] with non-zero mean        : 3211
 ARIMA(0,0,0)(2,0,0)[12] with zero mean            : Inf
 ARIMA(0,0,0)(1,0,0)[12] with non-zero mean        : 3344
 ARIMA(0,0,0)(2,0,1)[12] with non-zero mean        : Inf
 Now re-fitting the best model(s) without approximations...

 ARIMA(0,0,0)(2,0,0)[12] with non-zero mean        : Inf
 ARIMA(1,1,1)(1,1,2)[12] with non-zero mean        : 3211

 Best model: ARIMA(1,1,1)(1,1,2)[12] with non-zero mean
```

The ARIMA Forecast plot in Figure 4.52 shows the training data in black and the forecast in blue. It shows that the forecast exhibits seasonal characteristic inherent in the training data.

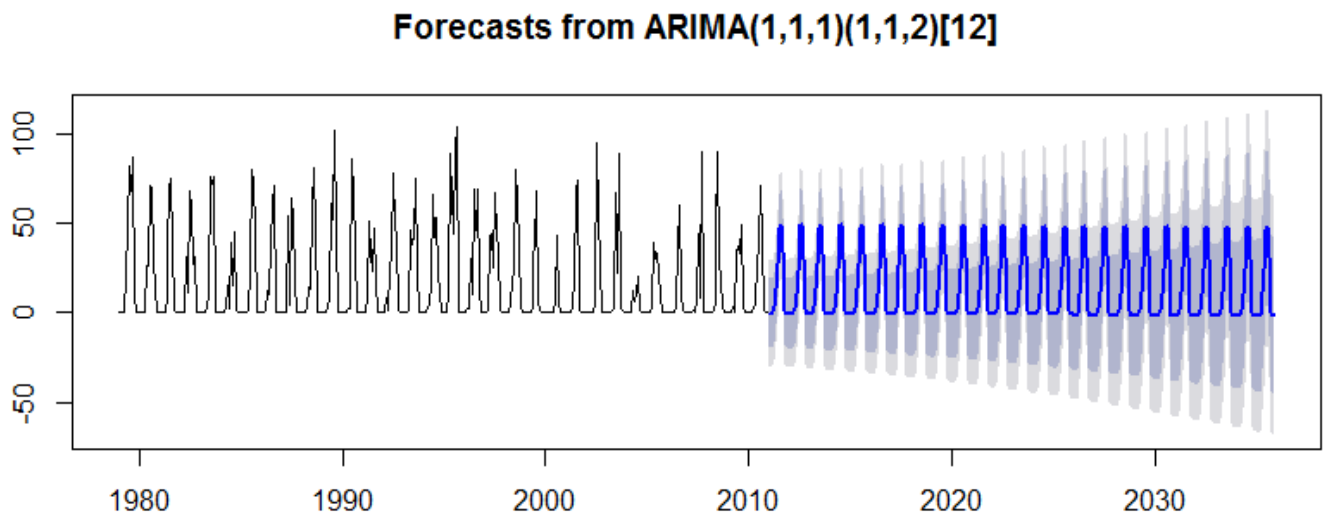


Figure 4.52: The ARIMA rainfall forecast plot

The plot of the training data residual Figure 4.53 provides the means of testing the ARIMA Model selection by the use of ACF and PACF plot.

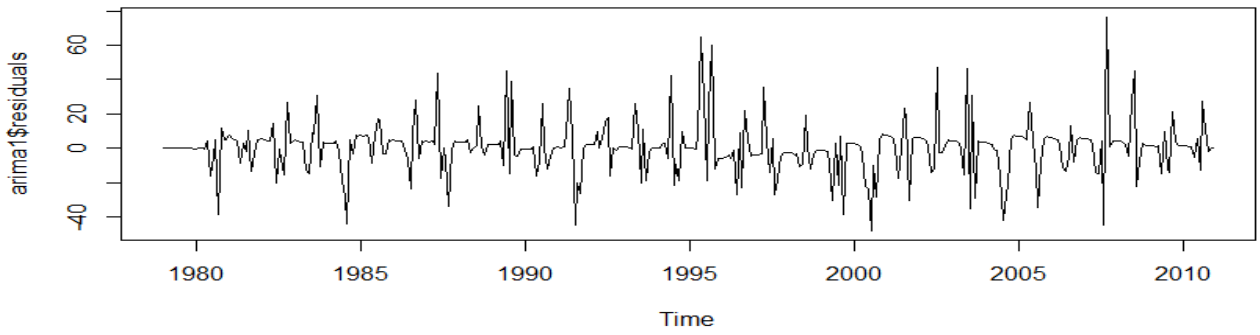


Figure 4.53: The plot of the rainfall residual

The ACF Figure 4.54 show that the ARIMA Model selected can be used in the rainfall prediction because all the spikes except the self-autocorrelation spike at one (1) as required were within the ACF boundary (dotted blue line)

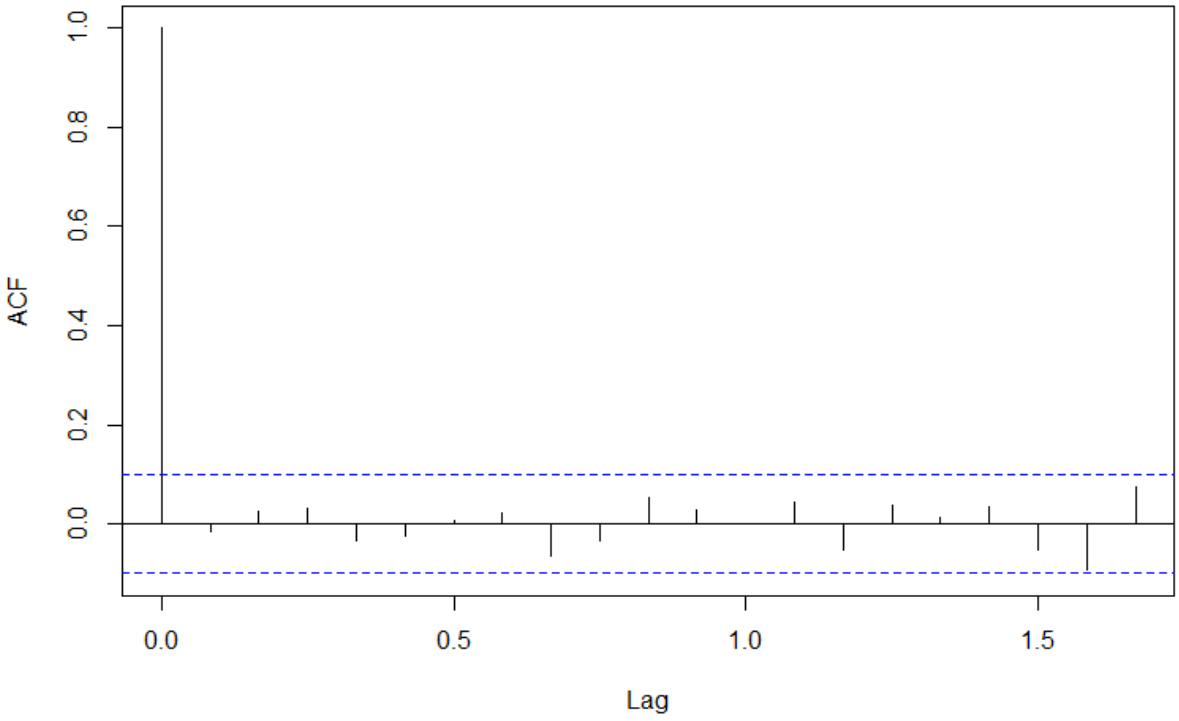


Figure 4.54: Rainfall ARIMA ACF plot

PACF plot shows that the ARIMA Model selected can be used in prediction because all spikes were within the significant limit (Figure 4.55).

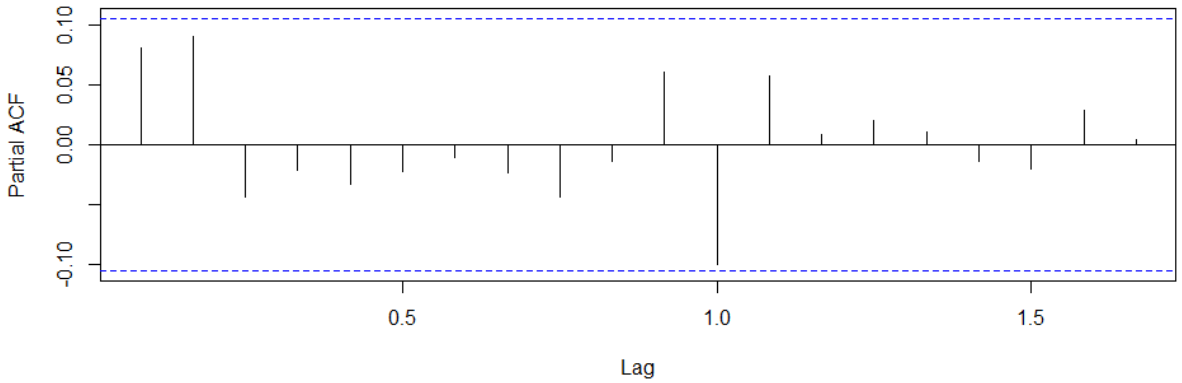


Figure 4.55: Rainfall ARIMA PACF plot

The forecast was done after confirming the ARIMA Model selection alright and the output generated is given below by the command arima1.forecast$mean in R programming.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	-3.93	-4.15	-3.52	-2.31	7.59	12.08	48.18	52.37	15.47	-0.96	-4.17	-4.18
2012	-4.64	-4.66	-4.43	-0.57	13.69	22.59	42.34	64.95	15.79	-4.13	-4.66	-4.66
2013	-5.16	-5.19	-4.54	-3.33	6.58	11.07	47.16	51.37	14.46	-1.98	-5.19	-5.20
2014	-5.66	-5.68	-5.45	-1.59	12.66	21.55	41.33	63.92	14.77	-5.15	-5.68	-5.68
2015	-6.18	-6.20	-5.56	-4.34	5.57	10.07	46.13	50.37	13.44	-3.00	-6.21	-6.22
2016	-6.68	-6.70	-6.46	-2.62	11.63	20.52	40.32	62.88	13.75	-6.16	-6.70	-6.70
2017	-7.20	-7.22	-6.58	-5.36	4.56	9.07	45.11	49.36	12.42	-4.02	-7.23	-7.24
2018	-7.70	-7.72	-7.48	-3.64	10.60	19.49	39.30	61.84	12.73	-7.18	-7.72	-7.72
2019	-8.22	-8.24	-7.60	-6.37	3.55	8.06	44.08	48.36	11.40	-5.05	-8.25	-8.26
2020	-8.71	-8.74	-8.50	-4.66	9.58	18.46	38.29	60.81	11.71	-8.19	-8.74	-8.74
2021	-9.24	-9.26	-8.62	-7.39	2.54	7.06	43.05	47.36	10.39	-6.07	-9.27	-9.28
2022	-9.73	-9.76	-9.52	-5.68	8.55	17.42	37.28	59.77	10.69	-9.21	-9.76	-9.75
2023	-10.26	-10.28	-9.64	-8.40	1.52	6.05	42.03	46.36	9.37	-7.09	-10.29	-10.30
2024	-10.75	-10.78	-10.54	-6.70	7.52	16.39	36.27	58.74	9.67	-10.23	-10.77	-10.77
2025	-11.28	-11.30	-10.66	-9.42	0.51	5.05	41.00	45.36	8.35	-8.11	-11.30	-11.31
2026	-11.77	-11.80	-11.56	-7.72	6.50	15.36	35.26	57.70	8.65	-11.24	-11.79	-11.79
2027	-12.29	-12.32	-11.68	-10.44	-0.50	4.04	39.98	44.36	7.33	-9.14	-12.32	-12.33
2028	-12.79	-12.81	-12.57	-8.75	5.47	14.32	34.24	56.67	7.63	-12.26	-12.81	-12.81
2029	-13.31	-13.34	-12.70	-11.45	-1.51	3.04	38.95	43.35	6.31	-10.16	-13.34	-13.35
2030	-13.81	-13.83	-13.59	-9.77	4.44	13.29	33.23	55.63	6.61	-13.27	-13.83	-13.83
2031	-14.33	-14.35	-13.72	-12.47	-2.52	2.03	37.93	42.35	5.30	-11.18	-14.36	-14.37
2032	-14.83	-14.85	-14.61	-10.79	3.41	12.26	32.22	54.59	5.59	-14.29	-14.85	-14.85
2033	-15.35	-15.37	-14.74	-13.48	-3.53	1.03	36.90	41.35	4.28	-12.20	-15.38	-15.39
2034	-15.85	-15.87	-15.63	-11.81	2.39	11.23	31.21	53.56	4.57	-15.30	-15.87	-15.87
2035	-16.37	-16.39	-15.76	-14.50	-4.54	0.02	35.87	40.35	3.26	-13.22	-16.40	-16.41

Figure 4:56 is the plot of the training data (the continuous black line from 1982 to 2010), the test data (the broken black line from 2011 to 2014) and the blue line (the forecast data). This was done to visualize the accuracy of the forecast.

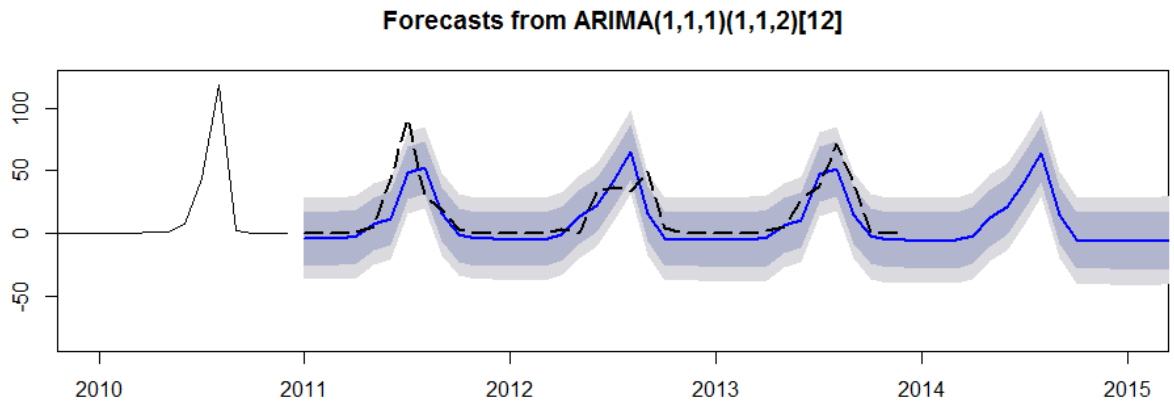


Figure 4.56: Rainfall forecast accuracy plot

The Ideal value of ME = 0; if ME > 0, model tends to under-forecast, ME < 0, model tends to over-forecast.

The ME value of 5.5 suggests that the model under predicts the rainfall, 5,5 on average is to be added to every element of the predicted values estimated. The RMSE is the deviation of data from the mean of 0. MAE shows that the model was under predicted by 10.17 units.

```
> accuracy(arima1.forecast,data.test)
                    ME     RMSE      MAE MPE MAPE      MASE         ACF1
Training set 0.3211582 16.06214  9.56798 NaN  Inf 0.8476392 -0.00506498
Test set     5.4584027 14.56958 10.17878 Inf  Inf 0.9017505 -0.17168848
```

4.6.3 Rainfall Dendrogram

The dendrogram (cluster analysis) in Figure 4.57 provide information on distinct groups based on the relative closeness of the data set. The dataset used in dendogram were the maximum of the mean monthly field rainfall from 1982 to 2013 and maximum of the mean forecast ARIMA Model for each year from 2015 to 2035. The knowledge can be used to develop plan for future event, for example the rainfall event 1987, 1994, 2007, 2003, 2008,

2017, 2019, 2021, 2023, 2015, 2012, 2014 are similar. If all conditions remain constant the event triggered by rainfall of 2014, 2015 is likely to repeat in 2019 and 2023.

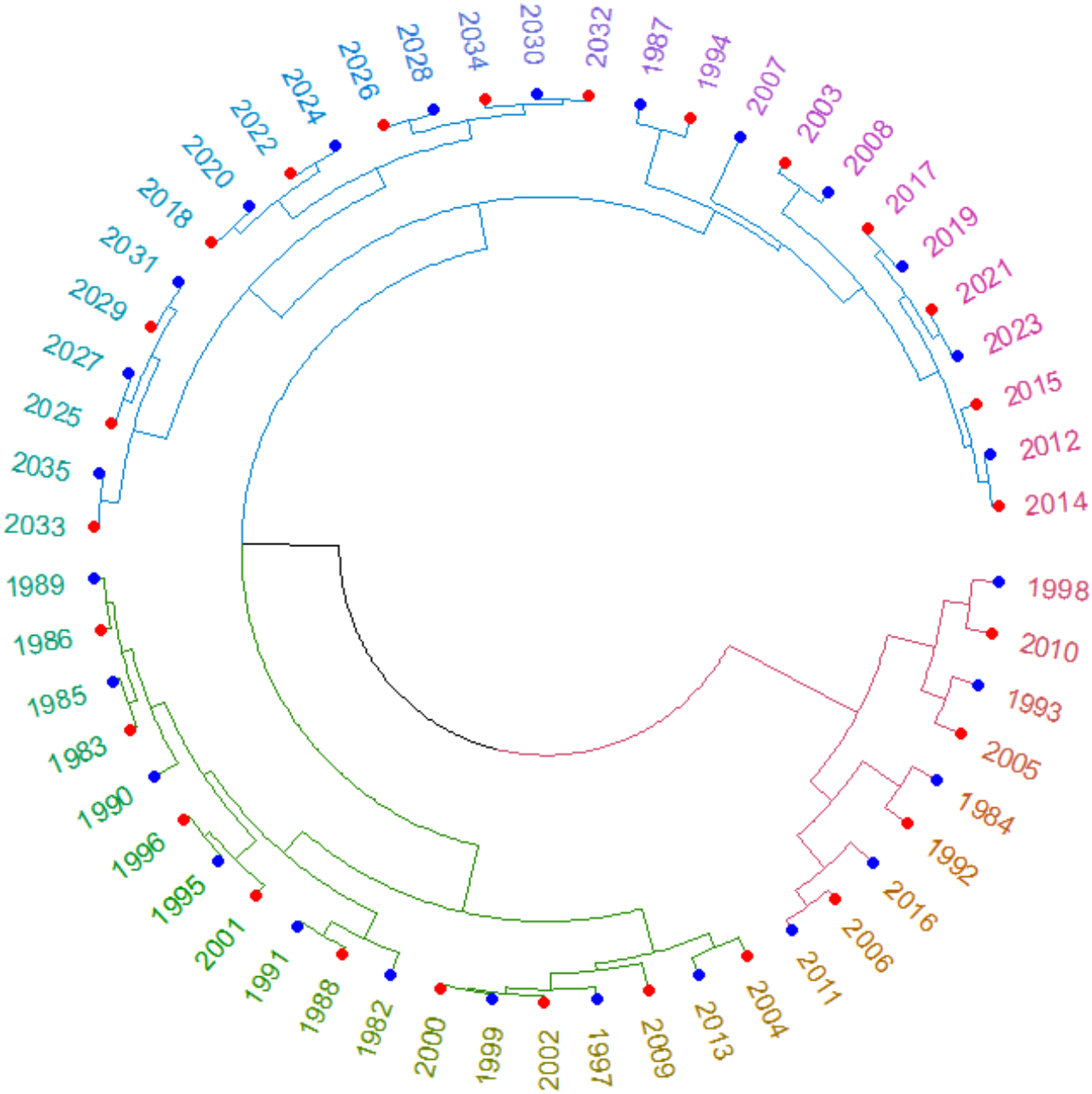


Figure 4.57: Rainfall dendrogram

4.7 ESTIMATION OF SENSITIVE PARAMETERS, CALIBRATION AND VALIDATION OF THE STREAM FLOW USING SWATCUP

4.7.1 Sensitivity analysis

Ten model parameters were identified as sensitive from the analysis. The parameters with respect to their relative sensitivities on which were based the ranking is presented in the Table 4.8. Clearly r__SURLAG.bsn (Surface runoff lag coefficient) is a sensitive parameter and its best fitting values is 0.045000 in relative change (r__). It could be categorized as 'very important' parameter and underlines the very important influence of land use and land cover on runoff generation. In *the* validation (2004 to 2013) r__CN2.mgt (moisture condition II curve number) is most sensitivity parameter fitted at 0.134000.

Table 4.8: Ranked sensitivity of behavioral parameters

S/No	Variable	Calibration	Rank	Validation	Rank
	r__EPCO.bsn	0.20000	4	0.200000	2
	r__ESCO.bsn	0.200000	4	0.200000	2
	r__CN2.mgt	0.063600	3	0.134000	1
	v__ALPHA_BF.gw	0.267000	5	0.381000	4
	v__GW_DELAY.gw	39.66000	9	33.779999	9
	v__GWQMN.gw	0.058000	2	0.778000	8
	r__SPCON.bsn	1.098000	8	0.626000	5
	r__SURLAG.bsn	0.045000	1	0.995000	3
	r__SEDPST_CONC.swq	0.525000	6	0.769000	7
	r__SOL_Z().sol	0.593000	7	0.737000	6

Key:
1. EPCO: plant uptake compensation factor
2. ESCO: soil evaporation compensation factor
3. CN2: moisture condition II curve number
4. ALPHA_BF.gw baseflow alpha factor
5. GW_DELAY: Delay time for aquifer recharge
6.GWQMN: threshold water level in shallow aquifer for base flow
7.SPCON: Channel sediment routing parameter
8. SURLAG: Surface runoff lag coefficient
9. SEDPST_CONC: sediment deposit concetration
10. r__SOL_Z().sol: Depth from soil surface to bottom layer (mm)
v__ means the existing parameter value is to be replaced by a given value,
r__ means an existing parameter value is multiplied by (1+ a given value)

Dot plots are the plots of parameter values or relative changes versus objective function which shows the distribution of sampling points as well as parameter sensitivity. Dot plots for the ten sensitive parameters are shown in Figure 4.59. The dotted plots also indicate that the most sensitive parameter is CN2.

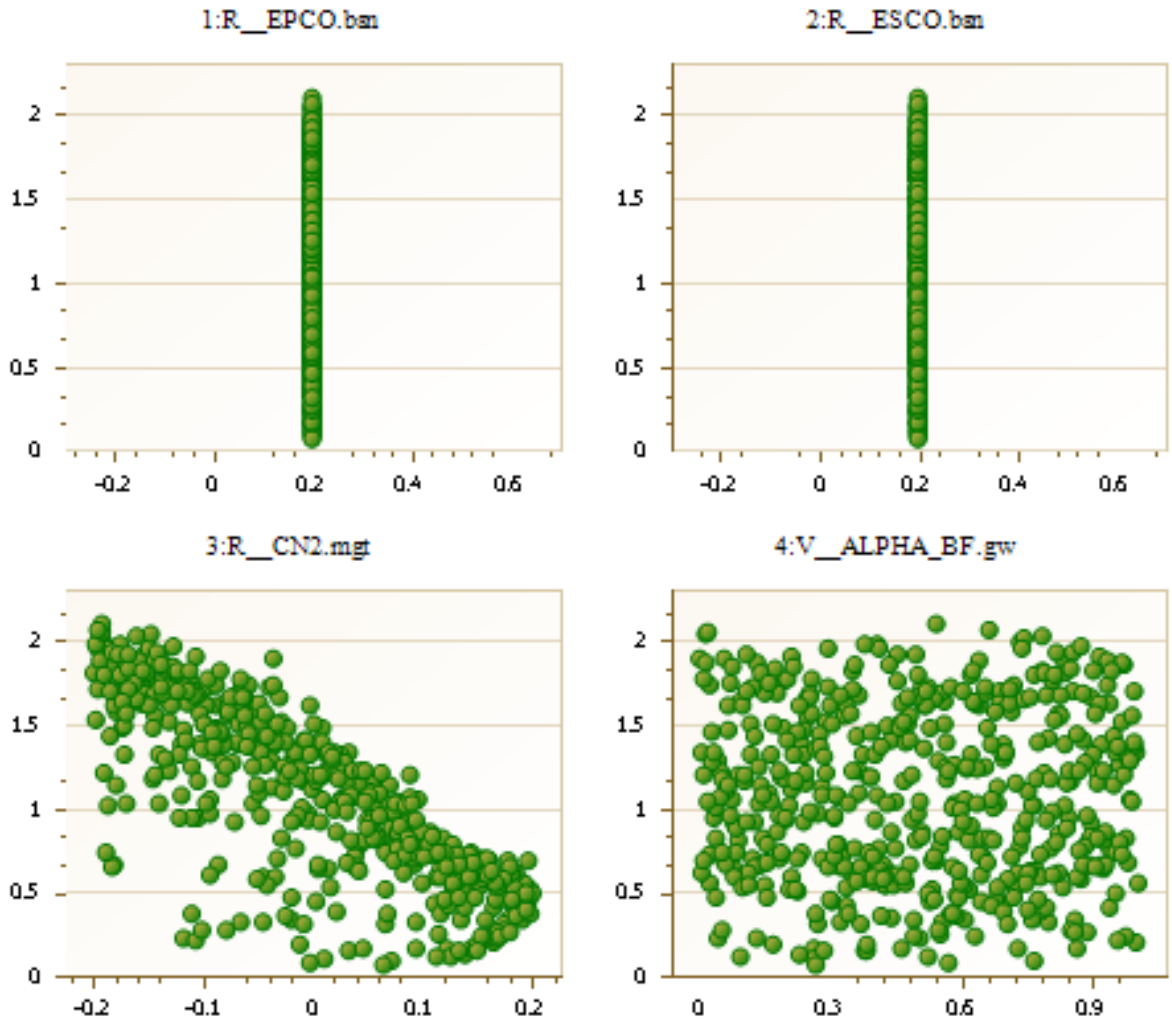


Figure 4.59: 8ensitivity parameters dots plot

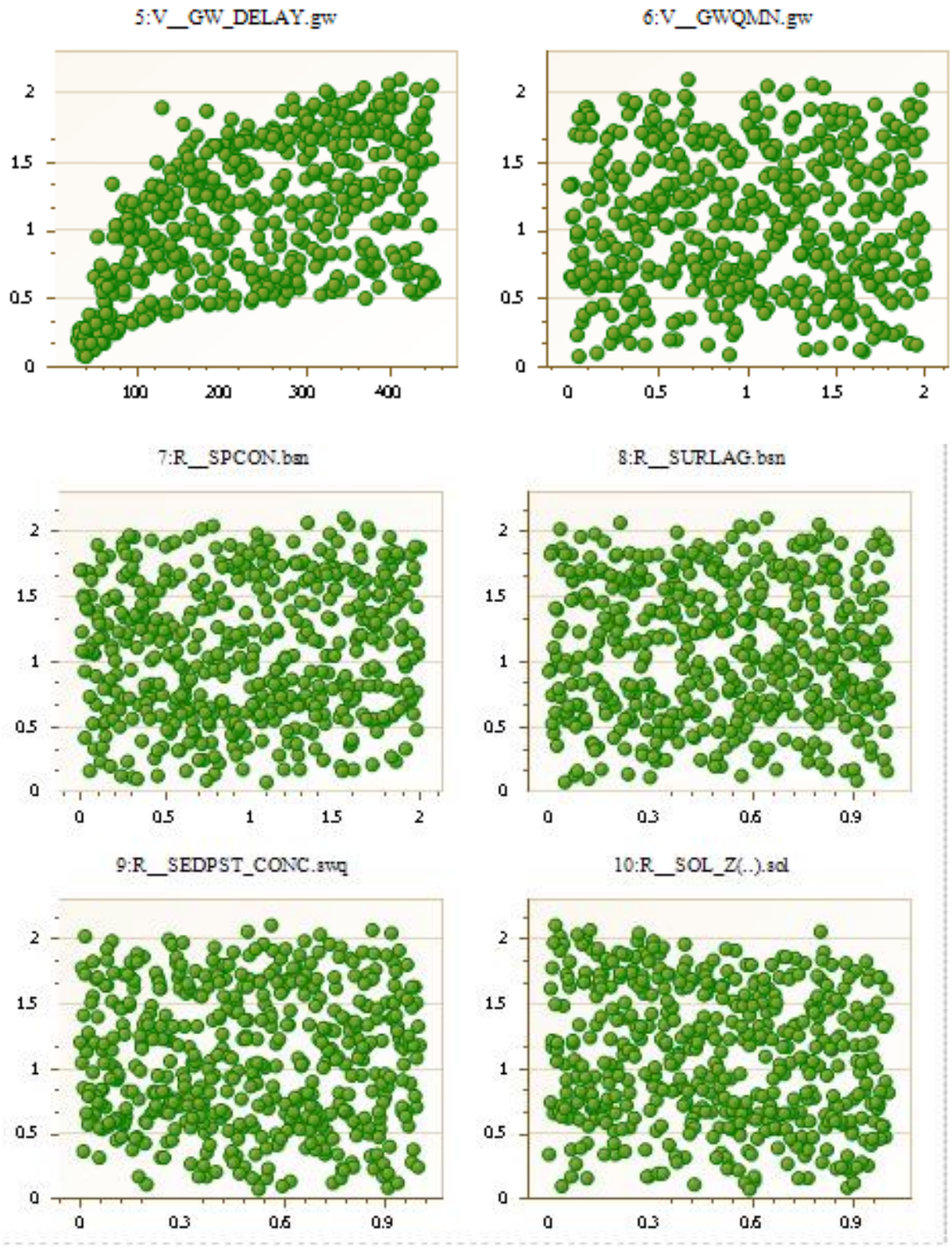


Figure 4.58: Sensitivity parameters dots plot (continue)

4.7.2 Calibration

To reduce the uncertainty associated with the SWAT/GIS model prediction, calibration was done by comparing the simulated and observed stream flow data from 1982 to 2003. Monitoring data were used only to verify the general range and magnitude of values simulated by the model, after achieving a reasonable stream-flow data from 2004 to2015 (Figure 4.59).

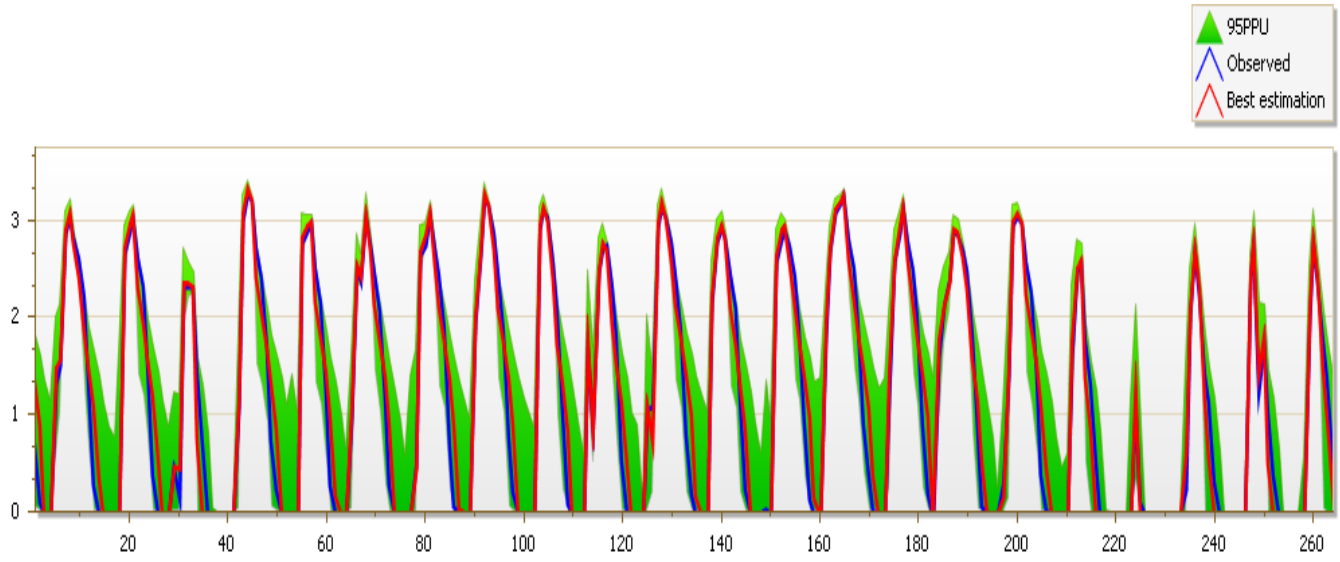


Figure 4.59: Calibration of the observed stream flow data

4.7.3 Validation

The same value of calibrated hydrological parameters was used for validation. The validation has been done thereafter to evaluate the performance of the model with calibrated parameters to simulate the hydrological functioning of the watershed over another time period that has not been used in the calibration phase (Figure 4.60).

