ASSESSMENT OF STREAMFLOW RELATIONSHIP MODELS OF SELECTED RIVERS IN SOUTHERN NIGERIA

BY

REGINA AKUDO UZOUKWU (B.Eng., M. Eng.)

Reg. No. 20134890018

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CERTIFICATION

This is to certify that this Thesis **"Assessment of Streamflow Relationship Models of Selected Rivers in Southern Nigeria"** was carried out by **Uzoukwu, Regina Akudo** with registration number 20134890018 in partial fulfilment of the requirements for the award of Doctor of Philosophy (Ph.D) Degree in Civil Engineering (Water Resources Engineering Option) in the School of Engineering and Engineering Technology, Federal University of Technology, Owerri.

Engr. Prof. B. C. Okoro (Supervisor)	25/10/2023 Date
Engr. Prof. J. C. Osuagwu (Supervisor)	25/10/2023 Date
Engr. Dr. H. U. Nwoke (Supervisor)	25/10/2023 Date
Engr. Dr. O. M. Ibearugbulem (Head, Civil Engineering Dept.)	25/10/2023 Date
Engr. Prof. R. Uche (Dean, School of Engineering and Engineering Technology)	25/3/24 Date
Prof. B. O. Esonu (Dean, Postgraduate School)	Date
Engr. Prof. T. C. Ogwueleka (External Examiner)	25/10/2023 Date

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DEDICATION

I dedicate is dissertation to the Almighty God, who have forever remained my ever present help, for His favours, supports, blessings and inspirations which led to my successful completion of the Ph.D Degree in Civil Engineering.

I also dedicate this work to my children Peace Chinonso Uzoukwu, Dorcas Chiamaka Uzoukwu, Ruth Chidinma Uzoukwu and Paul Uchechukwu Uzoukwu for their love and unwavering supports towards ensuring the realization of my Ph.D degree programme.

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ABSTRACT

This study focused on Assessment of Streamflow Relationship Models of Selected Rivers in Southern Nigeria. The rivers include; Cross River, River Niger, Owena River, Owan River, Ikpoba River, Ossiomo River and Imo River. Statistical methods of least squares (regression analysis) were used to develop streamflow mathematical models (Power model, Polynomial model and Analysis of Variance (ANOVA) model for regression) of the selected rivers. Models performance in calibration and verification were evaluated by means of coefficients of determination, coefficients of correlation, Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias, root mean square error or standard error of estimate andmean of residuesor mean absolute error. Verification results exhibited a similar pattern in model performance to the calibration results, indicating that the models have good curve fitting. Comparisons of the streamflow models were carried out using One-way ANOVA F-Test, Variance Ratio Test or Snedecor's F-distribution (F-Test). Further comparisons using graphs and a final comparison using Student's t-Test were done. The models developed will serve useful purposes in the design of dams, estimation of the sizes of reservoirs, public water supply, flood control and hydropower generation, pisciculture, recreation, irrigation, wild life protection, water sports and tourism thus ushering in an era of socio-economic and industrial development for the Southern Nigeria. This research will play an important role in ensuring that water resources management processes in the Southern Nigeria are scientifically based and efficiently used so as to satisfy the needs of both natural systems and humanity, as being demonstrated in the applications of the calibrated models.

Keywords: Discharge, Stage, Streamflow, Water Resources, Model Calibration, Model Verification.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Water is a natural resource of a country. It is essential for life and very crucial for sustaining human life as well as the lives of other living creatures. It is fundamental to the biochemistry of all living organisms. Water covers 71% of the Earth's Planet (Willcock as cited in Tsegha, 2014). The Planet's ecosystems are linked and maintained by water; it drives plant growth and provides a habitat for many species, such as 8,500 species of fish and most of the world's 4,200 species of amphibians and reptiles. Water is a resource under considerable pressure required for human and animal consumption. It is needed for drinking and for the growth of agricultural produce which sustains life on the earth.

Water is also used for other various purposes such as navigation, recreation and for production of hydropower. If water is properly controlled and made use of, it can prove a boom, and of great value to mankind. In case it is not properly controlled, it may become a curse and cause of disaster and misery to humanity (Lamidi, 2011; Okoro, Uzoukwu & Ademe, 2016; Arora, 2007; Gupta & Gupta, 2008). Water has always been intimately linked with human development, and its role is considered crucial for the transition of men from hunters to farmers. Now due to the advancement in scientific and technical knowledge of floods, their occurrence and magnitudes etc. the need for skilled planning and careful management has further increased to achieve the level of efficiency in water use, which will be much needed in future.

In many developed countries, people have constant access to water of good quality, and water is an indispensable component of clean outdoor environment, while in semi-arid countries, lack of sufficient water is a limiting factor for social and economic development (Ojha, Berndtsson & Bhunya, 2008). The issue of access to potable water is very important especially in the under developed countries. Only three percentage of the earth water is available as fresh water in lakes, rivers and groundwater. However, the requirement for these limited fresh waters is on the increase because of the growth in population and industrialization. The amount of drinking water required is variable and depends on physical activity, age, health issues and environmental conditions (Grandjean, 2004).

The unavailability of long period of record of hydrological data such as streamflow measurements is one of the major problems encountered by engineers and hydrologists in the planning and design of water resources structures in Nigeria and other underdeveloped countries. In developed countries such as America, France and Britain to mention but a few, hydrological data such as rainfall data and stream flow data abound up to and beyond one hundred years' duration.

There have been two broad categories of models such as physical and mathematical models. Physical models include scale models which represent the system on a reduced scale. Examples are a hydraulic model of a dam spillway; and analog models which use another physical system having properties similar to those of the prototype. The construction of physical models of systems and their performance monitoring over a wide range of real life operating conditions makes it possible to select optimum design parameter in the manufacture of ships, aircrafts, automobiles, etc.

The other categories of models are called mathematical or abstract models. This involves the simplified representation of some aspects of a real system using mathematical concepts; for example, functions, diagrams, equations and graphs to solve problems in a real world. Mathematical modeling is the act of translation of physical problems into tractable mathematical formulations whose theoretical and numerical analysis provides understanding of the real life phenomenon and solution to the problem. A mathematical model often takes the form of differential equation or system of differential equations. Since the goal is to use the equation to solve specific problems, the interest is in specific rather than general solutions. The specifics are obtained by imposing some initial and boundary conditions on the equation.

The procedure of developing working equations and models of hydrologic phenomena is similar to that in fluid mechanics, but in hydrology there is generally a greater degree of approximation in applying physical laws because the systems are large and more complex, and may involve several working media. Also most hydrological systems are inherently random as precipitation is their major input, which is a highly variable and unpredictable phenomenon. Consequently, in hydrologic analysis, statistical analysis plays a large role.

Strong nonlinear bivariate and multivariate correlations are common in hydrology and various mathematical models are used to describe the relations, such as parabolic, hyperbolic, exponential, power, and other forms provide better graphical fits than straight lines (Viessman & Lewis, 2008), but in developing streamflow models, exponential models are employed in data fitting, since the relationship between stage and discharge is an exponential function (Ojha et al., 2008). The approach was to utilize the original data in models calibration and using model verification, coefficient of correlation, coefficient of determination, Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias, mean residue and root mean square error and standard error of estimate as model performance measures and evaluation parameters for good curve fitting.

1.2 Problem Statement

The growing population and drying climate is putting enormous pressure on limited fresh water resources, and is forcing to revisit and assess how water resources is being managed in a region. In Nigeria, the two main problems man contends with are the quantity and quality of water. This is a problem experienced in most cities and towns not to mention the rural settings. Communities face a lot of challenges as it concerns meeting their water needs. These challenges include flooding associated with climate variability, increased water scarcity and economic uncertainty, aging and degrading infrastructures, impaired water resources, water pollution and a broad range of stakeholders with poor understanding of water issues. Water resources engineers and water scientists deal with various issues such as the design and operation of data retrieval and storage systems, forecasting, developing alternative water use futures, estimating water requirements for natural systems, developing more efficient systems for applying water in all water-using sectors, and analyzing and designing water management systems incorporating technical, economic, environmental, social, legal and political elements.

It is generally accepted that hydrological data are indispensable in the planning and design of water resources development programmes. The unavailability of long period of record of hydrological data such as streamflow measurements which are used for streamflow modeling has been one of the major problems encountered by hydrologists and water resources engineers in the design and planning of water resources processes in Nigeria and other underdeveloped countries of the world. This study will help to overcome these problems and will help to organize and operate key sustainability principles and practices in water resources management.

1.3 Objectives of the Study

The main objective of the study is Assessment of Streamflow Relationship Models of Selected Rivers in Southern Nigeria.The specific objectives are:

i. Obtaining streamflow data from streamflow gauging stations along the seven selected rivers; Cross River, River Niger, Owena River, Owan River, Ikpoba River, Ossiomo River and Imo River.
ii. Data cleaning which includes checking the data for consistency and treatment for missing value and also the extension of the streamflow records from the gauging stations that have some missing data.
iii. Calibration of streamflow mathematical models of the seven selected rivers based on the principle of regression and correlation using streamflow data obtained from the gauging stations along the rivers.
iv. Verification of the calibrated streamflow models for the determination of their level of accuracy and/or reliability and also appropriate comparisons of the streamflow models
v. Evaluation of model performance and computation of model performance measures or evaluation parameters including application of the calibrated models

1.4 Significance of the Study

This research work is typically necessary in order to estimate availability of water resources, size of reservoirs, flood estimation and prevention, and pollution transport. It is expected to serve as a useful tool in predicting streamflow events in Cross River, River Niger, Owena River, Owan River, Ikpoba River, Ossiomo River and Imo River, and in turn flood prediction in the areas close to them. It should also be useful to hydrologists and water resources engineers in predicting rivers having similar characteristics with the rivers studied. Its recommendations and implementation may constitute an instrument for improvement in the design and operations of hydraulic structures within the localities, as well as ensuring better development and management of water resources in the Southern Nigeria. This work is expected to further stir up the interest of Federal and State Ministries of Agriculture and Water Resources, Research Centers, Universities, River Basin Organization and other Non-Governmental Organizations (NGOs) in the subject of assessment of streamflow relationship models of rivers. This interest may ultimately contribute in no small way towards the actualization of better water resources management in this country.

1.5 Scope of the Study

This research covers stage and discharge data collection for Cross River, River Niger, Owena River, Owan River, Ikpoba River, Ossiomo River and Imo River, data cleaning which includes checking the data for consistency and treatment for missing value, analysis of the data, calibration of streamflow mathematical models from the data using regression data fitting method, verification of the calibrated streamflow models, then comparisons of the streamflow models are carried out followed by computation of model performance measures or evaluation parameters and finally application of the calibrated models.

1.6 Limitations of the Study

There were limited resources available in the core subject area of this research. Thus, the researcher complemented books from the University library, with online journal arcticles along with some other internet website publication. These apparently remedied the situation, but still poised with the challenge of the limited contents of the accessed materials.

This nation and other underdeveloped countries in the world have not succeeded in providing long term hydrological data such as streamflow measurements which are necessary in water resources management processes, design and planning of water resources structures. Also, some of the gauging stations for the rivers in the study area do not have streamflow data for some years due to spoilt staff gauges. Extension of the streamflow records were carried out by generating the missing data with the properties of the observed historical data.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Importance of Water

Water is one of the basic elements of life only second to air. Water is a basic necessity and an excellent resource of a nation as it can be made to serve various functions. It is required for drinking and many other purposes by humans and for animal breeding. It is needed for mechanized agriculture which is a more productive farming practice particularly when irrigation processes from rivers or lakes are made part of the scheme. Properly planned use of water may nourish our farms and forests, may run our turbines for generation of hydropower, may help in floating our ships, and may help in beautifying our surroundings and environment. Water is used for many other purposes such as navigation and recreation (Arora, 2007; Gupta & Gupta, 2008; Okoro & Uzoukwu, 2014). World Health Organization (WHO) (as cited in Ogunwemino, 2015) stated that water is a basic need of human development, health and well-being. Its availability for drinking has been internationally accepted human right, which is enlisted as one of the ten targets in Millennium Development Goals (M.D.G).

Garg (2005) stated that water is a chemical compound and can occur in a liquid, solid or gaseous form. All these three forms of water are veryuseful to man, providing him the luxuries and comforts, as well as fulfilling his basic necessities of life. Difficulties associated with the lack of adequate and quality water resources in Nigeria have threatened to place the health of about 40 million people at risk (WHO/UNEP, 1996). Water is an important natural resource that shapes regional landscapes and is very necessary for ecosystem functioning and human well-being. Water is essential for socio-economic growth and for the maintenance of healthy ecosystems (Global Water Partnership, 2012). Globally, there is a drawback in water availability which is increasing and duplicating itself therebyescalating the struggle for scarce water resource. Thus to make the best use of this natural resources (water), every interest should lie in the harness of the largest quantities of water flowing in the rivers (Gupta & Gupta, 2008; Okoro et al., 2016; Olukanni et al., 2015).

The tempo of water supply was raised in the 1980s with the preparation for and campaign in favour of the United Nation's International Drinking Water supply and Sanitation Decade from 1981 to 1990. The goal of the programme has been to provide water for all by the year 1990, 120 litres/day of water. However, just before the commencement of this programme, only22% of the rural and 55% of the urban population enjoyed potable water. These figures have increased only marginally. In absolute terms, by 1986, rural dweller had access to 25 litres of potable water per day while their urban counterpart had access to 60 litres/day. Water must not only be adequate in quantity; it must also be adequate in terms of its quality. The basic physiological requirement for drinking water has been estimated at about 20 litres per person per day. However, the daily supply of 140 litres per capita per day is considered adequate to meet the needs for all domestic purposes (WHO/UNEP, 1996). It is estimated that more one billion people in developing countries lack access to potable water.

WHO (as cited in Ahmed et al., 2011) reported that water has wide influence on well-being and health and the issues such as the quantity and quality of the water are vital in determining the health of individuals and whole community. Olukanni and Ugwu (as cited in Olukanni et al., 2015) observed that as a measure to reduce the daily shortage of water especially in most of our urban areas, attention is now shifted to open dug wells and boreholes for groundwater resources. For centuries, aquifers have been thought to be one of the veritable and sometimes the major reliable source of potable water resources in many nations of the world which is not always true in all cases. It is expected that the deeper the aquifer, the better its water quality. Gbadebo and Akinhanmi (2010) stated that maintenance of groundwater resources is a must to every home that consumes water.

The sources of water in the world include the entire range of natural waters that occur on the earth, which include groundwater, surface water and rain water. Surface water include rainwater collected from structures or prepared catchments, water from rivers, natural lakes, storage reservoirs and oceans. Groundwater supplies are a result of surface water percolating through the soil and rock (Fubara-Manuel & Jumbo, 2014). Providing access to drinking water poses a serious and growing challenge in Nigeria and other developing and underdeveloped countries in the world. Population increases expected in future is likely to worsen the existing conditions if proper measures are not taken (Ogunwemimo, 2015).

Nigeria is the most populous country in Africa with a population of over 160 million. The country is endowed with generous natural resources of water bodies. Nigerian water resources potential is estimated at 267 billion cubic metres of surface water and 92 billion cubic metres of ground water per year. Nwosah (2011) observed that Nigeria is blessed with abundant water resources with an average rainfall of 500mm/year in the North (April to September) and 3,000mm/year in the South (March to October). This culminates to 267.3 billion m^3 surface water and 51.9 billion m^3 ground water (Fed. Min. of Water Resources, as cited in Nwosah, 2011).

In the pre-historic era, provision of domestic water supply was largely through individual and community efforts. The regional government later got involved with the major concern of developing schemes for urban and semi-urban areas and neglected the rural communities. For this purpose, the regional governments established the Water Boards or Corporations to provide the services. The drought of the early seventies prompted the intervention of the Federal Government to take a number of actions. This resulted in the establishment of some Federal Agencies. These Agencies include the Federal Ministry of Water Resources, National Water Resources Institute and the River Basins Development Authorities (RBDA). While the Ministries have the responsibility to formulate policies and give advice, training and research, the RBDAs are executing agencies, providing irrigation water and domestic water supply to the communities.

According to Okoro and Uzoukwu (2014), the first and foremost requisite for planning of water resources development is the availability of accurate data of streamflow for a considerable period of time to determine the extent and pattern of available supply of water. Therefore, the importance of streamflow measurement and streamflow modeling need not to be over emphasized. But in many under developed countries like Nigeria not much attention has been paid for measurement of streamflow (Gupta & Gupta, 2008; Ojha et al., 2008; Viessman & Lewis, 2008; Raghunath, 2006; Sonuga, 1990).

A proper understanding of flow regime of river is vital for channel design and to estimate flood discharges such structure could tolerate (Awokola & Martins, 2001). The growing population is putting enormous pressure on limited fresh water resources, and is forcing a revisit and assess how water resources is managed in a region. Water accounting, which is identifying, quantifying and reporting information of water flow in a system, is the first step towards formulating productive and sustainable water management strategies in a region (Singh et al., 2009; Suresh, 2012; Garg, 2012; Okoro & Uzoukwu, 2014).

2.2 Water Resources Management

Water resources management refers the management of existing water resources including pre and post water resources development activities (Suresh, 2012). Faced with climate and land use change, population growth, rising water demand, urbanization and pollution, the existing water resources are under pressure (Kundzewicz et al., 2007). The competition over water quality and quantity of the shared water resources will increase in future and might result in conflict between different sectors on the one hand and riparian states on the other hand (Giordano & Wolf, 2003; Lange, Mungatana & Hassan, 2007). Therefore, the sustainable integrated basin wide management of transboundary water resources especially under the consideration of climate variability and un-stationarity due to climate change (Minville et al., 2008) is crucial to avoid and to resolve conflict among water users (Kundzewicz et al., 2007; Goulden et al., 2009).

Klemis (as cited in Suresh, 2012) defined the water management as a discipline that seeks the water balance between the demand and availability of water with the satisfaction of economic, political, sociological, ecological and environmental consideration. Compared to other natural resources, water is not stationary and does not respect administrative borders. Thus, drainage basin's boundaries are not necessarily identical to political boundaries resulting in the existence of International River Basins. Within the basin, (surface) water can be distributed unequally which might lead to conflict among the riparian states about transboundary waters especially surfacewaters (Wolf et al., 2003a). To prevent conflict and to manage the existing natural resource adequately, the partition of river flow can be regulated by bilateral or multilateral water allocation agreements (Matthews & St. Germain, 2007).

The purposes of water resources planning and management may be grouped roughly into two categories. One is water control, such as drainage, flood control, pollution abatement, sediment control, and salinity control. The other is water use and management, such as domestic and industrial water supply, irrigation, recreation, hydropower generation, fish and wild life improvement, low-flow augmentation for water quality management, and watershed management (Chow et al., 1988). In either case, the task of the engineer or the hydrologist is the same, namely to determine a design inflow, to route the flow through a system and to check whether the output is satisfactory. A properly managed water resource is a critical component of poverty reduction, growth and equity.

2.2.1 Water Resources Management Processes

Water resources management processes involve planning, developing, distributing and managing the optimum use of water resources. It aims at optimizing the available natural water flows (both groundwater and surface water) to satisfy competing water needs. The functions of water resources management are very complex tasks and may involve many different activities conducted by many different players. Global Water Partnership (2012) highlighted the following components which constitute water resources management: water allocation, river basin planning, stakeholder participation, pollution control, monitoring, economic and financial management, and information management.

2.2.1.1 Water Allocation to various Water using Sectors

Water allocation is the allocation of certain rate of flow of water to various water using sectors. It is used as a basis for designing the distributaries and water courses (Suresh, 2008). Effective allocation of water to major water users, maintaining minimum level for social and environmental uses, while addressing equity and development needs of society in the States are very necessary. The knowledge of the river basins of any State for sustainable water resources management will assist in effective water resources allocation in the State, to prevent conflict and to manage the existing natural resource adequately.

2.2.1.2 River Basin Planning involving Water and Land Resources Management Issues and Ongoing Activities in a Basin

The first step in developing a strategic plan is to get a clear idea of the water and land resource management issues and ongoing activities in a basin. Therefore, preparing and regular update of the Basin Plan with the incorporation of stakeholder views on development and management priorities for the basin is important. Legal principles requiring equal share of water resources and the sustainable management of the river basins and treaties according to water quantity and quality, administrative structures as well as geopolitical institutions like River Basin Organizations have to be created in several States, as basin wide networks and river basin organizations attenuate conflict.

2.2.1.3 Stakeholder Participation in DecisionMaking

A necessary component of water resources management is implementing stakeholder participation to be the basis for decision making which takes into account the best interests of the environment and the society in the development as well as in the use of water resources in the basin. All Stakeholders and water users in Southern part of the country could be enlightened through lectures and seminars by the State's Water Management Authorities for more efficient and sustainable water resources management. Procedures for involving stakeholders need to be designed thoughtfully and implemented carefully. Taking part in village meetings, 'town hall' meetings, surveys of basin stakeholders' opinions and basin advisory groups, are just some of the ways stakeholders can be encouraged to get involved. Workshops and field trips can help both stakeholders and basin organizations appreciate the array, size and extent of land and water resources issues in basin management, as well as how local actions impact other parts of the basin (Global Water Partnership and International Network of Basin Organizations, 2009).

2.2.1.4 Pollution Control using Polluter Pays Principles

Managing pollution using "polluter pays principles" and appropriate incentives to reduce most important pollution problems and minimize environmental and social impact are required. Refuse disposal and pollution of rivers can be controlled since most of the rivers are the main sources of potable water supply in their locality.

2.2.1.5 Monitoring through Enacting Local Water Laws and Policies

Local water laws and policies are the rules of the game that determine how all stakeholders play their respective roles in the development and management of water resources. Thus the States should implement effective monitoring systems that provide essential management information, and identifying and responding to infringements of laws, regulations and permits. State Governments should monitor public (administrative) allocation of water which it is used for intersectoral allocation of water, as the States usually are the only institutions that have jurisdiction over all sectors of the economy.

2.2.1.6 Economic and Financial Management Tools Application for Investment and Cost Recovery

Applying economic and financial tools for investment, cost recovery and behavior change to support the goals of equitable access and sustainable benefits to society from water use is important. The States should identify and implement measures for governance and increasing the efficiency of water use, by always carrying out cost-benefit analysis in order to compare the economic efficiency implication of alternative actions. Economic efficiency is one of the primary objectives in the development and allocation of water resources due to its importance as a social objective, as efficiency values have viable meaning in resolving conflicts and evaluating the opportunity costs of pursuing alternative uses of water.

2.2.1.7 Information Management Systems Created within a Basin to Generate Data and Indicators on Water Resources

Basin organizations need to create a basin information system that generate data and indicators on water resources and water use that will allow effective assessment of water management. Providing essential data necessary to make informed and transparent decision as well as development and sustainable management of water resources in the basin is very crucial to the development of an appropriate menu of adaptation and mitigation options for addressing hydrologic variability and climate change in water management. Information such as river(s) stage(s) and river(s) discharge(s) should be recorded by the State Government Water Management Authorities and River Basin Authorities, as they are necessary for water resources management.

2.3 Definition of Streamflow

The rate of flow or discharge of a stream is the quantity of water flowing through a given cross-section of the stream in a given time (Gupta & Gupta, 2008; Viessman & Lewis, 2008). Streamflow (also called discharge or surface runoff) is usually defined as the visible water on the ground (i.e., the surface water). This may include ponds, brooks, creeks, river, lake, reservoirs, etc. Surface water is available for water supply as well as irrigation. Correct evaluation of the amount of discharge is important because it has its effect on the water supply, irrigation, generation of hydropower, and environment.

The knowledge of streamflow is important for estimating groundwater recharge rates. Barlow and Leake (2012) explained that the effect of groundwater pumping on streamflow is one of the primary concerns related to the development of groundwater resources.There is a connection between the groundwater and surface-water systems,as groundwater discharge is often a substantial component of the total flow of a stream. The amount of groundwater that flows to streams are reduced by groundwater pumping and, in some cases, streamflow can be drawn into the underlying groundwater system. An important water-resource management issue is streamflow reductions (or depletions) caused by pumping due to the negative impacts that reduced flows can have on the availability of surface water, aquatic ecosystems, aesthetic value and quality of rivers and streams.

2.3.1 Sources of Streamflow

The watershed or catchment is the area of land draining into a stream at a given location. Channel flow is the main form of surface water flow, and all the other surface flow processes contribute to it. Determining flow rate in stream channels is the central task of surface water hydrology. Precipitation contributes to various storage and flow processes. The precipitation which becomes streamflow may reach the stream by overland flow, subsurface flow, or both (Chow et al., 1988).

2.3.2 Streamflow Hydrograph

According to Chow et al. (1988) and Raghunath (2008), a discharge or streamflow hydrograph is a table or graph showing the rate of flow as a function of time at a given location on the stream. In other words, an integral expression of the climatic and physiographic characteristics that govern the relations between runoff in a particular drainage basin and rainfall is called the hydrograph. Two types of a hydrograph are particularly important: The annual streamflow hydrograph and the storm hydrograph.

2.3.2.1 Annual Streamflow Hydrograph

This annual hydrograph is a plot of streamflow versus time over a year showing the long-term balance of precipitation, evaporation and streamflow in a watershed.

2.3.2.2 Storm Hydrograph

Study of annual streamflow hydrograph shows that peak stream flows are produced infrequently, and are the results of storm rainfall alone or storm rainfall and snowmelt combined. Figure 2.1 shows four components of a streamflow hydrograph during a storm. Prior to the time of intense rainfall, baseflow is gradually diminishing (segment AB). Direct runoff begins at B, peak at C and ends at D. Segment DE follows as normal baseflow recession begins again (Chow et al., 1988).

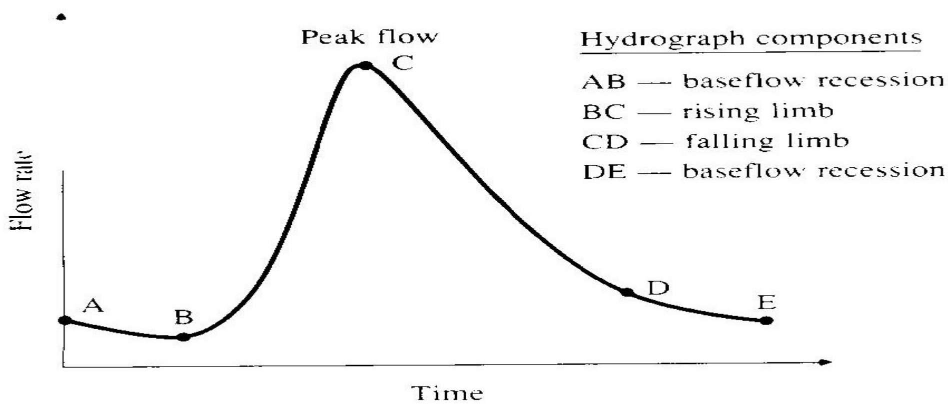


Figure 2.1: Components of the streamflow hydrograph during a storm
Source: Chow et al. (1988)

2.3.3 Streamflow Measurements

Reddy (2008) noted that the water which constitutes the flow in the surface stream is called streamflow. If the streamflow is unaffected by the artificialdiversions, storage or other works of man on or in the stream channels, then it is called as runoff. In other words, runoff means the virgin streamflow. Stream flow is one of the most important data needed by hydrologists and engineers as they are particularly interested with estimating rates and volumes of streamflow to values made by man-made causes.

2.3.4 Methods of Measuring Streamflow

According to Viesman and Lewis (2008), direct methods involving measurements of cross-section area and velocity, and then determining the discharge as the product are the most accurate measurement of streamflow rates. Indirect methods include construction of structures in the stream called a rating curve, that have a fixed relationship between water stage and discharge rate, or by calculation of discharge from channel roughness characteristics and high water marks at a known cross section. As highlighted by Raghunath (2006), the most satisfactory determination of the runoff from a catchment is by measuring the discharge of the stream draining it, which is termed stream gauging. A gauging station is the section or place on a stream where stage and then discharge measurements are made.

Even though stream flow or discharge is the most important hydrological studies, it is not directly recorded. It is rather difficult to measure the discharge of flow in the natural streams directly as it is done in the case of flow in pipes or laboratory flumes using the flow meters such as the venturimeter, venturiflume, notches etc. But it is very easy to make a direct and continuous measurement of stage in the river which is nothing but the height of water surface in the river above some arbitrary datum. Obviously the higher the stage in the river the higher is the discharge (Reddy, 2008).
Reddy (2008) further explains that the general practice in the stream flow measurement is, therefore, to record the river stage and to convert the data on stage into the discharge data. This is accomplished through the stage-discharge relationship or rating curve (see Figure 2.2), which is first established by actual measurement of the discharge in the river at different stages over a period of months or years so as to obtain an accurate relationship between the stream flow rate, or discharge, and the gauge

height of the gauging site. Once a stable stage-discharge relationship is established at a gauging site, the discharge measurement is discontinued and only the stage is recorded continuously.

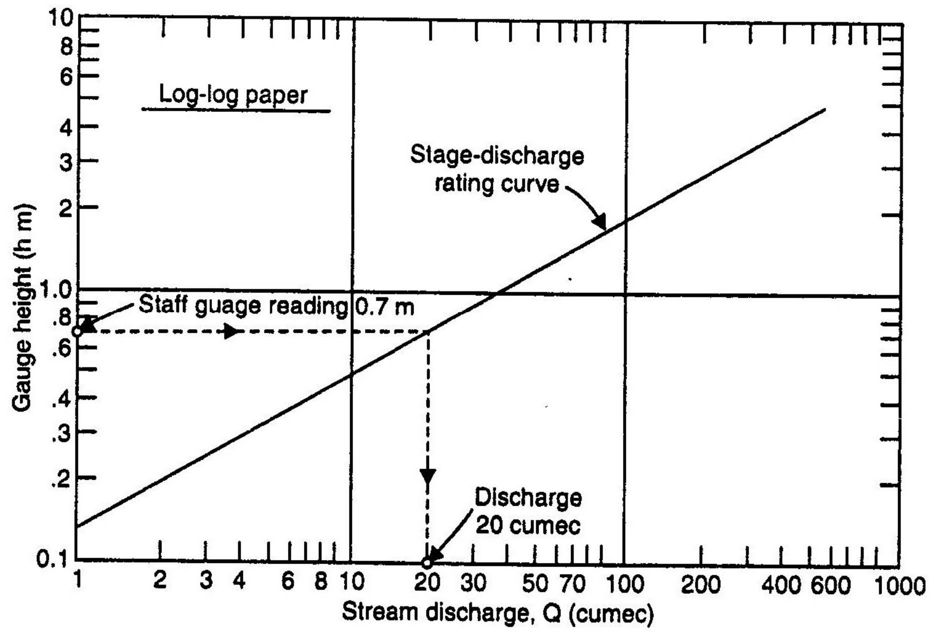


Figure 2.2: Stage-discharge rating curve

Source: Reddy (2008)

2.3.5 Stage-Discharge Measurement

According to Reddy (2008), the river stage (gauge height) which is the height of water surface in the river at a given section above any arbitrary datum is usually expressed in metres. The datum is taken as the mean sea level in many cases, Sometimes the datum may be selected at or slightly below the lowest point on the river bed. The stage is easily measured by installing a vertical staff gauge which is nothing but a graduated scale, which can be conveniently attached to a bridge pier or any other existing structure, such that a portion of the staff gauge is always in the water at all times.

Reddy (2008), further explains that when the flow in the stream is subjected to large variations resulting in correspondingly large fluctuations in the stage, it may be beyond the range of a single vertical staff gauge to record the entire rise and fall in the water surface. In such situation it may be convenient to use several vertical staff gauges as shown in Figure 2.3 covering the entire range, the graduations of all the gauges being reduced to the same datum. There should be a minimum overlap of 0.5m between any two successive staff gauges.

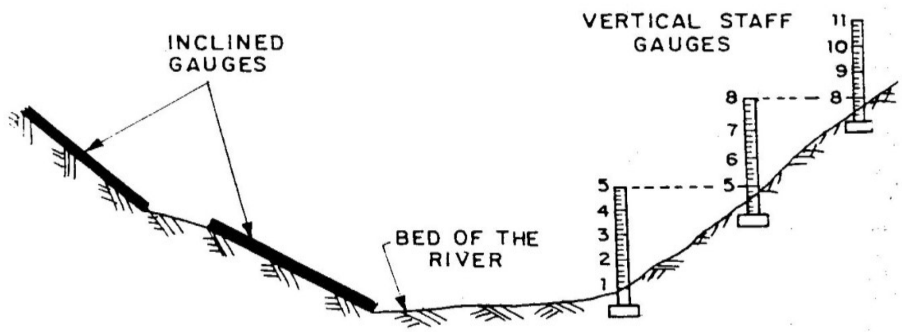


Figure 2.3: Measurement of stage in the river

Source: Reddy (2008)

Sometimes the gauge may be placed in an inclined position up the stream bank as shown in Figure 2.3. It must be properly anchored to the slope of the natural bank of the river channel. It is calibrated in the site by precise leveling and graduated accordingly. Inclined gauges may be constructed on one continuous slope or on more slopes. A flight of steps constructed alongside the inclined gauges is more convenient and observation is taken easily. Manual observations of water level or river stage measurement are made using staff gauges, which are graduated boards set in the water surface, or by means of sounding devices that signal the level at which they reach the water surface, such as a weight on a wire suspended from a bridge over the surface of a river which is called the suspended weight gauge.

Reddy (2008) explained that in the suspended weight gauge method, a weight attached to a rope is lowered from a fixed reference point on a bridge or other overhead structure till it touches the water surface. The stage is obtained by subtracting the length of the rope lowered from the reduced level of the fixed reference point. Though the manual gauges described above are simple and inexpensive they must be read frequently to get continuous curve of the stream flow, especially when the stage is changing rapidly. Furthermore, the peak stage may likely be missed when its occurrence is in between the observations. These difficulties may be overcome by installing recording type gauges or a crest gauge.

Automatic records of water levels are made using the sensor, such as a bubble gauge. A bubble gauge senses the water level by bubbling a continuous stream of gas (usually carbon dioxide) into the water. The pressure required to continuously push the gas stream out beneath the water surface is the measure of the depth of water over the nozzle of the bubble stream. A manometer in the recording house is used to measure the pressure. Continuous records of water levels are maintained for the calculation of stream flow rates (Chow, et al., 1988).

According to Reddy (2008), an automatic stage recorder is a recording type gauge used to measure the stage continuously with time. Usually it comprises a float tied to one end of a cable running over a pulley. A counterweight is attached to the other end of the cable. The counterweight always keeps the cable in tension as the float rest on the water surface.The float either rise or lower due to change in water surface which in turn makes the pulley rotate. A pen arm which rests on a clock-driven drum wrapped with a chart would be actuated by the movement of the pulley. The height of the drum represents the stage while the circumference of the drum represents the time axis. So, either some scaling mechanism or sufficient height of the drum is provided to cover the expected range of the stage. The chart may run for a specified period of time (like day or week or a month) unattended to due to the design of the drum and the clock.

The float type automatic stage recorder is sheltered in a stilling well as shown in Figure 2.4. The stilling well protects the counterweight and the float from floating debris. With proper design of intake pipes, the stilling well suppresses the fluctuations resulting from surface waves in the river. Generally, to allow the water from the river into the well two or more intake pipes are placed, so that at least one will admit water at all times. It is necessary to make provision for the removal of the silt from time to time as the stilling well is likely to get filled with sediment. It is customary to install staff gauges outside and inside the well, as they serve to check the performance of the recorder and these are read each time the section is visited (Reddy, 2008).

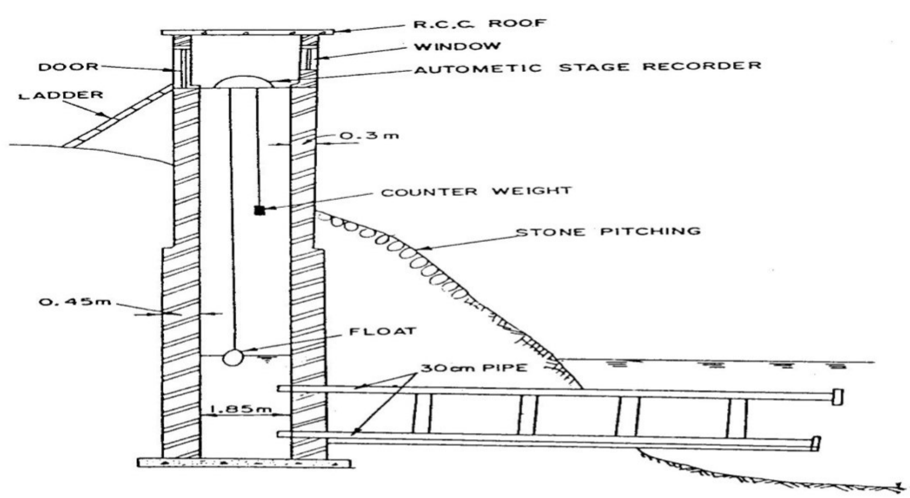


Figure 2.4: Shelter for automatic stage recorder
Source: Reddy(2008)

2.3.6 Discharge Measurement by Area -Velocity Method

According to Viessman and Lewis (2003), the most accurate measurement of stream flow rates is by direct methods, which involves the measurement of cross-sectional area and velocity, and then the discharge is determined as the by product. Reddy (2008) further explains that though there are several methods of discharge measurement, the most accurate of all of them is the area-velocity method. In this method the discharge is obtained as the product of the cross –sectional area of the flow in the river and the average velocity of flow.

That is $Q = A.V$ . . . . (2.1)

Discharge measurement here involves obtaining information at a number of points over the cross-section sufficient to determine the average velocity and also the area of flow. The procedure involves dividing the flow area into a number of strips by means of verticals selected along the width of the river and measuring the depths at these verticals. The velocities are measured at one or more points on the verticals to obtain the mean velocity for any vertical. Current meter is inserted at any point facing the flow in the river in order to measure the velocity at that point in the river.

2.3.7 Flow Measurement of a River using Current Meter

Current meter is an instrument for the measurement of the river velocity (i.e. the velocity of flow in channel). It is a device which measures the speed of water movement. The current meter consists of a rotating device, which revolution corresponds to the velocity of flow when placed on the flowing water surface (see Plate 1). For measuring the flow velocity, the meter is mounted on a rod or tied with cable and is lowered to the river water. The mounting rod is preferred for shallow rivers; and cable for the deep river flows.

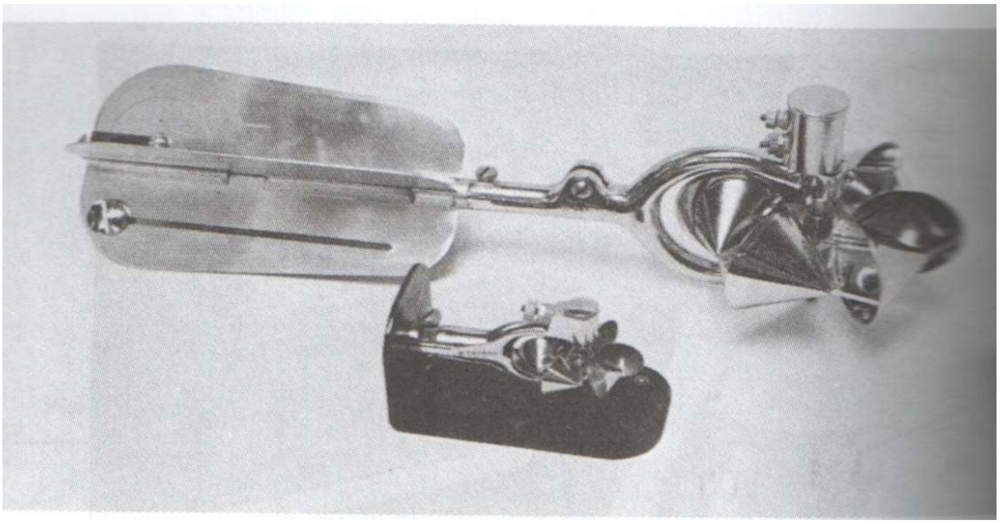


Plate 2.1: Current meter for measuring water velocity
Source: Chow et al. (1988)

Several observations are taken at each segment of the river section and the corresponding flow velocities are determined with the help of rating curve, which is supplied to the current meter. The mean flow velocity is obtained by averaging them.

2.3.7.1 Classification of Current Meter

In general, current meter consists of a wheel or a revolving element containing blades or cups, and a tail on which flat vanes or fins are fixed. According to the shape of the revolving element (i.e. depending on the design of the rotating element), the current meters may be classified as:
Cup type and Screw type (i.e. vane or propeller type).

i. **Cup Type Current Meter:**

   In a cup type current meter, the wheel or the revolving element has the form of a series of conical caps on a spindle which is held vertical at right angle to the direction of flow (see Figure 2.5).

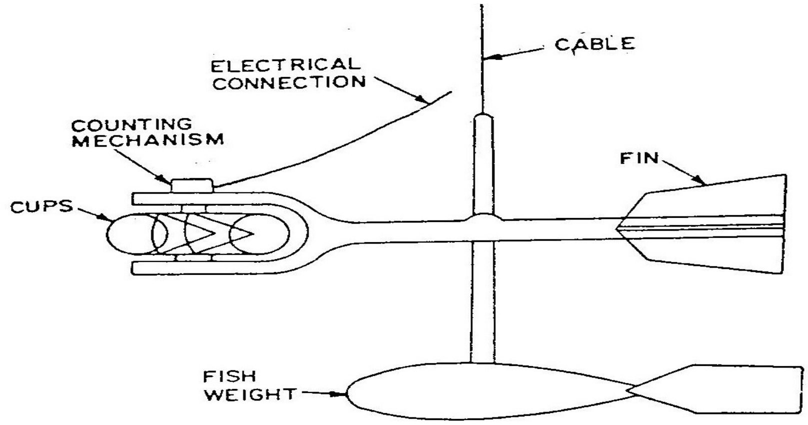


Figure 2.5: Cup type current meter

Source: Reddy (2008)

ii. Screw Type (Vane or Propeller Type) Current Meter:

In a screw or propeller type current meter, the revolving element consists of a shaft, with its axis parallel to the direction of flow, which carries a number of curved vanes or propeller blades mounted around the periphery of the shaft, as shown in Figure 2.6.

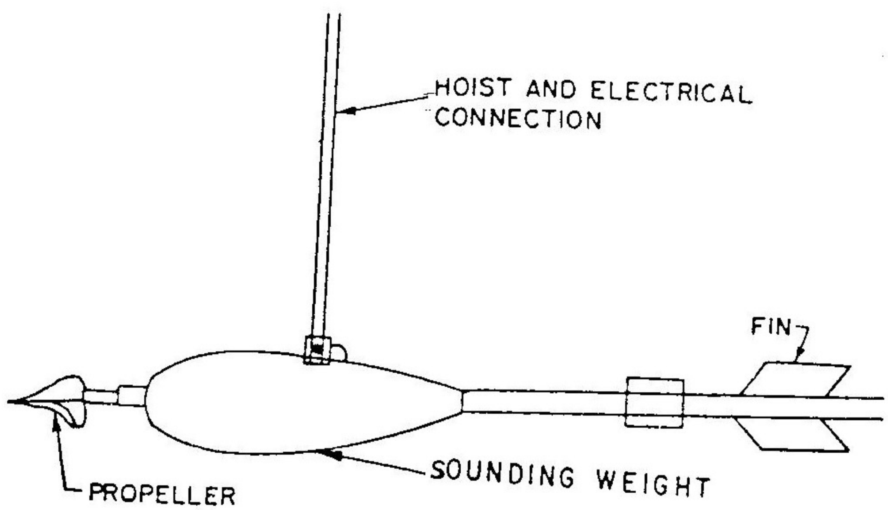


Figure 2.6: Propeller type current meter

Source: Reddy (2008)

2.3.7.2 How the Current Meter works when immersed in the River

i. The current meter is suspended by means of a cable and it is held vertically immersed in the floating stream of water to the required depth, such that the wheel or the revolving element is facing towards the upstream direction. The wheel is thus rotated by the dynamic thrust exerted on it by the flowing water.

ii. After setting the current meter to the required point in the flowing stream of water the number of revolutions of the wheel per unit time is noted and from the calibration curve the velocity of flow of water may be determined.

iii. In order to facilitate the counting of the number of revolutions of the wheel, usually an electrical transmission system is provided. By means of wires an electric current is passed to the wheel from a battery above the water, and to the spindle of the revolving blades or cups a commutator is fixed which makes and breaks the electric circuit during each revolution.

iv. An electric bell or a head phone is connected in series in the electric circuit to give an audible signal thereby facilitating the counting of the number of revolutions. Sometimes instead of this a revolution counter is provided.

v. The number of signals in a given time is noted by the observer with a stop watch, from which the speed of the wheel in terms of revolutions per minute may be computed.

vi. The current meter is required to be calibrated experimentally. This is done by towing the current meter at various speeds through still water contained in a long tank and noting the speed of the towing carriage and the rotational speed of the wheel of the current meter.

vii. The calibration curve for the current meter may then be prepared by plotting the rotational speed in revolution per minute versus the speed of the towing carriage in metres per second, which will correspond to the velocity of flow of water in the channel when the current meter is held stationary in the water flowing in the channel.

2.3.7.3 Stage-Discharge Measurement (using a Current Meter)

According to Raghunath (2006), once the rating curve of the current meter is known (see Figure 2.7), actual stream gauging can be done from bridges, cradle, boat or launch.

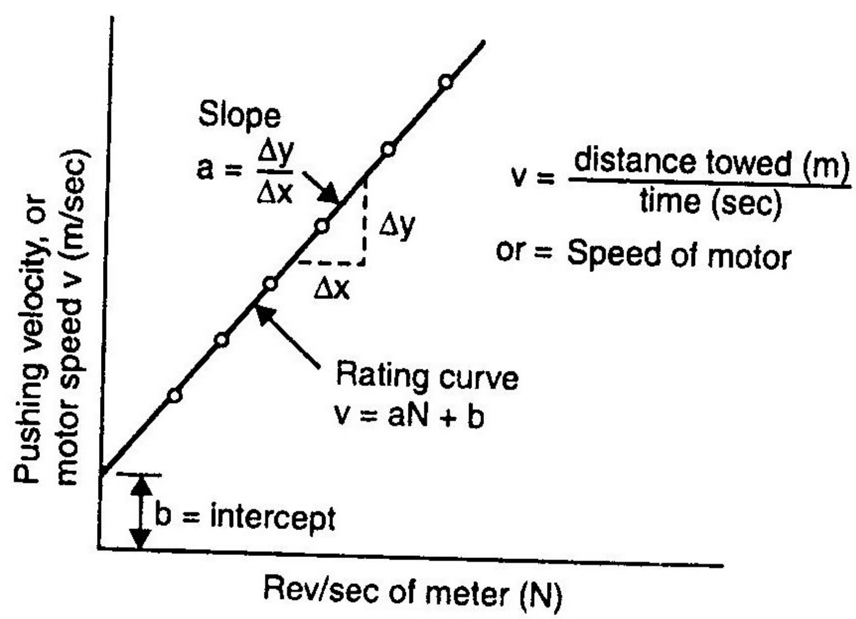


Figure 2.7: Current meter rating curve
Source: Raghunath (2006)

At the gauging site the cross section of the stream is divided into elemental strips of equal width b and the current meter is lowered to a depth of 0.4d from the bottom (or to a depth of 0.6d from the free water surface) in shallow depths (one-point method) and to depths of 0.2d and 0.8d (two points method) in deep waters, at the centre of each strip. The mean velocity is taken as that at 0.6d below water surface in shallow water (one-point method) and as the average of the velocities at 0.2d and 0.8d below the water surface (two-point method) in deep waters which is supposed to give a better result of average velocity than the single point method (see Figure 2.8). In the three-point method the velocities are obtained at 0.2d, 0.4d and 0.8d from the bottom which is preferred in very deep streams. The discharge in each elemental strip is determined and the discharge in the stream is the sum of the discharge in all the elemental strips.

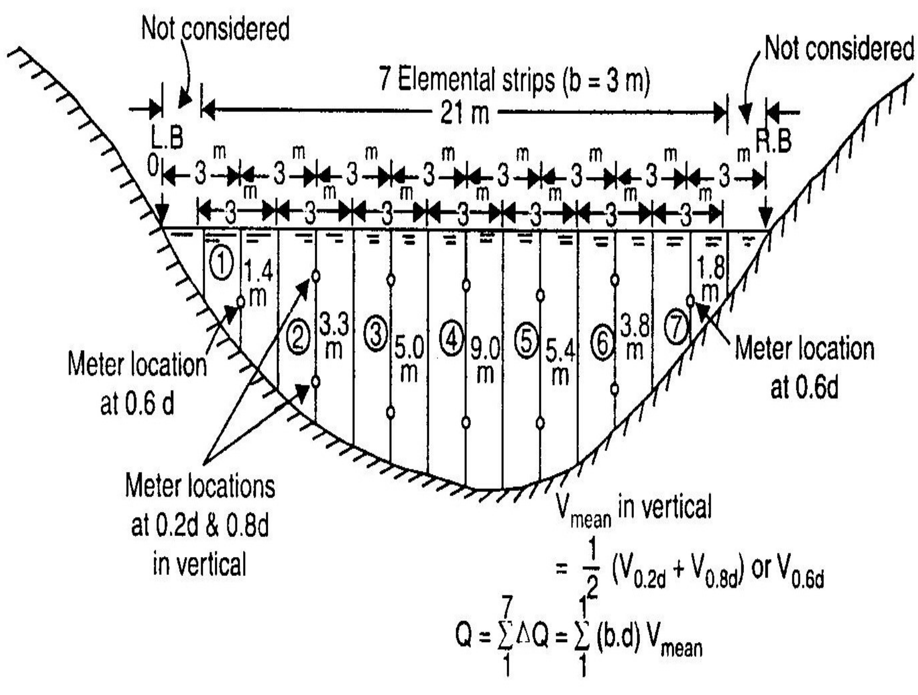


Figure 2.8: Discharge computation using current meter

Source: Raghunath (2006)

2.3.8 Extension of Streamflow Records

Raghunath (2006) opined that extension of streamflow records is possible by obtaining the stage–discharge relationship equation by linear regression and computer–based numerical analysis which is then used to extend the data. At any site in this country, the long- term streamflow data required for the design and planning of water resources projects are not available. The only options available for the hydrologist, according to Ojha et al. (2009) are to:

i. Extend the short-term data somehow, or
ii. Generate the data with the properties of observed historical data.

Some popular methods used under such circumstances are:

(a) Double-mass curve method
(b) Correlation with catchment areas
(c) Regression analysis between the flows at base and index stations.

2.3.8.1 Double-Mass Curve Method of Extension of Stream flow Record

i. Plot the cumulative stream flow of the base station under consideration and the index station on a graph.
ii. The slope of the double-mass curve gives the relation of the stream flows at two stations.

2.3.8.2 Correlation of Flow rates with Catchment Areas

$$Q_s = Q_i \, (A_s / A_i)^a \qquad . \quad . \quad . \quad . \quad . \qquad (2.2)$$

where Q is the flow values and A is the catchment area, and a is the coefficient which is generally taken as 0.75. It may be noted here that the area unit does not have any effect on the final outcome of Q.

2.3.8.3 Regression Analysis between Flows at Base and Index Stations

If Q_s is dependent variable and Q is independent variable, then;

$$Q_s = a + bQ_i \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2.3)$$

where a and b are regression coefficients and can be obtained by using linear regression analysis.

2.4 Use of Models

According to Mayor and Lenton (1976), three valuable functions that can be fulfilled by models are:

i. **Amplification-** When properly used, models can amplify our available knowledge of the behavior of complex systems. Models do not produce new information; however, they permit the extraction of greater amounts of information from our existing data base. In this sense they increase our understanding of the problem under study and of the options for dealing with it.

ii. **Organization-** Among the biggest problems encountered in planning are representing and displaying in simple terms the numerous characteristics of complex systems and proposed plans. Models can perform these functions as well as provide effective frameworks for organizing data.

iii. **Evaluation-** Models can and should be designed to incorporate measures of performance of the system under and may therefore be designed to produce comparative evaluation of performance. Optimization models serve this function by comparing the performance of various alternatives and identifying that which is best in some sense.

Viewed in these terms, models essentially are tools for supplementing the planners' judgment, intuition and past experience. Models provide only approximations to certain aspects of reality.

Data generated by models can be used to design reservoir capacity by using low-flow-frequency mass diagram and other techniques. Several hundred years of records are generated to obtain an adequate number of high and low-flow sequences. An abstract model which represents the system in mathematical form represents the mathematical core of a situation without extraneous information and helps to understand the modeled phenomenon better. Physical models which are an aspect of hydrologic models include scale models which represent the system on a reduced scale, such as a hydraulic model of a dam spillway that assists in improving the design operation and efficiency of hydrologic systems.

2.5 Hydrologic Models

As highlighted by Chow et al. (1988) hydrologic models may be divided into two categories: physical models and mathematical (abstract) models. Physical models include scale models which represent the system in a reduced scale, such as hydraulic model of a dam spillway: and analog models, which use another system having properties similar to those of the prototype. Abstract models represent the system in mathematical form. The system operation is described by set of equations linking the input and the output variables.

Hydrologic systems models are analyzed by using mathematical models. In most parts, mathematical models are designed to describe the way a system's elements respond to some types of stimulus (input). The models may be empirical or statistical, or founded on known physical laws. They may be used for such simple purpose as determining the rate of flow that a roadway grate must be designed to handle, or they may be used to guide decisions about the best way to develop a river basin for a multiplicity of objectives (Viessman & Lewis, 2008).

For the analysis and design of any hydrologic project adequate data and reasonable length of records are necessary (Raghunath, 2006). It is generally accepted that hydrological data and hydrologic modeling are indispensable in the planning and design of water resources development programmes. Water yield from basin - its occurrence, quantity and frequency, etc. is necessary for the design of dams, the size of storage reservoirs, municipal water supply, water power, river navigation, flood estimation, etc. (Raghunath, 2006; Ojha et al., 2008).

Hydrologic models have widely been used to explain and predict complex behaviors associated with the management of environmental systems and Land Use/Cover (LULC) of the watershed changes (Bronstert et al., 2002; Croke et al., 2004; Lin et al., 2007; Kalin & Hantush, 2009). Land Use/Cover (LULC) of the watershed effects and soil characteristics on water quantity have been addressed in the context of estimating streamflows in unmonitored watersheds as well as predicting changes in streamflow in response to Land Use/Cover (LULC) changes (Isik et al., 2012). There is strong experimental evidence that local water balance can be affected by Land Use/Cover (LULC) changes (van Dijk et al., 2011; Nagy et al., 2011). Reliable predictions of water availability and streamflow characteristics, and the impact of climate and land use change on water availability, are central to water resources planning and management. Accurate and realistic streamflow forecasts are essential for water resources planning and management. In many regions, agricultural, municipal, and environmental water uses increase demands on limited freshwater resources (Harshburger et al., 2012).

Mayor and Lenton (1976) viewed modern water resources planning process as the concepts of multi-objective investment criteria which will lead to the posing of better or more appropriate questions in the planning process and that the use of mathematical models will lead to better answers to these questions. Thus the role of models may be viewed as that of tools from which to derive answers to well-posed questions about the performance or behavior of the system that is being planned. However, because of the dynamics of the planning process, it may happen that the answers derived from models will suggest that the original questions need to be reformulated as they were not well conceived. Hence, the role of model is iterative. To aid in decision-making (i.e., plan formulation) they are used to produce information that may be fed forward and to aid in redefining the problem, with equal value, they may produce information that is fed back.

A further essential point concerning the role modelsplayin the planning process is that the information they provide must be quantitative and in sufficient detail and accuracy to provide real guidance to the decision-maker. There are three key words in this statement. The first of these is the word "quantitative." Model outputs can provide a basis for decision making only when the results have some measure or rank associated with them. The second key word is "sufficient." There is a natural tendency to use models to produce answers that are as detailed and accurate as possible. However, as in all planning and design, a balance must be struck between the needs of the problem at hand and the resources available for its solution. Third, operation of the model should provide "guidance" to the decision-maker. The role of the model is not to do the planning or to replace the planner. Nor is the role of models to provide completely precise answers to the questions posed. Rather, the model should produce information that will validly guide the thinking of the planner concerning the decision that must be made.

2.6 Types of Mathematical Models

According to Viessman and Lewis (2008), types of models are identified by The American Society of Civil Engineers' Task Committee on Hydraulic Modeling Terms. These are as follows:

- **Analytical model**. This is a mathematical model in which the solution of the governing equation is obtained by mathematical analysis as opposed to numerical manipulation.

- **Deterministic model.** Mathematical model in which the behaviour of every variable is completely determined by the governing equations.

- **Dynamic model.** Mathematical model in which time is included as an independent variable.

- **Empiricalmodel.** This is a representation of a real system by a mathematical description based on experimental data rather on general physical laws.

- **Heuristic model.** Representation of a real system by a mathematical description based on a reasoned, but unproven argument.

- **Interactive model.** This is a numerical model that allows interaction by the modeler during computation.

- **Linear model.** Mathematical model based entirely on linear equations.

- **Nonlinear model.** This is a mathematical model using one or more nonlinear equations.

- **Numerical model.** Mathematical model in which the governing equations are not solved analytically. Using discrete numerical values to represent the variables involved and using arithmetic operations, the governing equations are solved approximately.

- **Probablistic model.** This is a mathematical model in which the behaviour of the one or more of the variables is either completely or partially described by equations of probability.

- **Semi empirical model.** Representation of a real system by a mathematical description based on general physical laws but containing coefficients determined from experimental data.

- **Simulation model.** This is a Mathematical model that is used with actual or synthetic data, or both, to produce long-term time series or predictions.

- **Stochastic model.** This is another name for a probabilistic model.

- **Theoretical model.** This is a representation of real system by a mathematical description.

2.7 Classification of Hydrologic Models

According to Viessman and Lewis (2008), models can be classified as follows:

2.7.1 Physical versus Mathematical Models

Physical models include analog technologies and principles of similitude applied to small-scale models. In contrast, mathematical models rely on mathematical statements to represent the system. A laboratory model may be a 1:10 physical model of a stream, while the unit hydrograph theory is a mathematical model of the response.

2.7.2 Lumped versus Distributed-Parameter Models

Models that ignore spatial variations in parameters throughout an entire system are classified as lumped-parameter models. The use of a unit hydrograph for predicting time distributions of surface runoff for different storms over a homogeneous drainage area is an example of lumped parameter model. The lumped parameter is the X-hour unit hydrograph used for convolution with rain to give the storm hydrograph. The time from end of rain to end of runoff is also a lumped parameter as it is held constant for all storms. Distributed parameter model account for behaviour variations from point to point throughout the system. Examples of distributed-parameter models are most modern ground water simulation models in that they allow variations in storage and transmissivity parameters over a grid or lattice system superimposed over the plan of an aquifer. Most recently, surface water systems are being analyzed through use of distributed-parameter Geographical Information System (GIS) technologies.

2.7.3 Stochastic versus Deterministic Models

Deterministic methods of modeling hydrologic behaviour of a watershed have become popular. Deterministic simulation describes the behaviour of the hydrologic cycle in terms of mathematical relation outlining the interactions of various phases of the hydrologic cycle. Frequently, the models are structured to simulate a streamflow value, hourly or daily from given rainfall amounts within the watershed boundaries. The model is verified or calibrated by comparing results of the simulation with existing records. Once the model is adjusted to fit the known period of data, additional periods of streamflow can be generated. Many stochastic processes are approximated by deterministic approaches if they exclude all consideration of random parameters, or inputs. For example, the simulation of a reservoir system operating policy for water supply would properly include considerations of uncertainties in natural inflows, yet many water supply systems are designed on a deterministic basis by mass curve analysis, which assume that sequences of historical inflows are repetitive.

2.7.4 Linear versus Nonlinear Models

A mathematical model is linear if it is based entirely on linear equations. In other words, a linear model is one that has all the operators in the model as linear. But if any one of the constraint equations or objective function is non- linear, then the mathematical model is non-linear.

2.7.5 Steady versus Non-Steady State Models

Agunwamba (2007) stated that if time is present in the differential equation as an independent variable, the model is a non- steady model; otherwise it is a steady state model.

2.7.6 Event-Based versus Continuous Models

Many short-term hydrological models could be classified as single-event simulation models as contrasted with sequential or continuous models. Hydrological systems can be investigated in greater details if the time frame of simulation is shortened. An example of single-event simulation model is the Corps of Engineers' single event model. HEC-1, and an example of the sequential or continuous model is the Stanford watershed model, which is normally operated to simulate 3, 4, 5, or more years of streamflow. A typical single-event simulation model might use a time increment of 1hour or perhaps even 1minute.

2.7.7 Water Budget versus Predictive Models

A water budget model is defined as a model or set of relationships that confirm the historical balance of inflows, outflows, and changes in storage for a system under study. Several model classifications have arisen that distinguish between the purposes of the model types. One important comparison is whether the model proposes to predict future conditions using synthesized precipitation and watershed conditions or by verifying historical events. It is advised that simulation model studies begin by structuring a water budget model; then use the parameters that affirm the balance in any predictive simulation of the watershed response. For example, meteorologic data, streamflow records, crop patterns and water application amounts might be known for a given agricultural watershed. A water budget model would be used to determine the correct evapotranspiration (ET) formula parameters by testing a range of values until a balance in the continuity equation occurs for all time increments. This is often performed on a day-by-day or month-by-month basis.

Once the evapotranspiration (ET) parameters are derived from the water budget model, predictive simulations of different crop patterns, meterologic conditions, or farming practices could be performed with the satisfaction that the relationships in the model corroborate historical water budgets. Because only primary hydrologic inputs and outputs are measured (precipitation, temperature, runoff, land use), normal modeling studies require the simultaneous development of water budget parameters for secondary processes such as ET, infiltration, groundwater storage, and temporal and spatial distribution of water applications.

2.7.8 Black-Box and White-Box Models

Mathematical modeling can be further classified into black- box or white box model, according to how much a priori information is available of the system. A system of which there is no a priori information available is a black-box model. whereas a system where all the necessary information is available is a white box model. The knowledge of the type of functions relating different variables is an example of the priori information. Practically all systems are somewhere between the black-box and white-box, so this concept works as a guide to approach.

Figure 2.9 shows four types of hydrologic models by flow in a channel, while Figure 2.10classifies hydrologic models according to the way they treat the randomness and space and time variability of hydrologic phenomena.

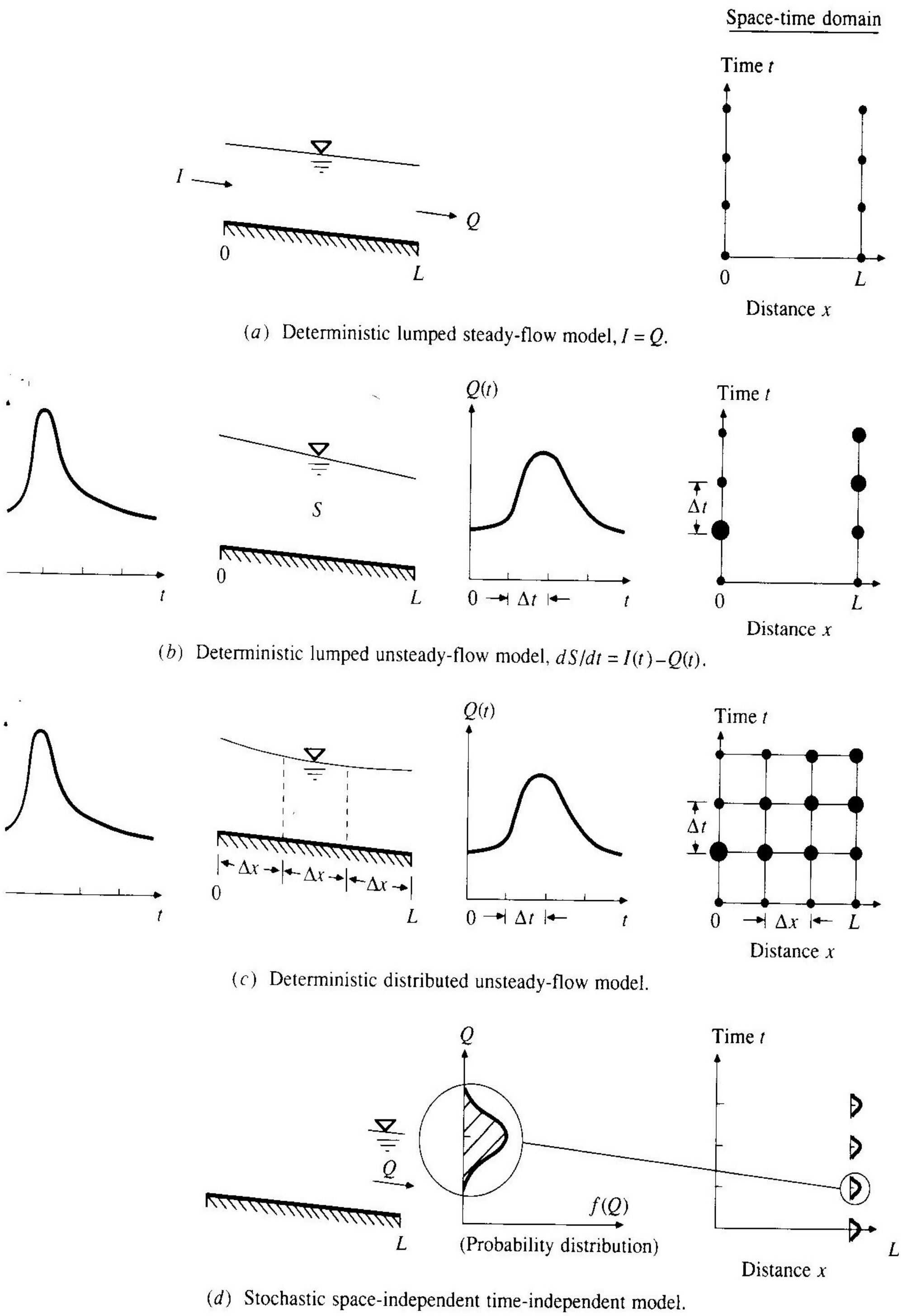


Figure 2.9: The four types of hydrologic models by flow in a channel

Source:Chow et al. (1988)

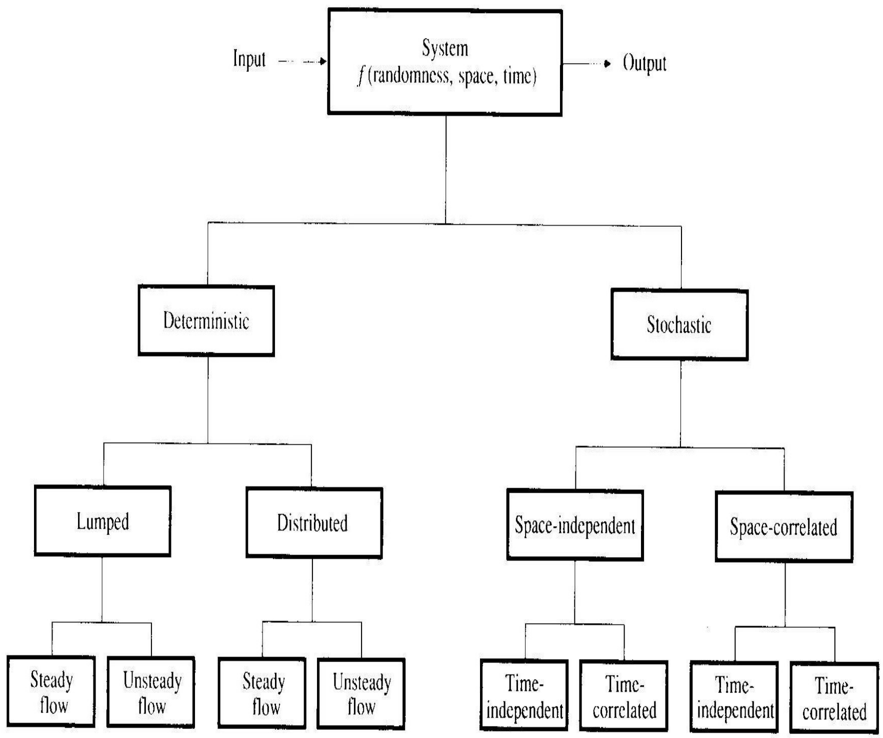


Figure 2.10: Classification of hydrologic models according to the way they treat the randomness and space time variability of hydrologic phenomena.

2.8 Hydrologic Systems Models and Complexity of Models

According to Chow et al. (1988), the study of the system operation and the prediction of its output is the objective of hydrologic system analysis.

2.8.1 Hydrologic Systems Models

An approximation of the actual system is called a hydrologic system model: measurable hydrologic variables areits inputs and outputs, a set of equations linking the inputs and outputs is its structure. Central to the model structure is the concept of a system transformation (Chow et al., 1988). Let's consider the input and output being expressed as function of time. I (t) and Q(t) respectively, for t belonging to the time range T under consideration. The system performs a transformation of the input into the output represented by Q(t) = ΩI(t) which is called the transformation equation of the system. The symbol Ω is a transfer function. This relationship if expressed by an algebraic equation, then Ω is an algebraic operator. For example, if Q (t) = CI (t) where C is a constant, then the transfer function is the operator

$$\Omega = \frac{Q(t)}{I(t)} = C \quad . \quad . \quad . \quad . \qquad (2.4)$$

Viessman and Lewis (2008) highlighted that hydrologic systems models are analyzed by using mathematical models. In most parts, mathematical models are designed to describe the way a system's elements respond to some types of stimulus (input). The models may be empirical or statistical, or founded on known physical laws. They may be used for such simple purpose as determining the rate of flow that a roadway grate must be designed to handle, or they may be used to guide decisions about the best way to develop a river basin for a multiplicity of objectives. The choice of the model should be tailored to the purpose for which the model is to be used. Generally, the simplest model capable of producing information adequate to deal with the issue should be chosen. The historical data necessary for meaningful hydrologic analysis are often lacking or unreliable, and with the consideration that hydrologic systems are generally probabilistic in nature, it is easy to understand that the tasks of the modeler is not an easy one.

2.8.2 Complexity of Models

Hydrologic phenomena are extremely complex and represented in a simplified way by the system concept. Approximations of reality are all hydrologic models, so the output of the actual system can never be forecast with certainty. In modeling of hydrologic phenomena, there is generally a greater degree of approximation in applying physical laws because the systems are larger and more complex, and may involve several working media (Chow et al., 1988). Inherently random are most hydrologic systems because a highly variable and unpredictable phenomenon which is precipitation is their major input. Chow et al. (1988) further highlighted that precipitation is the driving force of the land phase of the hydrologic cycle, and the random nature of precipitation means that at some future time the prediction of the resulting hydrologic processes (e.g., surface flow, evaporation, streamflow) is subject to a degree of uncertainty that is large when compared to the prediction of the future behaviour of soils or building structures.

Model uncertainty results from the approximations made when representing phenomena by equations, and parameter uncertainty stems from the unknown nature of the coefficients in the equations. Agunwamba (2007) pointed out that representing a real hydrologic problem mathematically is often a complex process of which the complexity is increased by the presence of several variables and uncertainty associated with physical problems which necessitate the use of approximations to obtain a more robust and simple models.

2.9 Model Calibration and Verification

A significantly longer period of record is used to calibrate a model due to climate's yearly variability. A similar but non-overlapping length of time is often used to validate the calibrated model to evaluate its accuracy (Malone, 2014).

2.9.1 Model Calibration

The calibration is the adjustment or modification of model parameters, within the recommended ranges, to optimize the model output to match with the observed set of data. Several different parameters for adjustment through user intervention are provided by the calibration. These parameters can be adjusted manually or automatically until the model output best matches with the observed data (Vilaysane et. al., 2014). For any model calibration, objective functions are set up for variables (e.g., streamflow) that will be optimized during the calibration process.

A common method in the model calibration, which is the least-squares method, is equivalent to the minimization of the sum of squares of the residuals (also known as fitness measure or objective function). The calibration exercise is aimed at reproducing an existing condition for assumed value(s) of a given parameter or set of parameters and once that is achieved the current value(s) of the parameters are used for prediction of future events.

2.9.2 Verification of the Models

An important aspect of the modeling process is the evaluation of the calibrated models. Verification is the process of determining the degree in which a model or prediction is an accurate representation of the observed set of data from the perspective of the intended uses of the model (Vilaysane et al., 2015). As highlighted by Agunwamba (2007), model evaluation involves determining how well the mathematical model describes the system. This is achieved by conducting a set of measurements from the system used in creating the model.

The data is split into two parts. A portion of the data is used for calibration (training); that is, to estimate the model parameters. The other called the verification data is used to evaluate the model performance (interpolation). A model is good for interpolation when it describes the verification data of the real system well. The model should also be good for extrapolation when it can be used for the prediction of events outside the measured data. The level of agreement between the measured and predicted values is judged by determining the coefficient of correlation and standard error of estimate (Agunwamba, 2007).

2.10 Statistical Models

2.10.1 Statistical Model for Linear Regression

According to Moore, McCabe and Craig (2014), the relationship between a response variable y and a single explanatory variable x is studied in simple linear regression. In linear regression the explanatory variable x can have different values. Different values of $x$are expected to produce different mean responses. The statistical model for simple linear regression has the assumption that for each value of x the observed values of the response variable y are normally distributed about a mean that depends on x. Let's consider n observations on the explanatory variable x and the response variable y.

$$(x_1, y_1), (x_2, y_2), \quad . . ., \quad (x_n, y_n) \qquad . \qquad . \qquad . \qquad (2.5)$$

the statistical model for linear regression states that for each i from 1 to n the observed response is

$$y_1 = \beta_0 + \beta_1 x_i + \in_i \qquad . \qquad . \qquad . \qquad . \qquad (2.6)$$

In equation (2.6), $\beta_0 + \beta_1 x_i$is the mean response when $x = x_{i.}$ The deviation $\in_i$ are to be normally distributed and independent with mean 0 and standard deviation σ (i.e. they are a simple random sample (SRS) from the N (0, σ) distribution). The parameters of the model are β_0 ,β_1 and σ.

2.10.2 Statistical Model for Multiple Regression

Moore et al. (2014) highlighted that for multiple regression, the response variable depends on not one but p explanatory variables. If the explanatory variables are denoted by

$x_1, x_2, \quad . . ., \quad x_p$, the mean response is a linear function of the explanatory variable

$$\mu_y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ . . . + \beta_p x_p \qquad . \qquad . \qquad . \qquad (2.7)$$

The expression in equation (2.7) is the population regression equation. Equation (2.7) cannot be directly observed as the observed values of y vary about their means. Subpopulation of responses is what one can think of, each corresponding to a particular set of values for all the explanatory variables $x_1, x_2, \quad . . ., \quad x_p$. For each subpopulation, y varies normally with mean given by population regression equation. There is the assumption in the regression model that the standard deviation σ of the responses is the same in all subpopulations. The statistical model for the multiple linear regressions is

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots \beta_p x_{ip} + \epsilon_i \quad . \quad . \quad . \quad (2.8)$$

for $i = 1, 2, \ldots, n$.

A linear function of the explanatory variable is the mean response. ϵ_i being the deviations are independent and normally distributed with mean 0 and standard deviation σ(i.e. they are an Simple Random Sample (SRS) from the $N(0, \sigma)$ distribution). The parameters of the model are β_0, β_1, $\beta_2, \ldots, \beta_p$ and σ.

2.10.3 The Analysis of Variance (ANOVA) Model

According to Moore et al. (2014), in the examination of data, the overall pattern and deviations from it are usually sought for. The idea is expressed through the equation

$$\text{DATA} = \text{FIT} + \text{RESIDUAL} \quad . \quad . \quad . \quad . \quad (2.9)$$

The population regression line represents the FIT in the regression model and the deviations of the data from the regression line are represented by the RESIDUAL. The same framework is applied in describe the statistical models used in ANOVA.

Let us recall the statistical model for a random sample of observations from a single normal population with standard deviation σ and mean μ. When the observations are:

$$x_1, x_2, \quad . \quad . \quad . \quad ., x_n \quad . \quad . \quad . \quad . \quad (2.10)$$

The model can be described by saying that the x_1 are an Simple Random Sample (SRS) from the N (μ, σ) distribution. Thinking of the x's varying about their population mean is another way to describe the same model. To do this, each observation is written x_j as:

$$x_j = \mu + \epsilon_j \quad . \quad . \quad . \quad . \quad (2.11)$$

A simple random sample from the N (μ, σ) distribution is the ϵ_j. The ϵ_j cannot actually be observed because μ is unknown. This form more closely corresponds to the way of thinkingof DATA = FIT + RESIDUAL. μ represents the FIT part of the model. It is the systematic part of the model, like the line in a regression. ϵ_j represents the RESIDUAL part, which represents the deviations of the data from the fit and is due to chance, or random, variation. μ and σ are two unknown parameters in this statistical model. The sample mean $\bar{x}$ is used to estimate μwhile standard deviation (s) is used to estimate σ. The sample residuals are the difference$e_j = x_j - \bar{x}$ and correspond to the ϵ_i in the statistical model.

The model for one-way ANOVA is very similar. Random samples are taken from each of I different populations. For the ith population, the sample size is n. Let x_{ij} represent the jth observation. The FIT part of the model are the I population means and are represented by μ_i. The RESIDUAL or random variation part of the model is represented by the deviation ϵ_{ij} of the observations from the means. The ANOVA model is

$$x_{ij} = \mu_i + \epsilon_{ij} \quad . \quad . \quad . \quad . \quad (2.12)$$

for $i = 1, . . ., I$ and $j = 1, . . ., n$. The standard deviation σ is the same in all the populations but the sample sizes n, may differ. The $\epsilon_{ii}$are assumed to be an simple random sample from an $N(0, \sigma)$ distribution. The null and alternative hypotheses are

H_0: $\mu_1 = \mu_2 = . . . = \mu_I$

H_a: not all of the μ_i are equal.

In the statistical model for ANOVA the unknown parameters are the population mean μ_i and the common population standard deviation σ. The sample mean for the *i*th group is used to estimate the μ_i as shown in equation 2.11.

$$\bar{x}_i = \frac{1}{n_i}\sum_{j=1}^{n_i} x_{ij} \quad . \quad . \quad . \quad . \quad (2.13)$$

$e_{ii} = x_{ij} - \bar{x}_i$ are the sample residuals. Hence for the sample data FIT is represented by $\bar{x}_i$ and the RESIDUAL by e_{ii}.

For the ANOVA model, there is the assumption that the population standard deviations are all equal. If the standard deviations are not all equal, the data is transformed so that they are approximately equal. Log x_{ii} or $\sqrt{x_{ij}}$ might be worked with. Formal test of equality of standard deviations as a preliminary to the ANOVA is not recommended. The following rule of thumb is used instead: The ratio of the largest sample standard deviation to the smallest sample standard deviation, if less than 2, methods based on assumption of equal standard deviations can be used and the results will still be approximately correct (Moore et al., 2014). Computer software is usually used in ANOVA calculations.

2.11 Analysis of Variance (ANOVA)

An extremely useful technique in researches is the analysis of variance. When multiple sample cases are involved analysis of variance is used. Either *z*-test or the *t*-test can be used to judge the significance of the difference between the means of two samples. But when one wants to examine the significance of the difference amongst more than two sample means at the same time, analysis of variance is used (Kothari & Garg. 2014). Analysis of variance technique can be used to investigate any number of factors which are hypothesized or said to influence the dependent variable. The differences amongst various categories within each of these factors which may have a large number of possible values may be investigated.

One-way ANOVA is used when only one factor is taken and investigation is made on the differences amongst its various categories having numerous possible values. Two-way ANOVA is used when one investigates two factors at the same time. The interaction or inter-relationship of two factors affecting the values of a variable can as well be studied for better decisions by using two-way ANOVA.

2.11.1 Analysis of Variance for Regression

The relationship between a response variable y and a single explanatory variable x is what simple linear regression studies. Multiple regressions involve one response variable and more than one explanatory variable. Analysis of variance (ANOVA) is included as a usual computer output for regression. The information about the sources of variation in the data are summarized by the analysis of variance. It is based on the framework of equation (2.9).

According to Moore et al. (2014), the deviation $y_i - \bar{y}$ expresses the total variation in the response y. The individual observations y_i are not always equal to their mean $\bar{y}$. The mean response for the specific x_i is estimated by the fitted value $\hat{y}_i$. The variation in mean response due to differences in the x_i is reflected by the differences $\hat{y}_i - \bar{y}$. Because the $\hat{y}'s$ lies exactly on the regression line, the variation is accounted for by the regression line. The residual $y_i - \hat{y}_i$ represents the variation that records the scatter of the actual observations about the fitted line. The sum of these two deviations is the overall deviation of any y observation from the mean of the $\hat{y}'s$:

$$(y_i - \bar{y}) = (\hat{y}_i - \bar{y}) + (y_i - \hat{y}_i) \quad . \quad . \quad . \quad (2.14)$$

For deviation, equation (2.12) expresses the idea of equation 2.9

Variations are sometimes measured by an average of squared deviations. By squaring each of the three deviations in equation (2.14) and then sum over all *n* observations, the sums of squares add is an algebraic fact:

$$\sum(y_i - \bar{y})^2 = \sum(\hat{y}_i - \bar{y})^2 + \sum(y_i - \hat{y}_i)^2 \quad . \quad . \quad . \quad (2.15)$$

Equation (2.15) can be rewritten as

$$SST = SSM + SSE \quad . \quad . \quad . \quad . \quad (2.16)$$

where,

$$SST = \sum(y_i - \bar{y})^2$$
$$SSM = \sum(\hat{y}_i - \bar{y})^2$$
$$SSE = \sum (y_i - \hat{y}_i)^2$$

The SS in each of the abbreviation stands for sum of squares and the T, M, E stand for total, model and error respectively

The analysis of variance table displays the ANOVA calculations. For simple linear regression, the format of the table is shown in Table 2.1

Table 2.1: One-way ANOVA table for linear regression

Source	**Degree of freedom**	**Sum of squares**	**Mean square**	**F**
Model	1	$\sum(\hat{y}_i - \bar{y})^2$	SSM/DFM	MSM/MSE
Error	n - 2	$\sum(\hat{y}_i - \bar{y})^2$	SSE/DFE	
Total	n – 1	$(y_i - \bar{y})^2$	SST/DFT	

where, the total degree of freedom DFT is the sum of DFM and DFE, the degrees of freedom for the model and for the error respectively. The model has one explanatory variable x, so the degree of freedom for this source is:

DFM = 1. Because DFT = n – 1, this leaves the degree of freedom for error DFE = n – 2. The ratio of the sum of squares to the degree of freedom for each source is called the mean square (MS).

The assumption that y is not linearly related to *x*in the null hypothesis can be tested by comparing mean square model (MSM) with mean square error (MSE). The ANOVA test statistics is an *F* statistic,

$$F = \frac{\text{MSM}}{\text{MSE}} \quad . \quad . \quad . \quad . \qquad (2.17)$$

The *F* distribution with 1 Degree of Freedom (DoF) in the numerator and degree of freedom *n*-1in the denominator is the statistics whenH_0 is true. There are many *F* statistics just as there are many *t* statistics and the ANOVA *F* statistics is not the same as the *F* statistic.

According to Kothari and Garg (2014), in a joint sample, the total variance is partitioned into two parts. (a) between samples variance and (b) within samples variance. Within samples variance is due to random unexplained disturbance, while between samples variance is due to different treatments. The test statistics is defined using these two variances as:

$$F = \frac{\text{Between samples variance}}{\text{Within samples variance}} \quad . \quad . \quad . \qquad (2.18)$$

Using this method one wishes to test

H_0 : all population means are the same (or effect of all treatments are the same)

H_1 : all population means are not the same (or effect of all treatments are not the same)

When the effect of all treatments is different, between samples variance will be large. The computed F_c will be large in such a case, and the null hypothesis is likely to be rejected. Thus, the test is a right tailed test.

The general form of two-way ANOVA is shown in Table 2.2.

Table 2.2: Two-way ANOVA table

Source	Degree of freedom	Sum of squares	Mean square	F
A	$I - 1$	SSA	SSA/DFA	MSA/MSE
B	J - 1	SSB	SSB/DFB	MSB/MSE
AB	$(I - 1)(J - 1)$	SSAB	SSAB/DFAB	MSAB/MSE
Error	$N - IJ$	SSE	SSE/DFE	
Total	N - 1	SST	SST/DFT	

2.12 Element of Statistics in Hydrological Data Analysis

The science of collecting, organizing and interpreting of data, which are numerical facts is called statistics. The goal of statistics is to gain information from data. Data must be produced, read critically with comprehension in order to provide clear answers to important questions; and one must learn sound methods of drawing trustworthy conclusions based on data (Moore et al., 2014). The first step is to display the data in a graph so that our eyes can take in the overall pattern and spot unusual observations. Next, we often summarize specific aspects of the data, such as the average values of a variable, by numerical measures.

As we study graphs and numerical summaries, we keep in mind where the data come from and what we hope to learn from them. Graphs and numbers are not ends in themselves, but aids to understanding. Any characteristic of a thing or person that can be expressed as a number is called variable. The actual number that describes a particular person or thing is the valu*e* of a variable. The values of a variable vary when measurements are made on different people or things or at different times. An important initial step in organizing the way we think about data is to observe how many variables are present.

2.12.1 Sample of Hydrologic data as an Element of Statistics in Hydrological Data Analysis

According to Raghunath (2006), samples are observed values of x (variate) for a finite number of years. Example of a sample is annual flood peak for 30 years or annual streamflow rate for 30 years. Streamflow or runoff is a random phenomenon characterized by a certain value, which varies in time and space. This characterization is called variable while its particular value is called a variate. When the value of one variate is independent of any other one, the variate is said to be a random variable. Hydrological processes are mostly random; invariably the respective variables are equally random.

2.12.2 Central Tendency as an Element of Statistics in Hydrological DataAnalysis

Methods of statistical analysis in hydrology provide ways to reduce and summarize observed data to present information in precise and meaningful form, to determine the underlying characteristics of the observed phenomena and to make predictions concerning future behaviour. These inferences include information about the central tendency, range, distribution within the range, variability around the central tendency, degree of uncertainty, and frequency of occurrence of value (Viessman & Lewis, 2003; Gupta, 2011).

There are three types of parameters generally used to represent measure of central tendency.

(i) Expected value. This value of random variable is given by

$$\mu = \int_{-\infty}^{\infty} x\, f(x) dx \quad . \quad . \quad . \quad . \quad (2.19)$$

Raghunath (2006) stated that the above population parameter can be estimated by the sample parameters as

(a) **Mean(Arithmeticmean)** $\bar{x} = \frac{\sum x}{n} \quad . \quad . \quad (2.20a)$

For grouped data $\bar{x} = \frac{\sum fx}{n} \quad . \quad . \quad . \quad (2.20b)$

(b) Geometric mean $\bar{x}_g = (x_1, x_2, x_3, \ldots x_n)^{1/n} \quad . \quad . \quad (2.21)$

(c) Harmonic mean $\bar{x}_h = \frac{n}{\sum \frac{1}{x}} \quad . \quad . \quad . \quad (2.22)$

where n =the sample size, say number of years of streamflow rate or discharge record.

x = variable (example is streamflow rate or discharge).

f = frequency of x

For any set of variates $\bar{x} > \bar{x}_g > \bar{x}_h$

The arithmeticmean gives the best estimate of the expected value in most cases (i.e., $\mu = \bar{x}$).

(ii) Median

The median of the series is the value of the variate such that half of the variates are below it and the other half above it. It is the value of the variate having a 50% cumulative frequency (see Figure 2.11). Mathematically, the median $\bar{x}$ of grouped data set with class frequencies f_1, f_2, f_3,…f_n is given as (Nwaogazie, 2006):

$$\bar{x} = L_o + \frac{{}^{N}/_{2} - (\sum f)_o)C}{f_m} \quad \cdot \quad \cdot \quad \cdot \qquad (2.23)$$

where,

L_o = lower class boundary of the median class

$(\sum f)_o$ = sum of x frequencies of classes lower than the median class

f_m = frequency of median class

c = class interval size

N = $\sum f$ (sum of frequencies of all classes or no of items in the data set)

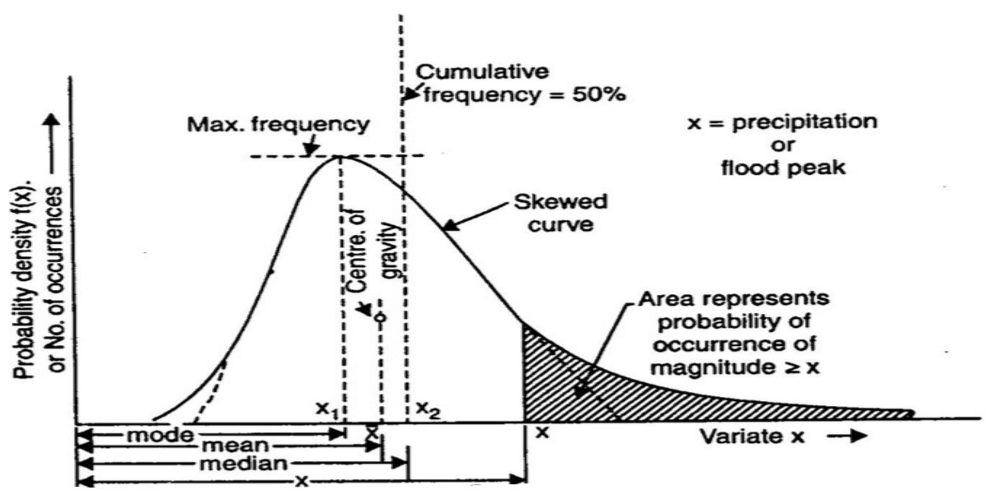


Figure 2.11: Skewed distribution curve
Source: Raghunath (2006)

(iii) Mode

According to Kothari and Garg (2014), mode is the most frequently occurring observation in the data set. Mode is a positional average just like median, and it is not affected by extreme values. A data set may not have any mode or a data set may have more than one modes. Mode is the value of the variate having the highest frequency (see Figure 2.11). Nwaogazie (2006) highlighted that mathematically, the mode $\bar{x}$ of grouped data set with class frequencies f_1, f_2, f_3 …f_n is given as:

$$\bar{x} = L_0 + \left[\frac{E_0}{E_0 + E_1}\right]_C \quad . \quad . \quad . \quad . \quad (2.24)$$

where,

L_o = lower class boundary of the modal class

E_o = excess of modal frequency over class (frequency to the left of the modal class)

E_1= excess of modal frequency over class (frequency to the right of the modal class)

C = class interval size.

2.12.3 Measure of Variability or Dispersion of a Probability Distribution Curve

The measures of the variability or dispersion of a probability distribution curve are given by the following parameters.

(i) Mean deviation (δ). The average of difference of the values of items from some average of the series is known mean deviation. Such a difference is technically described as deviation (Kothari & Garg, 2014).

In other words, mean deviation is the mean of the absolute deviations of values from their mean.

If deviations $(x_i - \bar{x})$ are obtained from arithmetic average, then

$$\text{Mean deviation from mean}(\delta_{\bar{x}}) = \frac{\sum(x_i - \bar{x})}{n} \quad \cdot \quad \cdot \quad \cdot \quad (2.25a)$$

If deviations $(x_i - M)$ are obtained from median, then

$$\text{Mean deviation from mediam}(\delta_m) = \frac{\sum(x_i - M)}{n} \quad \cdot \quad \cdot \quad \cdot \quad (2.25b)$$

If deviations $(x_i - M)$ are obtained from mode, then

$$\text{Mean deviation from mode}(\delta_z) = \frac{\sum(x - Z)}{n} \quad \cdot \quad \cdot \quad \cdot \quad (2.25c)$$

where, δ = Symbol for mean deviation (pronounced as delta)

$x_i =$ ith value of the variable x

$n =$ Number of items

$\bar{x} =$ arithmatic average

$M =$ median

$Z =$ Mode

(ii) ***Standard deviation***. Standard deviation is the most widely used measure of dispersion of a series. It is defined as the square-root of the average of squares of deviations (Kothari & Garg, 2014). In other words, standard deviation is the square root of the mean- squared deviation of the variates from their mean. The dispersion about the mean is measured by the standard deviation, which is also called the root mean square of the departures from the mean. Mathematically, the standard deviation for the population is given by

$$\sigma_p = \sqrt{\frac{\sum(x - \mu)^2}{n}} \quad . \quad . \quad . \quad . \quad (2.26)$$

For grouped data,

$$\sigma = \sqrt{\frac{\sum f(x - \bar{x})^2}{n - 1}} \quad . \quad . \quad . \quad . \quad (2.27)$$

(iii) Coefficient of standard deviation. Coefficient of standard deviation is obtained by using the arithmetic average of the series to dividethe standard deviation.

(iii) Variance. Variance is the square of the standard deviation. It is given by σ^2 for the sample. In the context of analysis of variation, variance is frequently used.

(iv) Range. Range is the simplest possible measure of dispersion and is defined as the difference between the values of the extreme items of a series.

$$\text{Range} = \begin{pmatrix}\text{Hightest value of an} \\ \text{item in a series}\end{pmatrix} - \begin{pmatrix}\text{Lowest value of an} \\ \text{item in a series}\end{pmatrix}$$

The usefulness of range is that it gives an idea of the variability very quickly, but the fluctuations of sampling is a problem that very greatly affects range. Its value is never stable, being based on only two values of the variable. As such, range is not considered as an appropriate measure in serious research studies, it is mostly used as a rough measure of variability (Kothari & Garg, 2014). Range denotes the difference between the largest and smallest values of the sample and is given as

$$R = \sigma(N/2)^K, \qquad 0.5 < K < 1 \quad . \quad . \qquad (2.28a)$$

$$R = 1.25\sigma_p\sqrt{n} \quad . \quad . \quad . \quad . \qquad (2.28b)$$

for a random normally distributed time series.

(v) Coefficient of variation (C$_{ove}$). The coefficient of variation is obtained by dividingthe standard deviation by the mean. Coefficient of variation is given by

$$C_V = \frac{\sigma_p}{\mu} = \frac{\sigma}{\bar{x}} \quad . \quad . \quad . \quad . \qquad (2.29)$$

2.12.4 Skewness (Asymmetry)

This is a term used to denote the lack of symmetry of a distribution. Mathematically, population skewness is given by

$$\alpha = \frac{\sum(x - \mu)^3}{n} \quad . \quad . \quad . \quad . \qquad (2.30)$$

Sample skewness is given by

$$\alpha = \frac{\sum(x - \mu)^3}{n - 1} \quad . \quad . \quad . \quad . \qquad (2.31)$$

For a grouped data the skewness is given below

$$\alpha = \frac{\sum f(x - \mu)^3}{n - 1} \quad . \quad . \quad . \quad . \qquad (2.32)$$

***Coefficient of skewness* (C$_s$)**. This is a measure of the degree of skewness of the distribution and is given by

$$\mathrm{C_s} = \frac{\alpha}{\sigma_p^3} = \frac{\alpha}{\sigma^3} \quad . \quad . \quad . \quad . \qquad (2.33a)$$

$$\mathrm{C_s} = \frac{(\text{Mean} - \text{Mode})}{\text{standard deviation}} = \quad . \quad . \qquad (2.33b)$$

In case mode is ill-defined, coefficient of skewness is

$$\mathrm{C_s} = \frac{3(\text{Mean} - \text{Midian})}{\text{standard deviation}} = \quad . \quad . \qquad (2.33c)$$

This coefficient of skewness has limits ±3. We have $0 < C_S < 3$ for positive skewness and $-3 < C_S < 0$ for negative skewness (Kothari & Garg, 2014).

2.13 Hydrological Data

For the analysis and design of any hydrologic project adequate data and length of records are necessary (Raghunath, 2006). Accurate and adequate hydrological data is very essential for dealing with hydrological problems (Sharma & Sharma, 2000). The basic hydrological data required are:

i. Climatological data
ii. Hydro-meteorological data like temperature, wind velocity, humidity, etc.
iii. Precipitation data

iv. Streamflow data
v. Seasonal fluctuation of ground water table and piezometric heads
vi. Evaporation, transpirationand infiltration data, soil maps
vii. Cropping pattern, crops and their consumptive use
viii. Water quality data of surface and ground water
ix. Topography maps
x. Geological maps
xi. Environmental data
xii. Ground and surface water development
xiii. Land use details

According to Sharma and Sharma (2000), the minimum data required for examining the success of irrigation projects are shown in Table 2.1. Since basin development has to be done by judicial combination of storage and diversion projects, data requirement of 20 to 25 years may be considered essential so that variation in flows is properly reflected.

Table 2.3: Minimum data required for success of irrigation projects

Nature of Project	Minimum length of data (Years)
Diversion projects with ponding	10
Diversion projects with ponding	10
Within the year storage projects	25
Over the year storage project	40
Complex system involving combination of above	Depending upon predominant aspect

2.14 Data Preparation

Proper data preparation process is a must to get reliable results. The results of the analysis are affected a lot by the form of the data. After collection of data, it has to be prepared for analysis. The data collected is raw, it must be converted to the form that is suitable for the required analysis (Kothari & Garg, 2014). Data arrangement and data cleaning which are parts of datapreparation are considered in sections 2.14.1 and 2.14.2 respectively.

2.14.1 Data Arrangement

The data arrangement involved sorting the data according to weeks, months or years (the earliest to the latest) as the case be. It also involves sorting the data considering minimum, mean or maximum values.

2.14.2 Data Cleaning

Data cleaning includes checking the data for consistency and treatment for missing value. In consistency check, data which are not consistent or outlines are looked for. Such data are either discarded or replaced by the mean value. Treatment for missing values is carried out by the extension of data records.

2.15 Data Relationships

Statistically investigations only rarely focus on single variable. We are more often interested in comparisons among several distributions, changes in a variable over time, or relationships among several variables. A study of data often leads us to ask whether there is a cause- and-effect relation between two variables that are closely linked in the data. When we examine the relation between two variables, in many studies, the goal is to show that changes in one or more explanatory variables actually cause changes in a response variable.

A response variable measures an outcome of a study, while an explanatory variable attempts to explain the observed outcomes.

Explanatory variables are often called independent variables, while response variables are often referred to as dependent variables. When changes in a variable x are thought to explain or even cause changes in a second variable y, x is called an explanatory variable and y is called a response variable. The explanatory variable is always plotted on the horizontal scale of a scatterplot. Relationships between two quantitative variables are best displayed graphically. The most useful graph for this purpose is a scatterplot. A scatterplot is a plot of observations x_i and y_i are the values of quantitative variables x and y for the same case, that is the same individual or object (Moore et al., 2014).

2.16 Curve Fitting to a Set of Hydrologic Data

A probability distribution is a function representing the probability of occurrence of a random variate. By fitting a distribution to a set of hydrologic data, a great deal of the probabilistic information in sample can be compactly summarized in the function and its associated parameters (Chow et al., 1988). The following are the methods by which fitting distribution can be accomplished:

(i) Method of moments
(ii) Method of maximum likelihood
(iii) Method of least squares (regression analysis). This research adopted this method.

2.16.1 Method of Moments in Curve Fitting

According to Chow et al. (1988), the method of moment was first developed by Karl Pearson in 1902. Pearson believed that good estimates of the parameters of a probability distribution are those for which moments of the probability density function about the origin are equal to the corresponding moments of the sample data. Figure 2.12 shows that if the data values are each assigned a hypothetical "mass" equal to their relative frequency of occurrence (1/n) and it is imagined that this system of masses is rotated about the origin x = 0, then the first moment of each observation x_i about the origin is the product of its moment arm x_i and its mass 1/n, and

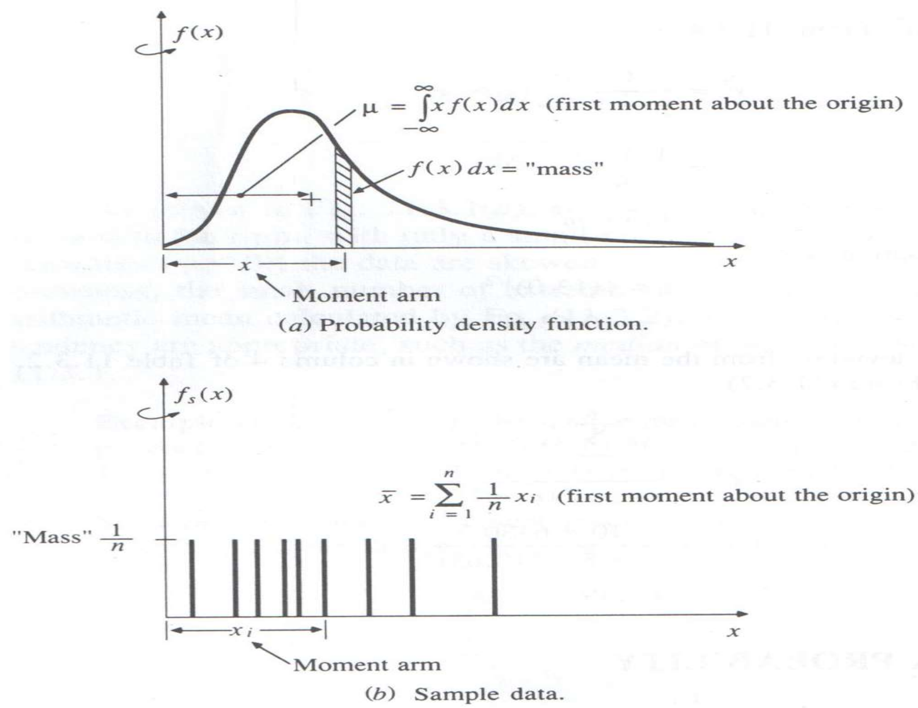


Figure 2.12: Method of moments selects values for the parameters of the probability density
Source: Chow et al. (1988).

the sum of these moments over all the data is the sample mean in Equation (2.34).

$$\sum_{i=1}^{n} \frac{x_i}{n} = \frac{1}{n} \sum_{i=1}^{n} x_i = \bar{x} \qquad . \quad . \quad . \quad . \qquad (2.34)$$

This is equivalent to the centroid of the body. The corresponding centroid of the probability density function is

$$\mu = \int_{-\infty}^{\infty} xf(x)dx \quad . \quad . \quad . \quad . \quad . \quad (2.35)$$

In like manner, the second and third moments of the probability distribution can be set equal to their sample values to determine the values of parameters of the probability distribution. Pearson initially considered only moments about the origin but later, the variance came into use as the second central moment,

$$\sigma^2 = E[(x - \mu)^2] \quad . \quad . \quad . \quad . \quad (2.36)$$

And the coefficient of skewness as the standardized third central moment,

$$Y = E[(x - \mu)^3] \quad . \quad . \quad . \quad . \quad (2.37)$$

to determine second and third parameters of the distribution if required.

2.16.2 Method of Maximum Likelihood in Curve Fitting

Fisher (as cited in Chow et al., 1988) developed the method of maximum likelihood. He reasoned that the best value of a parameter of a probability distribution should be that value which maximizes the likelihood or joint probability of occurrence of the observed sample. Let's consider the sample space being divided into intervals of length dx and that a sample of independent and identically distributed observations $x_1, x_2, \ldots, x_n$ is taken. The value of the probability density for $x = x_i$ is f(x), and the probability that the random variable will occur in the interval including x_i is $f(x_i)dx$. Since the observations are independent, their joint probability of occurrence is given from Equation (2.38).

$$P(A \cap B) = P(A)P(B) \quad . \quad . \quad . \quad . \quad (2.38)$$

as the product

$$f(x_1)dx\, f(x_2)dx \ldots f(x_n)dx = \left[\prod_{i=1}^{n} f(x_i)\right] dx^n. \quad . \quad . \qquad (2.39)$$

and since the interval size dx is fixed, maximizing the joint probability of the observed sample is equivalent to maximizing the likelihood function.

$$L = \prod_{i=1}^{n} f(x_i) \qquad . \qquad . \qquad . \qquad . \qquad (2.40)$$

it is sometimes more convenient to work with the log-likelihood function because many probability density function are exponential

$$\text{In}\, L = \sum_{i=1}^{n} \text{In}\,[f(x_i)] \qquad . \qquad . \qquad . \qquad . \qquad (2.41)$$

Chow et al. (1988) opined that the method of maximum likelihood is the most theoretically correct method of fitting probability distribution to data in the sense the most efficient parameters estimates are produced by it. But, for some probability distributions, there is no analytical solution for all the parameters in terms of sample statistics, and the log-likelihood function must then be numerically maximized, which may be quite difficult. The method of moments is easier to apply than the method of maximum likelihood and is more suitable for practical hydrologic analysis.

2.16.3 Method of Least Squares in Curve Fitting

According to Ojha et al. (2009), the least squares method is a statistical curve fitting procedure which yields a line of best fit. Raghunath (2006) noted that the method of least squares is one of the methods of fitting of a straight line. Two variables such as y being dependent and x being independent can be correlated by plotting them on x – and y – axis. If they are plotted on a straight line, there is a close linear relationship, but if the points depart appreciably, it is termed a scatter diagram or plot.

If the plot is a straight line, simple linear relationship exists which has the equation

$$y = a + bx \quad . \quad . \quad . \quad . \quad . \qquad (2.42a)$$

where a and b are the constants to be obtained from the regression analysis and number of lines can be obtained depending on the values of a and b. Linear relationship can also be represented by the equation for a multiple linear regression

$$y = a_o + a_1x_1 + a_2x_2 + \ldots\ldots + a_n x_n \quad . \quad . \quad . \qquad (2.42b)$$

where $a_{o,}$ $a_{1,}$ a_2, ….. a_n are the regression constants to be determined.

To select the line that fits the data best, the method of least squares is used, which states that the best line for fitting a series of observations is the one for which the sum of the squares of the departures is minimum. Whereas the departure is the difference between the observed value and the line, and since x is the independent variable, the departures of y are used. Nwaogazie (2006) pointed out that when n sets of data points (x,y) are plotted, for each data point we have a difference between the observed value of y and predicted value or fitted value, the departure which is also called error or residual, e_i may be positive, negative or zero.

The "goodness of fit" measure of the given data is provided by the sum of the sum of the deviations, that is $e_1^2+e_2^2+\ldots+e_n^2$. If the sum is small or minimum, then the fit is good, otherwise it is a bad fit. Curves having the property in Equation (2.43) are termed a best fitting curve and such curve is said to fit the data in the least square sense and is called a least square curve.

$$\text{Sum} = \sum_{i=1}^{n} (e_i^2) = \text{minimum} \qquad \cdot \qquad \cdot \qquad \cdot \qquad (2.43)$$

Mathematically, equation 2.43 can be denoted as follows:

$$\text{Sum} = S = \sum_{i=1}^{n} (e_i^2) \qquad \cdot \qquad \cdot \qquad \cdot \qquad (2.44)$$

$$= \sum[(\text{observed values}) \text{ minus } (\text{predicted values})]^2$$

$$= \sum [y_1 - (a + bx_1)]^2 \qquad . \qquad . \qquad . \qquad (2.45a)$$

$$= \sum (y_1 - a - bx_1)^2 \qquad . \qquad . \qquad . \qquad . \qquad (2.45b)$$

The least squares line for the simple linear regression Equation (2.42a) can be obtained by solving for the constant a and b, the two normal equations.

$$\sum y = na + b\sum x \qquad . \qquad . \qquad . \qquad (2.46)$$

$$\sum xy = a\sum x + b\sum x^2 \qquad . \qquad . \qquad . \qquad (2.47)$$

where n = number of pairs of observed values of x and y.

The two unknown parameters a and b in Equation (2.47) can be found by minimizing the equation which is achieved by taking the partial derivatives of the sum of the departures (s) with respect to the two constants and setting them equal to zero, respectively. Thus

$$\frac{\delta s}{\delta a} = \sum 2\,(y_i - a - bx_i)\,(-1) = 0 \qquad \cdot \qquad \cdot \qquad \cdot \qquad (2.48a)$$

$$\frac{\delta s}{\delta a} = \sum 2\,(y_i - a - bx_i)\,(-x_i) = 0 \qquad \cdot \qquad \cdot \qquad \cdot \qquad (2.48b)$$

Equations (2.48a and 2.48b) when rearranged give Equation (2.46 and 2.47), that is

$\sum y = na + b\sum x$

$\sum xy = a\sum x + b\sum x^2$

Which are solved simultaneously to give the values of the constants a and b as follows:

$$a = \frac{\sum y - b\sum x_1}{n} \qquad . \qquad . \qquad . \qquad (2.49a)$$

and

$$b = \frac{n\sum x_1 y - b\sum y x_1}{n\sum x_1{}^2 - (\sum x_1)^2} \qquad . \qquad . \qquad . \qquad (2.49b)$$

For the multiple linear regression for estimating a dependent variable, say y from independent variables $x_1, x_2, x_3 \ldots\ldots x_n$ as can be seen in Equation (2.41), the regression constants $a_o, a_1, a_2, \ldots.. a_n$ are determined.

Reddy (2008) noted that when the observations on the variables as ($y, x_{1i}, x_{2i}, x_{3i} \ldots\ldots x_{ni}$), the sum of the squared deviation is given by

$$S = \sum (y_i - a_o - a_1 x_{1i}, - a_2 x_{2i}, - \ldots - a_n x_{ni})^2 \qquad . \qquad . \qquad .(2.50)$$

where the summation runs from i = 1 to i = n, n being the number of observations. Equating the partial derivatives of this sum with respect to the regression constants to zero, the following normal equations are obtained.

$$\left.\begin{array}{l}\sum y_i = \sum a_o + a_1\sum x_{1i} + a_2\sum x_{2i} + \ldots + a_n \sum x_{ni} \\ \sum y_i x_{1i} = a_o\sum x_{1i} + a_1\sum x_{1i}^2 + a_2\sum x_{2i}x_{1i} + \ldots + a_n \sum x_{ni}\, x_{1i} \\ \vdots \\ \vdots \\ \sum y_i x_{ni} = a_o\sum x_{ni} + a_1\sum x_{1i}x_{ni} + a_2\sum x_{2i}x_{ni} + \ldots + a_n \sum x^2_{ni}\end{array}\right\} \quad . \quad (2.51)$$

where n is the set of data points (y, x_1, x_2). The solution of Equation (2.51) yields the values of a_o, a_1, a_2, ….. a_n

When there are only two independent variables (a case of n = 2), the equation reduces to the form

$$y = a_1 + a_1 x_1 + a_2 x_2 \quad . \quad . \quad . \quad . \quad (2.52)$$

$$\left.\begin{array}{l}\sum y_i = na_o + a_1\sum x_{1i} + a_2\sum x_{2i} \\ \sum y_i\, x_{1i} = a_o\sum x_{1i} + a_1\sum x_{1i}^2 + a_2\sum x_{2i}\, x_{1i} \\ \sum y_i\, x_{2i} = a_o\sum x_{2i} + a_1\sum x_{1i}\, x_{2i} + a_2\sum x^2_{2i}\end{array}\right\} \quad . \quad . \quad . \quad (2.53)$$

by solving simultaneously the three normal equations in Equation (2.53), the solutions for a_o, a_1, and a_2 are provided.

A quadratic parabola can be used as the fitting curve where a linear regression cannot be fitted. The quadratic curve is given by

$$y = a + b\,x + c\,x^2 \quad . \quad . \quad . \quad . \quad (2.54)$$

Constants a, b and c can be obtained from the principles of least squares by solving the three normal equations:

$$\left.\begin{aligned}\sum y &= n\,a + b\sum x + c\sum x^2\\ \sum x\,y &= a\sum x + b\sum x^2 + c\sum x^3\\ \sum x^2\,y &= a\sum x^2 + b\sum x^3 + c\sum x^4\end{aligned}\right\} \quad . \quad . \quad . \qquad (2.55)$$

where n = number of pairs of observed values of x and y.

An exponential function can be handled by transforming it to a straight line by using logarithms of the variables. For example, this exponential function in Equation (2.56).

$$y = c\,x^m \quad . \quad . \quad . \quad . \qquad (2.56)$$

can be transformed to a straight line by using logarithms of the variables as

$$\text{Log } y = \log c + m \log x \quad . \quad . \quad . \qquad (2.57)$$

where, Log y = y,

Log c = a

Log x = x

m = b

The transformed Equation (2.57) becomes similar to linear Equation (2.42a).

where a and b can be obtained by solving simultaneously from Equation (2.43) and the exponential function can be determined.

2.17 Reliability of Fitted Curves

A regression equation replaces (and extends) the data used in its development. Because the equation cannot reproduce all the base data, the process results in the loss of some information about particular pairs of data, but also about the variability of the data. How well the predicted curve describes the observed data determines the reliability of the regression line. Coefficient of correlation, coefficient of determination and standard error of estimate are some of the statistical methods used in determining the reliability of the curves (Ojha et al., 2008).

Ojha et al. (2008) highlighted that the Best-fit Evaluation Criteria are:

i. Coefficient of correlation (r)
ii. Coefficient of determination (r^2)
iii. Efficiency (EFF)
iv Standard error of estimate
v. Confidence interval

2.17.1 Pearson's Correlation Coefficient or Coefficient of Correlation (r)

Pearson's correlation coefficient (r) describes the degree of collinearity between measured and simulated data. A correlation arises when there is a relationship between a pair of variables (e.g. stage and discharge). The correlation coefficient is merely concerned with determining how strongly two such variables are related and is not capable of solving prediction problems. According to Raghunath (2006), correlation coefficient is the most commonly used statistical parameter for measuring the degree of association of two linearly dependent variables x and y. The degree of dependence between the variables is assessed through correlation analyses, which is a measure of correlation, summarizes in one number the direction and magnitude of correlation (Reddy, 2008; Spiegel et al., 2011; Moriasi et al., 2015).

For instance, if (x_i, y_i), i = 1, 2, …, n be the n pairs of observations of the random variables X and Y. then the sample correlation coefficient of these two variables is given by

$$r = \frac{\frac{1}{n} = \sum_{i=1}^{n} (x_i - \bar{x})(y - \bar{y})}{\sigma_x \sigma_y} \quad . \quad . \quad . \quad (2.58)$$

which is the same with equation (2.59)

$$\text{Correlation coefficient (r)} = \frac{\sum(\Delta x \cdot \Delta y)}{\sqrt{\sum(\Delta x)^2 \cdot \sum(\Delta y)^2}} \quad . \quad . \quad . \quad (2.59)$$

$$= \frac{\sum x y - n \bar{x} \bar{y}}{(n - 1)\sigma_x \sigma_y} \quad . \quad . \quad . \quad (2.60)$$

where,

$\Delta x = x - \bar{x}$

$\Delta y = y - \bar{y}$

x, y = middle of each class interval, respectively

$\sigma_{x,}$ σ_y = standard deviation of x and y respectively.

It can be shown that the value of r lies between –1 and +1. When the variables are dependent, r approaches zero. When r = +1 the variables are said to be perfectly positively correlated and when r = –1, the variables are said to be perfectly negatively correlated. In other word, if r = 1, the correlation is perfect giving a straight line plot (regression line). R = 0, no relation exists between x and y (scatter plot). R → 1, indicates a close linear relationship.

2.17.2 Coefficient of Determination (r^2)

According to Reddy (2008), the coefficient of determination (r^2)is the square of correlation coefficient and is perhaps more convenient and useful in interpreting the linear dependence among the variables. Coefficient of determination (r^2) describe the degree of collinearity between predicted and measured data. It describes the proportion of the variance in measured data explained by the model. Coefficient of determination is a measure of the variance, explained in one variable by its dependence on the other variable. That is,

$$r^2 = \frac{\text{variance explained}}{\text{total variance}} \quad . \quad . \quad . \quad (2.61)$$

So, if r = 0.6 between one set of variables and r = 0.3 between another set, it does not mean that the correlation between the first set is twice as strong as the correlation between the second set. This is because while r^2 =0.36 in first case, it is only 0.09 in the second case. It implies that in the first case 36% of the total variance is explained whereas in the second case, only 9% of the total variance is explained. A larger coefficient of determination (r^2) indicates a good fit of the regression equation to the data, because the equation accounts for or is able to explain a large percentage of the variation in the data.

The variance S_y^2 is a statistical measure of the variability of the measured values of y. The greater the value of S_y^2, the wider the spread of the points around the mean. The percentage of information about the variance in y that is retained in, or explained by, the regression equation is called the coefficient of determination. To determine its value, the residuals or departures (difference between actual and estimated y values) have known variance, which represents the unaccounted variance in the regression equation (Viessman & Lewis, 2008; Moriasi et al., 2015). According to Ojha et al. (2008), coefficient of determination is defined as the proportion of the total variability in y, as explained by the regression model. Coefficient of determination describes the extent of best-fit and is expressed as:

$$r^2 = \frac{\sum[(x_i - \bar{x})(y - \bar{y})]^2}{[\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2]^2} \quad . \quad . \quad . \quad (2.62)$$

where,

$$\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n}$$

and $\bar{x}$ $\frac{\sum_{i=1}^{n} x_i}{n}$

Coefficient of determination r^2 ranges from 0 to 1 with values greater than 0.5 being considered acceptable. Higher values of r^2 indicate less error variance.

2.17.3 Nash-Sutcliffe model Efficiency (NSE)

Nash-Sutcliffe model Efficiency (NSE) is defined as one minus the sum of the absolute squared differences between the predicted (simulated) and observed (measured) values normalized by the variance of the observed values during the period under investigation (Althoff & Rodrigues, 2021). NSE is calculated as:

$$NSE = 1 - \frac{\sum_{1=1}^{n}(O_i - P_i)^2}{\sum_{1=1}^{n}(O_i - \bar{O})^2} \quad . \quad . \quad . \quad (2.63a)$$

where,

O_i is the observed or measured value

P_i is the predicted or simulated value from the model

$\bar{O}$ is the mean of the observed values

n is total number of data points (x_i, y_i).

The range of NSE lies between 1.0 (perfect fit) and −∞. An efficiency of lowerthan zero indicates that the mean value of the observed time series would have been a better predictor than the model.

According to Moriasi et al., (2007) and Moriasi et al., 2015), the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") is determined by a normalized statistic known as Nash-Sutcliffe Model Efficiency (NSE). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. The computation of NSE is shown in Equation (2.63b).

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right] \quad . \quad . \quad . \quad (2.63b)$$

where,

Y_i^{obs} is the ith observation for the constituent being evaluated,

Y_i^{sim} is the ith simulated value for the constituent being evaluated,

Y^{mean} is the mean of observed data for the constituent being evaluated,

n is the total number of observations.

The range of NSE is between $-\infty$ and 1.0 (1 inclusive). The optimal value of NSE is 1. The acceptable levels of performance are values between 0.0 and 1.0, whereas values < 0.0 indicates unacceptable performance which indicates that the mean observed value is a better predictor than the simulated value.

2.17.4 Standard Error of Estimate of y with respect to x

As highlighted by Reddy (2008), Gupta (2011), and Moore et al. (2014), the regression line cannot make a perfect prediction unless the coefficient of correlation (r) = 1. What is needed then, is a measure which would indicate how precise the prediction y is bases on x. this measure is called the standard error of estimate which is given by Equation (2.64).

$$S_{yx} = \sqrt{\frac{\sum_{i=1}^{n} (y_i - y_i')^2}{n}} \quad . \quad . \quad . \quad . \quad (2.64)$$

which can be simplified to assume the forms

$$S_{yx} = \sqrt{(1 - r^2)S_y^2} \quad . \quad . \quad . \quad . \quad (2.65a)$$

$$S_{yx} = \sigma_y\sqrt{1 - r^2} \quad . \quad . \quad . \quad . \quad (2.65b)$$

$$S_{yx} = \sqrt{\frac{\sum y^2 - a\sum y - b\sum x y}{n}} \quad . \quad . \quad . \quad (2.65c)$$

where,

S_{yx} = the standard error of estimate of y with respect to x,

y_i = observed values of the dependent variable

y_i' = The predicted values of the dependent variable (i.e. the value of y for the given value of x)

n = number of samples

$\sum(y_i - y_i')^2$ = unexplained variation

S_y^2 = square of the standard deviation

σ_y = standard deviation of y

r^2 = coefficient of determination

Equation (2.65c) can be extended to non-linear regression equations.

According to Kothari and Garg (2014), all Y values in regression cannot be the same as predicted Y values. Standard error of estimate is used to measure the variability of Y values around the prediction lines. Standard error is small when the predicted values and observed values are close. Standard error is not a very good measure of judging the goodness of the fitted model, but should be considered along with coefficient of determination and other measures.

2.17.5 Root Mean Square Error (RMSE) or Root Mean Square Deviation (RMSD)

According to Wikipedia (2021), Moriasi, et al., (2007) and Moriasi et al., (2015), Root Mean Square Error (RMSE) which is also known as Root Mean Square Deviation (RMSD) is the standard deviation of the residuals (prediction errors).RMSE is one of the commonly used error index statistics. The Root Mean Square Error (RMSE) is the square root of Mean Square Error (MSE). The MSE is also known as standard error of the estimate in regression analysis. The RMSD represents the square root of the second sample moment of the differences between predicted values and observed values or the quadratic mean of these differences. RMSD is the square root of the average of squared errors. It measures how much error there is between two data sets. It compares a predicted value and an observed or known value.

It is commonly accepted that the lower the RMSE the better the model performance. Smaller RMSE value indicates thatthe predicted and observed values are closer. RMSD or (RMSE) is always non-negative, and a value of 0 (almost never achieved in practice) would indicate a perfect fit to the data. In general, a lower RMSD is better than a higher one. The effect of each error on RMSD is proportional to the size of the squared error; thus larger errors have a disproportionately large effect on RMSD. RMSE is obtained using the procedure: firstly, by squaring the residuals, secondly, finding the average of the residuals and finally taking the square root of the result. The RMSE formula is:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \qquad . \qquad . \qquad . \qquad . \qquad (2.66)$$

where,

O_i is the observed or measured value

P_i is the predicted or simulated value from the model

n is total number of data points (x_i, y_i).

2.17.6 Mean Absolute Relative Error (MARE)

Mean Absolute Relative Error (MARE) is one of the criteria for the evaluation of streamflow model. Mean Absolute Relative Error is obtained by subtracting Mean Relative Error from one. Mean relative error (MRE) is used to evaluate unit independent expected deviation of the simulation from the observed flow (Malathi & Sridhar, 2012; Dessu et al., 2016; Moriasi et al., 2015). The formula for MARE is:

$$MARE = 1 - MRE \quad . \quad . \quad . \quad . \quad (2.67)$$

where,

MRE is the Mean of magnitude of Relative Error

n is the total number observations in a dataset.

$$MRE = \frac{1}{n}\sum_{i}^{n}\frac{|Q_{obs} - Q_{sim}|}{Q_{obs}} \quad . \quad . \quad . \quad (2.68)$$

where,

Q_{obs} is the observed or measured discharge

Q_{sim} is the simulated or predicted discharge from the model

n is the total number observations in a dataset

2.17.7 Mean Absolute Error (MAE) or Mean of Residue (MR)

Mean Absolute Error (MAE) or Mean of Residues (MR) is the average of all absolute errors of the data collected. To obtain mean absolute error, the sum of all the absolute errors is divided by the number of errors. The formula for MAE is:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|x_i - x| \quad . \quad . \quad . \quad (2.69)$$

where,

$|x_i - x|$ = absolute errors

n = number of errors

MAE values of 0 indicate a perfect fit. MAE values less than half the standard deviation of the measured data may be considered low and that either is appropriate for model evaluation (Singh et al., as cited in Moriasi, et al., 2007; Moriasi et al., 2015).

2.17.8 Percent BIAS (PBIAS)

The average tendency of the simulated data to be larger orsmaller than their observed counterparts is measured by Percent bias (PBIAS). The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values of PBIAS indicate model underestimation bias, whereas negative values indicate model overestimation bias (Gupta et al., as cited in Moriasi, et al., 2015). PBIAS is calculated with Equation (2.70).

$$\mathrm{PBIAS} = 100 \frac{\sum_{\mathrm{i=1}}^{\mathrm{n}} (Y_i^{obs} - Y_i^{sim})}{\sum_{\mathrm{i=1}}^{\mathrm{n}} Y_i^{obs}} \quad . \quad . \quad . \quad (2.70)$$

Moriasi, et al., (2015) stated that PBIAS is useful for continuous long-term simulations and to determine how well the model simulates the average magnitudes for the output response of interest. PBIAS helps to identify average model simulation bias (over prediction vs. under prediction).

2.18 Linear Transformations in Hydrology

Strong nonlinear bivariate and multivariate correlations are common in hydrology and various mathematical models are used to describe the relations, such as parabolic, exponential, hyperbolic, power, and other forms provide better graphical fits than straight lines. Due to the difficulty in the derivation of normal equations using least squares for these models, many are transformed to linear forms. Linearization of nonlinear relations by using logarithms is a familiar form of transformation. Linear log transformation results in a linear form when the logarithms of one or both sets of measurements in Equations (2.49a) and (2.49b) are taken (Viessman & Lewis, 2008). For example, if the bivariate parabolic form as in Equation (2.71) is suggested by the data, taking logarithm allows use of linear form log Y = log k + β log X. That is,

$$Y = k(X)^{\beta} \qquad . \qquad . \qquad . \qquad . \qquad . \qquad (2.71)$$

becomes linear when logarithms are taken, or:

$$\log Y = \log k + b \log X \qquad . \qquad . \qquad . \qquad . \qquad (2.72)$$

The normal equations can be used by redefining y = log Y,

x = log X, a = log k, and b = β, therefore transforming the equation to

y = a + b x. the regression can now be performed on the logarithms, values of a and b are determined, and the estimate of k is found by taking the antilog of a. This transformation is possible for other nonlinear models, some of which are shown in Table 2.4.

Table 2.4 Linear Transformation of Nonlinear Forms

Equation	Abscissa	Ordinate	Equation in linear form
$Y = A + BX$	X	Y	[Y] = A + B[X]
$Y = Be^{AX}$	X	log Y	[log Y] = log B + A(log e) [X]
$Y = AX^{B}$	Log X	log Y	[log Y] = log A + B[log X]
$Y = AB^{X}$	X	log Y	[log Y] = log A + (log B)[X]

Note: variables in brackets are the regression variates

Source: Viessman & Lewis, (2008)

According to Moore, McCabe and Craig, (2014), the essential property of the logarithm transformation for our purposes is that it straightens an exponential growth curve. If a variable grows exponentially its logarithm grows linearly. Also the use of logarithms to obtain a linear pattern from exponential growth does complicate prediction a bit, because the regression line is fitted to the logarithms of the observations. It also predicts the logarithm. To express the prediction in easily understood terms, one must reinstate it in terms of the original units of measurement. This is done by using the fact that any number y can be obtained from its common (base 10) logarithm log y by

$$Y = 10^{\log y} \qquad . \qquad . \qquad . \qquad . \qquad (2.73)$$

2.19 Mathematical Representaton used in Streamflow Modelling

Ojha et al. (2008) highlighted that discharge (Q) is a function of water level (h) and can be represented in a theoretical equation as:

$$Q(h) = f(h) = a\,h^{b} \qquad . \qquad . \qquad . \qquad . \qquad (2.74)$$

where, a and b are constants,h is the water level or stage (m,) and Q is the discharge (m^3/s). Stage is the explanatory variables which actually causechanges in the discharge which is a response variable. The stage which is the explanatory variable is always plotted on the horizontal scale of a scatterplot while the discharge which is the response variable is always plotted on the vertical scale of a scatterplot (Moore et al., 2014). According to Reddy (2008), the relation between the stage (h) and the corresponding discharge (Q) can be expressed as:

$$Q = k\,h^{b} \qquad . \qquad . \qquad . \qquad . \qquad (2.75)$$

where k and b are dimensionless scale and shape parameters which are constants for any stream gauging.

The above relation is an exponential function which can be handled by transforming it to a straight line by using logarithms of the variables. Taking logarithms on both sides of equations:

$$\text{Log } Q = \text{Log } k + b \text{ Log } h \qquad . \qquad . \qquad . \qquad . \qquad (2.76)$$

Hence the plot of Q versus h on a log-log paper gives a straight line.

2.20 Probability Functions for Hypothesis Testing

The following distributions: normal, chi-square, student's t-distribution and F-distributions are the probability functions frequently used for hypothesis testing. To statistically test a hypothesis of concern, the last three distributions are primarily used. For both predictions of the variable and testing, the normal distribution is used. This testing is based on the derivation of critical values, derivable from generally available tables.

2.20.1 Normal Distribution

For continuous variables, normal distribution which is also called normal probability distribution is most useful theoretical distribution. The population parameters of the distribution are represented by μ and σ. The sample mean $\bar{x}$ and the standard deviation (S) are the best estimates of μ and σ respectively for the sample data. When the random variable *x* has a normal distribution, a new random variable *z* is defined as:

$$z = \frac{x - \mu}{\sigma} \qquad . \qquad . \qquad . \qquad . \qquad (2.77)$$

where, *z* is the standardized variate or normal reduced variate with mean and standard deviation of 0 and 1 respectively. This transformation enables Probability Density Function (PDF) to be expressed as a function of z, which is called the standard normal distribution (Ojha et al., 2009).

2.20.2 Student's *t*-Distribution

According to Kothari and Garg (2014) and Gupta (2011), when the sample is of a small size (i.e. n ⋜ 30), and when the population standard deviation (σ) is not known, t-distribution is used for the sampling distribution of mean and t-variable is worked out as:

$$t = \frac{\bar{x} + \mu}{s_i / \sqrt{n}} \quad . \quad . \quad . \quad . \quad (2.78)$$

$$\text{where } s_1^2 = \frac{I}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2 \text{ is sample variance}$$

The *t*-distribution (or student's *t*-distribution) is also symmetrical and is very close to the distribution of standard normal variate, z, except for small values of n. The difference between the variable t and z is that sample standard deviation (s_1) is used in the calculation of t, whereas standard deviation of population (σ) is used in the calculation of z. For different degrees of freedom (i. e. for every possible sample size), there is a different *t*-distribution. For a sample of size n, the degree of freedom is n-1. The shape of the *t*-distribution becomes approximately equal to the normal distribution as the sample size gets larger. The *t*-distribution is so close to the normal distribution for sample sizes of more than 30, that one can use the normal to approximate the *t*-distribution. The range of *t*-distribution is $(-\infty, \infty)$ just like normal distribution.

2.20.3 Chi-Square Distribution (Statistic)

According to Kothari and Garg (2014), when collection of values involving adding up squares are dealt with, chi-square distribution is encountered. Let x_1, x_2, ……x_n from $N(\mu, \sigma)$ population, then the distribution of the statistics

$$\sum_{i=1}^{n} \left(\frac{x_i - \mu}{\sigma}\right)^2 \quad . \quad . \quad . \quad (2.79)$$

is a chi-square distribution with *n* degree of freedom. Alternatively, the distribution of the statistics

$$\sum_{i=1}^{n} \left(\frac{x_i - \bar{x}}{\sigma}\right)^2 = \frac{(n-1){s_1}^2}{\sigma^2} = \frac{ns^2}{\sigma^2} \quad . \quad . \quad . \quad (2.80)$$

is a chi-square distribution with (n -1) degree of freedom. Moore et al. (2014) highlighted that chi-square statistics is a measure of how much the observed cell counts in a two-way table diverges from the expected cell count. The chi-square statistics is

$$X^2 = \sum \frac{(observed - expected)^2}{expected} \quad . \quad . \quad . \quad (2.81)$$

where,

"observed" = observed sample count

"expected" = expected count for the same cell and

the sum is over all r x c cells in the table.

A larger X^2 will result if the expected counts and the observed counts are very different. The evidence against null hypothesis is provided by a large value of X^2. The null hypothesis H_0 for a two-way table is that there is no association between the row and column variables. The alternative is that the variables are related. The chi-square distribution form a family described by a single parameter; which denotes the degree of freedom, like the *t*-distributions. Chi-square distribution is not symmetric, which makes it differs from *t*-distribution.

One should note that chi-square distribution or random variable is non-negative (i.e. positive value), and the probability distribution is skewed to the right (Ojha et al., 2008; Moore et al., 2014). Chi-square distribution is used in testing goodness of fit, taking decision about the variance and in testing independence attributes (Kothari & Garg 2014).

2.20.4 F-Distribution (Test)

Let X and Y be independent chi-square random variables with d_1 and d_2 degree of freedom respectively. Then distribution of the statistics

$$F = \frac{X/d_1}{Y/d_2} \qquad . \qquad . \qquad . \qquad . \qquad (2.82)$$

Equation (2.82) is F-distribution with d_1 degree of freedom in the numerator and d_2 degree of freedom in the denominator. The F-distribution is a function of two parameters, the degrees of freedom of the sample variances in the numerator and denominator of the F statistics. The degrees of the numerator are always mentioned first. The order is very important, as interchanging the degrees of freedom changes the distribution.F-distribution are right skewed and not symmetric. F-distribution has no probability below 0, as F-statistics takes only positive values because sample variances cannot be negative (Kothari & Garg 2014; Moore et al. 2014; Ojha et al., 2008).

2.21 Testing of Hypothesis

Hypothesis is a preposition or a set of proposition set forth as an explanation for the occurrence of some specified group of phenomena either accepted as highly probable in the light of established facts or asserted merely as a provisional conjecture to guide some investigation (Kothari & Garg 2014).

2.21.1 Null hypothesis and Alternative Hypothesis

In statistical analysis, when method A is to be compared with method B about its superiority and if the assumption that both methods are equally good is to be made, then this assumption is known as the null hypothesis (H_0). But if we assume that method A is superior or the method B is inferior, then an alternative hypothesis (H_1) is being considered. There is always 'equal to' sign in null hypothesis. The hypothesis which one wishes to prove is the alternative hypothesis, whereas the hypothesis which one wishes to disprove or reject (Kothari & Garg 2014).

According to Moore et al. (2014), null hypothesis is a statement being tested in a test of significance. The strength of the evidence against the null hypothesis is assessed by the test of significant. A statement of "no difference" or "no effect" is usually the null hypothesis.

2.22 General Description of the Seven Sellected Rivers in the Study Area

The seven selected Rivers in the study area are: Cross River, River Niger, Owena River, Owan River, Ikpoba River, Ossiomo River and Imo River.

2.22.1 General Description of Cross River

Cross River is the main river in South-Eastern Nigeria and gives its name to Cross River State. It originates in Cameroon, where it takes the name of the Manyu River (see Figures 2.13 and 2.14). Although not long by African standards its catchment has high rainfall and it becomes very wide. Over its last 80 kilometres to the sea it flows through swampy rainforest with numerous creeks and forms an inland delta near its confluence with the Calabar River, about 20 kilometres wide and 50 kilometres long between the cities of Oron on the west bank and Calabar, on the east bank, more than 30 kilometres from the open sea. The delta empties into a broad estuary which it shares with a few smaller rivers. The estuary is 24 kilometres wide at its mouth in the Atlantic Ocean. The eastern side of the estuary is in the neighbouring country of Cameroon (Zapfack et al., 2001; Chisholm, 1911). The major tributary of Cross River is the River Aloma coming from Benue State to merge with the Cross River in Cross River State. The population of the lower Cross River traditionally uses water transport.

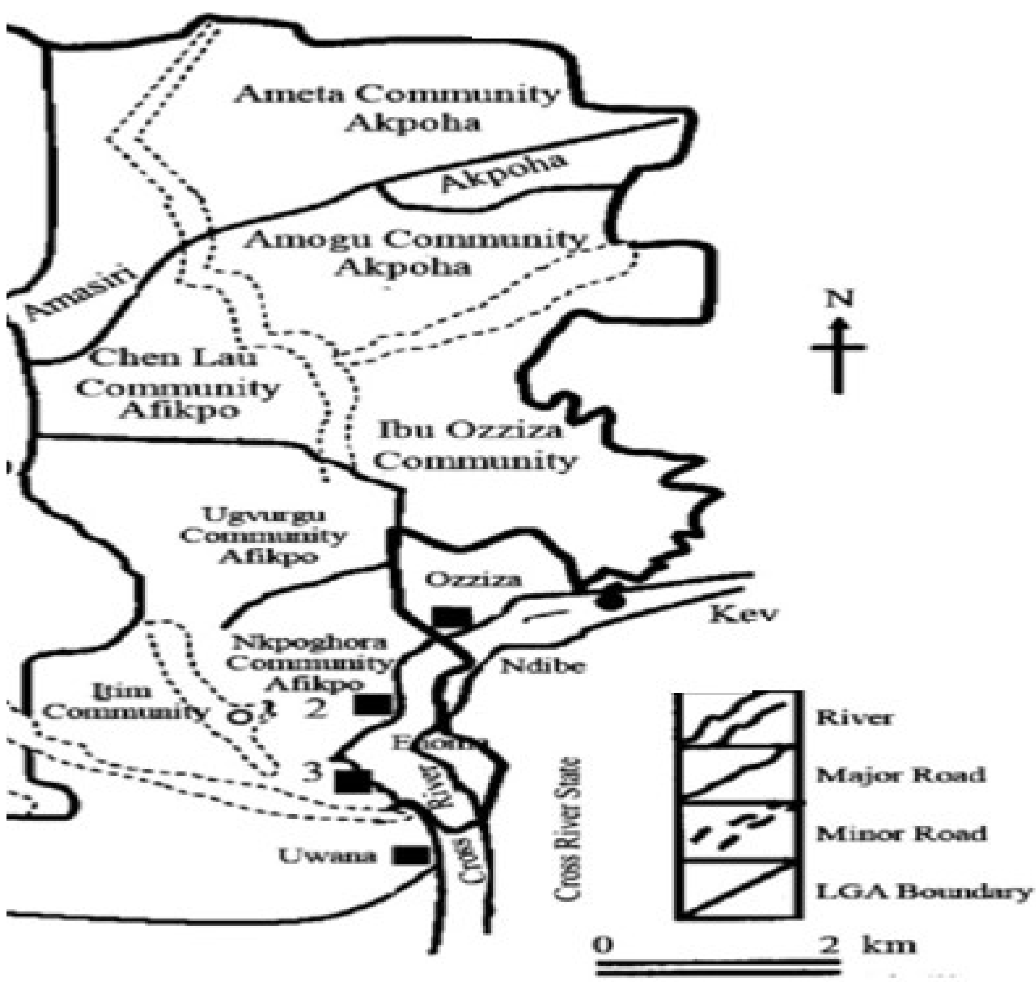


Figure 2.13: Map of Afikpo North Local Government Area showing Cross River
Source: Nwani (2014)

Figure 2.14: The Cross River, flowing through Cameroon and Nigeria
Source: Wikipedia (2021)

2.22.2 General Description of River Niger

According to Olivry (as cited in Abrate et al., 2013), the River Niger is the third longest river in Africa (4200 km), after the Nile and the Congo, draining a basin of about 1 100 000 km^2. The river has its sources on the Fouta Djallon massif in Guinea and, after a long arch through the Sahelian and Saharan regions, empties in the Gulf of Guinea with a large delta. Welcomme (1986) and Lae (1995) stated that the River Niger takes its source in the mountains of Fouta-Djalon in Guinea and crosses successively Mali, Niger, Benin and Nigeria where it's ended into the Atlantic Ocean after crossing approximately 4200 km. River Niger is the largest river in West Africa and the third longest river on the continent after the Nile and the Congo (see Figure 2.15).

With a total length of 4,200Km, the Niger is the eleventh longest river in the world and 9th from the point of view of the size of its catchment area.

Its active basin covers a surface of approximately 1,5 million km^2 shared by nine (9) countries gathered within the Niger Basin Authority (NBA), these are: Benin, Burkina Faso, Cameroun, Côte d'ivoire, Guinea, Mali, Niger, Nigeria and Chad. It has a total drainage area of 1,595,000km^2 out of which 482,300km^2 falls within the desert that produces no runoff. The major tributary Benue takes its source in Chad before crossing Cameroun to join the River Niger at Lokoja in Nigeria. Nigeria derives its name from the river, though only less than one-third of its length lies in its territory (Hydrological Bulletins, 2015).

Figure 2.15: Map showing the Niger River Basin and River Niger passing through Lokoja and Onitsha
Source: Wikipedia (2016)

2.22.3 General Description of Owena River

Owena River is one of the rivers in Ondo State. Owena River catchment areas stretch southwards from Ilawe Ekiti through Akfure, Idanre, Owena village and terminates at the Ondo/Edo State boundary (see Figure 2.16). The drainage area is about 783 km^2 and measures about 102 km from its source to the hydrological gauging station at Owena village in Siluko basin in Owena Local Government Area in Ondo State on latitude 07° 12´ N and longitude 05° 01´ E (BORBDA, as cited in Adewumi et al., 2011).

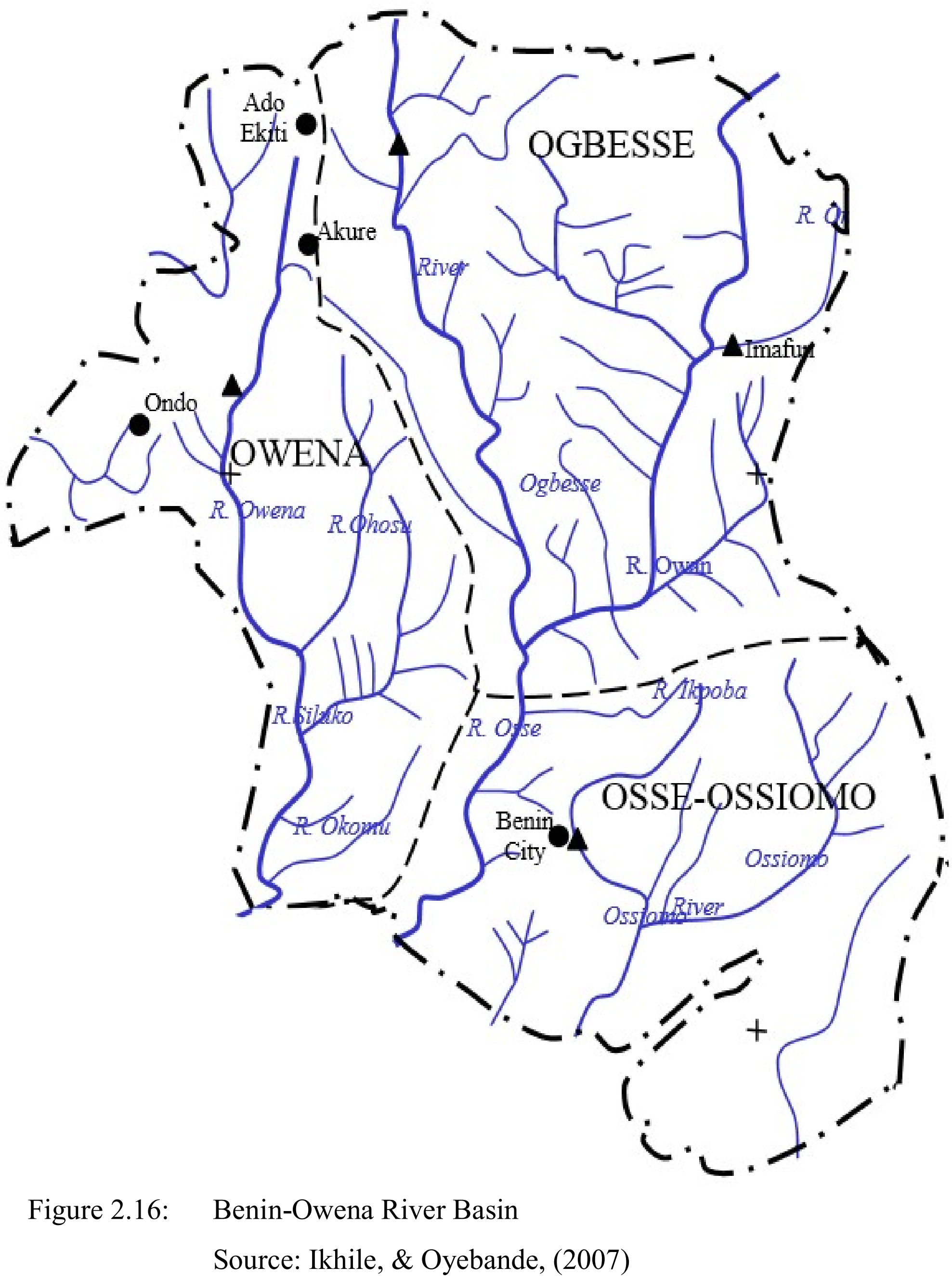


Figure 2.16: Benin-Owena River Basin
Source: Ikhile, & Oyebande, (2007)

2.22.4 General Description of Ikpoba River

Ikpoba River is a river situated within the rainforest belt of Edo State. It is located in Benin City, Edo State in Southern Nigeria. Ikpoba River takes its source from an extension of the western highland in the north and northeast of the region. The direction of its flows is from the east to west, then it meanders at Utekon to flow southwards with Ekosodon, Ugbowo, Okhoro and New Benin to the eastern bank. It crosses Temboga and winds again to flow southeast after Ikpoba-Hill where it is bridged along Benin-Agbor road. It flows towards the Ikpoba Okha LGA in the region (Catherine, 2016). Ikpoba River headwater originates from North West of Benin City and flows north to south through the city (see Figure 2.18). Ikpoba River rises from the Ishan Plateau in the northern part and flowing in south westerly direction in a steeply incised valley and through sandy areas before passing through Benin City and joining the Ossiomo River (Benka-Coker & Ojior, as cited in Edjere et al., 2016).

Ikpoba River is a perennial stream flowing throughout the year. Ikpoba River is high above the water table at the northern region and as such contributes an influent flow into the aquifer whereas in the southern reaches, the river becomes effluent flow as it receives groundwater from the water table aquifer. The width of the river varies from 5 - 11 m and has a depth of 3 - 8 m. It flows for a distance of 48 km across its sub-drainage catchment basin estimated at 722 km^2 and about 330 km^2 of this area is within the Benin City urban *i.e.* 46% of the entire Ikpoba drainage basin. The Ikpoba River lake reservoir is about 320 m wide and 2.15 - 3 km long impounding an area of 1.5 x 106 m^3 of water within an area of 1.1 x 106 m^3 with a spill rate of 312 m3·sec−1. The Ikpoba River dam was commissioned in 1987 (Catherine, 2016). The streamflow gauging station of Ikpoba River is in Benin City in Ossiomo basin. It lies on

Latitude 6^o 21′ N and longitude 5^o39′ E and has a drainage area of 922.00 Km^2.

2.22.5 General Description of Ossiomo River

Ossiomo River is one of the rivers in Edo State and Delta State. Ossiomo River stretches over a 250Km distance within Edo State and Delta State, South-South Nigeria (see Figure 2.16). It is supplied by Rivers Ikpoba, Okhuahie and Akhaianwan. Ossiomo River which is a tributary of Benin River drains in the Benin River at Koko, a coastal community in Delta State, Nigeria where River Benin empties into the Atlantic Ocean (Tawari-Fufeyin, et al., 2008; Ikhuoriah et al., 2015; Ikhuoriah & Oronsaye, 2016). For many rural settlers and communities, their source of water for domestic use is Ossiomo River. The river is fairly wide and flanked by secondary vegetation of rubber trees.

Ossiomo River has gauging stations at Ologbo and Abudu in Edo State. At the Ologbo streamflow gauging station which is in Ossiomo basin, it lies on Latitude 6^o03′ N and longitude 5^o40′ E and has a drainage area of 3974.15 Km^2. The streamflow data at Ologbo gauging station is not adequate for streamflow modeling. At the Abudu streamflow gauging station which is also in Ossiomo basin, it lies on Latitude 6^o18′ N and longitude 6^o02′ E and has a drainage area of 1230.65 Km^2. The streamflow data at Abudu gauging station is adequate for streamflow modeling.

2.22.6 General Description of Owan River

Owan River is one of the Rivers in North West Edo State of Nigeria. The Northwest of Otuo is where Owan River rises and it flows South West to Eme and Uhonmora before it turns South West to join River Ose in Ondo

State. Owan River has a hydrological gauging station at Owan village in Edo State, Nigeria. It lies on Latitude $6^{o}46'$ N and longitude $5^{o}46'$ E. It has a drainage area of 1256.75 Km^2 and is in Osse basin. Owan River is a freshwater body in the northern West of Edo State, Southern Nigeria. It lies between latitude 50.43’- 60. 00’N and longitude 60.48’ – 70. 18’E of the equator (see Figure 2.16). It is a municipal river flowing across two Local Government Areas (Owan East and Owan West) Local Government Areas of Edo State. The source of the river is from the Northwest of Otuo in Owan East Local Government Area and it flows southward through major towns like Afuze, Ogute, Sabongidda-Ora, Uzebba where it joins River Ose in Ondo State (Omoigberale et al., 2014).

2.22.7 General Description of Imo River

Imo River is the major river within the South Eastern States of Nigeria. It traverses from north to south of the Imo State with a length of about 225km. It has its source in the Ideato North Area of Imo State near Osina. Its middle reaches flow north to south for some 80km in the flat valley through the coastal plain lowland without receiving any significant tributaries (see Figure 2.17). The Imo River drained Imo State, Abia State and Akwa Ibom State and empties into the Atlantic Ocean. Aba River flowing from the North joins Imo River and then enters Akwa Ibom State enroute to the Ocean (Okoro et al., 2014). Imo River flows 240 kilometres into the Atlantic Ocean. Its estuary is around 40 kilometres wide, and the river has an annual discharge of 4 cubic kilometres with 26,000 hectares of wetland. Otamiri and Oramirukwa Rivers are the tributaries of Imo River (Russell, 1993). Imo River has five hydrological gauging stations at: Umuna, Ndimoko, Umuopara, Obigbo and

Owerrinta. The gauging station at Owerrinta does not have enough data for streamflow analysis. Hence it is not included in this modeling.

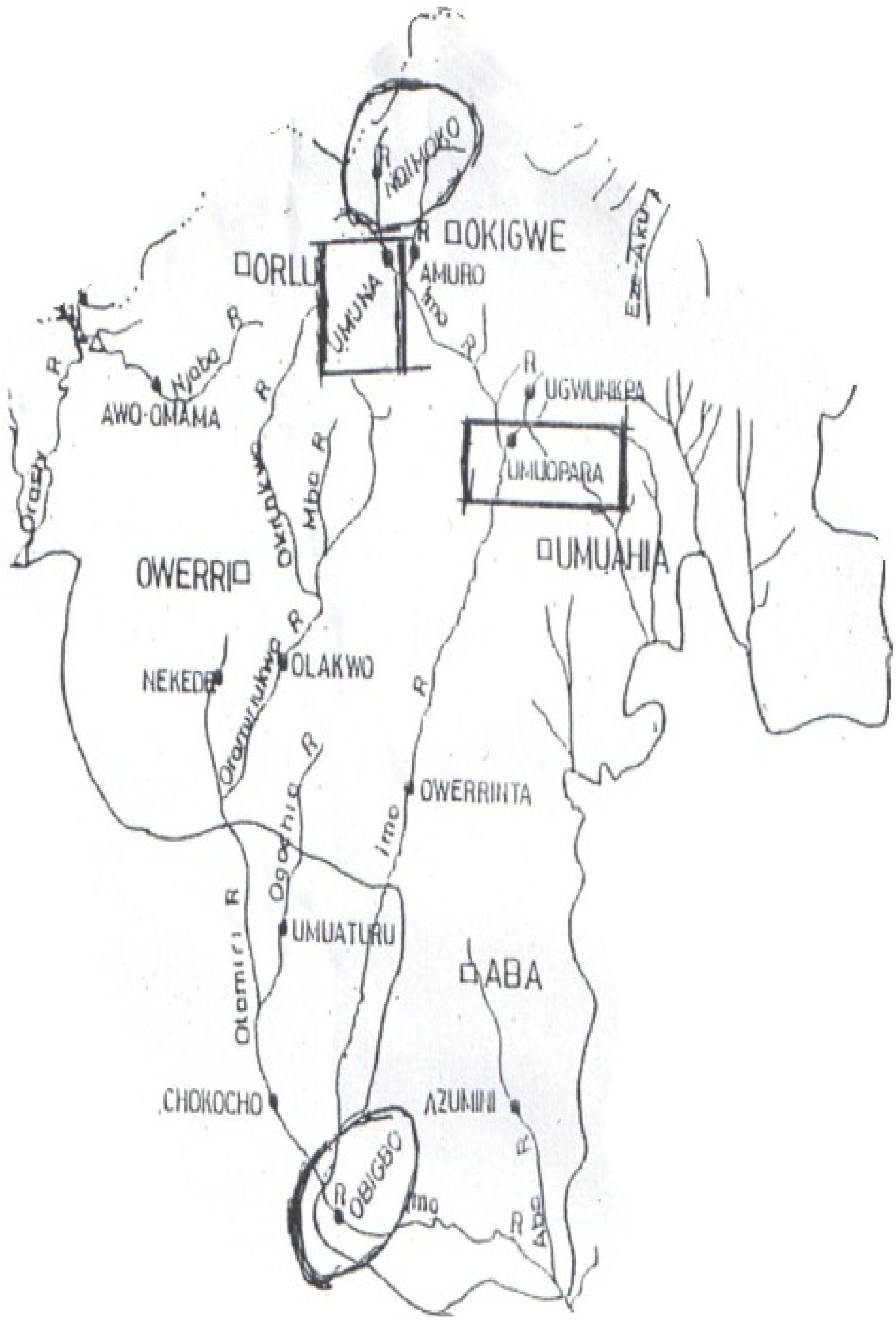


Figure 2.17:Imo River Basin – Showing Gauging Stations

Source: Anambra Imo River Basin Development Authority AIRBDA (1989)

2.23 Related Literature

Examples of the reports of what others have done in related areas: Areas not necessarily identical but collateral and similar to this research work are documented below.

2.23.1 Streamflow and Water Quality Regression Modeling of Imo River System (A Case Study)

Nwaogazie and Okah (2003) studied on the upper reaches of Imo River system between Otamiri River at Nekede hydrological station and Imo River at Obigbo hydrological station (a stretch of 24 km) for purpose of water quality and streamflow modeling. Microsoft Excel Software on multiple regressions was applied to the data. The approach adopted in developing streamflow regression models in this Nwaogazie and Okah (2003) work has to do with selecting flow depth at upstream Otamiri River at Nekede hydrological station as the independent variable and streamflow discharge of Imo River at downstream Obigbo station as the dependent variable. This arrangement was also reversed by selecting streamflow depth of Imo River at downstream Obigbo hydrological station as the independent variable and streamflow discharge of Otamiri River at upstream Nekede station as the dependent variable. The developed models are shown in Table 2.5.

Table 2.5: Streamflow regression Models of Imo River at Obigbo versus Otamiri River at Nekede

S/N	Independent variable (x)	Dependent variable (y)	Regression model	Coefficient of correlation
1	Flow depth of Otamiri River at Nekede	Discharge of Imo River at Obigbo	$y = 245.84x^3 + 758.47x^2 - 766.41x + 256.84$	0.9977
2	Flow depth of Imo River at Obigbo	Discharge of Otamiri River at Nekede	$y = 15.862x^3 - 47.879x^2 + 34.757x + 15.672$	0.9999

These streamflow regression models become handy in forecasting streamflow discharges for Imo River at Obigbo hydrological station and Otamiri River at Nekede hydrological station along Imo River system, as we know that Otamiri River is a tributary of Imo River. The regression models in Table 2.5 are simplified alternatives to the adoption of the Barre' de Saint Venant (as cited in Nwaogazie and Okah, 2003) one-dimensional equations of continuity and momentum, with necessary boundary conditions as the data gathering in Nigeria falls far short of the streamflow and transport parameters necessary for the adoption of Barre' de Saint Venant one-dimensional equations or the solute transport equation. Apparently, the use of mathematical modeling technique involving the governing equations (based on first principles) will continue to elude us in Nigeria until efforts are made by the Federal and State Agencies to collect relevant field data. Model verification for the streamflow regression models were carried out in order to determine their level of accuracy and /or reliability. Results indicated on the average that the models can be used with 89.7% confidence level.

The streamflow models that Nwaogazie and Okah (2003) developed here are for Imo River at Obigbo gauging station versus Otamiri River at Nekede gauging station. The model was developed using the flow depth of Otamiri River against the flow rate of Imo River at Obigbo streamflow gauging station and vice versa, which is different from my research work.

2.23.2 Modelling of Stage-Discharge Relationships affected by Hysteresis

Hysteresis due to unsteady flow affect stage–discharge relationship in some gauging stations and this has become a challenge in hydrometry. In such situations, fitting a single-valued rating curve to the available stage–

discharge measurements which is the standard hydrometric practice is inappropriate. As a solution to this problem, Petersen-Øverleir (2006) study provides a method based on the Jones formula and nonlinear regression, which requires no further data beyond the available stage–discharge measurements, given that either the stages before and after each measurement are known along with the duration of each measurement, or a stage hydrograph is available. Based on the Jones formula rating curve a regression model is developed by applying the generalized friction law for uniform flow and the monoclinal rising wave approximation, along with simplifying assumptions about the geometric and hydraulic properties of the river channel in conjunction with the gauging station.

It is very easy to derive a trustable single-valued rating curve (one-to-one correspondence between the stage and the discharge for steady and uniform flow) in situations where the hydraulic channel control is non-changing, and the stage–discharge relationship is not influenced by unsteadiness, by applying graphical methods or conventional regression methods to the available stage–discharge measurements, although compound controls complicate the latter approach (Herschy, 1995; Fenton & Keller, 2001; Venetis, 1970; Petersen-Øverleir, 2004; Moyeed & Clarke, 2005; Zarzer 1987; Petersen-Øverleir & Reitan, as cited in Petersen-Øverleir, 2006), However, rating curves estimated on the basis of a single-valued rating curve assumption become inaccurate if the stage–discharge relationship is significantly affected by unsteadiness.

Unsteady flow is concerned with flood wave propagation. When a flood wave passes down a river channel and through a given cross-section, the effect of the wave front at the upstream of the cross-section is to increase the velocity of approach at the cross-section (Mander, as cited in

Petersen-Øverleir, 2006). When the flood peak passes into the reach downstream of the cross-section, the rear of the wave increases the backwater conditions and so reduces the velocity at a given discharge at the cross-section (Mander, as cited in Petersen-Øverleir, 2006). The result is that, for the same stage, the discharge is higher during rising stage than during falling stage. These effects will be manifested as distinctive loops in the stage–discharge relationship in some streams, and in such situations, biased discharge estimates will be produced by a single-valued rating curve approach. In-depth discussions on the equations which govern unsteady flow and details on the physical background of the hysteresis phenomenon, can be found in many literatures (Chow, 1959; Henderson, 1966; Fenton & Keller, as cited in Petersen-Øverleir, 2006).

Jones formula can be estimated by standard nonlinear regression methods by invoking the generalized friction law for uniform flow, the monoclonal flood wave principle and assuming a wide and power-law channel. A commonly used approximation to flood waves in natural channels is the monoclonal rising wave, which is a wave of stable profile that does not change shape as it travels down the river channel (Chow, as cited in Petersen-Øverleir, 2006). The mathematical principles of this wave type were developed by Kleitz (as cited in Petersen-Øverleir, 2006), whereas Seddon (as cited in Petersen-Øverleir, 2006) demonstrated its applicability to natural streams. Fread (as cited in Petersen-Øverleir, 2006) obtained good results when he applied this principle to data from several sites in the Mississippi basin. Tang et al. (as cited in Petersen-Øverleir, 2006) applied this principle to model wave speeds in compound channels. Their model predictions agreed well with data from two reaches of two natural rivers in the United Kingdom (UK). If one assumes that all the flood waves passing the gauging station are monoclinal, their celerity, *c*, may be expressed as:

$$C = \frac{\partial \mathrm{Q}_n}{\partial \mathrm{A}} = \frac{1}{\mathrm{B}}\frac{\partial \mathrm{Q}_n}{\partial \mathrm{h}} \quad . \quad . \quad . \quad . \qquad (2.83)$$

where *B* is the top-width of the channel cross-section. Chow (as cited in Petersen-Øverleir, 2006) showed that this monoclinal wave approximation is theoretically justifiable for flood waves causing only small rises in stage. Hence, Equation (2.83) may give rise to considerable inaccuracies when applied to gauging stations in catchments which are subject to rapid andextensive runoff. Equation (2.83) can be used to determine *C*. First, one needs to assume that the channel is so-called power-law (Strelkoff & Clemmens, as cited in Petersen-Øverleir, 2006), i.e. the width of the river can be expressed as a power function of the depth of flow:

$$\mathrm{B} = \beta \mathrm{h}^{\mathrm{N}} \quad . \quad . \quad . \quad . \qquad (2.84)$$

where β and *N* are dimensionless scale and shape parameters. It is easy to see that Equation (2.84) covers a variety of idealized channel forms such as rectangular (*N* = 0), elliptical (*N* = 1/2), triangular (*N* = 1) and funnel-shaped (*N* > 1) types. However, even if natural channels usually vary from an approximate parabola to an approximate trapezoid, they are seldom perfectly describable by a power law due to irregularities, implying that, in most cases, Equation (2.84) must be considered as only representative for the average shape of the river cross-section. Finally, the Jones formula can be expressed as:

$$Q = \alpha h^{\zeta}\sqrt{1 + \theta \mathrm{h}^{-m}\frac{\partial \mathrm{h}}{\partial \mathrm{t}}} \quad . \quad . \quad . \qquad (2.85)$$

Until now h has represented the effective depth of water at the channel control. Usually, the reference gauge is not zero when the effective flow depth is zero. Therefore, $\eta + e$, where $-e$ is the unknown reference gauge height at zero flow and η the stage, or more precisely the water surface level in relation to the reference gauge must usually replace h in Equation (2.85). Hence, one obtains:

$$Q = \alpha(\eta + e)^{\zeta}\sqrt{1 + \theta(\eta + e)^{-m}\frac{\partial \eta}{\partial t}} \quad . \quad . \quad . \quad (2.86)$$

since $\partial h/\partial t = \partial(\eta + e)/\partial t = \partial\eta/\partial t + \partial e/\partial t = \partial\eta/\partial t$. Equation (2.86) is, from here onwards, referred to as the Jones formula rating curve.

2.23.3 Streamflow Models of Imo River for Regional Water Resources Allocation.

Okoro and Uzoukwu (2013) developed streamflow mathematical models of Imo River based on the statistical method of least squares. To assist the allocation of water resources within the South-East region of Nigeria, four streamflow models of Imo River were developed using streamflow measurements from Obigbo, Ndimoko, Umuna and Umuopara streamflow gauging stations along Imo River.

Equation 2.75 was applied to obtain the relationship between the stage (h) and the corresponding discharge (Q) of Imo River at the various stramflowgauging stations. The streamflow models of Imo River at Ndimoko, Umuna, Umuopara and Obigbo represented nonlinear relationship between annual maximum discharge and annual maximum stage. High and positive values of coefficients of determination (r^2) ranging between 0.908 to 0.997 and correlation coefficients (r) ranging between 0.953 to 0.998 were obtained indicating good curve fitting (see Table 2.6).

Table 2.6: Imo River Streamflow Models (using annual maximum discharge versus annual stage curve)

S/N	River System	Streamflow gauging station	Streamflow Model [+] $Q = k(h)^b$	Model Performance Indicator [*]
1	Imo River	Ndimoko	$Q = 4.423\ h^{1.495}$	$r^2 = 0.908$ $r = 0.953$ $S_{Q.h} = 1.82$
2		Umuna	$Q = 4.702\ h^{1.868}$	$r^2 = 0.997$ $r = 0.998$ $S_{Q.h} = 2.2$
3		Umuopara	$Q = 30.02h^{1.177}$	$r^2 = 0.959$ $r = 0.979$ $S_{Q.h} = 17.40$
4		Obigbo	$Q = 102.4\ h^{1.224}$	$r^2 = 0.969$ $r = 0.984$ $S_{Q.h} = 6.41$

[+] Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

[*] Model Performance Indicator

r^2 = Coefficient of determination

r = Coefficient of correlation

$S_{Q.h}$ = Standard error of estimate of discharge (Q) on stage (h)

2.23.4 Water Resources Management for Rural Development using Streamflow Model of Imo River at Umuopara

Okoro and Uzoukwu (2014) developed a streamflow mathematical model of Imo River at Umuopara community based on the statistical method of least squares. The study presents the mathematical model of annual maximum discharge versus annual maximum stage of Imo river at Umuopara. The calculated statistical measures such as coefficient of correlation (r), coefficient of determination ($r^{2)}$) and standard error of estimate ($S_{Q.h}$) suggest that the model satisfactorily produced a good curve fitting to be used for the model. The model represents the nonlinear relationship between annual maximum discharge and annual maximum stage. The model developed will serve a useful purpose in the design of dam, estimation of the size of reservoir, public water supply, flood control, pisciculture, recreation, irrigation, wild life protection, hydropower, water sports and tourism in Umuopara community and beyond, thus ushering in an era of socio-economic and industrial development for the area.

Equation 2.75 was applied to obtain the relationship between the stage (h) and the corresponding discharge (Q) of Imo River at Umuopara streamflow gauging stations. The streamflow model of Imo River at Umuopara gauging station obtained using annual maximum discharge versus annual maximum stage curve is shown in Table 2.7.

Table 2.7: Imo River Streamflow Model at Umuopara streamflow gauging station

Streamflow gauging station	Streamflow Model [+] $Q = k(h)^b$	Model Performance Indicator [*]
Umuopara	$Q = 30.02h^{1.177}$	$r^2 = 0.959$ $r = 0.979$ $S_{Q.h} = 17.40$

[+] Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

[*] Model Performance Indicator

r^2 = Coefficient of determination

r = Coefficient of correlation

$S_{Q.h}$ = Standard error of estimate of discharge (Q) on stage (h)

2.23.5 Developing Streamflow Model for Sustainable Rural Water Supply at Ndimoko, Imo State, Nigeria

Hydrologic modeling is applied in water resources planning, design and management activities for environmental sustainability. Okoro and Uzoukwu (2014) obtained a streamflow model of Imo River at Ndimoko using statistical method of least squares (see Table 2.8). High and positive values of coefficient of correlation (r) of 0.953 and coefficient of determination ($r^{2)}$) of 0.908 were obtained. The standard error of estimate ($S_{Q.h}$) has small value of 1.82 indicating that the regression model fits the data. The model represents the nonlinear relationship between annual maximum discharge and annual maximum stage.