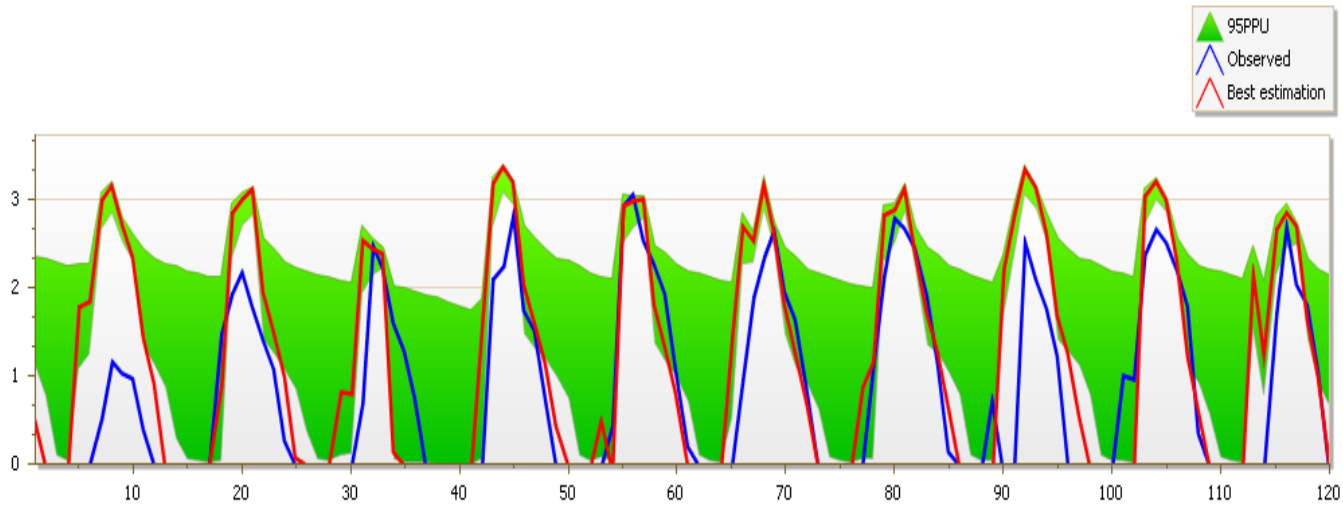


Figure 4.60: Validation of the observed stream flow data

4.7.4 Calibration and Validation Statistics

The statistics of comparing observed data with the simulation data through p-factor and r factor and the best simulation of the current iteration by using R2, NS, bR2, MSE, SSQR, PBIAS, KGE, RSR, and VOL_FR are presented in Table 4.9. The mean and standard deviation of the observed and simulated variables, best simulation number of the current iteration, and the best value of the objective function for the simulations are given at the end of the goal function type. The paramount statistic test of the simulation are R2 (R Square) and the NS. .

Table 4.9: Observed and simulation statistics for behavioral parameters

S/No	Variable	Calibration	Validation
1	Number of simulations	500	500
4	p-factor	0.76	0.28
5	r-factor	0.71	1.27
6	R2	0.95	0.62
7	NS	0.95	0.32
8	bR2	0.8844	0.5896
9	MSE	7.7e-002	6.9e-001
10	SSQR	2.8e-002	2.1e-001
11	PBIAS	-2.8	-39.8
12	KGE	0.94	0.50
13	RSK	0.23	0.83
14	MNS	0.00	0.40

Kjljhgio9h90i09---015	VOL_FR	0.97	0.72
16	Mean of simulated	1.31	1.25
17	Mean of observed data	1.27	0.90
18	Standard deviation of simulated	1.16	1.21
19	Standard deviation of observed data	1.21	1.00

Where;

Mult: This is a multiplicative form of the square error

Sum: This is the summation form of the square error

R2: Coefficient of determination

Chi2: chia square

NS: Nash-Sutcliffe

bR2: where Coefficient of determination R2 is multiplied by the coefficient of the regression line between measured and simulated data,

SSQR: The SSQR method aims at fitting the frequency distributions of the observed and the simulated series.

PBIAS: Percent bias measures the average tendency of the simulated data to be larger or smaller than the observations

KGE: Kling–Gupta efficiency

RSR: is the standardizes the RMSE using the observation standard deviation

MNS: Modified Nasch-Sutcliffe efficiency factor

CHAPTER FIVE

SUMMARY, CONCLUSION AND RCOMMENDATION

5.1 SUMMARY

The SWAT/GIS based hydrological modelling underscores that the model is a flexible and robust that can be used to simulate a variety of watershed problems. The process of configuring SWAT for a given watershed has also been greatly facilitated by the development of GIS-based interfaces, which provide a straightforward means of translating digital land use, topographic, and soil data into model inputs.

The coefficient of determination between the radar weather of temperature data and field temperature data was higher than 0.5 at all points in the sub-basin, than that of radar rainfall and field rainfall data. This suggests that where temperature field data is not available the radar temperature data set can be applied.

The delineated sub-basin area extent was estimated at 15,663.02 km^2 classified as large watershed (area> 2,500 km^2), perimeter of 1,323.5km, spot height from 784-351 km above sea level. The portion of the Hadeija River in study area is of 3^{rd} order river with bifurcation ration of 1.47. Some the land use/cover characteristics that have increases over the period 1975 to 2013 based on the area occupied in percentage are; agricultural land 8.92%, water bodies 79.22% due to dam construction in the later year, urban settlement 24.63%. The land use/cover category that has witness shrinkage are; range land by 60.74%, wetland 13.58%, bare land 16.91%, forest land 4.01%, and riparian forest 4.64%.

The three (3) principal soils revealed by the digital soil map that were validated with field data are ‘sand-sandyloam’, ‘sandyloam’, ‘sandyloam- sandyclayloam’. The sub-basin is

dominantly characterized by gentle slope from 0.02 to 0.90. Based on the similarity of the slope, land use/cover and soil characteristics the sub-basin was further delineated into twenty-one (21) categories.

The Soil Water Assessment Tool (SWAT) and Geographical Information System watershed-scale model were primarily used to predict and evaluate the effect of long-term land use and land cover management practices on the quantity of water that is exported from a watershed. Based on the 1975, 2000 and 2013 land use/cover dynamics respectively, the model shows insignificant impacts of the land use/cover dynamics on the basin hydrologic system with respect to annual total hydrologic parameters estimated in millimeter; Potential evapotranspiration (2,672.8, 2,674.1, 2,674.1), evaporation (349.5, 362.6, 362.2), cure number (82.35, 82.68, 82.69), surface runoff (296.3, 291.65, 292.1), return flow (97.12, 90.70, 90.62), lateral flow (0.48, 0.46, 0.43), recharge to shallow aquifer (152.8, 145.1, 145.0) and recharge to deep aquifer (7.64, 7.25, 7.25) under the varying climate factors.

By the application of auto.arima command based on the minimum AICs, ACF and PACF plot in R programming, the best ARIMA Model selection for rainfall and temperature were ARIMA(1,1,1)(1,1,2)[12] and ARIMA(3,1,3)(2,0,1)[12] respectively. The accuracy test revealed that the rainfall ARIMA Model under predicts the time series data with ME= 5.485, MAE=10.179 and RMSE=14.570 and the temperature was over fitted with ME= -5.558, MAE=1.26 and RMSE=1.501. It was applied to the mean monthly rainfall and temperature time series over the sub-basin to reveal the wet (July and August) and dry (November to March) months, hot months (March and April) and relatively lower moths of

temperature (July and August). This information was created in matrix plot of the rainfall and temperature that made it easy to observe the characteristics of the mean monthly dataset across the year.

Sensitivity analysis essential for the effective and efficient implementation of watershed management practices was done to determine the sensitivity parameters in the sub-basin. The ten (10) parameters selected in order of their sensitivity in the calibration and validation processes respectively are; SURLAG : CN2, GWQMN : EPCO/ESCO, CN2 : SURLAG, EPCO/ ESCO : ALPHA_BF, ALPHA_BF : SPCON, SEDPST_CONC : SOL_Z.sol, SOL_Z.sol : SEDPST_CONC, SPCON : GWQMN, GW_DELAY : GW_DELAY.

To determine the SWAT Model performance and obtain the best observed stream flow simulation, the output from the SWAT Model was calibrated and validated. The statistical parameter for the calibration and validation respectively are; p-factor (0.76, 0.28), r-factor (0.71, 1.27), R2 (0.95, 0.62), NS (0.95, 0.32), Mean_sim(Mean_obs) 1.31(1.27) and Mean_ StdDev_sim(StdDev_obs) 1.16(1.21) for calibration and Mean_sim(obs) 1.25(0.90), StdDev_sim(StdDev_obs) 1.21(1.00) for Validation. The value of R2=0.95 and NS=0.95 in the calibration shows a good performances of the SWAT Model, which indicates a very high goodness of fitness between the observed and stimulated stream flow.

5.2 CONCLUSION

The field temperature dataset and the unadjusted radar temperature shows a high value > 0.5 coefficient of correlation (adjusted R^2), while the correlation between the field rainfall and unadjusted weather rainfall was <0.3 at all points over the sub-basin. This suggests that

where temperature field data is not available the unadjusted radar weather of temperature data can be applied.

The estimation of the mean monthly of sub-basin hydrologic parameters show that the losses due to potential evapotranspiration is increasing while other parameters are declining as revealed by the trend line in evaporation losses, water yield, ground water recharge, lateral flow, surface runoff, and sediment yield.

The nonparametric trend test in the field data of temperature and rainfall shows that there is significant increases in temperature at rate of 2.609 above the critical Z value of 2.5 from 1982 to 2015, which increases from the southern to northern and from western to the northern part of sub-basin at a spatial rate of mean value of 33.7 to 38.5^{O}C. The rise in temperature started in the year 1998 as revealed by the Pettitt test. Rainfall shows fluctuating insignificant increases at the rate of 0.0296 below the Z value of 2.5 from 1982 to 2015, whose variation across the basin decreases from the southern to the northern and from western to northern part of the sub-basin at a spatial rate of mean annual total of 1,633.4mm to 657.9mm.

The accuracy of the Seasonal ARIMA Model predictions for temperature MA= -5.558, MAE= 1.26, RMSE= 1.501 was better than the accuracy of the Seasonal ARIMA Model prediction of rainfall in the basin with MA= 5.485, MAE= 10.179, RMSE=14.570, probably due to many outliers and zero's that were not completely smoothen out in dataset.

Analysis shows that the most sensitivity parameters in the basin are the SURLAG (surface runoff) and CN2 (moisture condition II curve). The value of R2=0.95 and NS=0.95 in the

calibration stage shows a good performances of the SWAT Model, which indicates a very high goodness of fitness between the observed and stimulated stream flow.

5.3 RCOMMENDATION

Any engineering solution to improve the quality and productivity of a watershed depend to a very large extent on the hydrologic parameters of the basin. More station equipped with state of the earth is required in the sub-basin that occupied an area of 15,663.02sqkm, with only one NiMET station.

Data acquisition for research is a big issue in the sub-basin, where such data manage to exist it is either there is no willingness on side of the custodian of the data to release it or it exist in an unorganized and discontinuous format difficulty to use. The ministry and government agencies involved in data acquisition in Nigeria Basins need to interphase with academics centre, with one of their targets to lessen the burdens on researcher with respect to data collection and it transfers. Such data should be archived with their coordinates for their easy of application in GIS related software.

Watershed productivity among other factors depends on the basin water quality that can be analyzed with the application of GIS/SWAT Model. The Hadeija Sub-basin water quality can be researched upon using the combining power of SWAT and GIS.

The result obtained in the research can be improved upon by the application of a very high satellite imagery required in the simulation, though at a cost.

The significant increases in the sub-basin temperature may require research into agricultural crops of high temperature resistance.

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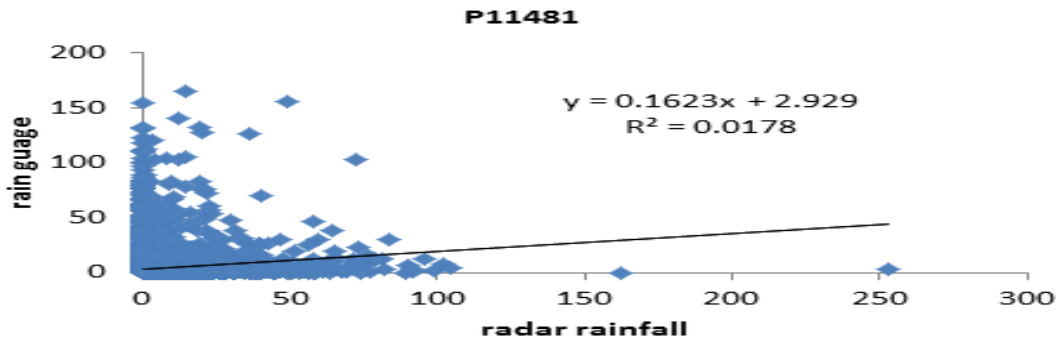
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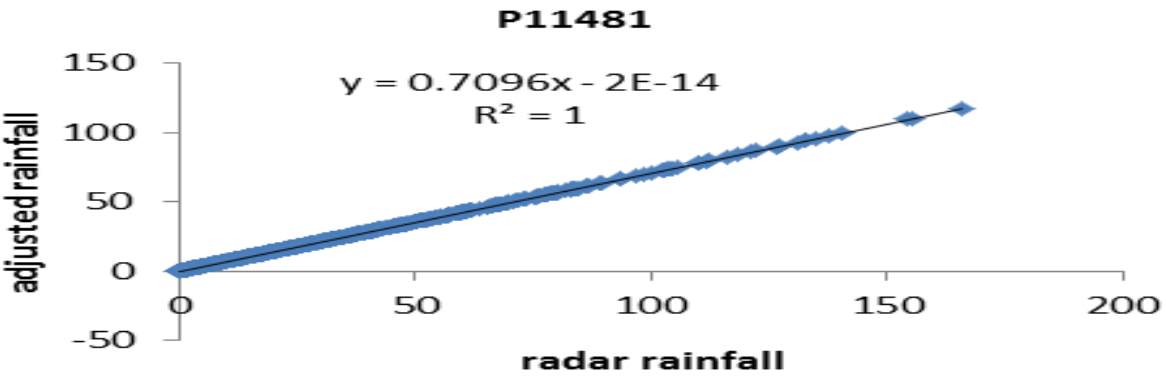
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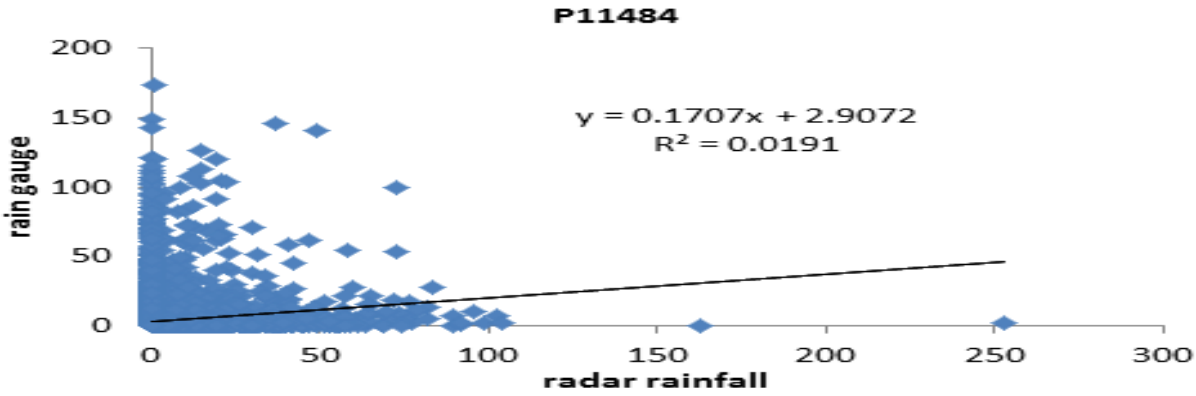
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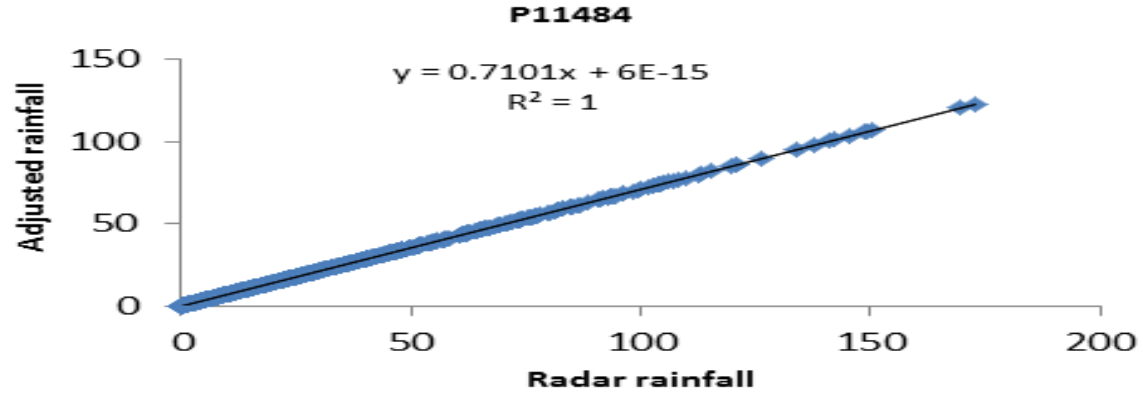
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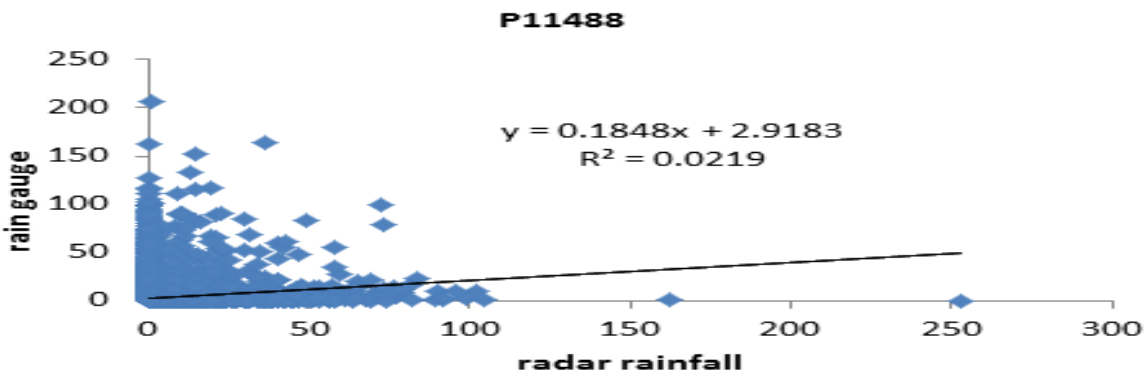
APPENDIX A1: Radar and adjustment rainfall correlation plots

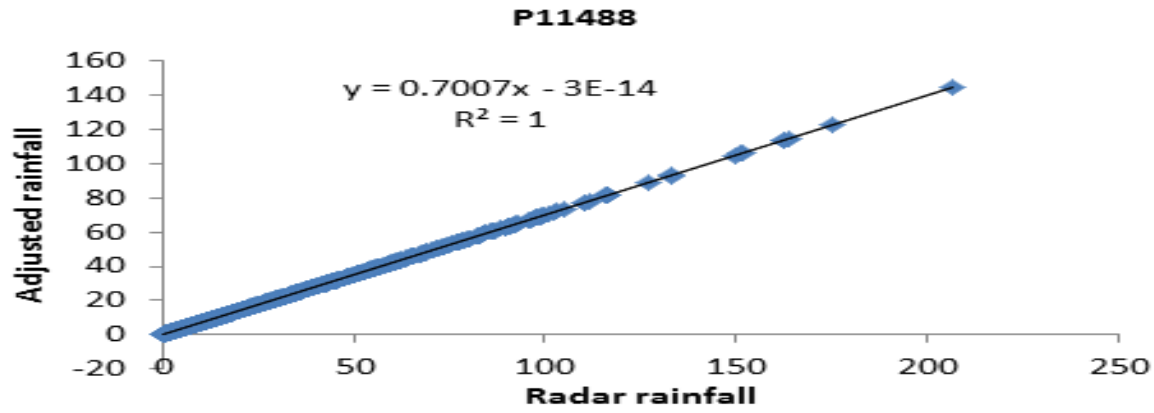


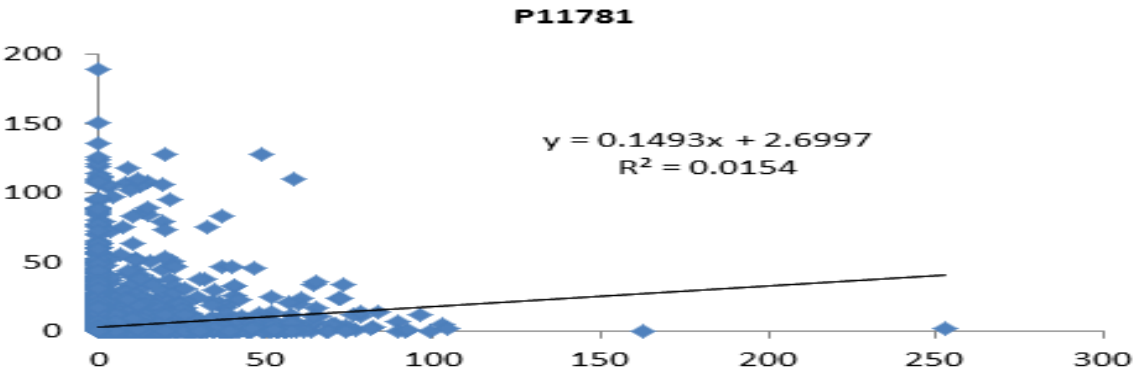


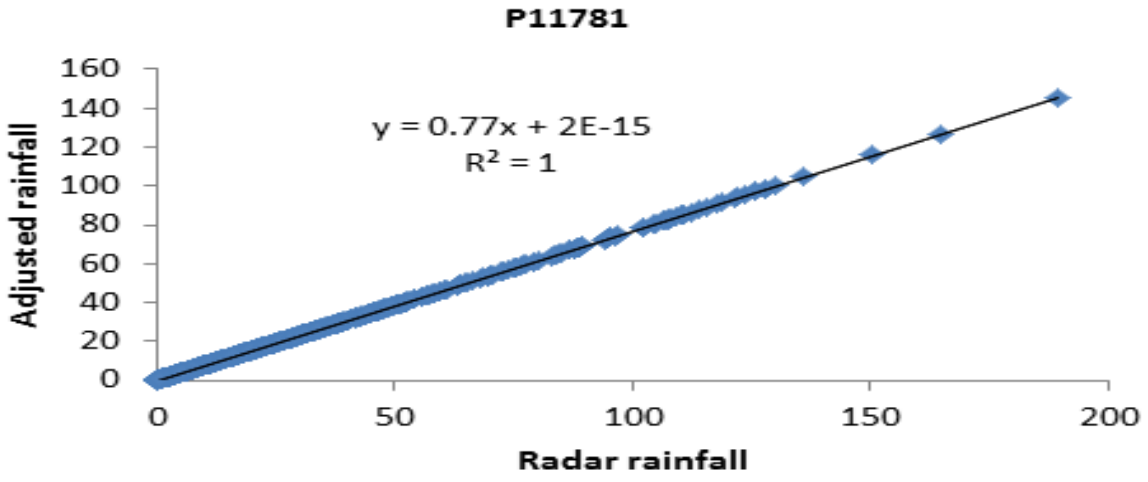


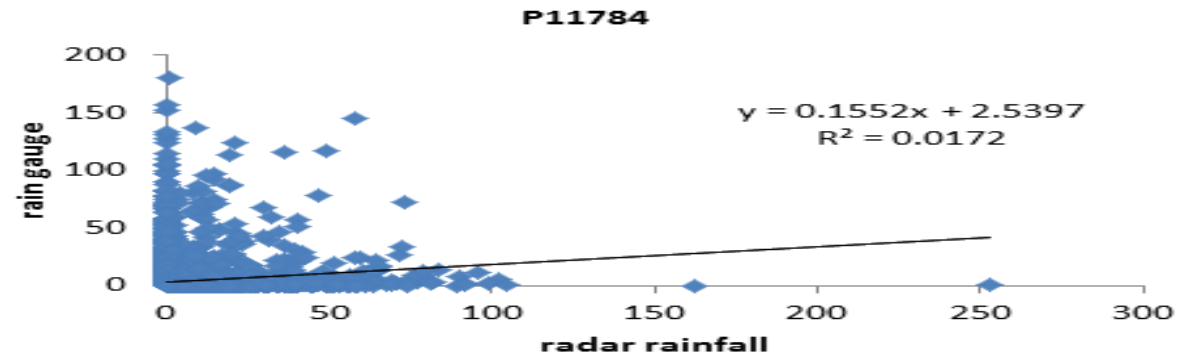


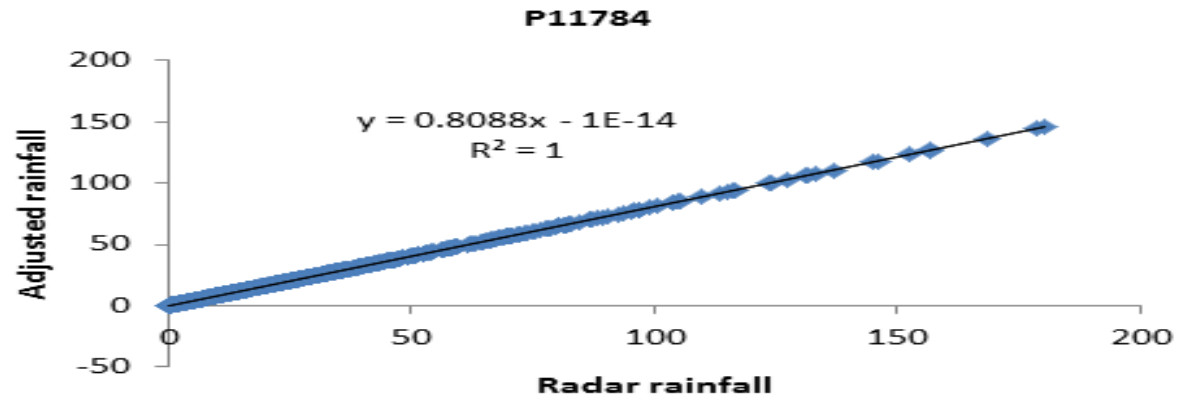

P11488
y = 0.1848x + 2.9183
R² = 0.0219
rain gauge
radar rainfall
0
50
100
150
200
250
300

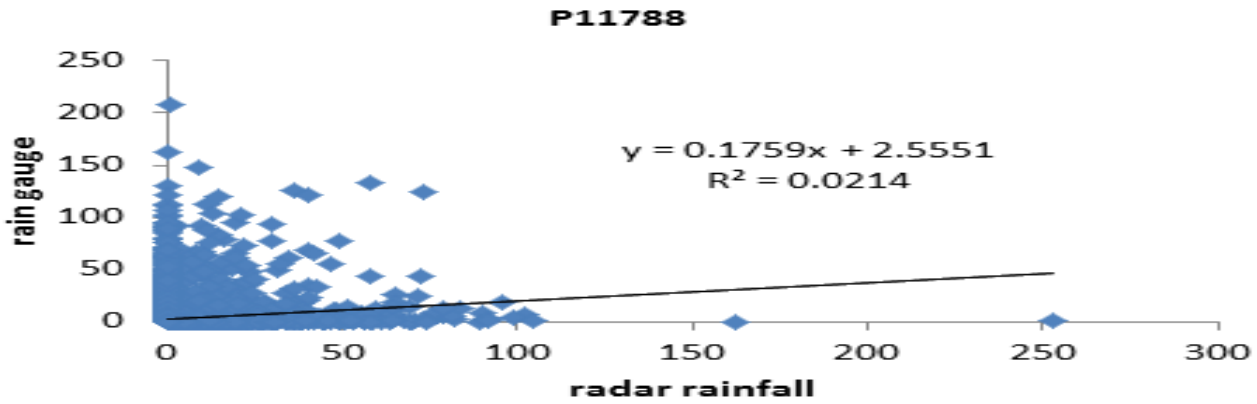

P11488
y = 0.7007x - 3E-14
R² = 1
Adjusted rainfall
Radar rainfall
-20
0
20
40
60
80
100
120
140
160
50
150
200
250

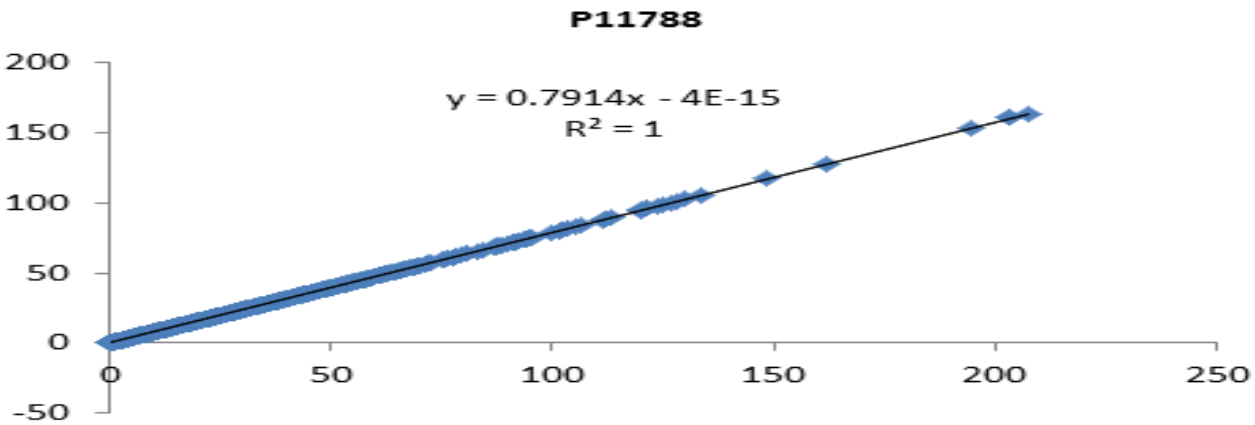

P11781
y = 0.1493x + 2.6997
R² = 0.0154
0
50
100
150
200
250
300

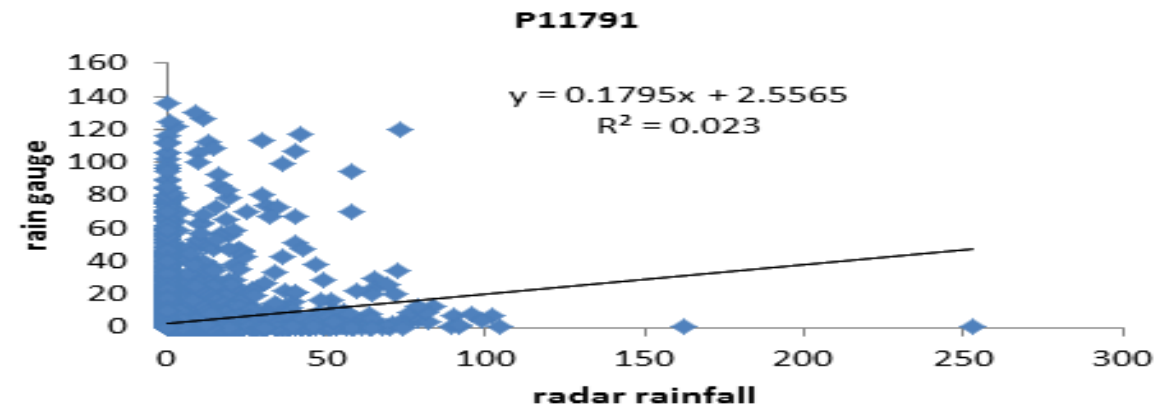

P11781
y = 0.77x + 2E-15
R² = 1
Adjusted rainfall
Radar rainfall
0
20
40
60
80
100
120
140
160
50
150
200

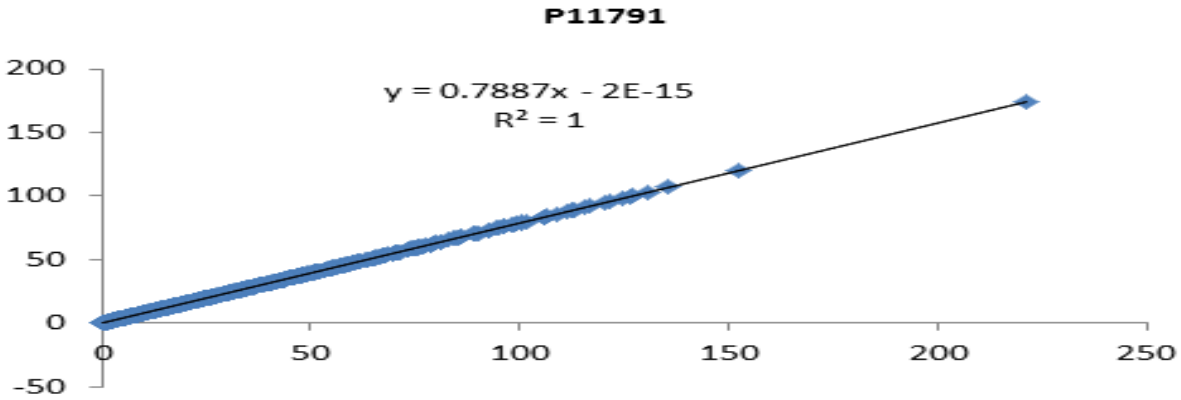

P11784
y = 0.1552x + 2.5397
R² = 0.0172
rain gauge
radar rainfall
200
150
100
50
0
0
50
100
150
200
250
300

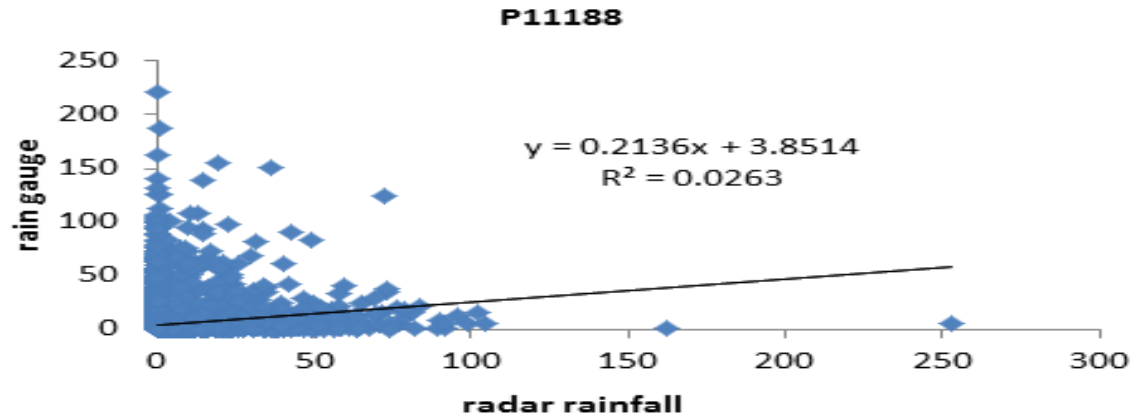

P11784
y = 0.8088x - 1E-14
R² = 1
Adjusted rainfall
Radar rainfall
200
150
100
50
0
-50
0
50
100
150
200

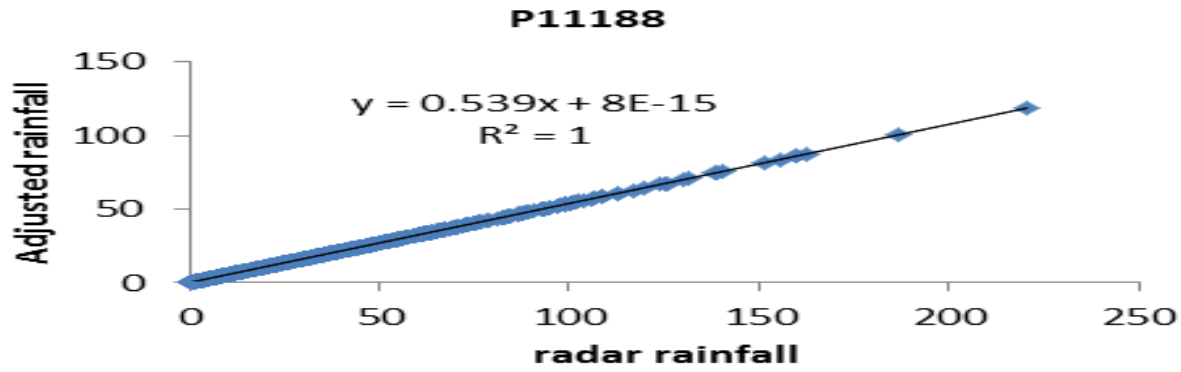

P11788
y = 0.1759x + 2.5551
R² = 0.0214
rain gauge
radar rainfall
250
200
150
100
50
0
0
50
100
150
200
250
300

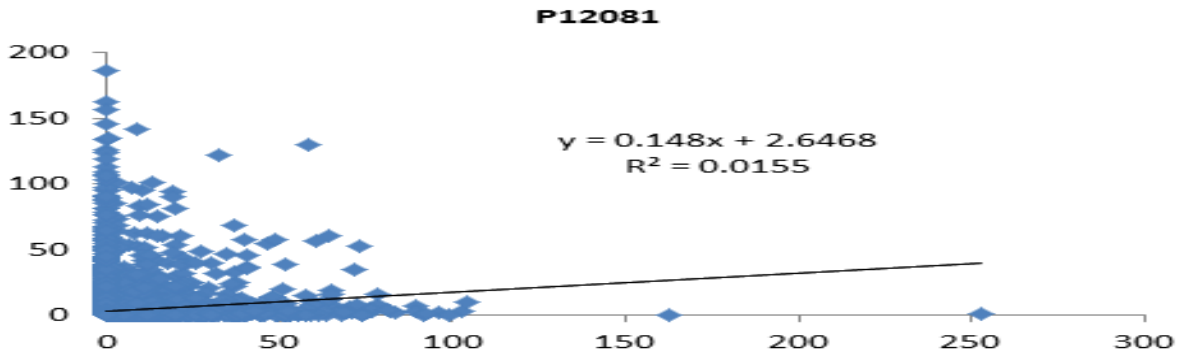

P11788
y = 0.7914x - 4E-15
R² = 1
200
150
100
50
0
-50
0
50
100
150
200
250