Equation 2.75 was applied to obtain the relationship between the stage (h) and the corresponding discharge (Q) of Imo River at Ndimoko streamflow gauging stations, the result is tabulated in Table 2.8.

Table 2.8: Imo River Streamflow Modelat Ndimoko Gauging Station

Streamflow gauging station	Streamflow Model $^{+}$ $Q = k\,(h)^{b}$	Model Evaluation Parameters *
Ndimoko	$Q = 4.423\,h^{1.495}$	$r^2 = 0.908$ $r = 0.953$ $S_{Q.h} = 1.82$

$^{+}$ Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

* Model Evaluation Parameters

r^2 = Coefficient of determination

r = Coefficient of correlation

$S_{Q.h}$ = Standard error of estimate of discharge (Q) on stage (h).

The model developed will play an important role in ensuring that potable water supply and future water resources planning and management in Ndimoko community is efficiently made and scientifically based in order to satisfy the water needs of both natural systems and humans, as hydrologic modeling is very important in water resources planning, design and management activities

2.23.6 Hydrological Streamflow Modelling for Calibration and Uncertainty Analysis using Swat Model in the Xedone River Basin

Vilaysane et al. (2015) studied how the hydrological streamflow modeling is applied by the Soil and Water Assessment Tool (SWAT) model in the Xedone Riverbasin, covering an area of 7,224.61 km2, in the southern part of Laos. The main objective of the study is to test the performance and feasibility of the SWAT 2009 model for prediction of streamflow in the Xedone River basin. The flow calibration and validation were performed for eight years from 1993 to 2000 for calibration and from 2001 to 2008 for validation. The model is calibrated and validated for two periods: 1993-2000 and 2001-2008, respectively, by using the SUFI-2 technique in the analysis.

The Soil and Water Assessment Tool (SWAT) is a physics-based, long-term, and distributed hydrological model and has been applied worldwide as an excellent assessment model for hydrological modelling and water resource management. This model is applied to runoff and soil loss prediction, water quality modelling, land use change effect assessment and climate change effects. The study focused on calibration, evaluation and application of SWAT 2009 model for simulation of the hydrology of the Xedone River basin. In SWAT the base of the hydrologic cycle simulation is the water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{t} (R_{day} + Q_{surf} - E_a - w_{seep} - Q_{gw}) \cdots (2.87)$$

where,

S_{Wt} is the final soil water content (mm),

S_{W0} is initial soil water content on day i (mm), t is the time (days),

R_{day} is the amount of precipitation on day i (mm),

Q_{surf} is the amount of surface runoff on day i (mm),

E_a is the amount of evapotranspiration on day i (mm),

w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and

Q_{gw} is the amount of return flow on day i (mm).

For the calibration of SWAT models, a computer program called the SWAT-CUP is used.The program is linked to five different algorithms such as Particle Swarm Optimization, (PSO), Sequential Uncertainty Fitting SUFI-2, Parameter Solution (ParaSol), Generalized Likelihood Uncertainty Estimation (GLUE) and Mark chain Monte Carlo (MCMC) procedures to SWAT. This enables the sensitivity analysis, calibration, validation, and uncertainty analysis of SWAT models.

SUFI-2 is the algorithm for calibration of SWAT model. SUFI-2 can provide the widest marginal parameter uncertainty intervals of model parameters among the five approaches. The parameter uncertainty is calculated from all the input and output source uncertainties such as the uncertaintyin the input rainfall data, the land use and soil type, parameters, and observed data, in SUFI-2.The goodness of calibration and prediction uncertainty is judged based on the closeness of the p-factor to 100%and the r-factor to 1. The goodness of fit in SUFI-2 is quantified by the R^2 and Nash-Sutcliffe (NS) coefficient between the observed data and the best simulation. The average thickness of the 95PPU band (r) and the r-factor are calculated by equations below:

$$\bar{r} = \frac{1}{n}\sum_{t_i}^{n}(y^{M}_{t_i,\,97.5\%} - y^{M}_{t_i,\,2.5\%}) \quad . \quad . \quad . \quad (2.88)$$

$$r - factor = \frac{p - factor}{\sigma_{obs}} \quad . \quad . \quad . \quad (2.89)$$

where the bracketed equation above represents the upper and lower boundaries of the 95PPU, and $\sigma_{obs}$is the standard deviation of the measured data.

Hydrological streamflow modelling is successfully calibrated and validated in this study by using the SWAT model in the Xedone River basin. The good result is shown with the likelihood measure of the model calibration and validation for two periods: 1993-2000 and 2001-2008. The daily simulation values of R^2 and NSE are 0.821 and 0.819 during the calibration period, and 0.732 and 0.707 during the validation period. Monthly results R^2 and NSE are 0.927 and 0.925 during the calibration period, and 0.910 and 0.856 during the validation period.

2.23.7 Streamflow Prediction in Ungauged Catchment: A Case Study of "Tiers" South Australia.

Hossain (2017) worked on streamflow prediction in ungauged catchment: A case study of "Tiers" South Australia, applying hydrologically similar catchment modelling concept to predict streamflow from an ungauged catchment. Catchment scale modelling concept was applied. Rainfall-runoff process was simulated by Storm Water Management Model EPA SWMM. First a model was made for a nearby gauged catchment that was assumed hydrologically similar to the target ungauged catchment. By using observed streamflow data at the gauged catchment, the model was calibrated. The calibrated model parameters were then used to setup the ungauged catchment model.

The model was assigned rainfall and evaporation data during the period of 1993-1998. As the rainfall and evaporation data time steps were on daily basis, the model was set up on daily time step. Dynamic wave routing option was selected for flow routing and the routing time steps were set to 60 seconds. As the EPA SWMM model allows to assign realistic value of surface runoff based on hydrological condition, for wet period, a time step of 5 minutes and for dry period, a time step of 10 minutes were assigned. The model was run for the period of 1993-1998 after completion of setup and defining all parameters.Automatic calibration method by a parameter optimization tool (PEST) was utilized for model calibration. As the first year (1993) was considered as model warm up period, the simulation output was counted from 1994-1998.

The performance of calibration was measured by using goodness of fit measures, R^2 and N-S efficiency. For this study R^2 and NSE values are 0.61 and 0.54 respectively. Model output of the first year (1993) was not counted in the calculation of R^2 and NSE as the first year (1993) was considered as model warm up period. Model's validity was tested after calibration, tested by using rainfall and runoff data for the period of 1999-2001. It was foundthat R^2 = 0.48 and NSE= 0.43 which was within the acceptable range. Hence it was considered that the calibration was sufficient.

To verify the Tiers model output, the ungauged catchment model output was tested in terms of ϕ index method. The ϕ index is a constant rate of water loss from land surface. The ϕ index was expected to be similar for both catchments since it was assumed that both catchments are hydrologically similar. It was found that ϕ index for Tiers catchment was 0.155 mm/hr which was close to Myponga upstream catchment (ϕ = 0.1424 mm/hr). Hence the prediction of ungauged streamflow was acceptable.

2.24 Summary of Literature Review

The Model review for Watershed Modelling (under Streamflow Prediction) are summarized in Table 2.9.

Table 2.9: Detail of the Summarized Models for Streamflow

Model	**Author**	**Model Description and Governing Equation or Model Equation**	**Functionality of the Model**	**Limitations of the Model**
(NRCR) Nonlinear Rating Curve Regression Model based on the Jones Formula	Petersen-Øverleir, (2006)	Based on the Jones formula rating curve a regression model is developed by applying the generalized friction law for uniform flow and the monoclinal rising wave approximation, along with simplifying assumptions about the geometric and hydraulic properties of the river channel in conjunction with the gauging station. At the cross-section of the river the discharge where the gauging station is placedis expressed by: $Q = VA$ where Q is the discharge, and V is the mean velocity in the cross-section of area A.	Hysteresis due to unsteady flow affect stage–discharge relationship in some gauging stations and this has become a challenge in hydrometry. In such situations, fitting a single-valued rating curve to the available stage–discharge measurements which is the standard hydrometric practice is inappropriate. As a solution to this problem, Petersen-Øverleir (2006)study provides a method based on the Jones formula and	Nonlinear Rating Curve Regression Model based on the Jones Formula should not be applied to steady flow and uniform flow. It should not be used in situations where the hydraulic channel control is non-changing, and the stage–discharge relationship is not influenced by unsteadiness.

		The mean velocity is expressed by the generalized friction law: $V = R^M S_f^{\frac{1}{2}}$ where K is the factor of flow resistance, R the hydraulic radius of the cross-section, S_f is the friction slope and M is an exponent dependent on the friction law used. Hence, the two equations above yields: $Q = R^M S_f^{\frac{1}{2}}$ The momentum equation for unsteady flow without lateral flow is given by $S_f = S_o - \frac{\partial h}{\partial x} - \frac{V}{g}\frac{\partial V}{\partial x} - \frac{1}{g}\frac{\partial V}{\partial t}$ where, S_0 is the bottom slope, x the longitudinal distance along the channel, h the depth of flow in the cross-section, above simply becomes $S_f = S_0$,	nonlinear regression to model unsteady streamflow affected by hysteresis	Nonlinear Rating Curve Regression Model Based on the Jones Formula is only applied to unsteady flow and non-uniform flow as non-steady flow is concerned with flood wave propagation.

		However, as mentioned already, strictly steady and uniform conditions are seldom encountered in natural streams. Monoclonal rising wave is a commonly used approximation to flood waves in natural channels. It is a wave of stable profile that does not change shape as it travels down the river channel. If one assumes that all the flood waves passing the gauging station are monoclinal, their celerity, *c*, may be expressed as: $C = \frac{\partial Q_n}{\partial A} = \frac{1}{B}\frac{\partial Q_n}{\partial h}$ where *B* is the top-width of the channel cross-section. Finally, the Jones formula can be expressed as:		

		$$Q = \alpha h^{\zeta}\sqrt{1 + \theta \mathrm{h}^{-m}\frac{\partial \mathrm{h}}{\partial \mathrm{t}}}$$ Until now the effective depth of water at the channel control is represented by *h*. Usually, when the effective flow depth is zero, the reference gauge is not zero. Therefore, $\eta + e$, where $-e$ is the unknown reference gauge height at zero flow and η the stage, or more precisely *h* is usually replaced by the water surface level in relation to the reference gauge. Hence, Jones formula rating curve below: $$Q = \alpha(\eta + \mathrm{e})^{\zeta}\sqrt{1 + \theta(\eta + \mathrm{e})^{-m}\frac{\partial \eta}{\partial \mathrm{t}}}$$ since $\partial h/\partial t = \partial(\eta + e)/\partial t = \partial\eta/\partial t + \partial e/\partial t = \partial\eta/\partial t$.		

Model	Author	Model Description and Governing Equation or Model Equation	Functionality of the Model	Limitations of the Model
HBV (HydrologiskaByråns Vattenavdelning) model	Pool et al., (2017)	The HBV (Hydrologiska Byråns Vattenavdelning) model (Bergström, 1976; Lindström et al., 1997 cited in Pool et al., (2017) is a bucket-type hydrologic model for simulating continuous runoff series. Model inputs are air temperature and daily rainfall including daily potential evaporation values. Hydrologic processes are represented by four different routines corresponding to soil water, snow, runoff routing and groundwater, with a combined total of 16 parameters. Snowmelt and snow accumulation are calculated by a degree-day method in the snow routine. Potential evaporation together with snowmelt and rainfall are input to the soil-water routine, where the groundwater recharge and the	By explicitly including one or several SFCs in the calibration process, Ecologically relevant streamflow characteristics (SFC) were improved from modeled runoff time series in gauged catchments.	Parameters in the HBV model cannot be determined a priori: instead they are identified by model calibration, just like for all bucket - type models. The gauged donor catchments and subsequently the ungauged catchments estimate of the ecologically relevant streamflow

		actual evaporation are computed based on the soil-moisture storage. The groundwater (or response) routine consists of a connected deep and shallow groundwater reservoir and simulates baseflow, intermediate runoff, and peak flow. During the routing process,to calculate the runoff at the catchment outlet, the three runoff components are taken together and transformed by a triangular weighting function.By separating a catchment into elevation bands, runoff can be modeled in a semi-distributed way. In the model calibration the objective functions were calculated with observed (obs) and simulated (sim) runoff (Q) or SFCs (I) as shown below:		characteristics (SFC) can be substantially uncertain when models are calibrated using traditional approaches based on optimization of statistical performance metrics (e.g., Nash–Sutcliffe model efficiency).

OBJECTIVE FUNCTION	ABBREVIATION	DEFINITION	OPTIMAL VALUE
Model efficiency	R_{eff}	$1-\frac{\sum(Q_{obs}-Q_{sim})^2}{\sum(Q_{obs}-\bar{Q}_{obs})^2}$	1
Efficiency for each IndividualSFC[2]	I_{Single}	$1-\frac{\lvert I_{obs}-I_{sim}\rvert}{I_{obs}}$	1
SFC and model efficiency	I_{Single_Reff}	$0.5\,(I_{Single}+R_{eff})$	1
Efficiency for the selected SFC_s^2	I_{multi}	$\frac{1}{n}\,(I_{Single_1}+\ldots+I_{Single\_n})$	1
SCF_s and model efficiency	I_{Multi_Reff}	$\frac{1-1}{n}I_{Multi}+\frac{1}{n}R_{eff}$	1

[1]For each of the 13 SFC_s a specific $I_{Single\ exists.}$
[2] I_{Multi} consists of the most robust and informative SFC_s.

In model evaluation, the performance measures used were calculated with observed (obs) and simulated (sim) runoff (Q) or SFCs (I) as shown below:

PERFORMANCE MEASURE	ABBREVIATION	DEFINITION	OPTIMAL VALUE
Model efficiency	R_{eff}	$1-\frac{\sum(Q_{obs}-Q_{sim})^2}{\sum(Q_{obs}-\bar{Q}_{obs})^2}$	1
Mean absolute relative error[1]	MARE	$1-\frac{1}{n}\sum\frac{\lvert Q_{obs}-Q_{sim}\rvert}{Q_{obs}}$	1
Normalized SFC error[2]	nSFC	$\frac{I_{obs}-I_{sim}}{R_{obs}})$	0

[1] n is the number of days.
[2] R is the range of possible values of a SFC for the respective catchment.

Model	Author	Model Description and Governing Equation or Model Equation	Functionality of the Model	Limitations of the Model
(PM) Power-law Model	Okoro and Uzoukwu, 2013; Okoro and Uzoukwu, 2014	The width of the river can be expressed as a power function of the depth of flow. The mathematical representation of the relationship between the stage (h) and the corresponding discharge (Q) can be expressed as: $Q = k\,(h)^{b}$ where, k and b are dimensionless scale and shape parameters which are constants for any stream gauging. h = gauge height or stage Q = discharge or flow rate The degree of dependence between the variables is assessed through correlation analyses,	In in situations where the hydraulic channel control is non-changing, and the stage–discharge relationship is not influenced by unsteadiness, it is very easy to derive a trustable single-valued rating curve (one-to-one correspondence between the stage and the discharge for steady and uniform flow) by applying graphical methods.	

		The performance of modelling effort is generally evaluated by calculating statistical measures such as the coefficient of correlation (r), coefficient of determination (r^2) and standard error of estimate (Syx).	The model is suitable for a country like Nigeria where the government ministries, departments and even specialized agencies such as River Basin Development Authorities, find it different to observe and keep records of streamflow data like stage and discharge, let alone observing and keeping records of other watershed characteristics which are used in some other streamflow modelling.	

Model	Author	Model Description and Governing Equation or Model Equation	Functionality of the Model	Limitations of the Model
Prediction Model and Peak Annual Flow Model **(PAFM)**	(Kwon et al., 2009)	The predictability of the peak annual flood on the Yangtze River at the site of the Three Gorges Dam is investigated by this study. At the Yichang hydrological station, a proxy for inflows to the Three Gorges Dam this investigation was done on the seasonal flow of the primary inflow season and the peak annual flow using sea-surface temperatures and upland snow cover available one season ahead of the prediction period. Using time-dependent climate predictors, hierarchical Bayesian based prediction model was developed to incorporate parameter and model uncertainty in a statistical approach.To compute the posterior distribution of the desired variables is the objective of Bayesian inference,	This is about the application of hierarchical Bayesian modelling for prediction of both peak annual and mean seasonal flow. It is also about the seasonal prediction of hydrological variables that are potentially useful for reservoir operation of the Three Gorges Dam in China. The major advantage of the approach is that it allows an empirical estimation of the	

		in this case the parameters of the prediction models for seasonal mean flow and the annual maximum flood distribution. The posterior distribution $p(\theta \mid x)$ is given by the Bayes theorem, as follows: $$p(\theta \mid x)=\frac{p(\theta)p(x\mid\theta)}{p(x)}=\frac{p(\theta)p(x\mid\theta)}{\int_{\theta} p(\theta)p(x\mid\theta)d\theta}\propto p(\theta)p(x\mid\theta)$$ x is the vector of observations and $p(\theta)$ is the prior distribution. A method for incorporating climate information into updated estimates of the parameters for the distribution (e.g. Normal and Gumbel) used to represent the annual maximum flood and seasonal mean flow is presented here. A hierarchical model allows the parameter values of the probability distribution (model) to be themselves functions of a (regression) model based on climate indices. Thus, the probability distribution, with two	parameter uncertainty and higher confidence in the uncertainty bands accompanying the prediction.	

		parameters is the first model layer and the second layer is a predictive regression model for these parameters. The distribution of seasonal mean flood $Y_{\text{mean}}(t)$, using the normal distribution can be modelled as follows: $$Y_{\text{mean}}(t) \sim \text{Normal}(\mu(t), \sigma(t))$$ where ~ signifies that the variable, $Y_{\text{mean}}(t)$ is distributed according to the distribution that follows, i.e. a normal distribution with mean $\mu(t)$ and standard deviation $\sigma(t)$. The standard deviation, $\sigma(t)$, in the present application,was not found to vary significantly as a function of time. As a result, to remove the time dependence of σ, the equation above is changed: $$Y_{\text{mean}}(t) \sim \text{Normal}(\mu(t), \sigma)$$ Then, the mean of the distribution is modelled as		

		a linear combination of the regression parameters and predictors: $$\mu(t) = \beta_1 \mathbf{X}_{1i}(t) + \ldots + \beta_k \mathbf{X}_{ki}(t)$$ where $\boldsymbol{X}_{i,}$ climate indices, are the ith rows of the known design matrices $\boldsymbol{X}$, and a vector of regression parameters which is normally distributed is β, $\beta_k \sim N(\eta_{\beta k}, \sigma_k)$. Aquadratic regression models, a hierarchical Bayesian prediction model is developed for seasonal mean flow and annual peak flow using selected climate variables, specifically SSTs and snow cover, using MAM values. The detailed prediction model for each case and for each year, t, can be formulated as follows:		

		Seasonal forecasting: $Y_{\text{mean}}(t) \sim \text{Normal}(\mu_{\text{mean}}(t), \sigma_{\text{mean}})$ $\mu_{\text{mean}}(t) = \beta_{m1} + \beta_{m2} \cdot \text{SST1}(t) + \beta_{m3} \cdot \text{SST1}^2(t) + \beta_{m4} \cdot \text{SST2}(t) + \beta_{m5} \cdot \text{Snow}^2(t)$ *Peak flow forecasting:* $Y_{\text{peak}}(t) \sim \text{Gumbel}(\mu_{\text{peak}}(t), \sigma_{\text{peak}})$ $\mu_{\text{peak}}(t) = \beta_{p1} + \beta_{p2}\text{SST1}^2(t) + \beta_{p3}\text{SST3}(t) + \beta_{p4}\text{Snow}^2(t)$		

Model	Author	Model Description and Governing Equation or Model Equation	Functionality of the Model	Limitations of the Model
(EMSPM) Empirical Monthly Streamflow Prediction Modelfor Ungauged Watersheds	Jose et al., (2007)	This is about the development and evaluation of a simple monthly streamflow estimation model. Monthly streamflow per unit area is correlated to Moisture Adequacy Index (MAI) and one or more watershed characteristic: terrain slope, soil infiltration rate, and/or a vegetation cover index. Different correlation methods were used, ranging from linear and power to exponential. Runoff from upland areas may take some time to reach the watershed outlet, depending on the time of concentration. A lag time of 15 days was considered and denoted as Q75L15 to account for the time of concentration. The value of Q75L15 (L $s^{-1}km^{-2}$) was computed as the average of the 75% probable stream flow (Q75, defined below) for a given month with	This is a simple hydrological model that can be transferable to other regions in the world for estimating monthly streamflow. The model is suitable for ungauged watersheds in the developing world where little or no data exists at field scale.	The limitation is that assigning infiltration rates and vegetation cover values without actual field data is undesirable.

		those of the next month. MAI is expressed as the ratio P75 ETo, where P75 can be calculated from a gamma probability distribution or from the standard deviation (SD) and the mean precipitation (Pm).The equation is: $P75 = Pm - (0.74 \times SD)$ For purposes of planning, monthly irrigation requirements are frequently estimated as reference crop evapotranspiration (ETo) in excess of 75% probable precipitation (P75). Following the Food and Agricultural Organization of the United Nations (FAO) guidance ETo can be computed or from maximum and minimum temperatures and extraterrestrial radiation. Similarly, 75% probability of exceedance for monthly stream flow (Q75) values can be obtained as: $Q75 = Q_m - (0.74 \times SD)$ where, Q_m is the mean monthly stream flow.		

		Land use classes were translated into vegetation Leaf Area Index (LAI). LAI is very distinct for different types of vegetation covers. It has values ranging from grassland, crops, shrubs, plantation, to different types of forest. In determining the energy balance of the land surface LAI plays an integral role, thus influencing how much water is consumed as evapotranspiration and how much water is left for infiltration and/or runoff. LAI was transformed into a vegetation cover index (fc) using Norman et al. (1995) equation: $fc = 1 - e^{\left(-0.5 LAI\right)}$ The model had the following form: $Q75L15 = a e^{\left(b MAI\right)}$		

Model	Author	Model Description and Governing Equation or Model Equation	Functionality of the Model	Limitations of the Model
(SWAT) Soil and Water Assessment Tool model	Vilaysane et al., (2015); Grey et al. (2014)	The Soil and Water Assessment Tool (SWAT) is a distributed hydrological model or physics-based, deterministic, continuous, long-term, watershed-scale simulation modelthat has been applied worldwide as an excellent assessment model for water resource management and hydrological modelling. The Soil, Water and Assessment Tool (SWAT) is applied on a watershed to evaluate the ability of the model to predict streamflow, and impacts of land-use changes on stream flow to allow for better understanding of how these tools can aid in water resources management.This model is applied to runoff and soil loss prediction, water quality modelling, land-use change effect assessment and climate change affects.	One advantage of SWAT is the integration of the basin-scale model with GIS providing much improved modelling linkages within a management basin. SWAT allows for the discretization of a watershed by dividing it into multiple sub-watersheds, which can then be further subdivided into hydrologic response units (HRUs) that	SWAT is lacking in relation to the spatial representation of the hydrological response units within sub-basins (Gassman et al., 2007 cited in Grey et al., 2014). The impacts on the predictions of evapotranspiration, percolation and soil water content are significantly affected despite the increase in spatial heterogeneity experiences with using large sized

		Evaluation of daily, monthly, and annual streamflow and pollutant outputs indicate that SWAT functioned well in a wide range of watersheds. In order to setup SWAT, various inputs are required. These include: Soil data, Digital Elevation Model (DEM), land-use data, weather data (rainfall and temperature), stream network layers and stream discharge data.SUFI-2 is the algorithm for calibration of SWAT model which can provide the widest marginal parameter uncertainty intervals of model parameters among the five approaches. The base of the hydrologic cycle simulation in SWAT is the water balance equation:	consist of homogeneous land use, management, and soil characteristics.	sub-basins. Generally, it is found that surface runoff is not significantly impacted by having larger and less sub-basins. Additionally, SWAT incorrectly models infiltration into aquifers in hard rock areas by assuming unlimited capacity for water infiltration.

		$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} + Q_{surf} - E_a - w_{seep} - Q_{gw})$ where, S_{Wt} is the final soil water content (mm), S_{W0} is initial soil water content on day i (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm) Q_{gw} is the amount of return flow on day i (mm).		

		The goodness of fit in SUFI-2 is quantified by the coefficient of determination (R^2) and Nash-Sutcliffe (NS) coefficient between the observed data and the best simulation. The r-factor and the average thickness of the 95PPU band (*r*) are calculated by equations: $$\bar{r} = \frac{1}{n}\sum_{t_i}^{n}\left(y^M_{t_i,97.5\%} - y^M_{t_i,2.5\%}\right)$$ $$r - factor = \frac{p - foctor}{\sigma_{obs}}$$ where the bracketed equation above represents the upper and lower boundaries of the 95PPU, and σ_{obs} is the standard deviation of the measured data.		

Model	Author	Model Description and Governing Equation or Model Equation	Functionality of the Model	Limitations of the Model
(LRM) linear regression model with only one predictor	Irving et al. (2018)	For use in ecological predictive modeling, this study creates a much-needed dataset of hydrological variables. large scale hydrological data at high spatiotemporal resolutions are in high demand to be used as input in models such as species distribution models.Such data should be either widely available or easy to reproduce. Streamflow for entire stream networks can be estimated using a linear regression model with only one predictor:the accumulativeprecipitation in the upper sub-catchment.While there are several other relevant processes influencing discharge (e.g. infiltration,groundwater storage, evapotranspiration, etc.), adding further predictors significantly increases computation time and model complexity,particularly if	Open and near global data sources were chosen so that the modeling framework can be easily applied globally at any scale,	Lower prediction accuracy is inevitably as a simple model is applied over a large scale and fine resolution, as it does not take into account important anthropogenicnatural Influences (e.g. water abstraction and river management such as dams). Another limitation is that the conditions where most of the discharge aredriven by precipitation is the assumption guiding theestimation of the dailystream flow values.

		models are of large scale and high spatiotemporal resolution. Extraction of the daily streamflow data from the gauging sites on a day by day basis for the entire study area was the first step in the modeling process. (i.e. first day of January). The response variable input for the model of that specific day is the discharge data available for the same day in all the gauging sites.The streamflow for that particular day only was estimated by performing a linear model. In other words, the discharge is predicted on a daily basis for all of the study area.The resulting weighted linear regression (LMWW) is described in equation below: Qs = ∑ s = 1 n W s (Q s − a − β x s) 2		Hence, of necessity is the awareness of the user in knowing the hydrological processes driving the streams within the study region of interest, such as the influence of groundwater and soil infiltration processes. The results of applying the model during extreme events and in headwaters should also be validated by the user. From the preliminary analysis it was noted thatthe models when applied within the alpine regionperformed least

		where, Q_s is the discharge, W is the weight at the sth gauging site, x is the predictor, α is the intercept and β is the slope of the model. The calculated weights differed daily as the configuration of gauges with stream flow data varied daily. To test for any difference between the root mean square error (RMSE) values of the training and testing datasets, Wilcoxon tests were applied, this helps to validate the newly-developed dataset The RMSE which is a measurement of the model's predictive ability, is an absolute measure of fit, computed throughthe comparison of the observed		well, although they worked very well when applied in lowland regions.

		and predicted streamflow values from corresponding sites as shown below **R M S E = ∑ i = 1 n (y$_{obs}$, i − y$_{sim}$, I) 2 n** where n is the number of sites, $y_{obs,i}$ is the observed discharge value at the *ith* site and $y_{sim,i}$ is the simulated discharge at the *ith* site. The lack of significant differences between the RMSE values of the training and testing datasets is an indication of good model performance.		

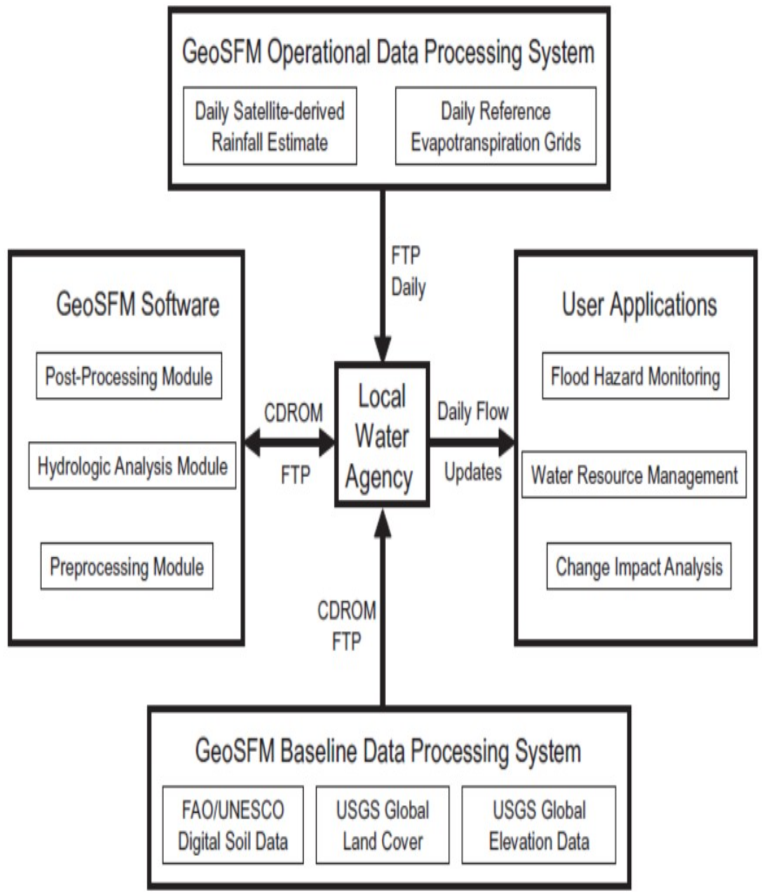
Model	Author	Model Description and Governing Equation or Model Equation	Functionality of the Model	Limitations of the Model
(PRMS) Precipitation Runoff Modeling System	Malone (2014).	Precipitation Runoff Modeling System (PRMS) was selected as the hydrologic modeling system for this study. PRMS is a deterministic, physical-process modeling system and is used to simulate streamflow in both urban and rural watersheds. The model uses computational modules representing hydrologic system components and is defined by one or more system of equations. PRMS has two modeling modes, and can function as either a lumped-parameter or distributed-parameter model. Lumped-parameter mode was used for this study. Watersheds are partitioned into parcels	Development of hydrologic model to validate streamflow estimates for sub-watersheds lacking a significant period of record is the functionality of Precipitation Runoff Modeling System (PRMS).	Spatial scale disparity between the two sub-watersheds, which translates into parameter error for the SCS is the primary limitation of Precipitation Runoff Modeling System (PRMS). The spatial difference directly translates into a temporal difference as well. Travel time for water to reach the stream gauge is likely significantly less in the

		of homogeneous hydrologic response based on watershed characteristics such as soil type, slope, percent impervious surface, vegetation type and density, and aspect. These parcels are called Hydraulic Response Units (HRUs). Both energy and water balance are calculated for each HRU for the time step chosen (e.g. daily). Vegetation catching precipitation before it is able to reach the ground is known as interception. It is therefore reasonable for it to be a function of storage available and cover density for the type of vegetation present. Equation below shows how cover density relates to precipitation received on an HRU. **PTN = [PPT * (1. – COVDN)] + (PTF * COVDN)**		smaller sub-watershed. While attempts to minimize limitations and error were made and until further research is made into the scientific validity of the methods involved, the results of this study and future results using the procedure applied should be taken only as supplemental information

		PTF is calculated in the following series of equations: PTF = PPT – (STOR – XIN) for PPT > (STOR – XIN) PTF = 0 for PPT ≤ (STOR – XIN) Evapotranspiration is the vaporization of soil moisture by vegetation, or the summation of transpiration and evaporation. Three methods available in the potential evapotranspiration subroutine are described below. The first method available is an equation based of pan-evaporation data. PET = EPAN * EVC		

		The second method available is a set of equations based on daily mean temperature $$PET = CTS * DYL^2 * VDSAT$$ $$VDSAT = 216.7 * \frac{VPSAT}{TAVC+273.3}$$ $$VPSAT = 6.180 * EXP\,[17.26939 * \frac{TAVC}{TAVC+273.3}]$$ The third method available is a set of equations also based on daily mean temperature $$PET = CTS * (TAVF\text{-}CTX) * RIN\ (13)$$ $$CTX = 27.5 - 0.25 * (e_2 - e_1) - (\frac{E2}{1000}])$$ $$CTS = [C1 + (13.0 * CH)]^{-1}$$ $$CH = (\frac{50}{e2 - e1})$$		

Model	Author	Model Description and Governing Equation or Model Equation	Functionality of the Model	Limitations of the Model
(GSM) Geospatial Streamflow Modeling	Asante et al., (2008)	Geospatial streamflow modeling system is parameterized with global terrain, soils and land cover data and run operationally with satellite-derived precipitation and evapotranspiration datasets. Water is transferred by simple linear methods through the subsurface, overland and river flow phases, and standard deviations are used to express the resulting flows from mean annual flow. **Geospatial streamflow modeling system** comprises a baseline parameterization service, the stand-alone Geospatial Streamflow Model (GeoSFM) software and an operational data processingservice supporting end user applications as shown in below.	For rapid characterization of the relative magnitude of seasonal flow changes and flood hazards in data sparsesettings, geospatial streamflow modeling is valuable.	The absolute magnitude of flow cannot be predicted by the uncalibrated model, although it can quantify flow anomalies in terms of relative departures from mean flow.

		 Components of the Geospatial Streamflow Modeling System.		

		An extension of the ArcView Geographic Information System (GIS) software is the GeoSFM software which is a semi-distributed hydrologic model. It contains a hydrologic routing module and a contains GIS-based preprocessing and post-processing modules which uses dynamically linked libraries (DLLs) which is created in a mixed-programming environment, performing time series manipulation and hydrologic computations. The modeling system was developed by the U.S. Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS), where the operational data services are maintained. A terrain analysis undertaken to subdivide the study area into river modeling and catchments units is the first pre-processing step, which also extract terrain-dependent parameters from a Digital Elevation Model (DEM). The parameterization of the hydrologic modeling units delineated in the first pre-processing step is the second pre-processing task in the GeoSFM model. There is an aggregation of the terrain analysis		

		parameters to obtain a single value of each parameter for each catchment. The operational data processing system also produces and distributes a daily reference evapotranspiration (ETo) dataset with global coverage $$ET_0 = \sum_{t=1}^{24} \left(\frac{1}{(\Delta + \gamma(1 + 0.34u_2))} \right) * \left[(0.408\Delta (R_n - G)) + \left(\frac{37\gamma u_2 (e_s - e_a)}{(T + 273)} \right) \right]$$ where ET_o is the reference evapotranspiration [mm day−1]. The change in soil moisture storage in each catchment is computed from the continuity equation for each daily time step.		

		The continuity equation is given below: $\frac{\Delta S_j^i}{\Delta t} = P_j^i - E_j^i - R_j^i - \|G_j^i$ A linear reservoir with residence time governs the rate of percolation to deep ground water computed as the total soil depth divided by the saturated hydraulic conductivity as shown in equation below: $G_j^i = S_j^i \cdot \frac{Ks_j}{SDEPTH_j} \cdot \exp\left(-\frac{Ks_j}{SDEPTH_j}\right)$ where, G_j^i is the percolation for each day in mm at time *i*, Ks_j is the saturated hydraulic conductivity in mm/day, $SDEPTH_j$ is the soil depth in mm.		

		By using partial contributing areas, runoff is generated as given by equation: $$R^i_j = P^i_j \cdot f\left(\frac{S^i_j}{SMAX_j}\right)$$ Runoff from the water balance to the catchment outlet is route by unit hydrograph where it enters the next downstream river reach as shown in equation: $$q^i_j = 0.001 \cdot A_j R^i_j * \sum_{i=1}^{m} U_j$$ where $q^i_j$is the overland flow in m^3/s arriving at the catchmentoutlet *j* at time *i*, $U_j$is the dimensionless unit hydrograph for catchment *j*, $A_j$is the surface area of the runoff generating unit in m^2, and $*$is the convolution integral. The computation of the distribution of inflow, at the upstream end of each river reach, that arrives at the		

		downstream end of the same reach, is by using the diffusion analog equation: $$h_j(t) = \frac{x_j}{\sqrt{4\pi D_j t^3}} \cdot \exp\left[-\frac{(x_j - v_j t)^2}{4D_j t}\right]$$ where, $h_j(t)$ is the fraction of inflow arriving at the downstream end of each river reach, $x_j$is the length of each river reach in m, $v_j$is the kinematic wave velocity in m/s, t is the time after input in seconds, $D_j$is the dispersion coefficient in m^2/s. At the downstream end of each river reach, the discharge is computed by convolving the diffusion analog response function as flow entering the upstream end, the next downstream river receives the discharge as inflow.		

		The discharge is calculated with the formula: $$Q_j^i = h_j(t) * \sum_{k=1}^{n} q_k^i$$ where, Q_j^i is the discharge arriving at the outlet of river reach *j* inm^3/s, *n* is the number of river reaches immediately upstream of reach *j*, q_k^i is the inflow from each river entering the upstream endof reach *j* in m^3/s, $*$is the convolution integral.		

Model	Author	Model Description and Governing Equation or Model Equation	Functionality of the Model	Limitations of the Model
Design models and Operation, and Management Models for Reservoirs	Singh and Cruise (1990).	Probability distributions of flood peaks have been derived in many ways. The probability distribution of the associated flood volumes are derived by using the peak discharge-duration joint distribution. Cross-entropy with tractile constraints is used is derive the distribution of inter-arrival times of flood peaks. Using the power transformation, the probability distributions of flood peak and flood duration were determined. The data is rendered normally distributed by the transformation. If x is a flood variable (peak or duration) and y is its transformed value, then	The fact that a model derived in this way would be applicable at lower thresholds than most current modelsis the major advantage of this approach. Operators can utilize the model to derive reservoir rule curves which can be used to estimate the risk associated with their actions. .	

		$y = \frac{x^{\lambda} - 1}{\lambda}, \lambda \neq 0$ and $y = \log x, \lambda = 0$ where x is a constant of transformation. with its probability density function (pdf) expressed as: $f(y) = \frac{1}{s\sqrt{2\pi}} \exp\left[\frac{-(y - \bar{y})^2}{2s^2}\right], y \geq 0$ the probability distribution of the flood variable (peak or duration) will be approximately normal. where, s is the standard deviation of y, and y is the mean of y, and f(y) is pdf of y.		

		The cumulative distribution function (cdf) or non-exceedance probability, F(y), is $$F(y) = \frac{1}{s\sqrt{2\pi}} \int_0^{\infty} \exp\left[-\frac{(y-\bar{y})^2}{2s^2}\right] dy$$ The flood duration is correlated with the flood peak and flood volume as the flood hydrograph is assumed to be a triangular hydrograph. This being so, the volume under the hydrograph is given by and the probability density function would be approximated by $$V_S = \frac{Q_S D_S}{2}$$ And the probability density functions are approximated by $$f(V_S) = f(Q_S, D_S)$$ where f(Qs ,Ds) is the joint distribution of peak and duration.		

Model	**Author**	**Model Description and Governing Equation or Model Equation**	**Functionality of the Model**	**Limitations of the Model**
Linear Fit Model	Yangand Liu (2011)	The impact of climate change on streamflow in the Yellow River basin (YRB), China was investigated. By the Mann–Kendall method and a linear fit model, the temporal trends of streamflow were explored, and the relationships between precipitation, streamflow, and potential evapotranspiration (ET_p) were investigated. precipitation, by Budyko's method and a simple water balance model, the contribution of climate changes to streamflow was revealed. Monthly ET_p was calculated with monthly data of hours of sunlight, wind speed, relative humidity, and average air temperature by the Penman equation which		

		captures optimally the dynamics in evaporative demand given climatic changes and land surface. $$\mathrm{ET}_p = \mathrm{ET}_{pR} + \mathrm{ET}_{pA} = \frac{\Delta}{\Delta+\gamma} R_n + \frac{\gamma}{\Delta+\gamma} \frac{6430(1+0.536u_2)D}{\lambda}$$ where, ET_p is the potential evapotranspiration (mm day^{-1}); ET_{pA} and ET_{pR} represent the aerodynamic and radiative components of the Penman equation, respectively; Δ is the slope of the saturation vapor pressure curve (Pa K^{-1}); R_n is the daily net radiation (mm day^{-1}); γ is the psychrometric constant (Pa K^{-1}); λ is the latent heat of vaporization of water (2.45×10^6 J kg^{-1}).		

		D is the vapor pressure deficit (Pa); u_2 is the daily average wind speed at 2 m height (m s^{-1}); The proportional change in streamflow, Q, resulting from a change in a climatic variable such as precipitation, P *is known as the* Climate elasticity of streamflow. Thus precipitation elasticity of streamflow is defined as $$\varepsilon_p(P,Q) = \frac{dQ/Q}{dP/P} = \frac{dQ}{dP}\frac{P}{Q}$$ At the basin scale, the water balance can be expressed as follows: $$P = \mathrm{ET}_a + Q + \Delta S$$ where, P is precipitation, ET_a is actual evapotranspiration, Q is streamflow, ΔS is change of basin water storage.		

		The changes of basin water storage can be neglected over a long period, In conclusion hydrological processes, controlled by interactions between vegetation, soil and climate, are reflected in changes of streamflow. The most important meteorological variables influencing the changes of streamflow are ET_p and precipitation, and the key issue for understanding the response of hydrological processes to climate changes at the basin scale is the partitioning of precipitation into ET_a and streamflow.		

Model	Author	Model Description and Governing Equation or Model Equation	Functionality of the Model	Limitations of the Model
(DGM) Digital Elevation Model	Gesch, (2018): Kroll et al., 2004	For global assessments, continental, or regional several digital elevation models (DEMs) are available for the required topographic information to project potential impacts of increased coastal water levels, whether a probabilistic model is employed, a more complex process-based or simple inundation model is used. The vertical accuracy of the DEM can be used to report assessment results with the uncertainty stated in terms of a specific confidence level or likelihood category, properly characterized. To quantify their inherent vertical uncertainty to demonstrate how accuracy information should be considered for a coastal flooding assessment		the main source of vertical uncertainty in elevation-based assessments is Digital Elevation Model Error, but the datum transformations required to bring the DEM into a tidal datum reference framework can also contribute to the error.

		or when planning and implementing a SLR, an accuracy evaluation has been conducted of global DEMs. Any coastal flooding assessment or elevation-based SLR that uses a DEM, whether a more complex hydraulic model or a simple bathtub model is employed, raises the water level on a geospatial dataset that represents the topography of the study area. Such a process is essentially an elevation contouring process whereby there is the derivation of a line of constant elevation (at the selected water level increase) from the spatial arrangement of individual elevation values at discrete locations (usually in a regular grid in the case of a raster DEM). Elevations determined from the map on 9 out of 10 points, from the map user perspective, will have true elevations that are within one-half of		

		the contour interval (CI). The contour accuracy standard is expressed in the following equation: $\mathrm{VMAS} = \mathrm{LE90} = \frac{\mathrm{CI}}{2}$ Rearranging this simple equation as $\mathrm{CI} = \mathrm{LE90} \times 2$ To illustrate as an example, from airborne lidar data, a DEM with an RMSE of 0.15 m derived. Assuming the errors are normally distributed and unbiased, the RMSE can be converted to LE95 by the following formula: LE95 = RMSE × 1.96 and $SLRI_{min}$ at 68% confidence is $SLRImin68$ = RMSE × 2		

Model	Author	Model Description and Governing Equation or Model Equation	Functionality of the Model	Limitations of the Model
(GWLF) General Watershed Loading Function Watershed Model	Li, Xuyong, et al., (2010)	Streamflow and the loads of sediment, nitrogen and phosphorus are predicted by General Watershed Loading Function (GWLF) watershed model, which is a lumped parameter watershed model. GWLF uses runoff predictions from the curve number (CN) method, average nutrient concentrations based on land use and the Universal Soil Loss Equation (USLE). At each calibration site, model parameters were first estimated by multi-objective optimization, and then finalized by weighted averaging the parameter values across sites.Using a number of empirical equations, the GWLF model calculates nutrient loads. InGWLF computations all nutrients are either dissolved or solid-phase, and the sums of		

		solid and dissolved forms are the total N or P. Monthly N discharge is calculated as: $$N_d = N_{dp} + N_{dr} + N_{dg} + N_{du}$$ $$N_s = N_{sp} + N_{sr} + N_{su}$$ The GWLF monthly nitrogen load from urban runoff is calculated as: $$N_{su} = \sum_k \sum_{t=1}^{m} W_{kt} \cdot A_k$$ where, m is number of days in the month; A_k is area (ha) of source area k. W_{kt} is a first-order wash off function: $$W_{kt} = 1 - e^{-1.81 \cdot Q_{kt}}$$ where Q_{kt} is runoff (cm) from source area k on day t.		

		The monthly groundwater nitrogen discharge to the stream is calculated as: $$N_{dg} = 0.1 \cdot C_g \cdot A \cdot \sum_{t=1}^{m} G_t$$ where, Cg is the nitrogen concentration in groundwater A is area (ha) of source area k m is the number of days in the month Gt is groundwater discharge (cm) to the stream on day t.		

CHAPTER THREE

3.0 METHODOLOGY

3.1 Method of Streamflow Regression Modelling

The investigation of the relationship of two variables such as stage and discharge usually begins with an attempt to discover the approximate form of the relationship by graphing the data as points in the x, y plane. Such a graph is called a scatter diagram. By means of it, one can quickly discern whether there is any pronounced relationship and if so, whether the relationship may be treated as approximately linear, exponential, power, parabolic etc. The relationship between stage (m) and the corresponding discharge (m^3/s) is an exponential function. Strong nonlinear bivariate and multivariate correlations are common in hydrology and various mathematical models are used to describe the relationships, such as parabolic, exponential, hyperbolic, power, and other forms that provide better graphical fits than straight lines.

The regression modelling offers a simple approach to model construction via curve fitting of field data. In case of streamflow regression modeling, stage (flow depth) was chosen as independent variable, while flow rate (river discharge), was chosen as dependent variable, as the independent variables are those variables that are easy and cheap to determine relative to the dependent variables (Nwaogazie & Okah, 2003). Least square regression modeling which is a statistical curve fitting procedure helps to study those changes in the value of dependable variable (e.g. discharge) which are resulted by the changes in the values of the independent variable (e.g. stage) or in other words, one regresses the dependent variable on the independent variable. In studying the relationship between two or more variables such as stage and discharge in the hope that the relationship that is found can be used to assist in making estimates or predictions of a particular one of the variables, least square regression method is used to select the line that fits the data best. It helps to obtain some reasonable good estimate of the regression coefficients (a and b), as such values help the most in studying the regression variable (e.g. discharge) as affected by the independent variable (e.g. stage).

In this study, regression modeling was adopted to fit historic streamflow data of Cross River, River Niger, Owena River, Owan River, Ikpoba River, Ossiomo River and Imo River. The approach was to utilize the original data in model calibration and using model verification, coefficient of determination, coefficient of correlation, Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias, root mean square error or standard error of estimate and mean of residue or mean absolute erroras model performance measures and evaluation parameters for good curve fitting.

3.2 Mathematical Representation of the Relationship between Stage and Discharge

The width of the river can be expressed as a power function of the depth of flow. The mathematical representation of the relationship between the stage (h) and the corresponding discharge (Q) is Equation 3.1

$$Q = k\,h^{b} \qquad (3.1)$$

where,

k and b are constants which are dimensionless scale and shape parameters for any streamflow gauging station.

h = gauge height or stage

Q = discharge or flow rate

The relationship in Equation 3.1 is a power-model which covers a variety of idealized channel forms such as rectangular, elliptical, triangular and funnel-shaped types. In this research work, least square regression method which is a statistical curve fitting procedure yielded line of best fit for each of the streamflow modelling.

3.3 Study Areas and Materials

Cross River, River Niger, Owena River, Owan River, Ikpoba River, Ossiomo River and Imo River constitute the study areas. The major materials used for this work are streamflow data showing stages (water heights) and discharges (flow rates) of Cross River at Afikpo North L.G.A. streamflow gauging station,River Niger at Lokoja and Onitsha streamflow gauging stations, Owena River at Owena village streamflow gauging station, Owan River at Owan village streamflow gauging station, Ikpoba River at Benin city streamflow gauging station, Ossiomo River at Abudu streamflow gauging station and four streamflow gauging stations along Imo River. These seven rivers were chosen for this study because of their size, data availability and potential in supporting industrial, agricultural and domestic uses if fully developed in meeting the ever-growing population in the Southern Nigeria.

3.3.1 Data Collection and Treatment

The hydrological stations established by the Federal Ministry of Water Resources Abuja at Lokoja and Onitsha along River Niger and Afikpo North along Cross River were used as monitoring stations for generating data used herein. The hydrological stations established by the Benin-Owena River Basin Development Authority along Owena River, Owan River, Ikpoba River and Ossiomo River were also used as monitoring stations for generating data used herein. Also the hydrological stations established by the Anambra Imo River Basin Development Authority at Umuna, Obigbo, Umuopara and Ndimoko, along Imo River system were also used as monitoring stations for generating data used herein.

The data treatment and arrangement involved sorting the data according to years (the earliest to the latest), stages and discharges. The stages and discharges are the maximum values in each year. These values are shown in Tables 3.1 to 3.5. The tables will provide data needed for the formulation of the models.

Table 3.1: Annual maximum streamflow data of Cross River at Afikpo North L.G.A. gauging station for the period 1987 - 2016

S/N	Year	Annual maximum stage (h) (m)	Annual maximum discharge (Q) (m^3/s)
1	1987	8.67	10,150.60
2	1988	9.41	12,512.00
3	1989	9.53	12,896.00
4	1990	9.19	11,808.00
5	1991	9.29	12,128.00
6	1992	9.54	12,944.00
7	1993	9.69	13,484.00
8	1994	8.40	9,328.00
9	1995	8.13	8,566.00
10	1996	7.92	7,995.20
11	1997	9.37	12,384.00
12	1998	8.79	10,532.20
13	1999	9.69	13,484.00
14	2000	8.40	9,328.00
15	2001	8.13	8,566.60
16	2002	7.92	7,995.20
17	2003	9.37	12,384.00
18	2004	8.79	10,532.20
19	2005	8.67	10,150.60
20	2006	9.41	12,512.00
21	2007	9.53	12,896.00
22	2008	9.19	11,808.00
23	2009	8.67	10,150.60
24	2010	9.41	12,512.00
25	2011	9.63	13.196.00
26	2012	9.19	11,808.00
27	2013	9.29	12,128.00
28	2014	9.61	13,196.00
29	2015	9.69	13,484.00
30	2016	9.61	13,196.00
31	2017	9.69	13,484.00

Source: Federal Ministry of Water Resources, Abuja (2018)

Table 3.2: Annual maximum streamflow measurements of River Niger at Lokoja gauging station for the period 1998 –2011 and 2013 – 2014

S/N	Year	Annual maximum stage (h) (m)	Annual maximum discharge (Q) (m^3/s)
1	1998	10.5	23,265.66
2	1999	10.36	22,827.27
3	2000	8.99	18,266.00
4	2001	9.13	18,742.00
5	2002	8.72	17,359.33
6	2003	10.11	22,296.60
7	2004	8.36	16,124.00
8	2005	7.66	13,846.00
9	2006	9.55	20,170.00
10	2007	9.33	19,422.00
11	2008	9.3	19,328.50
12	2009	9.95	21,530.00
13	2010	9.79	20,986.00
14	2011	8.56	16,794.08
15	2013	8.45	16,430.00
16	2014	9.40	19,595.26

Source: Federal Ministry of Water Resources, Abuja (2017)

Table 3.3: Annual maximum streamflow measurements of River Niger at Onitsha streamflow gauging station for the period 1980 – 1995 and 2000 – 2001

S/N	Year	Annual maximum stage h (m)	Annual maximum discharge (Q.) (m^3/s)
1	1980	11.19	17,840.15
2	1981	11.51	18,815.33
3	1982	9.43	13,018.67
4	1983	9.06	12,078.92
5	1984	8.80	11,494.75
6	1985	11.19	17,880.89
7	1986	10.14	14,725.93
8	1987	9.66	13,566.49
8	1988	11.05	17,480.00
10	1989	11.18	17,773.33
11	1990	10.35	15,410.80
12	1991	11.29	18,159.08
13	1995	10.91	17,025.82
14	2000	10.76	16,629.33
15	2001	10.87	16,943.85

Source: Federal Ministry of Water Resources Abuja (2020)

Table 3.4: Annual maximum streamflow data of Owena, Owan, Ikpoba and Ossiomo Rivers at their various streamflow gauging station

S/n	Year	Owena River at Owena village streamflow gauging station, Edo State		Owan River at Owan village streamflow gauging station, Edo State		Ikpoba River at Benin City streamflow gauging station in Edo State		Ossiomo River at Abudu streamflow gauging station in Edo State	
		Annual maximum stage (h) (m)	Annual maximum discharge (Q) (m^3/s)	Annual maximum stage (h) (m)	Annual maximum discharge (Q) (m^3/s)	Annual maximum stage (h) (m)	Annual maximum discharge (Q) (m^3/s)	Annual maximum stage (h) (m)	Annual maximum discharge (Q) (m^3/s)
1	1989	1.50	19.0	4.90	36.0	2.16	20.25	2.65	95.0
2	1990	1.28	12.4	4.55	33.4	2.86	36.80	1.92	41.8
3	1991	2.75	105.0	5.64	43.2	3.50	55.00	3.08	138.0
4	1992	2.43	66.6	4.74	34.8	2.90	38.00	2.95	125.0
5	1993	2.10	50.0	4.07	28.7	2.93	38.60	2.50	80.0
6	1994	2.11	50.6	5.47	42.0	3.30	50.0	2.47	77.7
7	1995	2.31	53.9	5.89	46.0	3.38	51.2	2.66	95.8
8	1996	2.80	110.0	5.94	46.5	2.87	36.9	2.65	94.7
9	1997	1.62	23.8	4.25	30.5	2.34	24.2	2.65	94.7
10	1998	2.25	60.0	4.28	30.8	2.35	24.4	2.35	70.1
11	1999	1.65	25.3	4.90	36.0	4.15	65.4	2.49	81.1
12	2000	1.99	43.2	5.04	38.5	4.07	65.1	2.55	86.3

Source: Benin-Owena River Basin Development Authority (2000)

Table 3.5: Annual maximum streamflow data of Imo River at the various streamflow gauging stations

Year	Imo River at Ndimoko streamflow gauging station in Imo State		Imo River at Umuna streamflow gauging station in Imo State		Imo River at Umuopara streamflow gauging station in Abia State		Imo River at Obigbo streamflow gauging station in River State	
	Annual maximum stage (h) at Ndimoko (m)	Annual maximum discharge (Q) at Ndimoko (m^3/s)	Annual maximum stage (h) at Umuna (m)	Annual maximum discharge (Q) at Umuna (m^3/s)	Annual maximum stage (h) at Umuopara (m)	Annual maximum discharge (Q) at Umuopara (m^3/s)	Annual maximum stage (h) at Obigbo (m)	Annual maximum discharge (Q) at Obigbo (m^3/s)
1978	3.02	25.00	4.48	77.50	5.66	270.00	2.06	246.00
1979	2.59	18.20	4.59	80.00	4.54	158.40	1.97	232.00
1980	3.30	27.50	4.84	96.00	3.95	118.00	2.14	261.50
1981	3.14	24.40	3.97	62.40	6.23	258.28	1.90	220.00
1982	3.16	22.20	1.99	17.00	4.75	187.50	1.91	240.80
1983	3.14	24.50	4.62	81.60	5.53	223.00	2.23	263.89
1984	3.00	22.84	4.18	68.40	3.22	126.20	1.54	176.40
1985	2.95	22.28	4.71	84.60	4.83	194.40	2.29	286.20
1986	2.79	20.49	4.87	89.10	3.00	115.00	1.75	200.00
1987	3.56	29.51	4.63	80.40	5.19	223.20	1.92	223.20
1988	3.52	29.02	4.89	89.70	1.32	42.85	2.40	306.80

Source: Anambra-Imo River Basin Development Authority (1989)

3.3.2 Data Cleaning

The second stage of the data treatment is data cleaning which includes checking the data for consistency and treatment for missing value. In consistency check, data which are not consistent or outlines are looked for. Such data are either discarded or replaced by the mean value. Treatment for missing values is carried out by the extension of streamflow records.

3.3.2.1 Consistency Test on the Streamflow Data of the Selected Rivers

Consistency tests on the streamflow data of the selected rivers are carried out using descriptive statistics of the data analysis tool of the computer as shown in Tables 3.6 through 3.16. Statistically, standard deviation, coefficient of standard deviation, sample variance, coefficient of variation, skewness, coefficient of skewness and kurtosis are used as measures of spread and data consistency (Kothari & Garg, 2014). These values are considered satisfactory in this work.

Table 3.6: Descriptive statistics of Cross River at Afikpo streamflow gauging station

	Observed (Measured) Annual Maximum Stage	Observed (Measured) Annual Maximum Discharge
Mean	9.090967742	11533.52258
Standard Error	0.102014499	318.9067814
Median	9.29	12128
Mode	9.69	13484
Standard Deviation	0.567992693	1775.597812
Sample Variance	0.322615699	3152747.591
Kurtosis	-0.610386463	-0.766396077
Skewness	-0.818393064	-0.740858146
Range	1.77	5488.8
Minimum	7.92	7995.2
Maximum	9.69	13484
Sum	281.82	357539.2
Count	31	31

Coefficient of variation (C_v) is a dimensionless dispersion parameter and is equal to the ratio of standard deviation to the mean.

Coefficient of variation (C_v) for the stage = $\frac{0.567992693}{9.090967742} = 0.06$

Coefficient of variation (C_v) for the discharge = $\frac{1775.597812}{11533.52258} = 0.15$

Coefficient of skewness (C_s) is a measure of the degree of skewness of the distribution. Coefficient of skewness has limits ±3. For positive skewness, $0 < C_S < 3$ and for negative skewness $-3 < C_S < 0$ (Kothari & Garg, 2014). Smaller values of coefficient of skewness (C_s) implies more closeness of the distribution to the normal distribution, because $C_s = 0$ for a normal distribution.

Coefficient of skewness (C_s) for the stage = $\frac{3(9.090967742 \quad 9.29)}{0.567992693} = -1.05$

Coefficient of skewness (C_s) for the discharge = $\frac{3(11533.52258 - 12128)}{1775.597812}$

$$= -1.00$$

Table 3.7: Descriptive statistics of River Niger at Lokoja streamflow gauging station

	Observed Annual Maximum Stage	Observed Annual Maximum Discharge
Mean	9.26	19186.41875
Standard Error	0.196158949	661.7933686
Median	9.315	19375.25
Standard Deviation	0.784635797	2647.173474
Sample Variance	0.615653333	7007527.404
Kurtosis	-0.387674074	-0.479600021
Skewness	-0.240072477	-0.232753136
Range	2.84	9419.66
Minimum	7.66	13846
Maximum	10.5	23265.66
Sum	148.16	306982.7
Count	16	16

Coefficient of variation (C_v) for the stage = $\frac{0.78}{9.26} = 0.08$

Coefficient of variation (C_v) for the discharge = $\frac{2647.17}{19186.42} = 0.14$

Coefficient of skewness (C_s) for the stage = $\frac{3(9.26 - 9.32)}{0.78} = -0.23$

Coefficient of skewness (C_s) for the discharge = $\frac{3(19186.42 - 19375.25)}{2647.17}$

$$= -0.21$$

Table 3.8: Descriptive statistics of River Niger at Onitsha streamflow gauging station

	Observed Annual Maximum Stage	Observed Annual Maximum Discharge
Mean	10.49	15922.89
Standard Error	0.226	615.4735
Median	10.87	16943.85
Standard Deviation	0.874	2383.718
Sample Variance	0.764	5682114
Kurtosis	-0.662	-0.87432
Skewness	-0.831	-0.73172
Range	2.71	7320.58
Minimum	8.8	11494.75
Maximum	11.51	18815.33
Sum	157.4	238843.3
Count	15	15

Coefficient of variation (C_v) for the stage $= \frac{0.87}{10.49} = 0.08$

Coefficient of variation (C_v) for the discharge $= \frac{2383.72}{15922.89} = 0.15$

Coefficient of skewness (C_s) for the stage $= \frac{3(10.49 - 10.87)}{0.87} = -1.31$

Coefficient of skewness (C_s) for the discharge $= \frac{3(15922.89 - 16943.85)}{2383.72}$

$$= -1.28$$

Table 3.9: Descriptive statistics of Owena River at Owena village streamflow gauging station

	Observed Annual Maximum stage	Observed Annual Maximum Discharge
Mean	2.058333333	51.65
Standard Error	0.137437773	9.003782875
Median	2.105	50.3
Standard Deviation	0.476098411	31.1900188
Sample Variance	0.226669697	972.8172727
Kurtosis	-0.745513905	0.020472677
Skewness	-0.013941119	0.786189813
Range	1.52	97.6
Minimum	1.28	12.4
Maximum	2.8	110
Sum	24.7	619.8
Count	12	12

Coefficient of variation (C_v) for the stage $= \frac{0.48}{2.06} = 0.23$

Coefficient of variation (C_v) for the discharge $= \frac{31.19}{51.65} = 0.60$

Coefficient of skewness (C_s) for the stage $= \frac{3(2.06 - 2.105)}{0.48} = -0.29$

Coefficient of skewness (C_s) for the discharge $= \frac{3(51.65-5\ \ .3)}{31.19} = 0.13$

Table 3.10: Descriptive statistics of Owan River at Owan village streamflow gauging station

	Observed Annual Maximum stage	Observed Annual Maximum Discharge
Mean	4.9725	37.195
Standard Error	0.185346216	1.754207712
Median	4.9	36
Mode	4.9	36
Standard Deviation	0.642058125	6.076753769
Sample Variance	0.412238636	36.92693636
Kurtosis	-1.209548603	-1.203491669
Skewness	0.233183109	0.276758586
Range	1.87	17.8
Minimum	4.07	28.7
Maximum	5.94	46.5
Sum	59.67	446.34
Count	12	12

Coefficient of variation (C_v) for the stage $= \frac{0.64}{4.97} = 0.13$

Coefficient of variation (C_v) for the discharge $= \frac{6.08}{37.20} = 0.16$

Coefficient of skewness (C_s) for the stage $= \frac{3(4.97 - 4.9)}{0.64} = 0.34$

Coefficient of skewness (C_s) for the discharge $= \frac{3(37.20-36)}{6.08} = 0.59$

Table 3.11 Descriptive statistics of Ikpoba River at Benin City streamflow gauging station

	Observed Annual Maximum Stage	Observed Annual Maximum Discharge
Mean	3.0675	42.15416667
Standard Error	0.184887865	4.419993565
Median	2.915	38.3
Standard Deviation	0.640470353	15.31130685
Sample Variance	0.410202273	234.4361174
Kurtosis	-0.607244896	-1.044575808
Skewness	0.363023298	0.172533769
Range	1.99	45.15
Minimum	2.16	20.25
Maximum	4.15	65.4
Sum	36.81	505.85
Count	12	12

Coefficient of variation (C_v) for the stage $= \frac{0.64}{3.07} = 0.21$

Coefficient of variation (C_v) for the discharge $= \frac{15.31}{42.15} = 0.36$

Coefficient of skewness (C_s) for the stage $= \frac{3(3.07 - 2.92)}{0.64} = 0.70$

Coefficient of skewness (C_s) for the discharge $= \frac{3(42.15-38.3)}{15.31} = 0.76$

Table 3.12: Descriptive statistics of Ossiomo River at Abudu village streamflow gauging station

	Observed Annual Maximum Stage	Observed Annual Maximum Discharge
Mean	2.576666667	90.01666667
Standard Error	0.083659966	7.121912764
Median	2.6	90.5
Mode	2.65	94.7
Standard Deviation	0.289806623	24.67102951
Sample Variance	0.083987879	608.659697
Kurtosis	2.055014666	1.24236509
Skewness	-0.519135265	0.219273118
Range	1.16	96.2
Minimum	1.92	41.8
Maximum	3.08	138
Sum	30.92	1080.2
Count	12	12

Coefficient of variation (C_v) for the stage $= \frac{0.29}{2.58} = 0.11$

Coefficient of variation (C_v) for the discharge $= \frac{24.67}{90.02} = 0.27$

Coefficient of skewness (C_s) for the stage $= \frac{3(2.58 - 2.6)}{0.29} = -0.24$

Coefficient of skewness (C_s) for the discharge $= \frac{3(90.02 - 90.5)}{24.67} = -0.06$

Table 3.13: Descriptive statistics of Imo River at Ndimoko streamflow gauging station

	Observed Annual Maximum Stage	Observed Annual Maximum Discharge
Mean	3.106363636	24.17636364
Standard Error	0.086836029	1.05478328
Median	3.14	24.4
Standard Deviation	0.288002525	3.498320376
Sample Variance	0.082945455	12.23824545
Kurtosis	-0.038198436	-0.526399287
Skewness	-0.017389881	0.063391578
Range	0.97	11.31
Minimum	2.59	18.2
Maximum	3.56	29.51
Sum	34.17	265.94
Count	11	11

Coefficient of variation (C_v) for the stage $= \frac{0.29}{3.11} = 0.09$

Coefficient of variation (C_v) for the discharge $= \frac{3.50}{24.18} = 0.14$

Coefficient of skewness (C_s) for the stage $= \frac{3(3.11 - 3.14)}{0.29} = -0.35$

Coefficient of skewness (C_s) for the discharge $= \frac{3(24.18 - 24.4)}{3.50} = -0.19$

Table 3.14: Descriptive statistics of Imo River at Umuna streamflow gauging station

	Observed Annual Maximum Stage	Observed Annual Maximum Discharge
Mean	4.342727273	75.15454545
Standard Error	0.250450833	6.479399013
Median	4.62	80.4
Standard Deviation	0.830651442	21.48973539
Sample Variance	0.689981818	461.8087273
Kurtosis	7.741573119	5.932882629
Skewness	-2.672789546	-2.251667907
Range	2.9	79
Minimum	1.99	17
Maximum	4.89	96
Sum	47.77	826.7
Count	11	11

Coefficient of variation (C_v) for the stage $= \frac{0.83}{4.34} = 0.19$

Coefficient of variation (C_v) for the discharge $= \frac{21.49}{75.15} = 0.29$

Coefficient of skewness (C_s) for the stage $= \frac{3(4.34 - 4.62)}{0.83} = -1.01$

Coefficient of skewness (C_s) for the discharge $= \frac{3(75.15 - 80.4)}{21.49} = -0.73$

Table 3.15: Descriptive statistics of Imo River at Umuopara streamflow gauging station

	Observed Annual Maximum Stage	Observed Annual Maximum Discharge
Mean	4.383636364	174.2572727
Standard Error	0.428558414	20.9075808
Median	4.75	187.5
Standard Deviation	1.421367459	69.34260077
Sample Variance	2.020285455	4808.396282
Kurtosis	0.779302013	-0.428981791
Skewness	-0.958282924	-0.387040246
Range	4.91	227.15
Minimum	1.32	42.85
Maximum	6.23	270
Sum	48.22	1916.83
Count	11	11

Coefficient of variation (C_v) for the stage $= \frac{1.42}{4.38} = 0.32$

Coefficient of variation (C_v) for the discharge $= \frac{69.34}{174.26} = 0.40$

Coefficient of skewness (C_s) for the stage $= \frac{3(4.38 - 4.75)}{1.42} = -0.78$

Coefficient of skewness (C_s) for the discharge $= \frac{3(174.26 - 187.5)}{69.34} = -0.57$

Table 3.16: Descriptive statistics of Imo River at Obigbo streamflow gauging station

	Observed Annual Maximum Stage	Observed Annual Maximum Discharge
Mean	2.01	241.5263636
Standard Error	0.074990909	11.29435678
Median	1.97	240.8
Standard Deviation	0.248716706	37.45914368
Sample Variance	0.06186	1403.187445
Kurtosis	-0.065779564	-0.084124784
Skewness	-0.240558029	0.050395961
Range	0.86	130.4
Minimum	1.54	176.4
Maximum	2.4	306.8
Sum	22.11	2656.79
Count	11	11

Coefficient of variation (C_v) for the stage $= \frac{0.248716706}{2.01} = 0.12$

Coefficient of variation (C_v) for the discharge $= \frac{37.45914368}{241.5263636} = 0.16$

Coefficient of skewness (C_s) for the stage $= \frac{3(2.01 - 1.97)}{0.248716706} = 0.48$

Coefficient of skewness (C_s) for the discharge $= \frac{3(241.5263636 - 240.8)}{37.45914368}$

$$= 0.06$$

Standard deviation along with several related measures like coefficient of standard deviation, variance, coefficient of variation etc. are used in research studies as a very satisfactory measure of dispersion in (scatteredness of) a series (Kothari & Garg, 2014).

3.3.2.2 Extension of Streamflow Records

Extension of streamflow records is possible by obtaining the stage–discharge relationship equation by linear regression and computer–based numerical analysis which is then used to extend the data. According to Ojha et al. (2009), methods of extension of streamflow records are:

(a) Double-mass curve method
(b) Correlation with catchment areas
(c) Regression analysis between the flows at base and index stations.

The streamflow data of the various streamflow gauging stations with missing data were extended as shown in the Appendix A.

3.4 Streamflow Data Analysis

Analysis is the ordering and structuring of data to produce knowledge. The streamflow (river stage and river discharge) data were analysed on annual times series basis using least square regression and correlation method. The following procedure is used in the streamflow data analysis in this project work:

i. The mathematical relationship which describes the inter-dependence of parameters in the system such as stage and discharge are first developed. These relationships are called *model*.
ii. The model is then calibrated by feeding the known stage-discharge record of the particular river and the numerical values of the various coefficients are found.
iii. The model is then tested by feeding another set of stage data for which the discharge data are known. This is known as *verification*.
iv. The model is now ready for the determination of the discharge (river flow) from water height (stage) on that river.

3.4.1 Methods of Analysis

Power model, polynomial model and ANOVA model for regression are employed in the streamflow modelling and curve fitting.

3.4.1.1 Power models

Power model which is used to fit streamflow data is of the form

$$Q = k\,h^{b} \qquad . \qquad . \qquad . \qquad . \qquad (3.1)$$

Using least square regression modelling, the constants k and b in Equation (3.1) can be evaluated. Microsoft Excel package offer automatic calibration, were by the regression constant are also obtained.

3.4.1.2 Polynomial models

Polynomial model which is also used to fit streamflow data may be of the forms

$$y = ax^3 + bx^2 - cx + d \qquad . \qquad . \qquad . \qquad . \qquad (3.2)$$

$$y = ax^3 + bx^2 - cx \qquad . \qquad . \qquad . \qquad . \qquad (3.3)$$

$$y = ax^2 - bx + d \qquad . \qquad . \qquad . \qquad . \qquad (3.4)$$

$$y = ax^2 - bx \qquad . \qquad . \qquad . \qquad . \qquad (3.5)$$

Equations 3.2 and 3.3 are third order polynomial equations while equations 3.4 and 3.5 are second order polynomial equations.

3.4.1.3 ANOVA model for regression

The ANOVA model is

$$x_{ij} = \mu_i + \epsilon_{ii} \qquad . \qquad . \qquad . \qquad . \qquad (3.6)$$

for $i = 1, \ldots, I$ and $j = 1, \ldots, n$. The standard deviation σ is the same in all the populations but the sample sizes *n*, may differ. The FIT part of ANOVA model are the *I* population means and are represented by μ_i. The residual or random variation part of the model is represented by the deviation $\in_{ii}$ of the observations from the means. The $\in_{ii}$ are assumed to be an simple random sample from an $N(0, \sigma)$ distribution. In the statistical model for ANOVA the unknown parameters are the population mean μ_i and the common population standard deviation σ. Computer software is usually used in ANOVA calculations and the ANOVA model uses linear regression equation.

3.5 Streamflow Model Calibration and Verification

In this project work, model calibration (training); that is, to estimate the model parameters and model verification which tests the model validity were carried out by the automatic calibration method of parameter optimization tool of Microsoft Excel Programme, as the use of modern software has cut down the stress of manual computations.

3.5.1 Streamflow Modelling of Cross River at Afikpo North L.G.A. gauging station

Thirty-one years' record of annual maximum stage and annual maximum discharge of Cross River at Afikpo North L.G.A. streamflow gauging station were obtained (Table 3.1). Twenty years' period (1987 – 2006) will be used for model calibration, while the remaining eleven years' period 2007 – 2017 will be used for model verification.

3.5.2 Streamflow Modelling of River Niger at Lokoja gauging Station

Sixteen years' record of annual maximum stage and annual maximum discharge of River Niger at Lokoja streamflow gauging station were obtained (Table 3.2). Eleven years' record from 1998 to 2008 will be used for streamflow model calibration, while the other five years' 2009 to

2011 and 2013 to 2014 will be used for the verification of the streamflow model.

3.5.3 Streamflow Modelling of River Niger at Onitsha gauging station

Fifteen years' record of annual maximum stage and annual maximum discharge of River Niger at Onitsha streamflow gauging station were obtained (Table 3.3). Eleven years' record from 1980 to 1990 will be used for streamflow model calibration, while the other four years; 1991, 1995, 2000 and 2001 will be used for the verification of the streamflow model.

3.5.4 Streamflow Modelling of Owena, Owan. Ikpoba and Ossiomo Rivers

The twelve years' record of streamflow measurements of Owena, Owan, Ikpoba and Ossiomo Rivers at their various gauging stations which are the only available records from the period 1989 to 2000 (Table 3.4) were used for models calibrations and verifications.

3.5.5 Streamflow Modelling of Imo River

The eleven years' available streamflow records of annual maximum stage and annual maximum discharge data from each of the four streamflow gauging stations along Imo River (Table 3.5) will be subjected to regression analysis by the automatic calibration method of Microsoft Excel Programme, which automatically computes the regression constants (parameters) and the coefficient of determination, which is a model evaluation parameter.

3.6 Appropriate Comparisons of the Streamflow Models

To draw conclusions from the data, it is necessary to make comparisons. Comparison cannot be made between two or more dissimilar things, rather comparison can only be made between two or more things when they are really alike. Comparisons of the streamflow models of the selected rivers at their various gauging station comprises four subheadings: One-way ANOVA F-Test, Variance Ratio Test or Snedecor's F-distribution (F-Test), comparison using graph and finally comparison using Student's t-Test (distribution).

3.7 Computation of the Streamflow Models Performance Measures or Evaluation Parameters

The comparison of the model's predictions with the known values of the dependent variable in a dataset is what model-performance is based on. The predictions and the dependent-variable values should be equal for an ideal model, but practice, it is never the case, and we want to quantify the disagreement. The performance of a modelling effort is generally evaluated by calculating statistical measures such as Coefficient of Determination (R^2), Coefficient of Correlation (R), Nash-Sutcliffe model Efficiency (NSE), Mean Absolute Relative Error (MARE), Percentage BIAS (PBAIS), Root Mean Square Error (RMSE) or Standard Error of Estimate (S_{yx}) and Mean of Residues (MR) or Mean Absolute Error (MAE) comparing the measured (observed) and the predicted (simulated) state variables. The performance evaluation measures are computed with the formulas in Table 3.17 which shows there range and optimal value.

Table 3.17: Model performance measures and their formulas

PERFORMANCE MEASURE	DEFINITION	RANGE	OPTIMAL VALUE
Coefficient of correlation (R)	$\frac{\sum x y - n \bar{x} \bar{y}}{(n - 1)\sigma_x \sigma_y}$	-1.0 to 1.0	-1.0 (negetive slope) 1.0 (positive slope)
Coefficient of determination (R^2)	$\frac{\sum[(x_i - \bar{x})(y - \bar{y})]^2}{[\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2]^2}$	0.0 to 1.0	1.0
Nash -Sutcliffe model Efficiency (NSE)	$1 - \frac{\sum(Q_{obs} - Q_{sim})^2}{\sum(Q_{obs} - \bar{Q}_{obs})^2}$	-∞ to 1.0	1.0
Mean Absolute Relative Error (MARE)	$1 - \frac{1}{n}\sum \frac{\lvert Q_{obs} - Q_{sim}\rvert}{Q_{obs}}$		1.0
Standard Error of Estimate (S_{yx})	$\sqrt{\frac{\sum_{1=n}^{n}(Q_{obs} - Q_{sim})^2}{n}}$	0.0 to ∞	0.0
Root Mean Square Error (RMSE)	$\sqrt{\frac{\sum(Q_{obs} - Q_{sim})^2}{n}}$	0.0 to ∞	0.0
Percentage BIAS (PBIAS)	$100 \; \frac{(\bar{Q}_{sim} - \bar{Q}_{obs})}{\bar{Q}_{obs}}$	-∞ to ∞	0.0
Mean Absolute Error (MAE) or Mean of Residue (MR)	$\frac{\sum(Q_{obs} - Q_{sim})}{n}$	0.0 to ∞	0.0

where,

Q_{obs} = observed values of the dependent variable

Q_{sim} = The predicted (simulated) values of the dependent variable

n = number of samples

$\bar{Q}_{obs}$ = Mean of the observed values of the dependent variable

$\bar{Q}_{sim}$ = Mean of the simulated values of the dependent variable

The flow predictions (simulations) in catchment streamflow estimates are considered *perfect* if the $R^2 \geq 0.97$ or $R^2 \geq 0.93$ and *acceptable* if the $R^2 \geq 0.90$ or $R^2 \geq 0.77$ (Chiew & McMahon, 1993). A large R^2 and a low root mean square error or standard error of estimate indicate a good fit of the regression analysis.

According to Moriasi et al. (2007) NSE = 1.0 is the perfect fit, NSE > 0.75 is a very good fit, NSE = 0.64 to 0.74 is a good fit, NSE = 0.5 to 0.64 is a satisfactory fit and NSE < 0.5 is an unsatisfactory fit. Other performance evaluation criteria are shown in Table 3.18.

Table 3.18: Performance evaluation criteria

Remarks	Statistical criterion	
	NSE	PBIAS
Very Good	0.75 <NSE< 1.00	PBIAS< ± 10
Good	0.65 <NSE< 0.75	± 10 <PBIAS< ± 15
Satisfactory	0.50 <NSE< 0.65	± 15 <PBIAS< ± 25
Unsatisfactory	NSE< 0.50	PBIAS> ± 25

3.8 Applications of the Streamflow Models

I demonstrated the application or the usefulness of the models by their application in the design of the capacity of water storage reservoir and generation of hydropower electricity. In this work, the size and capacity of water storage reservoir was designed at Benin City using the calibrated streamflow model of Ikpoba River. The calibrated streamflow model of Cross River was used to design hydropower electricity generation in Afikpo North L.G.A. in Ebonyi State. The calibrated streamflow model of River Niger at Onitsha gauging site was used to design hydropower electricity generation in Onitsha, Anambra State.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Streamflow Modelling of Cross River

4.1.1 Streamflow Model Calibration of Cross River at Afikpo North L.G.A. Gauging Station

The output of the Microsoft Excel programme for least square regression model calibration of streamflow data (Table 3.1) of Cross River at Afikpo North L.G.A. are shown in Figures 4.1 and 4.2 for the power and polynomial models respectively and Table 4.1 for the ANOVA model for regression.The resulting equations are shown below:

$$y = 37.814x^{2.5883} \quad . \quad . \quad . \quad . \quad (4.1)$$

$$y = -19.857x^3 + 734.63x^2 - 5208.1x + 13023 \quad . \quad . \quad . \quad (4.2)$$

$$y = 3105.182x - 16700.211 \quad . \quad . \quad . \quad (4.3)$$

Equations (4.1), (4.2) and (4.3) results in the power model, polynomial model and ANOVA model for regression are as expressed in Equations (4.4), (4.5) and (4.6) respectively:

$$Q = 37.814h^{2.5883} \quad . \quad . \quad . \quad . \quad (4.4)$$

$$Q = -19.857h^3 + 734.63h^2 - 5208.1h + 13023 \quad . \quad . \quad . \quad (4.5)$$

$$Q = 3105.182h - 16700.211 \quad . \quad . \quad . \quad . \quad (4.6)$$

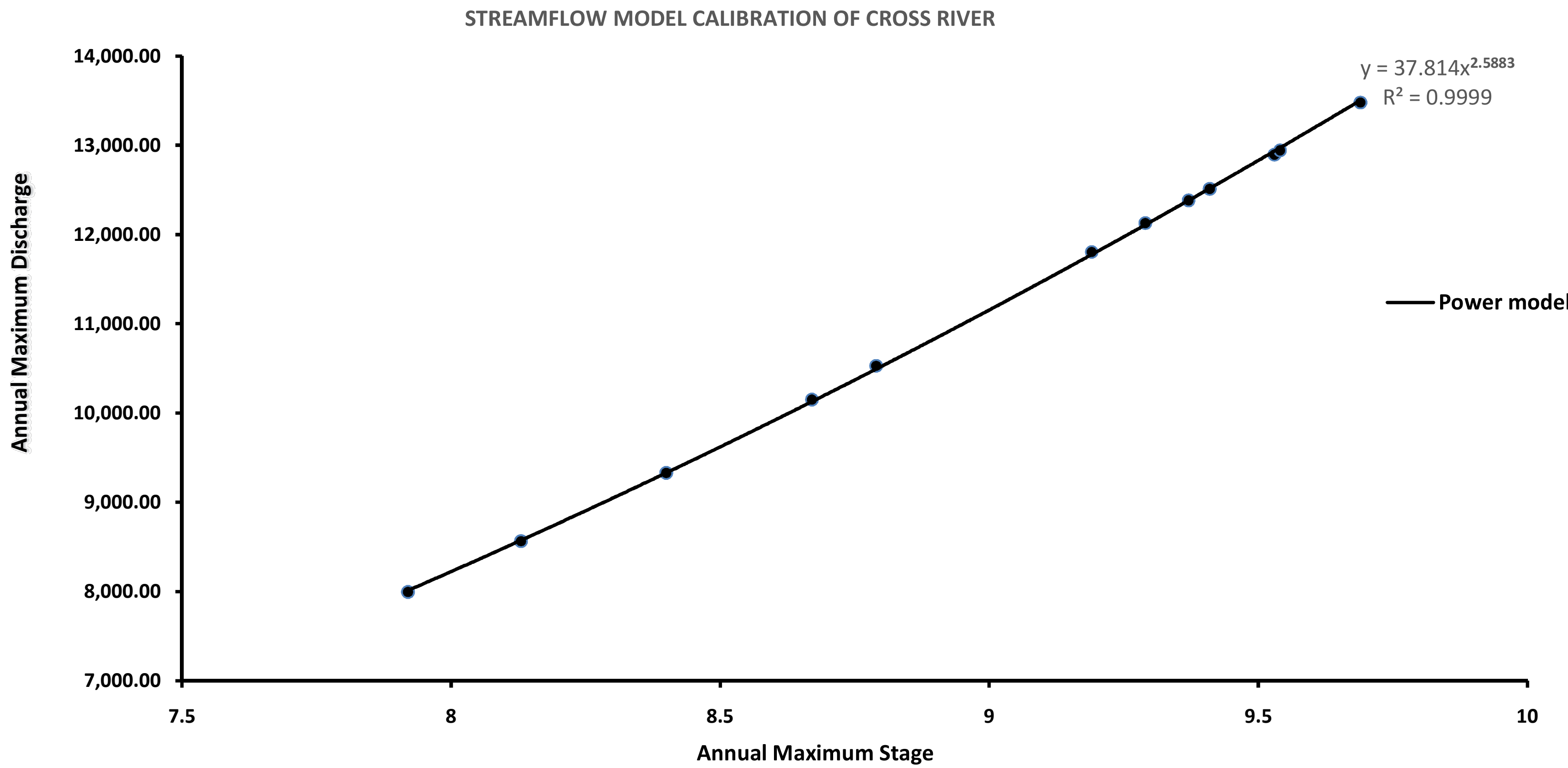


Figure 4.1: Plot of streamflow model calibration of Cross River at Afikpo North L.G.A. gauging station (power model)

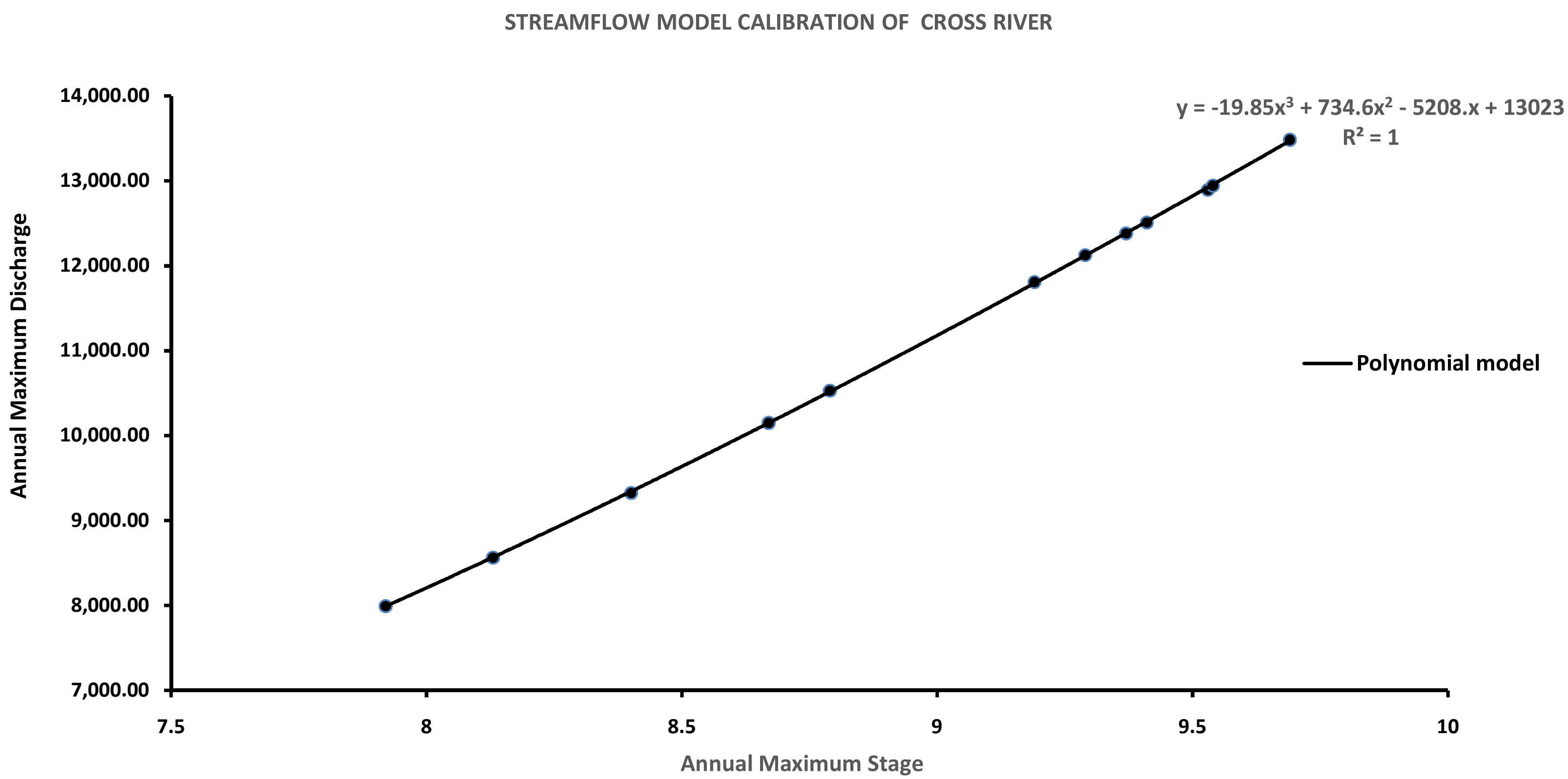


Figure 4.2: Plot of streamflow model calibration of Cross River at Afikpo North L.G.A. gauging station (polynomial Model)

Table 4.1: Summary output of ANOVA Model for regression for Cross River at Afikpo North L.G.A. streamflow gauging station

Regression Statistics	
Multiple R	0.999511393
R Square	0.999023026
Adjusted R Square	0.998968749
Standard Error	60.48927034
Observations	20

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	67347498.09	67347498.09	18406.22706	1.50458E-28
Residual	18	65861.13287	3658.951826		
Total	19	67413359.23			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-16700.21144	204.5042356	-81.66193424	1.37837E-24	-17129.85889	-16270.56398
X Variable 1	3105.181643	22.88783018	135.669551	1.50458E-28	3057.096096	3153.26719

From the coefficients section or the parameter estimate section the fitted regression equation is obtained: $y = 3105.182x – 16700.211$

4.1.2 Verification of the Streamflow Model of Cross River at Afikpo North L.G.A. gauging station

After calibration, model's validity was tested by using stage and discharge data for the period of 2007 – 2017. The verification values are shown in Table 4.2.

Table 4.2: Verification of the streamflow model of Cross River at Afikpo North L.G.A. gauging station for the period 2007 - 2017

S/N	Year	Measured Annual maximum stage (h) (m)	Measured Annual maximum discharge (Q) (m^3/s)	Predicted Annual maximum discharge (Q) (m^3/s) (Power model)	Predicted Annual maximum discharge (Q) (m^3/s) (Polynomial model)	Predicted Annual maximum discharge (Q) (m^3/s) (ANOVA model for Regression)
1	2007	9.53	12,896.00	12,937.15	12,922.87	12,892.16
2	2008	9.19	11,808.00	11,776.12	11,792.50	11,839.15
3	2009	8.67	10,150.60	10,128.09	10,149.01	10,221.70
4	2010	9.41	12,512.00	12,519.72	12,519.27	12,519.53
5	2011	9.63	13,196.00	13,291.46	13,262.89	13,202.67
6	2012	9.19	11,808.00	11,776.12	11,792.50	11,836.39
7	2013	9.29	12,128.00	12,110.66	12,120.68	12,146.91
8	2014	9.61	13,196.00	13,220.13	13,194.62	13,140.57
9	2015	9.69	13,484.00	13,506.86	13,468.45	13,388.98
10	2016	9.61	13,196.00	13,220.13	13,194.62	13,140.57
11	2017	9.69	13,484.00	13,506.86	12,922.87	13,388.98

The results of the measured and predicted discharge values of the streamflow models as presented in Table 4.2 were used for the verificationof the models as shown in Figures 4.3 through 4.5.

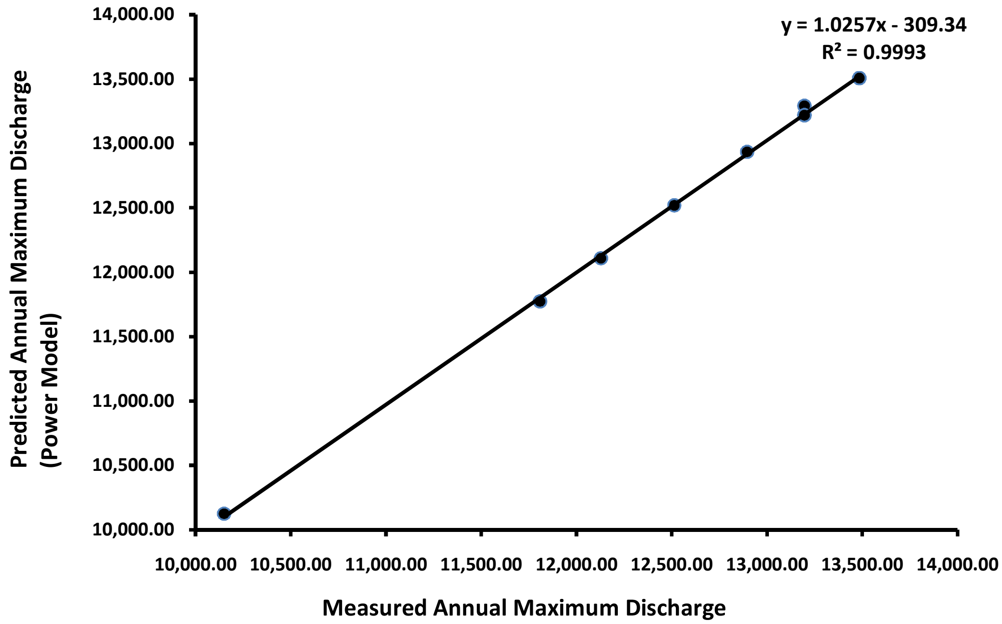


Figure 4.3: Verification of the streamflow model of Cross River at Afikpo North L.G.A. gauging station (for the *power model*).

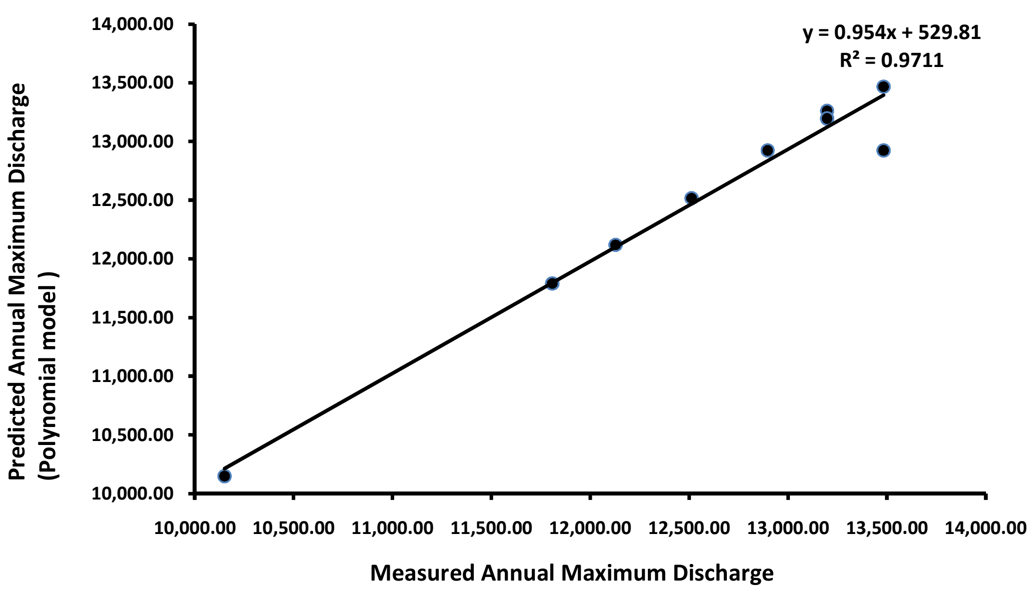


Figure 4.4: Verification of the streamflow model of Cross River at Afikpo North L.G.A. gauging station (for the *polynomial model*)

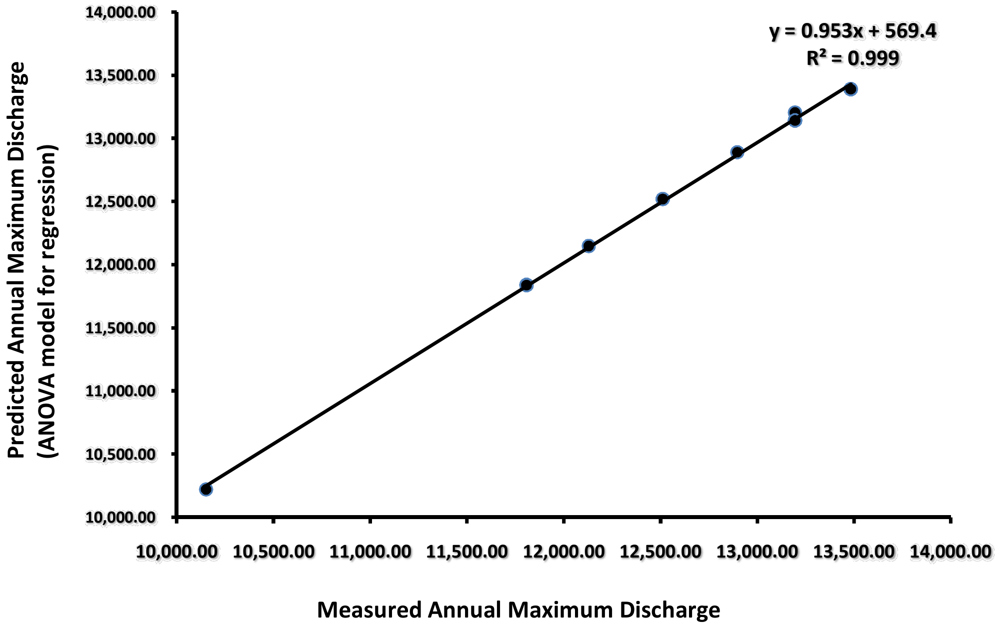


Figure 4.5: Verification of the streamflow model of Cross River at Afikpo North L.G.A. gauging station (for the ANOVA model for regression)

4.1.3 Comparisons of the streamflow models of Cross River at Afikpo North L.G.A. gauging station

Comparisons of the streamflow models of Cross River at Afikpo North L.G.A. gauging station comprises four subheadings: One-way ANOVA F-test, Variance Ratio Test or Snedecor's F-distribution (F-Test), comparison using graph and finally comparison using Student's t-Test.

4.1.3.1 Comparison of the streamflow models of Cross River at Afikpo North L.G.A. gauging station using One-way ANOVA F-Test

The comparison of the streamflow models verified for Cross River at Afikpo North L.G.A. gauging station using One-way ANOVA F-Testis shown in Table 4. 3.

Table 4. 3: One-way ANOVA F-Testfor streamflow models of Cross River

Groups	**Count**	**Sum**	**Average**	**Variance**
Power model	**11**	**137993.3**	**12544.8**	**1068603**
Polynomial model	**11**	**137340.3**	**12485.5**	**951273.1**
ANOVA Model for regression	**11**	**137717.6**	**12519.8**	**923726.6**

ANOVA

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	**19539.94**	**2**	**9769.97**	**0.009957**	**0.990096**	**3.31583**
Within Groups	**29436028**	**30**	**981201**			
Total	**29455568**	**32**				

4.1.3.2 Comparison of the streamflow models of Cross River Afikpo North L.G.A. gauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test).

The Comparisonof the streamflow models of Cross River Afikpo North L.G.A. gauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test) are shown in Tables 4.4 through 4.6.

Table 4. 4: F-Test Two-Sample for Variances (Power model and Polynomial model)

	Power model	**Polynomial model**
Mean	12544.84545	12485.48
Variance	1068603.142	951273.0858
Observations	11	11
df	10	10
F	1.123340035	
P(F<=f) one-tail	0.42884543	
F Critical one-tail	2.978237016	

Table 4. 5: F-Test Two-Sample for Variances (Power model and ANOVA model for regression)

	Power model	ANOVA model for regression
Mean	12544.84545	12519.78273
Variance	1068603.142	923726.6219
Observations	11	11
df	10	10
F	1.156839173	
P(F<=f) one-tail	0.411151679	
F Critical one-tail	2.978237016	

Table 4. 6: F-Test Two-Sample for Variances (Polynomial model and ANOVA model for regression)

	Polynomial model	ANOVA model for regression
Mean	12485.48	12519.78273
Variance	951273.0858	923726.6219
Observations	11	11
df	10	10
F	1.029821013	
P(F<=f) one-tail	0.481927832	
F Critical one-tail	2.978237016	

4.1.3.3 Comparisonof the streamflow models of Cross River Afikpo North L.G.A. gauging station using graph

The comparison of the streamflow models verified for Cross River at Afikpo North L.G.A. gauging station using graph is shown in Figure 4.6.

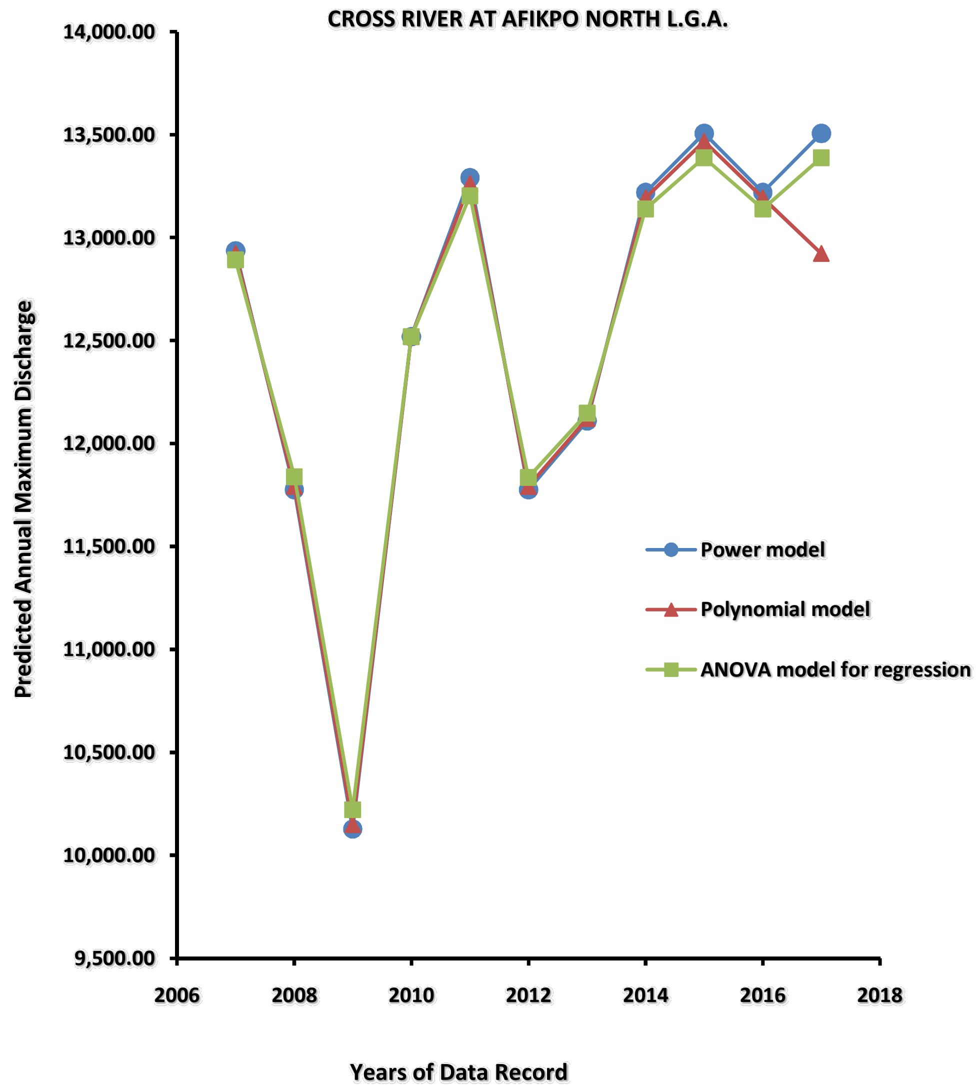


Figure 4.6: Comparison of the streamflow modelsverified for Cross River at Afikpo North L.G.A. streamflow gauging station using graph

4.1.3.4 Comparisonof the streamflow models of Cross River at Afikpo NorthL.G.A. gauging station using Student's t-Test

The streamflow models are further compared using Student's t-Test(distribution) as shown in Tables 4.7 through 4.9.

Table 4.7: t-Test: Paired Two Sample for Means (Power and Polynomial models)

	Power model	**Polynomial model**
Mean	12544.84545	12485.48
Variance	1068603.142	951273.0858
Observations	11	11
Pearson Correlation	0.986459309	
Hypothesized Mean Difference	0	
df	10	
t Stat	1.123454097	
P(T<=t) one-tail	0.143745656	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.287491311	
t Critical two-tail	2.228138852	

Table 4.8: t-Test: Paired Two Sample for Means (Power model and ANOVA model for regression)

	Power model	**ANOVA model for regression**
Mean	12544.84545	12519.78273
Variance	1068603.142	923726.6219
Observations	11	11
Pearson Correlation	0.999577942	
Hypothesized Mean Difference	0	
df	10	
t Stat	1.063145159	
P(T<=t) one-tail	0.156357539	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.312715077	
t Critical two-tail	2.228138852	

Table 4.9: t-Test: Paired Two Sample for Means (Polynomial model and ANOVA model for regression)

	Polynomial model	**ANOVA model for regression**
Mean	12485.48	12519.78273
Variance	951273.0858	923726.6219
Observations	11	11
Pearson Correlation	0.987780343	
Hypothesized Mean Difference	0	
df	10	
t Stat	-0.748356745	
P(T<=t) one-tail	0.235739516	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.471479033	
t Critical two-tail	2.228138852	

4.1.4 Computations of the model performance measures of the streamflow model of Cross River at Afikpo North L.G.A.

Computations of Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias, root mean square error or standard error of estimateand mean of residue or mean absolute error which are used as tools for the evaluation of the streamflow models of Cross River at Afikpo North L.G.A. gauging station are shown in Tables 4.10 and 4.11for the power and polynomial models respectively and Table 4.12 for the ANOVA model for regression.

Table 4.10: The computationsof model performance measuresof the streamflow model of Cross River at Afikpo North L.G.A. gauging station (*power model*)

Year	**Stage (h or x) metres**	**Measured Discharge (y_i or Q) (m^3/s)**	**Predicted Discharge (*Power model*) $y_i' = 37.955x^{2.5865}$ (m^3/s)**	$(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
2007	9.53	12,896.00	12,937.15	-41.15	1693.32	- 0.0032	363.4	132,059.56
2008	9.19	11,808.00	11,776.12	31.88	1016.33	0.0027	-724.6	525,045.16
2009	8.67	10,150.60	10,128.09	22.51	506.70	0.0022	-2.382	5.674
2010	9.41	12,512.00	12,519.72	-7.72	59.60	- 0.0006	-20.6	424.36
2011	9.63	13,196.00	13,291.46	-95.46	9112.61	- 0.0072	758.86	575,868.50
2012	9.19	11,808.00	11,776.12	31.88	1016.33	0.0027	-724.6	525,045.16
2013	9.29	12,128.00	12,110.66	17.34	300.68	0.0014	-404.6	163,701.16
2014	9.61	13,196.00	13,220.13	-24.13	582.26	- 0.0018	663.4	440,099.56
2015	9.69	13,484.00	13,506.86	-22.86	522.58	- 0.0017	951.4	905,161.96
2016	9.61	13,196.00	13,220.13	-24.13	582.26	- 0.0018	663.4	440,099.56
2017	9.69	13,484.00	13,506.86	-22.86	522.58	- 0.0017	951.4	905,161.96
		$\sum$ = 137858.6	**$\sum$ =137993.3**	**$\sum$ = -134.7**	**$\sum$ =15,914.57**	**$\sum$ = - 0.009**		**$\sum$ =4612672.614**

Computations of the model performance measures of the streamflow model of Cross River at Afikpo North L.G.A. gauging station (*power model*).

Mean for the measured annual maximum discharge = 12532.6

Mean for the predicted annual maximum discharge = 12544.85

i. Nash-Sutcliffe model Efficiency (NSE)

$$\text{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{15{,}914.57}{4612672.614} = 0.9965$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\text{RMSE}) \text{ or } S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{15{,}914.57}{11}} = 38.04$$

iii. Percentage BIAS (PBIAS)

$$\text{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{12544.85 - 12532.6}{12532.6}\right) = 0.098$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\text{MR or MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{-134.7}{11} = -12.25$$

v. Mean Absolute Relative Error (MARE)

$$\text{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{11}(-0.009) = 1.00$$

Table 4.11: Computations of the model performance measures of the streamflow models of Cross River at Afikpo North L.G.A. gauging station (for the p*olynomial model*)

S_{yx}

Year	Stage (h or x) metres	Measured Discharge (y_i or Q) (m^3/s)	Predicted Discharge (m^3/s) (*Polynomial model*) $y_i' = -19.857x^3 + 734.63x^2 - 5208.1x + 13023$	$(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
2007	9.53	12,896.00	12,922.87	-26.87	722.00	-0.0021	363.4	132,059.56
2008	9.19	11,808.00	11,792.50	15.50	240.12	0.0013	-724.6	525,045.16
2009	8.67	10,150.60	10,149.01	1.59	2.53	0.0002	-2.382	5.674
2010	9.41	12,512.00	12,519.27	-7.27	52.85	-0.0006	-20.6	424.36
2011	9.63	13.196.00	13,262.89	-66.89	4474.27	-0.0051	758.86	575,868.50
2012	9.19	11,808.00	11,792.50	15.50	240.12	0.0013	-724.6	525,045.16
2013	9.29	12,128.00	12,120.68	7.32	53.54	0.0006	-404.6	163,701.16
2014	9.61	13,196.00	13,194.62	1.38	1.90	0.0001	663.4	440,099.56
2015	9.69	13,484.00	13,468.45	15.55	241.87	0.0012	951.4	905,161.96
2016	9.61	13,196.00	13,194.62	1.38	1.90	0.0001	663.4	440,099.56
2017	9.69	13,484.00	13,468.45	15.55	241.87	0.0012	951.4	905,161.96
			$\sum$ = 137885.86	**$\sum$ = -27.26**	**$\sum$ = 6272.97**	**$\sum$ = -0.0018**		**$\sum$ =4612672.614**

Computations of the model performance measures of the streamflow model of Cross River at Afikpo North L.G.A. gauging station (*polynomial model*).

Mean for the measured annual maximum discharge = 12532.6

Mean for the measured annual maximum discharge = 12535.078

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{6272.97}{4612672.614} = 0.9986$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\ \text{or}\ S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{6272.97}{11}} = 23.88$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{12535.078 - 12532.6}{12532.6}\right) = 0.02$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\text{MR or MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{-27.26}{11} = -2.48$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{11}(-0.0018) = 1.00$$

Table 4.12: Computations of the model performance measures of the streamflow models of Cross River at Afikpo North L.G.A. gauging station (for the *ANOVA model for regression*)

Year	**Stage (h or x) metres**	**Measured Discharge (y_i or Q) (m^3/s)**	**Predicted Discharge (m^3/s) (ANOVA Model for regression) $y_i' = 3105.182h - 16700.211$**	$(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
2007	9.53	12,896.00	12,892.16	-3.84	14.75	0.0003	363.4	132,059.56
2008	9.19	11,808.00	11,839.15	-31.15	970.32	-0.0026	-724.6	525,045.16
2009	8.67	10,150.60	10,221.70	-71.10	5,055.21	-0.0070	-2.382	5.674
2010	9.41	12,512.00	12,519.53	-7.53	56.70	-0.0006	-20.6	424.36
2011	9.63	13,196.00	13,202.67	-6.67	44.49	-0.0005	758.86	575,868.50
2012	9.19	11,808.00	11,836.39	-28.39	805.99	-0.0024	-724.6	525,045.16
2013	9.29	12,128.00	12,146.91	-18.91	357.59	-0.0016	-404.6	163,701.16
2014	9.61	13,196.00	13,140.57	55.43	3,072.48	0.0042	663.4	440,099.56
2015	9.69	13,484.00	13,388.98	95.02	9,028.80	0.0070	951.4	905,161.96
2016	9.61	13,196.00	13,140.57	55.43	3,072.48	0.0042	663.4	440,099.56
2017	9.69	13,484.00	13,388.98	95.02	9,028.80	0.0070	951.4	905,161.96
		$\sum$ =137858.6	**$\sum$ = 137717.61**	**$\sum$ = 133.31**	**$\sum$ = 31,507.61**	**$\sum$ = 0.008**		**$\sum$ = 4612672.614**

Computations of the model performance measures of the streamflow model of Cross River at Afikpo North L.G.A. gauging station (*ANOVA model for regression*).

Mean for the measured annual maximum discharge = 12532.6

Mean for the predicted annual maximum discharge = 12519.783

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{31{,}507.61}{4612672.614} = 0.9932$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE}) \text{ or } S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{31{,}507.61}{11}} = 53.52$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{12519.783 - 12532.6}{12532.6}\right) = -0.10$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR} \quad \text{or} \quad \mathrm{MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{133.31}{11} = 12.12$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{11}(0.008) = 0.999$$

The summary of calibrated streamflow models of Cross River at Afikpo North gauging station obtained from Figures 4.1 and 4.2 and Tables 4.10 and 4.11 for the power and polynomial models respectively and Tables 4.1 and 4.12 for the ANOVA model for regression are shown in Table 4.13.

Table 4.13: Summary of streamflow models of Cross River at Afikpo North L.G.A. gauging station and the models evaluation parameters

RIVER	STREAMFLOW GAUGING STATION	STREAMFLOW MODEL[+]	MODEL EVALUATION PARAMETERS[*]						
			R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
Cross River	Afikpo North L.G.A	**Power model** $Q = 37.814h^{2.5883}$	0.9999	0.9999	0.9965	38.04	0.098	-12.25	1.00
		Polynomial model $Q = -19.857h^3 + 734.63h^2 - 5208.1h + 13023$	1	1	0.9986	23.88	0.02	-2.48	1.00
		ANOVA model for regression $Q = 3105.18h - 16700.21$	0.9990	0.9995	0.9932	53.52	-0.10	12.12	0.9993

[+] Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

[*] **Model Evaluation Parameters**
Coefficient of determination (R^2), Coefficient of correlation (R), Nash-Sutcliffe model Efficiency (NSE), Mean Absolute Relative Error (MARE), Root Mean Square Error (RMSE) or Standard error of estimate of discharge on stage ($S_{Q.h}$), Percentage BIAS (PBIAS), Mean Residue (MR).

4.2 Streamflow Modelling of River Niger

4.2.1 Streamflow Model Calibration of River Niger at Lokoja Gauging Station

The output of the Microsoft Excel programme for least square regression model calibration of streamflow data (Table 3.2) of River Niger at Lokoja gauging station are shown in Figures 4.7 and 4.8 for the power and polynomial models respectively and Table 4.14 for the ANOVA model for regression. The resulting equations are shown below:

$$y = 481.85x^{1.6537} \quad . \quad . \quad . \quad . \quad (4.7)$$

$$y = -16.973x^3 + 456.51x^2 - 698.16x \quad . \quad . \quad . \quad . \quad (4.8)$$

$$y = 3365.212x - 11967.088 \quad . \quad . \quad . \quad . \quad (4.9)$$

Equations (4.7), (4.8) and (4.9) results in the following power, polynomial and ANOVA models:

$$Q = 481.85h^{1.6537} \quad . \quad . \quad . \quad . \quad (4.10)$$

$$Q = -16.973h^3 + 456.51h^2 - 698.16h \quad . \quad . \quad . \quad (4.11)$$

$$Q = 3365.212h - 11967.088 \quad . \quad . \quad . \quad . \quad (4.12)$$

Equations (4.10) is a power model, Equations (4.11) is a polynomial model while Equations (4.12) is ANOVA model for regression

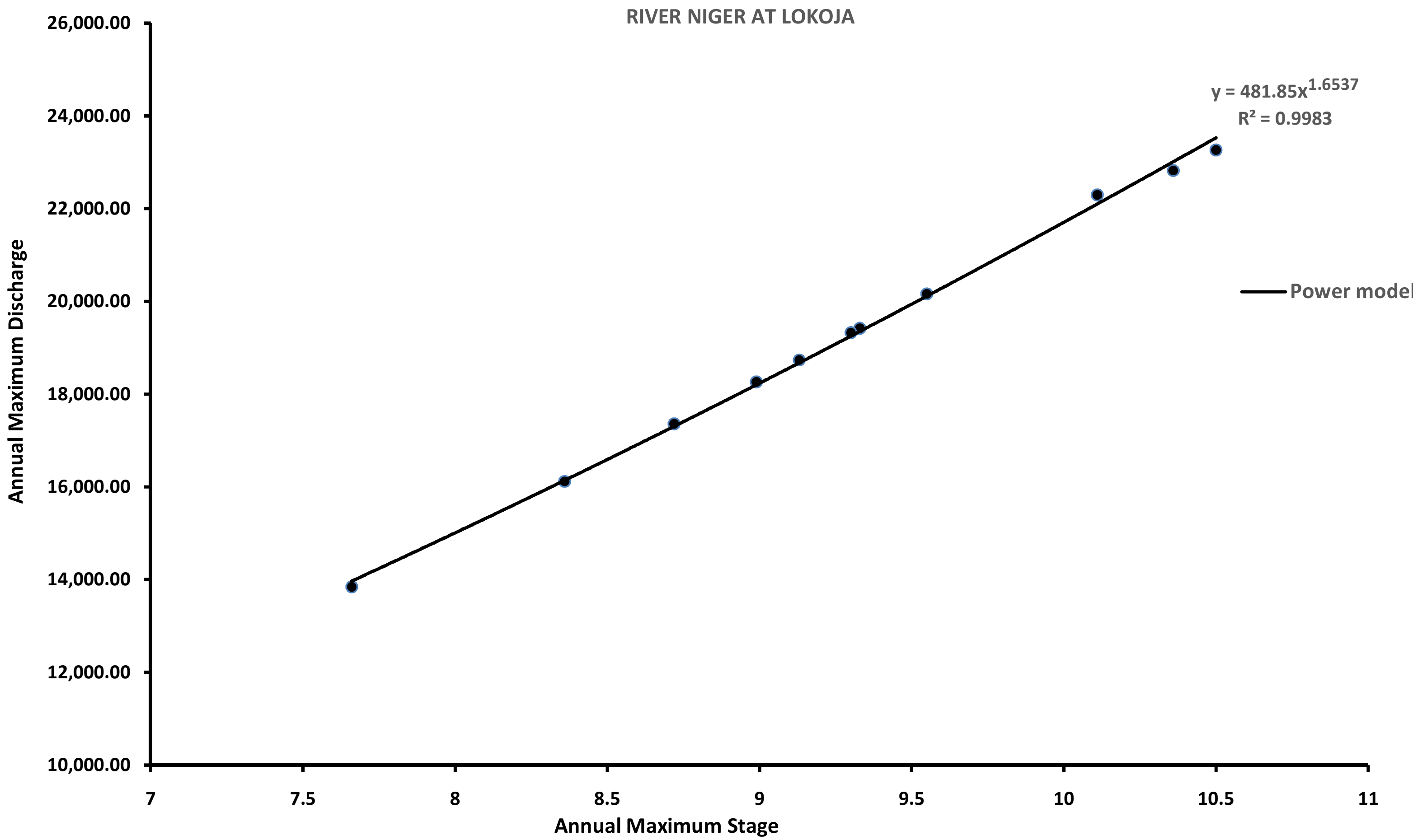


Figure 4.7: Plot of streamflow model calibration of River Niger at Lokoja gauging station (Power model)

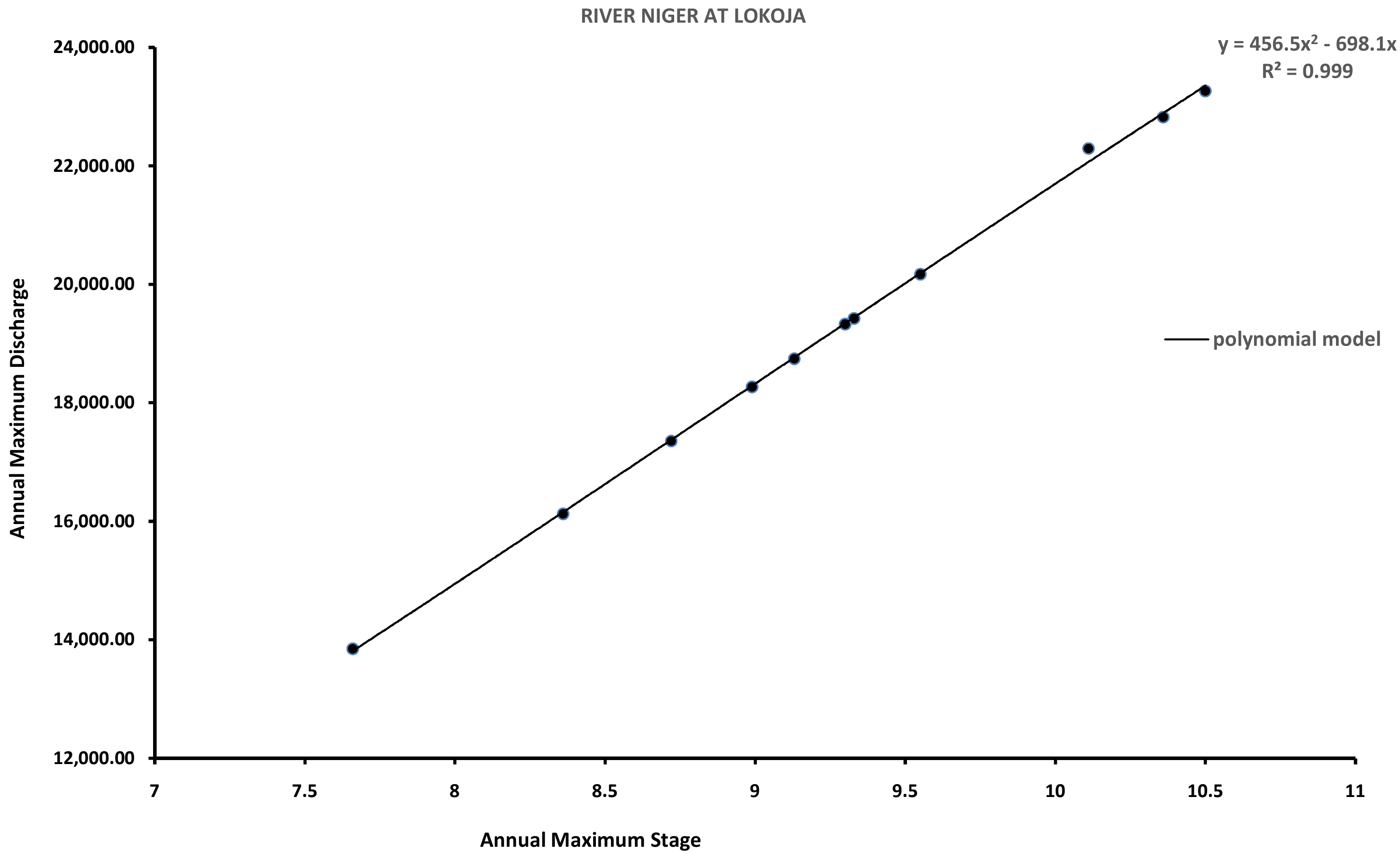


Figure 4.8: Plot of streamflowmodel calibration of River Niger at Lokoja gauging station (Polynomial model)

Table 4.14: Summary output of ANOVA model for regression for River Niger at Lokoja streamflow gauging station

Regression Statistics	
Multiple R	0.999531973
R Square	0.999064164
Adjusted R Square	0.998960182
Standard Error	92.82280884
Observations	11

ANOVA

	df	SS	MS	F	Significance F
Regression	1	82783846.36	82783846.36	9608.07067	6.07218E-15
Residual	9	77544.66456	8616.07384		
Total	10	82861391.02			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-11967.0878	319.6067713	-37.44316101	3.42885E-11	-12690.08855	-11244.08705
X Variable 1	3365.212487	34.33162794	98.02076652	6.07218E-15	3287.548949	3442.876025

From the coefficients section the fitted regression equation is obtained: $y = 3365.212x - 11967.088$

4.2.2 Verification of Streamflow Model of River Niger at Lokoja Gauging Station

After calibration, model's validity was tested by using stage and discharge data for the period of 2009 – 2011 and 2013 –2014. The verification values are shown in Table 4.15.

Table 4.15: Verification of streamflow model of River Niger at Lokoja gauging station

S/N	Year	Annual Maximum Stage (h) (m)	Measured Annual Maximum Discharge (Q) (m^3/s)	Predicted Annual Maximum Discharge (Q) (m^3/s) (Power Model)	Predicted Annual Maximum Discharge (Q) (m^3/s) (Polynomial Model)	Predicted Annual Maximum Discharge (Q) (m^3/s) (ANOVA Model) for regression
1	2009	9.95	21,530.00	21,528.41	21,529.26	21,516.77
2	2010	9.79	20,986.00	20,958.93	20,992.80	20,978.34
3	2011	8.56	16,794.08	16,753.45	16,794.18	16,805.47
4	2013	8.45	16,430.00	16,430.65	16,455.82	16,468.95
5	2014	9.40	19,595.26	19,596.27	19,677.02	19,665.90

The results of the measured and predicted discharge values of streamflow models as presented in Table 4.15 were used to plot linear streamflow model verification graphs as shown in Figures 4.9 through 4.11.

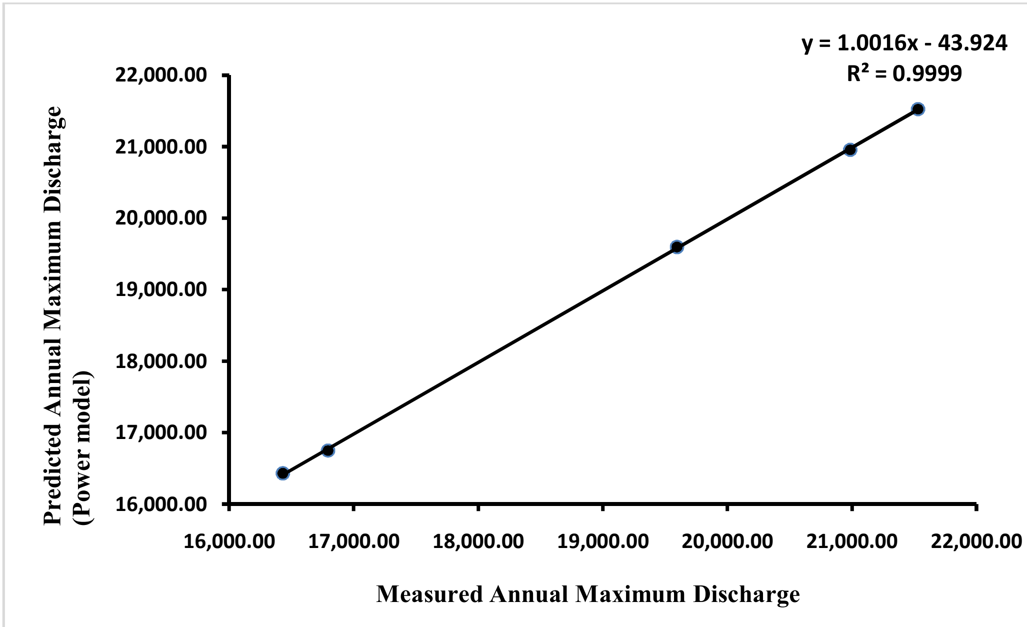


Figure 4.9: Verification of the streamflow model of River Niger at Lokoja gauging station (Power model)

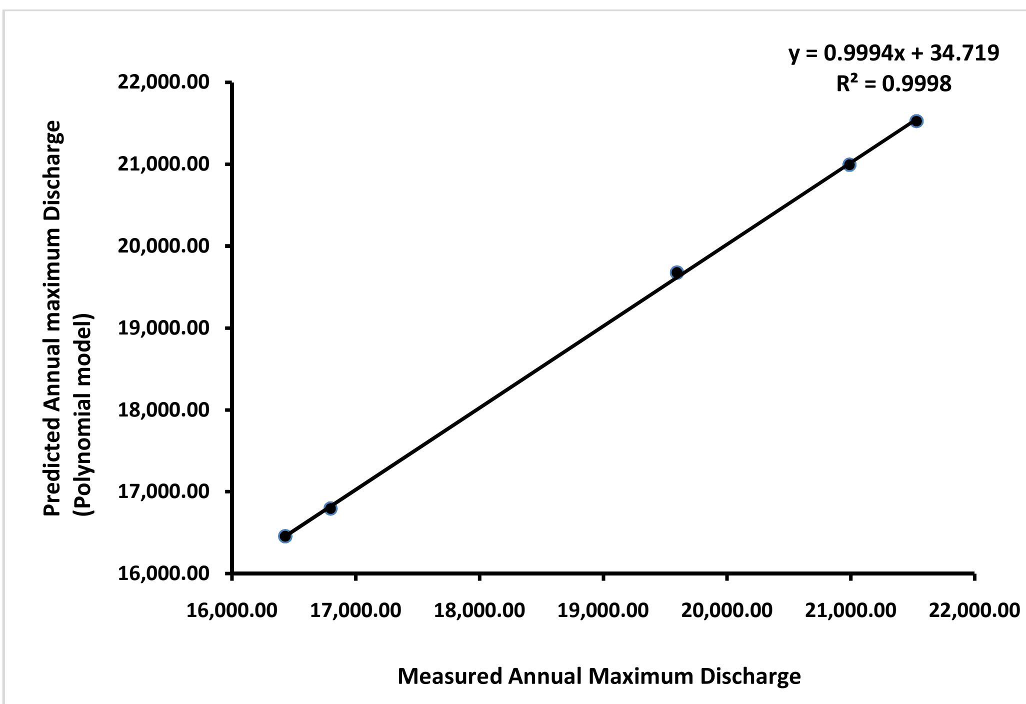


Figure 4.10: Verification of the streamflow model of River Niger at Lokoja gauging station (Polynomial model)

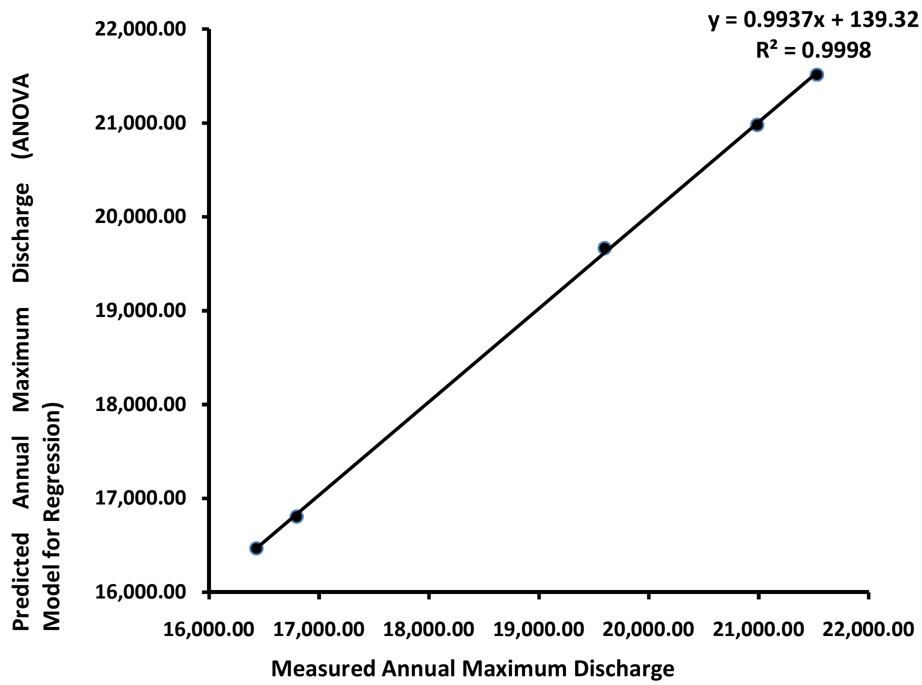


Figure 4.11: Verification of the streamflow model of River Niger at Lokoja gauging station (ANOVA model for regression)

4.2.3 Comparisons of the streamflow models of River Niger at Lokoja gauging station

Comparisons of the streamflow models of River Niger at Lokoja gauging station comprise four subheadings: One-way ANOVA F-Test, Variance Ratio Test or Snedecor's F-distribution (F-Test), comparison using graph and finally comparison using Student's t-Test.

4.2.3.1 The comparison of the streamflow models verified for River Niger at Lokoja gauging station using One-way ANOVA F-Test

The comparison of the streamflow models verified for River Niger at Lokoja gauging station using One-way ANOVA F-Test is shown in Table 4.16.

Table 4.16: One-way ANOVA F-Test for streamflow models of River Niger at Lokoja gauging station

Groups	**Count**	**Sum**	**Average**	**Variance**
Power model	**5**	**95267.71**	**19053.54**	**5555003.6**
Polynomial model	**5**	**95449.08**	**19089.82**	**5531230.81**
ANOVA model for regression	**5**	**95435.43**	**19087.09**	**5468909.84**

ANOVA

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	**4080.759853**	**2**	**2040.38**	**0.00036974**	**0.99963**	**3.88529**
Within Groups	**66220576.99**	**12**	**5518381**			
Total	**66224657.75**	**14**				

4.2.3.2 Comparison of the streamflow models of River Niger at Lokoja gauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test).

The Comparison of the streamflow models of River Niger at Lokoja gauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test) are shown in Tables 4.17 through 4.19.

Table 4. 17: F-Test Two-Sample for Variances (Power model and Polynomial model)

	Power model	**Polynomial model**
Mean	19053.542	19089.816
Variance	5555003.596	5531230.811
Observations	5	5
df	4	4
F	1.004297919	
P(F<=f) one-tail	0.498391739	
F Critical one-tail	6.388232909	

Table 4.18: F-Test Two-Sample for Variances (Power model and ANOVA model for regression)

	Power model	**ANOVA model for regression**
Mean	19067.068	19089.816
Variance	5536980.733	5531230.811
Observations	5	5
df	4	4
F	1.001039537	
P(F<=f) one-tail	0.499610376	
F Critical one-tail	6.388232909	

Table 4.19: F-Test Two-Sample for Variances (Polynomial model and ANOVA model for regression)

	Polynomial model	**ANOVA model for regression**
Mean	19089.816	19087.086
Variance	5531230.811	5468909.841
Observations	5	5
df	4	4
F	1.011395501	
P(F<=f) one-tail	0.495750943	
F Critical one-tail	6.388232909	

4.2.3.3 Comparisonof the streamflow models of River Niger at Lokoja gauging station using graph

The comparison of the streamflow models verified for River Niger at Lokoja gauging station using graph is shown in Figure 4.12.

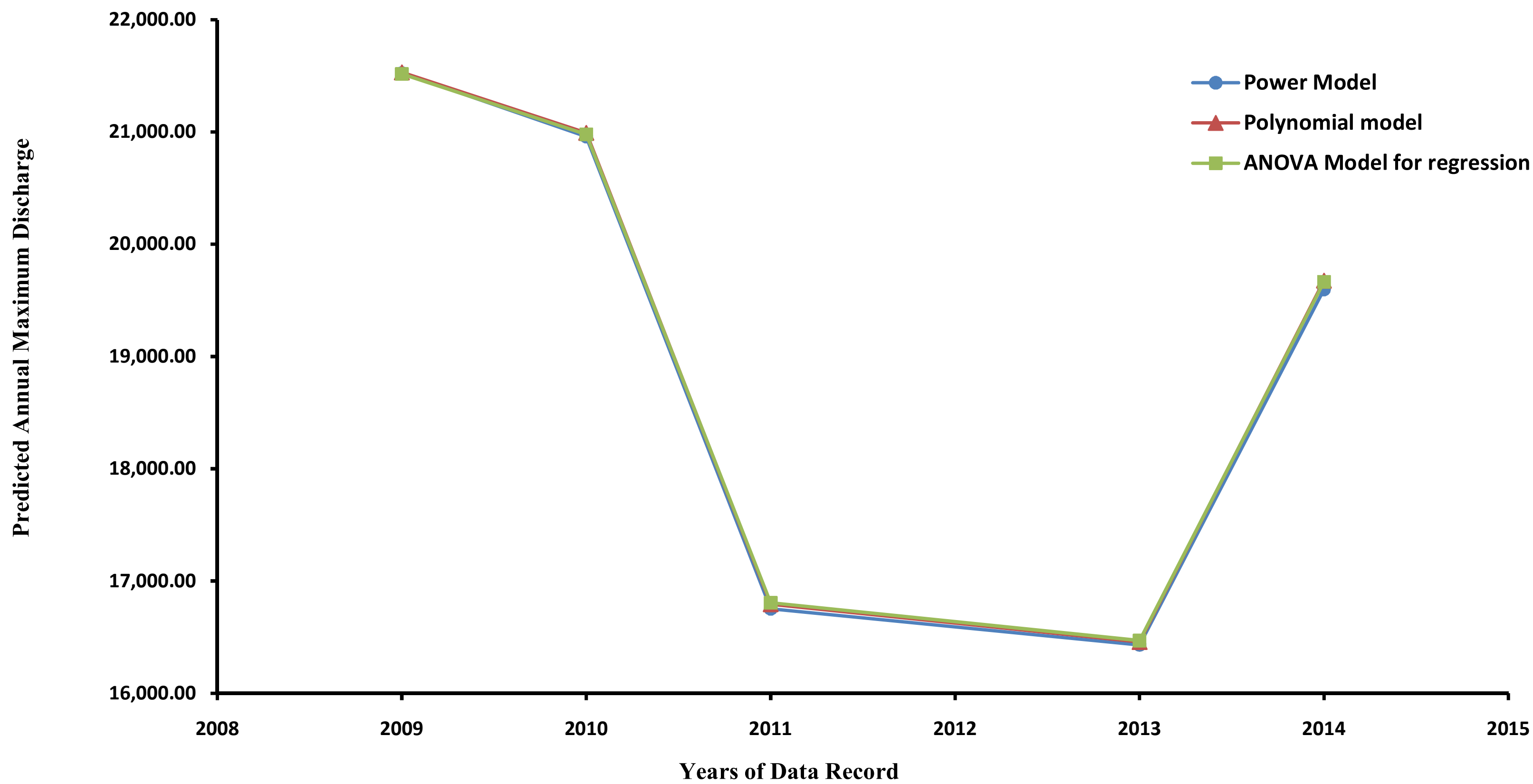


Figure 4.12: Comparison of the streamflow models verified for River Niger at Lokoja streamflow gauging station using graph

4.2.3.4 Comparisonof the streamflow models of River Niger at Lokoja gauging station using Student's t-Test

The streamflow models are further compared using Student's t-Test (distribution) as shown in Tables 4.20 through 4.22.

Table 4.20: t-Test: Paired Two Sample for Means (Power and Polynomial models)

	Power model	Polynomial model
Mean	19053.542	19089.816
Variance	5555003.596	5531230.811
Observations	5	5
Pearson Correlation	0.999926035	
Hypothesized Mean Difference	0	
df	4	
t Stat	-2.789520333	
P(T<=t) one-tail	0.024668103	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.049336206	
t Critical two-tail	2.776445105	

Table 4.21: t-Test: Paired Two Sample for Means (Power model and ANOVA model for regression)

	Power model	ANOVA model for regression
Mean	19053.542	19087.086
Variance	5555003.596	5468909.841
Observations	5	5
Pearson Correlation	0.999941879	
Hypothesized Mean Difference	0	
df	4	
t Stat	-2.399815397	
P(T<=t) one-tail	0.037185608	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.074371216	
t Critical two-tail	2.776445105	

Table 4.22: t-Test: Paired Two Sample for Means (Polynomial model and ANOVA model for regression)

	Polynomial model	**ANOVA model for regression**
Mean	19089.816	19087.086
Variance	5531230.811	5468909.841
Observations	5	5
Pearson Correlation	0.999998973	
Hypothesized Mean Difference	0	
df	4	
t Stat	0.445408641	
P(T<=t) one-tail	0.339533836	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.679067673	
t Critical two-tail	2.776445105	

4.2.4 Computations of the model performance measures of the streamflow model of River Niger at Lokoja streamflow gauging station

Computations of Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias, root mean square error or standard error of estimateand mean of residue or mean absolute error which are used as tools for the evaluation of the streamflow models ofRiver Niger at Lokoja gauging stationare shown in Tables 4.23 and 4.24 for the power and polynomial models respectively and Table 4.25 for the ANOVA model for regression.

Table 4.23: Computations of the model performance measures of the streamflow models of River Niger at Lokoja gauging station (for the *power model*)

Year	**Stage (h or x) metres**	**Measured Discharge (y_i or Q) (m^3/s)**	**Predicted Discharge (m^3/s) (*Power model*) $y_i' = 481.85x^{1.6537}$**	$(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
2009	9.95	21,530.00	21,528.41	1.59	2.53	0.00007	2,462.932	6,066,034.037
2010	9.79	20,986.00	20,958.93	27.07	732.78	0.00129	1,918.932	3,682,300.021
2011	8.56	16,794.08	16,785.87	8.21	67.40	0.00049	-2,272.988	5,166,474.448
2013	8.45	16,430.00	16,430.65	-0.65	0.42	-0.00004	-2,637.068	6,954,127.637
2014	9.40	19,595.26	19,596.27	-1.01	1.02	-0.00005	528.192	278,986.789
		$\sum$ = 95335.34	**$\sum$ = 95300.13**	**$\sum$ = 35.21**	**$\sum$ = 804.15**	**$\sum$ = 0.00176**		**$\sum$ = 22147922.932**

Computations of the model performance measures of the streamflow model of River Niger at Lokoja gauging station (p*ower model*).

Mean for the measured annual maximum discharge = 19067.068

Mean for the measured annual maximum discharge = 19060.026

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{804.15}{22147922.932} = 0.99996$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\ \text{or}\ S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{804.15}{5}} = 12.68$$

ii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{19060.026 - 19067.068}{19067.068}\right) = -0.037$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR}\ \text{or}\ \mathrm{MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{35.21}{5} = 7.042$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{5}\,(0.00176) = 0.9996$$

Table 4.24: Computations of the model performance measures of the streamflow models of River Niger at Lokoja gauging station (for the *polynomial model)*

Year	**Stage (h or x) metres**	**Measured Discharge (y_i or Q) (m^3/s)**	**Predicted Discharge (Polynomial model) $y_i' = -16.973x^3 + 456.51x^2 - 698.16x$ (m^3/s)**	**Residuals ($y_i - y_i'$)**	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
2009	9.95	21,530.00	21,529.26	0.74	0.55	0.000034	2,462.932	6,066,034.037
2010	9.79	20,986.00	20,992.80	- 6.80	46.24	-0.000324	1,918.932	3,682,300.021
2011	8.55	16,794.08	16,794.18	- 0.10	0.01	-0.000006	-2,272.988	5,166,474.448
2013	8.45	16,430.00	16,455.82	- 25.82	666.67	-0.001572	-2,637.068	6,954,127.637
2014	9.40	19,595.26	19,677.02	- 81.76	6, 684.70	-0.004172	528.192	278,986.789
			∑ = 95449.08	**∑ = -113.74**	**∑= 7,398.16**	**∑ = -0.00604**		**∑ = 22147922.932**

Computations of the model performance measures of the streamflow model of River Niger at Lokoja gauging station (*polynomial model*).

Mean for the measured annual maximum discharge = 19067.068

Mean for the measured annual maximum discharge =19089.816

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{\mathbf{7,398.16}}{\mathbf{22147922.932}} = 0.9997$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\ \text{or}\ S_{yx} = \sqrt{\frac{\sum(\mathbf{y_i} - \mathbf{y_i'})^2}{n}} = \sqrt{\frac{7{,}398.16}{5}} = 38.47$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\bar{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{19089.816 - 19067.068}{19067.068}\right) = 0.12$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR}\ \text{or}\ \mathrm{MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{-113.74}{5} = -22.748$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{5}(-0.00604) = 1.00$$

Table 4.25: Computations of the model performance measures of the streamflow models of River Niger at Lokoja gauging station (for the *ANOVA model for regression*)

Year	**Stage (h or x) metres**	**Measured Discharge (m^3/s) (y_i or Q)**	**Predicted Discharge (m^3/s) (*ANOVA model for regression*)** y = 3365.212x - 11967.088	**Residuals** $(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
2009	9.95	21,530.00	21,516.77	13.23	175.03	0.00061	2,462.932	6,066,034.037
2010	9.79	20,986.00	20,978.34	7.66	58.68	0.00037	1,918.932	3,682,300.021
2011	8.55	16,794.08	16,805.47	-11.39	129.73	-0.00068	-2,272.988	5,166,474.448
2013	8.45	16,430.00	16,468.95	-38.95	1517.10	-0.00237	-2,637.068	6,954,127.637
2014	9.40	19,595.26	19,665.90	-70.64	4990.01	-0.00360	528.192	278,986.789
			$\sum$ = **95435.43**	$\sum$ = **-100.09**	$\sum$ = **6870.55**	$\sum$ = **-0.00567**		$\sum$ = **22147922.932**

Computations of the model performance measures of the streamflow model of River Niger at Lokoja gauging station (*ANOVA model for regression*).

Mean for the measured annual maximum discharge = 19067.068

Mean for the measured annual maximum discharge =19087.086

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{6870.55}{22147922.932} = 0.9997$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\ \text{or}\ S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{6870.55}{5}} = 37.07$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{19087.086 - 19067.068}{19067.068}\right) = 0.105$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR}\ \text{or}\ \mathrm{MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{-100.09}{5} = -20.018$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{5}(-0.00567) = 1.001$$

The summary of streamflow models of River Niger at Lokoja gauging station obtained from Figures 4.7 and 4.8 for power and polynomial modelsrespectively and Table 4.14 for ANOVA model for regression are shown in Table 4.26.

Table 4.26 Summary of streamflow models of River Niger at Lokoja gauging station and the models evaluation parameters

RIVER	STREAMFLOW GAUGING STATION	STREAMFLOW MODEL [+]	MODEL EVALUATION PARAMETERS [*]						
			R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
River Niger	Lokoja	**Power model** $Q = 481.85h^{1.6537}$	0.9983	0.9991	0.99996	12.68	-0.037	7.042	0.9996
		Polynomial model $Q = -16.973h^3 + 456.51h^2 - 698.16h$	0.9992	0.9996	0.99967	38.47	0.12	-22.748	1.0012
		ANOVA model for regression $Q = 3365.212h - 11967.088$	0.9991	0.9995	0.99969	37.07	0.105	-20.018	1.0011

[+] Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

[*] **ModelEvaluation Parameters**

Coefficient of determination (R^2), Coefficient of correlation (R), Nash-Sutcliffe model Efficiency (NSE), Mean Absolute Relative Error (MARE), Root Mean Square Error (RMSE) or Standard error of estimate of discharge on stage ($S_{Q.h}$), Percentage BIAS (PBIAS), Mean Residue (MR).

4.3 Streamflow Modelling of River Niger at Onitsha Gauging Station

4.3.1 Streamflow Model Calibration of River Niger at Onitsha gauging station

The output of the Microsoft Excel programme for least square regression model calibration of streamflow data (Table 3.3) of River Niger at Onitsha streamflow gauging station are shown in Figures 4.13 and 4.14 for the power and polynomial models respectively and Table 4.27 for the ANOVA model for regression. The resulting equations are shown below:

$$y = 206.74x^{1.8456} \quad . \quad . \quad . \quad . \qquad (4.13)$$

$$y = -11.713x^3 + 527.48x^2 - 4363.2x + 17034 \quad . \quad . \quad . \qquad (4.14)$$

$$y = 2721.24x - 12630.79 \quad . \quad . \quad . \quad . \qquad (4.15)$$

Equations (4.13), (4.14) and (4.15) results in the following power model, polynomial model and ANOVA model for regression:

$$Q = 206.74h^{1.8456} \quad . \quad . \quad . \quad . \qquad (4.16)$$

$$Q = -11.713h^3 + 527.48h^2 - 4363.2h + 17034 \quad . \quad . \quad . \qquad (4.17)$$

$$Q = 2721.24h - 12630.79 \quad . \quad . \quad . \quad . \qquad (4.18)$$

Equations (4.16) is a power model, Equations (4.17) is a polynomial model while Equations (4.18) is ANOVA model for regression.

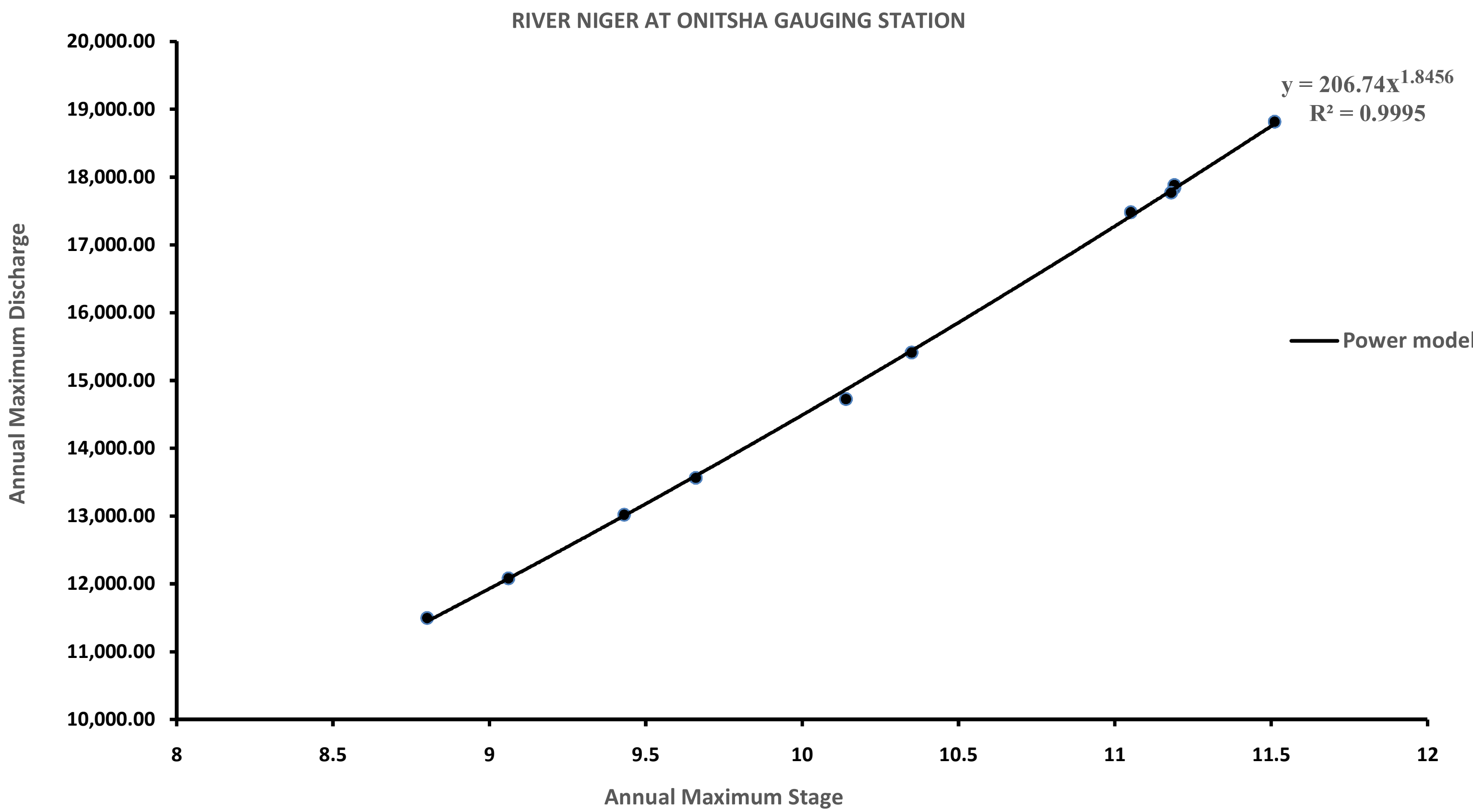


Figure 4.13: Plot of streamflow model calibration ofRiver Niger at Onitsha gauging station (power model)

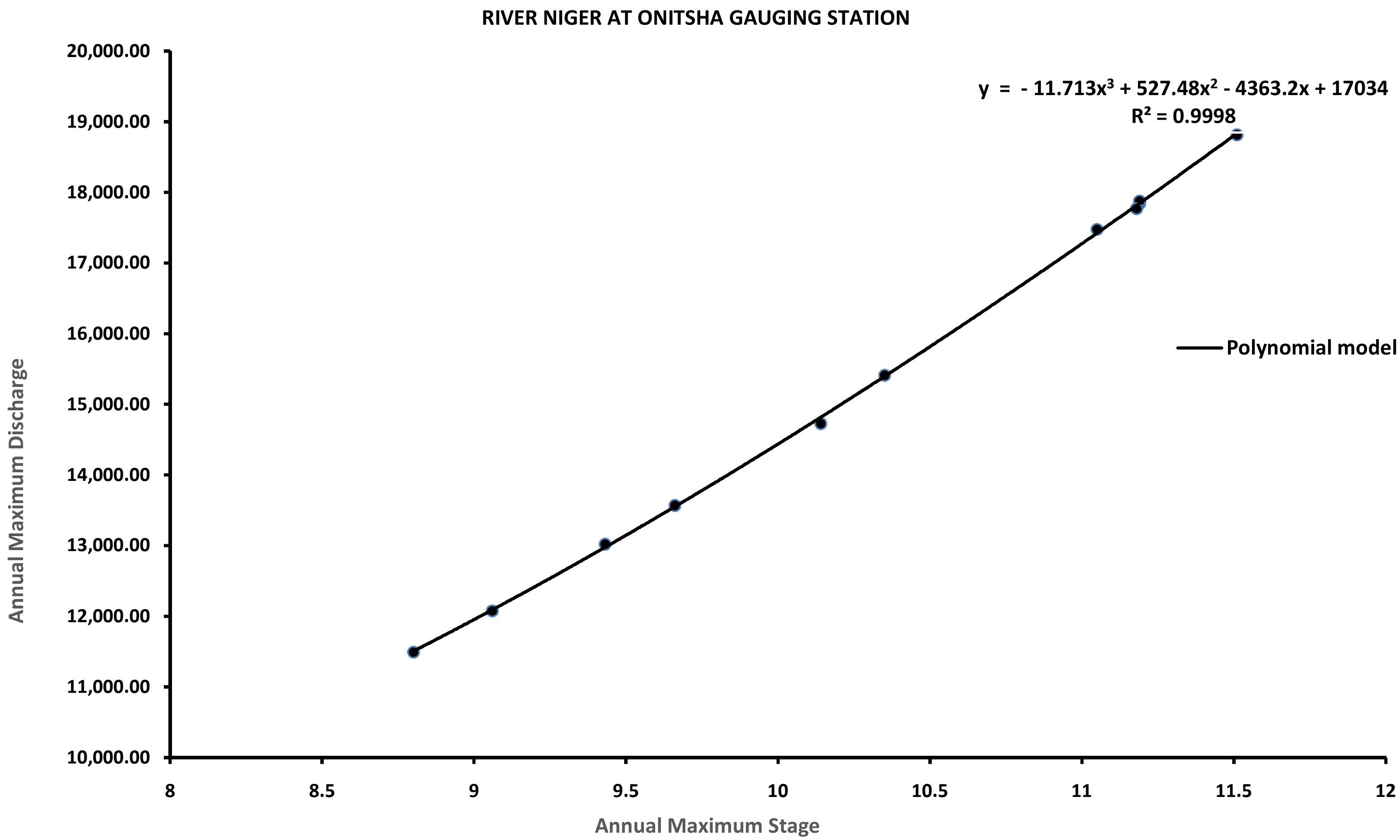


Figure 4.14: Plot of streamflow model calibration ofRiver Niger at Onitsha gauging station (polynomial model)

Table 4.27: Summary output of ANOVA model for regression of River Niger at Onitsha streamflow gauging station

Regression Statistics	
Multiple R	0.999019708
R Square	0.998040376
Adjusted R Square	0.99782264
Standard Error	122.9772792
Observations	11

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	69321450.03	69321450.03	4583.717858	1.69007E-13
Residual	9	136110.7009	15123.41121		
Total	10	69457560.73			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-12630.79235	416.5983934	-30.31886958	2.26018E-10	-13573.20339	-11688.38131
X Variable 1	2721.239661	40.19368765	67.70315988	1.69007E-13	2630.315223	2812.164099

From the coefficients section the fitted regression equation is obtained: $y = 2721.24x - 12630.79$

4.3.2 Verification of Streamflow Model of River Niger at Onitsha gauging station

Streamflow models verification of River Niger at Onitsha gauging station was tested by using stage and discharge data for the period of 1991, 1995, 2000 and 2001. The verification values are shown in Table 4.28.

Table 4.28: Verification of streamflow models of River Niger at Onitsha gauging station

S/N	Year	Annual Maximum Stage (h) (m)	Measured Annual Maximum Discharge (Q) (m^3/s)	Predicted Annual Maximum Discharge (Q) (m^3/s) (Power Model)	Predicted Annual Maximum Discharge (Q) (m^3/s) (Polynomial Model)	Predicted Annual Maximum Discharge (Q) (m^3/s) (ANOVA Model for Regression)
1	1991	11.29	18,159.08	18,124.93	18,159.08	18,092.01
2	1995	10.91	17,025.82	17,015.08	17,025.82	17,057.94
3	2000	10.76	16,629.33	16,585.83	16,629.33	16,649.75
4	2001	10.87	16,943.85	16,900.12	16,943.85	16,949.09

The results of the measured and predicted annual maximum discharge values of the streamflow models as presented in Table 4.28 were used to plot linear streamflow models verification graphs as shown in Figures 4.15 through 4.17.

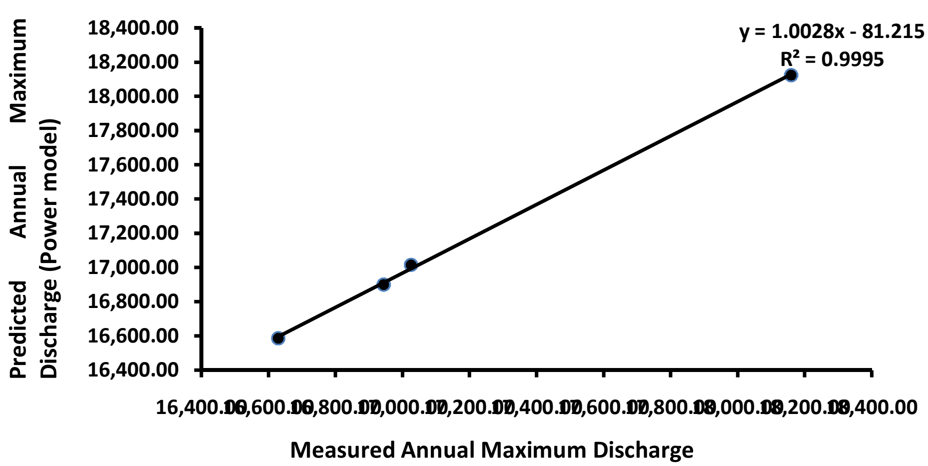


Figure 4.15: Verification of the streamflow models of River Niger at Onitsha gauging station (*Power model*)

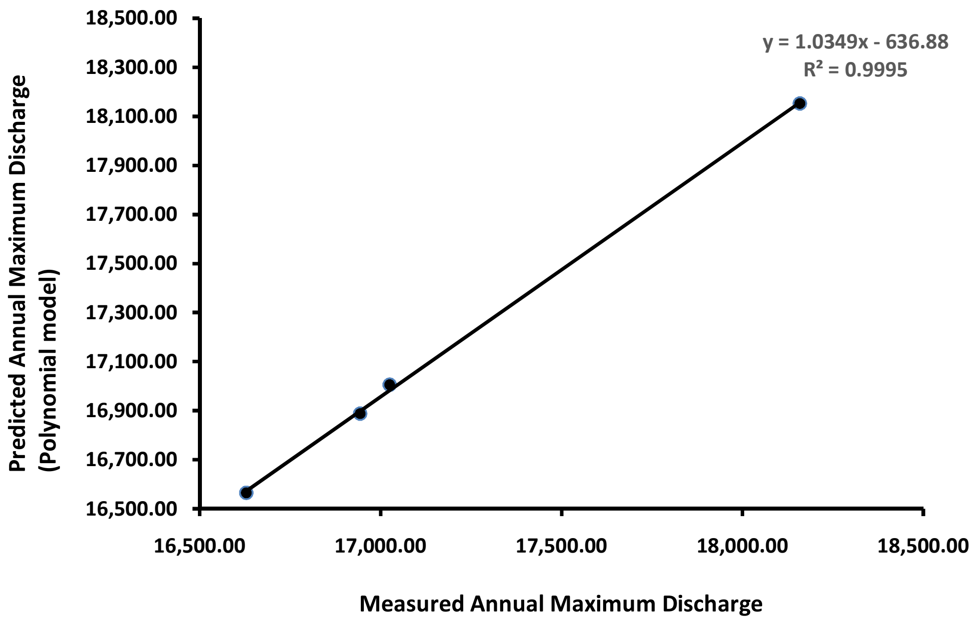


Figure 4.16: Verification of the streamflow models of River Niger at Onitsha gauging station (Polynomial model)

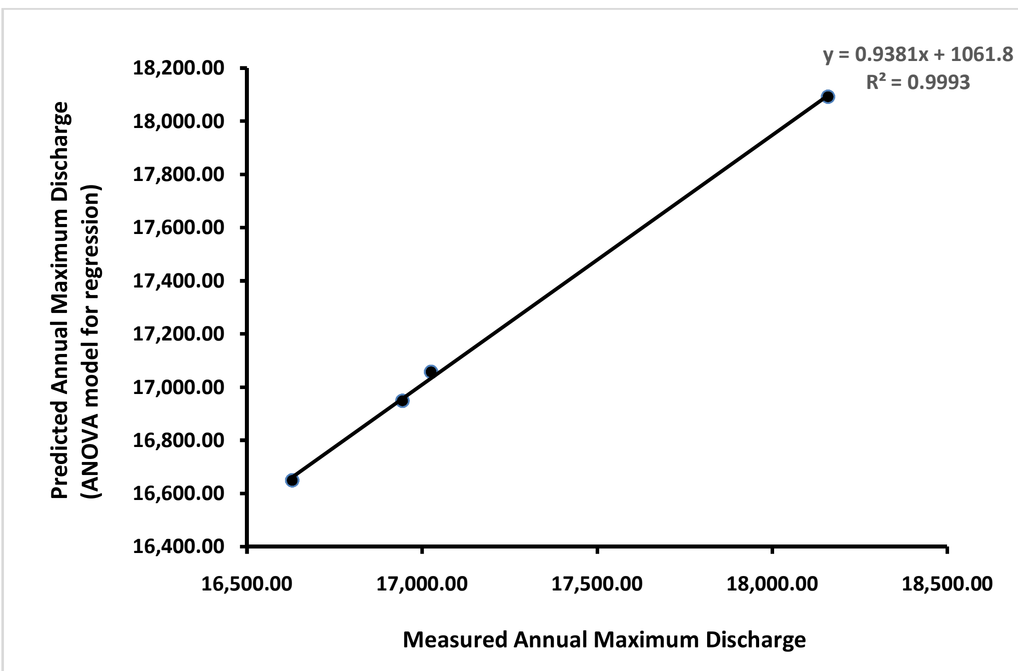


Figure 4.17: Verification of the streamflow models of River Niger at Onitsha gauging station (ANOVA model for regression)

4.3.3 Comparisons of the streamflow models of River Niger at Onitsha gauging station.

Comparisons of the streamflow models of River Niger at Onitsha gauging station comprise four subheadings: One-way ANOVA F-Test, Variance Ratio Test or Snedecor's F-distribution (F-Test), comparison using graph and finally comparison using Student's t-Test.

4.3.3.1 Comparison of the streamflow models of River Niger at Onitsha gauging station using One-way ANOVA F-Test

The comparison of the streamflow models verified for River Niger at Onitsha gauging station using One-way ANOVA F-Test is shown in Table 4.29.

Table 4.29: One-way ANOVA F-Testfor streamflow models of River Niger at Onitsha

Groups	Count	Sum	Average	Variance
Power model	4	68625.96	17156.49	449750.41
Polynomial model	4	68610.7	17152.68	478993.52
ANOVA model for regression	4	68748.79	17187.2	393646.05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2865.74372	2	1432.872	0.0032506	0.996756	4.256495
Within Groups	3967169.95	9	440796.7			
Total	3970035.69	11				

4.3.3.2 Comparison of the streamflow models of River Niger at Onitsha gauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test)

The Comparison of the streamflow models of River Niger at Onitsha gauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test) are shown in Tables 4.30 through 4.32.

Table 4.30: F-Test Two-Sample for Variances (Power model and Polynomial model)

	Power model	Polynomial model
Mean	17156.49	17152.675
Variance	449750.4114	478993.5193
Observations	4	4
df	3	3
F	0.938948844	
P(F<=f) one-tail	0.479958239	
F Critical one-tail	0.107797789	

Table 4.31: F-Test Two-Sample for Variances (Power model and ANOVA model for regression)

	Power model	ANOVA model for regression
Mean	17156.49	17187.1975
Variance	449750.4114	393646.0528
Observations	4	4
df	3	3
F	1.142524886	
P(F<=f) one-tail	0.45768208	
F Critical one-tail	9.276628153	

Table 4.32: F-Test Two-Sample for Variances (Polynomial model and ANOVA model for regression)

	Polynomial model	ANOVA model for regression
Mean	17152.675	17187.1975
Variance	478993.5193	393646.0528
Observations	4	4
df	3	3
F	1.216812708	
P(F<=f) one-tail	0.437835575	
F Critical one-tail	9.276628153	

4.3.3.3 Comparison of the streamflow model of River Niger at Onitsha gauging station using graph

The comparison of the streamflow models verified for River Niger at Onitsha streamflow gauging station using graph is shown in Figure 4.18.

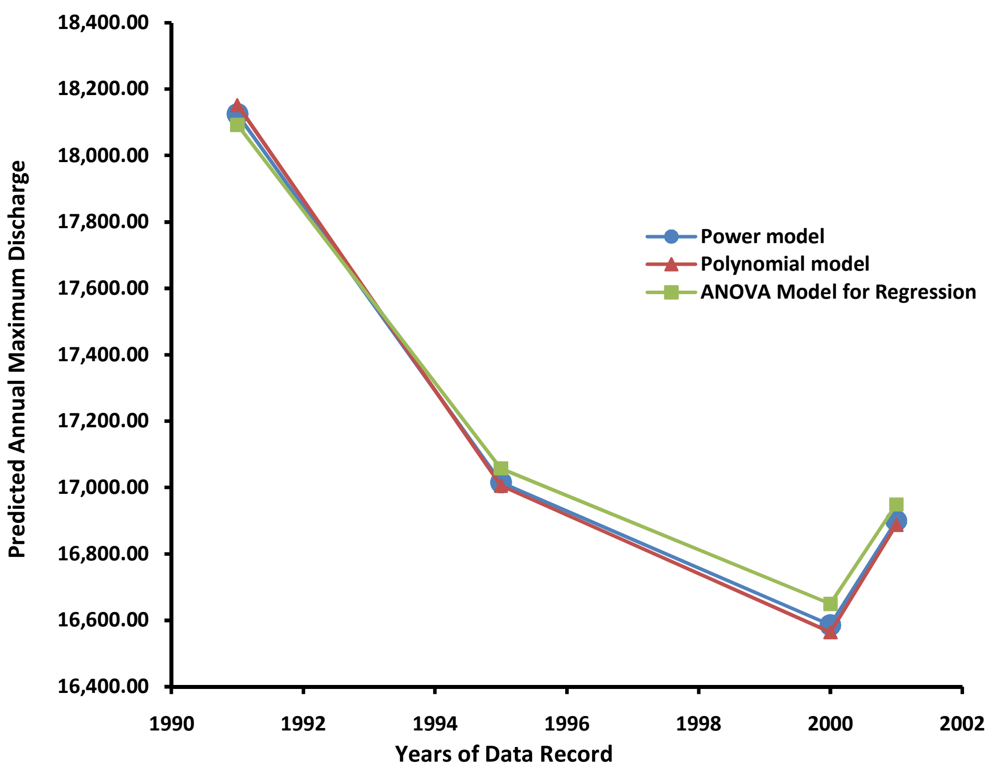


Figure 4.18: Comparison of the streamflow models verified for River Niger at Onitsha streamflow gauging station using graph

4.3.3.4 Comparison of the streamflow models of River Niger at Onitsha gauging station using Student's t-Test

The streamflow models of River Niger at Onitsha gauging station are further compared using Student's t-Test (distribution) as shown in Tables 4.33 through 4.35.