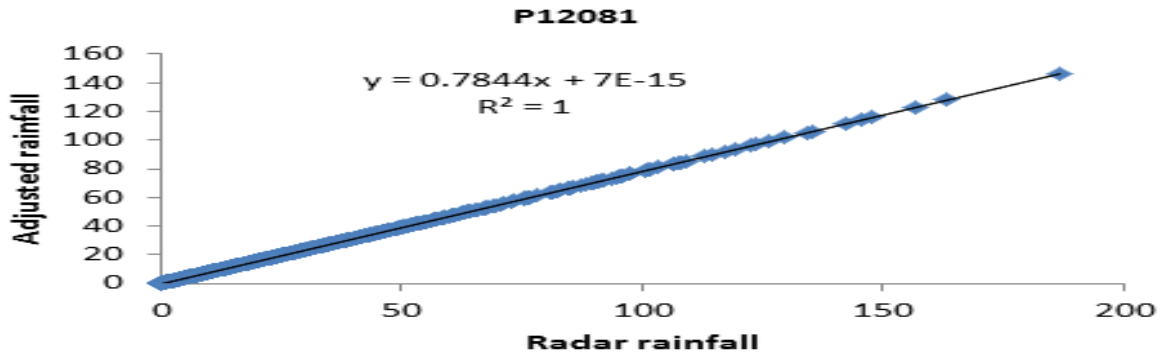

P11791
y = 0.1795x + 2.5565
R² = 0.023
rain gauge
radar rainfall
0
20
40
60
80
100
120
140
160
0
50
100
150
200
250
300

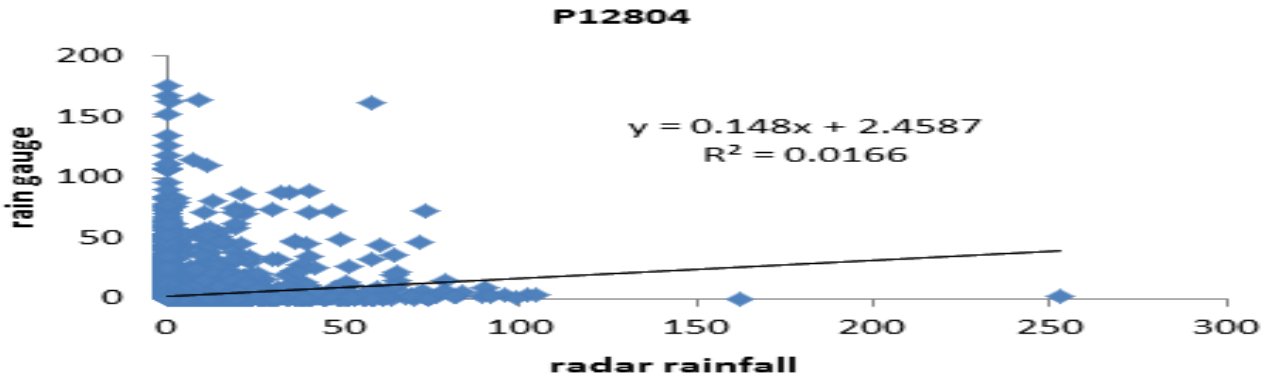

P11791
y = 0.7887x - 2E-15
R² = 1
200
150
100
50
0
-50
0
50
100
150
200
250

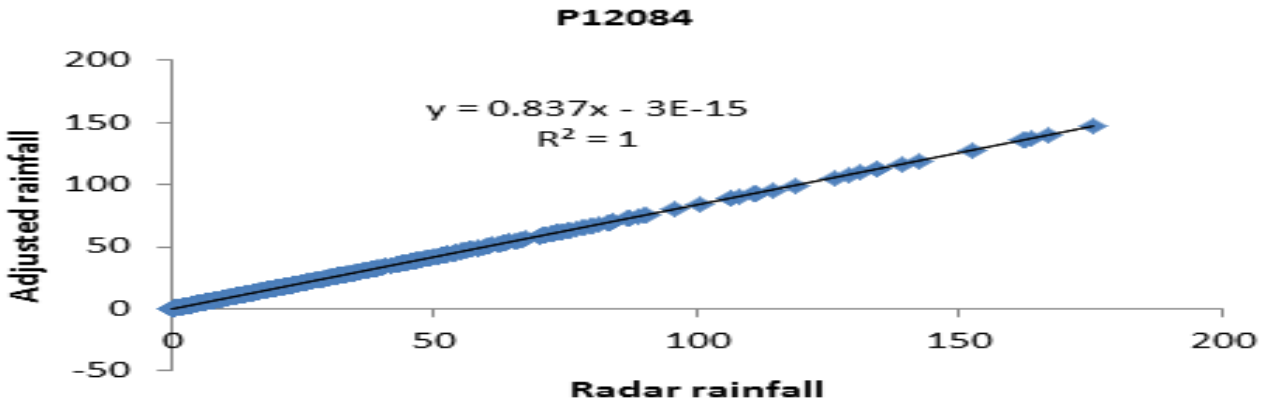

P11188
y = 0.2136x + 3.8514
R² = 0.0263
rain gauge
radar rainfall
250
200
150
100
50
0
0
50
100
150
200
250
300

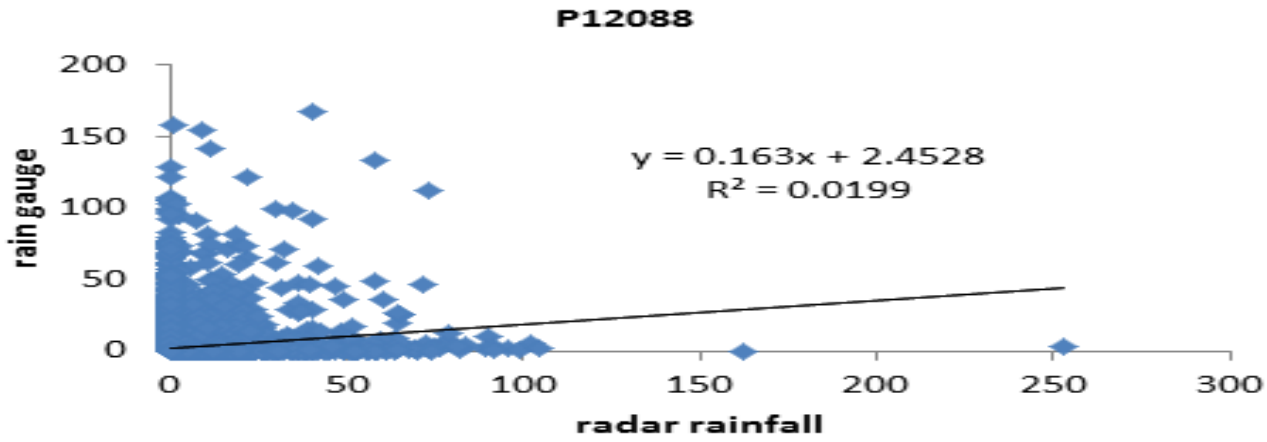

P11188
y = 0.539x + 8E-15
R² = 1
Adjusted rainfall
radar rainfall
150
100
50
0
0
50
100
150
200
250

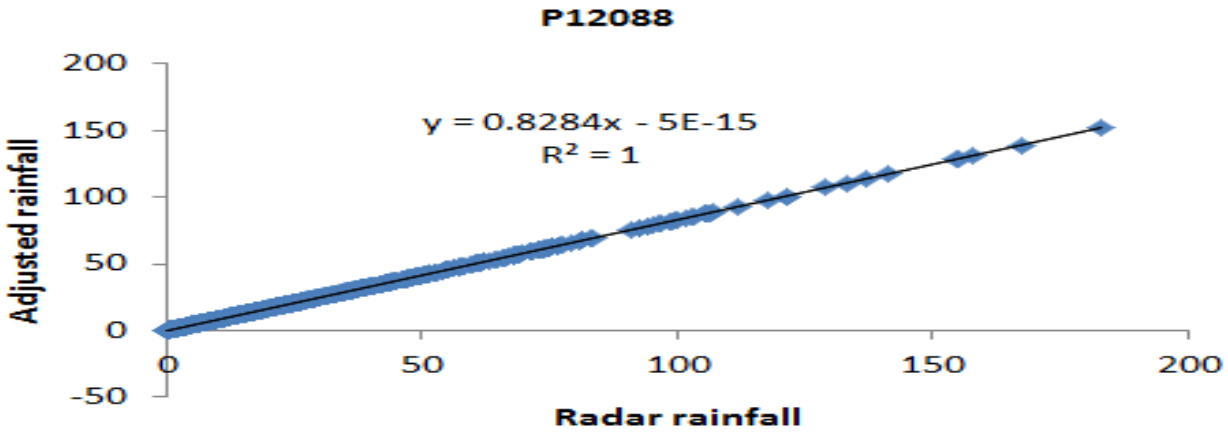

P12081
y = 0.148x + 2.6468
R² = 0.0155
200
150
100
50
0
0
50
100
150
200
250
300

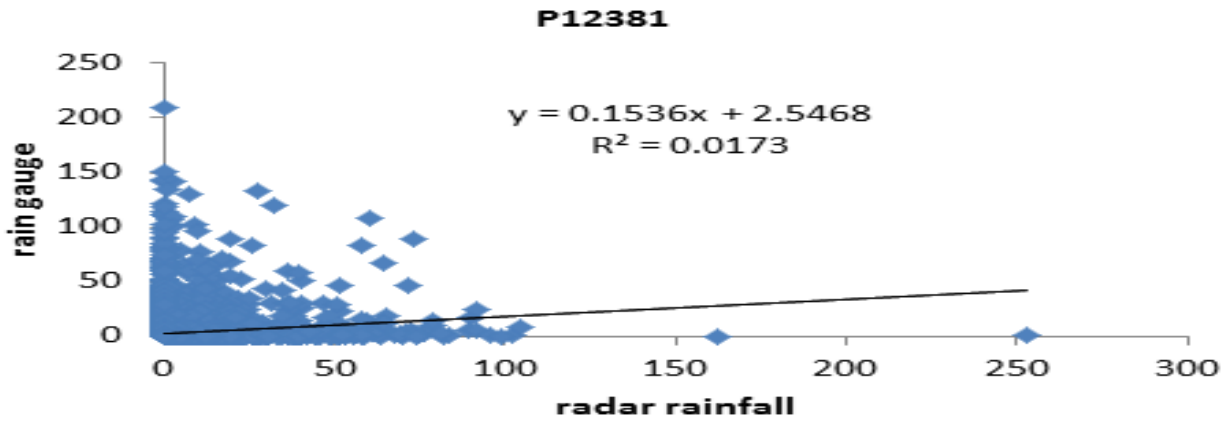

P12081
y = 0.7844x + 7E-15
R² = 1
Adjusted rainfall
160
140
120
100
80
60
40
20
0
0
50
100
150
200
Radar rainfall

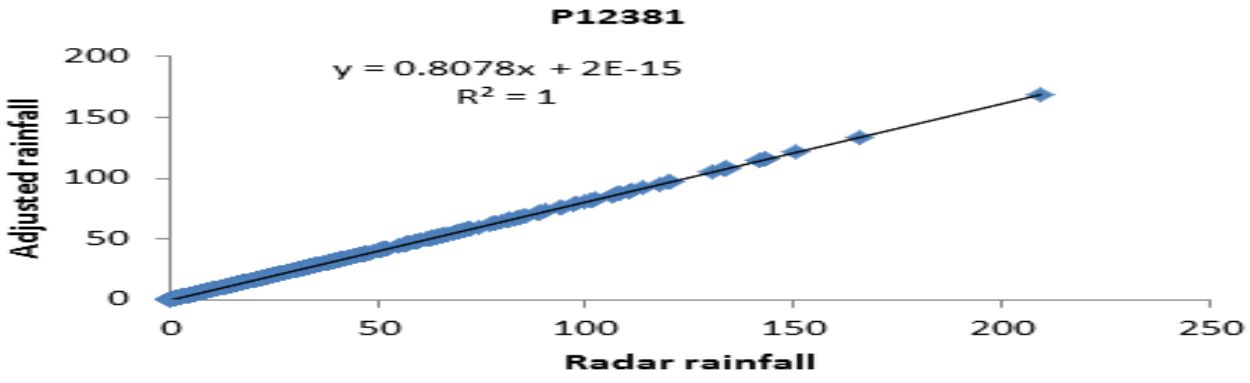

P12804
y = 0.148x + 2.4587
R² = 0.0166
rain gauge
200
150
100
50
0
0
50
100
150
200
250
300
radar rainfall

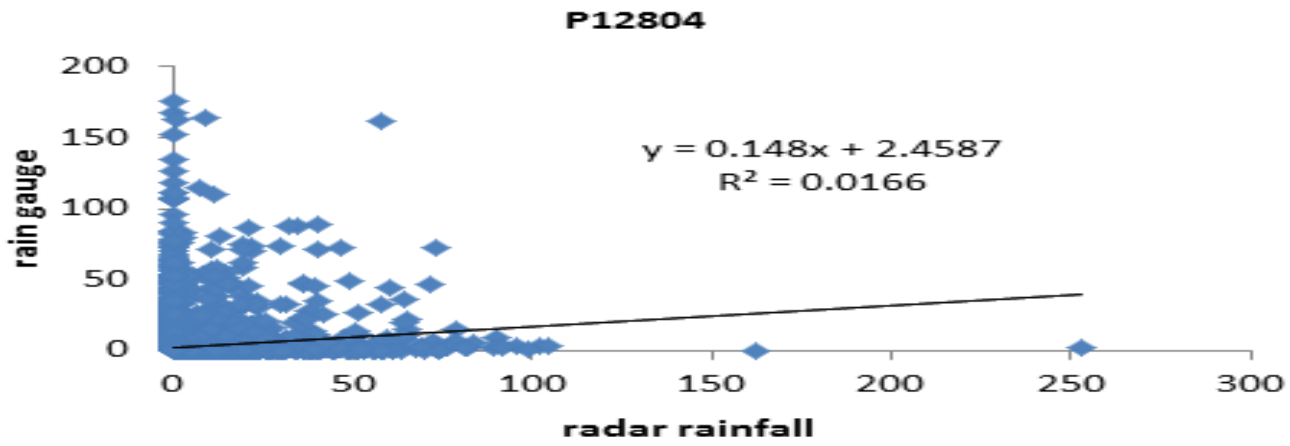

P12084
y = 0.837x - 3E-15
R² = 1
Adjusted rainfall
200
150
100
50
0
-50
0
50
100
150
200
Radar rainfall

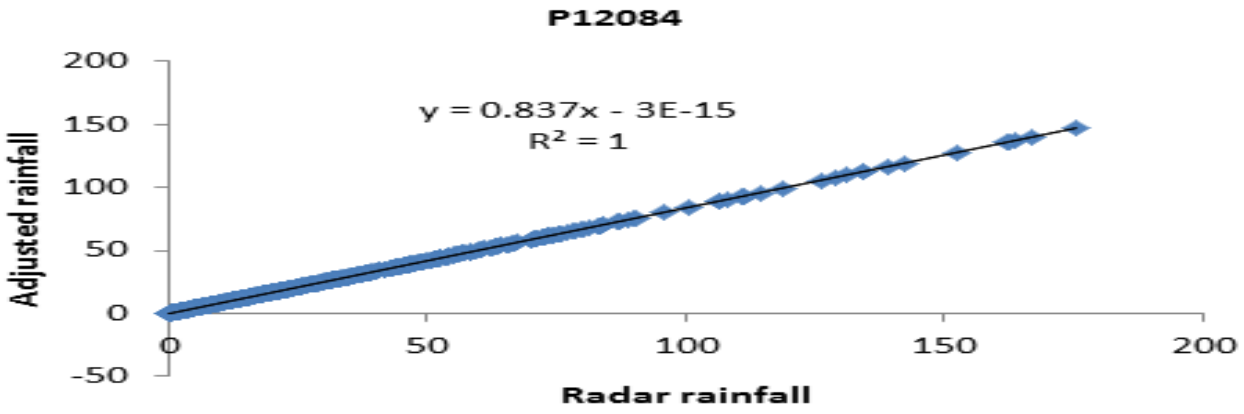

P12088
y = 0.163x + 2.4528
R² = 0.0199
rain gauge
radar rainfall
200
150
100
50
0
0
50
100
150
200
250
300

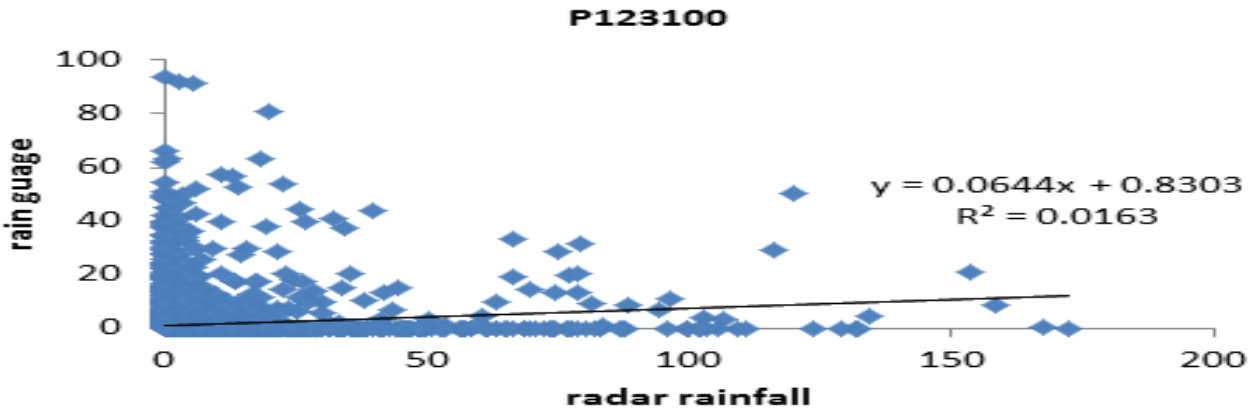

P12088
y = 0.8284x - 5E-15
R² = 1
Adjusted rainfall
Radar rainfall
200
150
100
50
0
-50
0
50
100
150
200

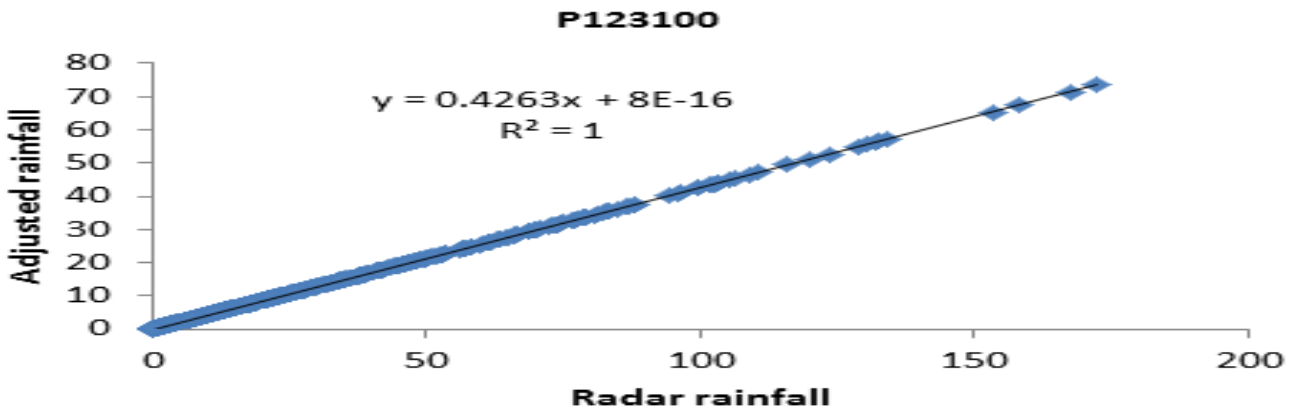

P12381
y = 0.1536x + 2.5468
R² = 0.0173
rain gauge
radar rainfall
250
200
150
100
50
0
0
50
100
150
200
250
300

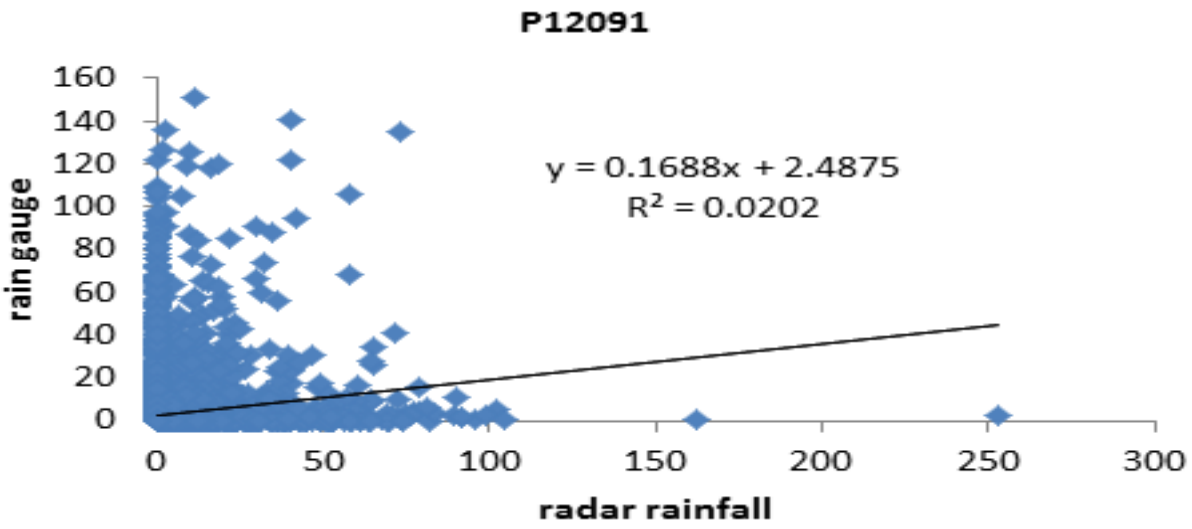

P12381
y = 0.8078x + 2E-15
R² = 1
Adjusted rainfall
Radar rainfall
200
150
100
50
0
0
50
100
150
200
250

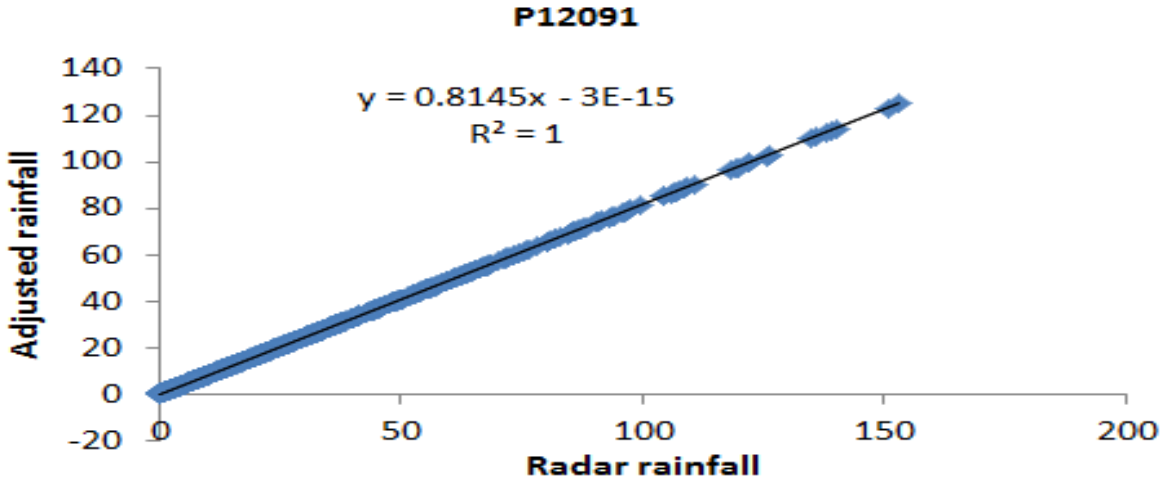

P12804
y = 0.148x + 2.4587
R² = 0.0166
rain gauge
radar rainfall
0
50
100
150
200
250
300


P12084
y = 0.837x - 3E-15
R² = 1
Adjusted rainfall
Radar rainfall
-50
0
50
100
150
200

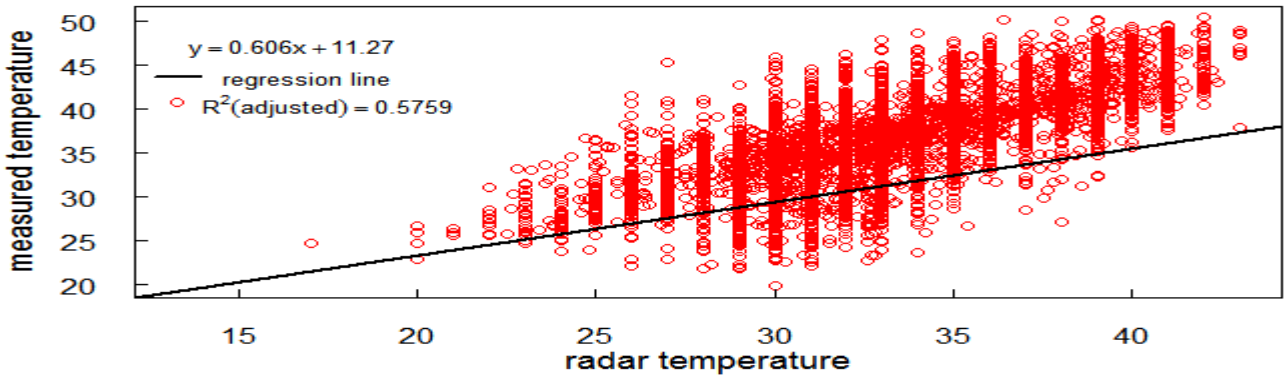

P123100
y = 0.0644x + 0.8303
R² = 0.0163
rain guage
radar rainfall
0
20
40
60
80
100
150
200

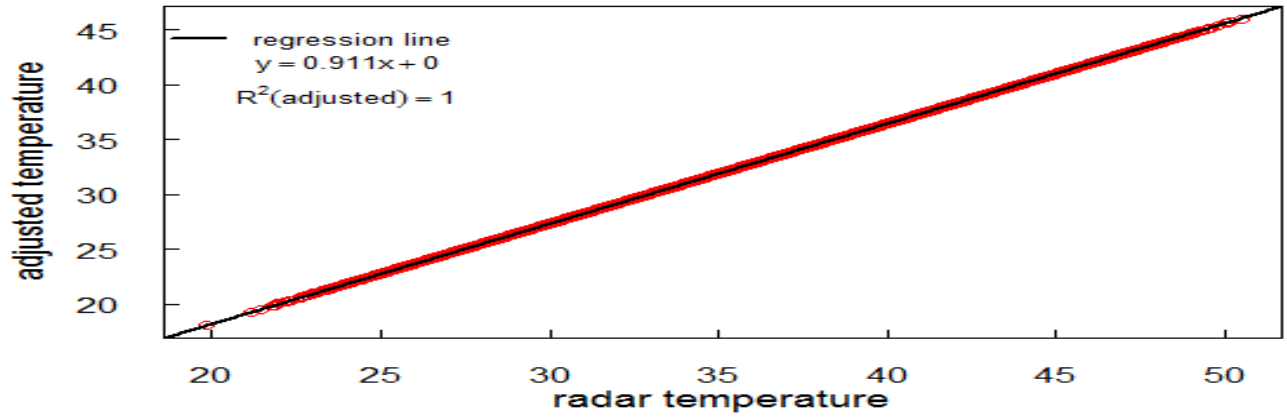

P123100
y = 0.4263x + 8E-16
R² = 1
Adjusted rainfall
Radar rainfall
0
10
20
30
40
50
60
70
80
150
200

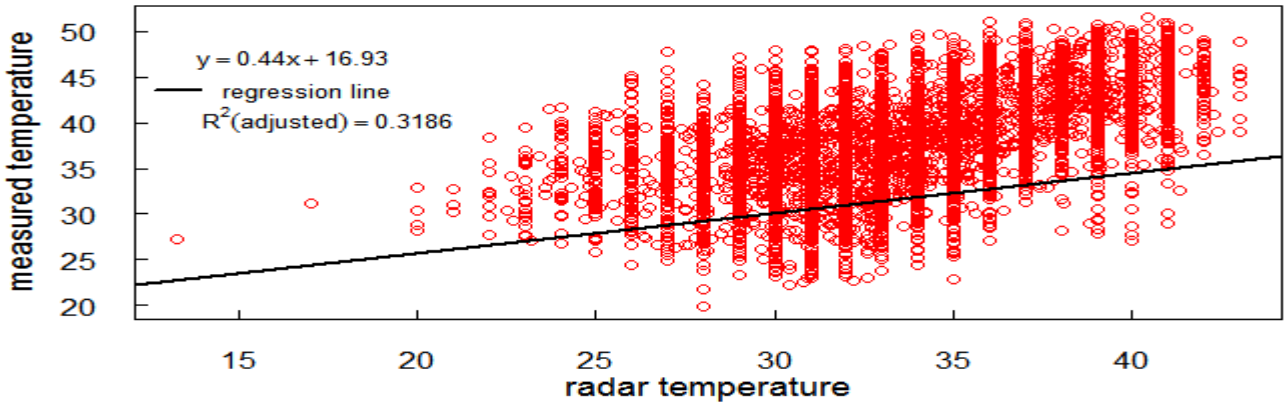

P12091
y = 0.1688x + 2.4875
R² = 0.0202
rain gauge
radar rainfall
0
20
40
60
80
100
120
140
160
0
50
100
150
200
250
300

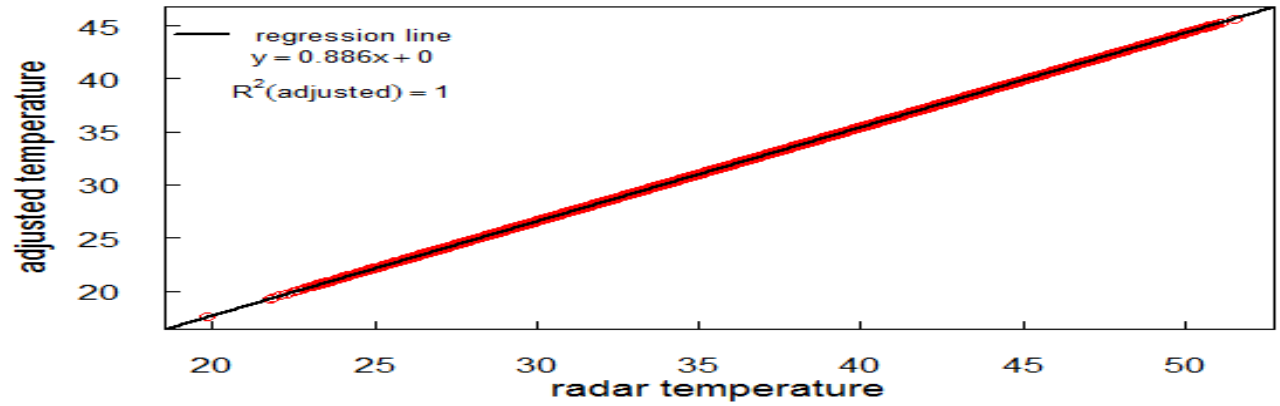

P12091
y = 0.8145x - 3E-15
R² = 1
Adjusted rainfall
Radar rainfall
-20
0
20
40
60
80
100
120
140
0
50
100
150
200

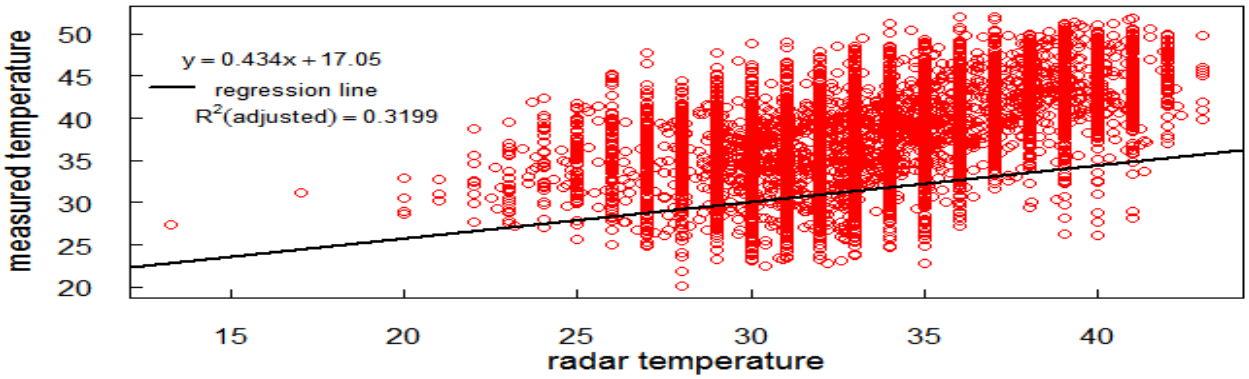
APPENDIX A2: Radar and adjustment temperature correlation plots

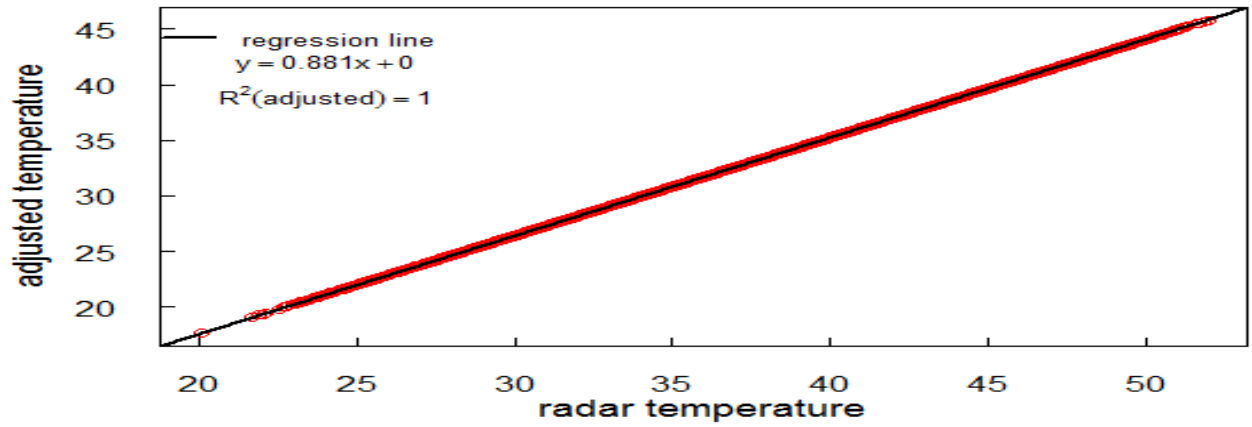


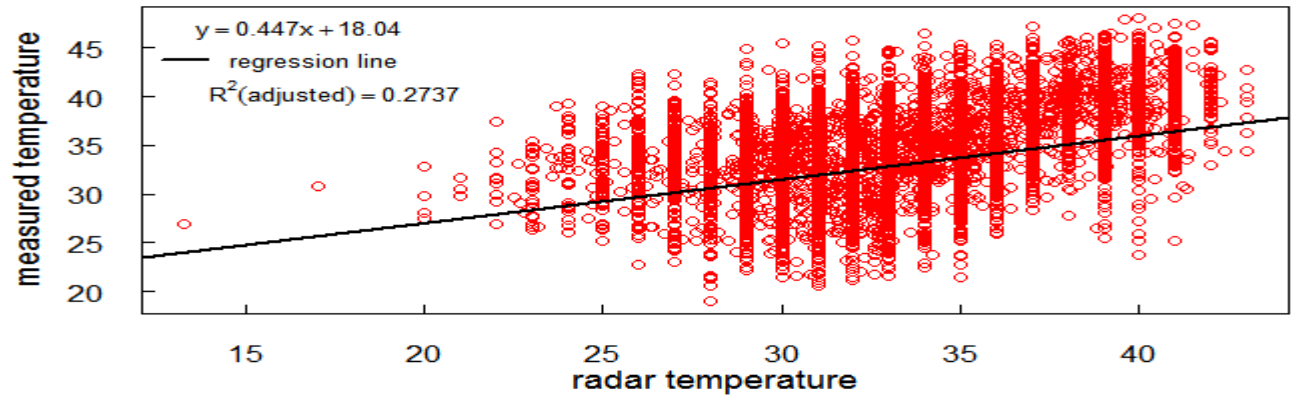


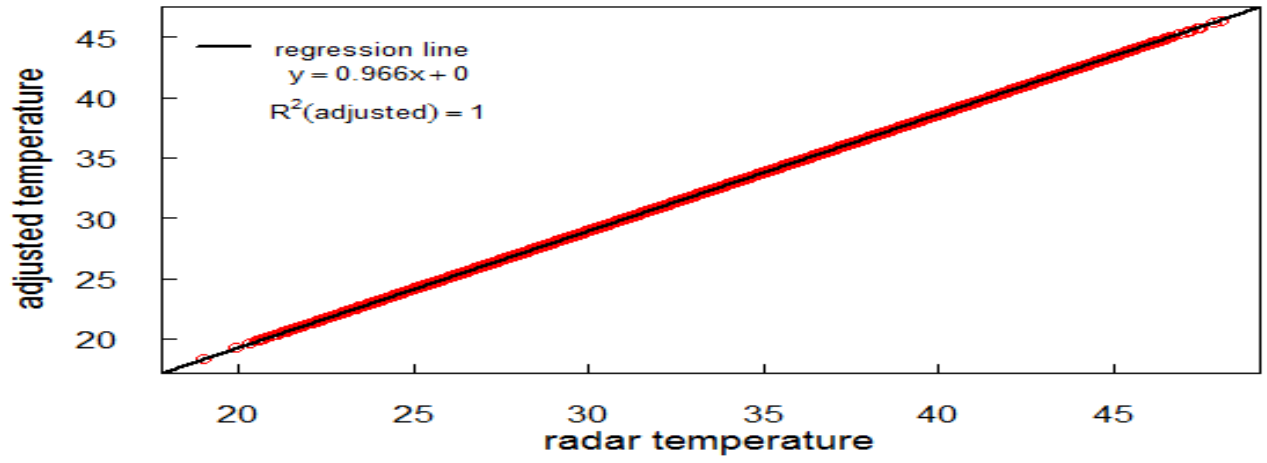


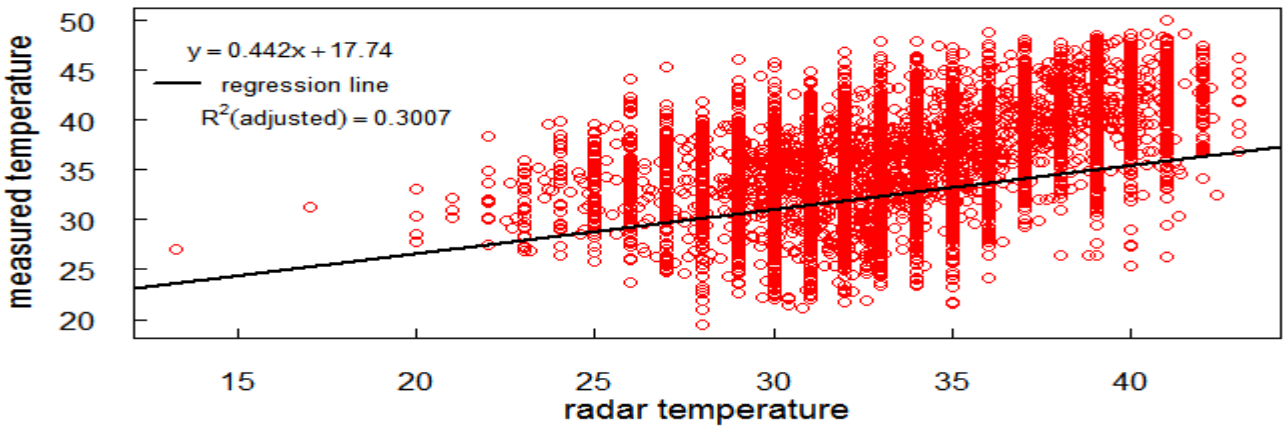


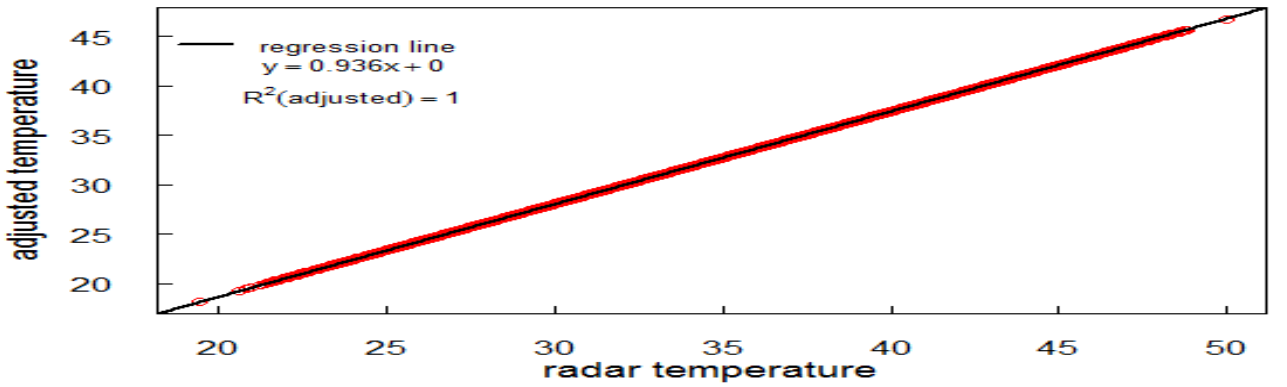

y = 0.434x + 17.05
regression line
R²(adjusted) = 0.3199
measured temperature
radar temperature

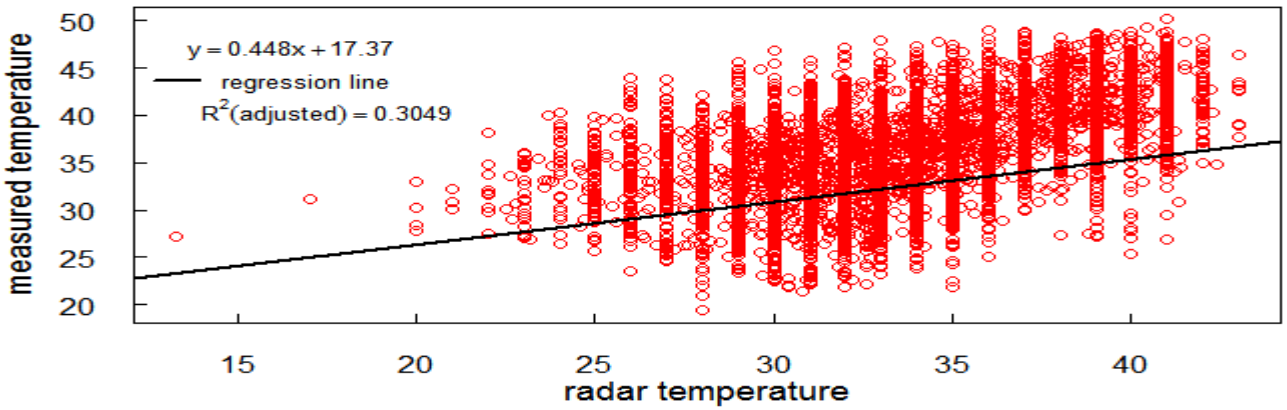

regression line
y = 0.881x + 0
R²(adjusted) = 1
adjusted temperature
radar temperature

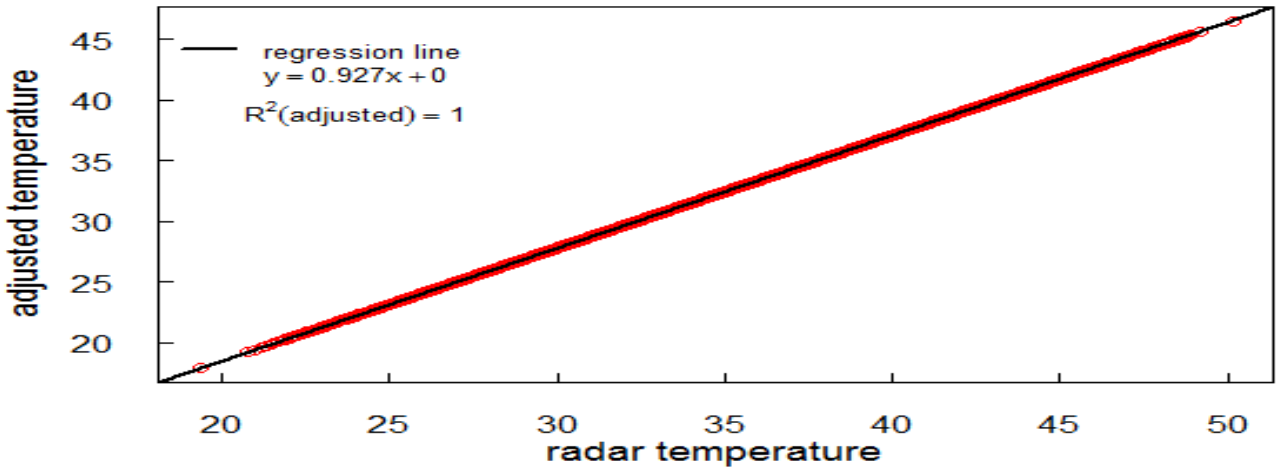

y = 0.447x + 18.04
regression line
R²(adjusted) = 0.2737
measured temperature
radar temperature

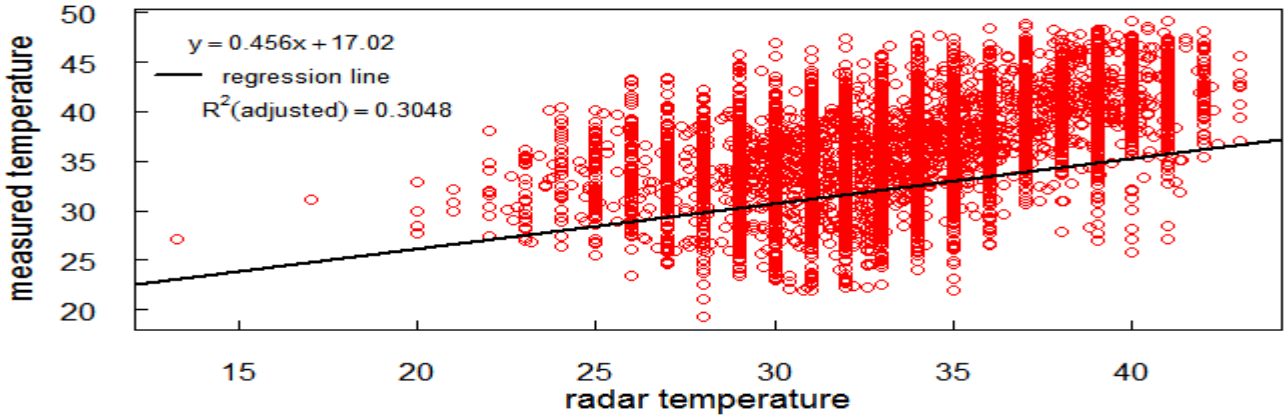

regression line
y = 0.966x + 0
R²(adjusted) = 1
adjusted temperature
radar temperature

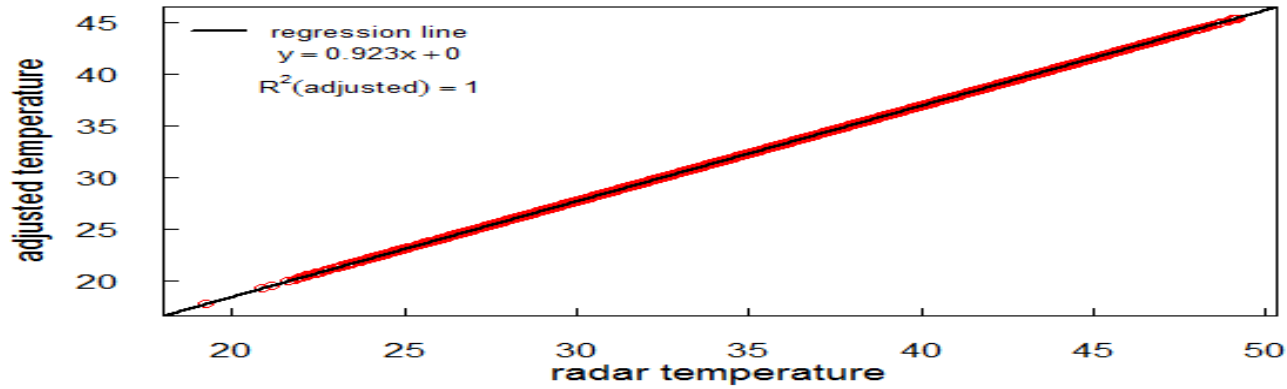

y = 0.442x + 17.74
regression line
R²(adjusted) = 0.3007
measured temperature
radar temperature
50
45
40
35
30
25
20
15
20
25
30
35
40

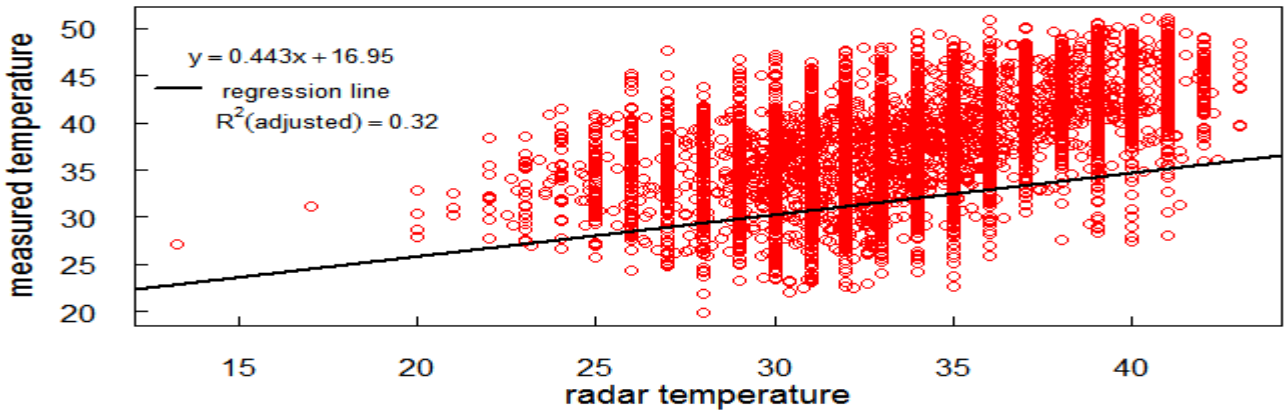

regression line
y = 0.936x + 0
R²(adjusted) = 1
adjusted temperature
radar temperature
45
40
35
30
25
20
20
25
30
35
40
45
50

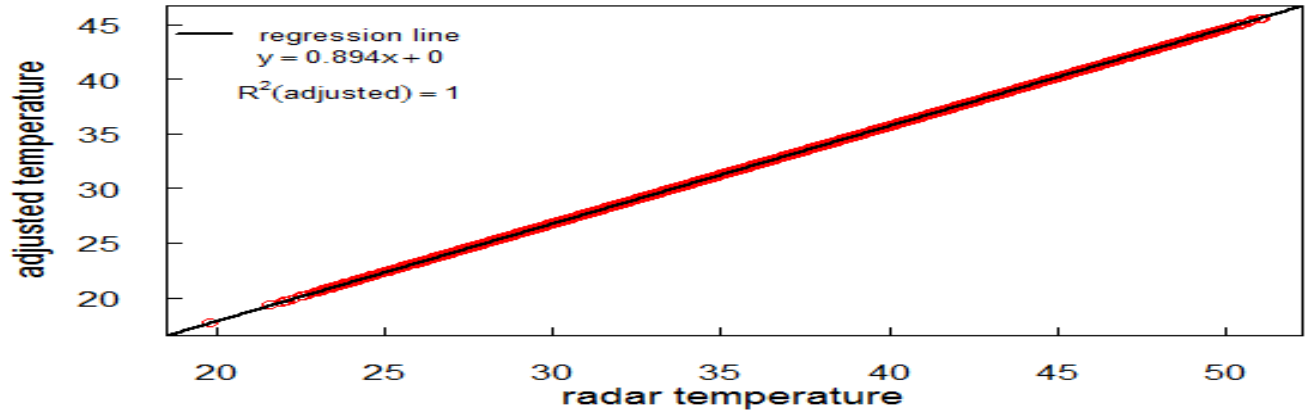

y = 0.448x + 17.37
regression line
R²(adjusted) = 0.3049
measured temperature
radar temperature
50
45
40
35
30
25
20
15
20
25
30
35
40

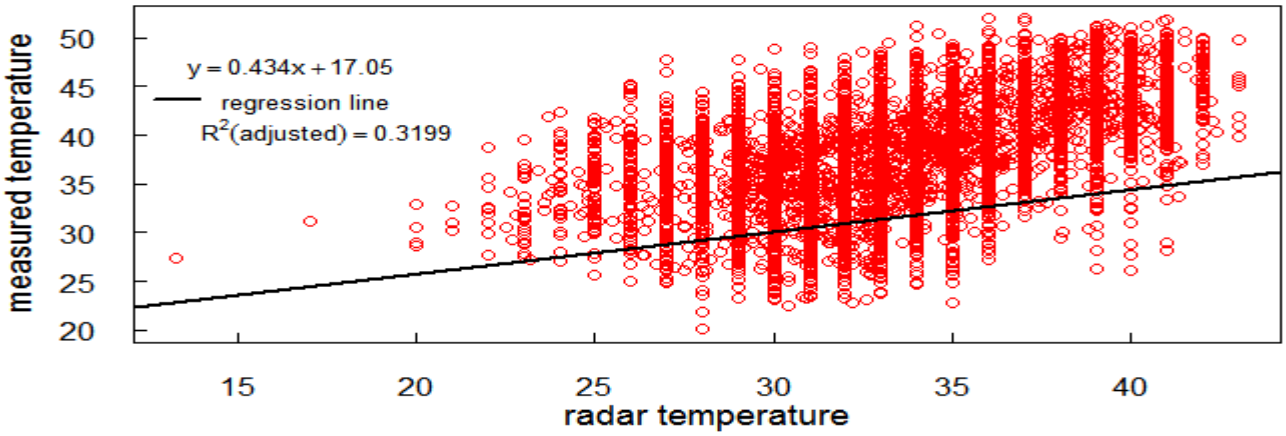

regression line
y = 0.927x + 0
R²(adjusted) = 1
adjusted temperature
radar temperature
45
40
35
30
25
20
20
25
30
35
40
45
50

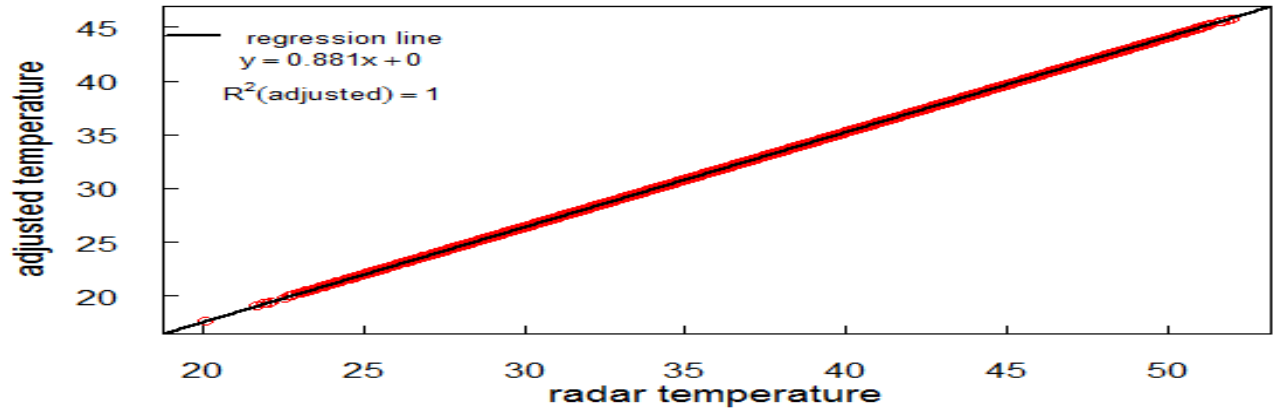

y = 0.456x + 17.02
regression line
R²(adjusted) = 0.3048
measured temperature
radar temperature

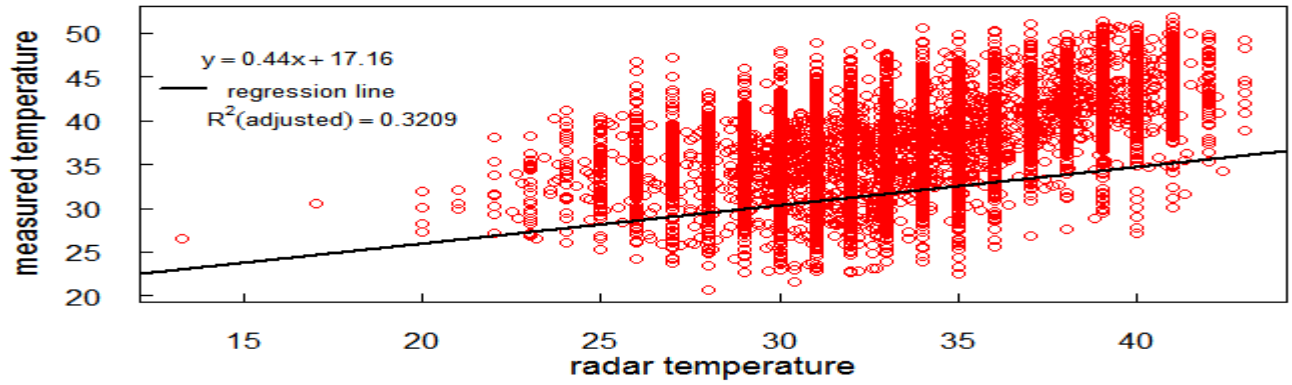

regression line
y = 0.923x + 0
R²(adjusted) = 1
adjusted temperature
radar temperature

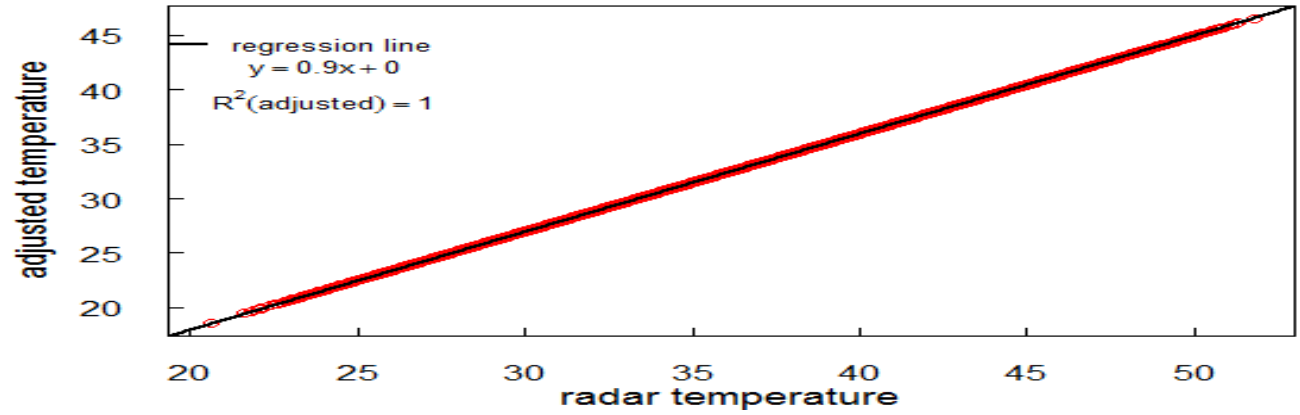

y = 0.443x + 16.95
regression line
R²(adjusted) = 0.32
measured temperature
radar temperature

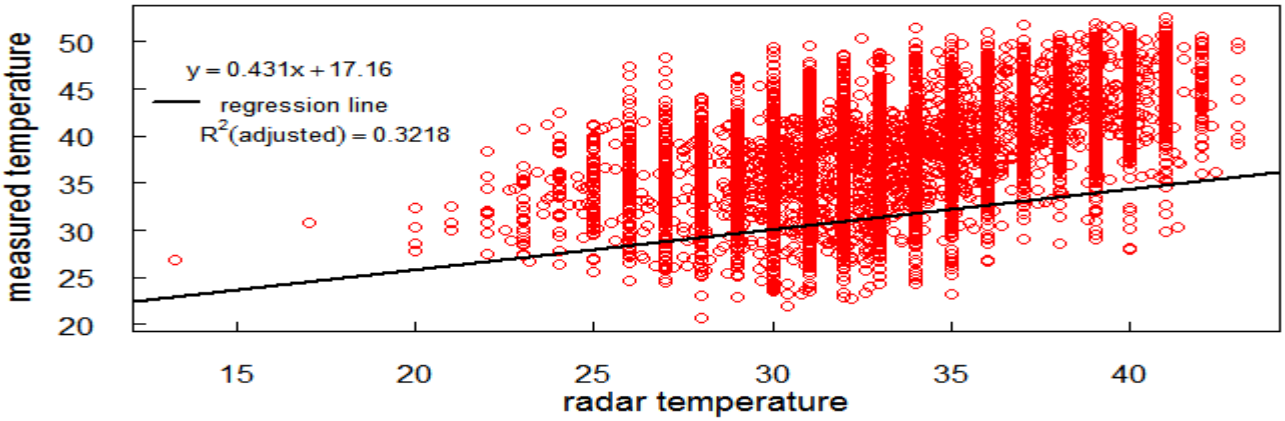

regression line
y = 0.894x + 0
R²(adjusted) = 1
adjusted temperature
radar temperature

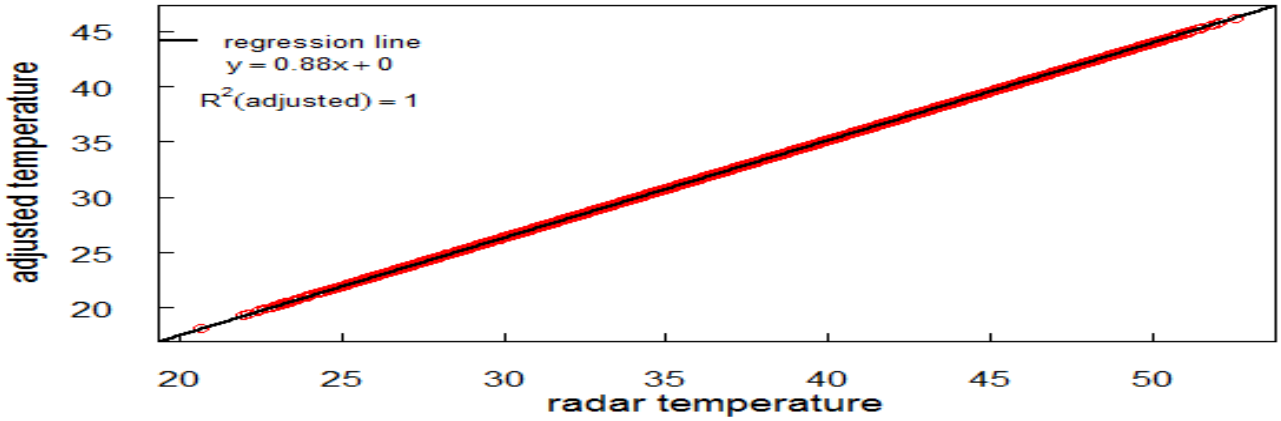

y = 0.434x + 17.05
regression line
R²(adjusted) = 0.3199
measured temperature
radar temperature

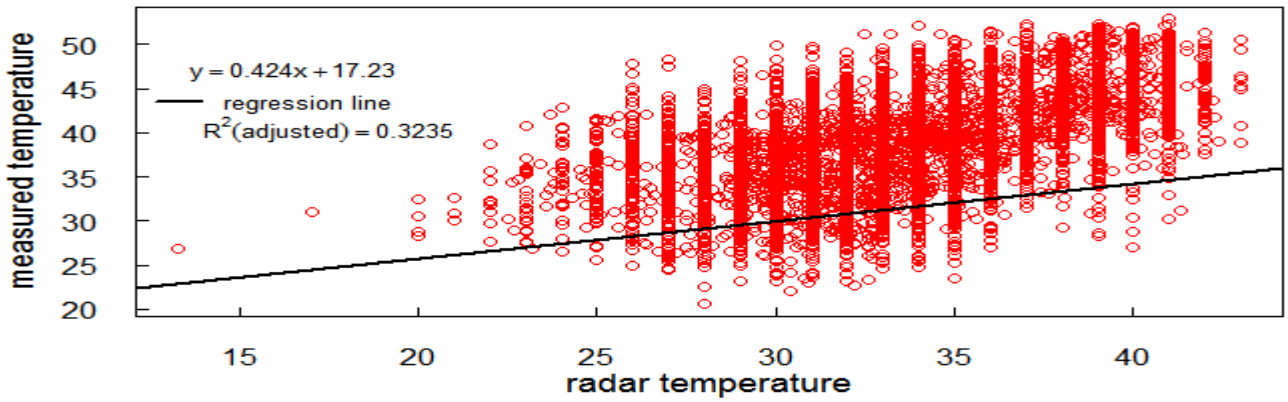

regression line
y = 0.881x + 0
R²(adjusted) = 1
adjusted temperature
radar temperature

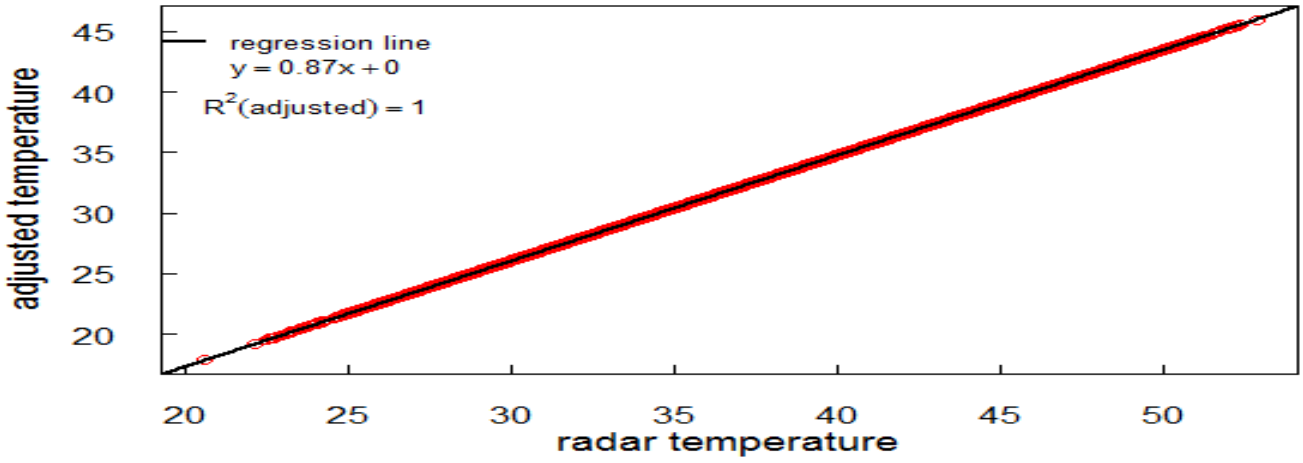

y = 0.44x + 17.16
regression line
R²(adjusted) = 0.3209
measured temperature
radar temperature

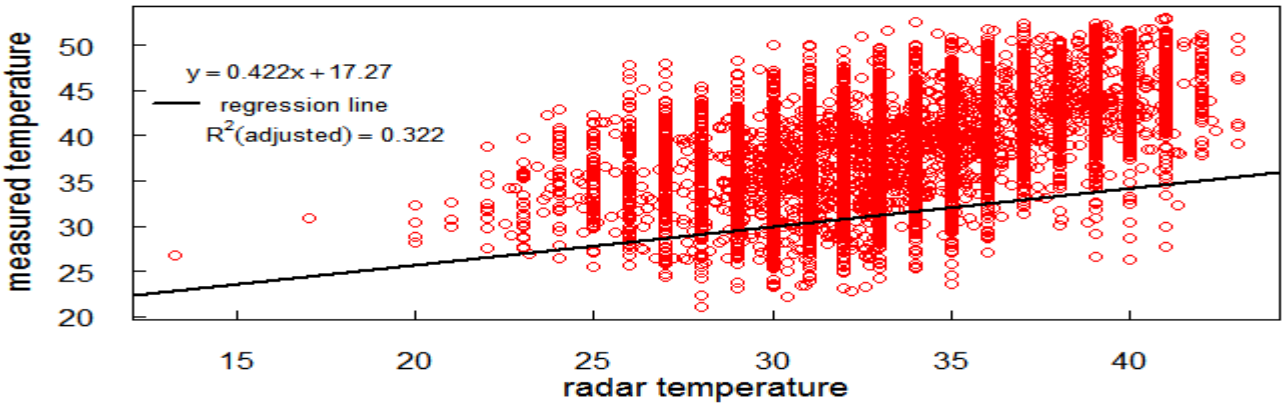

regression line
y = 0.9x + 0
R²(adjusted) = 1
adjusted temperature
radar temperature

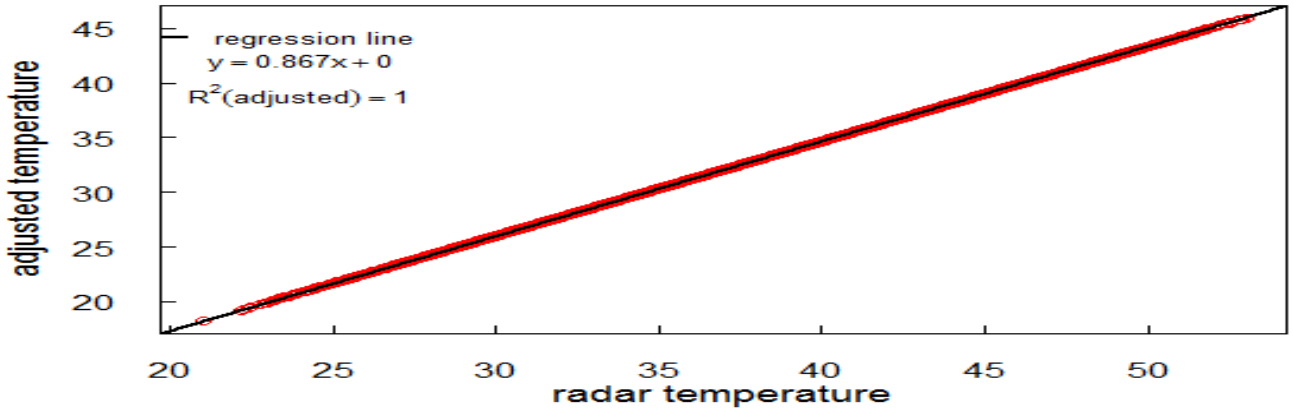

y = 0.431x + 17.16
regression line
R2(adjusted) = 0.3218
measured temperature
radar temperature

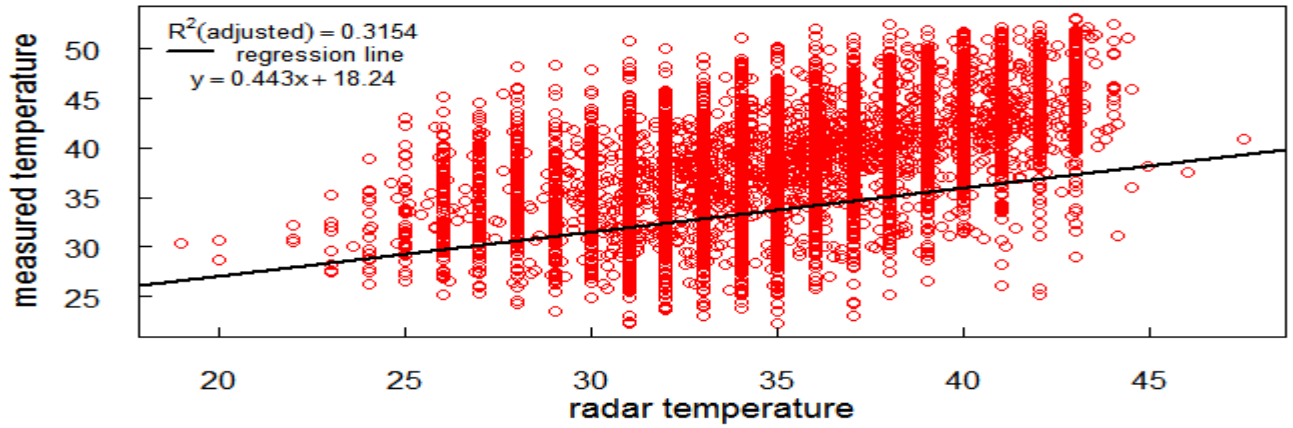

regression line
y = 0.88x + 0
R2(adjusted) = 1
adjusted temperature
radar temperature

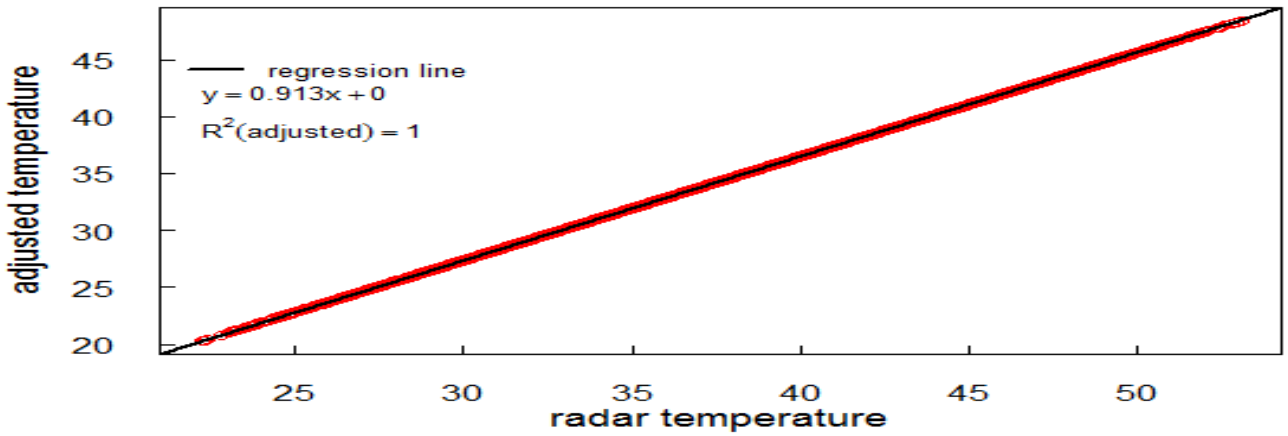

y = 0.424x + 17.23
regression line
R2(adjusted) = 0.3235
measured temperature
radar temperature

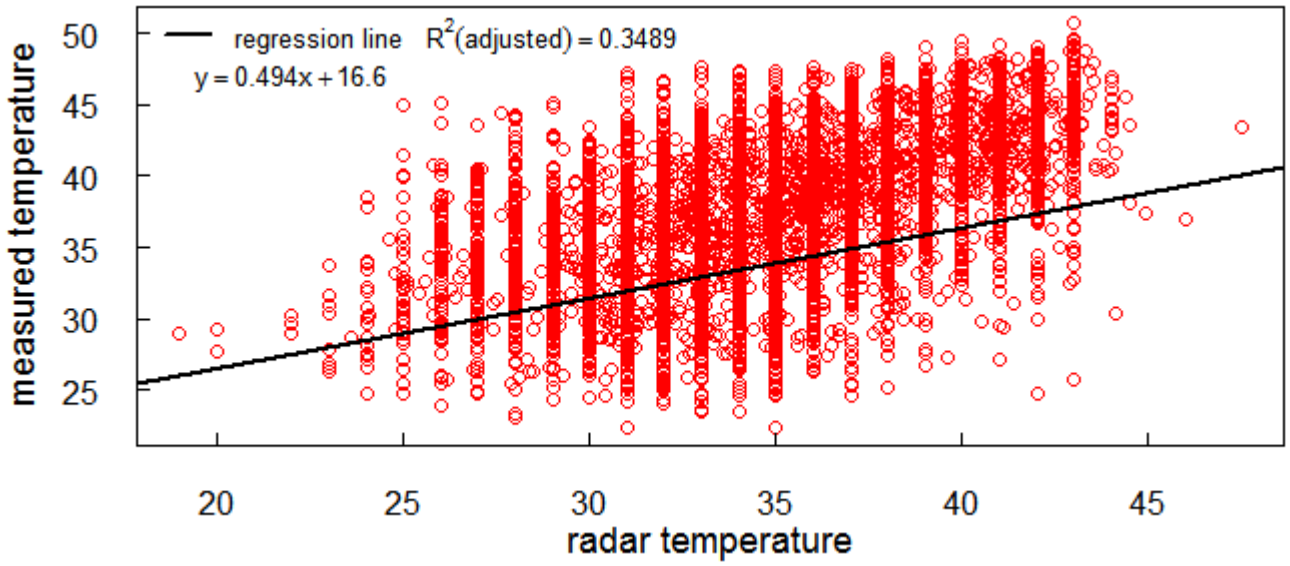

regression line
y = 0.87x + 0
R2(adjusted) = 1
adjusted temperature
radar temperature

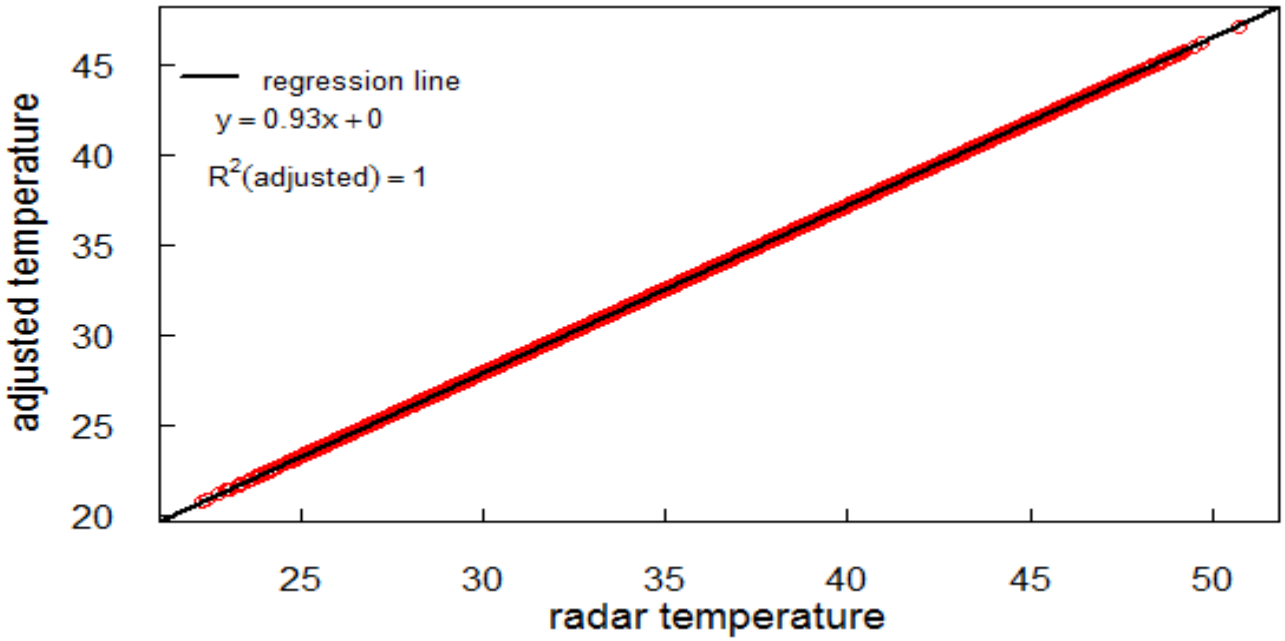

y = 0.422x + 17.27
regression line
R2(adjusted) = 0.322
measured temperature
radar temperature


regression line
y = 0.867x + 0
R2(adjusted) = 1
adjusted temperature
radar temperature


R2(adjusted) = 0.3154
regression line
y = 0.443x + 18.24
measured temperature
radar temperature


regression line
y = 0.913x + 0
R2(adjusted) = 1
adjusted temperature
radar temperature


regression line
R^2(adjusted) = 0.3489
y = 0.494x + 16.6
measured temperature
radar temperature
50
45
40
35
30
25
20
25
30
35
40
45


regression line
y = 0.93x + 0
R^2(adjusted) = 1
adjusted temperature
radar temperature
45
40
35
30
25
20
25
30
35
40
45
50

APPENDIX A3: Mean monthly field rainfall time series

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feb	0.1	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0
Mar	2.5	4.4	15.8	8.6	3.2	1.1	0.0	3.1	1.5	2.4
Apr	3.6	10.1	32.8	105.8	1.6	0.0	10.0	35.4	4.7	20.4
May	68.1	35.5	199.9	73.9	12.2	23.7	43.2	40.3	56.2	110.8
Jun	34.1	54.3	30.2	75.0	34.5	41.6	68.2	19.1	117.9	18.3
Jul	84.1	12.7	34.0	19.8	23.0	45.9	30.3	39.4	41.7	19.8
Aug	33.7	28.0	22.3	39.8	23.7	27.6	17.7	49.4	62.5	20.2
Sep	17.6	30.1	29.4	21.8	25.8	22.5	113.2	68.9	123.2	94.1
Oct	20.5	4.8	9.3	9.3	24.6	4.4	1.5	5.1	10.3	11.1
Nov	3.0	2.2	0.0	0.2	0.0	0.2	0.0	0.0	2.4	0.0
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.4	0.0

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feb	0.0	1.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Mar	7.3	3.6	14.0	1.5	5.8	4.2	0.3	1.2	0.0	0.0
Apr	30.2	40.0	4.5	13.2	8.5	22.9	74.2	1.5	18.9	15.6
May	71.5	42.6	15.8	19.8	18.0	35.6	92.7	16.1	38.6	58.4
Jun	14.0	42.9	38.9	121.6	26.6	18.3	6.6	53.0	80.1	55.5
Jul	24.8	19.5	14.1	17.4	57.6	33.6	44.6	5.3	83.7	42.6
Aug	38.2	50.9	76.3	76.6	53.0	24.8	47.4	58.8	108.1	82.8
Sep	73.0	39.5	107.8	100.8	20.3	86.9	15.7	36.4	87.9	60.1
Oct	3.7	3.9	62.4	5.3	9.7	14.7	3.7	26.5	72.5	3.6
Nov	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0
Feb	0.0	0.0	0.3	0.0	0.3	0.0	13.7	0.0	0.0	0.0
Mar	0.8	0.0	1.1	0.0	0.0	0.2	4.4	24.3	2.1	0.0
Apr	0.9	3.0	0.4	145.6	9.6	76.1	73.7	68.0	9.7	24.9
May	20.0	47.8	73.7	82.1	20.3	15.1	21.5	17.2	8.9	33.9
Jun	13.0	118.4	30.3	30.3	39.7	14.7	59.3	85.5	32.4	18.9
Jul	72.1	63.5	30.4	20.1	78.5	44.2	20.2	82.4	39.3	38.9
Aug	50.0	137.2	62.0	140.7	32.6	21.5	89.9	61.7	44.3	96.1
Sep	116.3	41.9	7.8	64.7	12.4	27.4	40.0	145.0	13.2	18.7
Oct	7.1	10.6	2.0	15.4	58.6	49.1	11.4	45.2	20.6	4.7
Nov	0.0	0.0	2.2	0.0	0.0	0.0	1.3	0.9	0.0	0.0
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	2012	2013	2014	2015
Jan	0.0	0.5	0.0	0.0
Feb	0.0	0.0	0.0	0.0
Mar	0.0	0.0	3.6	6.7
Apr	4.5	8.4	10.8	25.1
May	36.4	20.3	18.3	31.1
Jun	44.8	26.9	31.1	47.9
Jul	104.8	29.4	53.5	52.6
Aug	61.8	41.0	67.7	59.1
Sep	15.7	25.5	28.2	39.3
Oct	11.3	1.3	23.4	27.5
Nov	0.0	0.2	0.0	0.0
Dec	0.0	0.0	0.0	0.0

APPENDIX A4: Mean monthly field temperature time series

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Jan	33.7	27.5	32.2	35.2	33.5	34	33.5	28.5	33.9	33.1
Feb	35	35.7	35.4	33	37	36.9	36	31.8	33.3	39
Mar	38.3	36.5	39.4	39	40.1	38.4	39	37.5	36.1	39
Apr	40.1	40.4	40.4	38.5	42.2	38.4	39.6	39.6	41.2	39.8
May	36.7	41.2	39.2	39.9	39.7	39.8	37.6	37.5	37.9	34.7
Jun	36.2	34.8	36.9	35.6	36.4	33.7	35	35.3	36.3	37
Jul	30.7	31.5	32.8	28.6	29	34.2	28	29.3	29.1	29.8
Aug	27.2	27.7	34.4	29.3	28.7	28.7	24.9	27	29.7	27.4
Sep	29.3	30.5	33.5	30.7	29.3	30.9	27.7	28.9	32.5	32.7
Oct	32.2	33.4	36.5	35.3	33.7	33.9	31.5	31	35.1	33.9
Nov	32	34	35.2	35.4	34.3	34.8	33	33.1	36.3	34.1
Dec	33.2	33.3	32.6	32.5	29.8	34.1	31.5	31.6	35.2	31.2

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Jan	31.2	29.6	32.8	32.2	34.3	33.4	32.1	33	34.2	32.4
Feb	33.1	34.7	35	33.8	36.9	32	36	37.4	32.1	34.3
Mar	38.4	36.9	40	39.2	38.7	37.8	37.3	40.5	37.7	39.1
Apr	38.8	39.3	39.9	39.2	39.5	35.7	41.6	41.7	42.6	40.3
May	36	39.3	39.7	36.1	38.1	34.8	40.5	40.5	41.9	40
Jun	35.5	35.2	35.8	34.5	32.4	33.2	36.9	37.8	38.4	36.7
Jul	28.9	30.7	28.3	28.9	29	30	32	33	34.9	32.3
Aug	25.9	27.9	25.6	27.3	25.8	29.3	27.7	29.8	32.9	29.4
Sep	28.7	31	27.9	28.7	27.9	31.5	29.3	33.5	35.5	33.8
Oct	32.9	34.7	31.1	32.1	31.6	34.8	33.5	34.9	37.8	35.7
Nov	31.6	35.5	31.4	32.1	31.4	35.4	33.8	34.8	36.1	35.3
Dec	32	32.1	29	32.9	33	32.4	32	32.2	32.5	34

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Jan	31	34.3	34.1	32.1	36.4	31	30.8	35.5	34.6	31.2
Feb	35.5	37.8	35.2	39.3	39	36.7	33.8	37.5	38.2	36.8
Mar	40.4	38.4	37.9	40.5	39.4	39.3	39.6	39.3	39	38.9
Apr	42	40.8	42	41.4	40.3	41.8	39.5	40.3	42.2	41.3
May	42.6	41	39.7	39	40.4	41	38.7	38	40.9	39.8
Jun	38.9	38.1	38	36.7	39.5	37.3	36.6	36.9	37.4	37.7
Jul	34.2	34.1	35.9	32.4	35.8	31.9	30.9	33.2	29.5	34.9
Aug	32.1	30.8	32.8	30.7	30.9	28.2	28	30.9	28.8	29.5
Sep	34	32.7	36.6	34	31.7	31.1	31.6	32.8	30.6	31.8
Oct	33.8	35.7	37.8	35.9	35.5	35.3	34.2	35.1	33.9	34.2
Nov	34.9	35.6	37	35.7	33.3	35.1	35.1	34.6	35	33.6
Dec	32.8	33.3	35.1	34.8	31.4	33.3	34	33.9	31.8	31

	2012	2013	2014	2015
Jan	32.5	33.4	35.7	36.3
Feb	36.8	36.6	39	38.3
Mar	38	40.6	38.6	38.8
Apr	42.3	39.7	40.2	40.2
May	39.2	41.1	36.8	39.3
Jun	36.1	37.5	33.8	33.3
Jul	29.4	32.6	32.7	33.6
Aug	27.2	27.6	32.3	33
Sep	30	30.8	32.2	32.6
Oct	34.3	32.8	34.5	33.8
Nov	34.4	34.6	35.7	34.9
Dec	31.7	32.2	35.8	35.8

APPENDIX A5: Mean annual sub-basin hydrological parameters using 1975 land use/cover digital map

YEAR	PET(mm)	ET(mm)	GWQ(mm)	SURQ(mm)	WYLD(mm)	SYLDa(t/hect)	LATQ(mm)
1982	307.1	108.6	136.1	309	309.7	32	0.4
1983	322.9	108.7	111.8	278.1	323.5	31	0.3
1984	293.7	103.7	51.7	81.5	87	11	0.2
1985	301.3	115.2	170.6	399	481.1	71.2	0.5
1986	310.8	117.6	121.4	221	239.4	25.1	0.3
1987	322	100.6	153.4	395.7	453.3	65.2	0.3
1988	319.3	96.8	133.6	370.9	482.4	46.2	0.4
1989	291.6	101.3	173.6	360.7	392.3	88.8	0.4
1990	327.5	111.2	111.5	299.8	322.4	62.7	0.3
1991	303.4	109.5	122.6	147.8	227.5	20.6	0.3
1992	293.4	94.7	161.2	285.2	321.3	55.2	0.5
1993	293.8	104.4	151.9	266.8	313.1	39.4	0.3
1994	305.6	100.5	127.5	202.1	215.2	27.7	0.4
1995	293	108.3	164.1	350.4	446.1	52.9	0.5
1996	289.9	99.8	156.7	322.2	439.9	45.8	0.4
1997	284.4	109.8	112.4	203.2	212.3	23.7	0.3
1998	320.7	99.4	127.3	245.8	331.3	45.8	0.4
1999	307.3	106.4	77.1	185.8	198.5	23.7	0.2
2000	322.2	75.9	0	22.3	22.3	1.8	0.1
2001	318.1	103.1	60.1	315.9	316.2	53	0.2
2002	325.1	101	38	195.3	195.7	43.8	0.2
2003	309.3	98.2	85.4	268.6	268.7	46.8	0.2
2004	318	100.6	23.8	49	49.8	5.4	0.1
2005	315.6	104.7	73.5	128	172.2	13.8	0.2
2006	307.7	98.8	94.5	392.6	404.8	49.9	0.3
2007	306	101	96.9	198.6	224.4	50.2	0.3
2008	288.1	106.4	156.8	256.7	284.6	59.4	0.4
2009	321	96.9	83.6	143	194.6	16.1	0.2