Table 4.33: t-Test: Paired Two Sample for Means (Power and Polynomial models)

	Power model	Polynomial model
Mean	17156.49	17152.675
Variance	449750.4114	478993.5193
Observations	4	4
Pearson Correlation	0.999999399	
Hypothesized Mean Difference	0	
df	3	
t Stat	0.35534242	
P(T<=t) one-tail	0.372924275	
t Critical one-tail	2.353363435	
P(T<=t) two-tail	0.745848551	
t Critical two-tail	3.182446305	

Table 4.34: t-Test: Paired Two Sample for Means (Power model and ANOVA model for regression)

	Power model	ANOVA model for regression
Mean	17156.49	17187.1975
Variance	449750.4114	393646.0528
Observations	4	4
Pearson Correlation	0.999988803	
Hypothesized Mean Difference	0	
df	3	
t Stat	-1.417344997	
P(T<=t) one-tail	0.125694133	
t Critical one-tail	2.353363435	
P(T<=t) two-tail	0.251388267	
t Critical two-tail	3.182446305	

Table 4.35: t-Test: Paired Two Sample for Means (Polynomial model and ANOVA model for regression)

	Polynomial model	ANOVA model for regression
Mean	17152.675	17187.1975
Variance	478993.5193	393646.0528
Observations	4	4
Pearson Correlation	0.999983011	
Hypothesized Mean Difference	0	
df	3	
t Stat	-1.065585863	
P(T<=t) one-tail	0.182380919	
t Critical one-tail	2.353363435	
P(T<=t) two-tail	0.364761837	
t Critical two-tail	3.182446305	

4.3.4 Computations of the model performance measures of the streamflow models of River Niger at Onitsha gauging station

Computations of Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias, root mean square error or standard error of estimateand mean of residue or mean absolute error which are used as tools for the evaluation of the streamflow models ofRiver Niger at Onitsha gauging stationare shown in Tables 4.36 and 4.37 for the power and polynomial models respectively and Table 4.38 for the ANOVA model for regression.

Table 4.36: Computations of the model performance measures of the streamflow models of River Niger at Onitsha gauging station (for the *power model*)

Year	**Stage (h or x) metres**	**Measured Discharge (m^3/s) (y_i or Q)**	**Predicted Discharge (m^3/s) (*Power model*) $y_i' = 206.74x^{1.8456}$**	**Residuals $(y_i - y_i')$**	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1991	11.29	18,159.08	18,124.93	34.15	1,166.22	0.00188	969.56	940,046.59
1995	10.91	17,025.82	17,015.08	10.74	115.35	0.00063	-163.7	26,797.69
2000	10.76	16,629.33	16,585.83	43.5	1, 892.25	0.00262	-560.19	313,812.84
2001	10.87	16,943.85	16,900.12	43.73	1,912.31	0.00258	-245.67	60,353.75
		∑=68758.08	**∑=68625.96**	**∑=132.12**	**∑= 5,086.1**	**∑=0.00771**		**∑=1341010.87**

Computations of the model performance measures of the streamflow model of River Niger at Onitsha gauging station (*power model*)

Mean of the measured annual maximum discharge = 17189.52

Mean of the measured annual maximum discharge = 17156.49

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{5{,}086.1}{1341010.87} = 0.9962$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE}) \text{ or } S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{5{,}086.1}{4}} = 35.66$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{17156.49 - 17189.52}{17189.52}\right) = -0.192$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR} \text{ or } \mathrm{MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{132.12}{4} = 33.03$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{4}(0.00771) = 0.9981$$

Table 4.37: Computations of the model performance measures of the streamflow models of River Niger at Onitsha s gauging station (for the *polynomial model*)

Year	**Stage (h or x) metres**	**Measured Discharge (m^3/s) (y_i or Q)**	**Predicted Discharge (m^3/s) (*Polynomial model*)** $y_i' = -11.713x^3 + 527.48x^2 - 4363.2x + 17034$	**Residuals** $(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1991	11.29	18,159.08	18,152.41	6.67	44.49	0.00037	969.56	940,046.59
1995	10.91	17,025.82	17,005.97	19.85	394.02	0.00117	-163.7	26,797.69
2000	10.76	16,629.33	16,564.67	64.66	4,180.92	0.00389	-560.19	313,812.84
2001	10.87	16,943.85	16,887.65	56.20	3,158.44	0.00332	-245.67	60,353.75
			$\sum$ = 68610.7	**$\sum$= 147.38**	**$\sum$= 7,777.87**	**$\sum$=0.00875**		**$\sum$ = 1341010.87**

Computations of the model performance measures of the streamflow model of River Niger at Onitsha gauging station (*polynomial model*).

Mean for the measured annual maximum discharge = 17189.52

Mean for the measured annual maximum discharge = 17152.675

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{7{,}777.87}{1341010.87} = 0.9942$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\ \text{or}\ S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{7{,}777.87}{4}} = 44.10$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{17152.675 - 17189.52}{17189.52}\right) = -0.002$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR\ \ or\ \ MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{147.38}{4} = 36.85$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{4}(0.00875) = 0.9978$$

Table 4.38: Computations of the model performance measures of the streamflow models of River Niger at Onitsha s gauging station (for the *ANOVA model for regression*)

Year	Stage (h or x) metres	Measured Discharge (y_i or Q) (m^3/s)	Predicted Discharge $Q = 2721.24h - 12630.79$ (*ANOVA model for regression*) (m^3/s)	Residuals $(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1991	11.29	18,159.08	18,092.01	67.07	4,498.38	0.0037	969.56	940,046.59
1995	10.91	17,025.82	17,057.94	- 32.12	1,031.69	-0.0019	-163.7	26,797.69
2000	10.76	16,629.33	16,649.75	- 20.42	416.98	-0.0012	-560.19	313,812.84
2001	10.87	16,943.85	16,949.09	-5.24	183.06	-0.0003	-245.67	60,353.75
			$\sum$ =68748.79	**$\sum$ = 9.29**	**$\sum$ = 27,163.71**	**$\sum$ =0.0003**		**$\sum$ =1341010.87**

Computations of the model performance measures of the streamflow model of River Niger at Onitsha gauging station (*ANOVA model for regression model*).

Mean for the measured annual maximum discharge = 17189.52

Mean for the measured annual maximum discharge = 17187.198

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{27{,}163.71}{1{,}341{,}010.87} = 0.9797$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\ \text{or}\ S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{5{,}974.51}{4}} = 38.65$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{17187.198 - 17189.52}{17189.52}\right) = -0.014$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR\ or\ MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{9.29}{4} = 2.32$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{4}(0.0003) = 0.9999$$

The summary of streamflow models of River Niger at Onitsha gauging station obtained from Figures 4.21 and 4.22 for the power and polynomial modelsand Table 4.8 for the ANOVA model for regression are shown in Table 4.39.

Table 4.39 Summary of streamflow models of River Niger at Onitsha gauging station and the models evaluation parameters

RIVER	**STREAMFLOW GAUGING STATION**	**STREAMFLOW MODEL** +	**MODEL EVALUATION PARAMETERS** *						
			R^2	**R**	**NSE**	**RMSE or S_{QH}**	**PBIAS**	**MR or MAE**	**MARE**
River Niger	Onitsha	**Power model** $Q = 206.74h^{1.8456}$	0.9995	0.9997	0.9962	35.66	-0.192	33.03	0.9981
		Polynomial model $Q = -11.713h^3 + 527.48h^2 - 4363.2h + 17034$	0.9998	0.9999	0.9942	44.10	-0.002	36.85	0.9978
		ANOVA model for regression $Q = 2721.24h - 12630.79$	0.9980	0.9990	0.9797	38.65	-0.014	2.32	0.9999

+ Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

* **ModelEvaluation Parameters**

Coefficient of determination (R^2), Coefficient of correlation (R), Nash-Sutcliffe model Efficiency (NSE), Mean Absolute Relative Error (MARE), Root Mean Square Error (RMSE) or Standard error of estimate of discharge on stage ($S_{Q.h}$), Percentage BIAS (PBIAS), Mean Residue (MR).

4.4 Streamflow Modelling of Owena River

4.4.1 Streamflow Model Calibration of Owena River at Owena village gauging station

The outputs of the Microsoft Excel programme for least square regression model calibration of streamflow data (Table 3.4) of Owena River at Owena village streamflow gauging station are shown in Figures 4.19 and 4.20 for the power and polynomial models respectively and Table 4.40 for the ANOVA model for regression. The resulting equations are shown below:

$$y = 6.2766x^{2.7607} \quad . \quad . \quad . \quad . \qquad (4.19)$$

$$y = 14.714x^3 - 61.991x^2 + 125.69x - 78.708 \quad . \quad . \quad . \qquad (4.20)$$

$$y = 63.671x - 79.406 \quad . \quad . \quad . \quad . \qquad (4.21)$$

Equations (4.19), (4.20) and (4.21) results in the following power model, polynomial model and ANOVA model for regression:

$$Q = 6.2766h^{2.7607} \quad . \quad . \quad . \quad . \qquad (4.22)$$

$$Q = 14.714h^3 - 61.991h^2 + 125.69h - 78.708 \quad . \quad . \quad . \qquad (4.23)$$

$$Q = 63.671h - 79.406 \quad . \quad . \quad . \quad . \qquad (4.24)$$

Equations (4.22) is a power model, Equations (4.23) is a polynomial model while Equations (4.24) is ANOVA model for regression.

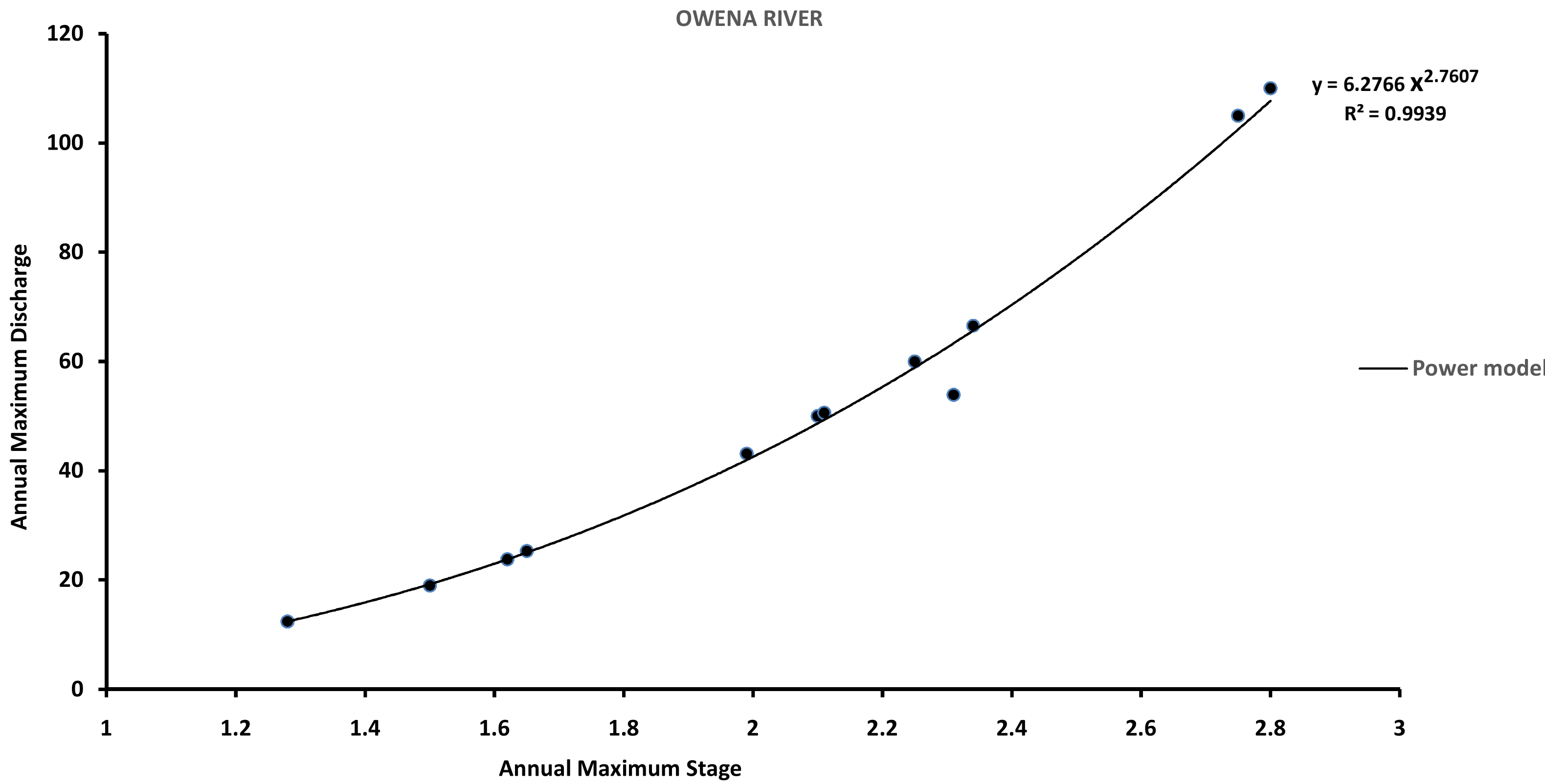


Figure 4.19: Plot of streamflow model calibration of Owena River at Owena village gauging station (Power model)

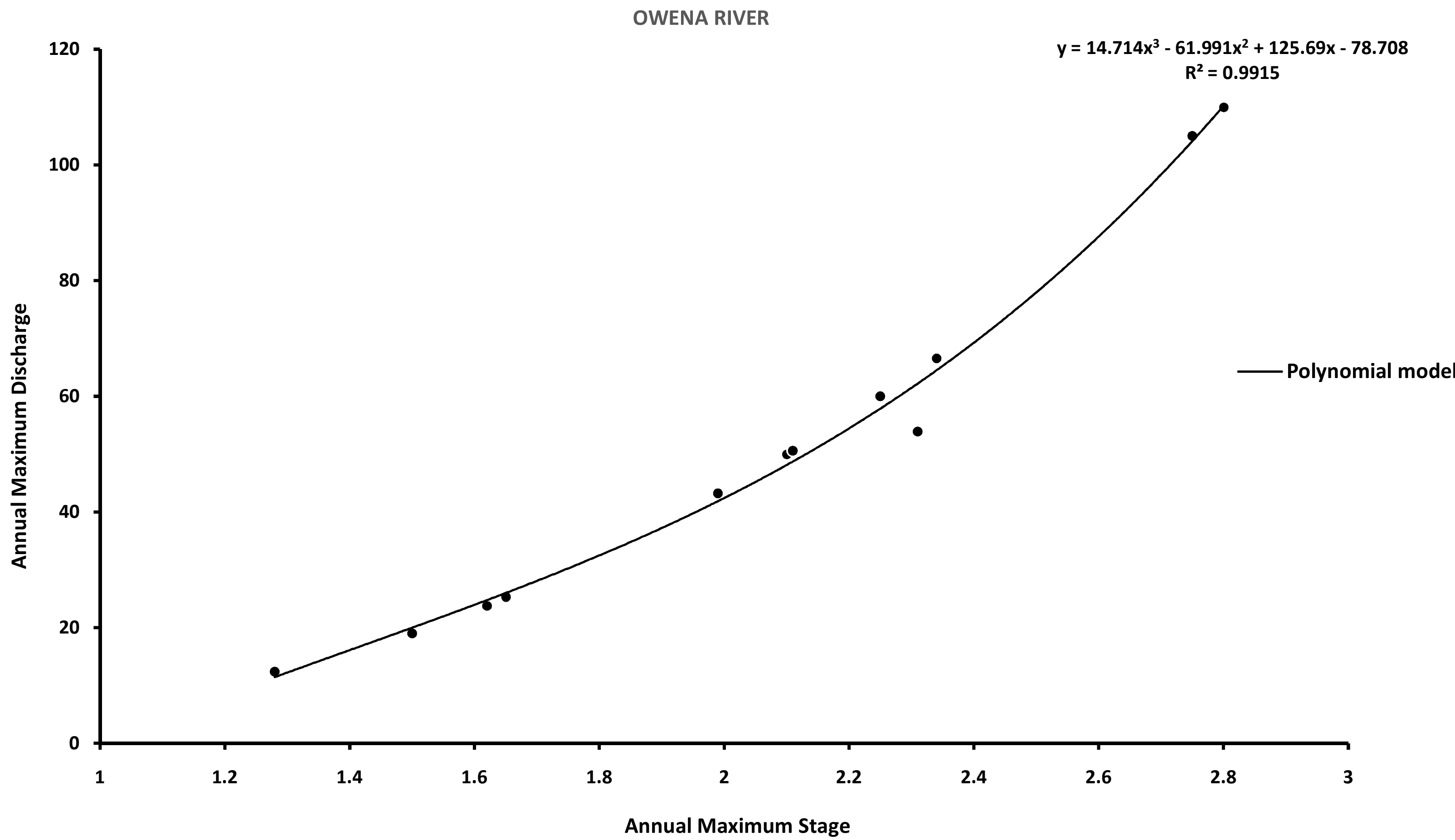


Figure 4.19: Plot of streamflow model calibration of Owena River at Owena village gauging station (Polynomial model)

Table 4.40: Summary output of ANOVA model for regression for Owena River at Owena village streamflow gauging station

Regression Statistics	
Multiple R	0.971901738
R Square	0.944592988
Adjusted R Square	0.939052287
Standard Error	7.700064182
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	10108.08012	10108.08012	170.4825706	1.31583E-07
Residual	10	592.9098841	59.29098841		
Total	11	10700.99			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-79.40601864	10.28048349	-7.723957602	1.59937E-05	-102.3123633	-56.49967395
X Variable 1	63.67094023	4.876421872	13.05689743	1.31583E-07	52.8055952	74.53628526

From the coefficients section the fitted regression equation is obtained: $y = 63.671x - 79.406$

4.4.2 Verification of Streamflow Models of Owena River at Owena village gauging station

Verificationof the streamflow models of Owena River at Owena village gauging station was carried out. The verified records are tabulated in Table 4.41.

Table 4.41: Verification of streamflow models of Owena River at Owena villagegauging station

S/N	Year	Annual Maximum Stage (h) (m)	Measured Annual Maximum Discharge (Q) (m^3/s)	Predicted Annual Maximum Discharge (Q) (m^3/s) (Power Model)	Predicted Annual Maximum Discharge (Q) (m^3/s) (Polynomial Model)	Predicted Annual Maximum Discharge (Q) (m^3/s) (ANOVA Model for regression)
1	1989	1.50	19.0	19.22	20.01	16.10
2	1990	1.28	12.4	12.41	11.50	2.09
3	1991	2.75	105.0	102.47	104.10	95.69
4	1992	2.34	66.6	65.62	64.50	69.58
5	1993	2.10	50.0	48.67	48.10	54.30
6	1994	2.11	50.6	49.31	48.70	54.94
7	1995	2.31	53.9	63.32	62.20	67.67
8	1996	2.80	110.0	107.69	110.20	98.87
9	1997	1.62	23.8	23.78	24.80	23.74
10	1998	2.25	60.0	58.88	57.90	63.85
11	1999	1.65	25.3	25.01	26.00	25.65
12	2000	1.99	43.2	41.95	41.90	47.30

The results of the measured and predicted discharge values of the streamflow models as presented in Table 4.41 were used to plot linear streamflow model verificationgraphs are shown in Figures 4.21 through 4.23.

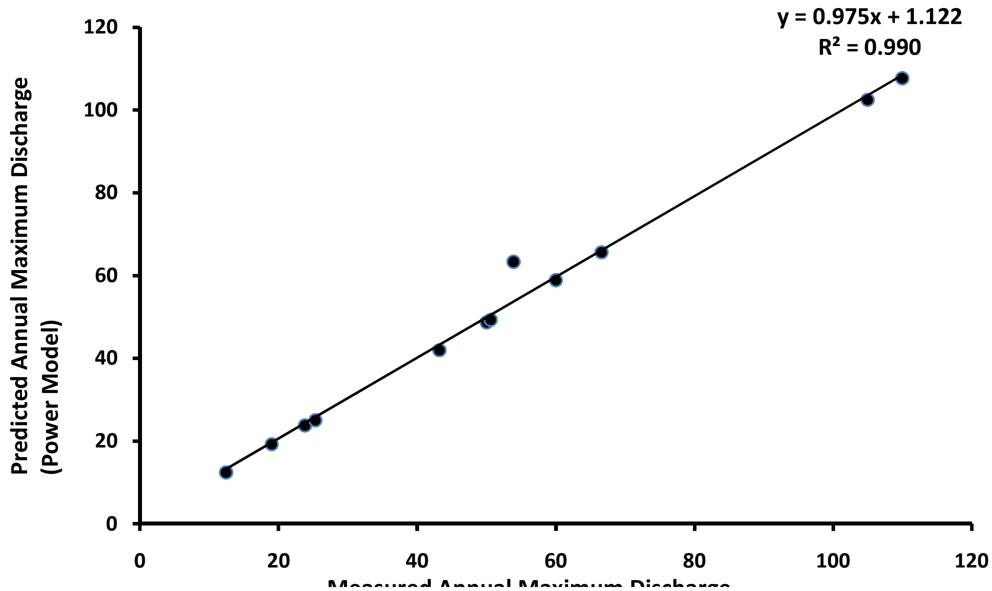


Figure 4.21: Verification of the streamflow model Owena River at Owena villagegauging station (for the power model)

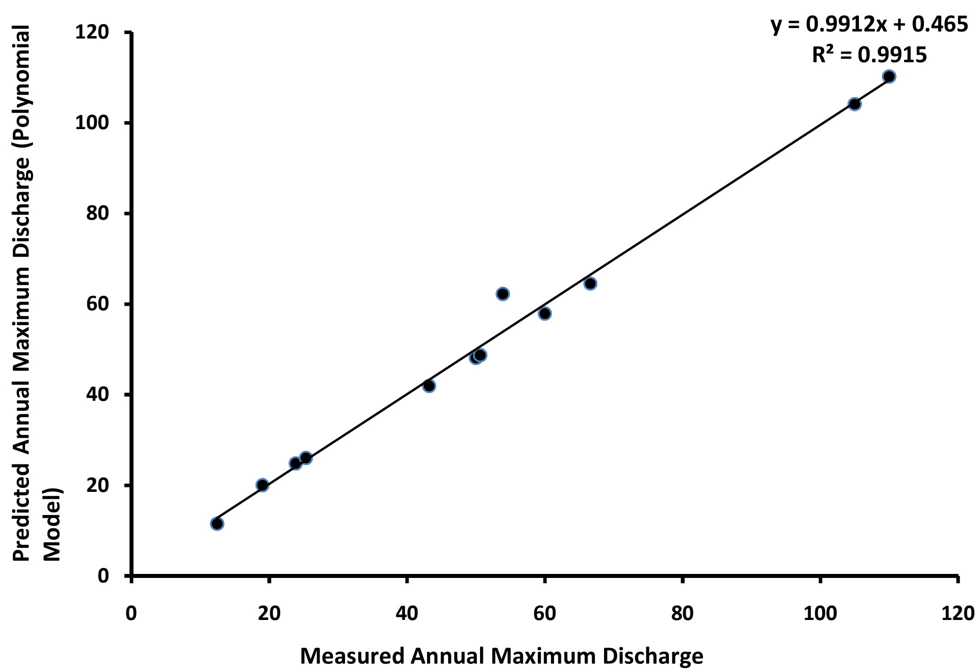


Figure 4.22: Verification of the streamflow model of Owena River at Owena village gauging station (for the polynomial model)

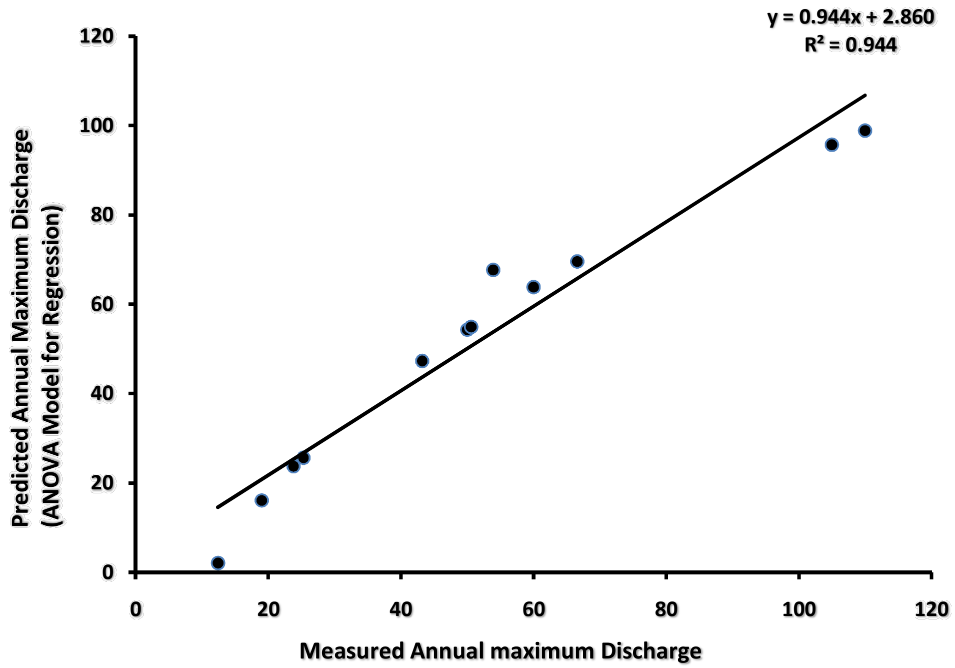


Figure 4.23: Verification of the streamflow model of Owena River at Owena village gauging station (for the ANOVA model for regression)

4.4.3 Comparisons of the streamflow models of Owena River at Owena village gauging station

Comparisons of the streamflow models of Owena River at Owena village gauging station comprises four subheadings: One-way ANOVA F-Test, Variance Ratio Test or Snedecor's F distribution (F-Test), comparison using graph and finally comparison using student's t-test.

4.4.3.1 Comparison of the streamflow models of Owena River at Owena village gauging station using One-way ANOVA F-Test

The comparison of the streamflow models verified for Owena River at Owena village gauging station using one-way ANOVAF-Test is shown in Table 4.42.

Table 4.42: One-way ANOVA F-Testfor streamflow models of Owena River

Groups	*Count*	*Sum*	*Average*	***Variance***		
Power model	12	618.33	51.5275	935.722875		
Polynomial model	12	619.91	51.6592	963.901463		
ANOVA model for regression	12	619.78	51.6483	918.904415		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.128217	2	0.06411	6.8236E-05	0.99993	3.28492
Within Groups	31003.82	33	939.51			
Total	31003.94	35				

4.4.3.2 Comparison of the streamflow models of Owena River at Owena village gauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test)

The Comparison of the streamflow models of Owena River at Owena villagegauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test) are shown in Tables 4.43 through 4.45.

Table 4. 43: F-Test Two-Sample for Variances (Power model and Polynomial model)

	Power model	**Polynomial model**
Mean	51.5275	51.65916667
Variance	935.722875	963.9014629
Observations	12	12
df	11	11
F	0.970766112	
P(F<=f) one-tail	0.480819598	
F Critical one-tail	0.35487036	

Table 4.44: F-Test Two-Sample for Variances (Power model and ANOVA model for regression)

	Power model	**ANOVA model for regression**
Mean	51.5275	51.64833333
Variance	935.722875	918.9044152
Observations	12	12
df	11	11
F	1.01830273	
P(F<=f) one-tail	0.488271957	
F Critical one-tail	2.81793047	

Table 4.45: F-Test Two-Sample for Variances (Polynomial model and ANOVA model for regression)

	Power model	**ANOVA model for regression**
Mean	51.5275	51.64833333
Variance	935.722875	918.9044152
Observations	12	12
df	11	11
F	1.01830273	
P(F<=f) one-tail	0.488271957	
F Critical one-tail	2.81793047	

4.4.3.3 Comparisonof the streamflow models of Owena River at Owena village gauging station using graph

The comparison of the streamflow models verified for Owena River at Owena villagegauging station using graph is shown in Figure 4.24.

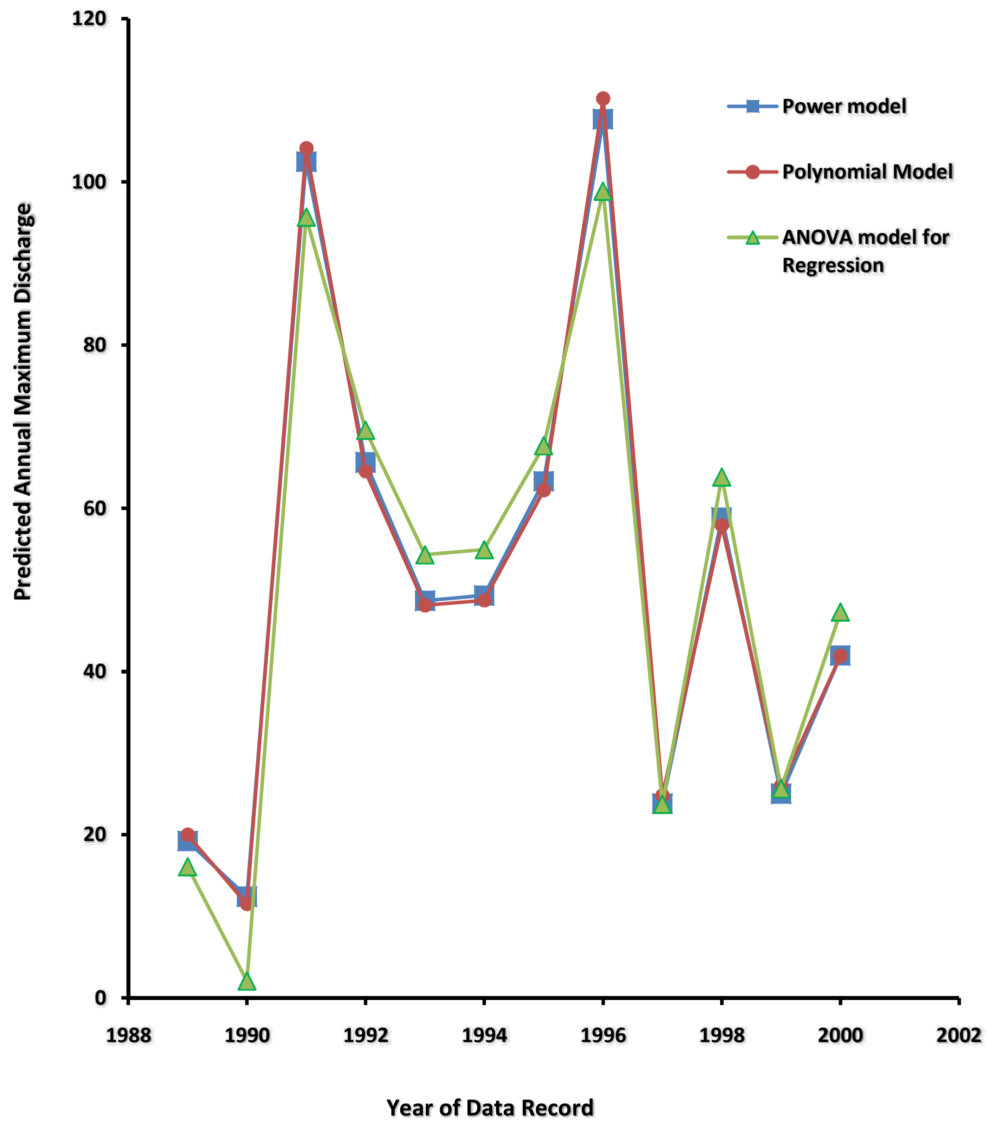


Figure 4.24: Comparison of the streamflow models verified for Owena River at Owena village streamflow gauging station using graph

4.4.3.4 Comparisonof the streamflow models of Owena River at Owena village gauging station using Student's t-Test

The streamflow models of Owena River at Owena village gauging station are further compared using Student's t-Test (distribution) as shown in Tables 4.46 through 4.48.

Table 4.46: t-Test: Paired Two Sample for Means (Power and Polynomial models)

	Power model	Polynomial model
Mean	51.5275	51.65916667
Variance	935.722875	963.9014629
Observations	12	12
Pearson Correlation	0.999325569	
Hypothesized Mean Difference	0	
df	11	
t Stat	-0.373652999	
P(T<=t) one-tail	0.357881992	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.715763985	
t Critical two-tail	2.20098516	

Table 4.47: t-Test: Paired Two Sample for Means (Power model and ANOVA model for regression)

	Power model	ANOVA model for regression
Mean	51.5275	51.64833333
Variance	935.722875	918.9044152
Observations	12	12
Pearson Correlation	0.980847311	
Hypothesized Mean Difference	0	
df	11	
t Stat	-0.070158031	
P(T<=t) one-tail	0.47266355	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.945327099	
t Critical two-tail	2.20098516	

Table 4.48: t-Test: Paired Two Sample for Means (Polynomial model and ANOVA model for regression)

	Polynomial model	**ANOVA model for regression**
Mean	51.65916667	51.64833333
Variance	963.9014629	918.9044152
Observations	12	12
Pearson Correlation	0.976047763	
Hypothesized Mean Difference	0	
df	11	
t Stat	0.005556024	
P(T<=t) one-tail	0.49783322	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.995666439	
t Critical two-tail	2.20098516	

4.4.4 Computations of the model performance measures of the streamflow model of Owena River

Computations of Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias, root mean square error or standard error of estimateand mean of residue or mean absolute error which are used as tools for the evaluation of the streamflow models ofOwena River at Owena village gauging stationare shown in Tables 4.49 and 4.50 for the power and polynomial models respectively and Table 4.51 for the ANOVA model for regression.

Table 4.49: Computations of the model performance measures of the streamflow models of Owena River at Owena village gauging station(for the *power model*)

Year	Stage (x or h) metres	Measured Discharge (y_i or Q) m^3/s	Predicted Discharge $y_i' = 6.276x^{2.760}$ (m^3/s) (Power model)	Residuals $(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1989	1.50	19.0	19.22	- 0.22	0.05	- 0.0116	- 32.65	1,066.0225
1990	1.28	12.4	12.41	- 0.01	0.00	- 0.0008	- 39.25	1,540.5625
1991	2.75	105.0	102.47	2.53	6.40	0.0241	53.35	2,846.2225
1992	2.34	66.6	65.62	0.98	0.96	0.0147	14.95	223.5025
1993	2.10	50.0	48.67	1.33	1.77	0.0266	- 1.65	2.7225
1994	2.11	50.6	49.31	1.29	1.66	0.0255	- 1.05	1.1025
1995	2.31	53.9	63.32	9.42	88.74	0.1748	2.25	5.0625
1996	2.80	110.0	107.69	2.31	5.34	0.021	58.35	3,404.7225
1997	1.62	23.8	23.78	0.02	0.00	0.0008	- 27.85	775.6225
1998	2.25	60.0	58.88	1.12	1.25	0.0187	8.35	69.7225
1999	1.65	25.3	25.01	0.29	0.08	0.0115	- 26.35	694.3225
2000	1.99	43.2	41.95	1.25	1.56	0.0289	- 8.45	71.4025
		$\sum$ = 619.8	**$\sum$ = 618.33**	**$\sum$ = 20.31**	**$\sum$ = 107.81**	**$\sum$ = 0.3342**		**$\sum$ = 10,700.99**

Computations of the model performance measures of the streamflow model of Owena River at Owena village gauging station (*power model*).

Mean of the measured annual maximum discharge $= 51.65$

Mean of the predicted annual maximum discharge $= 51.53$

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{107.81}{10{,}700.99} = 0.9899$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\text{ or } S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{107.81}{12}} = 3.0$$

iii Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{51.53 - 51.65}{51.65}\right) = -0.23$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR\ \ or\ \ MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{20.31}{12} = 1.69$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{12}(0.3342) = 0.9722$$

Table 4.50: Computations of the model performance measures of the streamflow models of Owena River streamflow modelat Owena village gauging station (for the *polynomial model*)

Year	Stage (x or h) metres	Discharge (y_i or Q) m^3/s	Predicted Discharge (m^3/s) $y_i' = 14.714x^3 - 61.991x^2 + 125.69x - 78.708$ (Polynomial model)	Residuals $(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1989	1.50	19.0	20.01	-1.01	1.02	- 0.0532	- 32.65	1,066.0225
1990	1.28	12.4	11.50	0.90	0.81	0.0726	- 39.25	1,540.5625
1991	2.75	105.0	104.10	0.90	0.81	0.0086	53.35	2,846.2225
1992	2.34	66.6	64.50	2.10	4.41	0.0315	14.95	223.5025
1993	2.10	50.0	48.10	1.90	3.61	0.0380	- 1.65	2.7225
1994	2.11	50.6	48.70	1.90	3.61	0.0375	- 1.05	1.1025
1995	2.31	53.9	62.20	-8.30	68.89	- 0.1540	2.25	5.0625
1996	2.80	110.0	110.20	-0.20	0.04	- 0.0018	58.35	3,404.7225
1997	1.62	23.8	24.80	-1.00	1.00	- 0.0420	- 27.85	775.6225
1998	2.25	60.0	57.90	2.10	4.41	0.0350	8.35	69.7225
1999	1.65	25.3	26.00	-0.70	0.49	- 0.0277	- 26.35	694.3225
2000	1.99	43.2	41.90	1.30	1.69	0.0301	- 8.45	71.4025
		$\sum$ = 619.8	**$\sum$ = 619.91**	**$\sum$= - 0.11**	**$\sum$= 90.79**	**$\sum$= -0.0254**		**$\sum$ = 10,700.99**

Computations of the model performance measures of the streamflow model of Owena River at Owena village gauging station (*polynomial model*).

Mean of the measured annual maximum discharge = 51.65

Mean of the predicted annual maximum discharge = 51.66

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{90.79}{10{,}700.99} = 0.9915$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE}) \text{ or } S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{90.79}{12}} = 2.75$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{51.66 - 51.65}{51.65}\right) = 0.019$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR} \text{ or } \mathrm{MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{-0.11}{12} = -0.009$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{12}(-0.0254) = 1.00$$

Table 4.51: Computations of the model performance measures of the streamflow model of Owena River at Owena village gauging station (for the *ANOVA model for regression*)

Year	Stage (x or h) metres	Discharge (y_i or Q) m^3/s	Predicted Discharge (m^3/s) $y = 63.671x - 79.406$ (ANOVA model for Regression)	Residuals $(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1989	1.50	19.0	16.10	2.90	8.41	0.153	- 32.65	1,066.0225
1990	1.28	12.4	2.09	10.31	106.30	0.831	- 39.25	1,540.5625
1991	2.75	105.0	95.69	9.31	86.68	0.089	53.35	2,846.2225
1992	2.34	66.6	69.58	- 2.98	8.88	-0.045	14.95	223.5025
1993	2.10	50.0	54.30	- 4.30	18.49	-0.086	- 1.65	2.7225
1994	2.11	50.6	54.94	- 4.34	18.84	-0.086	- 1.05	1.1025
1995	2.31	53.9	67.67	- 13.77	189.61	-0.255	2.25	5.0625
1996	2.80	110.0	98.87	11.13	123.88	0.101	58.35	3,404.7225
1997	1.62	23.8	23.74	0.06	0.00	0.003	- 27.85	775.6225
1998	2.25	60.0	63.85	- 3.85	14.82	-0.064	8.35	69.7225
1999	1.65	25.3	25.65	- 0.35	0.12	-0.014	- 26.35	694.3225
2000	1.99	43.2	47.30	- 4.10	16.81	-0.095	- 8.45	71.4025
			∑= 619.78	**∑= 0.02**	**∑= 592.84**	**∑ = 0.532**		**∑ = 10,700.99**

Computations of the model performance measures of the streamflow model of Owena River at Owena village gauging station (*ANOVA model for regression*).

Mean of the measured annual maximum discharge = 51.65

Mean of the predicted annual maximum discharge = 51.648

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{592.84}{10{,}700.99} = 0.9446$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE}) \text{ or } S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{592.84}{12}} = 7.03$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{51.648 - 51.65}{51.65}\right) = -0.004$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR} \text{ or } \mathrm{MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{0.02}{12} = 0.002$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{12}(0.532) = 0.9557$$

The summary of streamflow models of Owena River obtained from Figure 4.19 (power model), Figure 4.20 (polynomial model) and Table 4.40 (ANOVA model for regression) are shown in Table 4.52.

Table 4.52: Summary of streamflow model of Owena River at Owena village gauging station and the models evaluation parameters

RIVER	STREAMFLOW GAUGING STATION	STREAMFLOW MODEL +	MODEL EVALUATION PARAMETERS *						
			R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
Owena River	Owena Village	**Power model** $Q = 6.2766h^{2.7607}$	0.9939	0.9969	0.9899	3.0	-0.23	1.69	0.9722
		Polynomial model $Q = 14.714h^3 - 61.991h^2 + 125.69h - 78.708$	0.9915	0.9957	0.9915	2.75	0.019	-0.009	1.00
		ANOVA model for regression $Q = 63.671h - 79.406$	0.9446	0.9719	0.9446	7.03	-0.004	0.002	0.9557

+ Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

* **ModelEvaluation Parameters**
Coefficient of determination (R^2), Coefficient of correlation (R), Nash-Sutcliffe model Efficiency (NSE), Mean Absolute Relative Error (MARE), Root Mean Square Error (RMSE) or Standard error of estimate of discharge on stage ($S_{Q.h}$), Percentage BIAS (PBIAS), Mean Residue (MR).

4.5 Streamflow Modelling of Owan River

4.5.1 Streamflow Model Calibration of Owan River at Owan village streamflow gauging station

The outputs of the Microsoft Excel programmes for least square regression model calibration of streamflow data (Table 3.4) of Owan River at Owan village streamflow gauging station are shown in Figures 4.25 and 4.26 for the power and polynomial models respectively and Table 4.4 for the ANOVA model for regression. The resulting equations are shown below:

$$y = 4.8905x^{1.2633} \quad . \quad . \quad . \quad . \quad (4.25)$$

$$y = 0.0561x^3 - 0.5747x^2 + 10.931x - 9.9542 \quad . \quad . \quad . \quad (4.26)$$

$$y = 9.450x - 9.7976 \quad . \quad . \quad . \quad . \quad (4.27)$$

Equations (4.25), (4.26) and (4.27) results in the following power model, polynomial model and ANOVA model for regression:

$$Q = 4.8905h^{1.2633} \quad . \quad . \quad . \quad . \quad (4.28)$$

$$Q = 0.0561h^3 - 0.5747h^2 + 10.931h - 9.9542 \quad . \quad . \quad . \quad (4.29)$$

$$Q = 9.450h - 9.798 \quad . \quad . \quad . \quad . \quad (4.30)$$

Equations (4.28) is a power model, equations (4.29) is a polynomial model while equations (4.30) is ANOVA model for regression.

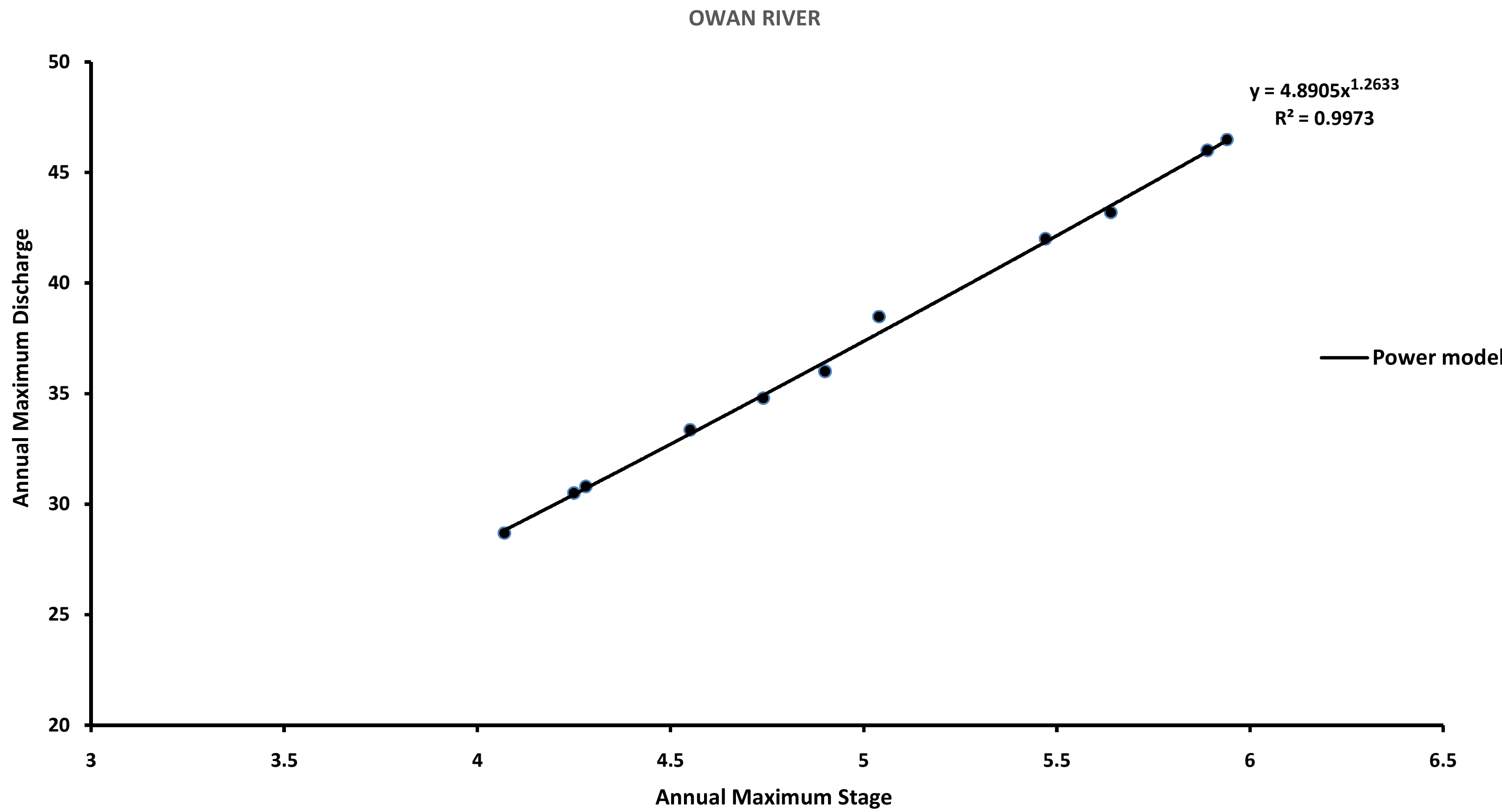


Figure 4.25: Plot of streamflow model calibration of Owan River at Owan village gauging station (Power model)

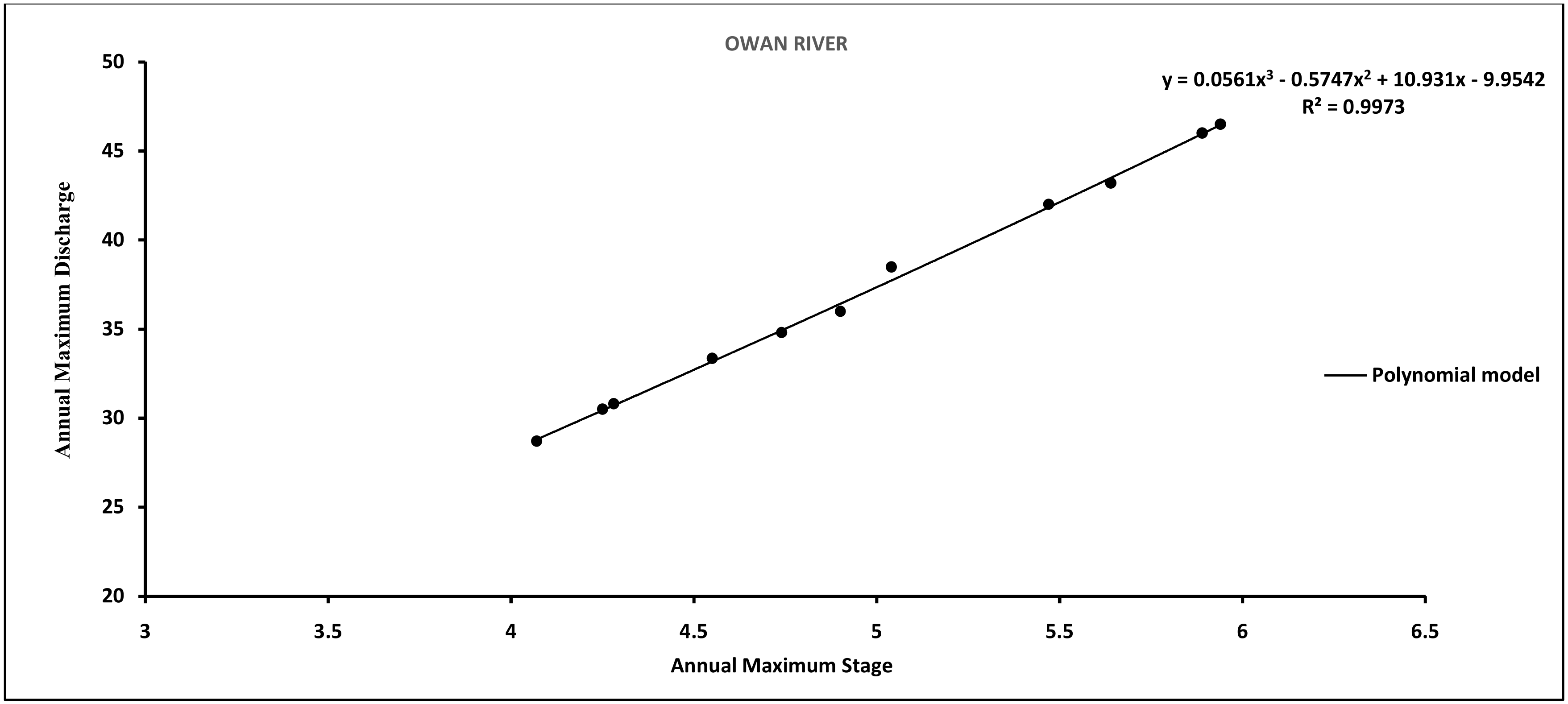


Figure 4.26: Plot of streamflow model calibration of Owan River at Owan village gauging station (Polynomial model)

Table 4.53: Summary output of ANOVA model for regression of Owan River at Owan village streamflow gauging station

Regression Statistics	
Multiple R	0.99852112
R Square	0.997044427
Adjusted R Square	0.996748869
Standard Error	0.346488521
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	404.995757	404.995757	3373.438295	5.55706E-14
Residual	10	1.200542952	0.120054295		
Total	11	406.1963			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-9.797585412	0.815241963	-12.01800921	2.88049E-07	-11.6140577	-7.981113122
X Variable 1	9.450494804	0.162711468	58.08130762	5.55706E-14	9.087951061	9.813038546

From Table 4.10, the fitted regression equation is $y = 9.450x - 9.798$

4.5.2 Verificationof the streamflow model of Owan River at Owan village gauging station

Verification of the streamflow models of Owan River at Owan village gauging station was carried out. The verified recordsare tabulated in Table 4.54.

Table 4.54: Verification of streamflow model of Owan River at Owan village gauging station

S/N	Year	Annual Maximum Stage (h) (m)	Measured Annual Maximum Discharge (Q) (m^3/s)	Predicted Annual Maximum Discharge (Q) (m^3/s) (Power Model)	Predicted Annual Maximum Discharge (Q) (m^3/s) (Polynomial Model)	Predicted Annual Maximum Discharge (Q) (m^3/s) (ANOVA Model for Regression)
1	1989	4.90	36.00	36.39	48.41	36.51
2	1990	4.55	33.35	33.14	33.17	33.20
3	1991	5.64	43.20	43.47	43.48	43.50
4	1992	4.74	34.80	34.90	34.92	35.00
5	1993	4.07	28.70	28.79	28.80	28.67
6	1994	5.47	42.00	41.82	41.82	41.90
7	1995	5.89	46.00	45.92	45.96	45.87
8	1996	5.94	46.50	46.41	46.46	46.34
9	1997	4.25	30.50	30.41	30.43	30.37
10	1998	4.28	30.80	30.68	30.70	30.65
11	1999	4.90	36.00	36.39	36.41	36.51
12	2000	5.04	36.49	37.71	34.13	37.83

The results of the measured and predicted discharge values of the models as presented in Table 4.54 were used to plot linear streamflow model verification graphs shown in Figures 4.27 through 4.29.

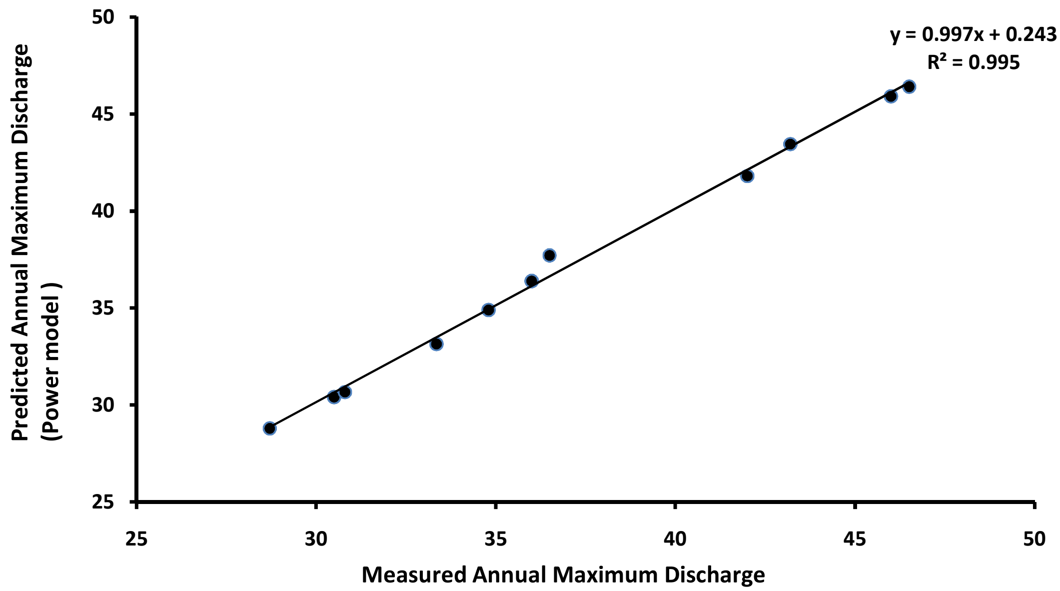


Figure 4.27: Verification of the streamflow model Owan River at Owan villagegauging station (for the *power model*)

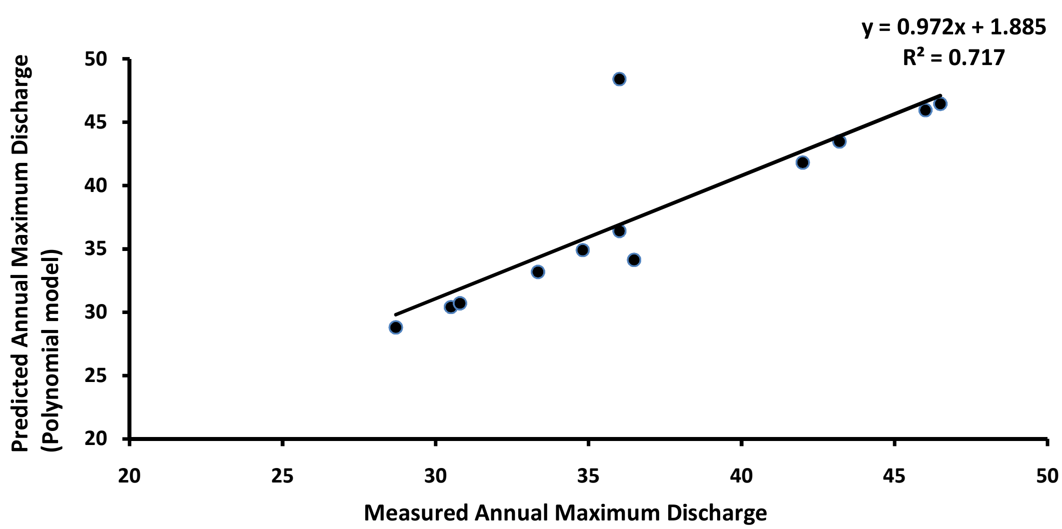


Figure 4.28: Verification of the streamflow model of Owan River at Owan village gauging station (for the *polynomial model*)

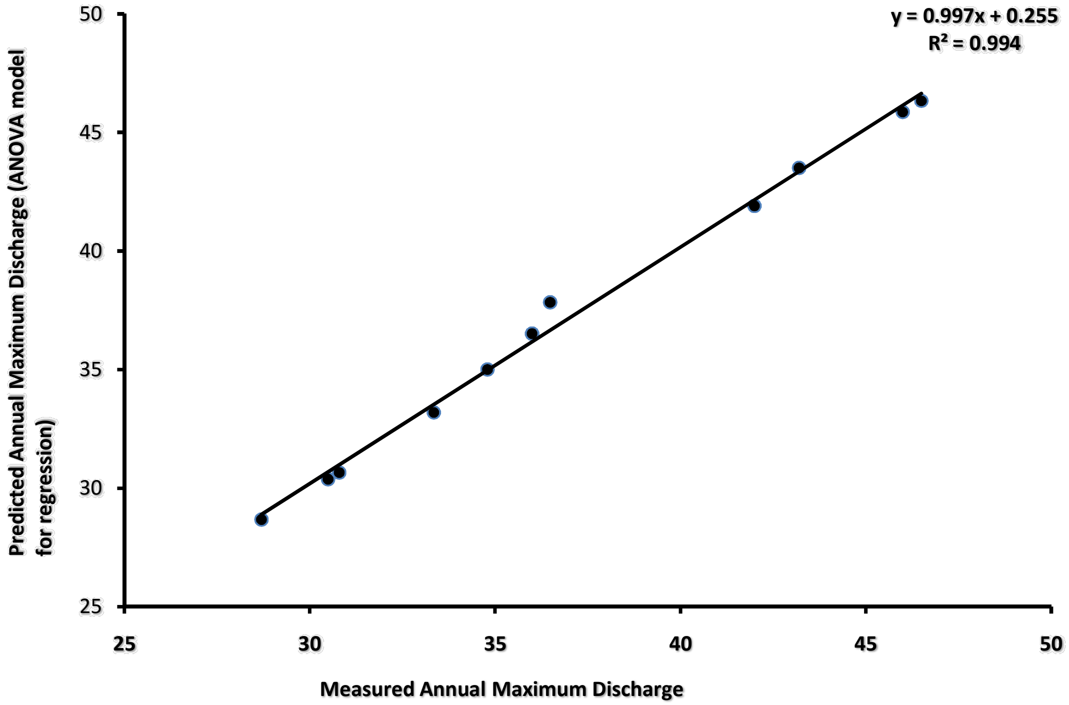


Figure 4.29: Verification of the streamflow model of Owan River at Owan village gauging station (for the *ANOVA model for regression*)

4.5.3 Comparisons of the streamflow models of Owan River at Owan village gauging station.

Comparisons of the streamflow models of Owan River at Owan village gauging station comprises four subheadings: One-way ANOVA F-Test, Variance Ratio Test or Snedecor's F-distribution (F-Test), comparison using graph and finally comparison using Student's t-Test.

4.5.3.1 Comparison of the streamflow models of Owan River at Owan village gauging station using One-way ANOVA F-Test

The comparison of the streamflow models verified for Owan River at Owan village gauging station using One-way ANOVAF-Test is shown in Table 4.55.

Table 4.55: One-way ANOVA F-Testfor the streamflow models of Owan River

Groups	Count	Sum	Average	Variance
Power model	12	446.03	37.169	36.745
Polynomial model	12	454.69	37.891	48.485
ANOVA model for regression	12	446.35	37.196	36.817

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.01816	2	2.00908	0.04938	0.95189	3.28492
Within Groups	1342.52	33	40.6825			
Total	1346.54	35				

4.5.3.2 Comparisonof the streamflow models of Owan River at Owan village gauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test)

The Comparisonof the streamflow models of Owan River at Owan villagegauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test) are shown in Tables 4.56 through 4.58.

Table 4.56: F-Test Two-Sample for Variances (Power model and Polynomial model)

	Power model	**Polynomial model**
Mean	37.16916667	37.89083333
Variance	36.74517197	48.48511742
Observations	12	12
Pearson Correlation	0.846954738	
Hypothesized Mean Difference	0	
df	11	
t Stat	-0.674617409	
P(T<=t) one-tail	0.25692382	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.513847639	
t Critical two-tail	2.20098516	

Table 4.57: F-Test Two-Sample for Variances (Power model and ANOVA model for regression)

	Power model	ANOVA model for regression
Mean	37.16916667	37.19583333
Variance	36.74517197	36.8172447
Observations	12	12
Pearson Correlation	0.99990178	
Hypothesized Mean Difference	0	
df	11	
t Stat	-1.084108921	
P(T<=t) one-tail	0.15075309	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.30150618	
t Critical two-tail	2.20098516	

Table 4.58: F-Test Two-Sample for Variances (Polynomial model and ANOVA model for regression)

	Polynomial model	ANOVA model for regression
Mean	37.89083333	37.19583333
Variance	48.48511742	36.8172447
Observations	12	12
Pearson Correlation	0.848571226	
Hypothesized Mean Difference	0	
df	11	
t Stat	0.652897089	
P(T<=t) one-tail	0.263616261	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.527232522	
t Critical two-tail	2.20098516	

4.5.3.3 Comparisonof the streamflow models of Owan River at Owan village gauging station using graph

The comparison of the streamflow models verified for Owan River at Owan villagegauging station using graph is shown in Figure 4.30.

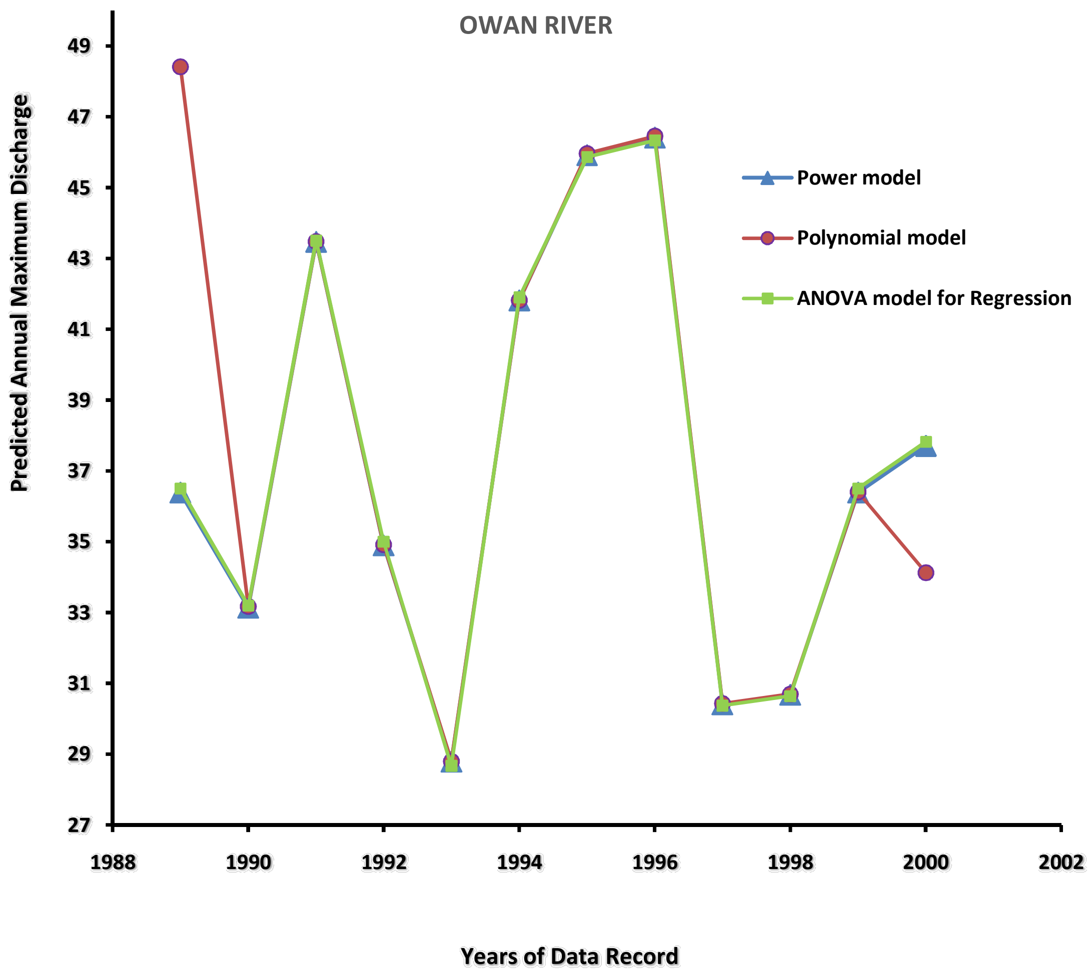


Figure 4.30: Comparison of the streamflow models verified for Owan River at Owan village gauging station using graph

4.5.3.4 Comparisonof the streamflow models of Owan River at Owan village gauging station using Student's t-Test

The streamflow models of Owan River at Owan village gauging station are further compared using Student's t-Test (distribution) as shown in Tables 4.59 through 4.61.

Table 4.59: t-Test: Paired Two Sample for Means (Power and Polynomial models)

	Power model	**Polynomial model**
Mean	37.16916667	37.89083333
Variance	36.74517197	48.48511742
Observations	12	12
Pearson Correlation	0.846954738	
Hypothesized Mean Difference	0	
df	11	
t Stat	-0.674617409	
P(T<=t) one-tail	0.25692382	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.513847639	
t Critical two-tail	2.20098516	

Table 4.60: t-Test: Paired Two Sample for Means (Power model and ANOVA model for regression

	Power model	**ANOVA model for regression**
Mean	37.16916667	37.19583333
Variance	36.74517197	36.8172447
Observations	12	12
Pearson Correlation	0.99990178	
Hypothesized Mean Difference	0	
df	11	
t Stat	-1.084108921	
P(T<=t) one-tail	0.15075309	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.30150618	
t Critical two-tail	2.20098516	

Table 4.61: t-Test: Paired Two Sample for Means (Polynomial Model and ANOVA model for regression

	Polynomial model	**ANOVA model for regression**
Mean	37.89083333	37.19583333
Variance	48.48511742	36.8172447
Observations	12	12
Pearson Correlation	0.848571226	
Hypothesized Mean Difference	0	
df	11	
t Stat	0.652897089	
P(T<=t) one-tail	0.263616261	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.527232522	
t Critical two-tail	2.20098516	

4.5.4 Computations of the model performance measures of the streamflow models of Owan River

Computations of Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias, root mean square error or standard error of estimateand mean of residue or mean absolute error which are used as tools for the evaluation of the streamflow models ofOwan River at Owan village gauging station are shown in Tables 4.62 and 4.63 for the power and polynomial models respectively and Table 4.64 for the ANOVA model for regression.

Table 4.62: Computations of the model performance measures of the streamflow model of Owan River at Owan village gauging station (for the *power model*)

Year	**Stage (x or h) metres**	**Measured Discharge m³/s (y_i or Q)**	**Predicted Discharge $y_i' = 4.89x^{1.263}$ m³/s (Power model)**	**Residuals $(y_i - y_i')$**	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1989	4.90	36.00	36.39	- 0.39	0.152	-0.0108	-1.028	1.057
1990	4.55	33.35	33.14	0.21	0.044	0.0063	-3.678	13.528
1991	5.64	43.2	43.47	- 0.27	0.073	0.0063	6.172	38.094
1992	4.74	34.80	34.90	- 0.10	0.010	-0.0029	-2.228	4.964
1993	4.07	28.70	28.79	- 0.09	0.008	-0.0031	-8.324	69.356
1994	5.47	42.00	41.82	0.18	0.032	0.0043	4.972	24.721
1995	5.89	46.00	45.92	0.08	0.006	0.0017	8.720	76.038
1996	5.94	46.50	46.41	0.09	0.008	0.0019	9.472	89.719
1997	4.25	30.50	30.41	0.09	0.008	0.0030	-6.528	42.615
1998	4.28	30.80	30.68	0.12	0.140	0.0039	-6.228	38.788
1999	4.90	36.00	36.39	- 0.39	0.152	-0.0108	-1.028	1.057
2000	5.04	36.49	37.71	0.78	0.608	-0.0334	-0.538	0.289
		$\sum$ = 444.34	**$\sum$ = 446.03**	**$\sum$ = 0.31**	**$\sum$ = 1.115**	**$\sum$ = - 0.0462**		**$\sum$ = 400.226**

Computations of the model performance measures of the streamflow model of Owan River at Owan village gauging station (*power model*).

Mean of measured (observed) discharge = 37.0283

Mean of predicted (simulated) discharge = 37.1692

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{1.115}{400.226} = 0.9972$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\ \text{or}\ \mathrm{S}_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{1.115}{12}} = 0.30$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{37.1692 - 37.0283}{37.0283}\right) = 0.0271$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR\ or\ MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{0.31}{12} = 0.0258$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{12}(0.0462) = 0.9962$$

Year	Stage in metres (x or h)	Measured Discharge (y_i or Q) m^3/s	Predicted Discharge (m^3/s) $y_i' = 0.0561x^3 - 0.5747x^2 + 10.931x - 9.9542$ (Polynomial model)	Residuals $(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1989	4.90	36.00	36.41	-0.41	0.17	-0.0114	-1.028	1.057
1990	4.55	33.40	33.17	0.23	0.05	0.0069	-3.678	13.528
1991	5.64	43.20	43.48	-0.28	0.08	-0.0065	6.172	38.094
1992	4.74	34.80	34.92	-0.21	0.04	0.0060	-2.228	4.964
1993	4.07	28.70	28.80	-0.1	0.01	-0.0035	-8.324	69.356
1994	5.47	42.00	41.82	0.18	0.03	0.0043	4.972	24.721
1995	5.89	46.00	45.96	0.04	0.00	0.0009	8.720	76.038
1006	5.94	46.50	46.46	0.04	0.00	0.0009	9.472	89.719
1997	4.25	30.50	30.43	0.07	0.01	0.0230	-6.528	42.615
1998	4.28	30.80	30.70	0.1	0.01	0.0028	-6.228	38.788
1999	4.90	36.00	36.41	-0.41	0.17	-0.0114	-1.028	1.057
2000	5.04	36.49	37.72	1.23	1.51	-0.0337	-0.538	0.289
			$\sum =$ 454.69	**$\sum =$ 0.48**	**$\sum =$ 2.08**	**$\sum =$ -0.0017**		**$\sum =$ 400.226**

Table 4.63: Computations of the model performance measures of the streamflow model of Owan River (for the *polynomial model*)

Computations of the model performance measures of the streamflow model of Owan River at Owan village gauging station (*polynomial model*)

Mean of measured (observed) discharge = 37.0283

Mean of predicted (simulated) discharge = 37.8908

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{2.08}{400.226} = 0.9948$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE}) \text{ or } S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{173.50}{12}} = 3.80$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{37.8908 - 37.0283}{37.0283}\right) = 0.0233$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR} \text{ or } \mathrm{MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{0.48}{12} = 0.04$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{12}(-0.0017) = 1.000$$

Table 4.64: Computations of the model performance measures of the streamflow model of Owan River at Owan village gauging station(for the *ANOVA model for regression*)

Year	**Stage in metres (x or h)**	**Measured Discharge m^3/s (y_i or Q)**	**Predicted Discharge y = 9.450x – 9.798 m^3/s (ANOVA model for regression)**	**Residuals $(y_i - y_i')$**	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1989	4.90	36.00	36.51	-0.51	0.26	-0.014	-1.028	1.057
1990	4.55	33.35	33.20	0.15	0.02	0.005	-3.678	13.528
1991	5.64	43.2	43.50	-0.30	0.09	-0.007	6.172	38.094
1992	4.74	34.80	35.00	-0.20	0.04	-0.006	-2.228	4.964
1993	4.07	28.70	28.67	0.03	0.00	0.001	-8.324	69.356
1994	5.47	42.00	41.90	0.10	0.01	0.002	4.972	24.721
1995	5.89	46.00	45.87	0.13	0.02	0.003	8.720	76.038
1996	5.94	46.50	46.34	0.16	0.03	0.003	9.472	89.719
1997	4.25	30.50	30.37	0.13	0.02	0.004	-6.528	42.615
1998	4.28	30.80	30.65	0.15	0.02	0.005	-6.228	38.788
1999	4.90	36.00	36.51	-0.51	0.26	-0.014	-1.028	1.057
2000	5.04	36.49	37.83	-1.34	1.80	-0.037	-0.538	0.289
			∑ = 446.35	**∑ =-2.01**	**∑ = 2.57**	**∑ =-0.055**		**∑ =400.226**

Computations of the model performance measures of the streamflow model of Owan River at Owan village gauging station (*ANOVA model for regression*).

Mean of measured (observed) discharge = 37.0283

Mean of predicted (simulated) discharge = 37.1958

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{2.57}{400.226} = 0.9936$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\ \text{or}\ S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{2.57}{12}} = 0.46$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{37.1958 - 37.0283}{37.0283}\right) = 0.4524$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR}\ \text{or}\ \mathrm{MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{-2.01}{12} = 0.1675$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{12}(-0.055) = 1.005$$

The summary of streamflow models of Owan River at Owan village gauging station obtained from Figures 4.25 and 4.26 for the power and polynomial modelsand Table 4.8 for the ANOVA model for regression are shown in Table 4.65.

Table 4.65 Summary of streamflow models of Owan River at Owan village gauging station and the models evaluation parameters

RIVER	STREAMFLOW GAUGING STATION	STREAMFLOW MODEL [+]	MODEL EVALUATION PARAMETERS [*]						
			R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
Owan River	Owan Village	**Power model** $Q = 4.8905\ h^{1.2633}$	0.9973	0.9986	0.9972	0.30	0.0271	0.0258	0.9962
		Polynomial model $Q = 0.0561h^3 - 0.5747h^2 + 10.931h - 9.9542$	0.9973	0.9986	0.9948	3.80	0.0233	0.04	1.000
		ANOVA model for regression $Q = 9.450h - 9.798$	0.9970	0.9985	0.9936	0.46	0.4524	0.1675	1.005

[+] Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

[*] **ModelEvaluation Parameters**
Coefficient of determination (R^2) , Coefficient of correlation (R), Nash-Sutcliffe model Efficiency (NSE), Mean Absolute Relative Error (MARE), Root Mean Square Error (RMSE) or Standard error of estimate of discharge on stage ($S_{Q.h}$), Percentage BIAS (PBIAS), Mean Residue (MR).

4.6 Streamflow Modelling of Ikpoba River

4.6.1 Streamflow Model Calibration of Ikpoba River at Benin City gauging station

The outputs of the Microsoft Excel programme for least square regression model calibration of streamflow data (Table 3.4) of Ikpoba River at Benin City gauging station are shown in Figures 4.31 and 4.32 for the power and polynomial models respectively and Table 4.66 for the ANOVA model for regression. The resulting equations are shown below:

$$y = 5.1663x^{1.8469} \quad . \quad . \quad . \quad . \quad (4.31)$$

$$y = -6.262x^3 + 56.982x^2 - 143.82x + 128.58 \quad . \quad . \quad . \quad (4.32)$$

$$y = 23.799x - 30.848 \quad . \quad . \quad . \quad . \quad (4.33)$$

Equations (4.31), (4.32) and (4.33) results in the following power model, polynomial model and ANOVA model for regression:

$$Q = 5.1663h^{1.8469} \quad . \quad . \quad . \quad . \quad (4.34)$$

$$Q = -6.262h^3 + 56.982h^2 - 143.82h + 128.58 \quad . \quad . \quad . \quad (4.35)$$

$$Q = 23.799h - 30.848 \quad . \quad . \quad . \quad . \quad (4.36)$$

Equation (4.34) is a power model, equation (4.35) is a polynomial model while equation (4.36) is ANOVA model for regression.

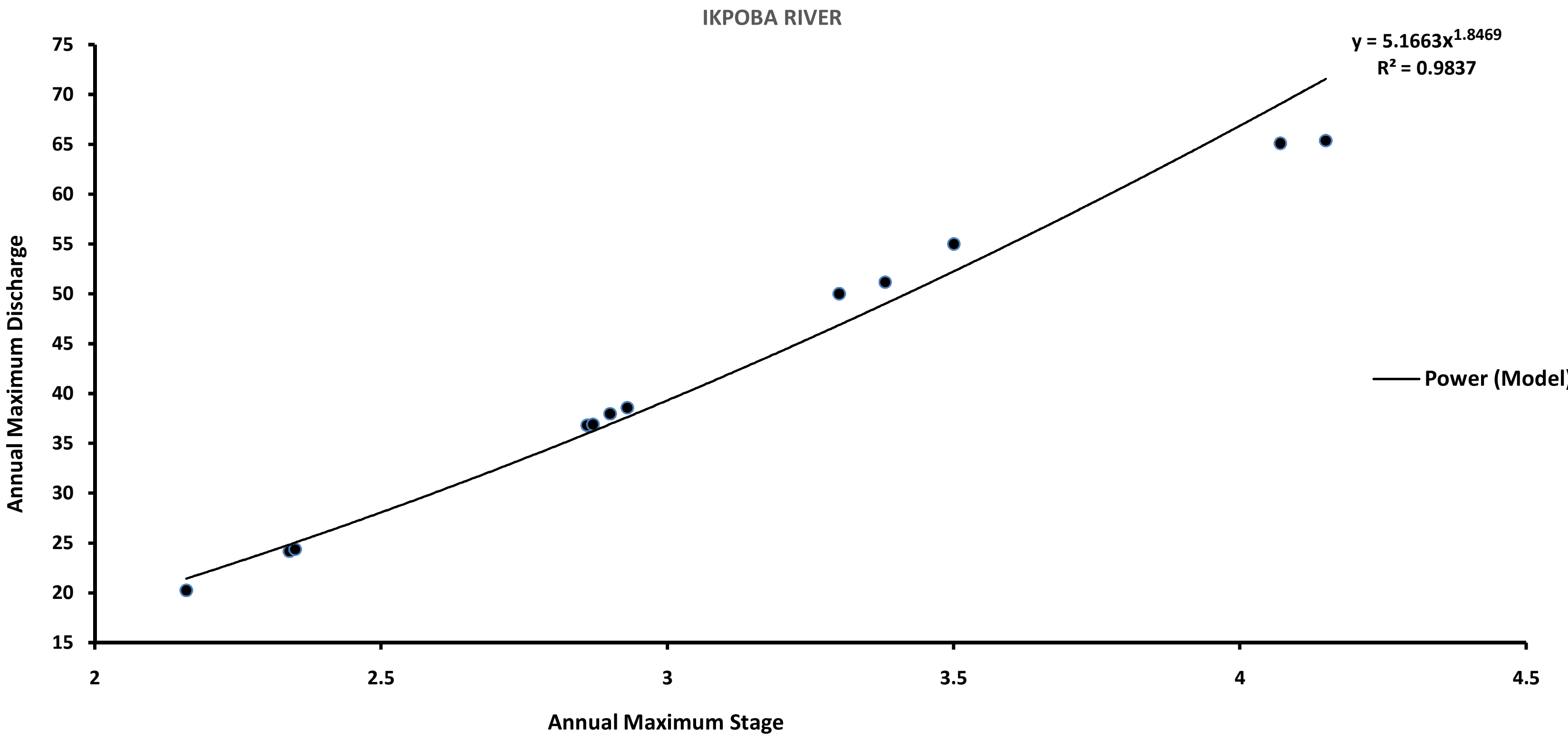


Figure4.31: Plot of streamflow model calibration of Ikpoba River at Benin City gauging station (power model)

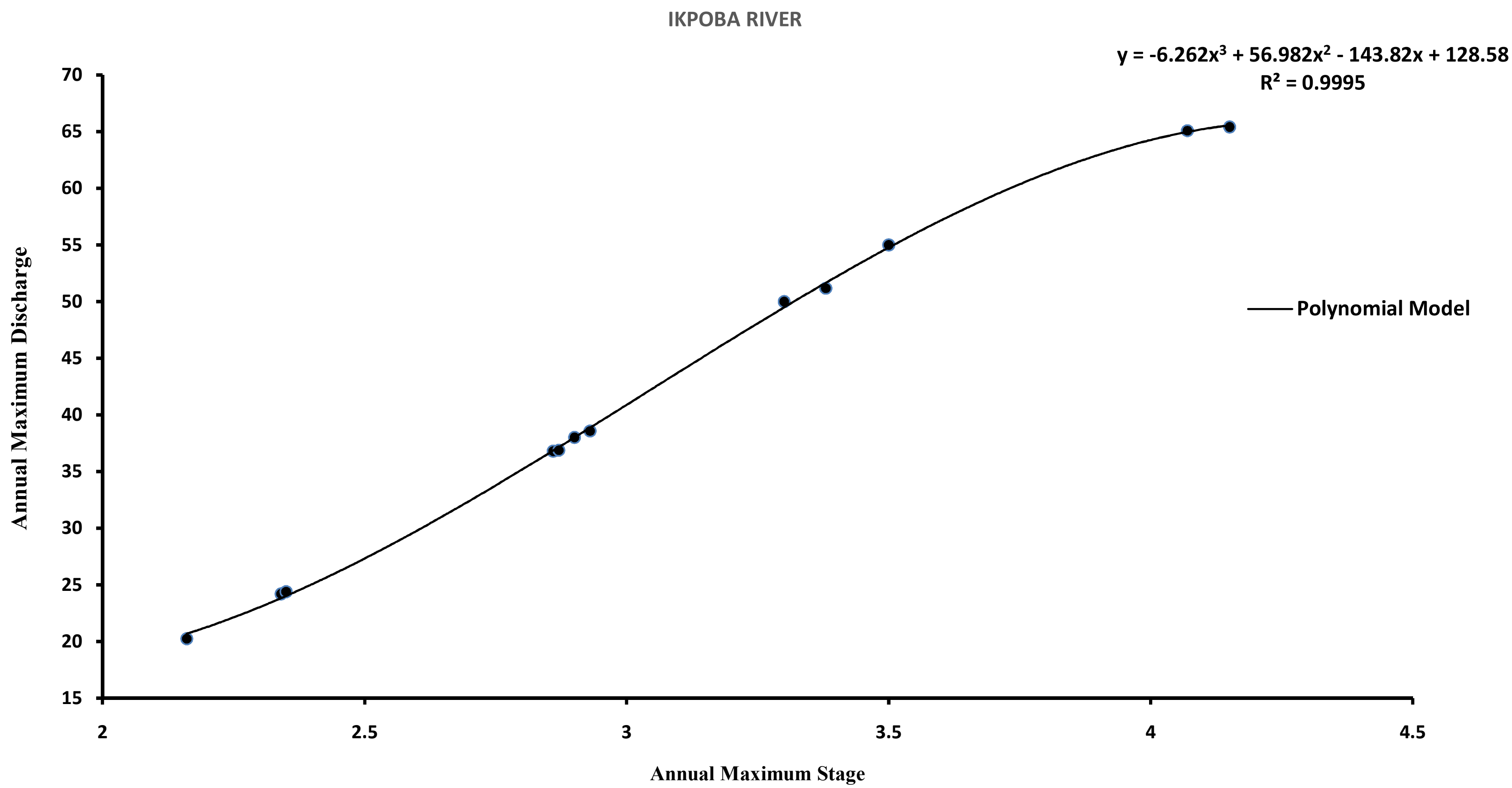


Figure 4.32: Plot of streamflow model calibration of Ikpoba River at Benin City gauging station (polynomial model)

Table 4.66: Summary output of ANOVA model for regression of Ikpoba River at Benin City streamflow gauging station

Regression Statistics	
Multiple R	0.995497447
R Square	0.991015167
Adjusted R Square	0.990116684
Standard Error	1.522171578
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2555.627229	2555.627229	1102.986735	1.44638E-11
Residual	10	23.17006313	2.317006313		
Total	11	2578.797292			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-30.84836998	2.241616991	-13.7616596	7.97878E-08	-35.84300389	-25.85373607
X Variable 1	23.79870795	0.716585861	33.2112441	1.44638E-11	22.20205516	25.39536075

From Table 4.10, the fitted regression equation is $y = 23.799x - 30.848$

4.6.2 Verification of the streamflow model of Ikpoba River at Benin City streamflow gauging station

Verification of the streamflow models of Ikpoba River at Benin City gauging station was carried out. The verified records are tabulated in Table 4.67.

Table 4.67: Verification of streamflow models of Ikpoba River at Benin City gauging station

S/N	Year	Annual Maximum Stage (h) (m)	Measured Annual Maximum Discharge (Q) (m^3/s)	Predicted Annual Maximum Discharge (Q) (m^3/s) (Power Model)	Predicted Annual Maximum Discharge (Q) (m^3/s) (Polynomial Model)	Predicted Annual Maximum Discharge (Q) (m^3/s) (ANOVA Model for regression)
1	1989	2.16	20.25	21.42	20.68	20.56
2	1990	2.86	36.80	35.98	36.83	37.22
3	1991	3.50	55.00	52.25	54.76	52.45
4	1992	2.90	38.00	36.92	38.00	38.17
5	1993	2.93	38.60	37.62	38.86	38.88
6	1994	3.30	50.00	46.87	49.47	47.69
7	1995	3.38	51.20	48.99	51.65	49.59
8	1996	2.87	36.90	36.21	37.14	37.46
9	1997	2.34	24.20	24.84	23.86	24.84
10	1998	2.35	24.40	25.03	24.02	25.08
11	1999	4.15	65.40	71.56	65.53	67.92
12	2000	4.07	65.10	69.04	64.96	66.01

The results of the measured and predicted discharge values of the power and polynomial models as presented in Table 4.67 were used to plot linear streamflow model verification charts as shown in Figures 4.33 through 4.35.

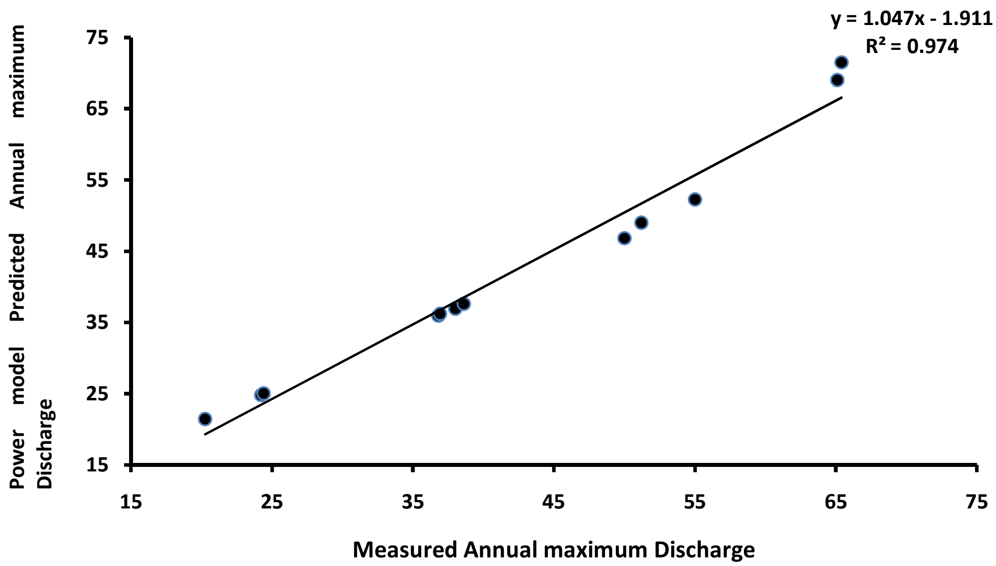


Figure 4.33: Verification of the streamflow model Ikpoba River at Benin City gauging station (for the *power model*)

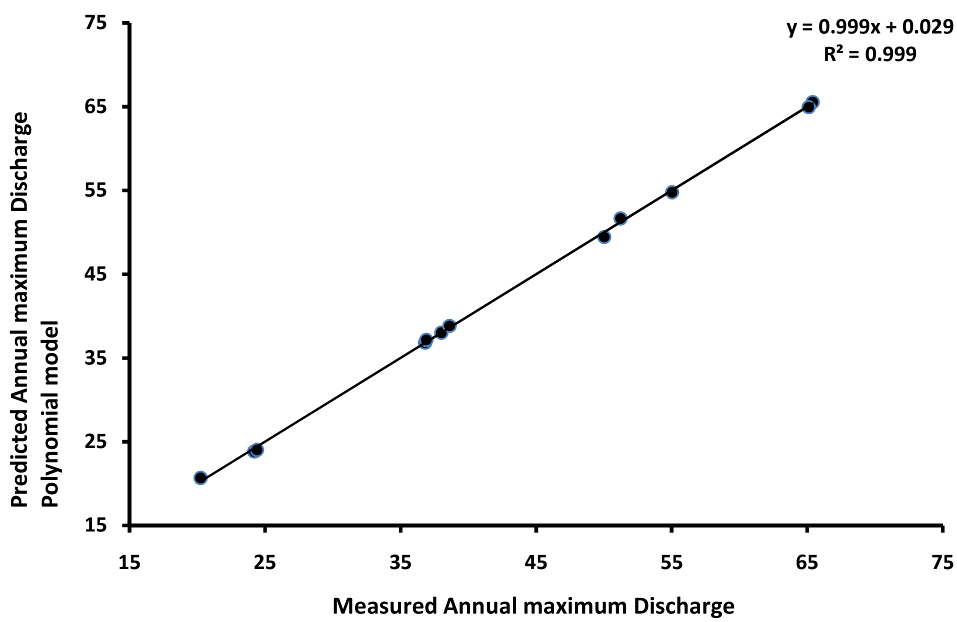


Figure 4.34: Verification of the streamflow model of Ikpoba River at Benin City gauging station (for the *polynomial model*)

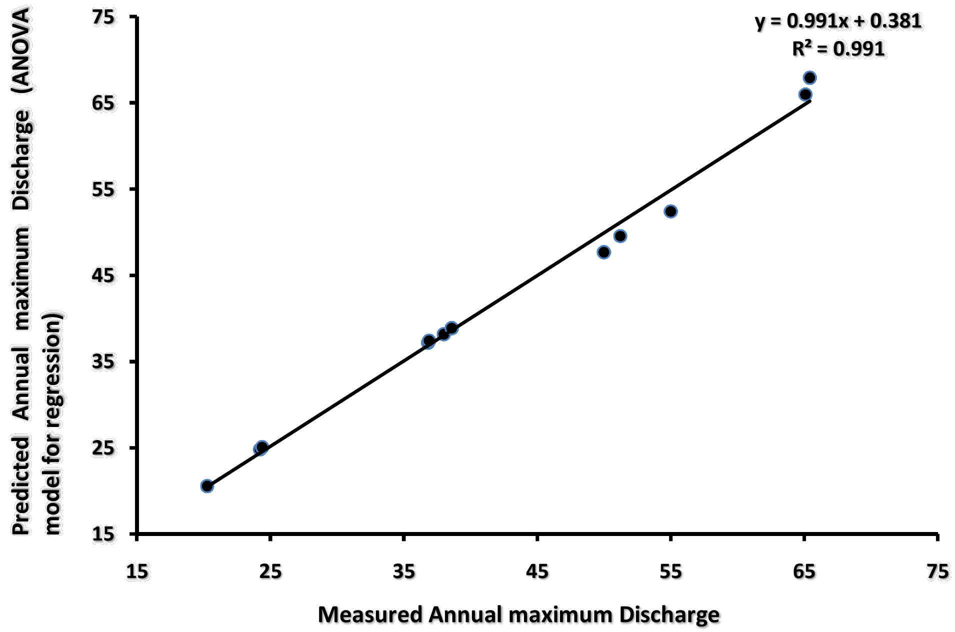


Figure 4.35: Verification of the streamflow model of Ikpoba River at Benin City gauging station (for the *ANOVA model for regression*)

4.6.3 Comparisons of the streamflow models of Ikpoba River at Benin City gauging station.

Comparisons of the streamflow models of Ikpoba River at Benin City gauging station comprises four subheadings: One-way ANOVA F-Test, Variance Ratio Test or Snedecor's F-distribution (F-Test), comparison using graph and finally comparison using Student's t-Test.

4.6.3.1 Comparison of the streamflow models of Ikpoba River at Benin City gauging station using One-way ANOVA F-Test

The comparison of the streamflow models verified for Ikpoba River at Benin City gauging station using One-way ANOVA F-testis shown in Table 4.68.

Table 4.68: One-way ANOVAF-Test for the streamflow models of Ikpoba River

Groups	Count	Sum	Average	Variance
Power model	13	575.77	44.29	297.193
Polynomial model	13	570.72	43.902	254.651
ANOVA model for regression	13	571.88	43.991	256.73

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.07642	2	0.5382	0.002	0.99801	3.25945
Within Groups	9702.89	36	269.52			
Total	9703.97	38				

4.6.3.2 Comparisonof the streamflow models of Ikpoba River at Benin City gauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test)

The Comparisonof the streamflow models of Ikpoba River at Benin Citygauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test) are shown in Tables 4.69 through 4.71.

Table 4.69: F-Test Two-Sample for Variances (Power model and Polynomial model)

	Power model	**Polynomial model**
Mean	42.2275	42.14666667
Variance	263.8828932	234.126897
Observations	12	12
df	11	11
F	1.127093455	
P(F<=f) one-tail	0.42312892	
F Critical one-tail	2.81793047	

Table 4.70: F-Test Two-Sample for Variances (Power model and ANOVA model for regression)

	Power model	ANOVA model for regression
Mean	42.2275	42.15583333
Variance	263.8828932	232.3191538
Observations	12	12
df	11	11
F	1.135863698	
P(F<=f) one-tail	0.418220075	
F Critical one-tail	2.81793047	

Table 4.71: F-Test Two-Sample for Variances (Polynomial model and ANOVA model for regression)

	Polynomial model	ANOVA model for regression
Mean	42.14666667	42.15583333
Variance	234.126897	232.3191538
Observations	12	12
df	11	11
F	1.007781292	
P(F<=f) one-tail	0.494987261	
F Critical one-tail	2.81793047	

4.6.3.3 Comparison of the streamflow models of Ikpoba River at Benin City gauging station using graph

The comparison of the streamflow models verified for Ikpoba River at Benin City gauging station using graph is shown in Figure 4.36.

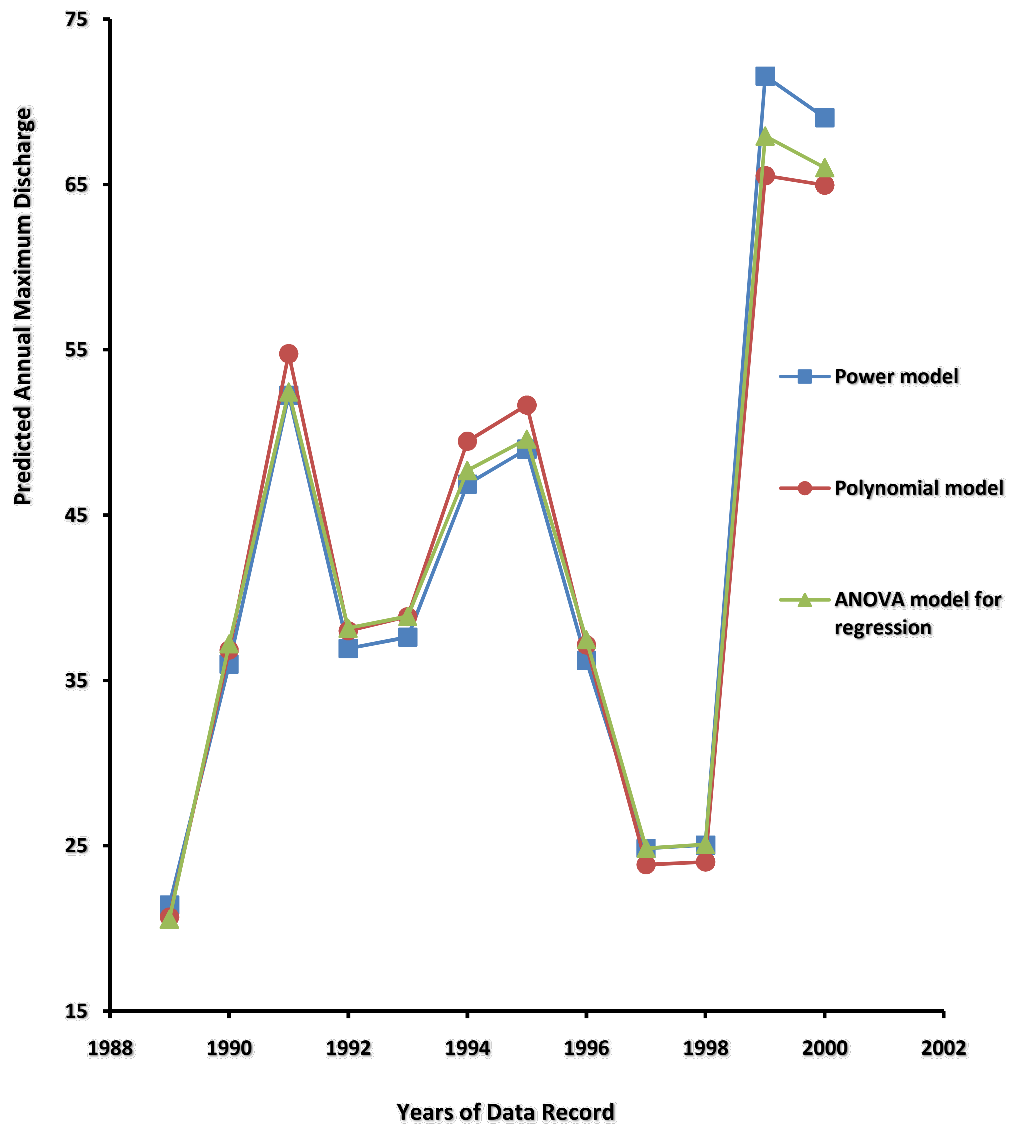


Figure 4.36: Comparison of the streamflow models verified for Ikpoba River at Benin City gauging station

4.6.3.4 Comparison of the streamflow models of Ikpoba River at Benin City gauging station using Student's t-Test

The streamflow modelsof Ikpoba River at Benin City gauging station are further compared using Student's t-Test (distribution) as shown in Tables 4.72 through 4.74.

Table 4.72: t-Test: Paired Two Sample for Means (Power and Polynomial models)

	Power model	**Polynomial model**
Mean	42.2275	42.14666667
Variance	263.8828932	234.126897
Observations	12	12
Pearson Correlation	0.98718129	
Hypothesized Mean Difference	0	
df	11	
t Stat	0.103907597	
P(T<=t) one-tail	0.459556486	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.919112972	
t Critical two-tail	2.20098516	

Table 4.73: t-Test: Paired Two Sample for Means (Power model and ANOVA model for regression)

	Power model	**ANOVA model for regression**
Mean	42.2275	42.15583333
Variance	263.8828932	232.3191538
Observations	12	12
Pearson Correlation	0.996442275	
Hypothesized Mean Difference	0	
df	11	
t Stat	0.149254607	
P(T<=t) one-tail	0.442026995	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.884053991	
t Critical two-tail	2.20098516	

Table 4.74: t-Test: Paired Two Sample for Means (Polynomial model and ANOVA model for regression)

	Polynomial model	**ANOVA model for regression**
Mean	42.14666667	42.15583333
Variance	234.126897	232.3191538
Observations	12	12
Pearson Correlation	0.995730672	
Hypothesized Mean		
Difference	0	
df	11	
t Stat	-0.022482344	
P(T<=t) one-tail	0.491232922	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.982465844	
t Critical two-tail	2.20098516	

4.6.4 Computations of the model performance measures of the streamflow models of Ikpoba River

Computations of Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias, root mean square error or standard error of estimateand mean of residue or mean absolute error which are used as tools for the evaluation of the streamflow models ofIkpoba River at Benin City gauging stationare shown in Tables 4.75 and 4.76 for the power and polynomial models respectively and Table 4.77 for the ANOVA model for regression.

Table 4.75: Computations of model performance measures of the streamflow models of Ikpoba River at Benin City(for the *power model*)

Year	**Stage in metres (x or h)**	**Measured Discharge in m^3/s (y_i or Q)**	**Predicted Discharge $y'_i = 5.166x^{1.847}$ (Power model)**	**Residuals $(y_i - y'_i)$**	$(y_i - y'_i)^2$	$\frac{(y_i - y'_i)}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1989	2.16	20.25	21.42	- 1.17	1.39	-0.0578	-21.904	479.785
1990	2.86	36.80	35.98	0.82	0.67	0.0223	-5.354	28.665
1991	3.50	55.00	52.25	2.75	7.56	0.0500	12.846	165.020
1992	2.90	38.00	36.92	1.08	1.17	0.0284	-4.154	17.256
1993	2.93	38.60	37.62	0.98	0.96	0.0254	-3.554	12.631
1994	3.30	50.00	46.87	3.13	9.80	0.0626	7.846	61.560
1995	3.38	51.20	48.99	2.21	4.88	0.0432	9.046	81.830
1996	2.87	36.90	36.21	0.69	0.48	0.0187	-5.,254	27.605
1997	2.34	24.20	24.84	- 0.64	0.41	0.0264	-17.954	322.346
1998	2.35	24.40	25.03	- 0.63	0.40	-0.0258	-17.754	315.205
1999	4.15	65.40	71.56	- 6.16	37.95	-0.0942	23.246	540.377
2000	4.07	65.10	69.04	- 3.94	14.40	-0.0605	22.946	526.519
			$\sum$ =506.73	**$\sum$ = -0.88**	**$\sum$ = 80.55**	**$\sum$ = -0.0145**		**$\sum$ = 2,578.8**

Computations of the model performance measures of the streamflow model of Ikpoba River at Benin City gauging station (*power model*).

Mean of measured (observed) discharge = 42.154

Mean of predicted (simulated) discharge = 42.228

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{80.55}{2{,}578.8} = 0.969$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\text{ or } S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{80.55}{12}} = 2.59$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{42.228 - 42.154}{42.154}\right) = 0.176$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR\ or\ MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{-0.88}{12} = -0.07$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{12}(-0.0145) = 1.00$$

Table 4.76: Computations of model performance measures of the streamflow models of Ikpoba River at Benin Citygauging station (for the *polynomial model*)

Year	**Stage in metres (x or h)**	**Measured Discharge (y_i or Q) m^3/s**	**Predicted Discharge (m^3/s)** $y_i' = -6.262x^3 + 56.982x^2 - 143.82x + 128.58$ **(Polynomial model)**	$(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1989	2.16	20.25	20.68	-0.43	0.18	-0.0212	-21.904	479.785
1990	2.86	36.80	36.83	-0.03	0.00	-0.0008	-5.354	28.665
1991	3.50	55.00	54.76	0.24	0.06	0.0044	12.846	165.020
1992	2.90	38.00	38.00	0.00	0.00	0.0000	-4.154	17.256
1993	2.93	38.60	38.86	- 0.26	0.07	-0.0067	-3.554	12.631
1994	3.30	50.00	49.47	0.53	0.28	0.0106	7.846	61.560
1995	3.38	51.20	51.65	- 45.00	0.20	-0.0088	9.046	81.830
1996	2.87	36.90	37.14	-0.24	0.06	-0.0065	-5.,254	27.605
1997	2.34	24.20	23.86	0.34	0.12	0.0140	-17.954	322.346
1998	2.35	24.40	24.02	0.38	0.14	0.0156	-17.754	315.205
1999	4.15	65.40	65.53	- 0.13	0.02	0.0020	23.246	540.377
2000	4.07	65.10	64.96	0.14	0.02	0.0022	22.946	526.519
			$\sum$ = 505.76	**$\sum$ = 0.09**	**$\sum$ = 1.15**	**$\sum$ = 0.0048**		**$\sum$ = 2,578.8**

Computations of the model performance measures of the streamflow model of Ikpoba River at Benin City gauging station (*polynomial model*).

Mean of measured (observed) discharge = 42.154

Mean of predicted (simulated) discharge = 42.147

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{1.15}{2{,}578.8} = 0.9986$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\ \text{or}\ S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{1.15}{12}} = 0.31$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{42.147 - 42.154}{42.154}\right) = -0.017$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR}\ \text{or}\ \mathrm{MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{0.09}{12} = 0.008$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{12}(0.0048) = 0.9996$$

Table 4.77: Computations of the model performance measures of the streamflow model of Ikpoba River at Benin City gauging station (for the *ANOVA model for regression*)

Year	**Stage (x or h) metres**	**Measured Discharge (y_i or Q) m^3/s**	**Predicted Discharge (m^3/s) Q = 23.799h – 30.848 (ANOVA model for regression)**	**Residuals $(y_i - y_i')$**	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1989	2.16	20.25	20.56	-0.31	0.10	-0.0153	-21.904	479.785
1990	2.86	36.80	37.22	-0.42	0.18	-0.0114	-5.354	28.665
1991	3.50	55.00	52.45	2.55	6.50	0.0464	12.846	165.020
1992	2.90	38.00	38.17	- 0.17	0.03	-0.0045	-4.154	17.256
1993	2.93	38.60	38.88	- 0.28	0.08	-0.0073	-3.554	12.631
1994	3.30	50.00	47.69	2.31	5.34	0.0462	7.846	61.560
1995	3.38	51.20	49.59	1.61	2.59	0.0314	9.046	81.830
1996	2.87	36.90	37.46	- 0.56	0.31	-0.0152	-5.,254	27.605
1997	2.34	24.20	24.84	- 0.64	0.41	-0.0264	-17.954	322.346
1998	2.35	24.40	25.08	- 0.68	0.46	-0.0279	-17.754	315.205
1999	4.15	65.40	67.92	- 2.52	6.35	-0.0385	23.246	540.377
2000	4.07	65.10	66.01	- 0.91	0.83	-0.0140	22.946	526.519
			$\sum$ = 505.87	**$\sum$ = -0.02**	**$\sum$ = 23.18**	**$\sum$ =-0.0365**		**$\sum$ = 2,578.8**

Computations of the model performance measures of the streamflow model of Ikpoba River at Benin City gauging station (*ANOVA model for regression*).

Mean of measured (observed) discharge = 42.154

Mean of predicted (simulated) discharge = 42.156

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{23.18}{2{,}578.8} = 0.9910$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\ \text{or}\ S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{23.18}{12}} = 1.39$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{42.156 - 42.154}{42.154}\right) = 0.005$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR\ \ or\ \ MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{-0.02}{12} = -0.002$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{12}(-0.0365) = 1.00$$

The summary of streamflow models of Ikpoba River at Benin City gauging station obtained from Figures 4.31 and 4.32 for the power and polynomial modelsand Table 4.66 for the ANOVA model for regression are shown in Table 4.78.

Table 4.78 Summary of streamflow models of Ikpoba River at Benin City gauging station and the models evaluation parameters

RIVER	STREAMFLOW GAUGING STATION	STREAMFLOW MODEL +	MODEL EVALUATION PARAMETERS*						
			R^2	R	NSE	RMSE or S_{QH}	PBIAS	MRor MAE	MARE
Ikpoba River	Benin City	**Power model** $Q = 5.1663h^{1.847}$	0.9837	0.9918	0.969	2.59	0.176	-0.07	1.00
		Polynomial model $Q = -6.262h^3 + 56.982h^2 - 143.82h + 128.58$	0.9995	0.9997	0.9986	0.31	-0.017	0.008	0.9996
		ANOVA model for regression $Q = 23.799h – 30.848$	0.9980	0.9990	0.9910	38.65	0.005	-0.002	1.00

+ Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

* **ModelEvaluation Parameters**
Coefficient of determination (R^2), Coefficient of correlation (R), Nash-Sutcliffe model Efficiency (NSE), Mean Absolute Relative Error (MARE), Root Mean Square Error (RMSE) or Standard error of estimate of discharge on stage ($S_{Q.h}$), Percentage BIAS (PBIAS), Mean Residue (MR).

4.7 Streamflow Modelling of Ossiomo River

4.7.1 Streamflow Model Calibration of Ossiomo River at Abudu gauging station

Plots of the streamflow model calibrations of annual maximum stage and annual maximum discharge of Ossiomo River at Abudu gauging station (Table 3.4) are shown in Figures 4.37 and 4.38 for power and polynomial models respectively and Table 4.79 for ANOVA model for regression. The resulting equations are:

$$y = 7.9311x^{2.5429} \quad . \quad . \quad . \quad . \qquad (4.37)$$

$$y = -8.7679x^3 + 91.738x^2 - 208.23x + 165.57 \quad . \quad . \quad . \qquad (4.38)$$

$$y = 84.294x - 127.182 \quad . \quad . \quad . \quad . \qquad (4.39)$$

Equations (4.37), (4.38) and (4.39) results in the following models:

$$Q = 7.9311h^{2.5429} \quad . \quad . \quad . \quad . \qquad (4.40)$$

$$Q = -8.7679h^3 + 91.738h^2 - 208.23h + 165.57 \quad . \quad . \quad . \qquad (4.41)$$

$$Q = 84.294h - 127.182 \quad . \quad . \quad . \quad . \qquad (4.42)$$

Equations (4.40) is a power model, equations (4.41) is a polynomial model while equations (4.42) is ANOVA model for regression.

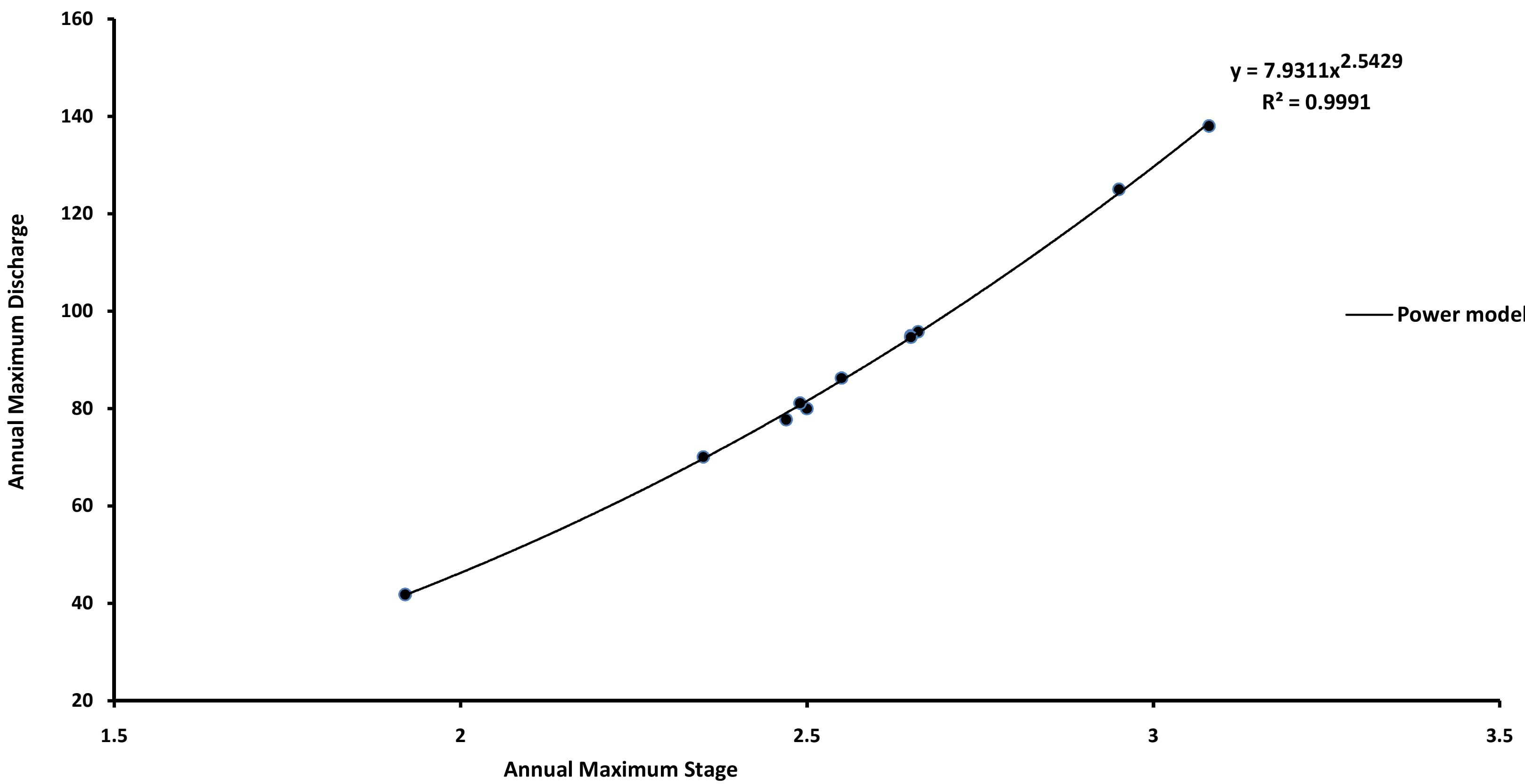


Figure 4.37: Plot of streamflow model calibration of Ossiomo River at Abudu gauging station (Power model)

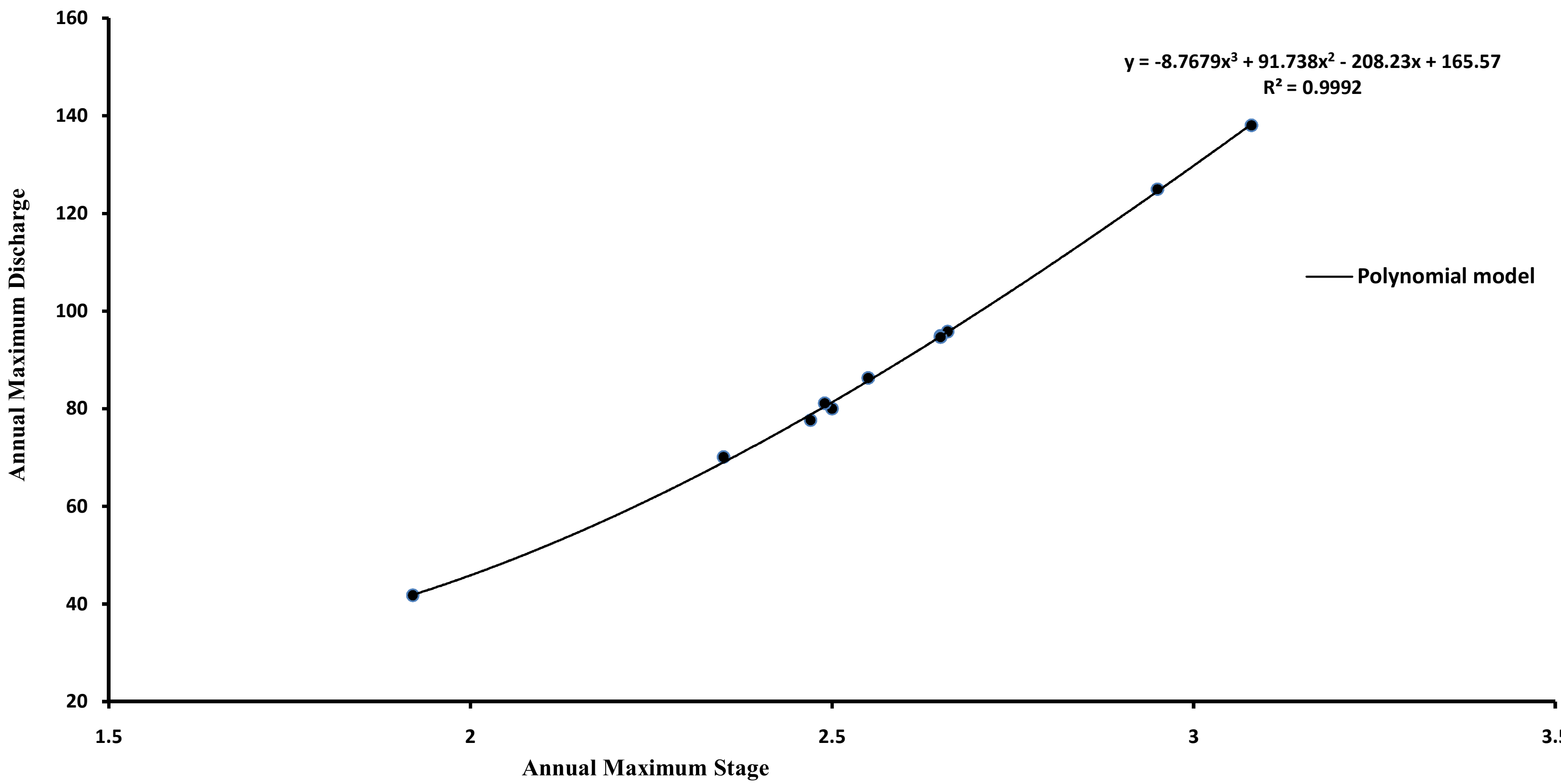


Figure 4.38: Plot of streamflow model calibration of Ossiomo River at Abudu gauging station (Polynomial model)

Table 4.79: Summary output of ANOVA model for regression of Ossiomo River at Abudu gauging station

Regression Statistics	
Multiple R	0.990191263
R Square	0.980478737
Adjusted R Square	0.978526611
Standard Error	3.61524362
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6564.556802	6564.556802	502.2619446	7.03401E-10
Residual	10	130.6998643	13.06998643		
Total	11	6695.256667			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	-127.1815702	9.747533347	-13.04756452	1.32479E-07	-148.900428
X Variable 1	84.29427046	3.761256224	22.41120132	7.03401E-10	75.91366933

From Table 4.10, the fitted regression equation is $y = 84.294x - 127.182$

4.7.2 Verificationof the streamflow models of Ossiomo River at Abudu gauging station

Verification of the streamflow models of Ossiomo River at Abudu gauging station was carried out. The verified recordsare tabulated in Table 4.80.

Table 4.80: Verification of streamflow models of Ossiomo River at Abudugauging station

S/N	Year	Annual Maximum Stage (h) (m)	Measured Annual Maximum Discharge (Q.) (m^3/s)	Predicted Annual Maximum Discharge (Q.) (m^3/s) (Power Model)	Predicted Annual Maximum Discharge (Q.) (m^3/s) (Polynomial Model)	Predicted Annual Maximum Discharge (Q.) (m^3/s) (ANOVA Model for regression)
1	1989	2.65	95.0	94.5	94.82	96.20
2	1990	1.92	41.8	41.6	41.89	34.66
3	1991	3.08	138.0	138.4	138.30	132.44
4	1992	2.95	125.0	124.1	124.55	121.49
5	1993	2.50	80.0	81.5	81.36	83.55
6	1994	2.47	77.7	79.0	78.80	81.03
7	1995	2.66	95.8	95.4	95.76	97.04
8	1996	2.65	94.7	94.5	94.82	96.20
9	1997	2.65	94.7	94.5	94.82	96.20
10	1998	2.35	70.1	69.6	69.06	70.91
11	1999	2.49	81.1	80.6	80.50	82.71
12	2000	2.55	86.3	85.7	85.68	87.77

The results of the measured and predicted discharge values of the models as presented in Table 4.80 were used to plot linear streamflow models verification graphs shown in Figures 4.39 through 4.41.

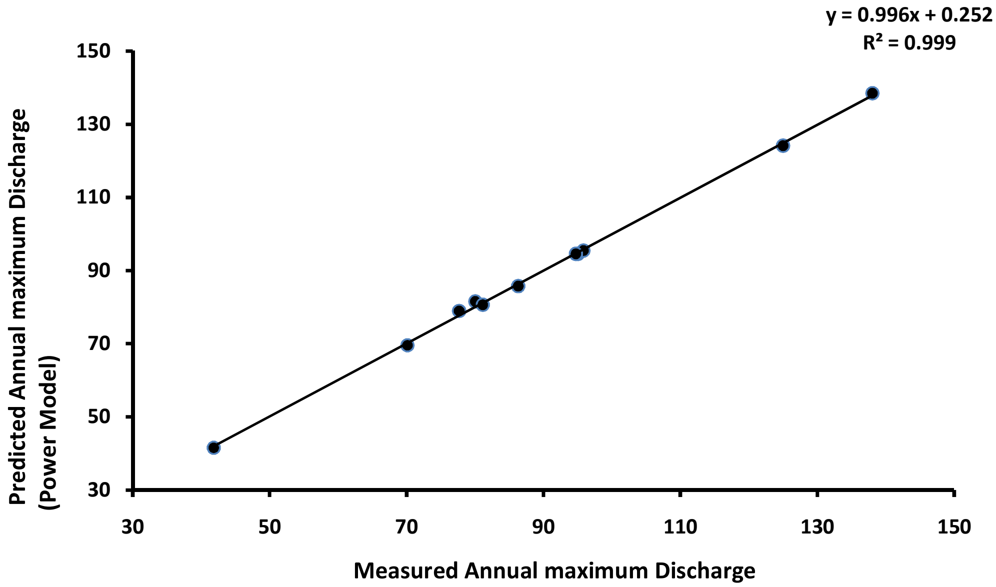


Figure 4.39: Verification of the streamflow model of Ossiomo River at Abudugauging station (for the power model)

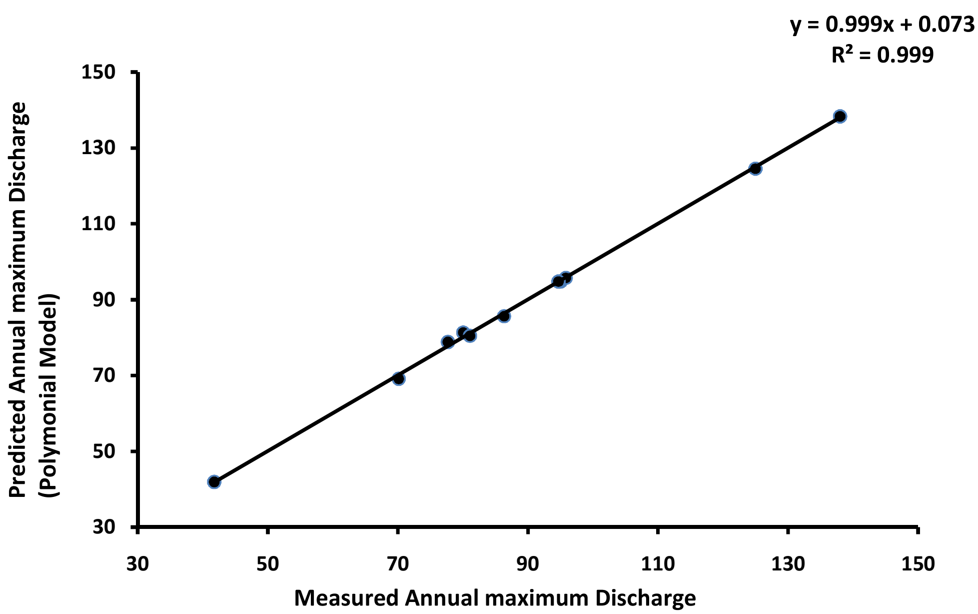


Figure 4.40: Verification of the streamflow model of Ossiomo River at Abudu gauging station (for the polynomial model)

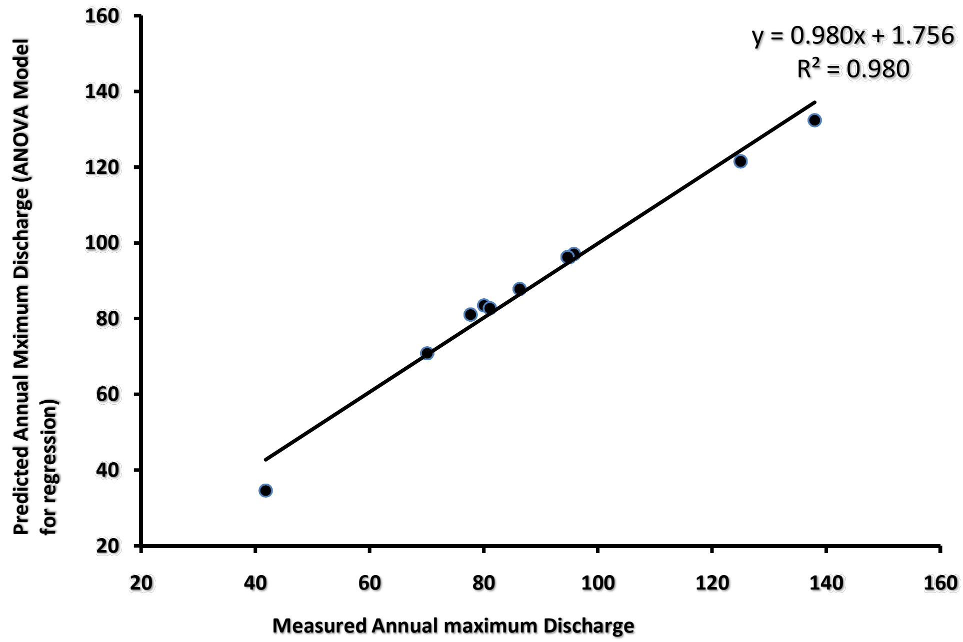


Figure 4.41: Verification of the streamflow model of Ossiomo River at Abudu gauging station (for the ANOVA model for regression)

4.7.3 Comparisons of the streamflow models of Ossiomo River at Abudu gauging station.

Comparisons of the streamflow models of Ossiomo River at Abudu gauging station comprises four subheadings: One-way ANOVA F-Test, Variance Ratio Test or Snedecor's F-distribution (F-Test), comparison using graph and finally comparison using Student's t-Test.

4.7.3.1 Comparison of the streamflow models of Ossiomo River at Abudu gauging station using One-way ANOVA F-Test

The comparison of the streamflow models verified for Ossiomo River at Abudu gauging station using One-way ANOVA F-test is shown in Table 4.81.

Table 4. 81: One-way ANOVA F-Testfor streamflow models of Ossiomo River

Groups	Count	Sum	Average	Variance
Power model	12	1079.4	89.95	604.9155
Polynomial model	12	1080.36	90.03	608.3195
ANOVA model for regression	12	1080.2	90.0167	596.7978

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.044089	2	0.02204	3.65E-05	0.999963	3.284918
Within Groups	19910.36	33	603.344			
Total	19910.4	35				

4.7.3.2 Comparisonof the streamflow models of Ossiomo River at Abudu gauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test)

The Comparisonof the streamflow models of Ossiomo River at Abudugauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test) are shown in Tables 4.82 through 4.84.

Table 4. 82: F-Test Two-Sample for Variances (Power model and Polynomial model)

	Power model	**Polynomial model**
Mean	89.95	90.03
Variance	604.9154545	608.3194727
Observations	12	12
df	11	11
F	0.994404226	
P(F<=f) one-tail	0.496370963	
F Critical one-tail	0.35487036	

Table 4. 83: F-Test Two-Sample for Variances (Power model and ANOVA model for regression)

	Power model	ANOVA model for regression
Mean	89.95	90.01666667
Variance	604.9154545	596.7978242
Observations	12	12
df	11	11
F	1.013601977	
P(F<=f) one-tail	0.491263284	
F Critical one-tail	2.81793047	

Table 4. 84: F-Test Two-Sample for Variances (Polynomial model and ANOVA model for regression)

	Polynomial model	ANOVA model for regression
Mean	90.03	90.01666667
Variance	608.3194727	596.7978242
Observations	12	12
df	11	11
F	1.019305782	
P(F<=f) one-tail	0.487635536	
F Critical one-tail	2.81793047	

4.7.3.3 Comparisonof the streamflow models of Ossiomo River at Abudu gauging station using graph

The comparison of the streamflow models verified for Ossiomo River at Abudu gauging station using graph is shown in Figure 4.42.

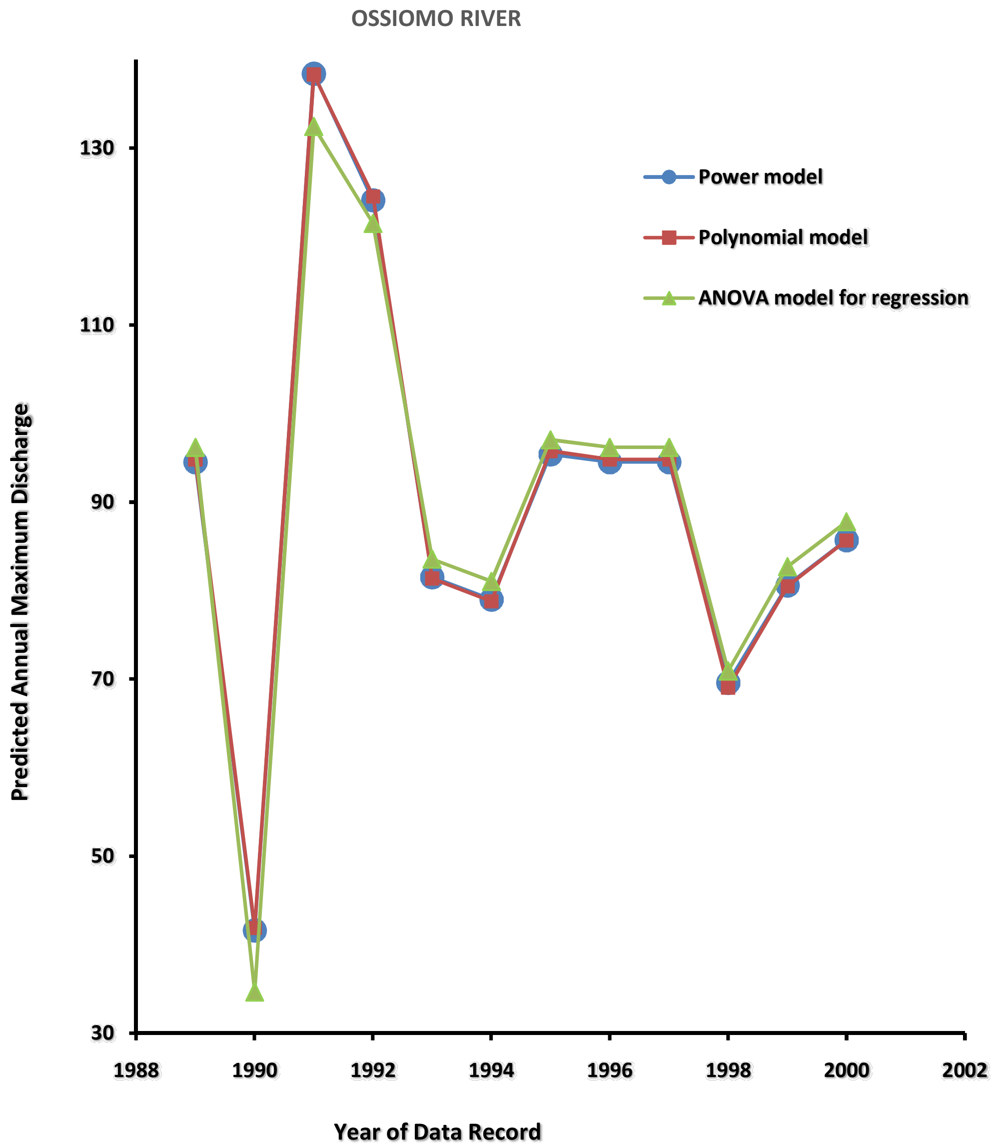


Figure 4.42: Comparison of the streamflow models verified for Ossiomo River at Abudu streamflow gauging station

4.7.3.4 Comparisonof the streamflow models of Ossiomo River at Abudu gauging station using Student's t-Test

The streamflow modelsof Ossiomo River at Abudu gauging station are further compared using Student's t-Test (distribution) as shown in Tables 4.85 through 4.87.

Table 4.85: t-Test: Paired Two Sample for Means (Power and Polynomial Models)

	Power model	Polynomial model
Mean	89.95	90.03
Variance	604.9154545	608.3194727
Observations	12	12
Pearson Correlation	0.999927641	
Hypothesized Mean Difference	0	
df	11	
t Stat	-0.910878406	
P(T<=t) one-tail	0.190943321	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.381886642	
t Critical two-tail	2.20098516	

Table 4.86: t-Test: Paired Two Sample for Means (Power Model and ANOVA Model for regression)

	Power model	ANOVA model for regression
Mean	89.95	90.01666667
Variance	604.9154545	596.7978242
Observations	12	12
Pearson Correlation	0.990900778	
Hypothesized Mean Difference	0	
df	11	
t Stat	-0.069752206	
P(T<=t) one-tail	0.472821396	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.945642791	
t Critical two-tail	2.20098516	

Table 4.87: t-Test: Paired Two Sample for Means (Polynomial Model and ANOVA Model for regression)

	Polynomial model	ANOVA model for regression
Mean	90.03	90.01666667
Variance	608.3194727	596.7978242
Observations	12	12
Pearson Correlation	0.990557756	
Hypothesized Mean Difference	0	
df	11	
t Stat	0.013659614	
P(T<=t) one-tail	0.494673071	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.989346142	
t Critical two-tail	2.20098516	

4.7.4 Computations of the model performance measures of the streamflow model of Ossiomo River at Abudu gauging station

Computations of Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias, root mean square error or standard error of estimateand mean of residue or mean absolute error which are used as tools for the evaluation of the streamflow models ofOssiomo River at Abudu village gauging stationare shown in Tables 4.88 and 4.89 for the power and polynomial models respectively and Table 490 for the ANOVA model for regression.

Table 4.88: Computations of model performance measures of the streamflow model ofOssiomo River at Abudu gauging station(for the *power model*)

Year	Stage (x or h) metres	Measured Discharge (y_i or Q) m^3/s	Predicted Discharge (m^3/s) $y_i' = 7.931h^{2.542}$ (Power model)	Residuals $(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1989	2.65	95.0	94.54	0.45	0.20	0.0047	4.983	24.830
1990	1.92	41.8	41.66	0.14	0.02	0.0033	-48.217	2324.879
1991	3.08	138.0	138.57	- 0.57	0.32	-0.0041	47.983	2302.386
1992	2.95	125.0	124.18	0.82	0.67	0.0066	34.983	1223.810
1993	2.50	80.0	81.52	- 1.52	2.31	-0.0190	-10.017	100.340
1994	2.47	77.7	79.05	- 1.35	1.82	-0.0174	-12.317	151.708
1995	2.66	95.8	95.45	0.32	0.12	0.0033	5.783	33.443
1996	2.65	94.7	94.54	0.16	0.03	0.0017	4.683	21.930
1997	2.65	94.7	94.54	0.16	0.03	0.0017	4.683	21.930
1998	2.35	70.1	69.65	0.45	0.20	0.0064	-19.917	396.687
1999	2.49	81.1	80.69	0.41	0.17	0.0051	-8.917	79.513
2000	2.55	86.3	85.73	0.57	0.32	0.0066	-3.717	13.816
		$\sum$ = 1080.2	**$\sum$ = 1080.12**	**$\sum$= 0.04**	**$\sum$ =6.21**	**$\sum$ = 0.016**		**$\sum$ =6695.272**

Computations of the model performance measures of the streamflow model of Ossiomo River at Abudu gauging station (*power model*).

Mean of measured (observed) discharge = 90.017

Mean of predicted (simulated) discharge = 90.01

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{6.21}{6695.272} = 0.9991$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\ \text{or}\ S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{6.21}{12}} = 0.72$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{90.01 - 90.017}{90.017}\right) = -0.008$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR\ or\ MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{0.04}{12} = 0.003$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{12}(0.016) = 0.9987$$

Table 4.89: Computations of model performance measures of the streamflow model ofOssiomo River at Abudugauging station (for the *polynomial model*)

Year	**Stage in metres (x or h)**	**Measured Discharge (y_i or Q) m^3/s**	**Predicted Discharge (m^3/s)** $y_i' = -8.7679x^3 + 91.738x^2 - 208.23x + 165.57$ **(Polynomial model)**	**Residuals** $(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1989	2.65	95.0	94.82	0.18	0.03	0.0019	4.983	24.830
1990	1.92	41.8	41.89	-0.09	0.01	-0.0022	-48.217	2324.879
1991	3.08	138.0	138.30	-0.30	0.09	-0.0022	47.983	2302.386
1992	2.95	125.0	124.55	0.45	0.20	0.0036	34.983	1223.810
1993	2.50	80.0	81.36	-1.36	1.85	0.0017	-10.017	100.340
1994	2.47	77.7	78.80	-1.10	1.21	-0.0142	-12.317	151.708
1995	2.66	95.8	95.76	0.04	0.00	0.0004	5.783	33.443
1996	2.65	94.7	94.82	-0.12	0.01	-0.0013	4.683	21.930
1997	2.65	94.7	94.82	-0.12	0.01	-0.0013	4.683	21.930
1998	2.35	70.1	69.06	1.04	1.08	0.0148	-19.917	396.687
1999	2.49	81.1	80.50	0.60	0.36	0.0074	-8.917	79.513
2000	2.55	86.3	85.68	0.62	0.38	0.0072	-3.717	13.816
			$\sum$=1080.36	**$\sum$=-0.16**	**$\sum$= 5.22**	**$\sum$= 0.0158**		**$\sum$=6695.272**

Computations of the model performance measures of the streamflow model of Ossiomo River at Abudu gauging station (*polynomial model*).

Mean of measured (observed) discharge = 90.017

Mean of predicted (simulated) discharge = 90.03

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{5.22}{6695.272} = 0.9992$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE}) \text{ or } S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{5.22}{12}} = 0.66$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{90.03 - 90.017}{90.017}\right) = 0.014$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR \ or \ MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{-0.16}{12} = -0.013$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{12}(0.0158) = 0.9987$$

Table 4.90: Computations of model performance measures of the streamflow modelofOssiomo River at Abudugauging station (for the

Year	**Stage (x or h) metres**	**Measured Discharge (y_i or Q) m^3/s**	**Predicted Discharge y = 84.294x - 127.182 (ANOVA model for regression) (m^3/s**	**Residuals** $(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1989	2.65	95.0	96.20	-1.20	1.44	-0.0126	4.983	24.830
1990	1.92	41.8	34.66	7.14	50.98	0.1708	-48.217	2324.879
1991	3.08	138.0	132.44	5.56	30.91	0.0403	47.983	2302.386
1992	2.95	125.0	121.49	3.51	12.32	0.0281	34.983	1223.810
1993	2.50	80.0	83.55	-3.55	12.60	-0.0444	-10.017	100.340
1994	2.47	77.7	81.03	-3.33	11.09	-0.0429	-12.317	151.708
1995	2.66	95.8	97.04	-1.24	1.54	-0.0129	5.783	33.443
1996	2.65	94.7	96.20	-1.50	2.25	-0.0158	4.683	21.930
1997	2.65	94.7	96.20	-1.50	2.25	-0.0158	4.683	21.930
1998	2.35	70.1	70.91	-0.81	0.66	-0.0116	-19.917	396.687
1999	2.49	81.1	82.71	-1.61	2.59	-0.0199	-8.917	79.513
2000	2.55	86.3	87.72	-1.42	2.02	-0.0165	-3.717	13.816
			$\sum$ =433.74	**$\sum$ = 0.05**	**$\sum$ = 130.65**	**$\sum$ =0.0468**		**$\sum$ =6695.272**

ANOVA model for regression)

Computations of the model performance measures of the streamflow model of Ossiomo River at Abudu gauging station (*ANOVA model for regression*).

Mean of measured (observed) discharge = 90.017

Mean of predicted (simulated) discharge = 86.748

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{130.65}{6695.272} = 0.9805$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE}) \text{ or } S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{130.65}{12}} = 3.30$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\bar{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{86.748 - 90.017}{90.017}\right) = -3.632$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR \ or \ MAE} = \frac{(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{0.05}{12} = 0.004$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{12}(0.0468) = 0.9961$$

The summary of streamflow models of Ossiomo River River at Abudu gauging station obtained from Figures 4.37 and 4.38 for the power and polynomial modelsand Table 4.79 for the ANOVA model for regression are shown in Table 4.91.

Table 4.91 Summary of streamflow models of Ossiomo River at Abudu gauging station and the models evaluation parameters

RIVER	STREAMFLOW GAUGING STATION	STREAMFLOW MODEL +	MODEL EVALUATION PARAMETERS *						
			R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
Ossiomo River	Abudu	**Power model** $Q = 7.9311\ h^{2.5429}$	0.9991	0.9995	0.9991	0.72	-0.008	0.003	0.9987
		Polynomial model $Q = -\ 8.7679h^3 + 91.738h^2 - 208.23h + 165.57$	0.9992	0.9996	0.9992	0.66	0.014	-0.013	0.9987
		ANOVA model for regression $Q = 84.294h - 127.182$	0.9980	0.9990	0.9805	38.65	-3.632	0.004	0.9961

+ Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

* **ModelEvaluation Parameters**
Coefficient of determination (R^2) , Coefficient of correlation (R), Nash-Sutcliffe model Efficiency (NSE), Mean Absolute Relative Error (MARE), Root Mean Square Error (RMSE) or Standard error of estimate of discharge on stage ($S_{Q.h}$), Percentage BIAS (PBIAS), Mean Residue (MR).

4.7.5 Comparisons of the streamflowmodels of Owena, Owan, Ikpoba and Ossiomo Rivers

Comparison is carried out for rivers having similar years of record as the abscissa and the predicted discharge as the ordinate. Comparisons of the streamflow models of Owena, Owan, Ikpoba and Ossiomo Rivers at their various streamflow gauging stations are shown in Figure 4.43(power model), Figure 4.44 (polynomial model) and Figure 4.45 (ANOVA model for regression).

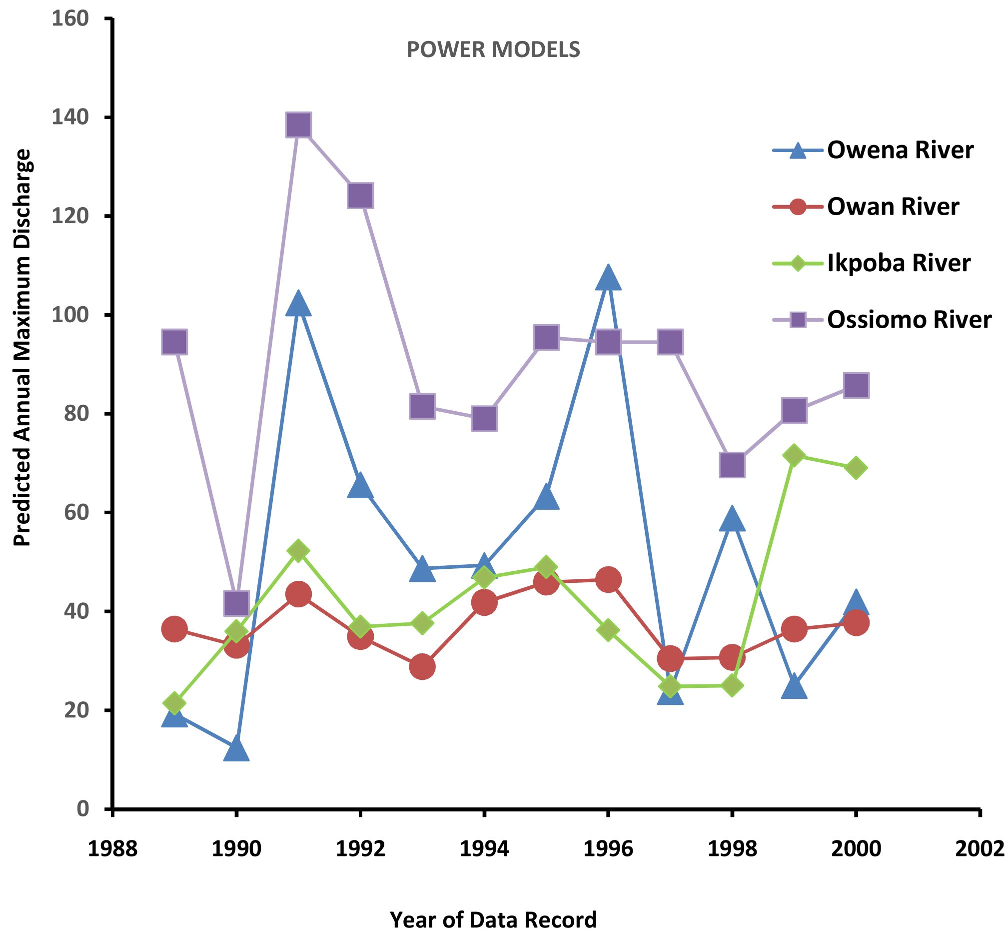


Figure 4.43: Comparison of the streamflow models verified for Owena River, Owan River, Ikpoba River and Ossiomo River (power model)

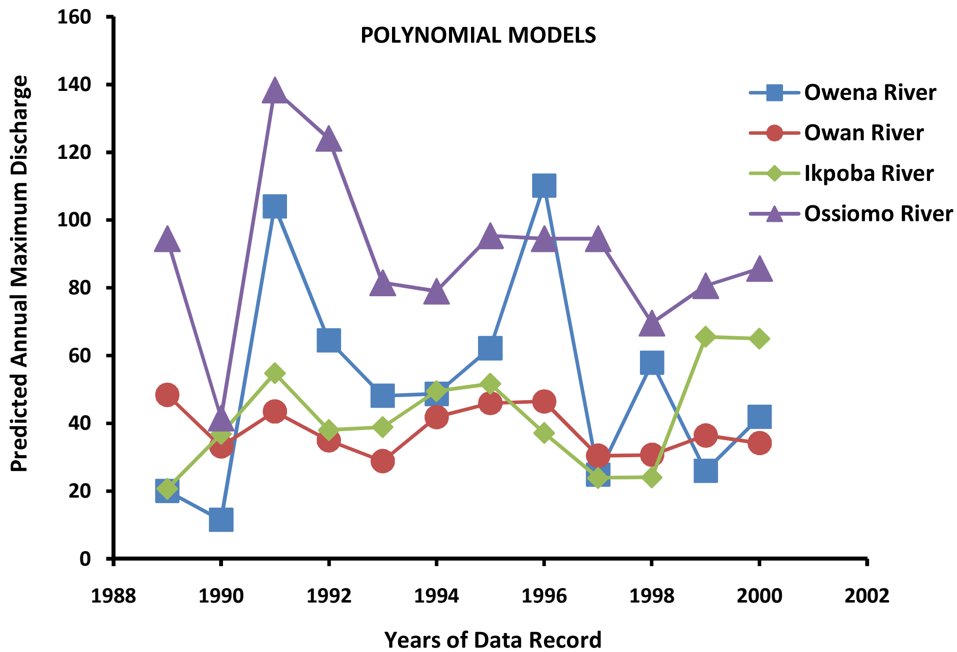


Figure 4.44: Comparison of the streamflow models verified for Owena River, Owan River, Ikpoba River and Ossiomo River (polynomial model)

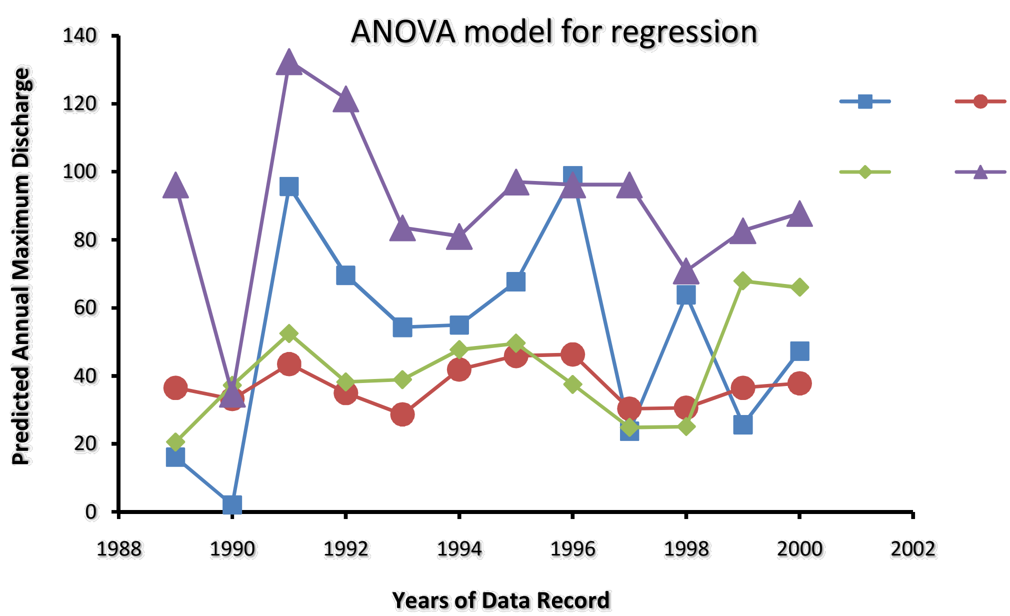


Figure 4.45: Comparison of the streamflow models verified for Owena River, Owan River, Ikpoba River and Ossiomo River (ANOVA model for regression)

4.8 Streamflow Modelling of Imo River

4.8.1 Streamflow Model Calibration of Imo River at Ndimoko gauging station

Plots of the streamflow model calibration of annual maximum stage and annual maximum discharge (Table 3.5) of Imo River at Ndimoko gauging stationare shown in Figures 4.46 and 4.47 for power and polynomial models respectively and Table 4.92 for ANOVA model for regression. The resulting equations are:

$$y = 4.4233x^{1.4952} \quad . \quad . \quad . \quad . \quad (4.43)$$

$$y = 5.9499x^3 - 54.234x^2 + 175.17x - 175.06 \quad . \quad . \quad . \quad (4.44)$$

$$y = 11.573x - 11.772 \quad . \quad . \quad . \quad . \quad (4.45)$$

Equations (4.43), (4.44) and (4.45) results in the following streamflow models:

$$Q = 4.4233h^{1.4952} \quad . \quad . \quad . \quad . \quad (4.46)$$

$$Q = 5.9499h^3 - 54.234h^2 + 175.17h - 175.06 \quad . \quad . \quad . \quad (4.47)$$

$$Q = 11.573h - 11.772 \quad . \quad . \quad . \quad . \quad (4.48)$$

Equations (4.46) is a power model, equations (4.47) is a polynomial model while equations (4.48) is ANOVA model for regression.

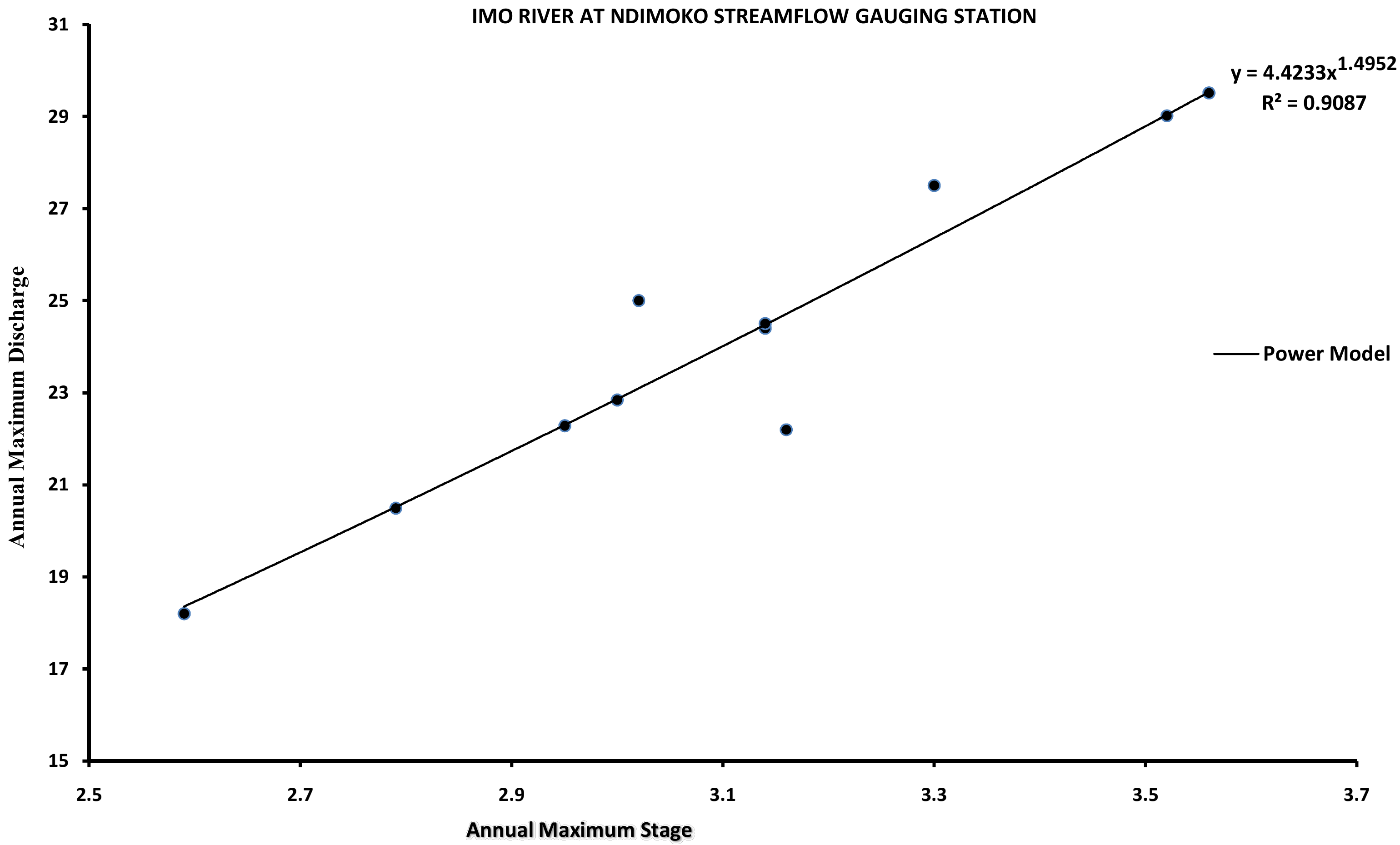


Figure 4.46: Plot of streamflow model calibration of Imo River at Ndimoko streamflow gauging station (power model)

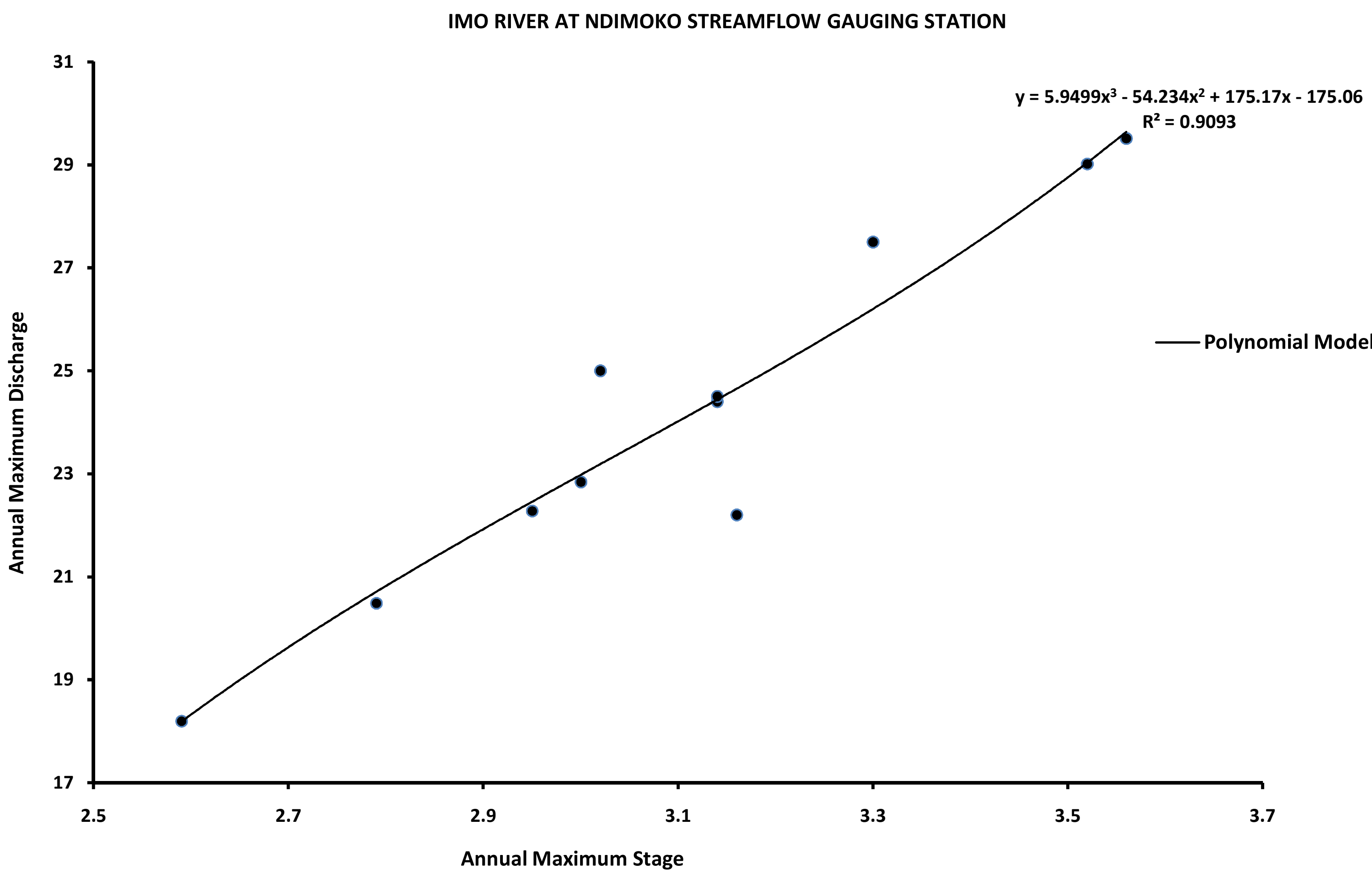


Figure 4.47: Plot of streamflow model calibration of Imo River at Ndimoko gauging station (polynomial model)

Table 4.92: Summary output of ANOVA model for regression of Imo River at Ndimoko streamflow gauging station

Regression Statistics	
Multiple R	0.952706242
R Square	0.907649184
Adjusted R Square	0.897387983
Standard Error	1.120620834
Observations	11

ANOVA

	df	SS	MS	F	Significance F
Regression	1	111.0803351	111.0803351	88.45447233	5.94785E-06
Residual	9	11.30211949	1.255791054		
Total	10	122.3824545			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-11.7716244	3.837116356	-3.067830971	0.013400892	-20.45178465	-3.091464148
X Variable 1	11.57236957	1.230445541	9.405023781	5.94785E-06	8.788908381	14.35583077

From Table 4.10, the fitted regression equation is $y = 11.572x – 11.772$

4.8.2 Verification of the streamflow models of Imo River at Ndimoko

Verification of the streamflow models of Imo River at Ndimoko gauging station was carried out. The verified records are tabulated in Table 4.93.

Table 4.93: Verification of streamflow model of Imo River at Ndimoko gauging station

Year	Stage (x or h) metres	Measured Annual Maximum Discharge (y_i or Q) m^3/s	Predicted Annual Maximum Discharge m^3/s (Power model)	Predicted Annual Maximum Discharge m^3/s (Polynomial model)	Predicted Annual Maximum Discharge m^3/s (ANOVA model for regression)
1979	3.02	25.00	23.09	23.20	23.18
1980	2.59	18.20	18.35	18.20	18.20
1981	3.30	27.50	26.36	26.22	26.42
1982	3.14	24.40	24.47	24.45	24.57
1983	3.16	22.20	24.70	24.66	24.80
1984	3.14	24.50	24.47	24.45	24.57
1985	3.00	22.84	22.86	22.99	22.95
1986	2.95	22.28	22.29	22.47	22.37
1987	2.79	20.49	20.51	20.72	20.52
1988	3.56	29.51	29.52	29.65	29.43
1989	3.52	29.02	29.03	29.06	28.96

The results of the measured and predicted discharge values of the models as presented in Table 4.93 were used to plot linear streamflow models verification graphs shown in Figures 4.48 through 4.50.

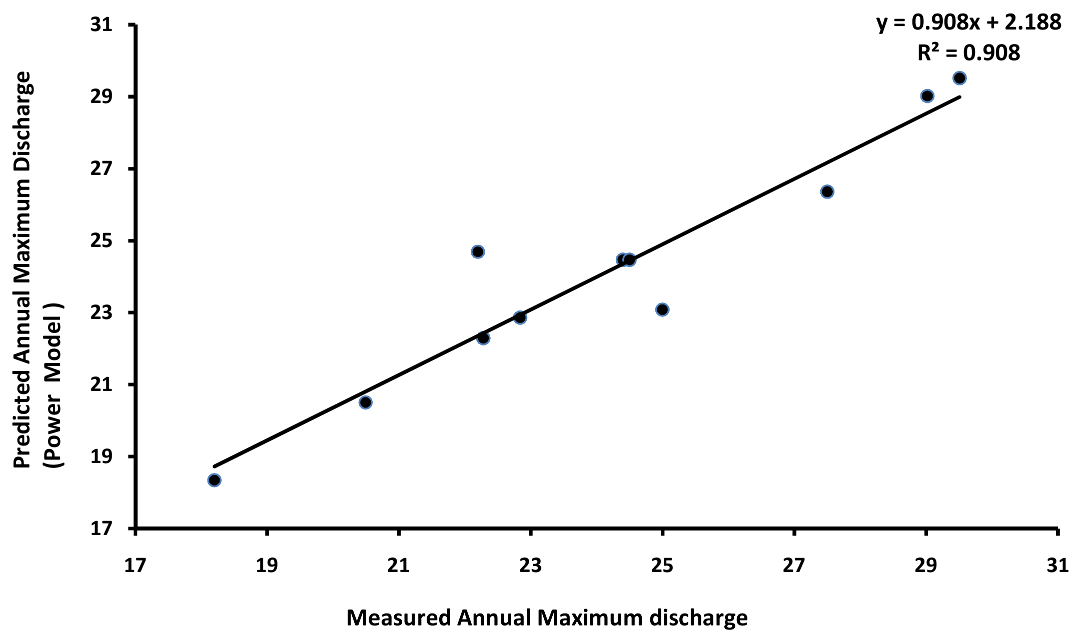


Figure 4.48: Verification of the streamflow model of Imo River at Ndimoko gauging station (for the *power model*)

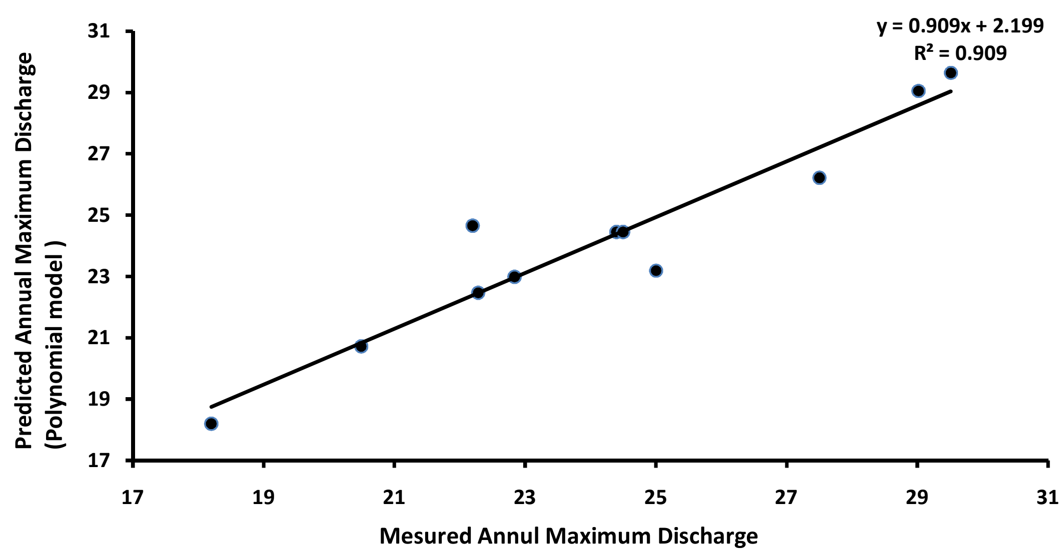


Figure 4.49: Verification of the streamflow model of Imo River at Ndimoko gauging station (for the *polynomial model*)

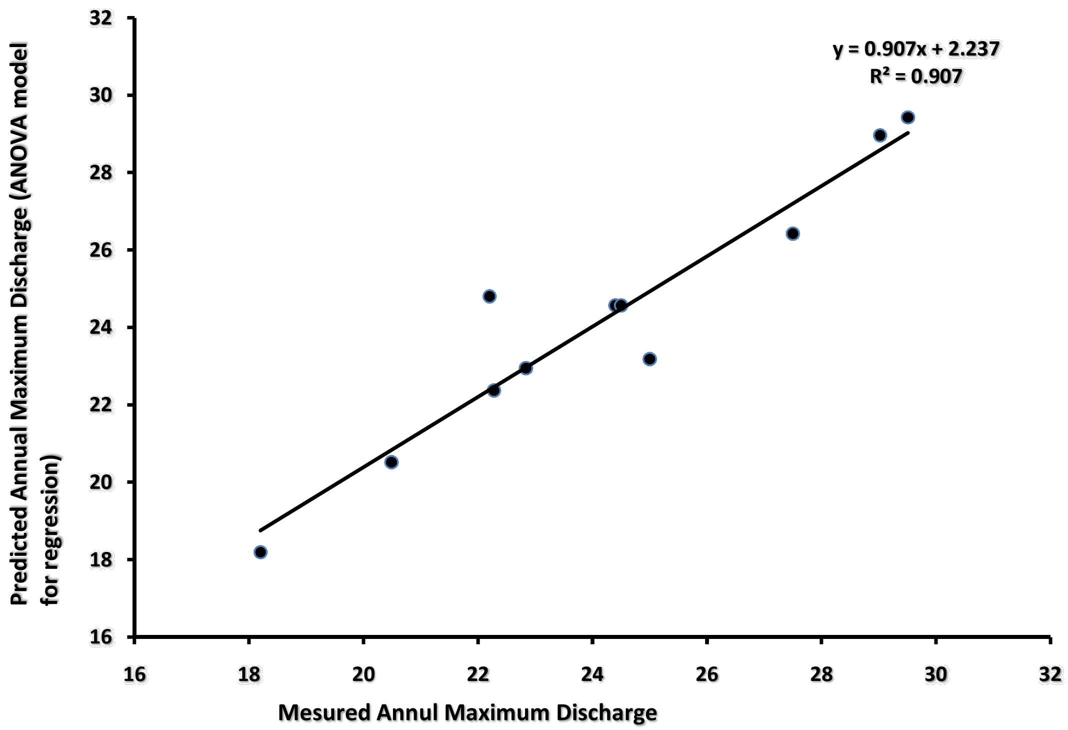


Figure 4.50: Verification of the streamflow model of Imo River at Ndimoko gauging station (for the *ANOVA model for regression*)

4.8.3 Comparisons of the streamflow models of Imo River at Ndimoko gauging station

Comparisons of the streamflow models of Imo River at Ndimoko comprises four subheadings: One-way ANOVA F-Test, Variance Ratio Test or Snedecor's F- distribution (F-Test), comparison using graph and finally comparison using Student's t-Test.