2010	314.2	93.4	107.5	228.8	267.9	32.7	0.3
2011	343.9	95.8	26.7	169.9	170.3	14.6	0.2
2012	321.9	96.2	85.5	157.8	160.7	19.8	0.2
2013	310.6	96.4	34.4	217.5	217.8	49	0.2

APPENDIX A6: Mean annual sub-basin hydrological parameters using 2000 land use/cover digital map

YEAR	PET(mm)	Et(mm)	GWQ(mm)	SURQ(mm)	WYLD(mm)	SYLD(t/hecter)	LATQ(mm)
1982	307.1	112.3	133.2	307.3	307.9	30.4	0.3
1983	322.9	110.1	108.8	285	325.4	29.5	0.3
1984	293.7	102.4	49.4	85.4	86.1	10.6	0.2
1985	301.3	115.1	165.7	401.3	486.1	69.9	0.4
1986	310.8	122.8	118.1	221.8	239.4	23.9	0.3
1987	322	104.1	149	405.8	456.9	61.5	0.3
1988	319.3	104.1	130.3	376.7	485	44.8	0.4
1989	291.6	104.4	169.4	370.3	392.3	83.6	0.4
1990	327.5	113	108.8	307.2	322.6	59.2	0.3
1991	303.4	116	119.6	151.6	228	18.8	0.3
1992	293.4	96	156.5	285.8	321	40.5	0.5
1993	293.8	111.4	147.9	273.4	314.5	37.7	0.3
1994	305.6	100	125	202.4	215.6	26.5	0.4
1995	293	114.7	160.4	350.2	446.1	45.9	0.4
1996	289.9	105.4	152.8	331	443.7	44.8	0.4
1997	284.4	108.7	109.5	198.7	212.5	19.2	0.3
1998	320.7	107.1	124	247.4	332.7	43.4	0.4
1999	307.3	106.2	74.7	191.1	202.9	23.3	0.2
2000	322.2	77.6	0	25.1	25.1	1.9	0
2001	318.1	111.8	56.3	317.1	317.3	47.5	0.2
2002	325.1	100.7	36.6	195.2	195.5	41.8	0.2
2003	309.3	100.5	81.4	268.9	269	45.6	0.2
2004	318	99.8	21.2	51.4	51.9	5	0.1
2005	315.6	109.9	71.1	131.3	172.2	12.6	0.2
2006	307.7	98.5	91.3	401.2	412.6	48.9	0.3
2007	306	102.9	94.2	198.8	224.1	49.1	0.3
2008	288.1	106.3	152.2	261.3	286.4	56.4	0.4
2009	321	96.4	81	146.7	195.8	15.8	0.2
2010	314.2	101.9	104.4	233	269.8	32.1	0.3
2011	343.9	95.9	24.7	169.9	170.3	12.9	0.2
2012	321.9	102.6	82.5	160.3	162	17.4	0.2
2013	310.6	106	33.1	217.5	217.8	47.2	0.2

APPENDIX A7: Mean annual sub-basin hydrological parameters using 2013 land use/cover digital map

YEAR	PET(mm)	Et(mm)	GWQ(mm)	SURQ(mm)	WYLD(mm)	SYLD(t/hecter)	LATQ(mm)
1982	307.1	112.3	133.2	307.3	307.9	30.4	0.3
1983	322.9	110.1	108.8	285	325.4	29.5	0.3
1984	293.7	102.4	49.4	85.4	86.1	10.6	0.2
1985	301.3	115.1	165.7	401.3	486.1	69.9	0.4
1986	310.8	122.8	118.1	221.8	239.4	23.9	0.3
1987	322	104.1	149	405.8	456.9	61.5	0.3
1988	319.3	104.1	130.3	376.7	485	44.8	0.4
1989	291.6	104.4	169.4	370.3	392.3	83.6	0.4
1990	327.5	113	108.8	307.2	322.6	59.2	0.3
1991	303.4	116	119.6	151.6	228	18.8	0.3
1992	293.4	96	156.5	285.8	321	40.5	0.5
1993	293.8	111.4	147.9	273.4	314.5	37.7	0.3
1994	305.6	100	125	202.4	215.6	26.5	0.4
1995	293	114.7	160.4	350.2	446.1	45.9	0.4
1996	289.9	105.4	152.8	331	443.7	44.8	0.4
1997	284.4	108.7	109.5	198.7	212.5	19.2	0.3
1998	320.7	107.1	124	247.4	332.7	43.4	0.4
1999	307.3	106.2	74.7	191.1	202.9	23.3	0.2
2000	322.2	77.6	0	25.1	25.1	1.9	0
2001	318.1	111.8	56.3	317.1	317.3	47.5	0.2
2002	325.1	100.7	36.6	195.2	195.5	41.8	0.2
2003	309.3	100.5	81.4	268.9	269	45.6	0.2
2004	318	99.8	21.2	51.4	51.9	5	0.1
2005	315.6	109.9	71.1	131.3	172.2	12.6	0.2
2006	307.7	98.5	91.3	401.2	412.6	48.9	0.3
2007	306	102.9	94.2	198.8	224.1	49.1	0.3
2008	288.1	106.3	152.2	261.3	286.4	56.4	0.4
2009	321	96.4	81	146.7	195.8	15.8	0.2
2010	314.2	101.9	104.4	233	269.8	32.1	0.3
2011	343.9	95.9	24.7	169.9	170.3	12.9	0.2
2012	321.9	102.6	82.5	160.3	162	17.4	0.2
2013	310.6	106	33.1	217.5	217.8	47.2	0.2

APPENDIX A8: R programming plots commands

Rainfall Area Plot

```
rainfl=read.table(file.choose(),sep=",",header = F)
rainfl
rainflts=ts(rainfl,start = c(1979,1),frequency = 12)
raint=aggregate(rainflts,FUN=sum)
rainflyear <- data.frame(Year = as.numeric(time(raint)),precipitation = as.numeric(raint))
ht=ggplot(rainflyear, aes(x=Year, y=precipitation),cex=0.8) + geom_area(colour="black",
fill="lightblue",alpha=.5)+scale_x_continuous(breaks=seq(1982,2015))+theme_bw()+them
e(axis.text.x=element_text(angle=90,hjust=1,vjust=.5,colour="darkred",size=rel(1.5)))+the
me(axis.text.y=element_text(colour="blue", size=rel(1.5)))
ht+theme(axis.title.y=element_text(angle=90,size=14))+theme(axis.title.x=element_text(siz
e=14))
hc=ht+theme(axis.title.y=element_text(angle=90,size=14))+theme(axis.title.x=element_text
(size=14))
hc+theme(panel.grid.major\=element_blank(),panel.grid.minor=element_blank())+geom_hl
ine(yintercept=34.65)+ annotate("text", x=2, y=0.3, parse=TRUE,label="frac(1, sqrt(2 *
pi)) * e ^ {-x^2 / 2}")+arrow=arrow(ends="both", angle=90, length=unit(.2,"cm")))
```

Dendrogram Plot Command

```
library(circlize)
library("cluster")
anuualtotal=c(87,71,112,68,76,45,80,72,64,81,102,133,51,79,76,66,114,69,67,80,69,43,74,
138,90,21,40,60,118,91,
49,71,47,42,100,52,65,51,64,50,63,49,62,48,61,47,60,46,59,45,58,44,57,43)
Year=seq(1982,2035,1)
pnt=data.frame(Year,anuualtotal)
dd <- dist(scale(pnt), method = "euclidean")
hc <- hclust(dd, method = "ward.D2")
labs = paste(pnt$Year)
nodePar <- list(lab.cex = 0.6, pch = c(NA, 19), cex = 0.7, col = "blue")
rownames(pnt)<-labs
dend <- pnt%>% dist %>%hclust %>% as.dendrogram %>% set("labels_colors") %>%
set("labels_cex", c(1,1))
 %>%set("leaves_pch", 19) %>% set("leaves_col", c("blue", "red"))
plot(dend)
mtext("Year",side=1,lines=2)
```

Mean Temperature Plot

```
tp=ggplot(tepyear,aes(x=Year,y=temperature))+theme_set(theme_bw())+geom_point(size=
3) +geom_segment(aes(x=Year,xend=Year,y=0,yend=temperature)) +theme(axis.text.x =
element_text(angle=90, vjust=0.6))+geom_point(col="tomato2", size=3)
tp+scale_x_continuous(breaks=seq(1982, 2013, 1))+ theme_set(theme_bw())+
theme(axis.text.x = element_text(angle=90, hjust=1, vjust=.5,colour="darkred"("text",
x=1993, y=36, label="Mean Line",col="navyblue"), size=rel(1.5)))+
theme(axis.text.y=element_text(colour="red2",size=rel(1.5)),tcl=0.3)+theme(axis.title.y=el
ement_text(angle=90,size=14))+theme(axis.title.x=element_text(size=14))+theme(panel.gri
d.major = element_blank(),panel.grid.minor = element_blank())+
geom_hline(yintercept=34.65,linetype="dashed",lwd=1.1)+annotate
```

Matrix Plot Command

```
matrix=read.table(file.choose(),sep=",",header=T)
m1=subset(matrix,select=-year)
monthplot(tmps,xlab="",ylab="",las=1,tcl=0.3,col="red",xaxt="n")
axis(1,at=1:12,labels=month.abb,cex=0.8)
mtext(ylab.text,side=2,line=2,cex=1.1)
 mtext("month",side=1,line=2,cex=1.1)
```

APPENDIX A9: 500 iterations to obtain the best simulation for observed stream flow

1	0.2000	0.2000	-0.0756	0.5130	410.1000	0.9220	1.3220	0.0690	0.2390	0.8690	1.612288
2	0.2000	0.2000	0.0324	0.3770	44.7000	0.4300	0.0540	0.8730	0.5510	0.7610	0.155390
3	0.2000	0.2000	0.1572	0.4330	449.5800	1.3180	0.1540	0.6650	0.4150	0.6010	0.616372
4	0.2000	0.2000	-0.0540	0.6770	105.1800	0.4020	1.2060	0.0230	0.5090	0.3690	1.027248
5	0.2000	0.2000	-0.0916	0.9970	173.2200	0.0140	1.6740	0.5150	0.6130	0.6430	1.331104
6	0.2000	0.2000	-0.1252	0.8310	437.8200	1.7940	0.1660	0.1950	0.6790	0.7550	1.805143
7	0.2000	0.2000	0.1492	0.9990	327.7800	0.8060	0.5500	0.1010	0.8170	0.9830	0.557508
8	0.2000	0.2000	0.0772	0.4450	295.8600	0.9540	1.2540	0.9290	0.3290	0.0770	1.044268
9	0.2000	0.2000	-0.0092	0.4670	197.5800	0.5060	1.6260	0.1910	0.3190	0.7010	1.167621
10	0.2000	0.2000	0.1652	0.9370	134.5800	1.5300	0.6780	0.4290	0.5810	0.3550	0.416932
11	0.2000	0.2000	0.1228	0.2590	59.8200	0.3460	1.6060	0.6690	0.3730	0.2950	0.169477
12	0.2000	0.2000	-0.0284	0.2870	448.7400	1.7780	1.6780	0.2470	0.4610	0.5450	1.523598
13	0.2000	0.2000	-0.1204	0.8330	174.9000	0.7300	1.1100	0.3050	0.7770	0.9170	1.387475
14	0.2000	0.2000	-0.1668	0.0570	405.9000	0.1020	1.0460	0.9550	0.4530	0.8090	1.901478
15	0.2000	0.2000	0.1404	0.3230	242.1000	0.7260	0.6180	0.6790	0.7810	0.0130	0.661197
16	0.2000	0.2000	-0.1404	0.5810	77.4600	0.8180	0.5420	0.1370	0.7830	0.0470	1.035406
17	0.2000	0.2000	0.0596	0.8490	293.3400	1.6700	1.8980	0.2570	0.1790	0.0110	1.165525
18	0.2000	0.2000	0.0756	0.4830	205.1400	1.1940	1.6980	0.8630	0.5110	0.0810	0.940065
19	0.2000	0.2000	0.0908	0.8950	295.0200	1.3500	1.4620	0.6770	0.1070	0.2310	0.912431
20	0.2000	0.2000	-0.0004	0.6950	404.2200	1.8660	1.2340	0.4690	0.8750	0.4950	1.385366
21	0.2000	0.2000	0.0212	0.4390	115.2600	0.3380	1.2500	0.1390	0.9050	0.3190	0.864887
22	0.2000	0.2000	-0.1220	0.1630	126.1800	0.8100	1.6620	0.7930	0.3070	0.4430	1.323796
23	0.2000	0.2000	0.0676	0.7650	392.4600	1.9900	1.9380	0.7750	0.3350	0.7570	1.022532
24	0.2000	0.2000	-0.0820	0.9790	146.3400	0.7460	1.3300	0.7250	0.0230	0.4690	1.271651
25	0.2000	0.2000	0.1412	0.2110	287.4600	0.2220	1.6700	0.9710	0.3110	0.7430	0.597767
26	0.2000	0.2000	-0.1652	0.8070	232.0200	1.8300	1.0780	0.4050	0.8710	0.2450	1.758423
27	0.2000	0.2000	-0.0044	0.4990	148.0200	1.5180	0.7980	0.4370	0.0390	0.9150	0.975889
28	0.2000	0.2000	-0.1260	0.7810	394.9800	1.2620	1.9460	0.0670	0.9190	0.4050	1.825292
29	0.2000	0.2000	0.0092	0.9830	207.6600	0.6380	0.0860	0.1250	0.3790	0.9070	1.052326
30	0.2000	0.2000	0.0156	0.3370	72.4200	1.3900	1.0740	0.1030	0.8830	0.6750	0.538110
31	0.2000	0.2000	-0.0596	0.0910	415.9800	1.8500	1.3460	0.6130	0.0790	0.5130	1.638823
32	0.2000	0.2000	-0.0884	0.6350	420.1800	1.1460	0.5380	0.3690	0.5970	0.9970	1.621035
33	0.2000	0.2000	-0.0428	0.6910	171.5400	1.4500	0.4740	0.2190	0.7370	0.2670	1.301483
34	0.2000	0.2000	0.1852	0.3350	124.5000	1.1180	0.9020	0.5690	0.1890	0.1130	0.419886
35	0.2000	0.2000	0.1772	0.5410	439.5000	0.7340	1.5900	0.3350	0.6910	0.0290	0.695165
36	0.2000	0.2000	0.0148	0.0770	69.0600	0.1660	0.6700	0.1770	0.0310	0.1550	0.638887
37	0.2000	0.2000	-0.0292	0.9730	92.5800	1.4380	0.4140	0.2270	0.4330	0.7730	0.826791
38	0.2000	0.2000	-0.0668	0.8510	364.7400	1.9620	0.0140	0.8150	0.2290	0.2070	1.699730
39	0.2000	0.2000	-0.1756	0.4050	397.5000	0.4900	1.0420	0.9730	0.0910	0.2590	1.984206
40	0.2000	0.2000	0.0452	0.3650	383.2200	1.5140	0.0060	0.4170	0.8190	0.2690	1.226217
41	0.2000	0.2000	-0.1124	0.1910	362.2200	0.5580	1.2620	0.4850	0.3990	0.4490	1.758077

42	0.2000	0.2000	-0.1524	0.2570	294.1800	1.6340	0.6860	0.8250	0.6370	0.4670	1.770404
43	0.2000	0.2000	-0.0524	0.5110	225.3000	1.6100	1.7540	0.6450	0.7890	0.5390	1.361363
44	0.2000	0.2000	-0.1628	0.7930	253.0200	1.4140	1.0860	0.7390	0.5310	0.6110	1.681516
45	0.2000	0.2000	0.0076	0.4410	358.8600	0.4100	0.7700	0.7790	0.2070	0.0410	1.485258
46	0.2000	0.2000	-0.1172	0.6830	278.2200	0.0340	1.4380	0.1150	0.2890	0.3230	1.701448
47	0.2000	0.2000	-0.1148	0.6270	203.4600	0.7140	1.9700	0.2930	0.9850	0.1390	1.625258
48	0.2000	0.2000	0.1132	0.0930	176.5800	1.4780	0.7780	0.3730	0.6250	0.6450	0.590201
49	0.2000	0.2000	-0.1332	0.5570	241.2600	1.8980	1.3940	0.7990	0.9270	0.4770	1.636390
50	0.2000	0.2000	0.1604	0.0550	380.7000	0.3220	1.9420	0.7870	0.5530	0.1230	0.697732
51	0.2000	0.2000	-0.1540	0.4490	334.5000	1.9220	1.2580	0.7490	0.0770	0.1270	1.922713
52	0.2000	0.2000	0.1484	0.3730	443.7000	1.9060	0.2260	0.6170	0.2110	0.6690	0.655983
53	0.2000	0.2000	-0.1900	0.7310	326.1000	1.2060	1.7060	0.3750	0.2610	0.1050	1.989221
54	0.2000	0.2000	-0.0660	0.7950	46.3800	1.4300	0.0820	0.2230	0.8570	0.7530	0.330702
55	0.2000	0.2000	0.0956	0.7370	365.5800	0.7740	0.0900	0.7590	0.9710	0.4350	0.884441
56	0.2000	0.2000	-0.0676	0.2330	166.5000	0.2580	1.8180	0.6070	0.9170	0.2350	1.387090
57	0.2000	0.2000	0.1788	0.4370	104.3400	0.6780	1.5940	0.0250	0.3710	0.5070	0.352498
58	0.2000	0.2000	0.0332	0.6890	377.3400	0.8340	0.2580	0.8590	0.6730	0.1370	1.336181
59	0.2000	0.2000	-0.1868	0.2090	381.5400	1.9100	0.2540	0.7570	0.5670	0.5510	1.914196
60	0.2000	0.2000	-0.0804	0.3270	256.3800	0.7900	1.1340	0.0710	0.3770	0.1830	1.623116
61	0.2000	0.2000	-0.1876	0.7590	78.3000	0.5620	1.9300	0.6030	0.6490	0.8530	1.018682
62	0.2000	0.2000	-0.1052	0.0310	53.1000	0.6900	1.1740	0.3950	0.8290	0.1770	0.950384
63	0.2000	0.2000	-0.0052	0.7450	111.0600	1.5820	1.1500	0.0790	0.2570	0.2990	0.935057
64	0.2000	0.2000	0.1108	0.6870	109.3800	1.5900	0.8900	0.3330	0.2550	0.7230	0.434895
65	0.2000	0.2000	0.1980	0.6150	251.3400	1.5620	0.1380	0.7890	0.7250	0.1910	0.528477
66	0.2000	0.2000	-0.0308	0.4350	394.1400	1.1260	0.7660	0.2130	0.0090	0.9570	1.413460
67	0.2000	0.2000	-0.1268	0.6530	319.3800	0.2260	1.5260	0.3630	0.6150	0.7990	1.687433
68	0.2000	0.2000	0.0996	0.0350	344.5800	0.8460	1.5340	0.4130	0.2170	0.9290	0.829100
69	0.2000	0.2000	-0.1492	0.3610	230.3400	1.5500	0.9540	0.1230	0.6010	0.4230	1.673568
70	0.2000	0.2000	-0.0996	0.1150	223.6200	0.9460	1.7580	0.1110	0.9030	0.7850	1.507994
71	0.2000	0.2000	-0.1940	0.7390	323.5800	1.2260	0.7140	0.0330	0.0150	0.0310	2.017376
72	0.2000	0.2000	0.0964	0.0730	414.3000	1.2420	1.9940	0.6830	0.7270	0.0210	1.056062
73	0.2000	0.2000	-0.1028	0.9170	184.9800	1.9740	0.1020	0.4250	0.4090	0.8710	1.380148
74	0.2000	0.2000	-0.0180	0.4010	97.6200	1.5980	0.2980	0.0050	0.1130	0.1350	0.941463
75	0.2000	0.2000	-0.0732	0.2450	318.5400	0.7500	0.5900	0.0990	0.5870	0.2490	1.664804
76	0.2000	0.2000	0.0692	0.5490	172.3800	1.8380	0.6140	0.5510	0.8970	0.7810	0.779625
77	0.2000	0.2000	0.0204	0.6710	143.8200	1.1780	1.1980	0.7130	0.1030	0.1990	1.012066
78	0.2000	0.2000	-0.0228	0.6570	436.1400	0.5740	1.0900	0.0730	0.8430	0.5550	1.485435
79	0.2000	0.2000	-0.1388	0.8290	403.3800	0.0900	0.8860	0.4410	0.8350	0.2790	1.900940
80	0.2000	0.2000	0.0396	0.7990	121.1400	0.8020	0.3940	0.5310	0.1730	0.7630	0.761283
81	0.2000	0.2000	0.1356	0.8550	96.7800	0.4420	0.9820	0.6110	0.7210	0.1630	0.340845
82	0.2000	0.2000	-0.0068	0.1850	191.7000	0.5180	1.3140	0.9170	0.1830	0.4210	1.186457
83	0.2000	0.2000	-0.1108	0.8430	79.9800	0.2180	0.6060	0.9870	0.3950	0.3110	0.953123

84	0.2000	0.2000	-0.0300	0.6810	132.0600	0.9740	0.8660	0.2490	0.7330	0.2470	1.131261
85	0.2000	0.2000	-0.0324	0.1790	74.1000	0.7580	1.1260	0.8930	0.0750	0.4510	0.708739
86	0.2000	0.2000	0.0108	0.0870	284.9400	0.2980	0.5020	0.3370	0.7910	0.8030	1.207990
87	0.2000	0.2000	0.0644	0.9870	384.0600	1.3460	0.5260	0.5990	0.6550	0.7110	1.045029
88	0.2000	0.2000	-0.1884	0.2930	387.4200	0.3140	0.6460	0.8030	0.2690	0.4010	1.961663
89	0.2000	0.2000	0.0268	0.0430	389.9400	1.3620	1.7260	0.4970	0.7470	0.6910	1.287438
90	0.2000	0.2000	-0.1740	0.1890	148.8600	1.7380	0.2140	0.6150	0.8470	0.7710	1.487894
91	0.2000	0.2000	0.1908	0.6050	95.1000	0.6140	0.8980	0.5230	0.7570	0.0010	0.337810
92	0.2000	0.2000	0.0716	0.8870	219.4200	0.7700	1.5540	0.7310	0.2150	0.6610	0.818965
93	0.2000	0.2000	-0.0356	0.9930	351.3000	1.7460	0.6500	0.5330	0.3890	0.9950	1.375461
94	0.2000	0.2000	-0.0636	0.1710	375.6600	1.6140	1.8300	0.3590	0.8490	0.1570	1.728560
95	0.2000	0.2000	0.1524	0.3450	263.9400	1.9300	1.1220	0.8110	0.1350	0.0750	0.633728
96	0.2000	0.2000	0.0948	0.5530	81.6600	0.3580	1.9180	0.8130	0.4410	0.8810	0.333758
97	0.2000	0.2000	-0.0172	0.3710	363.0600	0.2900	0.5100	0.4910	0.9350	0.9850	1.322178
98	0.2000	0.2000	0.1884	0.4230	244.6200	1.2820	1.7980	0.3290	0.3270	0.2390	0.545474
99	0.2000	0.2000	-0.1700	0.1330	75.7800	1.3660	0.7540	0.9570	0.0870	0.4930	1.034134
100	0.2000	0.2000	0.0564	0.5090	137.1000	0.9420	1.5580	0.1310	0.3530	0.1150	0.867243
101	0.2000	0.2000	-0.1004	0.7090	310.9800	0.4860	0.9100	0.0410	0.8090	0.2750	1.717011
102	0.2000	0.2000	0.0836	0.8850	321.9000	1.3380	0.6900	0.6370	0.1110	0.2830	0.960121
103	0.2000	0.2000	-0.0372	0.0010	130.3800	1.9700	0.0980	0.7230	0.7010	0.2050	1.901339
104	0.2000	0.2000	0.1956	0.3010	184.1400	0.1980	1.3700	0.3210	0.1090	0.7470	0.444611
105	0.2000	0.2000	-0.1500	0.7330	352.1400	0.5260	1.8260	0.0950	0.5410	0.0430	1.957595
106	0.2000	0.2000	0.0924	0.4190	153.0600	1.9980	0.0940	0.1790	0.7850	0.4330	0.662577
107	0.2000	0.2000	-0.1564	0.0690	260.5800	1.2500	1.3060	0.7110	0.3410	0.5250	1.752692
108	0.2000	0.2000	-0.0396	0.7970	240.4200	1.6820	1.9860	0.9630	0.2050	0.3010	1.422477
109	0.2000	0.2000	0.0420	0.3870	250.5000	0.3820	0.1340	0.4030	0.5750	0.0690	1.186566
110	0.2000	0.2000	-0.0964	0.5070	288.3000	0.7380	1.4980	0.3490	0.1390	0.1470	1.722525
111	0.2000	0.2000	0.0356	0.2430	245.4600	1.2940	1.4060	0.1430	0.7410	0.2230	1.156532
112	0.2000	0.2000	-0.1788	0.4970	301.7400	1.2460	1.8660	0.6490	0.4230	0.5810	1.797399
113	0.2000	0.2000	0.1708	0.2230	215.2200	0.9620	0.7580	0.3770	0.3670	0.5570	0.507577
114	0.2000	0.2000	-0.1772	0.5510	227.8200	0.4940	0.0460	0.9050	0.4990	0.5470	1.688022
115	0.2000	0.2000	-0.0012	0.2070	164.8200	0.2620	0.1860	0.7430	0.8250	0.3810	1.114016
116	0.2000	0.2000	-0.0564	0.2470	339.5400	0.8780	0.4620	0.9590	0.7050	0.5110	1.543960
117	0.2000	0.2000	0.0812	0.4470	216.9000	1.6500	1.4140	0.3890	0.2930	0.8990	0.771312
118	0.2000	0.2000	-0.0404	0.5710	432.7800	1.0860	0.9900	0.9670	0.6670	0.0490	1.726713
119	0.2000	0.2000	-0.1972	0.4070	283.2600	0.6700	0.3180	0.5410	0.7350	0.0990	1.954352
120	0.2000	0.2000	0.1540	0.4250	257.2200	1.1620	0.5220	0.0510	0.3850	0.8150	0.542533
121	0.2000	0.2000	0.0244	0.2350	360.5400	0.0060	1.6940	0.1830	0.5630	0.2570	1.323650
122	0.2000	0.2000	-0.1212	0.1690	335.3400	0.7060	1.3660	0.4730	0.1250	0.7150	1.728771
123	0.2000	0.2000	0.0868	0.9390	284.1000	1.5420	1.0060	0.5650	0.6570	0.9110	0.808114
124	0.2000	0.2000	-0.0156	0.9330	88.3800	1.3860	1.9820	0.9450	0.2770	0.4970	0.763964
125	0.2000	0.2000	-0.1572	0.7630	349.6200	0.4580	1.8220	0.9210	0.9650	0.5970	1.799539

126	0.2000	0.2000	-0.1588	0.1310	273.1800	1.4460	0.8020	0.6390	0.4970	0.1430	1.869880
127	0.2000	0.2000	0.0100	0.2610	37.9800	1.6580	0.3060	0.2990	0.1950	0.4290	0.108463
128	0.2000	0.2000	0.1556	0.1210	374.8200	0.9300	1.2980	0.9410	0.9890	0.0670	0.699265
129	0.2000	0.2000	-0.1556	0.1750	226.9800	1.7700	1.4100	0.6590	0.8590	0.4170	1.695144
130	0.2000	0.2000	-0.1420	0.4310	337.8600	0.1060	1.6500	0.5770	0.1850	0.2550	1.858874
131	0.2000	0.2000	0.1116	0.8910	418.5000	1.5780	0.1700	0.5450	0.0650	0.3710	0.836688
132	0.2000	0.2000	-0.1580	0.6850	163.1400	1.6380	0.9340	0.8310	0.6630	0.0590	1.633449
133	0.2000	0.2000	-0.0876	0.9310	347.9400	1.0220	1.1780	0.6670	0.0970	0.2410	1.733042
134	0.2000	0.2000	0.0884	0.3170	409.2600	1.1740	0.0780	0.7530	0.8310	0.0730	1.066535
135	0.2000	0.2000	-0.0980	0.2970	331.9800	0.5300	1.7700	0.5270	0.1590	0.6470	1.620360
136	0.2000	0.2000	-0.1644	0.5330	229.5000	1.4580	0.2460	0.7190	0.8390	0.6030	1.649079
137	0.2000	0.2000	0.1380	0.1410	417.6600	1.7900	1.3580	0.5630	0.9610	0.7390	0.669727
138	0.2000	0.2000	-0.0764	0.9350	297.5400	1.3420	0.0660	0.2510	0.4790	0.2810	1.629001
139	0.2000	0.2000	0.0668	0.3670	66.5400	0.9340	0.5860	0.7630	0.0550	0.5210	0.310837
140	0.2000	0.2000	0.0052	0.9210	80.8200	0.1620	0.8540	0.1690	0.7310	0.6850	0.642641
141	0.2000	0.2000	-0.1724	0.4290	122.8200	0.8980	0.1820	0.4190	0.5450	0.0170	1.500536
142	0.2000	0.2000	0.1452	0.8890	279.9000	0.4500	1.2260	0.6930	0.4210	0.0270	0.669939
143	0.2000	0.2000	0.0580	0.9230	119.4600	1.3980	1.6460	0.9610	0.2490	0.0510	0.809288
144	0.2000	0.2000	-0.1364	0.4510	306.7800	1.8460	0.8300	0.4930	0.5710	0.3970	1.765916
145	0.2000	0.2000	-0.0380	0.5450	201.7800	0.5100	0.1620	0.5930	0.7950	0.4810	1.286451
146	0.2000	0.2000	-0.0588	0.7170	399.1800	0.0820	0.8740	0.6810	0.2210	0.1070	1.740238
147	0.2000	0.2000	-0.1356	0.1730	389.1000	1.9260	1.0820	0.2390	0.3910	0.4830	1.831000
148	0.2000	0.2000	0.1436	0.9510	379.8600	0.7100	1.0700	0.0110	0.2650	0.0050	0.739293
149	0.2000	0.2000	0.1084	0.4930	415.1400	1.3020	1.4020	0.6210	0.7650	0.7590	0.810902
150	0.2000	0.2000	-0.1980	0.3750	361.3800	0.6500	1.4660	0.1350	0.6610	0.3070	1.981980
151	0.2000	0.2000	-0.1116	0.5650	121.9800	1.3740	0.3820	0.6910	0.1990	0.4410	1.251187
152	0.2000	0.2000	0.0620	0.1430	199.2600	0.3700	1.9220	0.2910	0.1410	0.9930	0.825937
153	0.2000	0.2000	0.0196	0.0030	71.5800	0.5860	0.1060	0.5210	0.1270	0.7250	1.340900
154	0.2000	0.2000	0.0084	0.4710	320.2200	1.7340	0.7220	0.2970	0.9210	0.1530	1.395025
155	0.2000	0.2000	-0.1660	0.2510	169.8600	0.0660	1.0020	0.1530	0.4270	0.0570	1.684852
156	0.2000	0.2000	0.1148	0.5470	76.6200	1.8580	0.4380	0.6290	0.3630	0.9390	0.253678
157	0.2000	0.2000	-0.1476	0.0130	367.2600	1.4340	0.7820	0.5610	0.9150	0.2630	2.044611
158	0.2000	0.2000	0.1428	0.7770	421.0200	0.9940	0.0580	0.3090	0.0590	0.1670	0.726091
159	0.2000	0.2000	0.0276	0.8350	214.3800	0.4220	1.9500	0.7030	0.1630	0.7950	1.019757
160	0.2000	0.2000	-0.0188	0.4870	50.5800	1.6940	0.4860	0.1450	0.8770	0.1970	0.345632
161	0.2000	0.2000	0.0388	0.3690	95.9400	1.6780	1.2140	0.1970	0.3970	0.7170	0.654014
162	0.2000	0.2000	-0.1812	0.9150	54.7800	0.7540	1.2420	0.9010	0.9490	0.4390	0.670519
163	0.2000	0.2000	-0.0388	0.2790	142.1400	0.8540	1.7780	0.2290	0.0170	0.5090	1.131135
164	0.2000	0.2000	-0.1300	0.5210	276.5400	0.2500	1.4780	0.4830	0.5590	0.3530	1.722364
165	0.2000	0.2000	-0.1292	0.0630	187.5000	1.1060	1.9060	0.2150	0.2910	0.3910	1.610740
166	0.2000	0.2000	-0.0780	0.3310	213.5400	1.1580	1.5020	0.3850	0.4550	0.1410	1.556563
167	0.2000	0.2000	0.0004	0.4750	435.3000	0.5140	0.0620	0.5390	0.9910	0.2210	1.506800

168	0.2000	0.2000	-0.0572	0.9430	222.7800	0.1540	1.3780	0.7770	0.5570	0.3510	1.432713
169	0.2000	0.2000	0.1644	0.9950	53.9400	1.7100	1.7180	0.4890	0.4010	0.8890	0.203594
170	0.2000	0.2000	-0.0956	0.1990	391.6200	1.4860	1.3100	0.6090	0.0030	0.3250	1.777155
171	0.2000	0.2000	0.1252	0.8810	315.1800	0.6940	1.8620	0.7850	0.5730	0.0910	0.771867
172	0.2000	0.2000	-0.1748	0.2130	338.7000	0.6620	1.0620	0.3810	0.7970	0.7270	1.849036
173	0.2000	0.2000	0.1916	0.8270	429.4200	1.5220	0.1500	0.9110	0.8270	0.6530	0.537289
174	0.2000	0.2000	-0.1828	0.1250	49.7400	0.1500	1.2180	0.6230	0.4290	0.7050	0.650898
175	0.2000	0.2000	0.1716	0.4430	272.3400	1.4820	1.1460	0.3410	0.5130	0.5010	0.547171
176	0.2000	0.2000	-0.1092	0.9910	347.1000	1.0900	0.5060	0.0370	0.6350	0.6810	1.706737
177	0.2000	0.2000	-0.0316	0.8930	440.3400	0.6860	1.5180	0.5010	0.2310	0.1490	1.662741
178	0.2000	0.2000	-0.0492	0.1570	127.8600	0.0180	1.0220	0.9530	0.7590	0.6350	1.090956
179	0.2000	0.2000	0.0572	0.4030	398.3400	1.9660	0.1900	0.9390	0.6430	0.7490	1.082804
180	0.2000	0.2000	0.0116	0.0470	266.4600	1.6980	0.4460	0.6970	0.5210	0.5710	1.226489
181	0.2000	0.2000	0.0036	0.1970	198.4200	1.0700	0.8780	0.9930	0.9990	0.3430	1.183054
182	0.2000	0.2000	-0.0220	0.9570	185.8200	0.8700	0.5460	0.0350	0.4170	0.2610	1.267089
183	0.2000	0.2000	0.0532	0.8370	425.2200	1.8420	0.2660	0.7090	0.4190	0.4150	1.159773
184	0.2000	0.2000	-0.1308	0.9650	211.0200	1.4420	0.6980	0.1090	0.0930	0.8370	1.519125
185	0.2000	0.2000	-0.1804	0.7130	156.4200	1.2540	0.6820	0.6270	0.3130	0.2770	1.585789
186	0.2000	0.2000	0.0548	0.0390	179.9400	1.5060	0.2020	0.0530	0.5430	0.3130	1.011763
187	0.2000	0.2000	-0.1036	0.2550	279.0600	0.9500	0.8140	0.3570	0.3510	0.6650	1.566951
188	0.2000	0.2000	-0.0724	0.4610	343.7400	1.3540	0.3140	0.8470	0.6890	0.4110	1.629732
189	0.2000	0.2000	0.0732	0.8030	341.2200	1.8780	0.8180	0.8270	0.4650	0.6830	0.978661
190	0.2000	0.2000	-0.1996	0.7850	211.8600	1.4700	1.1380	0.2650	0.2830	0.1710	1.805395
191	0.2000	0.2000	-0.1468	0.0490	82.5000	1.8140	1.7220	0.8390	0.9430	0.5890	1.175289
192	0.2000	0.2000	0.0804	0.0890	195.9000	0.7820	1.7500	0.9510	0.3830	0.4730	0.813245
193	0.2000	0.2000	0.1892	0.2050	317.7000	0.3420	0.0700	0.1070	0.6090	0.6370	0.523505
194	0.2000	0.2000	-0.1180	0.2390	165.6600	0.7660	1.8540	0.4070	0.1150	0.3610	1.476396
195	0.2000	0.2000	-0.0100	0.5770	159.7800	1.6460	0.4220	0.2770	0.7170	0.9630	1.013477
196	0.2000	0.2000	0.1212	0.7690	239.5800	1.5540	0.7420	0.9330	0.6710	0.5490	0.627735
197	0.2000	0.2000	0.1740	0.2710	93.4200	1.5860	0.4540	0.2730	0.2370	0.3990	0.320668
198	0.2000	0.2000	0.0124	0.3990	423.5400	1.1900	1.4820	0.4810	0.3450	0.7210	1.329456
199	0.2000	0.2000	0.1052	0.8210	368.9400	1.7020	1.1180	0.8950	0.0070	0.3750	0.847109
200	0.2000	0.2000	0.0748	0.4270	445.3800	1.8940	1.0100	0.8350	0.9550	0.6770	1.036386
201	0.2000	0.2000	-0.1932	0.0170	447.9000	1.1140	1.5780	0.7950	0.4950	0.8010	2.055778
202	0.2000	0.2000	0.1900	0.4690	434.4600	0.7020	0.3020	0.6530	0.1230	0.5530	0.559855
203	0.2000	0.2000	0.0972	0.2310	154.7400	1.4540	1.3340	0.1710	0.6390	0.0850	0.736161
204	0.2000	0.2000	0.1924	0.5270	212.7000	0.7980	0.5340	0.0150	0.2710	0.9310	0.451729
205	0.2000	0.2000	0.1780	0.1490	330.3000	0.3940	0.6620	0.3250	0.4810	0.6630	0.549310
206	0.2000	0.2000	-0.1852	0.9690	331.1400	1.1220	0.9500	0.4670	0.2850	0.6890	1.862363
207	0.2000	0.2000	-0.1412	0.8970	117.7800	0.0020	0.2940	0.5830	0.8150	0.2910	1.327969
208	0.2000	0.2000	0.0828	0.0810	188.3400	0.2340	0.7340	0.4610	0.9470	0.0530	0.916440
209	0.2000	0.2000	0.0252	0.6030	263.1000	0.9700	0.8100	0.8070	0.3390	0.9370	1.060626

210	0.2000	0.2000	-0.0700	0.5630	228.6600	1.2580	1.8060	0.1930	0.0510	0.7970	1.399857
211	0.2000	0.2000	0.1972	0.5870	271.5000	1.2020	1.2660	0.5810	0.8130	0.5610	0.491379
212	0.2000	0.2000	0.1612	0.0410	55.6200	0.9180	0.1180	0.7610	0.8670	0.8450	0.225222
213	0.2000	0.2000	-0.1076	0.9110	411.7800	0.3660	0.5300	0.8610	0.9390	0.0330	1.913293
214	0.2000	0.2000	0.0436	0.9590	142.9800	1.1020	1.8100	0.1570	0.7930	0.6150	0.801211
215	0.2000	0.2000	0.0284	0.0290	354.6600	0.5340	1.7380	0.1730	0.2090	0.7070	1.273433