4.8.3.1 Comparison of the streamflow models of Imo River at Ndimoko gauging station using One-way ANOVA F-Test

The comparison of the streamflow models verified for Imo River at Ndimoko gauging station using One-way ANOVA F-Test is shown in Table 4.94.

Table 4.94: One-way ANOVA F-Test for streamflow models of Imo River at Ndimoko

Groups	Count	Sum	Average	Variance
Power model	11	265.65	24.15	11.118
Polynomial model	11	266.07	24.188	11.13
ANOVA model for regression	11	265.97	24.179	11.106

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.00875	2	0.0044	0.0004	0.99961	3.31583
Within Groups	333.547	30	11.118			
Total	333.555	32				

4.8.3.2 Comparisonof the streamflow models of Imo River at Ndimoko gauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test).

The Comparisonof the streamflow models of Imo River at Ndimokogauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test) are shown in Tables 4.95 through 4.97.

Table 4.95: F-Test Two-Sample for Variances (Power and Polynomial models)

	Power model	**Polynomial model**
Mean	24.15	24.18818182
Variance	11.11796	11.13049636
Observations	11	11
df	10	10
F	0.998873692	
P(F<=f) one-tail	0.499306667	
F Critical one-tail	0.335769113	

Table 4.96: F-Test Two-Sample for Variances (Power model and ANOVA model for regression)

	Power model	Polynomial model for regression
Mean	24.15	24.17909091
Variance	11.11796	11.10620909
Observations	11	11
df	10	10
F	1.001058049	
P(F<=f) one-tail	0.499349397	
F Critical one-tail	2.978237016	

Table 4.97: F-Test Two-Sample for Variances (Polynomial model and ANOVA model for regression)

	Polynomial model	ANOVA model for regression
Mean	24.18818182	24.17909091
Variance	11.13049636	11.10620909
Observations	11	11
df	10	10
F	1.002186819	
P(F<=f) one-tail	0.498656065	
F Critical one-tail	2.978237016	

4.8.3.3 Comparisonof the streamflow models of Imo River Ndimoko gauging station using graph

The comparison of the streamflow models verified for Imo River at Ndimoko gauging station using graph is shown in Figure 4.51.

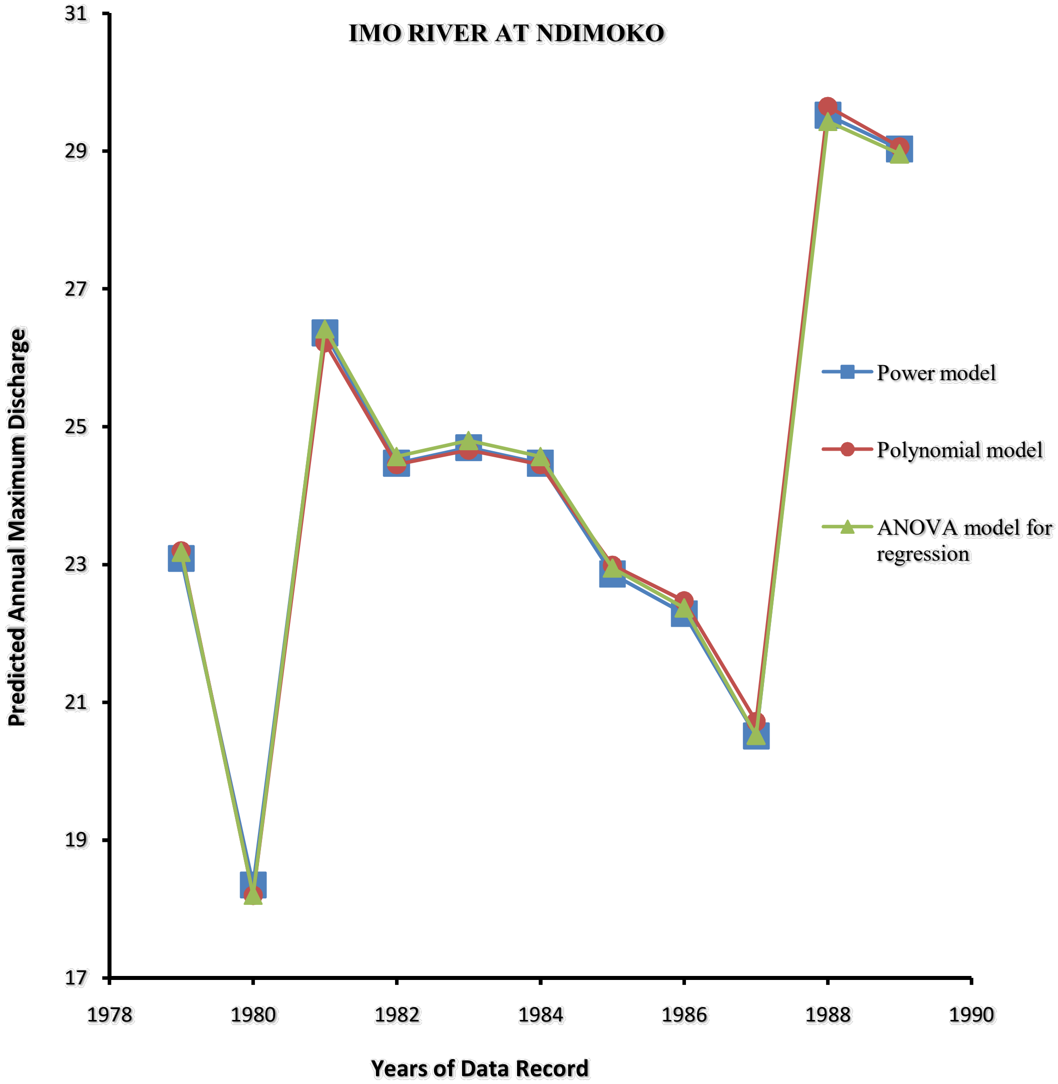


Figure 4.51: Comparison of the streamflow models verified for Imo River at Ndimoko gauging station

4.8.3.4 Comparisonof the streamflow models of Imo River at Ndimoko gauging station using Student's t-Test

The streamflow modelsof Imo River at Ndomoko gauging station are further compared using Student's t-Test (distribution) as shown in Tables 4.98 through 4.100.

Table 4.98: t-Test: Paired Two Sample for Means (Power and Polynomial models)

	Power model	Polynomial model
Mean	24.15	24.18818182
Variance	11.11796	11.13049636
Observations	11	11
Pearson Correlation	0.999318028	
Hypothesized Mean Difference	0	
df	10	
t Stat	-1.027943124	
P(T<=t) one-tail	0.164099304	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.328198609	
t Critical two-tail	2.228138852	

Table 4.99: t-Test: Paired Two Sample for Means (Power model and ANOVA model for regression)

	Power model	ANOVA model for regression
Mean	24.15	24.17909091
Variance	11.11796	11.10620909
Observations	11	11
Pearson Correlation	0.999628963	
Hypothesized Mean Difference	0	
df	10	
t Stat	-1.062308339	
P(T<=t) one-tail	0.156538302	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.313076604	
t Critical two-tail	2.228138852	

Table 4.100: t-Test: Paired Two Sample for Means (Polynomial model and ANOVA model for regression)

	Polynomial model	**ANOVA model for regression**
Mean	24.18818182	24.17909091
Variance	11.13049636	11.10620909
Observations	11	11
Pearson Correlation	0.999110667	
Hypothesized Mean Difference	0	
df	10	
t Stat	0.214333835	
P(T<=t) one-tail	0.417297066	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.834594133	
t Critical two-tail	2.228138852	

4.8.4 Computations of the model performance measures of the streamflow models of Imo River at Ndimoko gauging station

Computations of Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias, root mean square error or standard error of estimateand mean of residue or mean absolute error which are used as tools for the evaluation of the streamflow models ofImo River at Ndimoko gauging stationare shown in Tables 4.101 and 4.102 for the power and polynomial models respectively and Table 4.103 for the ANOVA model for regression

Table 4.101 Computations of model performance measures of the streamflow modelof Imo River at Ndimoko gauging station (for the *power model*)

Year	Stage (x or h) metres	Measured Discharge (y_i or Q) m^3/s	Predicted Discharge $y_i' = 4.423x^{1.495}$ Power model	Residuals $(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1979	3.02	25.00	23.09	1.91	3.65	0.0764	0.824	0.679
1980	2.59	18.20	18.35	- 0.15	0.02	0.0082	-5.976	35.713
1981	3.30	27.50	26.36	1.14	2.30	0.0041	3.324	11.049
1982	3.14	24.40	24.47	- 0.07	0.01	0.0029	0.224	0.050
1983	3.16	22.20	24.70	- 2.50	6.25	0.1126	-1.976	3.905
1984	3.14	24.50	24.47	0.03	0.00	0.0012	0.324	0.105
1985	3.00	22.84	22.86	- 0.02	0.00	0.0009	-1.336	1.785
1986	2.95	22.28	22.29	- 0.01	0.00	0.0004	-1.896	3.595
1987	2.79	20.49	20.51	- 0.02	0.00	0.0010	-3.686	13.587
1988	3.56	29.51	29.52	- 0.01	0.00	0.0003	5.334	28.452
1989	3.52	29.02	29.03	- 0.01	0.00	0.0003	4.844	23.464
		$\sum$ = 265.94	**$\sum$ = 265.65**	**$\sum$ =0.29**	**$\sum$ = 12.23**	**$\sum$ =0.2083**		**$\sum$ =122.384**

Computations of the model performance measures of the streamflow model of Imo River at Ndimoko gauging station (*power model*).

Mean of Measured discharge = 24.176

Mean of predicted discharge = 24.15

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{12.23}{122.384} = 0.9001$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\text{ or } S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{12.23}{11}} = 1.054$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{24.15 - 24.176}{24.176}\right) = -0.108$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR} \text{ or } \mathrm{MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{0.29}{11} = 0.026$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{11}(0.2083) = 0.981$$

Table 4.102: Computations of model performance measures of the streamflow modelof Imo River at Ndimoko gauging station (for the *polynomial model*)

Year	**Stage in metres (x or h)**	**Measured Discharge in m^3/s (y_i or Q)**	**Predicted Discharge $y_i' = 5.9499x^3 - 54.234x^2 + 175.17x - 175.06$ Polynomial model**	**Residuals $(y_i - y_i')$**	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1979	3.02	25.00	23.20	1.80	3.24	0.072	0.824	0.679
1980	2.59	18.20	18.20	0.00	0.00	0.000	-5.976	35.713
1981	3.30	27.50	26.22	1.28	1.64	0.047	3.324	11.049
1982	3.14	24.40	24.45	-0.05	0.00	0.002	0.224	0.050
1983	3.16	22.20	24.66	-2.46	6.05	0.011	-1.976	3.905
1984	3.14	24.50	24.45	0.05	0.00	0.002	0.324	0.105
1985	3.00	22.84	22.99	-0.15	0.02	0.007	-1.336	1.785
1986	2.95	22.28	22.47	-0.19	0.04	0.009	-1.896	3.595
1987	2.79	20.49	20.72	-0.23	0.05	0.011	-3.686	13.587
1988	3.56	29.51	29.65	-0.14	0.02	0.005	5.334	28.452
1989	3.52	29.02	29.06	-0.04	0.00	0.001	4.844	23.464
			$\sum$ = **266.07**	$\sum$ = **-0.13**	$\sum$ = 11.06	$\sum$ = **0.167**		$\sum$ = **122.384**

Computations of the model performance measures of the streamflow model of Imo River at Ndimoko gauging station (*polynomial model*).

Mean of measured discharge = 24.176

Mean of predicted discharge = 24.188

i. Nash-Sutcliffe model Efficiency (NSE)

$$\text{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{11.06}{122.384} = 0.9096$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\text{RMSE}) \text{ or } S_{yx} = \sqrt{\frac{\sum(\mathbf{y_i} - \mathbf{y_i'})^2}{n}} = \sqrt{\frac{11.06}{11}} = 1.00$$

iii. Percentage BIAS (PBIAS)

$$\text{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{24.188 - 24.176}{24.176}\right) = 0.050$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\text{MR or MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{-0.13}{11} = -0.012$$

v. Mean Absolute Relative Error (MARE)

$$\text{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{11}(0.167) = 0.985$$

Table 4.103: Computations of model performance measures of the streamflow modelof Imo River at Ndimoko gauging station (for the *ANOVA model for regression*)

Year	**Stage in metres (x or h)**	**Measured Discharge in m^3/s (y_i or Q)**	**Predicted Discharge $Y = 11.572x - 11.772$ ANOVA modelfor regression**	**Residuals $(y_i - y_i')$**	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1979	3.02	25.00	23.18	1.82	3.31	0.073	0.824	0.679
1980	2.59	18.20	18.20	-0.00	0.00	0.000	-5.976	35.713
1981	3.30	27.50	26.42	1.08	1.17	0.039	3.324	11.049
1982	3.14	24.40	24.57	-0.17	0.03	-0.007	0.224	0.050
1983	3.16	22.20	24.80	-2.60	6.76	-0.117	-1.976	3.905
1984	3.14	24.50	24.57	-0.07	0.00	-0.003	0.324	0.105
1985	3.00	22.84	22.95	-0.11	0.01	-0.005	-1.336	1.785
1986	2.95	22.28	22.37	-0.09	0.01	-0.004	-1.896	3.595
1987	2.79	20.49	20.52	-0.03	0.00	-0.001	-3.686	13.587
1988	3.56	29.51	29.43	0.08	0.01	0.003	5.334	28.452
1989	3.52	29.02	28.96	0.06	0.00	0.002	4.844	23.464
			$\sum$ = **265.97**	$\sum$ = **-0.03**	$\sum$ = **11.30**	$\sum$ = **-0.022**		$\sum$ = **122.384**

Computations of the model performance measures of the streamflow model of Imo River at Ndimoko gauging station (*ANOVA model for regression*).

Mean of measured discharge = 24.176

Mean of predicted discharge = 24.179

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{11.30}{122.384} = 0.9077$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\ \text{or}\ \mathrm{S}_{yx} = \sqrt{\frac{\sum(\mathbf{y_i} - \mathbf{y_i'})^2}{n}} = \sqrt{\frac{11.30}{11}} = 1.014$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{24.179 - 24.176}{24.176}\right) = 0.012$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR}\ \text{or}\ \mathrm{MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{-0.03}{11} = -0.003$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{11}(-0.022) = 1.00$$

The summary of streamflow models of Imo River at Ndimoko gauging station obtained from Figures 4.46 and 4.47 for the power and polynomial models and Table 4. 92 for the ANOVA model for regression are shown in Table 4.104.

Table 4.104 Summary of streamflow models of Imo River at Ndimoko gauging station and the models evaluation parameters

RIVER	STREAMFLOW GAUGING STATION	STREAMFLOW MODEL +	MODEL EVALUATION PARAMETERS *						
			R^2	R	NSE	RMSE or S_{QH}	PBIAS	MRor MAE	MARE
Imo River	Ndimoko	**Power model** $Q = 4.4233h^{1.4952}$	0.9087	0.9533	0.9001	1.054	-0.108	0.026	0.981
		Polynomial model $Q = 5.9499h^3 – 54.234h^2 + 175.17h – 175.06$	0.9093	0.9536	0.9096	1.003	0.050	-0.012	0.985
		ANOVA model for regression $Q = 11.573h – 11.772$	0.9076	0.9527	0.9077	1.014	0.012	-0.003	1.002

+ Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

* **ModelEvaluation Parameters**
Coefficient of determination (R^2), Coefficient of correlation (R), Nash-Sutcliffe model Efficiency (NSE), Mean Absolute Relative Error (MARE), Root Mean Square Error (RMSE) or Standard error of estimate of discharge on stage ($S_{Q.h}$), Percentage BIAS (PBIAS), Mean Residue (MR).

4.9 Streamflow Modelling of Imo River at Umuna

4.9.1 Streamflow Model Calibration of Imo River at Umuna gauging station

Plots of the streamflow model calibration of annual maximum stage and annual maximum discharge (Table 3.5) of Imo River at Umuna gauging station are shown in Figures 4.52 and 4.53 for power and polynomial models respectively and Table 4.105 for ANOVA model for regression. The resulting equations are:

$$y = 4.7025x^{1.8685} \qquad (4.49)$$

$$y = 2.6699x^3 - 25.874x^2 + 103.49x - 107.52 \qquad (4.50)$$

$$y = 25.6003x - 36.0205 \qquad (4.51)$$

Equations (4.49), (4.50) and (4.51) results in the following models:

$$Q = 4.7025h^{1.8685} \qquad (4.52)$$

$$Q = 2.6699h^3 - 25.874h^2 + 103.49h - 107.52 \qquad (4.53)$$

$$Q = 25.600h - 36.021 \qquad (4.54)$$

Equations (4.52) is a power model, equations (4.53) is a polynomial model while equations (4.54) is ANOVA model for regression.

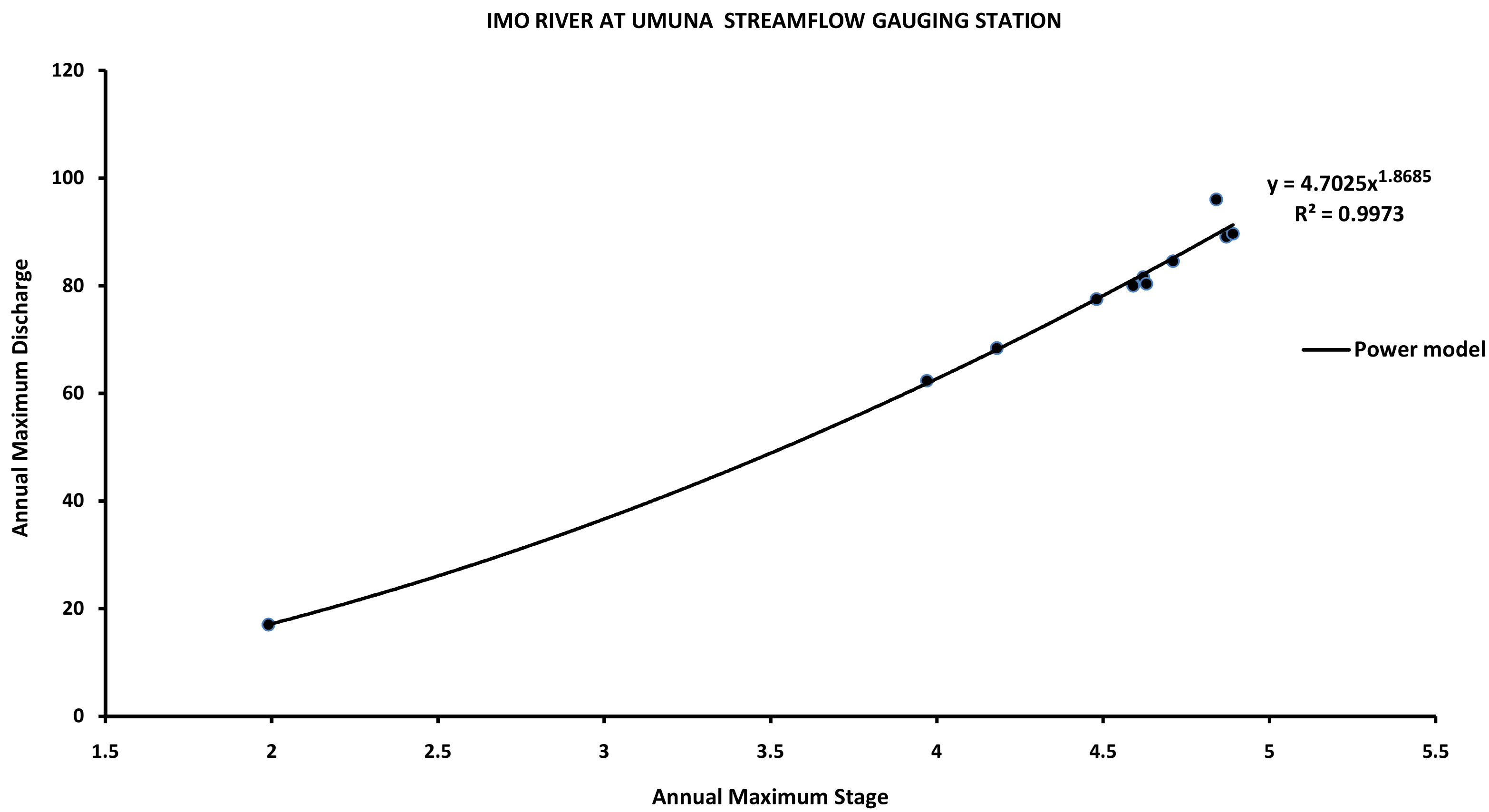


Figure 4.52: Plot of streamflow model calibration of Imo River at Umuna gauging station (Power model)

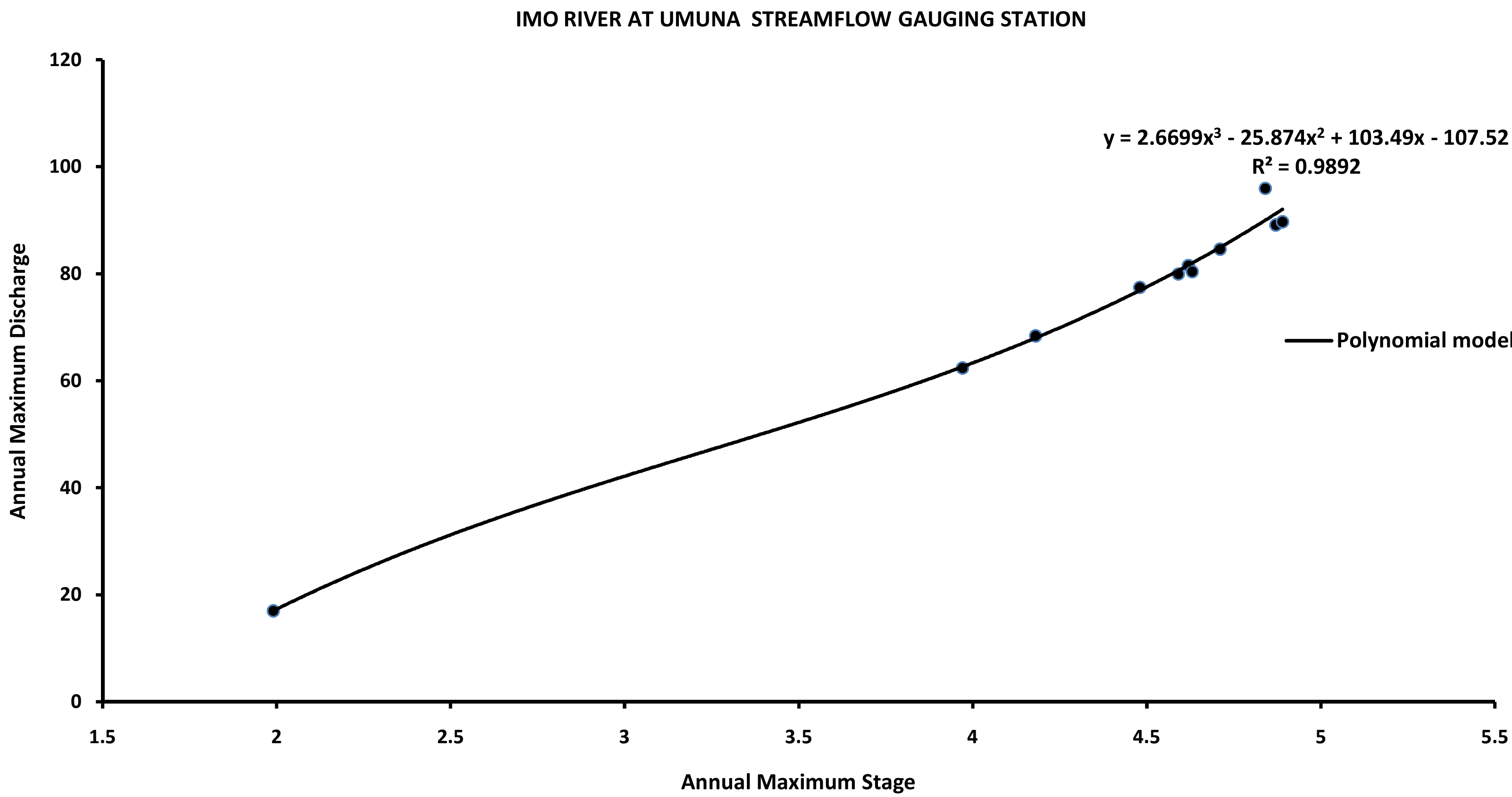


Figure 4.53: Plot of streamflow model calibration of Imo River at Umuna gauging station (Polynomial model)

Table 4.106: Summary output of ANOVA model for regression of Imo River at Umunastreamflow gauging station

Regression Statistics	
Multiple R	0.98953847
R Square	0.979186383
Adjusted R Square	0.976873759
Standard Error	3.268011587
Observations	11

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4521.968175	4521.968175	423.409235	7.06439E-09
Residual	9	96.11909759	10.67989973		
Total	10	4618.087273			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-36.02054297	5.492019751	-6.558706013	0.000104118	-48.44435478	-23.59673115
X Variable 1	25.6002925	1.244127141	20.57691024	7.06439E-09	22.78588138	28.41470362

From Table 4.10, the fitted regression equation is y = 25.6003x - 36.0205

4.9.2 Verificationof the streamflow models of Imo River at Umuna gauging station

Verification of the streamflow models of Imo River at Umuna gauging station was carried out. The verified records are tabulated in Table 4.107.

Table 4.107: Verification of streamflow model of Imo River at Umuna streamflow gauging station

Year	Stage (x or h) metres	Measured Annual Maximum Discharge (y_i or Q) m^3/s	Predicted Annual Maximum Discharge m^3/s (Power model)	Predicted Annual Maximum Discharge m^3/s (Polynomial model)	Predicted Annual Maximum Discharge m^3/s (ANOVA model for regression)
1979	4.48	77.50	77.42	78.88	78.67
1980	4.59	80.00	81.01	80.57	81.48
1981	4.84	96.00	89.45	89.97	87.88
1982	3.97	62.40	61.78	62.60	65.61
1983	1.99	17.00	17.00	17.00	14.92
1984	4.62	81.60	82.00	81.62	82.25
1985	4.18	68.40	68.02	67.98	70.99
1986	4.71	84.60	85.01	84.90	84.56
1987	4.87	89.10	90.49	91.20	88.65
1988	4.63	80.40	82.34	81.98	82.51
1989	4.89	89.70	91.18	92.04	89.16

The results of the measured and predicted discharge values of the models as presented in Table 4.107 were used to plot linear streamflow models verification graphs shown in Figures 4.54 through 4.56

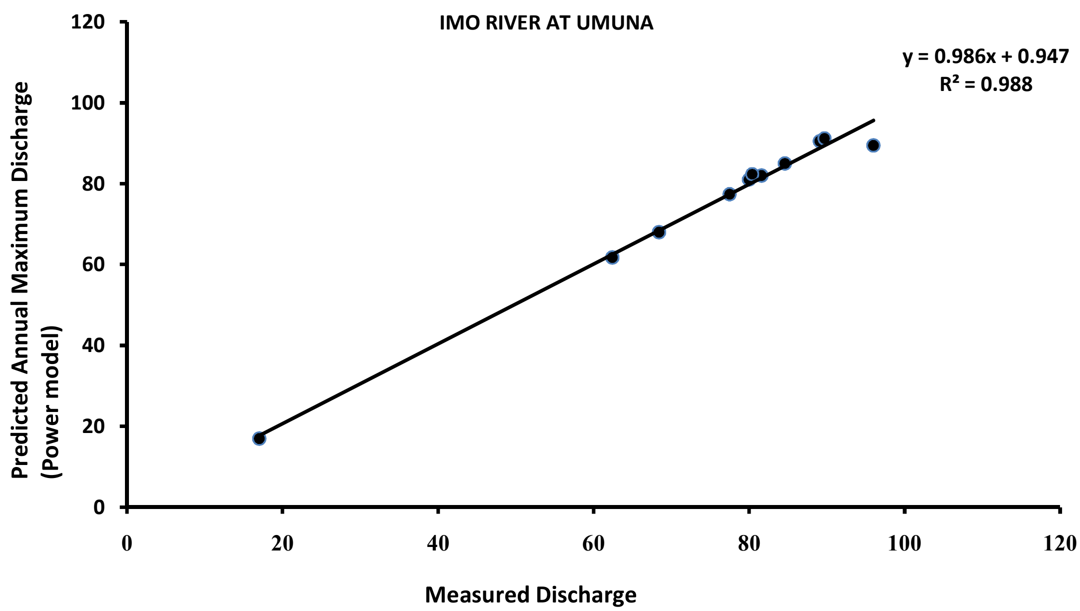


Figure 4.54: Verification of the streamflow model of Imo River at Umuna gauging station (for the *power model*)

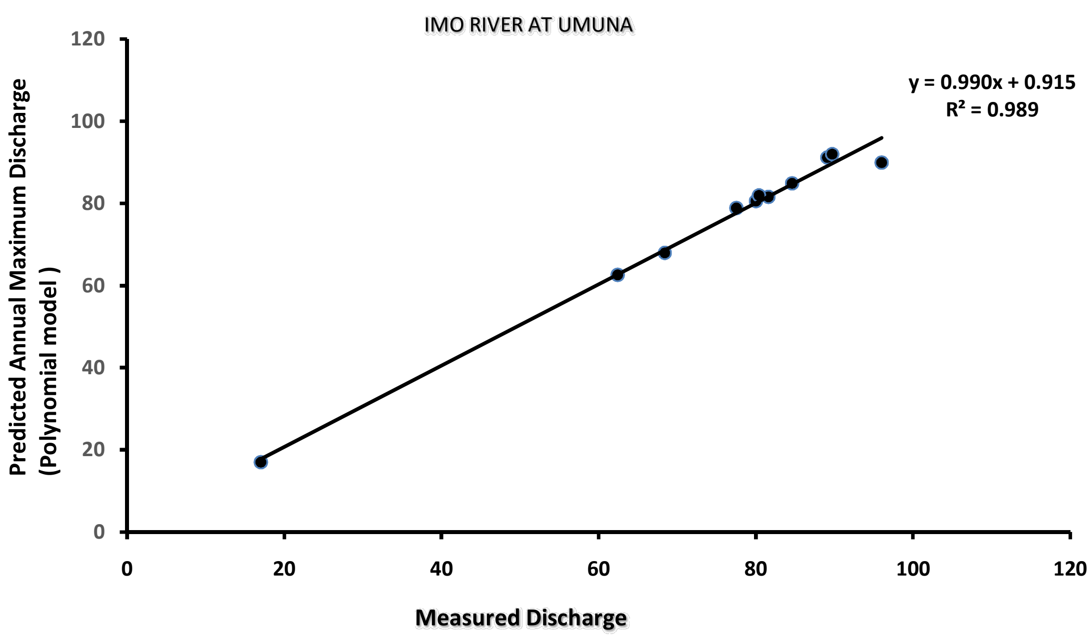


Figure 4.55: Verification of the streamflow model of Imo River at Umuna gauging station (for the *polynomial model*)

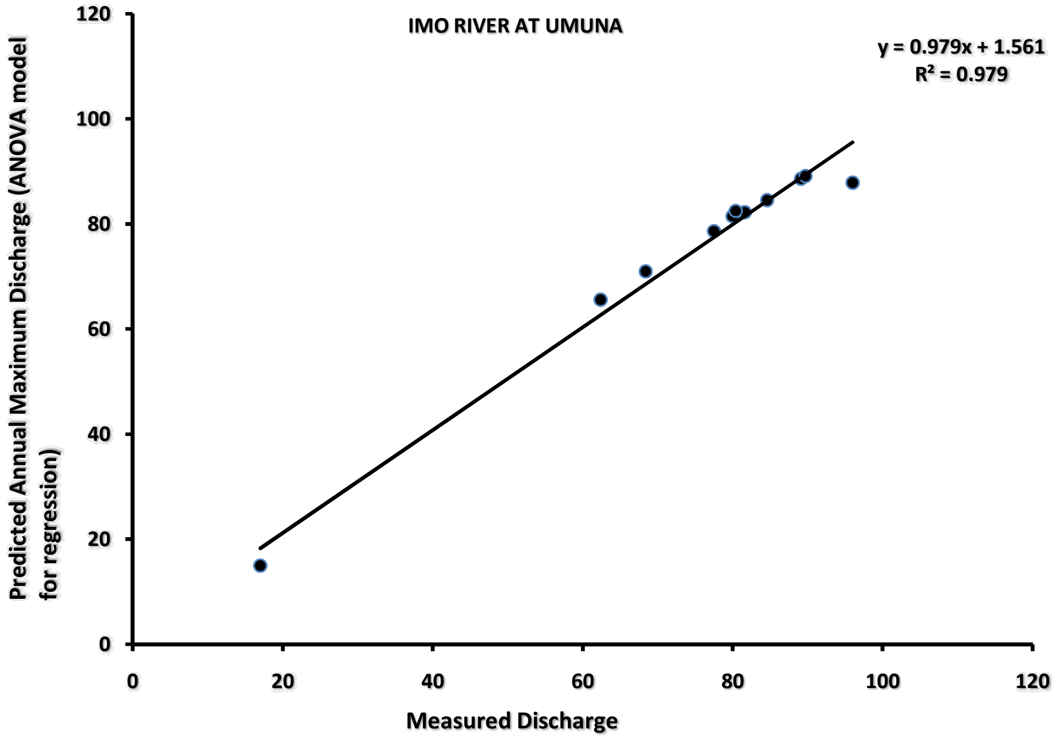


Figure 4.56: Verification of the streamflow model of Imo River at Umuna gauging station (for the *ANOVA model for regression*)

4.9.3 Comparisons of the streamflow models of Imo River at Umuna gauging station

Comparisons of the streamflow models of Imo River at Umuna comprises four subheadings: One-way ANOVA F-Test, Variance Ratio Test or Snedecor's F-distribution (F-Test), comparison using graph and finally comparison using Student's t-Test.

4.9.3.1 Comparison of the streamflow models of Imo River at Umuna gauging station using One-way ANOVA F-Test

The comparison of the streamflow models verified for Imo River at Umuna gauging station using One-way ANOVA F-Testis shown in Table 4.108.

Table 4.108: One-way ANOVA F-Testfor streamflow models of Imo River at Umuna

Groups	Count	Sum	Average	Variance
Power model	11	825.7	75.063636	454.3031
Polynomial model	11	828.74	75.34	457.9305
ANOVA model for regression	11	826.68	75.152727	452.214

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.437745	2	0.2188727	0.000481	0.999519	3.3158295
Within Groups	13644.48	30	454.8159			
Total	13644.91	32				

4.9.3.2 Comparisonof the streamflow models of Imo River at Umuna gauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test).

The Comparisonof the streamflow models of Imo River at Umunagauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test) are shown in Tables 4.109 through 4.111.

Table 4.109: F-Test Two-Sample for Variances (Power model and Polynomial model)

	Power model	**Polynomial model**
Mean	75.06363636	75.34
Variance	454.3031455	457.93054
Observations	11	11
df	10	10
F	0.992078723	
P(F<=f) one-tail	0.495107283	
F Critical one-tail	0.335769113	

Table 4.110: F-Test Two-Sample for Variances (Power model and ANOVA model for regression)

	Power model	ANOVA model for regression
Mean	75.06363636	75.15272727
Variance	454.3031455	452.2140018
Observations	11	11
df	10	10
F	1.004619812	
P(F<=f) one-tail	0.497164303	
F Critical one-tail	2.978237016	

Table 4.111: F-Test Two-Sample for Variances (Polynomial model and ANOVA model for regression)

	Polynomial model	ANOVA model for regression
Mean	75.34	75.15272727
Variance	457.93054	452.2140018
Observations	11	11
df	10	10
F	1.012641223	
P(F<=f) one-tail	0.49227194	
F Critical one-tail	2.978237016	

4.9.3.3 Comparisonof the streamflow models of Imo River at Umuna gauging station using graph

The comparison of the streamflow models verified for Imo River at Umunagauging station using graph is shown in Figure 4.57.

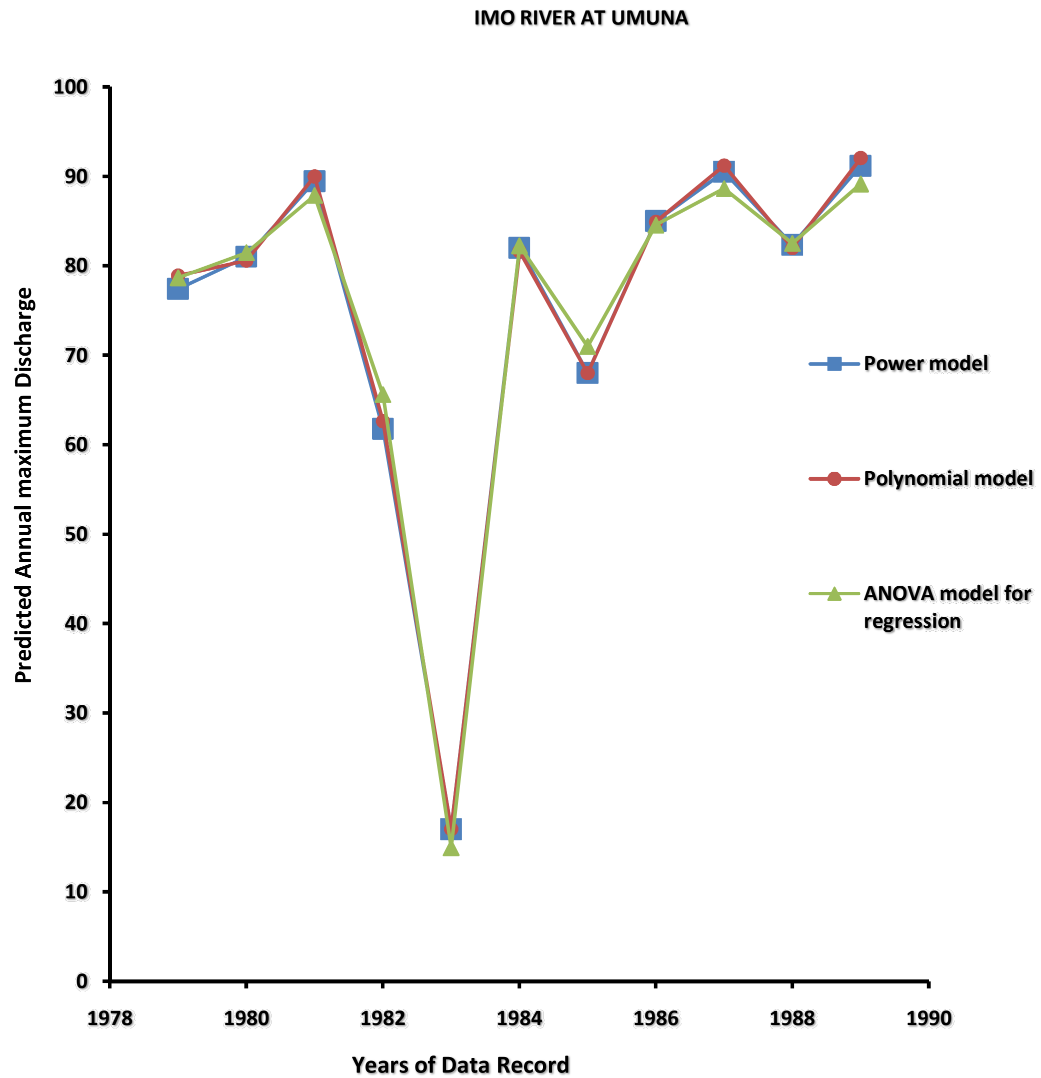


Figure 4.57: Comparison of the models verified for Imo River at Umuna streamflow gauging station

4.9.3.4 Comparisonof the streamflow models of Imo River at Umuna gauging station using Student's t-Test

The streamflow modelsof Imo River at Umuna gauging station are further compared using Student's t-Test (distribution) as shown in Tables 4. 112 through 4.114.

Table 4.112 t-Test: Paired Two Sample for Means (Power and Polynomial Models)

	Power model	Polynomial model
Mean	75.06363636	75.34
Variance	454.3031455	457.93054
Observations	11	11
Pearson Correlation	0.999573885	
Hypothesized Mean Difference	0	
df	10	
t Stat	-1.456701371	
P(T<=t) one-tail	0.087934901	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.175869803	
t Critical two-tail	2.228138852	

Table 4.113: t-Test: Paired Two Sample for Means (Power Model and ANOVA Model for regression)

	Power model	ANOVA model for regression
Mean	75.06363636	75.15272727
Variance	454.3031455	452.2140018
Observations	11	11
Pearson Correlation	0.995619154	
Hypothesized Mean Difference	0	
df	10	
t Stat	-0.148228495	
P(T<=t) one-tail	0.442554389	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.885108779	
t Critical two-tail	2.228138852	

Table 4.114: t-Test: Paired Two Sample for Means (Polynomial Model and ANOVA Model for regression)

	Polynomial model	ANOVA model for regression
Mean	75.34	75.15272727
Variance	457.93054	452.2140018
Observations	11	11
Pearson Correlation	0.995307038	
Hypothesized Mean Difference	0	
df	10	
t Stat	0.299906359	
P(T<=t) one-tail	0.385194989	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.770389977	
t Critical two-tail	2.228138852	

4.9.4 Computations of the model performance measures of the streamflow models of Imo River at Umuna gauging station

Computations of Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias and root mean square error or standard error of estimate which are used as tools for the evaluation of the streamflow model of Imo River at Umuna gauging stationare shown in Tables 4.115 and 4.116 for the power and polynomial models respectively and Table 4117 for the ANOVA model for regression.

Table 4.115: Computations of model performance measures of the streamflow modelof Imo River at Umuna gauging station (for the *power model*)

Year	**Stage in metres (x or h)**	**Measured Discharge (y_i or Q) m^3/s**	**Predicted Discharge $y_i' = 4.702x^{1.868}$ Power model**	$(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1979	4.48	77.50	77.42	0.08	0.01	0.0010	2.345	5.499
1980	4.59	80.00	81.01	-1.01	1.02	-1.0126	4.845	23.474
1981	4.84	96.00	89.45	6.55	42.90	0.0683	20.845	434.514
1982	3.97	62.40	61.78	0.62	0.38	0.0099	-12.755	162.690
1983	1.99	17.00	17.00	0.00	0.00	0.0000	-58.155	3382.004
1984	4.62	81.60	82.00	-0.40	0.16	-0.0049	6.445	41.538
1985	4.18	68.40	68.02	0.38	0.14	-0.0056	-6.755	45.630
1986	4.71	84.60	85.01	-0.41	0.17	0.0424	9.445	89.208
1987	4.87	89.10	90.49	-1.39	1.93	-0.0156	13.945	194.463
1988	4.63	80.40	82.34	-1.94	3.76	-0.0241	5.245	27.510
1989	4.89	89.70	91.18	-1.48	2.19	-0.0165	14.545	211.557
		$\sum =$ **826.7**	$\sum =$ **825.7**	$\sum =$ **1.00**	$\sum =$ **52.66**	$\sum =$ **-0.9577**		$\sum =$ **4618.087**

Computations of the model performance measures of the streamflow model of Imo River at Umuna gauging station (*power model*).

Mean of measured discharge = 75.155

Mean of predicted discharge = 75.064

i. Nash-Sutcliffe model Efficiency (NSE)

$$\text{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{52.66}{4618.087} = 0.9886$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\text{RMSE}) \text{ or } S_{yx} = \sqrt{\frac{\sum(\mathbf{y_i} - \mathbf{y_i'})^2}{n}} = \sqrt{\frac{52.66}{11}} = 2.19$$

iii. Percentage BIAS (PBIAS)

$$\text{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{75.064 - 75.155}{75.155}\right) = -0.121$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\text{MR or MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{1.00}{11} = 0.091$$

v. Mean Absolute Relative Error (MARE)

$$\text{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{11}(-0.9577) = 1.09$$

Table 4.116: Computations of model performance measures of the streamflow modelof Imo River at Umuna gauging station (for the *polynomial model*)

Year	**Stage in metres (x or h)**	**Discharge in m³/s (y_i or Q)**	**Predicted Discharge** $y_i' = 2.6699x^3 - 25.874x^2 + 103.49x - 107.52$ **(Polynomial model)**	**Residuals** $(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1979	4.48	77.5	78.88	-1.38	1.9	-0.0178	2.345	5.499
1980	4.59	80.00	80.57	-0.57	0.32	-0.0071	4.845	23.474
1981	4.84	96.00	89.97	-6.03	36.36	-0.0628	20.845	434.514
1982	3.97	62.40	62.60	-0.20	0.04	-0.0032	-12.755	162.690
1983	1.99	17.00	17.00	0.00	0.00	0.0000	-58.155	3382.004
1984	4.62	81.60	81.62	-0.02	0.00	-0.0002	6.445	41.538
1985	4.18	68.40	67.98	0.42	0.18	0.0061	-6.755	45.630
1986	4.71	84.60	84.90	-0.30	0.09	-0.0035	9.445	89.208
1987	4.87	89.10	91.20	-2.10	4.41	-0.0236	13.945	194.463
1988	4.63	80.40	81.98	-1.58	2.50	-0.0197	5.245	27.510
1989	4.89	89.70	92.04	-2.34	5.48	-0.0261	14.545	211.557
			∑ = 828.74	**∑ = -14.1**	**∑ = 51.28**	**∑ = -0.1579**		**∑ = 4618.087**

Computations of the model performance measures of the streamflow model of Imo River at Umuna gauging station (*polynomial model*).

Mean of measured discharge = 75.155

Mean of predicted discharge = 75.34

i. Nash-Sutcliffe model Efficiency (NSE)

$$\text{NSE} = 1 - \frac{\sum(y_i - y_i')^2}{\sum(y_i - \bar{y})^2} = 1 - \frac{51.28}{4618.087} = 0.9889$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\text{RMSE}) \text{ or } S_{yx} = \sqrt{\frac{\sum(\mathbf{y_i} - \mathbf{y_i'})^2}{n}} = \sqrt{\frac{51.28}{11}} = 2.16$$

iii. Percentage BIAS (PBIAS)

$$\text{PBIAS} = 100\left(\frac{\bar{\hat{y}} - \bar{y}}{\bar{y}}\right) = 100\left(\frac{75.34 - 75.155}{75.155}\right) = 0.246$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\text{MR or MAE} = \frac{\sum(y_i - y_i')}{n} = \frac{-14.1}{11} = 1.282$$

v. Mean Absolute Relative Error (MARE)

$$\text{MARE} = 1 - \frac{1}{n}\frac{(y_i - y_i')}{y_i} = 1 - \frac{1}{11}(-0.1579) = 1.01$$

Table 4.117: Computations of model performance measures of the streamflow modelof Imo at Umuna gauging station (for the *ANOVA model for regression*)

Year	**Stage (x or h) metres**	**Measured Annual Maximum Discharge (y_i or Q) m^3/s**	**Predicted Annual Maximum Discharge y = 25.6003x - 36.0205 m^3/s (ANOVA model for regression)**	**Residuals $(y_i - y_i')$**	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1979	4.48	77.50	78.67	-1.17	1.37	-0.0151	2.345	5.499
1980	4.59	80.00	81.48	-1.48	2.19	-0.0185	4.845	23.474
1981	4.84	96.00	87.88	8.12	65.93	0.0846	20.845	434.514
1982	3.97	62.40	65.61	-3.21	10.30	-0.0514	-12.755	162.690
1983	1.99	17.00	14.92	2.08	4.33	0.1224	-58.155	3382.004
1984	4.62	81.60	82.25	-0.65	0.42	-0.0080	6.445	41.538
1985	4.18	68.40	70.99	-2.59	6.71	-0.0379	-6.755	45.630
1986	4.71	84.60	84.56	0.04	0.00	0.0005	9.445	89.208
1987	4.87	89.10	88.65	0.45	0.20	0.0051	13.945	194.463
1988	4.63	80.40	82.51	-2.11	4.45	-0.0262	5.245	27.510
1989	4.89	89.70	89.16	0.54	0.29	0.0060	14.545	211.557
			$\sum =$ **826.68**	$\sum =$ **0.02**	$\sum =$ **96.19**	$\sum =$ **0.0615**		$\sum =$ **4618.087**

Computations of the model performance measures of the streamflow model of Imo River at Umuna gauging station (*ANOVA model for regression*).

Mean of measured discharge = 75.155

Mean of predicted discharge = 75.153

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{96.19}{4618.087} = 0.9792$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\text{ or } S_{yx} = \sqrt{\frac{\sum(\mathbf{y_i} - \mathbf{y_i'})^2}{n}} = \sqrt{\frac{96.19}{11}} = 2.96$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{75.153 - 75.155}{75.155}\right) = -0.003$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR} \text{ or } \mathrm{MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{0.02}{11} = 0.002$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{11}(0.0615) = 0.99$$

The summary of streamflow models of Imo River at Umuna gauging station obtained from Figures 4.52and 4.53 for the power and polynomial models and Table 4. 106 for the ANOVA model for regression are shown in Table 4.118.

Table 4.118: Summary of streamflow models of Imo River at Umuna gauging station and the models evaluation parameters

RIVER	STREAMFLOW GAUGING STATION	STREAMFLOW MODEL +	MODEL EVALUATION PARAMETERS *						
			R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
Imo River	Umuna	**Power model** $Q = 4.7025h^{1.8685}$	0.9973	0.9986	0.9886	2.19	-0.121	0.091	1.09
		Polynomial model $Q = 2.6699h^3 - 25.874h^2 + 103.49h - 107.52$	0.9892	0.9946	0.9889	2.16	0.246	1.282	1.01
		ANOVA model for regression $Q = 25.6003h - 36.0205$	0.9792	0.9895	0.9792	2.96	-0.003	0.002	0.99

+ Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

* **ModelEvaluation Parameters**
Coefficient of determination (R^2), Coefficient of correlation (R), Nash-Sutcliffe model Efficiency (NSE), Mean Absolute Relative Error (MARE), Root Mean Square Error (RMSE) or Standard error of estimate of discharge on stage ($S_{Q.h}$), Percentage BIAS (PBIAS), Mean Residue (MR).

4.10 Streamflow Modelling of Imo River at Umuopara

4.10.1 Streamflow Model Calibration of Imo River at Umuopara gauging station

Plots of the streamflow model calibration of annual maximum stage and annual maximum discharge (Table 3.5) of Imo River at Umuopara gauging station are shown in Figures 4.58 and 4.59 for power and polynomial models respectively and Table 4.119 for ANOVA model for regression. The resulting equations are:

$$y = 30.021x^{1.177} \qquad (4.55)$$

$$y = -0.0778x^3 + 4.6138x^2 + 15.43x + 17.757 \qquad (4.56)$$

$$y = 46.9704x - 31.6438. \qquad (4.57)$$

Equations (4.55), (4.56) and (4.57) results in the following models:

$$Q = 30.021h^{1.177} \qquad (4.58)$$

$$Q = -0.0778h^3 + 4.6138h^2 + 15.43h + 17.757 \qquad (4.59)$$

$$Q = 46.9704h - 31.6438 \qquad (4.60)$$

Equations (4.58) is a power model, equations (4.59) is a polynomial model while equations (4.60) is ANOVA model for regression.

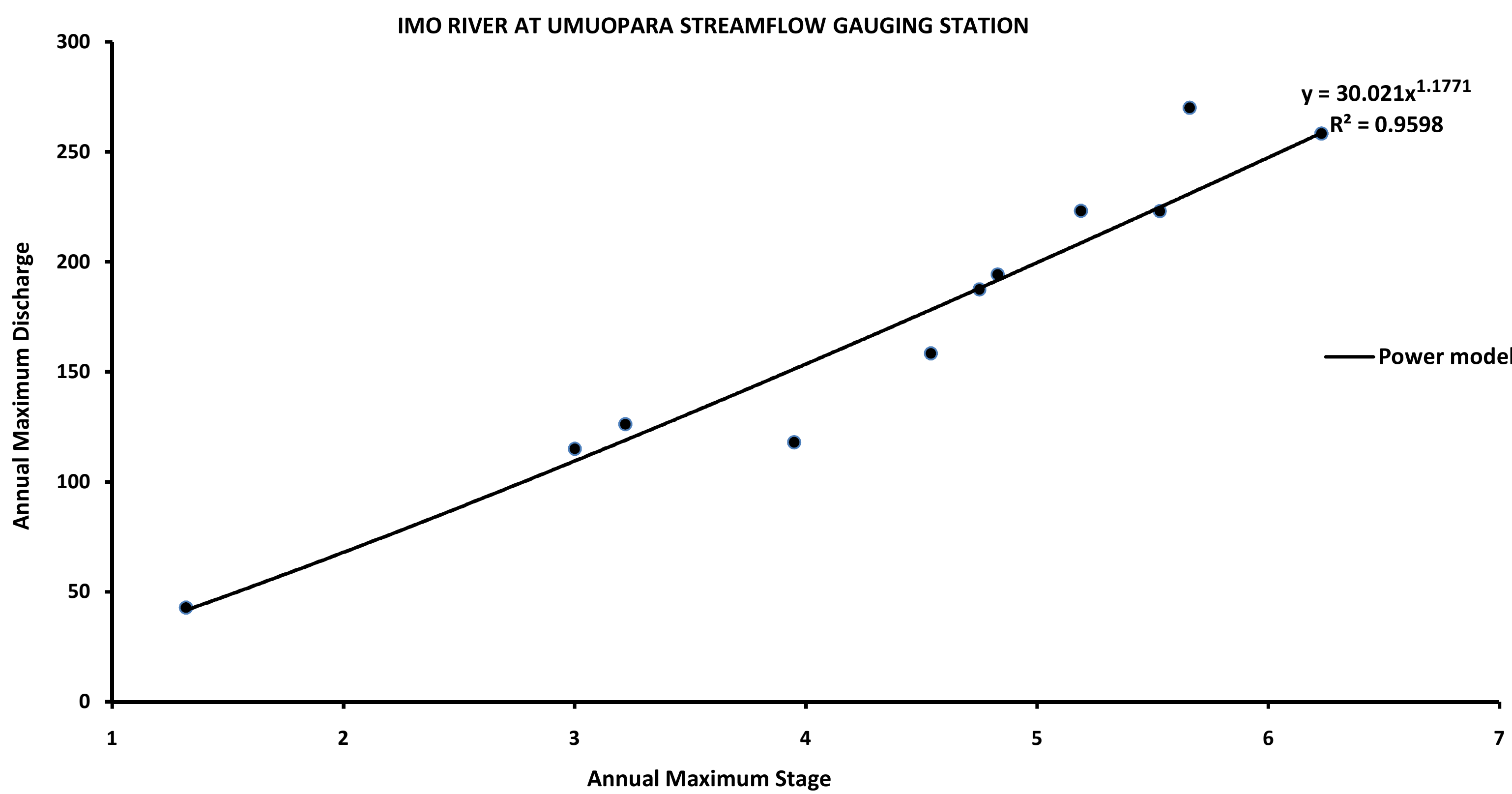


Figure 4.58: Plot of streamflow model calibration of Imo River at Umuopara gauging station (power model)

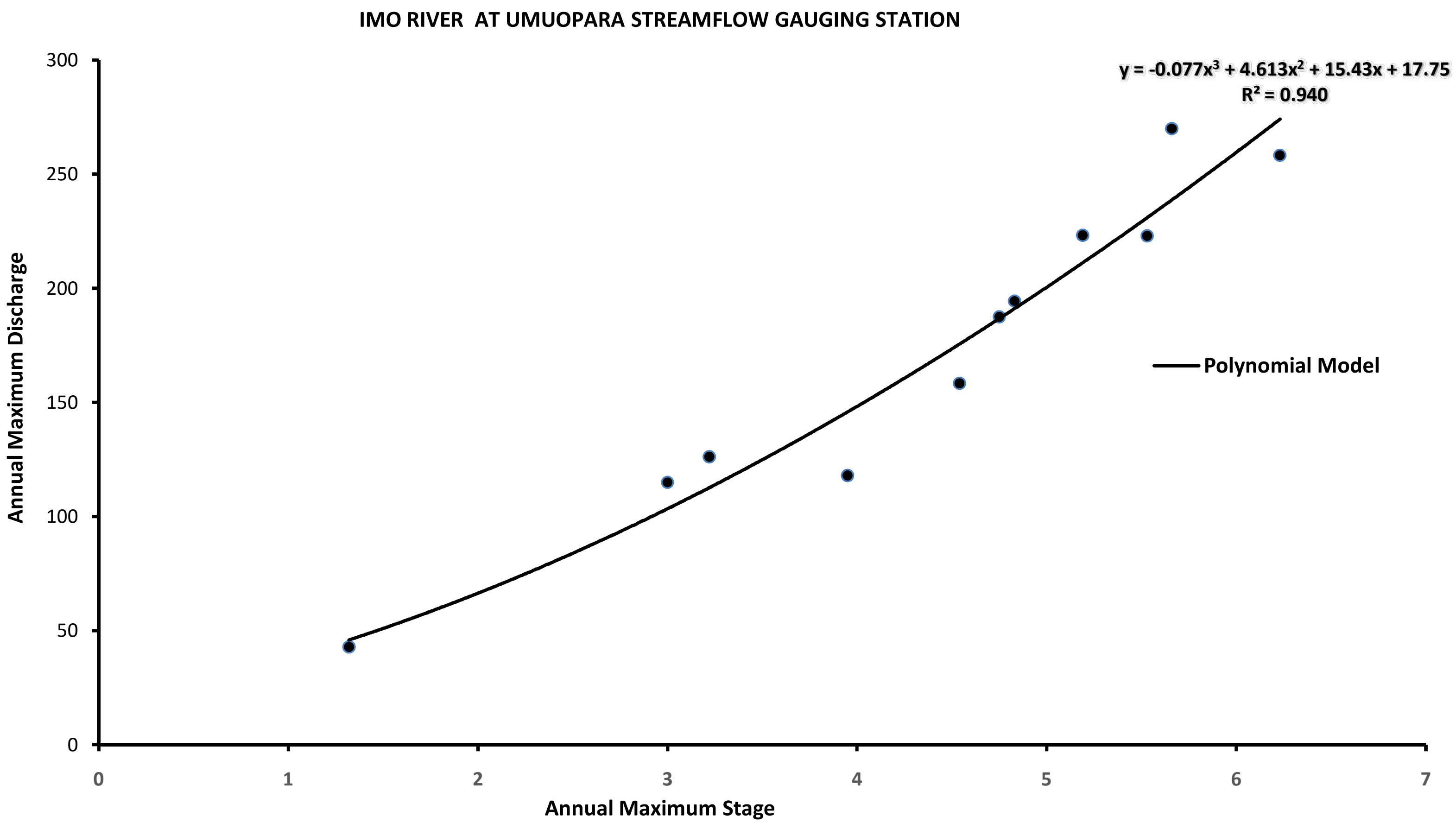


Figure 4.59: Plot of streamflow model calibration of Imo River at Umuopara gauging station (polynomial model)

Table 4.119: Summary output of ANOVA model for regression of Imo River at Umuopara streamflow gauging station

Regression Statistics	
Multiple R	0.962787171
R Square	0.926959137
Adjusted R Square	0.918843486
Standard Error	19.7543079
Observations	11

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	44571.86869	44571.86869	114.2186979	2.05224E-06
Residual	9	3512.094127	390.2326808		
Total	10	48083.96282			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-31.64378307	20.16560798	-1.569195588	0.151048251	-77.2615576	13.97399146
X Variable 1	46.97037772	4.394965297	10.68731481	2.05224E-06	37.0282755	56.91247995

From Table 4.10, the fitted regression equation is $y = 46.970x - 31.644$

4.10.2 Verificationof the streamflow model of Imo River at Umuopara gauging station

Verification of the streamflow models of Imo River at Umuopara gauging station was carried out. The verified records are tabulated in Table 4.120.

Table 4.120: Verification of streamflow model of Imo River at Umuopara streamflow gauging station

Year	Stage (x or h) metres	Measured Annual Maximum Discharge (y_i or Q) m^3/s	Predicted Annual Maximum Discharge m^3/s (Power model)	Predicted Annual Maximum Discharge m^3/s (Polynomial model)	Predicted Annual Maximum Discharge m^3/s (ANOVA model for regression)
1979	5.66	270.00	230.93	238.79	234.21
1980	4.54	158.40	178.14	140.11	181.60
1981	3.95	118.00	151.22	145.90	153.89
1982	6.23	258.28	258.54	274.15	260.98
1983	4.75	187.50	187.88	186.81	191.47
1984	5.53	223.00	224.70	231.02	228.10
1985	3.22	126.20	118.89	112.68	119.60
1986	4.83	194.40	191.61	191.15	195.22
1987	3.00	115.00	109.39	103.47	109.27
1988	5.19	223.20	208.53	211.24	212.13
1989	1.32	42.85	41.62	45.99	30.36

The results of the measured and predicted discharge values of the models as presented in Table 4.120were used to plot linear streamflow models verification graphs shown in Figures 4.60 through 4.61.

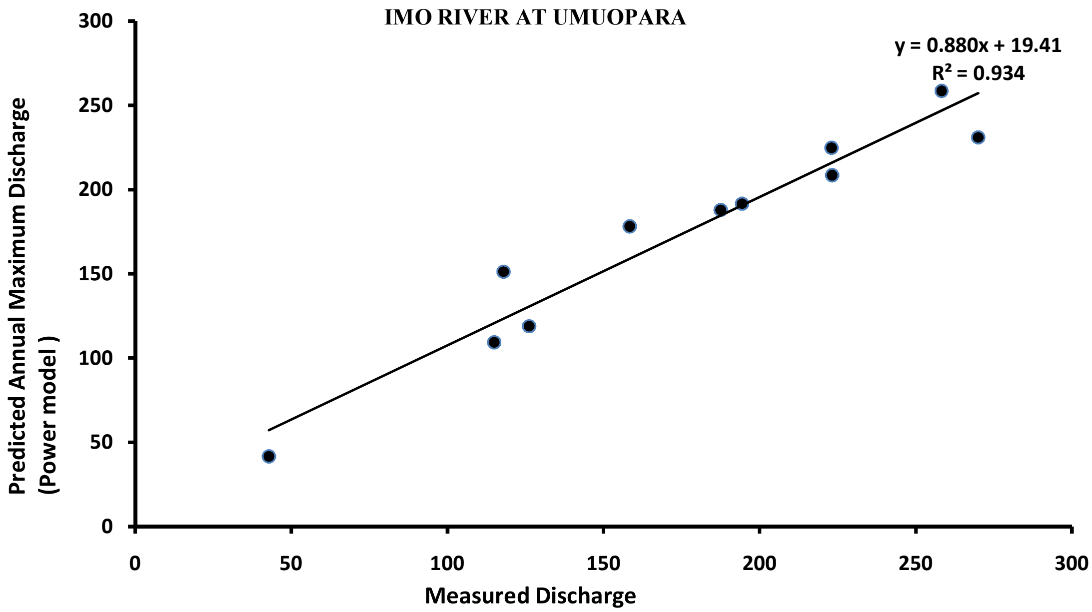


Figure 4.60: Verification of the streamflow model of Imo River at Umuopara gauging station (for the *power model*)

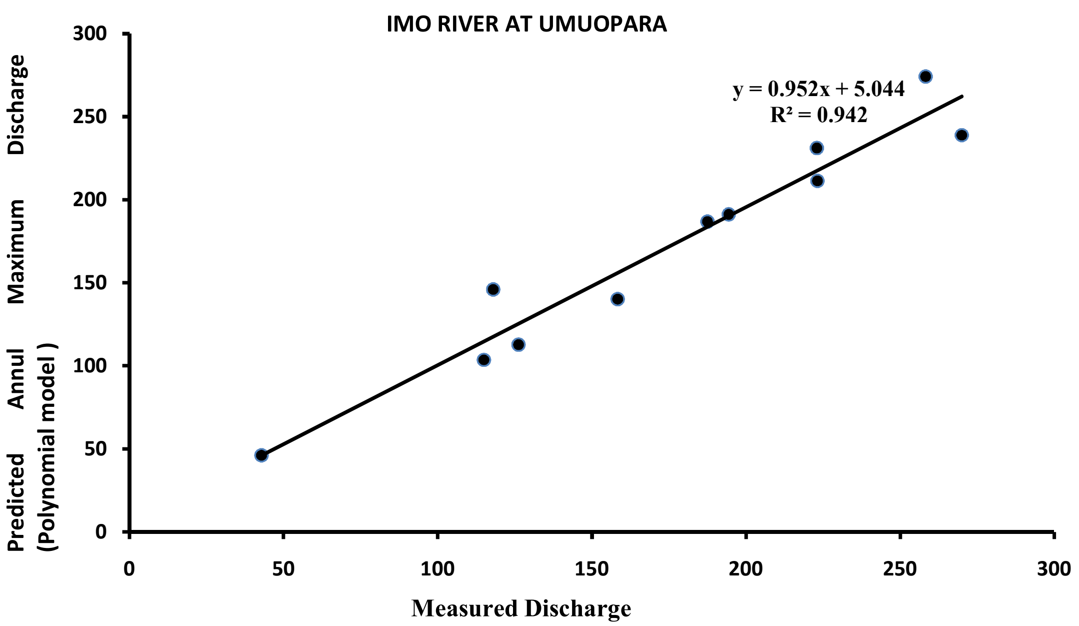


Figure 4.61: Verification of the streamflow model of Imo River at Umuopara gauging station (for the *polynomial model*)

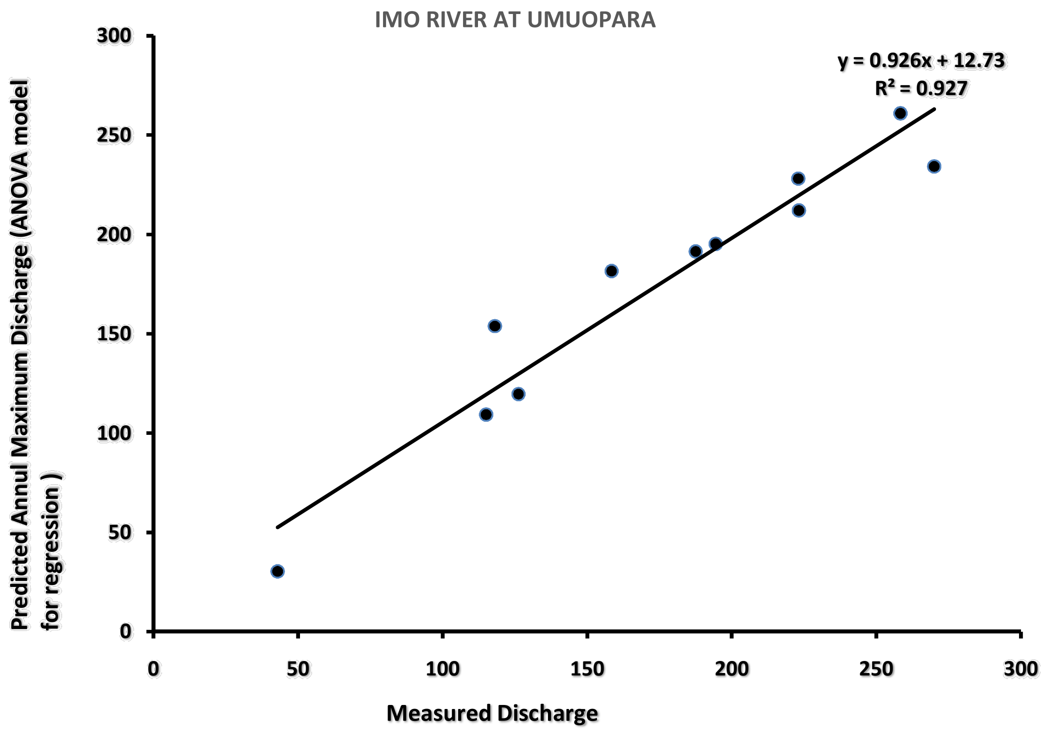


Figure 4.62: Verification of the streamflow model of Imo River at Umuopara gauging station (for the *ANOVA model for regression*)

4.10.3 Comparisons of the streamflow models of Imo River at Umuopara gauging station.

Comparisons of the streamflow models of Imo River at Umuopara gauging station comprises four subheadings: One-way ANOVA F-Test, Variance Ratio Test or Snedecor's F-distribution (F-Test), comparison using graph and finally comparison using Student's t-Test.

4.10.3.1 Comparison of the streamflow models of Imo River at Umuopara gauging station using One-way ANOVA F-Test

The comparison of the streamflow models verified for Imo River at Umuopara gauging station using One-way ANOVA F-Test is shown in Table 4.121.

Table 4.121: One-way ANOVA F-Test for streamflow models of Imo River at Umuopara

Groups	Count	Sum	Average	Variance
Power model	11	1901.45	172.859	3991.139
Polynomial model	11	1881.31	171.028	4628.626
ANOVA model for regression	11	1916.83	174.257	4457.019

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	57.691952	2	28.846	0.006618	0.99341	3.31583
Within Groups	130767.84	30	4358.93			
Total	130825.53	32				

4.10.3.2 Comparisonof the streamflow models of Imo River at Umuopara gauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test)

The Comparisonof the streamflow models of Imo River at Umuoparagauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test) are shown in Tables 4.122through 4.124.

Table 4.122: F-Test Two-Sample for Variances (Power model and Polynomial model)

	Power model	**Polynomial model**
Mean	172.8590909	171.0281818
Variance	3991.139209	4628.625996
Observations	11	11
df	10	10
F	0.862272997	
P(F<=f) one-tail	0.409659351	
F Critical one-tail	0.335769113	

Table 4.123: F-Test Two-Sample for Variances (Power model and ANOVA model for regression)

	Power model	ANOVA model for regression
Mean	172.8590909	174.2572727
Variance	3991.139209	4457.018722
Observations	11	11
df	10	10
F	0.895472839	
P(F<=f) one-tail	0.432419332	
F Critical one-tail	0.335769113	

Table 4.124: F-Test Two-Sample for Variances (Polynomial model and ANOVA model for regression)

	Polynomial Model	ANOVA model for regression
Mean	171.0281818	174.2572727
Variance	4628.625996	4457.018722
Observations	11	11
df	10	10
F	1.038502704	
P(F<=f) one-tail	0.47677028	
F Critical one-tail	2.978237016	

4.10.3.3 Comparisonof the streamflow models of Imo River at Umuopara gauging station using graph

The comparison of the streamflow models verified for Imo River at Umuoparagauging station using graph is shown in Figure 4.63.

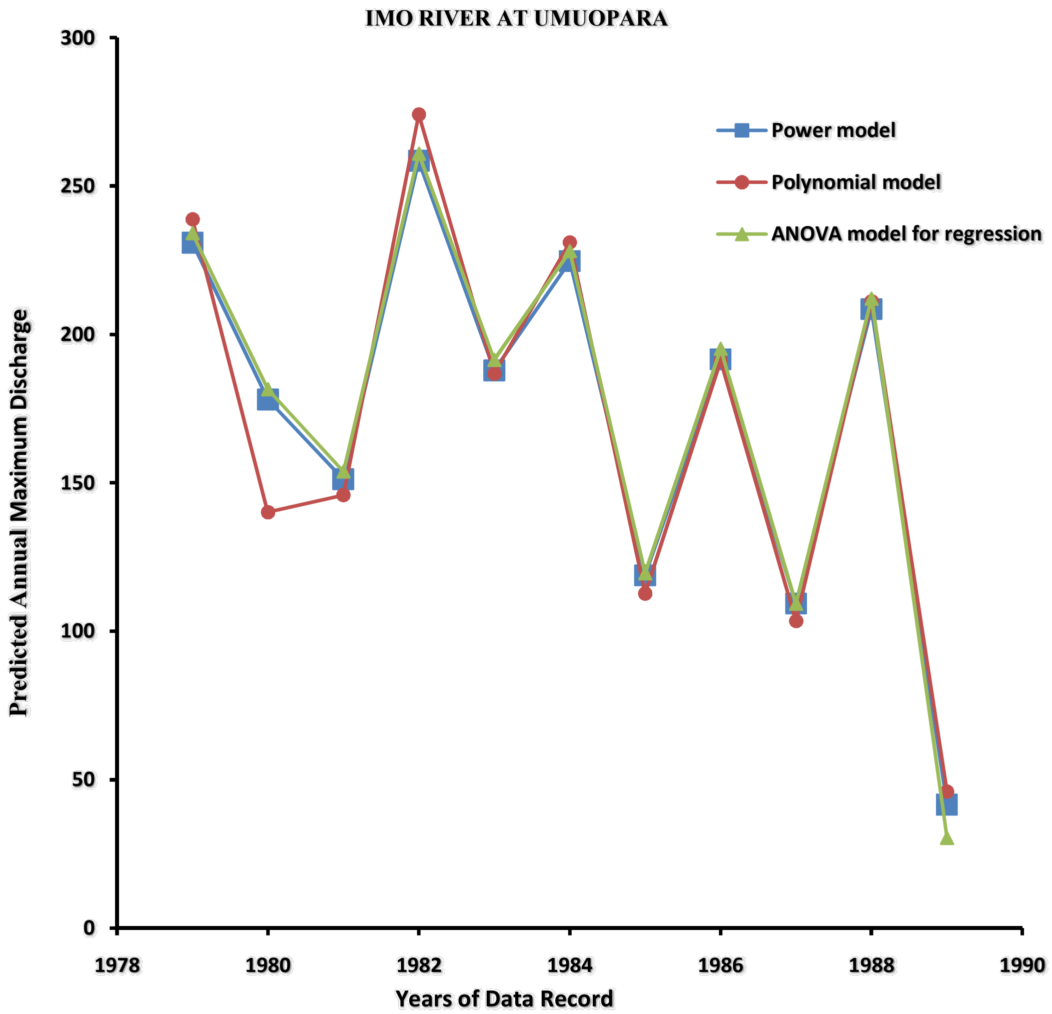


Figure 4.63: Comparison of the models verified for Imo River at Umuopara streamflow gauging station

4.10.3.4 Comparisonof the streamflow models of Imo River at Umuopara gauging station using Student's t-Test

The streamflow modelsof Imo River at Umuopara gauging station are further compared using Student's t-Test (distribution) as shown in Table 4.125 through 4.127.

Table 4.125: t-Test: Paired Two Sample for Means (Power and Polynomial models)

	Power model	Polynomial model
Mean	172.8590909	171.0281818
Variance	3991.139209	4628.625996
Observations	11	11
Pearson Correlation	0.980823338	
Hypothesized Mean Difference	0	
df	10	
t Stat	0.442347725	
P(T<=t) one-tail	0.333825694	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.667651387	
t Critical two-tail	2.228138852	

Table 4.126: t-Test: Paired Two Sample for Means (Power model and ANOVA model for regression)

	Power model	ANOVA model for regression
Mean	172.8590909	174.2572727
Variance	3991.139209	4457.018722
Observations	11	11
Pearson Correlation	0.999247203	
Hypothesized Mean Difference	0	
df	10	
t Stat	-1.058150523	
P(T<=t) one-tail	0.157438798	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.314877597	
t Critical two-tail	2.228138852	

Table 4.127: t-Test: Paired Two Sample for Means (Polynomial Model and ANOVA Model for regression)

	Polynomial model	**ANOVA model for regression**
Mean	171.0281818	174.2572727
Variance	4628.625996	4457.018722
Observations	11	11
Pearson Correlation	0.975537243	
Hypothesized Mean Difference	0	
df	10	
t Stat	-0.715824813	
P(T<=t) one-tail	0.245238273	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.490476546	
t Critical two-tail	2.228138852	

4.10.4 Computations of the model performance measures of the streamflow models of Imo River at Umuopara gauging station

Computations of Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias, root mean square error or standard error of estimateand mean of residue or mean absolute error which are used as tools for the evaluation of the streamflow models ofImo River at Umuopara gauging stationare shown in Tables 4.128 and 4.129 for the power and polynomial models respectively and Table 4.130 for the ANOVA model for regression.

Table 4.128: Computations of model performance measures of the streamflow modelof Imo River at Umuopara gauging station (for the *power model)*

Year	**Stage (x or h) metres**	**Measured Discharge (y_i or Q) m^3/s**	**Predicted Discharge $y_i' = 30.02x^{1.177}$ (m^3/s) (Power model)**	**Residuals $(y_i - y_i')$**	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1979	5.66	270.00	230.93	39.07	1526.47	0.1447	95.743	9,166.722
1980	4.54	158.40	178.14	- 19.74	389.67	-0.1246	-15.857	251.444
1981	3.95	118.00	151.22	- 33.22	1103.57	-0.2815	-56.257	3,164.850
1982	6.23	258.28	258.54	- 0.26	0.07	-0.0010	84.023	7,059.865
1983	4.75	187.50	187.88	- 0.38	0.14	-0.0020	13.243	175.377
1984	5.53	223.00	224.70	- 1.70	2.89	-0.0076	48.743	2,375.880
1985	3.22	126.20	118.89	7.31	53.44	0.0579	-48.057	2,309.475
1986	4.83	194.40	191.61	2.79	7.78	0.0144	20.143	405.740
1987	3.00	115.00	109.39	5.61	31.47	0.0488	-59.257	3,511.392
1988	5.19	223.20	208.53	14.67	215.21	0.0657	48.943	2,395.417
1989	1.32	42.85	41.62	1.23	1.51	0.0287	-131.407	17,267.800
		∑ = 1916.83	**∑ = 1901.45**	**∑ = 15.38**	**∑ = 3332.22**	**∑ = -0.0565**		**∑ = 48083.962**

Computations of the model performance measures of the streamflow model of Imo River at Umuopara gauging station (*power model*).

Mean of measured annual maximum discharge = 174.257

Mean of predicted annual maximum discharge = 172.859

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{3332.22}{48083.962} = 0.9307$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE})\ \text{or}\ S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{3332.22}{11}} = 17.40$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{172.859 - 174.257}{174.257}\right) = -0.802$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR}\ \text{or}\ \mathrm{MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{15.38}{11} = 1.398$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{11}(-0.0565) = 1.005$$

Table 4.129: Computations of model performance measures of the streamflow modelof Imo River at Umuopara gauging station (for the *polynomial model)*

Year	**Stage (x or h) metres**	**Measured Discharge (y_i or Q) m^3/s**	**Predicted Discharge $y_i' = -0.0778x^3 + 4.6138x^2 + 15.43x + 17.757$ (m^3/s) Polynomial model**	**Residuals $(y_i - y_i')$**	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1979	5.66	270.00	238.79	31.21	974.06	0.1156	95.743	9,166.722
1980	4.54	158.40	140.11	18.29	334.52	0.1155	-15.857	251.444
1981	3.95	118.00	145.90	-27.9	778.41	-0.2364	-56.257	3,164.850
1982	6.23	258.28	274.15	-15.87	251.86	-0.0614	84.023	7,059.865
1983	4.75	187.50	186.81	0.69	0.48	0.0037	13.243	175.377
1984	5.53	223.00	231.02	-8.02	64.32	-0.0360	48.743	2,375.880
1985	3.22	126.20	112.68	13.52	182.79	0.1071	-48.057	2,309.475
1986	4.83	194.40	191.15	3.25	10.56	0.0167	20.143	405.740
1987	3.00	115.00	103.47	11.53	132.94	0.1003	-59.257	3,511.392
1988	5.19	223.20	211.24	11.96	143.04	0.0536	48.943	2,395.417
1989	1.32	42.85	45.99	-3.14	9.86	-0.0733	-131.407	17,267.800
			$\sum$ = 1881.31	**$\sum$ = 35.52**	**$\sum$ = 2882.84**	**$\sum$ = 0.1054**		**$\sum$ = 48083.962**

Computations of the model performance measures of the streamflow model of Imo River at Umuopara gauging station (*polynomial model*).

Mean of measured annual maximum discharge = 174.257

Mean of predicted annual maximum discharge = 171.028

i. Nash-Sutcliffe model Efficiency (NSE)

$$\text{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{2882.84}{48083.962} = 0.9400$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\text{RMSE}) \text{ or } \mathrm{S}_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{2882.84}{11}} = 16.19$$

iii. Percentage BIAS (PBIAS)

$$\text{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{171.028 - 174.257}{174.257}\right) = -1.853$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\text{MR or MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{35.52}{11} = 3.229$$

v. Mean Absolute Relative Error (MARE)

$$\text{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{11}(0.1054) = 0.9904$$

Table 4.130: Computations of model performance measures of the streamflow modelof Imo River at Umuopara gauging station (for the *ANOVA model for regression)*

Year	**Stage (x or h) metres**	**Measured Annual Maximum Discharge (y_i or Q) m^3/s**	**Predicted Annual Maximum Discharge $y = 46.9704x - 31.6438$ (ANOVA model for regression)m^3/s**	**Residuals $(y_i - y_i')$**	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1979	5.66	270.00	234.21	35.79	1,280.92	0.133	95.743	9,166.722
1980	4.54	158.40	181.60	-23.20	538.24	-0.146	-15.857	251.444
1981	3.95	118.00	153.89	-35.89	1,288.09	-0.304	-56.257	3,164.850
1982	6.23	258.28	260.98	-2.70	7.29	-0.010	84.023	7,059.865
1983	4.75	187.50	191.47	-3.97	15.76	-0.021	13.243	175.377
1984	5.53	223.00	228.10	-5.10	26.01	-0.023	48.743	2,375.880
1985	3.22	126.20	119.60	6.60	43.56	0.052	-48.057	2,309.475
1986	4.83	194.40	195.22	-0.82	0.67	-0.004	20.143	405.740
1987	3.00	115.00	109.27	5.73	32.83	0.050	-59.257	3,511.392
1988	5.19	223.20	212.13	11.07	122.54	0.050	48.943	2,395.417
1989	1.32	42.85	30.36	12.49	156.00	0.291	-131.407	17,267.800
		$\sum$ = **1916.83**	$\sum$ = **1916.83**	$\sum$ = **0.00**	$\sum$ = **3511.91**	$\sum$ = **0.068**		$\sum$ = **48083.962**

Computations of the model performance measures of the streamflow model of Imo River at Umuopara gauging station (*ANOVA model for regression*).