216	0.2000	0.2000	-0.1484	0.0150	182.4600	0.4660	1.9980	0.0390	0.6470	0.2870	1.875388
217	0.2000	0.2000	-0.1964	0.3470	208.5000	0.2860	1.4460	0.1510	0.4030	0.4610	1.715180
218	0.2000	0.2000	0.0700	0.1370	329.4600	1.1420	1.5220	0.9350	0.0630	0.0250	1.148443
219	0.2000	0.2000	0.1628	0.9710	74.9400	1.7820	1.4300	0.9850	0.4850	0.5370	0.244820
220	0.2000	0.2000	0.1372	0.5290	202.6200	1.0780	1.4420	0.5030	0.6750	0.8950	0.517648
221	0.2000	0.2000	0.0060	0.2370	127.0200	0.4380	1.4260	0.4310	0.0890	0.5330	0.923948
222	0.2000	0.2000	0.0380	0.6450	112.7400	1.6060	1.9540	0.9990	0.6770	0.8410	0.716865
223	0.2000	0.2000	0.0724	0.0850	268.9800	0.1820	1.5660	0.5370	0.5230	0.9330	0.884349
224	0.2000	0.2000	0.1388	0.2270	43.8600	1.4100	0.7860	0.2310	0.6210	0.6070	0.134310
225	0.2000	0.2000	0.1012	0.8670	220.2600	0.2940	0.4500	0.8510	0.5470	0.3170	0.754660
226	0.2000	0.2000	-0.0148	0.6970	372.3000	0.5460	0.3540	0.1610	0.1870	0.9270	1.336189
227	0.2000	0.2000	-0.0812	0.6630	157.2600	1.1100	1.6660	0.8670	0.1970	0.2110	1.389809
228	0.2000	0.2000	0.0028	0.1010	206.8200	0.4620	1.8860	0.9310	0.8410	0.6870	1.170308
229	0.2000	0.2000	0.0492	0.1930	194.2200	1.9500	1.1580	0.8530	0.4430	0.4750	0.936575
230	0.2000	0.2000	-0.0452	0.3190	47.2200	0.0740	1.3860	0.6470	0.4590	0.3730	0.324724
231	0.2000	0.2000	0.0660	0.2190	85.0200	1.8700	0.5580	0.0090	0.4370	0.3150	0.518399
232	0.2000	0.2000	0.0516	0.0590	281.5800	0.0260	0.6740	0.4110	0.4050	0.3790	1.100470
233	0.2000	0.2000	-0.0268	0.6490	237.0600	0.6660	0.4300	0.3930	0.4870	0.8570	1.250236
234	0.2000	0.2000	0.0796	0.8130	153.9000	1.7180	1.5820	0.8550	0.6850	0.1250	0.799654
235	0.2000	0.2000	0.0020	0.6430	63.1800	0.3340	0.9660	0.3650	0.7070	0.7310	0.445581
236	0.2000	0.2000	0.1300	0.3790	254.7000	0.8580	1.8380	0.4350	0.3610	0.8850	0.584501
237	0.2000	0.2000	-0.0868	0.4770	64.0200	0.2060	0.3420	0.8210	0.2450	0.4790	0.668425
238	0.2000	0.2000	-0.0556	0.8190	303.4200	1.1300	1.0500	0.3870	0.6590	0.3030	1.563774
239	0.2000	0.2000	-0.1444	0.4790	204.3000	0.2020	1.8700	0.2250	0.4250	0.7910	1.554698
240	0.2000	0.2000	-0.1716	0.2150	116.9400	1.2180	0.3700	0.5790	0.2350	0.6190	1.328619
241	0.2000	0.2000	0.0540	0.3090	243.7800	0.0420	0.9860	0.5110	0.8010	0.8170	0.948443
242	0.2000	0.2000	-0.1908	0.7870	86.7000	0.5980	0.2780	0.1490	0.2670	0.0710	1.219842
243	0.2000	0.2000	0.0764	0.5890	247.1400	0.2660	0.6220	0.8710	0.5690	0.5030	0.867887
244	0.2000	0.2000	0.1548	0.8690	384.9000	0.8140	1.0380	0.8230	0.1310	0.8590	0.589030
245	0.2000	0.2000	-0.0684	0.4550	350.4600	0.6300	0.0180	0.5970	0.9230	0.9690	1.503153
246	0.2000	0.2000	-0.0108	0.4150	300.0600	1.2140	1.7140	0.6310	0.4910	0.3650	1.374819
247	0.2000	0.2000	-0.1796	0.9450	91.7400	1.6180	0.0740	0.1410	0.0950	0.8310	1.141344
248	0.2000	0.2000	-0.1948	0.6390	286.6200	1.4980	0.4980	0.7810	0.1690	0.3270	1.881344
249	0.2000	0.2000	0.0012	0.9670	302.5800	0.4700	1.6340	0.7050	0.0410	0.9490	1.197552
250	0.2000	0.2000	-0.1436	0.1470	255.5400	0.1180	0.2740	0.0610	0.6990	0.7090	1.686351
251	0.2000	0.2000	0.1164	0.4110	237.9000	1.9580	0.7620	0.6350	0.0430	0.8130	0.642430

252	0.2000	0.2000	-0.0236	0.2890	210.1800	1.2900	0.8700	0.8830	0.8890	0.8110	1.215066
253	0.2000	0.2000	-0.0276	0.7510	125.3400	1.7260	0.3380	0.0130	0.3370	0.2190	1.101969
254	0.2000	0.2000	0.1076	0.5050	401.7000	1.9340	0.6340	0.8450	0.0610	0.4530	0.832726
255	0.2000	0.2000	0.1068	0.9270	427.7400	1.6860	0.6540	0.6610	0.5030	0.3950	0.862067
256	0.2000	0.2000	-0.0892	0.4570	232.8600	1.5940	1.4740	0.9250	0.1430	0.5730	1.478687
257	0.2000	0.2000	0.0260	0.5030	205.9800	0.1420	1.4540	0.2830	0.0710	0.4870	1.046599
258	0.2000	0.2000	0.0524	0.1230	177.4200	1.4220	1.7620	0.0010	0.4510	0.3850	0.927664
259	0.2000	0.2000	-0.0364	0.0210	426.9000	0.7620	0.9700	0.8430	0.2950	0.2090	1.741384
260	0.2000	0.2000	-0.1636	0.9610	304.2600	1.5460	0.2500	0.5070	0.9010	0.2290	1.871603
261	0.2000	0.2000	0.0604	0.3070	268.1400	1.1340	1.0140	0.7150	0.8690	0.5630	0.956496
262	0.2000	0.2000	-0.1604	0.7830	431.1000	1.9780	1.6900	0.6010	0.7090	0.0830	2.030811
263	0.2000	0.2000	-0.1764	0.6190	326.9400	1.5380	1.6580	0.1210	0.2970	0.8350	1.800431
264	0.2000	0.2000	-0.0940	0.4530	56.4600	0.1940	1.1140	0.0190	0.1170	0.1330	0.604330
265	0.2000	0.2000	-0.1924	0.5390	410.9400	0.6740	1.5500	0.6430	0.5610	0.0190	2.099340
266	0.2000	0.2000	-0.0932	0.2690	85.8600	0.1260	0.5820	0.6710	0.5050	0.4450	0.969913
267	0.2000	0.2000	0.1444	0.7270	60.6600	1.5260	0.9620	0.1550	0.8910	0.2890	0.170968
268	0.2000	0.2000	-0.0028	0.0990	428.5800	1.3340	0.4900	0.2630	0.5990	0.0030	1.617524
269	0.2000	0.2000	0.0988	0.0230	84.1800	0.9900	0.1980	0.8750	0.6410	0.9870	0.556770
270	0.2000	0.2000	0.1516	0.8170	353.8200	0.0300	1.1940	0.4570	0.8850	0.4250	0.622460
271	0.2000	0.2000	0.1044	0.3250	285.7800	0.3100	1.6220	0.7730	0.3650	0.8770	0.728052
272	0.2000	0.2000	0.0684	0.3410	69.9000	0.2420	0.7740	0.3790	0.7190	0.2850	0.370706
273	0.2000	0.2000	-0.1284	0.0750	298.3800	0.3300	1.8460	0.0070	0.5890	0.1650	1.847048
274	0.2000	0.2000	-0.1516	0.1390	395.8200	1.2660	0.3220	0.2950	0.1510	0.8730	1.816221
275	0.2000	0.2000	-0.0484	0.0710	89.2200	1.1700	1.9140	0.2690	0.8990	0.6930	0.965559
276	0.2000	0.2000	-0.0692	0.3330	270.6600	1.4620	0.3460	0.7650	0.7530	0.1510	1.622193
277	0.2000	0.2000	0.1996	0.5190	370.6200	1.7860	0.2340	0.8770	0.8510	0.8930	0.497771
278	0.2000	0.2000	-0.0900	0.0670	224.4600	1.3780	0.1580	0.0650	0.9770	0.9090	1.469779
279	0.2000	0.2000	-0.1532	0.9130	217.7400	1.8100	0.7300	0.5190	0.4930	0.5050	1.627569
280	0.2000	0.2000	0.0652	0.1870	131.2200	1.6300	0.4820	0.2530	0.3330	0.4030	0.742686
281	0.2000	0.2000	0.0364	0.0450	175.7400	0.3540	0.0340	0.8870	0.7550	0.3590	1.064133
282	0.2000	0.2000	0.1364	0.7750	267.3000	0.2140	0.8580	0.3610	0.1910	0.7690	0.590164
283	0.2000	0.2000	-0.1508	0.5150	193.3800	1.1660	1.6180	0.5470	0.2330	0.3410	1.620427
284	0.2000	0.2000	0.0140	0.8410	322.7400	1.6660	1.3420	0.9830	0.2510	0.5290	1.232083
285	0.2000	0.2000	0.0188	0.5950	168.1800	0.3780	1.9100	0.4430	0.3750	0.4990	0.995952
286	0.2000	0.2000	-0.0468	0.9490	190.0200	0.9140	1.7740	0.3710	0.6110	0.3390	1.334878
287	0.2000	0.2000	0.0412	0.7190	348.7800	1.0540	0.4700	0.5890	0.9530	0.4310	1.159638
288	0.2000	0.2000	0.1028	0.7290	292.5000	0.6060	0.1940	0.8970	0.6310	0.5150	0.772913
289	0.2000	0.2000	0.1100	0.6370	373.1400	0.1460	1.2380	0.0310	0.7630	0.9470	0.733383
290	0.2000	0.2000	0.1036	0.3550	282.4200	0.0700	1.9340	0.9190	0.3210	0.7190	0.764116
291	0.2000	0.2000	0.1620	0.6410	252.1800	1.2340	0.9740	0.2870	0.0270	0.0890	0.607322
292	0.2000	0.2000	0.1764	0.3570	291.6600	1.5020	1.5300	0.5570	0.0250	0.4190	0.567270
293	0.2000	0.2000	0.0588	0.9090	151.3800	1.3100	0.4660	0.0970	0.3430	0.3630	0.822290

294	0.2000	0.2000	-0.1596	0.9290	321.0600	1.3580	1.9740	0.7350	0.8650	0.2150	1.888062
295	0.2000	0.2000	0.1828	0.6070	277.3800	1.0620	1.7100	0.0590	0.8530	0.4270	0.550900
296	0.2000	0.2000	-0.0708	0.2530	280.7400	0.2100	0.9940	0.2430	0.5290	0.1010	1.662663
297	0.2000	0.2000	-0.0252	0.5850	51.4200	0.8300	0.7180	0.7330	0.4470	0.2250	0.365835
298	0.2000	0.2000	-0.0532	0.9850	412.6200	0.9660	0.3980	0.7290	0.0350	0.6210	1.557825
299	0.2000	0.2000	0.1468	0.0610	438.6600	0.8620	0.5620	0.0830	0.7870	0.5230	0.664655
300	0.2000	0.2000	-0.0436	0.5830	200.1000	0.4980	0.8060	0.7410	0.1290	0.5850	1.268611
301	0.2000	0.2000	0.1748	0.5430	79.1400	1.7580	0.9220	0.9470	0.7990	0.9210	0.277012
302	0.2000	0.2000	0.0916	0.2810	196.7400	1.6540	1.4220	0.1850	0.2810	0.8510	0.708405
303	0.2000	0.2000	-0.0828	0.2730	226.1400	1.6260	0.8620	0.3530	0.7490	0.7770	1.447307
304	0.2000	0.2000	-0.0860	0.0270	158.1000	0.6420	0.4260	0.1130	0.1190	0.8250	1.464525
305	0.2000	0.2000	0.1676	0.5010	38.8200	0.0460	1.8580	0.6190	0.7710	0.8750	0.233381
306	0.2000	0.2000	0.0780	0.4090	141.3000	0.2380	0.2180	0.2370	0.4750	0.1730	0.763895
307	0.2000	0.2000	-0.0500	0.7070	363.9000	1.5340	1.6820	0.2610	0.9790	0.2650	1.624982
308	0.2000	0.2000	0.0476	0.6130	123.6600	1.3940	0.3780	0.2810	0.2250	0.2370	0.818470
309	0.2000	0.2000	-0.0204	0.5930	61.5000	1.0580	0.9260	0.2890	0.1670	0.7450	0.477728
310	0.2000	0.2000	0.0708	0.7610	41.3400	0.1580	0.3300	0.1170	0.5950	0.0390	0.095207
311	0.2000	0.2000	-0.0260	0.3890	145.5000	1.0980	0.5780	0.3030	0.0690	0.2170	1.186244
312	0.2000	0.2000	-0.1324	0.1190	258.0600	0.8500	1.9660	0.8370	0.4730	0.3470	1.725647
313	0.2000	0.2000	0.0820	0.1130	106.0200	0.2780	0.9060	0.4270	0.8370	0.2510	0.621200
314	0.2000	0.2000	-0.1844	0.3590	138.7800	0.7860	1.6380	0.8810	0.4570	0.6410	1.438188
315	0.2000	0.2000	0.0940	0.4590	57.3000	1.9140	1.2020	0.8190	0.1710	0.6050	0.169311
316	0.2000	0.2000	-0.0604	0.5590	342.9000	1.8740	1.9260	0.4510	0.1450	0.8550	1.502992
317	0.2000	0.2000	-0.0516	0.0650	103.5000	0.8260	1.9900	0.5850	0.7290	0.2330	1.145751
318	0.2000	0.2000	-0.0132	0.1810	120.3000	1.1820	1.7300	0.0430	0.3010	0.7670	0.963230
319	0.2000	0.2000	-0.0164	0.0330	269.8200	1.6220	0.3340	0.9150	0.8450	0.8910	1.333412
320	0.2000	0.2000	0.1868	0.1550	235.3800	0.4180	0.5140	0.2090	0.5350	0.9910	0.476447
321	0.2000	0.2000	0.0612	0.3630	316.8600	1.2780	0.0500	0.8410	0.4390	0.2530	1.090675
322	0.2000	0.2000	0.1180	0.6470	328.6200	1.7140	1.1900	0.4530	0.8610	0.0950	0.821776
323	0.2000	0.2000	-0.0476	0.4650	296.7000	0.4140	1.7660	0.6250	0.8230	0.3490	1.514730
324	0.2000	0.2000	0.1348	0.1510	422.7000	1.0180	1.0300	0.9790	0.2190	0.5750	0.675055
325	0.2000	0.2000	-0.1020	0.2650	160.6200	1.9180	0.3260	0.6730	0.8110	0.7510	1.359845
326	0.2000	0.2000	-0.0244	0.7730	402.5400	0.2460	1.5860	0.0210	0.5650	0.9610	1.391855
327	0.2000	0.2000	0.1932	0.7230	340.3800	1.7500	1.7340	0.1050	0.7110	0.3310	0.560445
328	0.2000	0.2000	0.0236	0.9070	416.8200	0.4340	0.6020	0.7910	0.4770	0.8490	1.228281
329	0.2000	0.2000	0.1988	0.5730	135.4200	1.3140	1.2300	0.1270	0.1530	0.7650	0.380509
330	0.2000	0.2000	-0.1836	0.8150	345.4200	0.3740	1.1060	0.7690	0.3930	0.3330	1.927399
331	0.2000	0.2000	-0.0116	0.6090	170.7000	1.0820	1.0260	0.5250	0.9410	0.1190	1.244862
332	0.2000	0.2000	0.0300	0.9050	357.1800	1.4740	0.9460	0.2850	0.1810	0.8270	1.159082
333	0.2000	0.2000	0.0788	0.6170	369.7800	0.8660	0.2100	0.7550	0.6830	0.9890	0.898159
334	0.2000	0.2000	-0.0460	0.4630	67.3800	0.2740	1.8420	0.7670	0.6970	0.9590	0.593116
335	0.2000	0.2000	0.0404	0.2910	101.8200	0.0100	1.8940	0.0910	0.6050	0.6170	0.659717

336	0.2000	0.2000	0.0556	0.6610	150.5400	1.3060	1.0540	0.6850	0.1550	0.4070	0.824100
337	0.2000	0.2000	0.1260	0.0950	48.0600	1.3260	0.4580	0.5670	0.7450	0.5790	0.117950
338	0.2000	0.2000	-0.1428	0.8530	442.8600	1.0060	0.4180	0.7450	0.7670	0.3090	1.930064
339	0.2000	0.2000	-0.1820	0.2290	192.5400	0.5380	1.8140	0.2170	0.3230	0.6330	1.610667
340	0.2000	0.2000	0.1724	0.0790	442.0200	1.7060	1.4340	0.3970	0.6330	0.8230	0.594701
341	0.2000	0.2000	0.1844	0.0050	189.1800	0.7420	1.5420	0.7970	0.1050	0.9230	0.619662
342	0.2000	0.2000	0.0628	0.2410	359.7000	0.5220	1.9580	0.4330	0.9590	0.0070	1.217385
343	0.2000	0.2000	-0.1100	0.2630	43.0200	0.0860	0.6420	0.3150	0.9810	0.0630	0.381936
344	0.2000	0.2000	-0.0740	0.8790	169.0200	1.2740	1.9020	0.4710	0.2030	0.6390	1.271875
345	0.2000	0.2000	0.0316	0.9770	98.4600	1.8020	1.3620	0.3010	0.7750	0.5410	0.675446
346	0.2000	0.2000	0.0340	0.6690	144.6600	0.0380	1.7020	0.2410	0.6690	0.9990	0.811216
347	0.2000	0.2000	0.1692	0.8830	32.1000	0.9380	1.8340	0.4950	0.8930	0.0790	0.261389
348	0.2000	0.2000	0.0740	0.5310	158.9400	0.5020	0.8260	0.6330	0.3570	0.9670	0.696564
349	0.2000	0.2000	-0.0948	0.6670	100.9800	1.1980	0.5180	0.8790	0.2630	0.7790	1.056457
350	0.2000	0.2000	-0.0716	0.6010	90.0600	1.8060	1.3540	0.9750	0.3090	0.5170	0.927056
351	0.2000	0.2000	-0.0652	0.0110	155.5800	1.0020	0.9300	0.8090	0.6290	0.0090	1.772881
352	0.2000	0.2000	0.0164	0.6210	333.6600	0.1740	0.6380	0.2790	0.2750	0.2710	1.324348
353	0.2000	0.2000	-0.1340	0.6330	110.2200	1.2380	0.4940	0.4590	0.0990	0.3890	1.245123
354	0.2000	0.2000	0.1876	0.7790	114.4200	1.0940	0.3660	0.5430	0.6650	0.0930	0.390025
355	0.2000	0.2000	0.1340	0.3810	33.7800	0.7780	0.6260	0.9950	0.7690	0.7370	0.153966
356	0.2000	0.2000	0.1284	0.7210	149.7000	0.3620	0.8820	0.5530	0.0670	0.2130	0.531390
357	0.2000	0.2000	-0.1612	0.7410	218.5800	0.4540	1.6420	0.6870	0.3150	0.4710	1.657331
358	0.2000	0.2000	0.1756	0.6730	195.0600	1.5580	1.2220	0.5350	0.4670	0.9770	0.459952
359	0.2000	0.2000	-0.0852	0.2210	209.3400	1.8820	1.3020	0.5490	0.8730	0.6670	1.460192
360	0.2000	0.2000	-0.0348	0.9890	274.0200	1.2860	0.0420	0.3670	0.7730	0.4570	1.399020
361	0.2000	0.2000	0.1292	0.5750	337.0200	0.0220	1.3900	0.4390	0.2590	0.5670	0.656461
362	0.2000	0.2000	0.1316	0.3950	242.9400	0.1100	1.7860	0.7710	0.4690	0.8650	0.573652
363	0.2000	0.2000	0.1580	0.7250	275.7000	0.5700	0.6300	0.4090	0.6170	0.1590	0.617075
364	0.2000	0.2000	0.0348	0.2770	325.2600	0.6820	0.0100	0.2030	0.9930	0.9550	1.083112
365	0.2000	0.2000	-0.1316	0.8650	118.6200	0.6980	1.8020	0.0870	0.2430	0.6250	1.230868
366	0.2000	0.2000	-0.0124	0.3830	42.1800	0.6020	1.5380	0.5050	0.9090	0.3210	0.191882
367	0.2000	0.2000	-0.1620	0.1590	312.6600	0.5500	1.2780	0.4010	0.9290	0.9010	1.747781
368	0.2000	0.2000	0.1420	0.4210	332.8200	1.6900	1.9620	0.6550	0.8050	0.8870	0.591780
369	0.2000	0.2000	0.1172	0.5790	102.6600	1.5100	1.6020	0.7830	0.6950	0.8210	0.375157
370	0.2000	0.2000	0.0876	0.0070	314.3400	0.6580	0.6940	0.7170	0.8550	0.0230	1.199079
371	0.2000	0.2000	-0.0772	0.6750	305.1000	1.9420	1.8900	0.9070	0.5930	0.4630	1.580827
372	0.2000	0.2000	0.1236	0.6650	106.8600	0.1300	0.1460	0.4210	0.6810	0.1890	0.419885
373	0.2000	0.2000	-0.0796	0.0510	32.9400	1.3220	1.2860	0.2750	0.9750	0.3770	0.285054
374	0.2000	0.2000	0.0372	0.1830	419.3400	1.2300	1.1660	0.0270	0.5850	0.4890	1.223038
375	0.2000	0.2000	0.0228	0.7670	371.4600	0.1140	0.1100	0.8690	0.2870	0.9030	1.181839
376	0.2000	0.2000	0.0428	0.7550	100.1400	0.9260	0.2300	0.8570	0.3550	0.8330	0.636441
377	0.2000	0.2000	-0.1372	0.8770	299.2200	0.8220	1.6100	0.5170	0.0470	0.6310	1.683416

378	0.2000	0.2000	0.1188	0.7110	290.8200	1.6740	0.4100	0.3110	0.2990	0.3930	0.715412
379	0.2000	0.2000	0.1860	0.4130	113.5800	0.8900	1.2740	0.1290	0.0110	0.5870	0.362839
380	0.2000	0.2000	0.0500	0.8390	139.6200	1.1500	0.8500	0.8650	0.8870	0.1750	0.881786
381	0.2000	0.2000	0.1588	0.2250	430.2600	0.9780	1.6140	0.6570	0.9510	0.1290	0.700068
382	0.2000	0.2000	-0.1892	0.3850	58.1400	0.9820	1.5700	0.1650	0.2730	0.5830	0.743348
383	0.2000	0.2000	-0.0988	0.3030	216.0600	1.4940	0.2060	0.7370	0.9250	0.6710	1.505193
384	0.2000	0.2000	0.1500	0.1670	30.4200	0.5660	0.1740	0.4870	0.4710	0.3350	0.196603
385	0.2000	0.2000	0.1396	0.7910	136.2600	1.3820	0.0260	0.1890	0.3810	0.9510	0.408311
386	0.2000	0.2000	0.1244	0.5350	231.1800	0.8860	0.2620	0.9650	0.5270	0.0370	0.718476
387	0.2000	0.2000	0.0508	0.3130	346.2600	0.6340	0.5660	0.5550	0.4450	0.7410	1.081008
388	0.2000	0.2000	0.0292	0.1610	246.3000	0.8940	1.4900	0.5730	0.0050	0.9190	1.040211
389	0.2000	0.2000	0.1276	0.3150	405.0600	0.9980	1.1620	0.5290	0.0450	0.1950	0.786053
390	0.2000	0.2000	0.0852	0.0250	128.7000	0.4460	0.6100	0.9270	0.6070	0.9730	0.731702
391	0.2000	0.2000	-0.1276	0.8710	413.4600	1.0340	0.2900	0.8170	0.3030	0.0150	1.969082
392	0.2000	0.2000	-0.1196	0.1450	87.5400	0.4740	1.6300	0.6750	0.8210	0.3830	1.082036
393	0.2000	0.2000	0.1836	0.0970	259.7400	1.9860	0.7500	0.2450	0.2790	0.5350	0.536886
394	0.2000	0.2000	-0.0036	0.5690	35.4600	0.9060	0.7460	0.9090	0.9070	0.8790	0.089030
395	0.2000	0.2000	-0.1188	0.1290	34.6200	1.8220	0.2820	0.3170	0.5550	0.5270	0.235322
396	0.2000	0.2000	0.0844	0.2030	313.5000	1.1860	1.2100	0.6510	0.5790	0.0970	1.016599
397	0.2000	0.2000	0.1004	0.1770	307.6200	0.6180	0.1780	0.4650	0.3050	0.3050	0.857211
398	0.2000	0.2000	0.0860	0.7350	316.0200	1.7740	1.1420	0.0630	0.2410	0.9750	0.825791
399	0.2000	0.2000	-0.0340	0.3970	68.2200	0.1900	1.0580	0.1670	0.1010	0.8610	0.590515
400	0.2000	0.2000	-0.1916	0.8110	300.9000	0.6460	0.1260	0.4450	0.4350	0.6570	1.798247
401	0.2000	0.2000	-0.0140	0.8010	238.7400	0.9860	0.4020	0.3190	0.9730	0.9250	1.184903
402	0.2000	0.2000	0.1564	0.7570	108.5400	1.5740	0.1300	0.9490	0.5150	0.5950	0.338781
403	0.2000	0.2000	0.1460	0.6550	408.4200	0.5940	0.3900	0.7010	0.4130	0.2970	0.685091
404	0.2000	0.2000	0.1308	0.9630	311.8200	0.3500	1.1860	0.6990	0.3490	0.1310	0.730211
405	0.2000	0.2000	-0.1860	0.1050	247.9800	1.8860	1.7900	0.4770	0.1470	0.9790	1.701831
406	0.2000	0.2000	-0.0836	0.5610	133.7400	0.3980	1.0940	0.3550	0.9830	0.8670	1.178151
407	0.2000	0.2000	0.0444	0.5670	342.0600	1.3300	1.1300	0.5130	0.2130	0.1810	1.227306
408	0.2000	0.2000	0.0308	0.2490	180.7800	0.0500	0.8940	0.5090	0.1750	0.6790	0.988110
409	0.2000	0.2000	0.1156	0.8630	200.9400	1.0100	0.5980	0.7210	0.5010	0.8430	0.599271
410	0.2000	0.2000	-0.1380	0.2950	368.1000	1.8900	0.8380	0.7470	0.0130	0.9450	1.729449
411	0.2000	0.2000	0.1124	0.5230	48.9000	1.6420	0.2380	0.0750	0.9370	0.8970	0.120052
412	0.2000	0.2000	-0.0628	0.4910	305.9400	0.8740	1.0340	0.5590	0.6230	0.1030	1.664441
413	0.2000	0.2000	0.0980	0.3930	234.5400	0.7180	0.2860	0.5950	0.3170	0.6490	0.715174
414	0.2000	0.2000	0.1820	0.7470	289.9800	0.5540	0.3860	0.0570	0.3310	0.0550	0.622337
415	0.2000	0.2000	-0.0420	0.1110	58.9800	1.2980	1.5740	0.9030	0.0570	0.5310	0.542184
416	0.2000	0.2000	0.1532	0.6290	31.2600	1.7660	0.7260	0.4470	0.8030	0.9050	0.245745
417	0.2000	0.2000	-0.1060	0.8230	407.5800	1.0460	1.5100	0.4150	0.1570	0.9410	1.676987
418	0.2000	0.2000	0.1060	0.1530	379.0200	0.6220	1.4860	0.0290	0.9870	0.6290	0.792657
419	0.2000	0.2000	-0.0924	0.3910	163.9800	0.2820	1.8820	0.1590	0.4310	0.1850	1.454337

420	0.2000	0.2000	0.1268	0.5970	152.2200	0.9100	1.6860	0.2330	0.0850	0.1170	0.564814
421	0.2000	0.2000	0.0900	0.6310	444.5400	1.0260	0.4340	0.0890	0.5330	0.1790	1.036630
422	0.2000	0.2000	-0.0084	0.4810	426.0600	1.4260	0.0380	0.0170	0.9310	0.5910	1.406489
423	0.2000	0.2000	0.1796	0.3290	446.2200	0.1380	0.7060	0.6410	0.0190	0.1930	0.660518
424	0.2000	0.2000	-0.0060	0.8730	308.4600	0.1700	1.8500	0.8850	0.4070	0.2430	1.406463
425	0.2000	0.2000	0.1204	0.0830	366.4200	1.9940	0.7100	0.1470	0.8950	0.5430	0.736250
426	0.2000	0.2000	0.1196	0.2990	132.9000	1.2700	1.7460	0.9910	0.7430	0.6130	0.462874
427	0.2000	0.2000	-0.0332	0.1650	424.3800	0.1780	1.1820	0.3830	0.0330	0.6270	1.502722
428	0.2000	0.2000	-0.1044	0.2170	111.9000	1.7420	1.3740	0.9690	0.8330	0.7870	1.165114
429	0.2000	0.2000	-0.1676	0.8470	373.9800	1.0500	1.8740	0.4230	0.0810	0.8050	1.837186
430	0.2000	0.2000	-0.0020	0.1170	336.1800	0.8420	0.4420	0.2110	0.9950	0.5690	1.319570
431	0.2000	0.2000	-0.1548	0.6230	431.9400	0.1340	1.7820	0.0470	0.1490	0.9350	1.821750
432	0.2000	0.2000	-0.1068	0.9550	37.1400	0.2700	0.8220	0.8010	0.7790	0.5590	0.218672
433	0.2000	0.2000	0.1660	0.7710	186.6600	0.9020	0.6660	0.3470	0.1610	0.9530	0.459201
434	0.2000	0.2000	0.0932	0.7890	289.1400	0.7220	0.7940	0.7070	0.9110	0.1090	0.931617
435	0.2000	0.2000	-0.0620	0.8250	382.3800	0.6100	1.5060	0.3390	0.3590	0.8290	1.554695
436	0.2000	0.2000	0.0484	0.0190	99.3000	0.3020	1.4940	0.3910	0.5190	0.1610	1.039918
437	0.2000	0.2000	0.1948	0.7490	147.1800	1.6620	1.5980	0.6950	0.9130	0.7290	0.405337
438	0.2000	0.2000	0.0132	0.6990	265.6200	1.8620	1.4580	0.9430	0.2010	0.0870	1.333605
439	0.2000	0.2000	0.1020	0.3050	178.2600	0.5820	0.5700	0.3990	0.2230	0.2270	0.716557
440	0.2000	0.2000	0.1732	0.7030	253.8600	1.5660	0.4780	0.2350	0.1930	0.1690	0.586978
441	0.2000	0.2000	0.1684	0.6790	248.8200	1.0660	0.9140	0.3510	0.6450	0.6990	0.536932
442	0.2000	0.2000	-0.1156	0.2010	179.1000	1.1540	0.3740	0.9770	0.2530	0.9130	1.404661
443	0.2000	0.2000	0.1508	0.2830	36.3000	1.9540	1.5460	0.0850	0.5070	0.1110	0.157215
444	0.2000	0.2000	0.1940	0.9470	236.2200	1.4060	0.9380	0.0810	0.5770	0.4130	0.500898
445	0.2000	0.2000	-0.0788	0.1350	137.9400	0.6260	1.1540	0.8910	0.9690	0.7350	1.245904
446	0.2000	0.2000	-0.0580	0.8610	324.4200	0.3860	0.8420	0.1190	0.6190	0.9430	1.444508
447	0.2000	0.2000	-0.1684	0.7050	262.2600	0.4060	1.5620	0.5750	0.3690	0.7890	1.709305
448	0.2000	0.2000	-0.0212	0.3510	233.7000	1.8540	0.2220	0.2010	0.4890	0.6550	1.231934
449	0.2000	0.2000	0.0468	0.9190	433.6200	0.1860	0.9580	0.4490	0.7030	0.3290	1.230306
450	0.2000	0.2000	-0.0748	0.7530	400.8600	0.4780	1.7940	0.1750	0.5830	0.4650	1.670177
451	0.2000	0.2000	0.1140	0.0530	386.5800	1.0740	0.5940	0.4790	0.0530	0.9650	0.740333
452	0.2000	0.2000	-0.1348	0.9750	129.5400	0.0980	1.7420	0.6630	0.7230	0.7930	1.298152
453	0.2000	0.2000	-0.1460	0.5250	174.0600	1.2220	0.0220	0.4750	0.6930	0.5990	1.484660
454	0.2000	0.2000	-0.1244	0.9410	356.3400	0.1220	1.4700	0.1990	0.8070	0.2930	1.820940
455	0.2000	0.2000	-0.0412	0.1270	310.1400	1.4020	0.3580	0.7270	0.4630	0.7830	1.438424
456	0.2000	0.2000	-0.1780	0.1090	388.2600	1.7220	1.5140	0.9890	0.5170	0.5190	1.922384
457	0.2000	0.2000	-0.1084	0.3210	261.4200	0.5780	1.1020	0.2670	0.6510	0.2730	1.676099
458	0.2000	0.2000	-0.1956	0.6590	396.6600	1.3700	1.3380	0.2070	0.8630	0.1210	2.061316
459	0.2000	0.2000	0.1092	0.5550	378.1800	0.0780	1.3180	0.7510	0.0290	0.3370	0.839654
460	0.2000	0.2000	-0.1228	0.1950	73.2600	0.3900	0.8460	0.8050	0.2270	0.2030	0.947651
461	0.2000	0.2000	0.0460	0.8590	45.5400	0.2300	1.2900	0.8990	0.3470	0.0650	0.167225

462	0.2000	0.2000	0.0220	0.6930	62.3400	0.4260	1.0660	0.9130	0.5490	0.6730	0.391505
463	0.2000	0.2000	0.1476	0.7150	167.3400	1.9020	1.9780	0.9370	0.1210	0.7750	0.471356
464	0.2000	0.2000	0.1332	0.9250	447.0600	1.4900	1.0180	0.0770	0.8810	0.6510	0.668392
465	0.2000	0.2000	0.1324	0.0370	116.1000	0.3260	1.3260	0.4550	0.8790	0.4850	0.478193
466	0.2000	0.2000	-0.1452	0.1030	94.2600	0.8820	1.6540	0.8330	0.7130	0.4370	1.204878
467	0.2000	0.2000	-0.0612	0.9530	190.8600	0.3060	0.2420	0.3450	0.4830	0.3670	1.373082
468	0.2000	0.2000	0.0068	0.4850	221.9400	1.0300	0.9180	0.8890	0.0010	0.3450	1.199965
469	0.2000	0.2000	-0.0196	0.1070	107.7000	1.7620	0.0300	0.5910	0.3870	0.6590	0.921118
470	0.2000	0.2000	-0.1132	0.8990	352.9800	0.4820	0.9980	0.0030	0.1650	0.1870	1.824411
471	0.2000	0.2000	0.0172	0.9810	355.5000	1.0140	0.1140	0.4630	0.9330	0.4090	1.289055
472	0.2000	0.2000	0.1812	0.5370	162.3000	1.8180	0.6580	0.4990	0.5910	0.7130	0.457667
473	0.2000	0.2000	0.0892	0.3110	258.9000	1.8340	0.1420	0.9230	0.0210	0.8390	0.792388
474	0.2000	0.2000	0.0044	0.8750	83.3400	1.8260	1.2940	0.2550	0.6270	0.4590	0.667140
475	0.2000	0.2000	-0.0844	0.3490	376.5000	0.0540	0.2700	0.3230	0.0370	0.0610	1.817733
476	0.2000	0.2000	-0.1732	0.6250	221.1000	0.7940	1.3500	0.2050	0.0730	0.8190	1.641690
477	0.2000	0.2000	-0.1708	0.3430	183.3000	1.5700	1.3980	0.1870	0.9450	0.5770	1.573329
478	0.2000	0.2000	0.1668	0.7430	421.8600	0.8380	0.4060	0.2210	0.9670	0.9810	0.559649
479	0.2000	0.2000	0.1596	0.8050	441.1800	0.0940	0.7380	0.0490	0.6870	0.6090	0.607252
480	0.2000	0.2000	0.1700	0.4890	70.7400	0.2540	0.7020	0.3430	0.9970	0.8630	0.247053
481	0.2000	0.2000	-0.0444	0.9010	390.7800	1.1380	1.2460	0.9810	0.5390	0.4550	1.563246
482	0.2000	0.2000	-0.1692	0.4950	309.3000	1.0380	0.5540	0.1630	0.6030	0.1450	1.919045
483	0.2000	0.2000	0.1636	0.5910	274.8600	1.9380	1.8780	0.5870	0.9570	0.0350	0.630981
484	0.2000	0.2000	-0.1012	0.8450	40.5000	1.7300	1.1700	0.3130	0.4490	0.8070	0.280232
485	0.2000	0.2000	-0.1988	0.8090	161.4600	1.4660	0.3620	0.8490	0.9630	0.8470	1.535364
486	0.2000	0.2000	0.1804	0.8570	65.7000	0.3180	0.7900	0.3070	0.3250	0.7030	0.261474
487	0.2000	0.2000	-0.0644	0.4730	406.7400	1.9460	1.4500	0.1810	0.4110	0.3870	1.669508
488	0.2000	0.2000	-0.1164	0.6510	358.0200	1.4180	0.3100	0.2590	0.1370	0.7330	1.722354
489	0.2000	0.2000	-0.1140	0.5170	393.3000	1.9820	0.0020	0.0930	0.7510	0.8830	1.705212
490	0.2000	0.2000	-0.0076	0.7010	52.2600	0.5900	0.5740	0.1330	0.2470	0.4910	0.310257
491	0.2000	0.2000	0.1220	0.9030	264.7800	1.7540	1.2820	0.0550	0.7390	0.6950	0.660022
492	0.2000	0.2000	0.1964	0.0090	249.6600	0.0620	0.8340	0.3270	0.1330	0.0450	0.693559
493	0.2000	0.2000	-0.1396	0.3530	436.9800	1.6020	1.4180	0.9970	0.7610	0.6970	1.859710
494	0.2000	0.2000	-0.0908	0.2750	140.4600	0.6540	0.9780	0.3310	0.5370	0.2010	1.367462
495	0.2000	0.2000	0.0180	0.2850	400.0200	1.2100	1.2700	0.5710	0.7150	0.4470	1.316468
496	0.2000	0.2000	-0.0508	0.4170	64.8600	0.9580	1.3820	0.6050	0.0830	0.5650	0.589029
497	0.2000	0.2000	-0.1236	0.5990	385.7400	1.0420	0.1220	0.2710	0.0490	0.9710	1.697896
498	0.2000	0.2000	-0.0972	0.3390	90.9000	0.5420	0.9420	0.8290	0.6530	0.3570	1.037998
499	0.2000	0.2000	-0.0548	0.6110	181.6200	1.7980	0.3500	0.6890	0.1770	0.6230	1.252970
500	0.2000	0.2000	0.0636	0.2670	39.6600	0.0580	1.0980	0.0450	0.5250	0.5930	0.077426

APPENDIX A10: SWATCUP Sensitivity parameters ranking in the calibration phase

Goal_type= Multiplicative_MSE No_sims= 500 Best_sim_no= 500 Best_goal = 7.742634e-002

Parameter_Name	Fitted_Value	Min_value	Max_value
1:R__EPCO.bsn	0.200000	0.200000	0.200000
2:R__ESCO.bsn	0.200000	0.200000	0.200000
3:R__CN2.mgt	0.063600	-0.200000	0.200000
4:V__ALPHA_BF.gw	0.267000	0.000000	1.000000
5:V__GW_DELAY.gw	39.660000	30.000000	450.000000
6:V__GWQMN.gw	0.058000	0.000000	2.000000
7:R__SPCON.bsn	1.098000	0.000000	2.000000
8:R__SURLAG.bsn	0.045000	0.000000	1.000000
9:R__SEDPST_CONC.swq	0.525000	0.000000	1.000000
10:R__SOL_Z(..).sol	0.593000	0.000000	1.000000

r__EPCO.bsn	0.200000
r__ESCO.bsn	0.200000
r__CN2.mgt	0.063600
v__ALPHA_BF.gw	0.267000
v__GW_DELAY.gw	39.660000
v__GWQMN.gw	0.058000
r__SPCON.bsn	1.098000
r__SURLAG.bsn	0.045000
r__SEDPST_CONC.swq	0.525000
r__SOL_Z().sol	0.593000

APPENDIX A11: Calibration of the observed stream flow (obsed) to obtain the best simulation (simted) (1982-2003)

S/No	Obsed	Simted	S/No	Obsed	Simted	S/No	Obsed	Simted
1	0.7070	1.3590	89	0.0000	0.0000	177	3.1980	3.2310
2	0.1130	0.8924	90	1.9470	2.0200	178	2.7880	2.5920
3	0.0000	0.0000	91	2.6380	2.6990	179	2.4870	2.1370
4	0.0000	0.0000	92	3.2680	3.3250	180	2.0000	1.7930
5	1.3120	1.4950	93	3.1630	3.1570	181	0.9040	1.4250
6	1.5150	1.5730	94	2.8620	2.7020	182	0.1880	0.9785
7	2.8660	2.9020	95	2.4630	2.0910	183	0.0000	0.1500
8	3.0700	3.1350	96	1.8900	1.7490	184	1.5990	1.7700
9	2.8280	2.7580	97	0.7710	1.3750	185	2.1350	2.1450
10	2.6210	2.4230	98	0.2040	0.9307	186	2.3790	2.3570
11	2.2130	1.8650	99	0.0000	0.0000	187	2.9170	2.9270
12	1.3760	1.5110	100	0.0000	0.0000	188	2.8740	2.8960
13	0.2800	1.0820	101	0.0000	0.0000	189	2.7100	2.6180
14	0.0000	0.3498	102	0.0000	0.0000	190	2.4950	2.3090
15	0.0000	0.0000	103	2.9100	2.9440	191	1.8350	1.5610
16	0.0000	0.0000	104	3.1430	3.1920	192	0.8560	1.1550
17	0.0000	0.0000	105	3.0270	3.0040	193	0.0660	0.5161
18	0.0000	0.0000	106	2.5820	2.3820	194	0.0000	0.0000
19	2.6630	2.7110	107	2.0770	1.7130	195	0.0000	0.0000
20	2.8920	2.9640	108	1.0410	1.3490	196	0.0000	0.0000
21	3.0840	3.1130	109	0.0740	0.8469	197	0.2990	0.1526
22	2.6090	2.3080	110	0.0000	0.0000	198	1.3990	1.5140
23	2.3330	1.9540	111	0.0000	0.0000	199	2.9570	2.9950
24	1.5740	1.5960	112	0.0000	0.0000	200	3.0460	3.1080
25	0.3720	1.1920	113	1.9290	2.0310	201	2.9720	2.9650
26	0.0000	0.5659	114	1.0510	1.0390	202	2.5760	2.2500
27	0.0000	0.0000	115	2.4600	2.5000	203	2.2590	1.8880
28	0.0000	0.0000	116	2.7120	2.7990	204	1.4240	1.5290
29	0.5150	0.4889	117	2.7540	2.7070	205	0.3790	1.1190
30	0.2280	0.4683	118	2.3340	1.9320	206	0.0270	0.4601
31	2.3220	2.3740	119	1.8240	1.5290	207	0.0000	0.0000
32	2.3170	2.3630	120	0.5240	1.1300	208	0.0000	0.0000
33	2.3340	2.3320	121	0.0000	0.5076	209	0.0000	0.0000
34	1.4460	0.7300	122	0.0000	0.0000	210	0.0000	0.0000
35	0.7200	0.0000	123	0.0000	0.0000	211	1.5960	1.7670
36	0.0000	0.0000	124	0.0000	0.0000	212	2.4630	2.5070
37	0.0000	0.0000	125	1.0660	1.2190	213	2.6100	2.6410
38	0.0000	0.0000	126	1.0940	0.8373	214	1.7710	1.3750
39	0.0000	0.0000	127	2.9370	2.9730	215	1.3210	0.8533

40	0.0000	0.0000	128	3.1710	3.2410	216	0.5180	0.0000
41	0.0000	0.0000	129	3.0260	3.0180	217	0.0000	0.0000
42	1.0580	1.1610	130	2.7840	2.5940	218	0.0000	0.0000
43	3.0030	3.0830	131	2.4490	2.1310	219	0.0000	0.0000
44	3.3050	3.3640	132	1.8840	1.7910	220	0.0000	0.0000
45	3.2130	3.2020	133	0.8020	1.4300	221	0.0000	0.0000
46	2.7150	2.3990	134	0.1950	1.0070	222	0.0000	0.0000
47	2.4080	2.0520	135	0.0000	0.1755	223	0.0000	0.0000
48	1.7180	1.7060	136	0.0000	0.0000	224	1.2920	1.5540
49	0.7250	1.3370	137	0.0000	0.0000	225	0.1120	0.0000
50	0.2270	0.8673	138	2.1590	2.2280	226	0.0000	0.0000
51	0.0000	0.0000	139	2.7890	2.8280	227	0.0000	0.0000
52	0.0000	0.0000	140	2.9540	2.9930	228	0.0000	0.0000
53	0.0000	0.0000	141	2.8200	2.8030	229	0.0000	0.0000
54	0.0000	0.0000	142	2.4520	2.0890	230	0.0000	0.0000
55	2.7620	2.8210	143	2.0870	1.7200	231	0.0000	0.0000
56	2.8970	2.9530	144	1.1900	1.3440	232	0.0000	0.0000
57	3.0060	3.0060	145	0.2320	0.8598	233	0.0000	0.0000
58	2.5020	2.1540	146	0.0000	0.0000	234	0.2250	0.6043
59	2.1580	1.7930	147	0.0000	0.0000	235	2.0350	2.0820
60	1.2380	1.4460	148	0.0000	0.0000	236	2.7820	2.8210
61	0.2690	0.9833	149	0.0360	0.0000	237	2.2420	2.3190
62	0.0000	0.1672	150	0.0000	0.0000	238	1.4250	1.1650
63	0.0000	0.0000	151	2.5650	2.6290	239	1.1380	0.5353
64	0.0000	0.0000	152	2.8130	2.9100	240	0.3160	0.0000
65	0.9730	1.0850	153	2.9400	2.9720	241	0.0000	0.0000
66	2.5700	2.5970	154	2.7370	2.5750	242	0.0000	0.0000
67	2.4370	2.4670	155	2.4340	2.1100	243	0.0000	0.0000
68	3.1160	3.1700	156	1.9120	1.7690	244	0.0000	0.0000
69	2.7710	2.6990	157	0.9140	1.4040	245	0.0000	0.0000
70	2.4780	2.1330	158	0.1300	0.9736	246	0.0000	0.0000
71	2.0760	1.7610	159	0.0000	0.1456	247	2.4240	2.4590
72	1.1690	1.3940	160	0.0000	0.0000	248	2.8970	2.9380
73	0.2670	0.9107	161	1.7980	1.9630	249	1.3510	1.5200
74	0.0000	0.0000	162	2.6810	2.7150	250	1.8370	1.9280
75	0.0000	0.0000	163	3.0700	3.1180	251	1.0490	0.5099
76	0.0000	0.0000	164	3.1800	3.2060	252	0.3860	0.0000
77	0.0000	0.0000	165	3.3140	3.3170	253	0.0000	0.0000
78	0.4740	0.4457	166	2.8080	2.5940	254	0.0000	0.0000
79	2.6320	2.6890	167	2.5120	2.1760	255	0.0000	0.0000
80	2.7430	2.8450	168	1.9550	1.8350	256	0.0000	0.0000
81	3.1240	3.1520	169	0.8950	1.4800	257	0.0000	0.0000

82	2.7290	2.5540	170	0.3830	1.0670	258	0.0000	0.0000
83	2.4430	2.1060	171	0.0260	0.3765	259	1.9840	2.1010
84	1.9150	1.7640	172	0.0000	0.0000	260	2.8970	2.9300
85	0.6840	1.3910	173	0.0000	0.0000	261	2.3570	2.4240
86	0.0700	0.9261	174	1.2240	1.4670	262	1.7840	1.4810
87	0.0000	0.0508	175	2.5680	2.6030	263	1.3760	0.9880
88	0.0000	0.0000	176	2.8640	2.9550	264	0.5790	0.2718

APPENDIX A12: SWATCUP observed stream flow calibration statistics

---- Results for behavioral parameters ---
Behavioral threshold= 0.500000
Number of behavioral simulations = 68

Variable	p-factor	r-factor	R2	NS	bR2	MSE	SSQR	PBIAS	KGE
	0.76	0.71	0.95	0.95	0.8844	7.7e-002	2.8e-002	-2.8	0.94

RSR	MNS	VOL_FR	Mean_sim(Mean_obs)	StdDev_sim(StdDev_obs)
0.23	0.00	0.97	1.31(1.27)	1.16(1.21

APPENDIX A**13:** SWATCUP Sensitivity parameters ranking in the validation phase

Goal_type= Multiplicative_MSE No_sims= 500 Best_sim_no= 355 Best_goal = 6.878862e-001

Parameter_Name	Fitted_Value	Min_value	Max_value
1:R__EPCO.bsn	0.200000	0.200000	0.200000
2:R__ESCO.bsn	0.200000	0.200000	0.200000
3:R__CN2.mgt	0.134000	-0.200000	0.200000
4:V__ALPHA_BF.gw	0.381000	0.000000	1.000000
5:V__GW_DELAY.gw	33.779999	30.000000	450.000000
6:V__GWQMN.gw	0.778000	0.000000	2.000000
7:R__SPCON.bsn	0.626000	0.000000	2.000000
8:R__SURLAG.bsn	0.995000	0.000000	1.000000
9:R__SEDPST_CONC.swq	0.769000	0.000000	1.000000
10:R__SOL_Z(..).sol	0.737000	0.000000	1.000000

r__EPCO.bsn	0.200000
r__ESCO.bsn	0.200000
r__CN2.mgt	0.134000
v__ALPHA_BF.gw	0.381000
v__GW_DELAY.gw	33.779999
v__GWQMN.gw	0.778000
r__SPCON.bsn	0.626000
r__SURLAG.bsn	0.995000
r__SEDPST_CONC.swq	0.769000
r__SOL_Z().sol	0.737000

APPENDIX A14: SWATCUP Validation of the observed stream flow data (obsed) to obtain the best simulation (simted) (2004-2013)

S/No	Obsed	Simted	S/No	Obsed	Simted	S/No	Obsed	Simted
1	0.0000	0.5244	41	0.0000	0.0000	81	2.6970	3.1740
2	0.0000	0.0000	42	0.0000	1.5930	82	2.4560	2.4160
3	0.0000	0.0000	43	2.1070	3.1800	83	1.9220	1.7170
4	0.0000	0.0000	44	2.2530	3.3870	84	1.1370	1.2800
5	0.0000	1.7990	45	2.8980	3.1990	85	0.1500	0.6546
6	0.0000	1.8440	46	1.7430	2.0450	86	0.0000	0.0000
7	0.5210	2.9960	47	1.5190	1.5970	87	0.0000	0.0000
8	1.1970	3.1820	48	0.7500	1.1370	88	0.0000	0.0000
9	1.0420	2.7190	49	0.0000	0.4316	89	0.7900	0.0000
10	0.9860	2.3450	50	0.0000	0.0000	90	0.0000	2.2150
11	0.4010	1.4410	51	0.0000	0.0000	91	0.0000	2.8290
12	0.0000	0.9203	52	0.0000	0.0000	92	2.5920	3.3650
13	0.0000	0.0000	53	0.0000	0.5516	93	2.0970	3.1510
14	0.0000	0.0000	54	0.4370	0.0000	94	1.7730	2.6200
15	0.0000	0.0000	55	2.9270	2.9470	95	1.2220	1.6820
16	0.0000	0.0000	56	3.0760	3.0040	96	0.0000	1.2430
17	0.0000	0.0000	57	2.5420	3.0200	97	0.0000	0.5670
18	1.4820	0.9008	58	2.2710	1.8150	98	0.0000	0.0000
19	1.9290	2.8450	59	1.9370	1.3390	99	0.0000	0.0000
20	2.2090	3.0200	60	1.0840	0.8130	100	0.0000	0.0000
21	1.7960	3.1380	61	0.2160	0.0000	101	1.0280	0.0000
22	1.4170	1.9640	62	0.0000	0.0000	102	0.9700	0.0000
23	1.0880	1.5090	63	0.0000	0.0000	103	2.3710	3.0310
24	0.2670	1.0050	64	0.0000	0.0000	104	2.6770	3.2320
25	0.0000	0.0836	65	0.0000	1.4280	105	2.5270	2.9930
26	0.0000	0.0000	66	0.9660	2.7270	106	2.1980	2.3190
27	0.0000	0.0000	67	1.9010	2.5570	107	1.7890	1.2250
28	0.0000	0.0000	68	2.3620	3.2220	108	0.3560	0.6100
29	0.0000	0.8338	69	2.6850	2.6450	109	0.0000	0.0000
30	0.0000	0.8082	70	1.9570	1.8120	110	0.0000	0.0000
31	0.6810	2.5650	71	1.6550	1.2800	111	0.0000	0.0000
32	2.5270	2.4550	72	0.8130	0.6628	112	0.0000	0.0000
33	2.2380	2.3970	73	0.0000	0.0000	113	0.0000	2.2790
34	1.6080	0.1431	74	0.0000	0.0000	114	0.0000	1.3370
35	1.2950	0.0000	75	0.0000	0.0000	115	1.7040	2.6560
36	0.7480	0.0000	76	0.0000	0.0000	116	2.7610	2.8790
37	0.0000	0.0000	77	0.0000	0.8795	117	2.0470	2.7050
38	0.0000	0.0000	78	1.1050	1.1710	118	1.8020	1.6500
39	0.0000	0.0000	79	2.1200	2.8310	119	1.0540	0.9951
40	0.0000	0.0000	80	2.8140	2.9010	120	0.0000	0.0714

APPENDIX A15: SWATCUP observed stream flow validation statistics

Goal_type= Multiplicative_MSE No_sims= 500 Best_sim_no= 355 Best_goal = 6.878862e-001

Variable	p-factor	r-factor	R2	NS	bR2	MSE	SSQR	PBIAS	KGE
	0.28	1.27	0.62	0.32	0.5896	6.9e-001	2.1e-001	-39.8	0.50

RSR	MNS	VOL_FR	---	Mean_sim(Mean_obs)	StdDev_sim(StdDev_obs)
0.83	0.40	0.72		1.25(0.90)	1.21(1.00)

APPENDIX A16: Field soil sample validation procedure using Hydrometer Method

SOIL PARTICLE-SIZE ANALYSIS

HYDROMETER METHOD

Reagent

Calgon (Sodium Hexametaphosphate)

Procedure

1. Weigh 50g of 2mm sieved soil if soil is little clayey or more and 100g if the soil is a sandy or loamy sand soil into a 25ml plastic beaker.
2. Add 100ml calgon into the beaker and stir with a glass rod. Add about 100ml of distilled water and stir, leave beaker to stand for about 30 minutes with occasional stirring.
3. Transfer the sample into a mixing cup wash every content of the soil in beaker into the cup and stir for five minutes or transfer into a 25ml plastic container and shake on an to end shaker for ten minutes.
4. Transfer the mixed or shaken sample into a $1000cm^3$ measuring cylinder; make sure that the contents in the containers are washed completely into the cylinder. Make to $1000cm^3$ marked with water.
5. Before starting hydrometer reading, mix the suspension vigorously using along handle plunger and making. Sure that the sediment at the bottom is thoroughly disturbed.
6. Take hydrometer readings for 40 second, 4 minutes and 2 hours, 8 hours, 24 hours (these are the times recommended by bouyoucos for the 20um and 2um fractions respectively)
7. Before reading is due gently lower the hydrometer slower into the suspension. Take readings at the top of the meniscus.
8. Prepare a blank cylinder by making 100ml of the 50% calgon solution up to the 1 litre mark with water. Take also the blank hydrometer reading at each of the readings.
9. Take the temperature of the suspension and blank.

10. After the last reading pour the suspension through a 2mm or 72 mesh sieve. Wash the sand grains retained on the sieve with water and then transfer the washing into a beaker and dry in an oven at 105^0C
11. Finally weigh the sand. This will give the course sand fraction

Calculations

The corrected hydrometer reading C (g/L) from the hydrometer are obtained by subtracting the blank reading R_L (g/l) from the hydrometer readings in the soil suspensions R(g/L) and adding 0.36g/L for every degree above 20^0c.

$$C = R - R_L + (0.36T)$$

Where T = Room Temperature minus 20,

The percentages by weight of the SILT, CLAY and SAND fractions are given by:

$$\% \text{ CLAY} = \frac{\text{Corrected 8 hrs reading} - \text{BLANK} \times 100}{\text{Wt of soil taken}}$$

$$\% \text{ Silt} = \frac{\textit{Corrected } 40 \text{ Sec Reading} - \text{Blank} \times 100 - \% \text{ Clay}}{\text{Wt of soil taken}}$$

% Sand = 100 - % Clay -% Silt.

The samples can now be classified according to the USDA or international systems of textural classifications.