Mean of measured annual maximum discharge = 174.257

Mean of predicted annual maximum discharge = 174.257

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{3511.91}{48083.962} = 0.9270$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE}) \text{ or } \mathrm{S}_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{3511.91}{11}} = 17.87$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{174.257 - 174.257}{174.257}\right) = 0.000$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR} \text{ or } \mathrm{MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{0.00}{11} = 0.00$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{11}(0.068) = 0.9938$$

The summary of streamflow models of Imo River at Umuopara gauging station obtained from Figures 4.58 and 4.59 for the power and polynomial modelsand Table 4.119 for the ANOVA model for regression are shown in Table 4.131.

Table 4.131: Summary of streamflow models of Imo River at Umopara gauging station and the models evaluation parameters

RIVER	STREAMFLOW GAUGING STATION	STREAMFLOW MODEL +	MODEL EVALUATION PARAMETERS *						
			R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
Imo River	Umuopara	**Power model** $Q = 30.021h^{1.177}$	0.9598	0.9797	0.9307	17.40	-0.802	1.398	1.005
		Polynomial model $Q = -0.0778h^3 + 4.6138h^2 + 15.43h + 17.757$	0.9408	0.9699	0.9400	16.19	-1.853	3.229	0.9904
		ANOVA model for regression $Q = 46.9704h - 31.6438$	0.9270	0.9628	0.9270	17.87	0.000	0.000	0.9938

+ Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

* **ModelEvaluation Parameters**
Coefficient of determination (R^2) , Coefficient of correlation (R), Nash-Sutcliffe model Efficiency (NSE), Mean Absolute Relative Error (MARE), Root Mean Square Error (RMSE) or Standard error of estimate of discharge on stage ($S_{Q.h}$), Percentage BIAS (PBIAS), Mean Residue (MR).

4.11 Streamflow Modelling of Imo River at Obigbo

4.11.1 Streamflow Model Calibration of Imo River at Obigbo gauging station

Plots of the streamflow models calibration of annual maximum stage and annual maximum discharge (Table 3.5) of Imo River at Obigbo gauging station are shown in Figures 4.64 and 4.65 for power and polynomial models respectively and Table 4.132 for ANOVA model for regression. The resulting equations are:

$$y = 102.46x^{1.2249} \quad . \quad . \quad . \quad . \qquad (4.61)$$

$$y = 104.58x^3 - 581.01x^2 + 1204.1x - 683.11 \quad . \quad . \quad . \qquad (4.62)$$

$$y = 148.048x - 56.051 \quad . \quad . \quad . \quad . \qquad (4.63)$$

Equations (4.61), (4.62) and (4.63) results in the following models:

$$Q = 102.46h^{1.2249} \quad . \quad . \quad . \quad . \qquad (4.64)$$

$$Q = 104.58h^3 - 581.01h^2 + 1204.1h - 683.11 \quad . \quad . \quad . \qquad (4.65)$$

$$Q = 148.048h - 56.051 \quad . \quad . \quad . \quad . \qquad (4.66)$$

Equations (4.64) is a power model, equations (4.65) is a polynomial model while equations (4.66) is ANOVA model for regression.

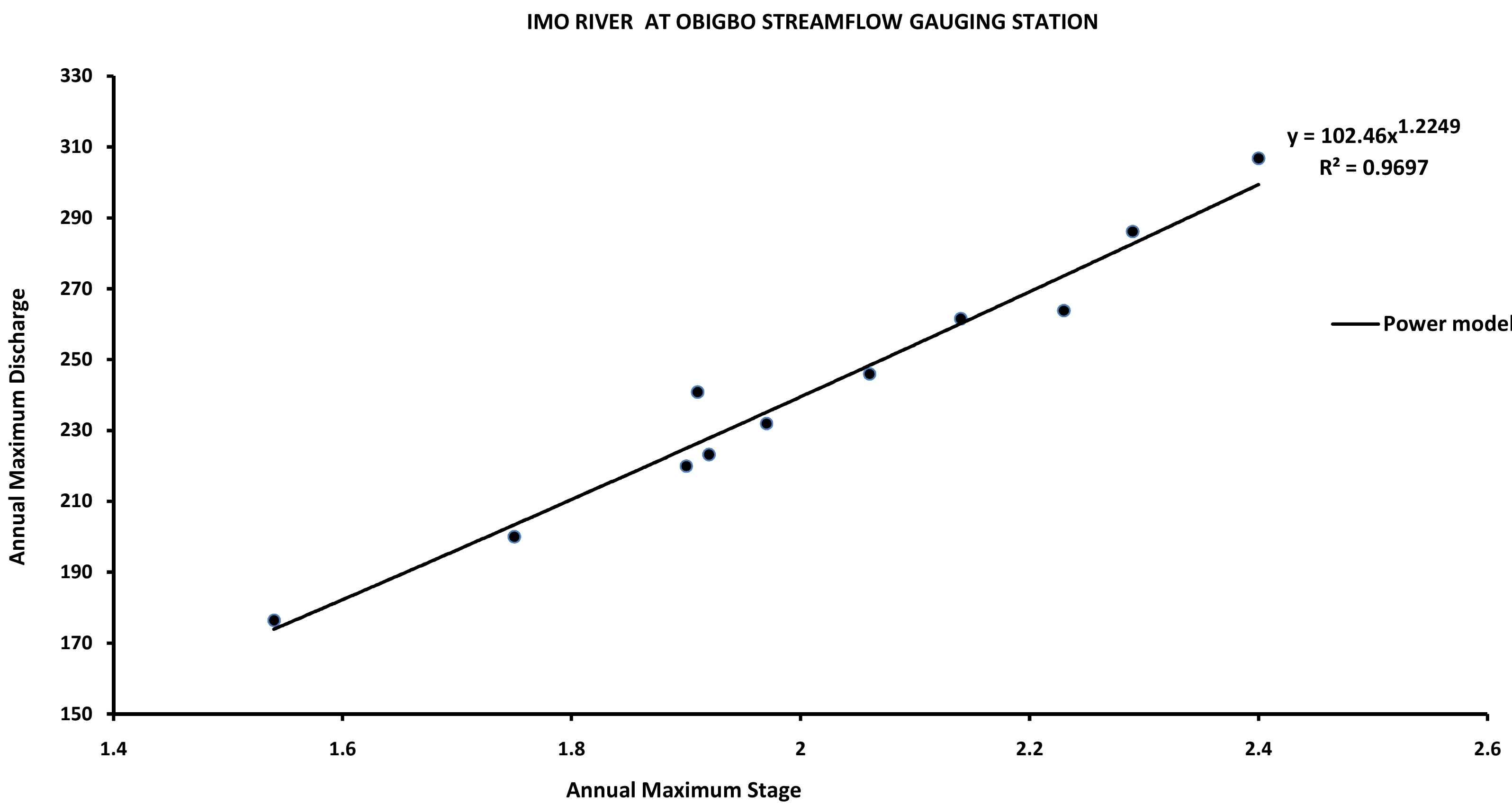


Figure 4.64: Plot of streamflow modelling and calibration of Imo River at Obigbo gauging station (power model)

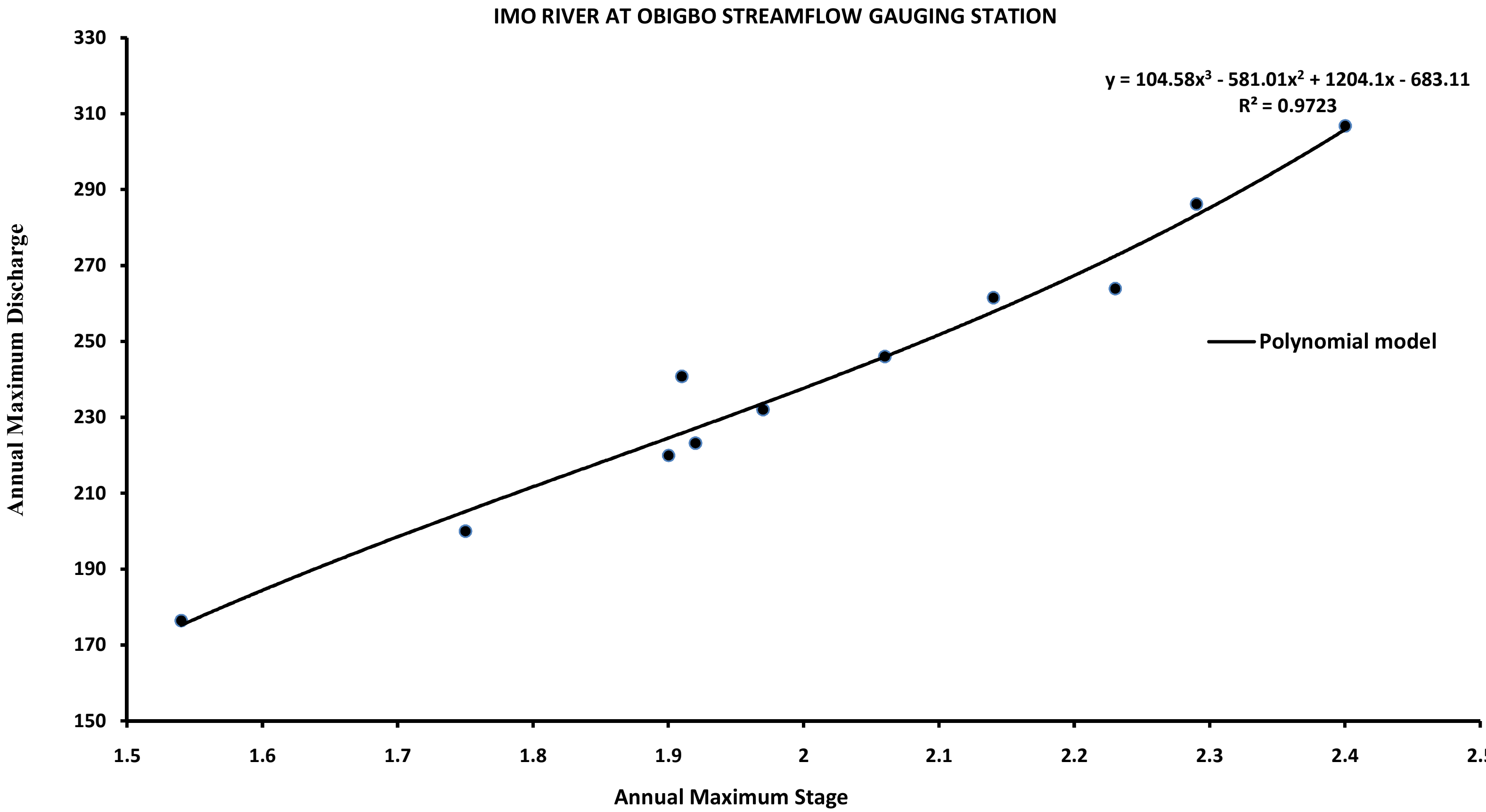


Figure 4.65: Plot of streamflow model calibration of Imo River at Obigbo gauging station (polynomial model)

Table 4.132: Summary output of ANOVA model for regression of Imo River at Obigbo streamflow gauging station

Regression Statistics	
Multiple R	0.98299456
R Square	0.966278304
Adjusted R Square	0.962531449
Standard Error	7.250889598
Observations	11

ANOVA

	df	SS	MS	F	Significance F
Regression	1	13558.69585	13558.69585	257.8904937	6.22948E-08
Residual	9	473.1785996	52.57539996		
Total	10	14031.87445			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-56.05111454	18.6588185	-3.004001274	0.014859647	-98.26029446	-13.84193463
X Variable 1	148.0484966	9.219053489	16.05896926	6.22948E-08	127.1935487	168.9034445

From Table 4.10, the fitted regression equation is $y = 148.048x - 56.051$

4.11.2 Verificationof the streamflow models of Imo River at Obigbo gauging station

Verification of the streamflow models of Imo River at Obigbo gauging station was carried out. The verified records are tabulated in Table 4.133.

Table 4.133: Verification of streamflow model of Imo River at Obigbo gauging station

Year	Stage (x or h) metres	Measured Annual Maximum Discharge m^3/s	Predicted Annual Maximum Discharge m^3/s (Power model)	Predicted Annual Maximum Discharge m^3/s (Polynomial model)	Predicted Annual Maximum Discharge m^3/s (ANOVA model for regression)
1979	2.06	246.00	248.34	245.98	248.93
1980	1.97	232.00	235.11	233.68	235.60
1981	2.14	261.50	260. 20	257.79	260.77
1982	1.90	220.00	224.92	224.55	225.24
1983	1.91	240.80	226.37	225.84	226.72
1984	2.23	263.89	273.67	272.48	274.10
1985	1.54	176.40	173.89	175.24	171.94
1986	2.29	286.20	282.72	283.08	282.98
1987	1.75	200.00	203.36	205.21	203.03
1988	1.92	223.20	227.82	227.13	228.20
1989	2.40	306.80	299.44	305.83	299.27

The results of the measured and predicted discharge values of the models as presented in Table 4.133 were used to plot linear streamflow models verification graphs shown in Figures 4.66 through 4.68.

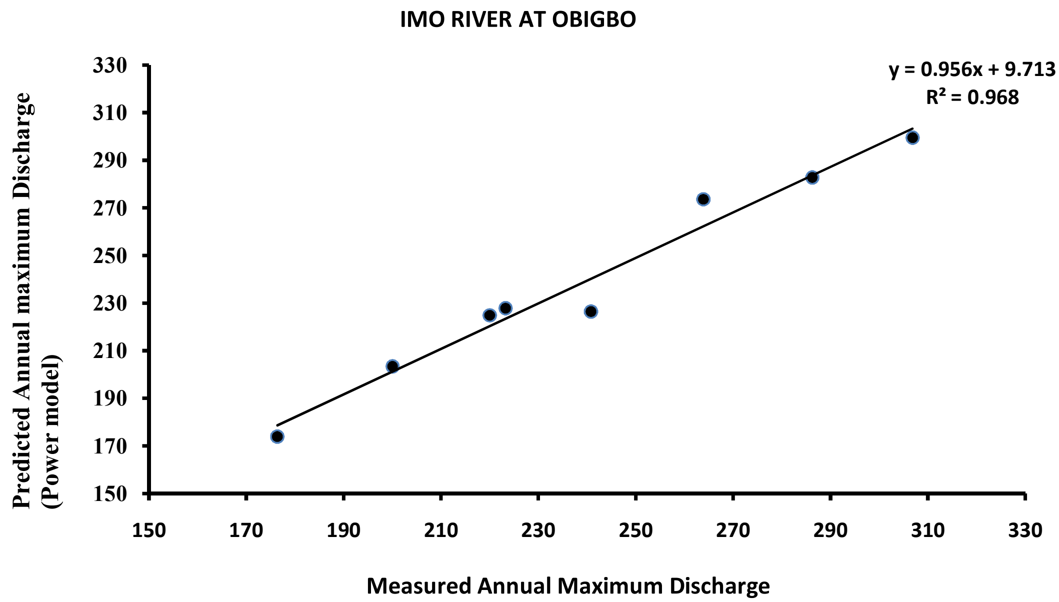


Figure 4.66: Verification of the streamflow model of Imo River at Obigbo gauging station (for the *power model*)

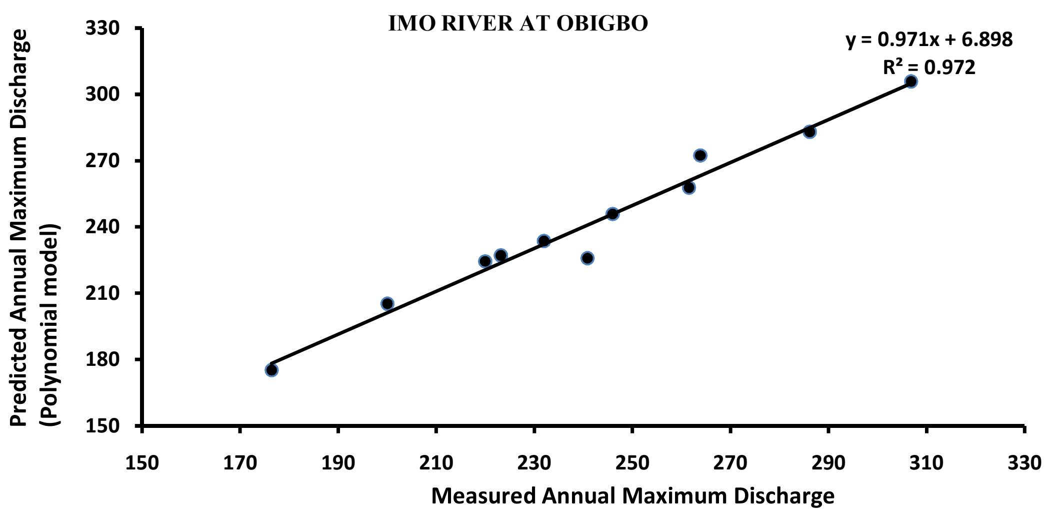


Figure 4.67: Verification of the streamflow model of Imo River at Obigbo gauging station (for the *polynomial model*)

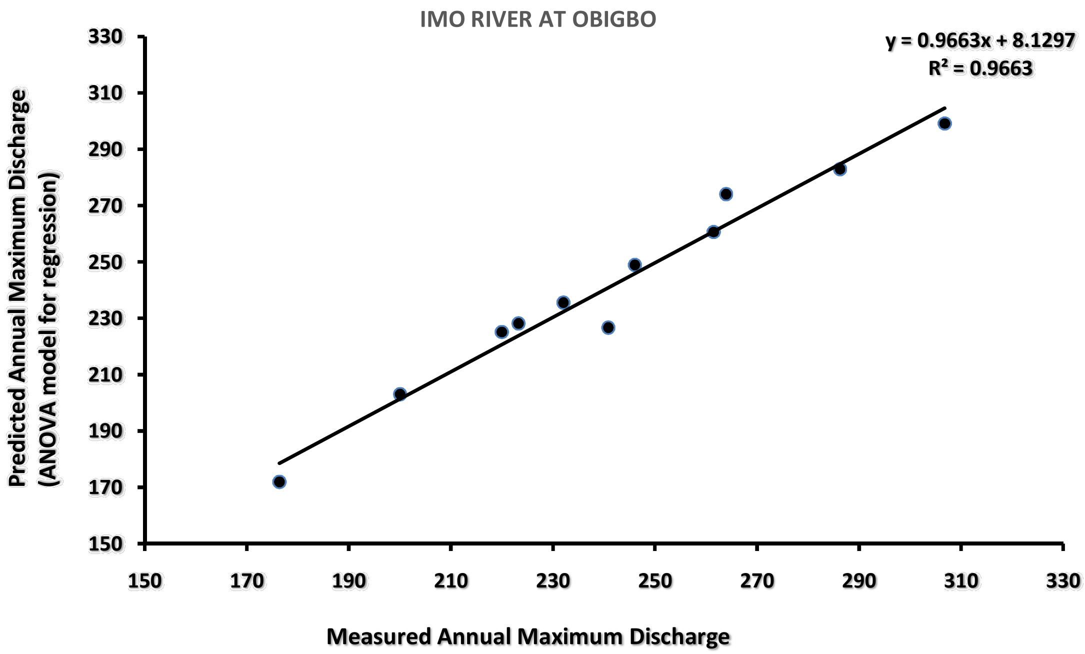


Figure 4.68: Verification of the streamflow model of Imo River at Obigbo gauging station (for the *ANOVA mode for regression*)

4.11.3 Comparisons of the streamflow models of Imo River at Obigbo gauging station

Comparisons of the streamflow models of Imo River at Obigbo gauging station comprises four subheadings: One-way ANOVA F-Test, Variance Ratio Test or Snedecor's F-distribution (F-Test), comparison using graph and finally comparison using Student's t-Test.

4.11.3.1 Comparison of the streamflow models of Imo River at Obigbo gauging station using One-way ANOVA F-Test

The comparison of the streamflow models verified for Imo River at Obigbo gauging station using One-way ANOVAF-Test is shown in Table 4.134.

Table 4.134: One-way ANOVA F-Testfor streamflow models of Imo River at Obigbo

Groups	Count	Sum	Average	Variance
Power model	11	2655.84	241.44	1324.50364
Polynomial model	11	2656.81	241.5282	1361.99706
ANOVA model for regression	11	2656.78	241.5255	1356.03245

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.055315	2	0.027658	2.0525E-05	0.999979	3.31583
Within Groups	40425.33	30	1347.511			
Total	40425.39	32				

4.11.3.2 Comparisonof the streamflow models of Imo River at Obigbo gauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test)

The Comparisonof the streamflow models of Imo River at Obigbogauging station using the Variance Ratio Test or Snedecor's F-distribution (F-Test) are shown in Tables 4.135 through 4.137.

Table 4.135: F-Test Two-Sample for Variances (Power model and Polynomial model)

	Power model	**Polynomial model**
Mean	241.44	241.5281818
Variance	1324.50364	1361.997056

Observations	11	11
df	10	10
F	0.972471735	
P(F<=f) one-tail	0.482831757	
F Critical one-tail	0.335769113	

Table 4.136: F-Test Two-Sample for Variances (Power model and ANOVA model for regression)

	Power model	**ANOVA model for regression**
Mean	241.44	241.5254545
Variance	1324.50364	1356.032447
Observations	11	11
df	10	10
F	0.976749224	
P(F<=f) one-tail	0.485529739	
F Critical one-tail	0.335769113	

Table 4. 137: F-Test Two-Sample for Variances (Polynomial model and ANOVA model for regression)

	Polynomial model	**ANOVA model for regression**
Mean	241.5281818	241.5254545
Variance	1361.997056	1356.032447
Observations	11	11
df	10	10
F	1.004398574	
P(F<=f) one-tail	0.497299802	
F Critical one-tail	2.978237016	

4.11.3.3 Comparisonof the streamflow models of Imo River at Obigbo gauging station using graph

The comparison of the streamflow models verified for Imo River at Obigbogauging station using graph is shown in Figure 4.69.

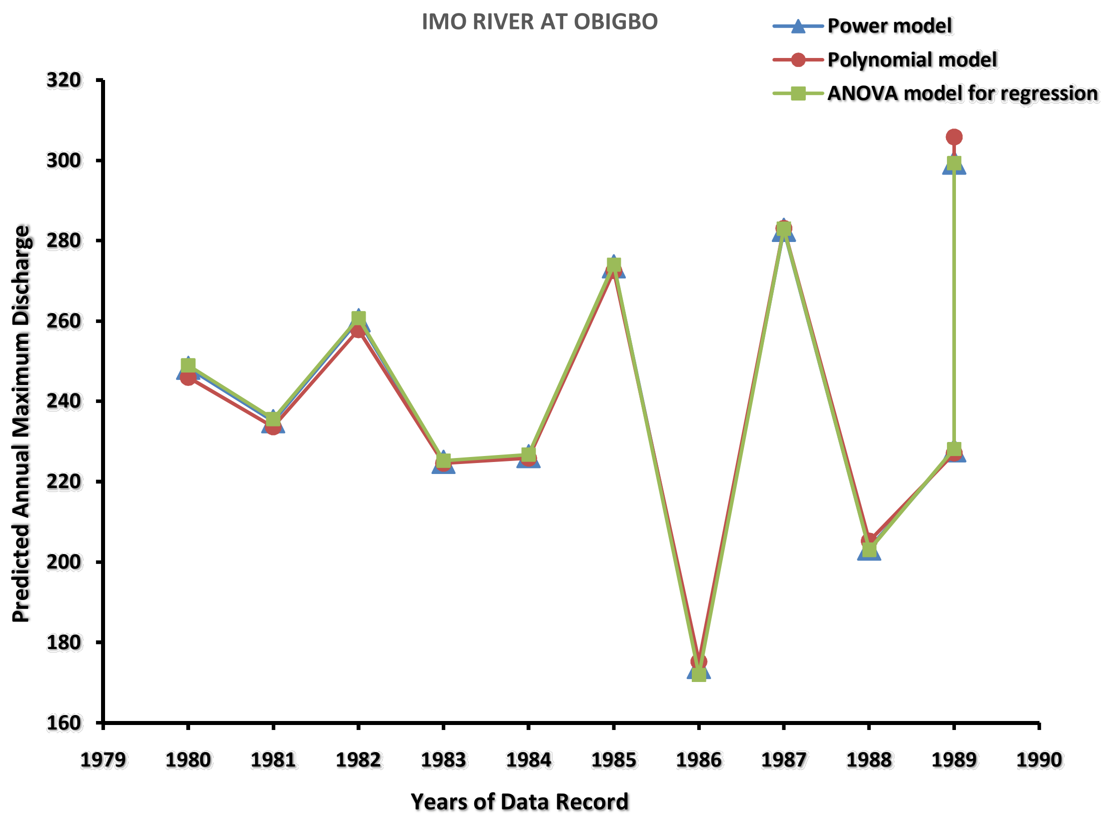


Figure 4.69: Comparison of the models verified for Imo River at Obigbo streamflow gauging station

4.11.3.4 Comparison of the streamflow models of Imo River at Obigbo gauging station using student's t-test

The streamflow models of Imo River at Obigbo gauging station are further compared using student's t-test (distribution) as shown in Tables 4.138 through 4.140.

Table 4.138: t-Test: Paired Two Sample for Means (Power and Polynomial models)

	Power model	Polynomial model
Mean	241.44	241.5281818
Variance	1324.50364	1361.997056
Observations	11	11
Pearson Correlation	0.997794787	
Hypothesized Mean Difference	0	
df	10	
t Stat	-0.11759594	
P(T<=t) one-tail	0.45435813	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.90871626	
t Critical two-tail	2.228138852	

Table 4.139: t-Test: Paired Two Sample for Means (Power model and ANOVA model for regression)

	Power model	ANOVA model for regression
Mean	241.44	241.5254545
Variance	1324.50364	1356.032447
Observations	11	11
Pearson Correlation	0.999867906	
Hypothesized Mean Difference	0	
df	10	
t Stat	-0.385869906	
P(T<=t) one-tail	0.353837464	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.707674928	
t Critical two-tail	2.228138852	

Table 4.140: t-Test: Paired Two Sample for Means (Polynomial model and ANOVA model for regression)

	Polynomial model	**Polynomial model**
Mean	241.5281818	241.5254545
Variance	1361.997056	1356.032447
Observations	11	11
Pearson Correlation	0.996876054	
Hypothesized Mean Difference	0	
df	10	
t Stat	0.003102982	
P(T<=t) one-tail	0.498792606	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.997585212	
t Critical two-tail	2.228138852	

4.11.4 Computations of the model performance measures of the streamflow model of Imo River at Obigbo gauging station

Computations of Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias, root mean square error or standard error of estimateand mean of residue or mean absolute error which are used as tools for the evaluation of the streamflow models ofImo River at Obigbo gauging stationare shown in Tables 4.141 and 4.142 for the power and polynomial models respectively and Table 4.143 for the ANOVA model for regression.

Table 4.141: Computations of model performance measures of the streamflow model of Imo River streamflow model at Obigbo gauging station (for the *power model*)

Year	**Stage in metres (x or h)**	**Measured Discharge in m^3/s (y_i or Q)**	**Predicted Discharge $y_i' = 102.46x^{1.225}$ m^3/s (power model)**	**Residuals $(y_i - y_i')$**	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1979	2.06	246.00	248.34	- 2.34	5.48	-0.0095	4.474	20.017
1980	1.97	232.00	235.11	- 3.11	9.67	-0.0134	-9.526	90.745
1981	2.14	261.50	260. 20	1.30	1.69	0.0050	19.974	398.961
1982	1.90	220.00	224.92	- 4.92	24.21	-0.0224	-21.526	463.369
1983	1.91	240.80	226.37	14.43	208.22	0.0599	-0.726	0.527
1984	2.23	263.89	273.67	- 9.78	95.65	-0.0371	22.364	500.148
1985	1.54	176.40	173.89	2.51	6.30	0.0142	-65.126	4,241.396
1986	2.29	286.20	282.72	3.48	12.11	0.0122	44.674	1,995.766
1987	1.75	200.00	203.36	- 3.36	11.29	0.0168	-41.526	1,724.409
1988	1.92	223.20	227.82	- 4.62	21.34	0.0207	-18.326	335.842
1989	2.40	306.80	299.44	7.36	54.17	0.0240	65.274	4,260.695
		$\sum$ = 2656.79	**$\sum$ = 2,655.84**	**$\sum$ = 0.95**	**$\sum$ = 450.13**	**$\sum$ = 0.0704**		**$\sum$ = 14031.875**

Computations of the model performance measures of the streamflow model of Imo River at Obigbo gauging station (for the *power model*).

Mean of measured annual maximum discharge = 241.526

Mean of predicted annual maximum discharge = 241.44

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{450.13}{14031.875} = 0.9679$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE}) \text{ or } S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{450.13}{11}} = 6.40$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{241.44 - 241.526}{241.526}\right) = -0.0356$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\text{MR or MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{0.95}{11} = 0.086$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{11}(0.0704) = 0.9936$$

Table 4.142: Computations of model performance measures of the streamflow modelof Imo at Obigbo gauging station (for the *polynomial model*)

Year	**Stage (x or h) metres**	**Measured Discharge (y_i or Q) m^3/s**	**Predicted Discharge** $y_i' = 104.58x^3 - 581.01x^2 + 1204.1x - 683.11$ **m^3/s Polynomial model**	**Residuals** $(y_i - y_i')$	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1979	2.06	246.00	245.98	0.02	0.00	0.0001	4.474	20.017
1980	1.97	232.00	233.68	-1.68	2.82	-0.0072	-9.526	90.745
1981	2.14	261.50	257.79	3.71	13.76	0.0142	19.974	398.961
1982	1.90	220.00	224.55	- 4.55	20.68	-0.0207	-21.526	463.369
1983	1.91	240.80	225.84	14.96	223.80	0.0621	-0.726	0.527
1984	2.23	263.89	272.48	- 8.59	73.79	-0.0326	22.364	500.148
1985	1.54	176.40	175.24	1.16	1.35	0.0066	-65.126	4,241.396
1986	2.29	286.20	283.08	3.12	9.73	0.0109	44.674	1,995.766
1987	1.75	200.00	205.21	- 5.21	27.14	-0.0261	-41.526	1,724.409
1988	1.92	223.20	227.13	-3.93	15.44	-0.0176	-18.326	335.842
1989	2.40	306.80	305.83	0.97	0.94	0.0032	65.274	4,260.695
			∑=2656.81	**∑ = -0.02**	**∑= 389.45**	**∑=-0.0071**		**∑=14031.875**

Computations of the model performance measures of the streamflow model of Imo River at Obigbo gauging station (*polynomial model*).

Mean of measured annual maximum discharge = 241.526

Mean of predicted annual maximum discharge = 241.528

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{389.45}{14031.875} = 0.9722$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE}) \text{ or } S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{389.45}{11}} = 5.95$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{241.528 - 241.526}{241.526}\right) = 0.0008$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\text{MR or MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{-0.02}{11} = 1.818$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{11}(-0.0071) = 1.0006$$

Table 4.143: Computations of model performance measures of the streamflow modelof Imo River at Obigbo gauging station (for the *ANOVA model for regression*)

Year	**Stage (x or h) metres**	**Measured Annual Maximum Discharge (y_i or Q) m^3/s**	**Predicted Annual Maximum Discharge $y = 148.048x - 56.051$ (ANOVA model for regression) m^3/s**	**Residuals $(y_i - y_i')$**	$(y_i - y_i')^2$	$\frac{(y_i - y_i')}{y_i}$	$(y_i - \bar{y})$	$(y_i - \bar{y})^2$
1979	2.06	246.00	248.93	-2.93	8.58	-0.0119	4.474	20.017
1980	1.97	232.00	235.60	-3.60	12.96	-0.0155	-9.526	90.745
1981	2.14	261.50	260.77	0.73	0.53	0.0028	19.974	398.961
1982	1.90	220.00	225.24	-5.24	27.46	-0.0238	-21.526	463.369
1983	1.91	240.80	226.72	14.08	198.25	0.0585	-0.726	0.527
1984	2.23	263.89	274.10	-10.21	04.24	-0.0387	22.364	500.148
1985	1.54	176.40	171.94	4.46	19.89	0.0253	-65.126	4,241.396
1986	2.29	286.20	282.98	3.22	10.37	0.0113	44.674	1,995.766
1987	1.75	200.00	203.03	-3.03	9.18	-0.0152	-41.526	1,724.409
1988	1.92	223.20	228.20	-5.00	25.00	-0.0224	-18.326	335.842
1989	2.40	306.80	299.27	7.53	56.70	0.0245	65.274	4,260.695
			$\sum$ =2656.78	**$\sum$ = 0.010**	**$\sum$= 473.16**	**$\sum$ =-0.00510**		**$\sum$ =14031.875**

Computations of the model performance measures of the streamflow model of Imo River at Obigbo gauging station (ANOVA model for regression).

Mean of measured annual maximum discharge = 241.526

Mean of predicted annual maximum discharge = 241.525

i. Nash-Sutcliffe model Efficiency (NSE)

$$\mathrm{NSE} = 1 - \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{\sum(\mathrm{y_i} - \bar{\mathrm{y}})^2} = 1 - \frac{2656.78}{14031.875} = 0.8107$$

ii. Root Mean Square Error (RMSE) or standard error of estimate of y with respect to x (S_{yx})

$$(\mathrm{RMSE}) \text{ or } S_{yx} = \sqrt{\frac{\sum(\mathrm{y_i} - \mathrm{y_i'})^2}{n}} = \sqrt{\frac{473.16}{11}} = 6.56$$

iii. Percentage BIAS (PBIAS)

$$\mathrm{PBIAS} = 100\left(\frac{\bar{\hat{\mathrm{y}}} - \bar{\mathrm{y}}}{\bar{\mathrm{y}}}\right) = 100\left(\frac{241.525 - 241.526}{241.526}\right) = -0.0004$$

iv. Mean of Residue (MR) or Mean Absolute Error (MAE)

$$\mathrm{MR} \text{ or } \mathrm{MAE} = \frac{\sum(\mathrm{y_i} - \mathrm{y_i'})}{n} = \frac{0.010}{11} = 0.0009$$

v. Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = 1 - \frac{1}{n}\frac{(\mathrm{y_i} - \mathrm{y_i'})}{\mathrm{y_i}} = 1 - \frac{1}{11}(-0.00510) = 1.000$$

The summary of streamflow models of Imo River at Obigbo gauging station obtained from Figures 4.64 and 4.65 for the power and polynomial modelsand Table 4.132 for the ANOVA model for regression are shown in Table 4.144.

Table 4.144: Summary of streamflow models of Imo River at Obigbo gauging station and the models evaluation parameters

RIVER	STREAMFLOW GAUGING STATION	STREAMFLOW MODEL [+]	MODEL EVALUATION PARAMETERS [*]						
			R^2	R	NSE	RMSE or S_{QH}	PBIAS	MRor MAE	MARE
Imo River	Obigbo	**Power model** $Q = 102.461h^{1.2249}$	0.9697	0.9847	0.9679	6.40	-0.0356	0.086	0.9936
		Polynomial model $Q = 104.58h^3 - 581.01h^2 + 1204.1h - 683.11$	0.9723	0.9861	0.9722	5.95	0.0008	1.818	1.0006
		ANOVA model for regression $Q = 148.048h - 56.051$	0.9663	0.9830	0.8107	6.56	0.0004	0.0009	1.0005

[+] Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

[*] **ModelEvaluation Parameters**
Coefficient of determination (R^2), Coefficient of correlation (R), Nash-Sutcliffe model Efficiency (NSE), Mean Absolute Relative Error (MARE), Root Mean Square Error (RMSE) or Standard error of estimate of discharge on stage ($S_{Q.h}$), Percentage BIAS (PBIAS), Mean Residue (MR).

4.12 Comparisons of the Streamflow Models of Imo River at the various Streamflow Gauging Stations

Comparison is carried out for rivers having similar years of data record as the abscissa and the predicted discharges as the ordinate. Comparisons of the streamflow models of Imo River at Ndimoko, Umuna, Umuopara and Obigbo streamflow gauging stations are shown in Figures 4.70 through 4.72.

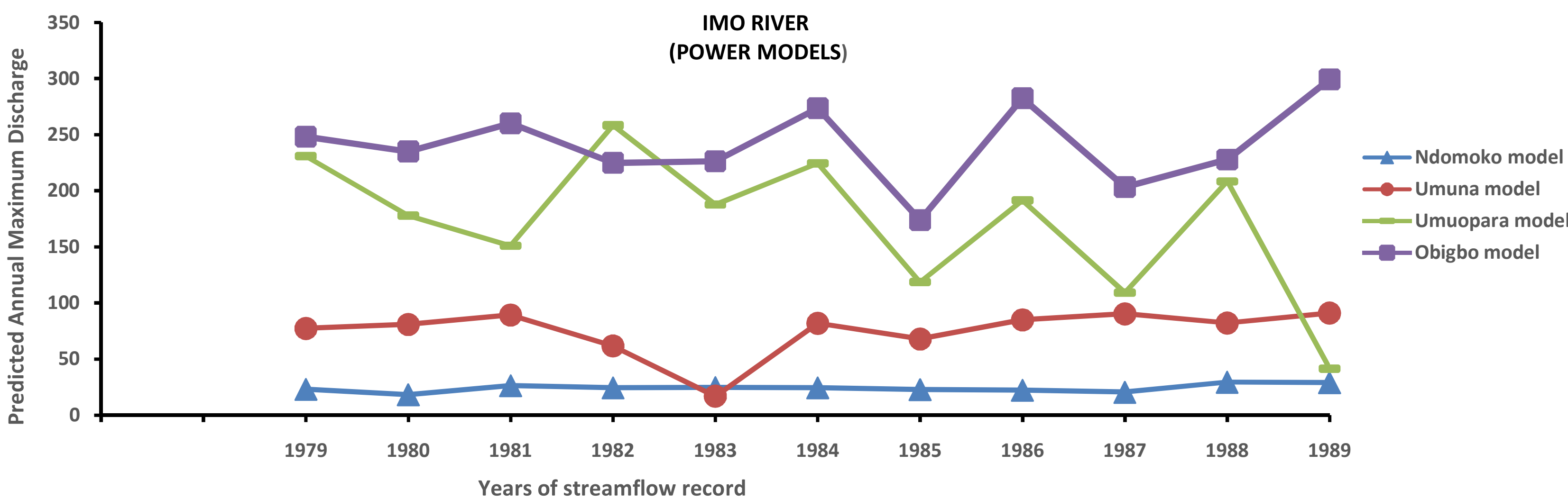


Figure 4.70: Comparison of the streamflow model of Imo River at the Ndimoko, Umuna, Umuopara and Obigbo gauging stations (power model)

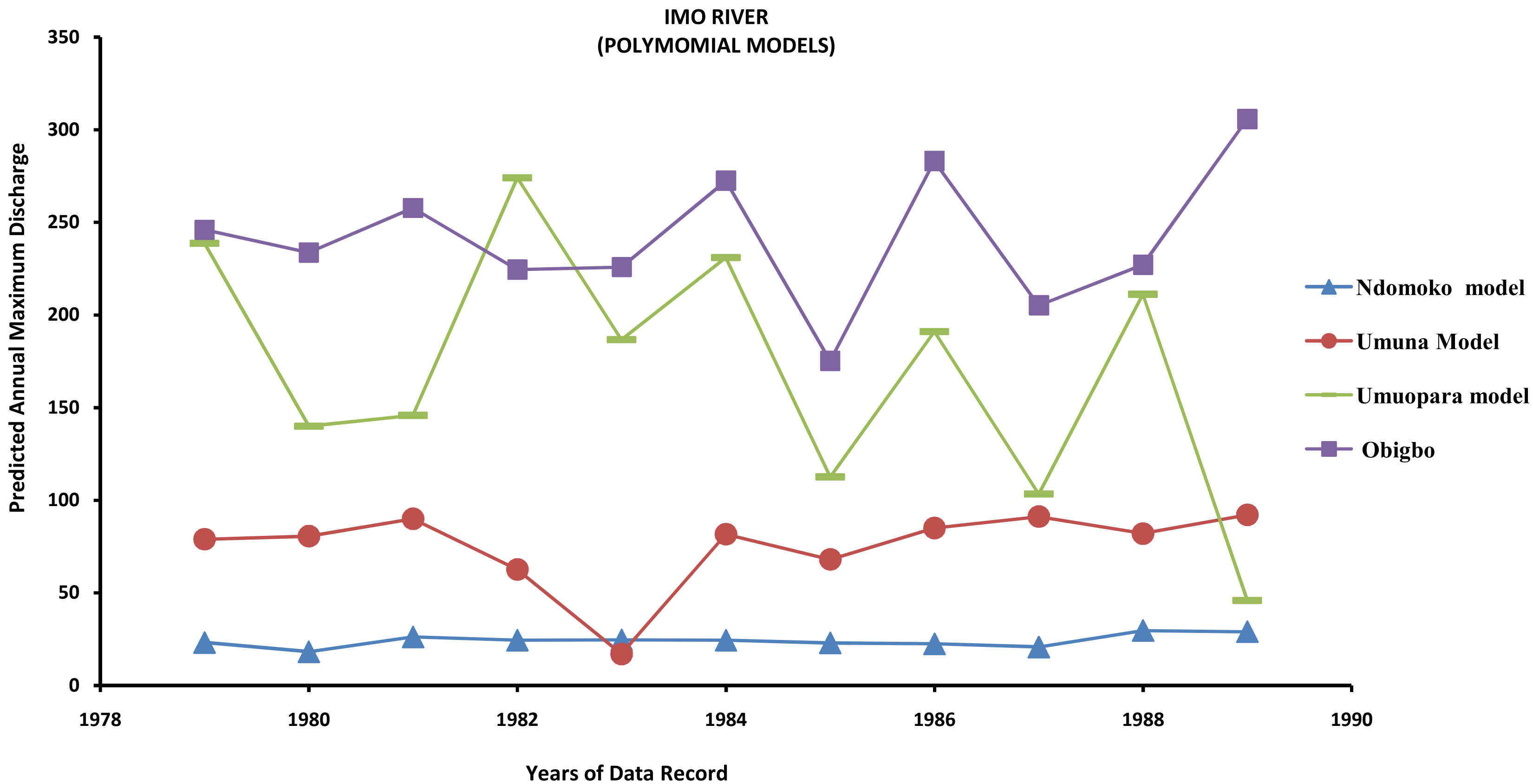


Figure 4.71: Comparison of the streamflow model of Imo River at the Ndimoko, Umuna, Umuopara and Obigbo gauging stations (polynomial model)

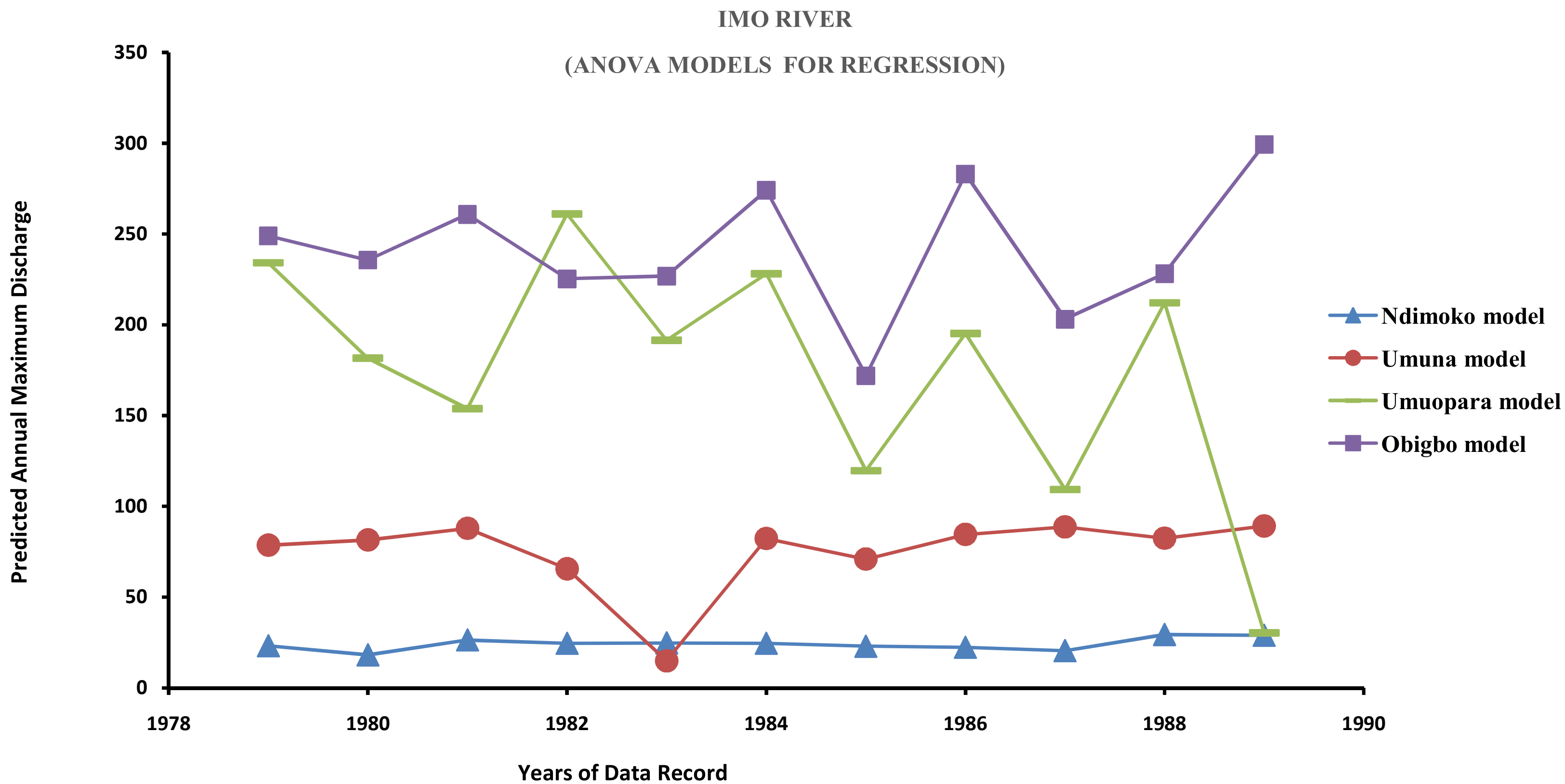


Figure 4.72: Comparison of the streamflow model of Imo River at the Ndimoko, Umuna, Umuopara and Obigbo gauging stations (ANOVA model for regression)

4.13 The Summaries of the Calibrated Streamflow Models for the Seven Selected Rivers

The Summary of the calibrated streamflow models for the seven selected rivers are tabulated in Tables 4.145 through 4.147

Table 4.145: Summary of calibrated streamflow models of the seven selected rivers at their various streamflow gauging stations (*for the power model*)

S/n	RIVER SYSTEM	CALIBRATED STREAMFLOW MODEL *(Power Model)*	MODEL EVALUATION PARAMETERS						
			R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
1	Cross River at Afikpo North LG.A. streamflow gauging station, Ebonyi State	$Q = 37.814h^{2.5883}$	0.9999	0.9999	0.9965	38.04	0.098	-12.25	1.00
2	River Niger at Lokoja streamflow gauging station, Kogi State	$Q = 481.85h^{1.6537}$	0.9983	0.9991	0.99996	12.68	0.037	7.042	0.9996
	River Niger at Onitsha streamflow gauging station, Anambra State	$Q = 206.74h^{1.8456}$	0.9995	0.9997	0.9962	35.66	-0.192	33.03	0.9981
3	Owena River at Owena Village streamflow gauging station, Ondo State	$Q = 6.2766h^{2.7607}$	0.9939	0.9969	0.9899	3.00	-0.23	1.69	0.972
4	Owan River at Owan Village streamflow gauging station, Edo State	$Q = 4.8905 h^{1.2633}$	0.9973	0.9986	0.9972	0.30	0.0271	0.0258	0.9962
5	Ikpoba River at Benin City streamflow gauging station, Edo State	$Q = 5.1663h^{1.847}$	0.9837	0.9918	0.969	2.59	0.176	-0.07	1.000
6	Ossiomo River at Abudu streamflow gauging station, Edo State	$Q = 7.9311 h^{2.5429}$	0.9991	0.9995	0.9991	0.72	-0.008	0.003	0.9987
7	Imo River at Ndimoko streamflow gauging station, Imo State	$Q = 4.4233h^{1.4952}$	0.9087	0.9533	0.9001	1.054	-0.108	0.026	0.981
	Imo River at Umuna streamflow gauging station, Imo State	$Q = 4.7025h^{1.8685}$	0.9973	0.9986	0.9886	2.19	-0.121	0.091	1.09
	Imo River at Umuopara streamflow gauging station, Abia State	$Q = 30.021h^{1.177}$	0.9598	0.9797	0.9307	17.40	-0.802	1.398	1.005
	Imo River at Obigbo streamflow gauging Station, River State	$Q = 102.461h^{1.2249}$	0.9697	0.9847	0.9679	6.40	-0.0356	0.086	0.9936

Table 4.146: Summary of calibrated streamflow models of the seven selected rivers at their various streamflow gauging stations(*for the polynomial model*)

S/n	RIVER SYSTEM	CALIBRATED STREAMFLOW MODEL (*Polynomial Model)*	MODEL EVALUATION PARAMETERS						
			R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
1	Cross River at Afikpo North L.G.A. streamflow gauging station, Ebonyi State	$Q = -19.857h^3 + 734.63h^2 - 5208.1h + 13023$	1	1	0.9986	23.88	0.02	–12.25	1.00
2	River Niger at Lokoja streamflow gauging station, Kogi State	$Q = -16.973h^3 + 456.51h^2 - 698.16h$	0.9992	0.9996	0.99967	38.47	0.12	–22.748	1.0012
	River Niger at Onitsha streamflow gauging station, Anambra State	$Q = -11.713h^3 + 527.48h^2 - 4363.2h + 17034$	0.9998	0.9999	0.9942	44.10	–0.002	36.85	0.9978
3	Owena River at Owena Village streamflow gauging station, Ondo State	$Q = 14.714h^3 - 61.991h^2 + 125.69h - 78.708$	0.9915	0.9957	0.9915	2.75	0.019	–0.009	1.000
4	Owan River at Owan Village streamflow gauging station, Edo State	$Q = 0.0561h^3 - 0.5747h^2 + 10.931h - 9.9542$	0.9973	0.9986	0.9948	3.80	0.0233	0.04	1.000
5	Ikpoba River at Benin City streamflow gauging station, Edo State	$Q = -6.262h^3 + 56.982h^2 - 143.82h + 128.58$	0.9995	0.9997	0.9986	0.31	-0.017	0.008	0.9996
6	Ossiomo River at Abudu streamflow gauging station, Edo State	$Q = -8.7679h^3 + 91.738h^2 - 208.23h + 165.57$	0.9992	0.9996	0.9992	0.66	0.014	–0.013	0.9987
7	Imo River at Ndimoko streamflow gauging station, Imo State	$Q = 5.9499h^3 - 54.234h^2 + 175.17h - 175.06$	0.9093	0.9536	0.9096	1.003	0.050	–0.012	0.985
	Imo River at Umuna streamflow gauging station, Imo State	$Q = 2.6699h^3 - 25.874h^2 + 103.49h - 107.52$	0.9892	0.9946	0.9889	2.16	0.246	1.282	1.01
	Imo River at Umuopara streamflow gauging station, Abia State	$Q = -0.0778h^3 + 4.6138h^2 + 15.43h + 17.757$	0.9408	0.9699	0.9400	16.19	–1.853	3.229	0.9904
	Imo River at Obigbo streamflow gauging Station, River State	$Q = 104.58h^3 - 581.01h^2 + 1204.1h - 683.11$	0.9723	0.9861	0.9722	5.95	0.0008	1.818	1.0006

Table 4.147: Summary of calibrated streamflow models of the seven selected rivers at their various streamflow gauging stations (*for the ANOVA model for regression*)

S/n	RIVER SYSTEM	CALIBRATED STREAMFLOW MODEL (*ANOVA model for regression*)	MODEL EVALUATION PARAMETERS						
			R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
1	Cross River at Afikpo North L.G.A. streamflow gauging station, Ebonyi State	Q = 3105.18h – 16700.21	0.9990	0.9995	0.9932	53.52	-0.10	12.12	0.9993
2	River Niger at Lokoja streamflow gauging station, Kogi State	Q = 3365.212h – 11967.088	0.9991	0.9995	0.99969	37.07	0.105	–20.018	1.0011
	River Niger at Onitsha streamflow gauging station, Anambra State	Q = 2721.24h– 12630.79	0.9980	0.9990	0.9797	38.65	-0.014	2.32	0.9999
3	Owena River at Owena Village streamflow gauging station, Ondo State	Q = 63.671h –79.406	0.9446	0.9719	0.9446	7.03	– 0.004	0.002	0.956
4	Owan River at Owan Village streamflow gauging station, Edo State	Q = 9.450h – 9.798	0.9970	0.9985	0.9936	0.46	0.4524	0.1675	1.005
5	Ikpoba River at Benin City streamflow gauging station, Edo State	Q = 23.799h – 30.848	0.9980	0.9990	0.9910	38.65	0.005	-0.002	1.000
6	Ossiomo River at Abudu streamflow gauging station, Edo State	Q = 84.294h– 127.182	0.9980	0.9990	0.9805	38.65	-3.632	0.004	0.9961
7	Imo River at Ndimoko streamflow gauging station, Imo State	Q = 11.573h – 11.772	0.9076	0.9527	0.9077	1.014	0.012	-0.003	1.002
	Imo River at Umuna streamflow gauging station, Imo State	Q = 25.6003h–36.0205	0.9792	0.9895	0.9792	2.96	-0.003	0.002	0.99
	Imo River at Umuopara streamflow gauging station, Abia State	Q = 46.9704h – 31.6438	0.9270	0.9628	0.9270	17.87	0.000	0.000	0.9938
	Imo River at Obigbo streamflow gauging Station, River State	Q = 148.048h– 56.051	0.9663	0.9830	0.8107	6.56	0.0004	0.0009	1.0005

4.14 Discussion of Results

The design of hydraulic structures such as dams, reservoirs, drains etc, is a problem when there are no good ideas of streamflow and rainfall histories of such an environment. The flow rate of the river after the construction of the dam or reservoir and the quantity of water the drains collect are assumed rather than calculated. Sometimes this assumption of the flow rate (discharge) of the river can reduce the efficiency of the hydraulic structure. This occurrence is presently witnessed in most areas of Nigeria. Hence, the need for the Assessment of Streamflow Relationship Models of Selected Rivers in Southern Nigeria.

4.14.1 Cross River at Afikpo North L.G.A. streamflow gauging station

The results of streamflow model calibration and verification of Cross River at Afikpo North L.G.A. streamflow gauging stationare presented in section 4.1. Model performance in calibration and verification in Tables 4.2are within the acceptable range.Hence it was considered that the calibration was sufficient. The streamflow models of Cross River and their models evaluation parameters are shown in Table 4.13.

STREAMFLOW MODELS OF CROSS RIVER	**MODEL EVALUATION PARAMETERS**						
	R^2	**R**	**NSE**	**RMSE or S_{QH}**	**PBIAS**	**MR or MAE**	**MARE**
Power model $Q = 37.814h^{2.5883}$	**0.9999**	**0.9999**	**0.9965**	**38.04**	**0.098**	**-12.25**	**1.00**
Polynomial model $Q = -19.857h^3 + 734.63h^2 - 5208.1h + 13023$	**1**	**1**	**0.9986**	**23.88**	**0.02**	**-2.478**	**1.00**
ANOVA Model for Regression $Q = -16700.21 + 3105.18h$	**0.9990**	**0.9995**	**0.9932**	**53.52**	**-0.10**	**12.12**	**0.999**

The results suggest that the calibrated streamflow models of Cross River performed satisfactorily in the prediction of streamflow in Afikpo North L.G.A. streamflow gauging station. From Table 4.3 which is the One – way ANOVA F-test, the calculated value of F is 0.009957. The calculated value (0.009957) is less than the table value (F critical) of 3.31583 at 5% level of significance, we conclude that there is no significant difference between the three streamflow models of Cross River at Afikpo L.G.A. gauging station. Therefore, the difference in the three streamflow models is insignificant. From Tables 4.4 through 4.6 which represent the Variance Ratio Test or Snedecor's F distribution (F-Test), the calculated values of F are less than the table values (critical values) of F. Hence the hypothesis that the difference of two samples is not significant at 5% level is accepted.

From Figure 4.6 which is the comparison of the streamflow models verified for Cross River at Afikpo North L.G.A. streamflow gauging station using graph, there is no significant difference in the three streamflow models. From Table 4.7 which represent the T-test, the observed value of t is less than the critical value of t which is in the acceptance region for both one-tail and two-tail tests. and thus we conclude that the difference in streamflow rate in the power model and polynomial model of Cross River at Afikpo North L.G.A. gauging station is insignificant.

From Table 4.8 the observed value of t is less than the critical value of t using table of t-distribution for 10 degrees of freedom which is in the acceptance region and thus we accept the conclusion that the difference in streamflow rate in the power model and ANOVA model for regression of Cross River at Afikpo North L.G.A. gauging station is insignificant. From Table 4.9 we conclude that the difference in the streamflow rate in the polynomial model and ANOVA model for regression of Cross River at

Afikpo North L.G.A. gauging station is insignificant since the observed value of t is less than the critical value of t using table of t-distribution for 10 degrees of freedom which is in the acceptance region.

Streamflow models developed in CrossRiver is an intelligent decision support tool for optimizing water management, flood risk reduction, hydropower generation and irrigation of the extensive farmland in Afikpo North L.G.A of Ebonyi State in Southern Nigeria.I did not find other researchers work in the internet nor other related work for use for comparison or discussion.

4.14.2 River Niger at Lokoja and Onitsha streamflow gauging stations

The streamflow models for River Niger at Lokoja and Onitsha gauging stations are shown in Tables 4.8 and 4.14, The models calibrationsare in agreement with the models verifications indicating good fits of the regression analysis.

4.14.2.1 River Niger at Lokoja streamflow gauging station

The streamflow models of River Niger at Lokoja and their models evaluation parameters are shown in Table 4.26.

STREAMFLOW MODEL OF RIVER NIGER AT LOKOJA	MODEL EVALUATION PARAMETERS						
	R^2	R	NSE	RMSE or S_{QH}	PBIAS	MRor MAE	MARE
Power model $Q = 481.85h^{1.6537}$	0.9983	0.9991	0.99996	12.68	0.037	7.042	0.9996
Polynomial model $Q = -16.973h^3 + 456.51h^2 - 698.16h$	0.9992	0.9996	0.99967	38.47	0.12	-22.748	1.0012
ANOVA Model for regression $Q = 3365.212h - 11967.088$	0.9991	0.9995	0.99969	37.07	0.105	-20.018	1.0011

The results suggest that the calibrated streamflow models of River Niger at Lokoja gauging station performed satisfactorily in the prediction of streamflow events.

From Table 4.16 which is the one–way ANOVA F-Test, the calculated value of F is 0.00036974which is less than the table value (F critical) of 3.88529at 5% level of significance. This analysis shows that there is no significant difference between the three streamflow models of River Niger at Lokoja gauging station. Therefore, the difference in the three streamflow models is insignificant. From Tables 4.17 through 4.19 which represent the Variance Ratio Test or Snedecor's F distribution (F-Test), the calculated values of F are less than the table values (critical values) of F. Hence there is no reason to doubt the hypothesis that the difference of two samples is not significant at 5% level.

From Figure 4.12 which is the comparison of the streamflow models verified for River Niger at Lokoja gauging station using graph, there is no significant difference in the three streamflow models. From Tables 4.20 which represent the T-test, the observed value of t is less than the critical value of t which is in the acceptance region for both one-tail and two-tail tests. We therefore conclude that the streamflow rate in the power model and polynomial model of River Niger at Lokoja gauging station do not differ insignificantly.

From Table 4.21 the observed value of t is less than the critical value of t using table of t-distribution for 4 degrees of freedom which is in the acceptance region and thus we accept the conclusion that the difference in streamflow rate in the power model and ANOVA model for regression of River Niger at Lokoja gauging station is insignificant. From Table 4.22

the observed value of t is less than the critical value of t using table of t-distribution for 4 degrees of freedom. We conclude that the difference in the streamflow rate in the polynomial model and ANOVA model for regression of River Niger at Lokoja gauging station is insignificant.

4.14.2.2 River Niger at Onitsha streamflow gauging station

The streamflow models of River Niger at Onitsha and their models evaluation parameters are shown in Table 4.39.

STREAMFLOW MODEL OF RIVER NIGER AT ONITSHA	MODEL EVALUATION PARAMETERS						
	R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
Power model $Q = 206.74h^{1.8456}$	0.9995	0.9997	0.9962	35.66	-0.192	33.03	0.9981
Polynomial model $Q = -11.713h^3 + 527.48h^2 - 4363.2h + 17034$	0.9998	0.9999	0.9942	44.10	-0.002	36.85	0.9978
ANOVA Model for regression $Q = 2721.24h - 12630.79$	0.9980	0.9990	0.9797	38.65	-0.014	2.32	0.9999

The calibrated models of River Niger at Onitsha were capable of reproducing the observed streamflow's for the study catchments reasonably well.

From Table 4.29 which is the One–way ANOVA F-Test, the calculated value of F is 0.0032506which is less than the table value (F critical) of 4.256495at 5% level of significance. This analysis shows that there is no significant difference between the three streamflow models of River Niger at Onitsha gauging station. Therefore, the difference in the three streamflow models is insignificant. From Tables 4.30 through 4.32 which represent the Variance Ratio Test or Snedecor's F distribution (F-Test), the calculated values of F are less than the table values (critical values) of F. Hence the hypothesis holds true that the difference of two samples is not significant at 5% level is accepted.

From Figure 4.18 which is the comparison of the streamflow models verified for River Niger at Onitsha gauging station using graph, there is no significant difference in the three streamflow models calibrated for River Niger at Onitsha. From Tables 4.33 which represent the T-test, the observed value of t is less than the critical value of t which is in the acceptance region for both one-tail and two-tail tests. and thus we conclude that the difference in streamflow rate in the power model and polynomial model of River Niger at Onitsha gauging station is insignificant.

From Table 4.34 the observed value of t is less than the critical value of t using table of t-distribution for 3 degrees of freedom which is in the acceptance region and thus we accept the conclusion that the difference in streamflow rate in the power model and ANOVA model for regression of River Niger at Onitsha gauging station is insignificant. From Table 4.35 we conclude that the difference in the streamflow rate in the polynomial model and ANOVA model for regression of River Niger at Onitsha gauging station is insignificant since the observed value of t is less than the critical value of t using table of t-distribution for 3 degrees of freedom which is in the acceptance region.

The streamflow models of River Niger developed in this research are very useful as River Niger is an important water way both for navigation associated with active trading and for small canoe traffic over its whole course. The riparian rural and urban populations benefit from its important fish resources while the plains and its inland delta are used extensively for agriculture. Riparian cities like Onitsha and Lokoja, located on the banks of River Niger, will need to have ports in the future and developments such as hydroelectric power generation. Irrigation have also given the river a significant economic role, therefore the streamflow modeling information of River Niger will become more relevant and useful for design of water resources structures and hydropower generation, as the basin witnesses' various forms of development in the future.I did not find other researchers work for use for comparison.

4.14.3 Owena River at Owena streamflow gauging station

The performance of modeling effort of Owena River as shown in Table 4.52, suggests that there are good tests of good fits of the regression analysis done using annual maximum discharge versus annual maximum stage of Owena River.

STREAMFLOW MODEL OF OWENA RIVER AT OWENA VILLAGE	**MODEL EVALUATION PARAMETERS**						
	R^2	**R**	**NSE**	**RMSE / S_{QH}**	**PBIAS**	**MR**	**MARE**
Power model $Q = 6.2766h^{2.7607}$	**0.9939**	**0.9969**	**0.9899**	**3.0**	**-0.23**	**1.69**	**0.972**
Polynomial model $Q = 14.714h^3 - 61.991h^2 + 125.69h - 78.708$	**0.9915**	**0.9957**	**0.9915**	**2.75**	**0.019**	**-0.009**	**1.000**
ANOVA Model for Regression $Q = 63.671h - 79.406$	**0.9446**	**0.9719**	**0.9446**	**7.03**	**-0.004**	**0.002**	**0.956**

The results suggest that the calibrated streamflow models of Owena River at Owena village gauging station performed satisfactorily in the prediction of streamflow events. From Table 4.42 which is the One –way ANOVA F-Test, the calculated value of F is 06.8236E-05 which is less than the table value (F critical) of 3.28492at 5% level of significance. we conclude that there is no significant difference between the three streamflow models of Owena River at Owena village gauging station. From Tables 4.43 through 4.45 which represent the Variance Ratio Test or Snedecor's F distribution (F-Test), the calculated values of F are less than the table values (critical values) of F. Hence the hypothesis that the difference of two samples is not significant at 5% level is accepted.From Figure 4.24 which is the comparison of the streamflow models verified for Owena Riverat Owena village gauging station using graph, there is no significant difference in the three streamflow models calibrated for Owena River at Owena village.

From Table 4.46 which represent the T-test, the observed value of t is less than the critical value of t which is in the acceptance region for both one-tail and two-tail tests. We therefore conclude that the streamflow rate in the power model and polynomial model of Owena River at Owena village gauging station do not differ insignificantly.From Table 4.47 the observed value of t is less than the critical value of t using table of t-distribution for 11 degrees of freedom which is in the acceptance region and thus we accept the conclusion that the difference in streamflow rate in the power model and ANOVA model for regression of Owena River at Owena village gauging station is insignificant. From Table 4.48 we conclude that the difference in the streamflow rate in the polynomial model and ANOVA model for regression of Owena River at Owena village gauging station is insignificant as the observed value of t is less than the critical value of t using table of t-distribution for 11 degrees of freedom.

The streamflow model of Owena River developed in this research will be useful in water resources planning and in the determination of the quantity of water required at any time for water supply and management in that part of the Southern Nigeria.I did not find other researchers work in the internet nor other related work for use for comparison or discussion.

4.14.4 Owan River at Owan village streamflow gauging station

The streamflow models of Owan River at Owan village and their models evaluation parameters are shown in Table 4.65.

STREAMFLOW MODEL OF OWAN RIVER AT OWAN VILLAGE	MODEL EVALUATION PARAMETERS						
	R^2	R	NSE	RMSE / S_{QH}	PBIAS	MR	MARE
Power model $Q = 4.8905\, h^{1.2633}$	0.9973	0.9986	0.9972	0.30	0.0271	0.0258	0.9962
Polynomial model $Q = 0.0561h^3 - 0.5747h^2 + 10.931h - 9.9542$	0.9973	0.9986	0.9948	3.80	0.0233	0.04	1.000
ANOVA model for regression $Q = 9.450h - 9.798$	0.9970	0.9985	0.9936	0.46	0.4524	0.1675	1.005

The calibrated models of Owan River at Owan villagegauging station were capable of reproducing the observed streamflow's for the study catchments reasonably well. From the model evaluation parameters, the three models are good, but the power model is the best and better than others, followed by the polynomial model as it provides more confident and helpful result in dealing with streamflow prediction etc.

From Table 4.55 which is the one–way ANOVA F-Test, the calculated value of F is 0.04938which is less than the table value (F critical) of 3.28492at 5% level of significance. Hence the models do not differ significantly with respect to there streamflow rates.From Tables 4.56 through 4.58 which represent the Variance Ratio Test or Snedecor's F distribution (F-Test), the calculated values of F are less than the table values (critical values) of F. Hence the hypothesis that the difference of two samples is not significant at 5% level is accepted.From Figure 4.30 which is the comparison of the streamflow models verified for Owan River Owan village gauging station using graph, there is no significant difference in the three streamflow models calibrated for Owena River Owan village.

From Table 4.59 which represent the T-test, the observed value of t is less than the critical value of t which is in the acceptance region for both one-tail and two-tail tests. and thus we conclude that the difference in streamflow rate in the power model and polynomial model of Owan River at Owan village gauging station is insignificant. From Table 4.60 the observed value of t is less than the critical value of t using table of t-distribution for 11 degrees of freedom which is in the acceptance region and thus we accept the conclude that the difference in streamflow rate in the power model and ANOVA model for regression of Owan River at Owan village gauging station is insignificant.

From Table 4.61 the observed value of t is less than the critical value of t using table of t-distribution for 11 degrees of freedom. We conclude that the difference in the streamflow rate in the polynomial model and ANOVA model for regression of Owan River at Owan village gauging station is insignificant. Streamflow model developed for Owan River can be used for aiding policy formulation for future practices in water resources in the locality.I did not find other related work for use for comparison and discussion.

4.14.5 Ikpoba River at Benin City streamflow gauging station

The performance of modeling effort of Ikpoba River at Benin City gauging station as shown in Table 4.78, suggests that there are good tests of good fits of the regression analysis done using annual maximum discharge versus annual maximum stage of Ikpoba River.

STREAMFLOW MODEL OF IKPOBA RIVER AT BENIN CITY	MODEL EVALUATION PARAMETERS						
	R^2	R	NSE	RMSE or S_{QH}	PBIAS	MRor MAE	MARE
Power model $Q= 5.1663h^{1.847}$	0.9837	0.9918	0.969	2.59	0.176	-0.07	1.00
Polynomial model $Q = - 6.262h^3 + 56.982h^2 - 143.82h + 128.58$	0.9995	0.9997	0.9986	0.31	-0.017	0.008	0.9996
ANOVA Model for regression $Q = 23.799h – 30.848$	0.9980	0.9990	0.9910	38.65	0.005	-0.002	1.00

The results suggest that the calibrated streamflow models of ikpoba River at Benin City gauging station performed satisfactorily in the prediction of streamflow events.From the model evaluation parameters, the three models are good, but the polynomial model is the best and better than others, followed by the power model.

From Table 4.68 which is the one –way ANOVA F-Test, the calculated value of F is 0.002which is less than the table value (F critical) of 3.25945at 5% level of significance. This analysis shows that there is no significant difference between the three streamflow models of Ikpoba River at Benin City gauging station. Therefore, the difference in the three streamflow models is insignificant. From Tables 4.69 through 4.71 which represent the Variance Ratio Test or Snedecor’s F distribution (F-Test), the calculated values of F are less than the table values (critical values) of F. Hence we accept the hypothesis that the difference of two samples is not significant at 5% level is accepted.

From Figure 4.36which is the comparison of the streamflow models verified for Ikpoba Riverat Benin City gauging station using graph, there is no significant difference in the three streamflow models calibrated for Ikpoba River at Benin City. From Table 4.72 which represent the T-test, the observed value of t is less than the critical value of t which is in the acceptance region for both one-tail and two-tail tests. and thus we conclude that the difference in streamflow rate in the power model and polynomial model of Ikpoba River at Benin City gauging station is insignificant. From

Table 4.73 the observed value of t is less than the critical value of t using table of t-distribution for 11 degrees of freedom which is in the acceptance region and thus we accept the conclusion that the difference in streamflow rate in the power model and ANOVA model for regression of Ikpoba River at Benin City gauging station is insignificant.From Table 4.74 we conclude that the difference in the streamflow rate in the polynomial model and ANOVA model for regression of Ikpoba River at Benin City gauging station is insignificant since the observed value of t is less than the critical value of t using table of t-distribution for 11 degrees of freedom which is in the acceptance region.
The streamflow model of Ikpoba River will be useful in the design of size and capacity of reservoir for water storage needed for water supply and irrigation of the extensive farmland in Benin City, Edo State in Southern Nigeria.I did not find other researchers work in the internet nor other related work for use for comparison or discussion.

4.14.6 Ossiomo River at Abudu streamflow gauging station

The streamflow models of Ossiomo River at Abudu gauging station and their models evaluation parameters are shown in Table 4.91.

STREAMFLOW MODEL OF OSSIOMO RIVER AT ABUDU	MODEL EVALUATION PARAMETERS						
	R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
Power model $Q = 7.9311\ h^{2.5429}$	0.9991	0.9995	0.9991	0.72	-0.008	0.003	0.9987
Polynomial model $Q = -8.7679h^3 + 91.738h^2 - 208.23h + 165.57$	0.9992	0.9996	0.9992	0.66	0.014	-0.013	0.9987
ANOVA model for regression $Q = 84.294h - 127.182$	0.9980	0.9990	0.9805	38.65	-3.632	0.004	0.9961

The calibrated models of Ossiomo River at Abudu villagegauging station were capable of reproducing the observed streamflow's for the study catchments reasonably well. From the model evaluation parameters, the three models are good, but the polynomial model is the best and better than others, followed by the power model. From Table 4.81 which is the one –way ANOVA F-test, the calculated value of F is 3.65E-05which is less than the table value (F critical) of 3.284918at 5% level of significance. we conclude that there is no significant difference between the three streamflow models of Ossiomo River at Abudu village gauging station.

From Tables 4.82 through 4.84 which represent the Variance Ratio Test or Snedecor's F distribution (F-Test), the calculated values of F are less than the table values (critical values) of F. Hence the hypothesis that the difference of two samples is not significant at 5% level is accepted.From Figure 4.42 which is the comparison of the streamflow models verified for Ossiomo River at Abudu gauging station using graph, there is no significant difference in the three streamflow models calibrated for Ossiomo River at Abudu. From Table 4.85 which represent the T-test, the observed value of t is less than the critical value of t which is in the acceptance region for both one-tail and two-tail tests. and thus we conclude that the difference in streamflow rate in the power model and polynomial model of Ossiomo River at Abudu gauging station is insignificant.

From Table 4.86 the observed value of t is less than the critical value of t using table of t-distribution for 11 degrees of freedom which is in the acceptance region and thus we accept the conclude that the difference in streamflow rate in the power model and ANOVA model for regression of Ossiomo River at Abudu gauging station is insignificant. From Table 4.87 the observed value of t is less than the critical value of t using table of t-distribution for 11 degrees of freedom. We conclude that the difference in the streamflow rate in the polynomial model and ANOVA model for regression of Ossiomo River at Abudu gauging station is insignificant.

The streamflow models of Ossiomo River developed in this research will be useful in water resources planning and in the determination of the quantity of water required throughout the year for water supply and management in that part of Edo State in Southern Nigeria.I did not find other related work for use for comparison and discussion.

4.14.7 Imo River

The streamflow models of Imo River at the four gauging stationsare presented in section 4.8. The calibrated models of Imo River were capable of reproducing the observed streamflow’s for the study catchments reasonably well.

4.14.7 1 Imo River at Ndimoko gauging station

The performance of modeling effort of Imo River at Ndimoko gauging station as shown in Table 4.104, suggests that there are good tests of good fits of the regression analysis done using annual maximum discharge versus annual maximum stage of Imo River at Ndimoko gauging station.

STREAMFLOW MODEL OF IMO RIVER AT NDIMOKO	MODEL EVALUATION PARAMETERS						
	R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
Power model $Q = 4.4233h^{1.4952}$	0.9087	0.9533	0.9001	1.054	-0.108	0.026	0.981
Polynomial model $Q = 5.9499h^3 - 54.234h^2 + 175.17h - 175.06$	0.9093	0.9536	0.9096	1.003	0.050	-0.012	0.985
ANOVA model for regression $Q = 11.573h - 11.772$	0.9076	0.9527	0.9077	1.014	0.012	-0.003	1.002

The results suggest that the calibrated streamflow models of Imo River at Ndimoko gauging station performed satisfactorily in the prediction of streamflow events. From the model evaluation parameters, the three models are good, but the polynomial model is the best and better than others, followed by the power model. The result in the power model supports the findings of Okoro and Uzoukwu (2013) and Okoro and Uzoukwu (2014) who described the use of streamflow models for regional water resources allocation and for sustainable rural water supply.

From Table 4.94 which is the one –way ANOVA F-Test, the calculated value of F is 0.0004which is less than the table value (F critical) of 3.31583 at 5% level of significance. This analysis shows that there is no significant difference between the three streamflow models of Imo River at Ndimoko gauging station. Therefore, the difference in the three streamflow models is insignificant. From Tables 4.95 through 4.97 which represent the Variance Ratio Test or Snedecor's F-distribution (F-Test), the calculated values of F are less than the table values (critical values) of

F. Hence the hypothesis that the difference of two samples is not significant at 5% level is accepted.

From Figure 4.51 which is the comparison of the streamflow models verified for Imo River at Ndimoko gauging station using graph, there is no significant difference in the three streamflow models calibrated for Imo River at Ndimoko gauging station. From Table 4.98 which represent the T-test, the observed value of t is less than the critical value of t which is in the acceptance region for both one-tail and two-tail tests. and thus we conclude that the difference in streamflow rate in the power model and polynomial model of Imo River at Ndimoko gauging station is insignificant.

From Table 4.99 the observed value of t is less than the critical value of t using table of t-distribution for 10 degrees of freedom which is in the acceptance region and thus we accept the conclusion that the difference in streamflow rate in the power model and ANOVA model for regression of Imo River at Ndimoko gauging station is insignificant. From Table 4.100, conclusion is made that the difference in the streamflow rate in the polynomial model and ANOVA model for regression of Imo River at Ndimoko gauging station is insignificant since the observed value of t is less than the critical value of t using table of t-distribution for 10 degrees of freedom which is in the acceptance region.

4.14.7 2 Imo River at Umuna gauging station

The streamflow models of Imo River at Umuna gauging station and their models evaluation parameters are shown in Table 4.118.

STREAMFLOW MODEL OF IMO RIVER AT UMUNA	MODEL EVALUATION PARAMETERS						
	R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
Power model $Q = 4.7025h^{1.8685}$	0.9973	0.9986	0.9886	2.19	-0.121	0.091	1.09
Polynomial model $Q = 2.6699h^3 - 25.874h^2 + 103.49h - 107.52$	0.9892	0.9946	0.9889	2.16	0.246	1.282	1.01
ANOVA model for regression $Q = 25.6003h - 36.0205$	0.9792	0.9895	0.9792	2.96	-0.003	0.002	0.99

The calibrated models of Imo River at Umuna gauging station were capable of reproducing the observed streamflow's for the study catchments reasonably well. From the model evaluation parameters, the three models are good, but the power model is the best and better than others, followed by the polynomial model as it provides more confident and helpful result in dealing with streamflow prediction etc. The findings of this study are consistent with the results of Okoro and Uzoukwu (2013) who describe the power model method as being useful in regional water resources allocation.

From Table 4.108 which is the one –way ANOVA F-Test, the calculated value of F is 0.000481which is less than the table value (F critical) of 3.3158295at 5% level of significance. Hence the models of Imo River at Umuna gauging station do not differ significantly with respect to their streamflow rates. From Tables 4.109 through 4.111 which represent the Variance Ratio Test or Snedecor's F-distribution (F-Test), the calculated values of F are less than the table values (critical values) of F. Hence the hypothesis holds true that the difference of two samples is not significant at 5% level.From Figure 4.57 which is the comparison of the streamflow models verified for Imo River at Umuna gauging station using graph, there is no significant difference in the three streamflow models calibrated for Imo River at Umuna. From Table 4. 112 which represent the T-test, the observed value of t is less than the critical value of t which is in the acceptance region for both one-tail and two-tail tests. and thus we conclude that the difference in streamflow rate in the power model and polynomial model of Imo River at Umuna gauging station is insignificant.

From Table 4.113 the observed value of t is less than the critical value of t using table of t-distribution for 10 degrees of freedom which is in the acceptance region and thus we accept the conclusion that the difference in streamflow rate in the power model and ANOVA model for regression of Imo River at Umuna gauging station is insignificant. From Table 4.114 the observed value of t is less than the critical value of t using table of t-distribution for 10 degrees of freedom. We conclude that the difference in the streamflow rate in the polynomial model and ANOVA model for regression of Imo River at Umuna gauging station is insignificant.

4.14.7.3 Imo River at Umuopara gauging station

The performance of modeling effort of Imo River at Umuopara gauging station as shown in Table 4.131, suggests that there are good tests of good fits of the regression analysis done using annual maximum discharge versus annual maximum stage of Imo River at Umuopara gauging station.

STREAMFLOW MODEL OF IMO RIVER AT UMUOPARA	MODEL EVALUATION PARAMETERS						
	R^2	R	NSE	RMSE or S_{QH}	PBIAS	MR or MAE	MARE
Power model $Q = 30.021h^{1.177}$	0.9598	0.9797	0.9307	17.40	-0.802	1.398	1.005
Polynomial model $Q = -0.0778h^3 + 4.6138h^2 + 15.43h + 17.757$	0.9408	0.9699	0.9400	16.19	-1.853	3.229	0.9904
ANOVA model for regression $Q = 46.9704h - 31.6438$	0.9270	0.9628	0.9270	17.87	0.000	0.000	0.9938

The results suggest that the calibrated streamflow models of Imo River at Umuopara gauging station performed satisfactorily in the prediction of streamflow events. The result in the power model supports the findings of Okoro and Uzoukwu (2013) and Okoro and Uzoukwu (2014) who describe the use of sreamflow models in sustainable rural water supply and for regional water resources allocation.

From Table 4.121 which is the one –way ANOVA F-Test, the calculated value of F is 0.006618which is less than the table value (F critical) of 3.31583at 5% level of significance. This analysis shows that there is no significant difference between the three streamflow models of Imo River at Umuopara gauging station. Therefore, the difference in the three streamflow models is insignificant. From Tables 4.122 through 4124 which represent the Variance Ratio Test or Snedecor's F distribution (F-Test), the calculated values of F are less than the table values (critical values) of F. Hence the hypothesis that the difference of two samples is not significant at 5% level is accepted.

From Figure 4.63 which is the comparison of the streamflow models verified for Imo Riverat Umuopara gauging station using graph, there is no significant difference in the three streamflow models calibrated for Imo River at Ndimoko gauging station. From Table 4.125 which represent the T-test, the observed value of t is less than the critical value of t which is in the acceptance region for both one-tail and two-tail tests. and thus we conclude that the difference in streamflow rate in the power model and polynomial model of Imo Riverat Umuoparagauging station is insignificant.

From Table 4.126 the observed value of t is less than the critical value of t using table of t-distribution for 10 degrees of freedom which is in the acceptance region and thus we accept the conclusion that the difference in streamflow rate in the power model and ANOVA model for regression of Imo Riverat Umuopara gauging station is insignificant. From Table 4.127, conclusion is made that the difference in the streamflow rate in the polynomial model and ANOVA model for regression of Imo Riverat Umuopara gauging station is insignificant since the observed value of t is less than the critical value of t using table of t-distribution for 10 degrees of freedom which is in the acceptance region.

4.14.7.4 Imo River at Obigbo gauging station

The streamflow models of Imo River at Obigbo gauging station and their models evaluation parameters are shown in Table 4.144.

STREAMFLOW MODEL OFIMO RIVER AT OBIGBO	**MODEL EVALUATION PARAMETERS**						
	R^2	**R**	**NSE**	**RMSE or S_{QH}**	**PBIAS**	**MR or Mae**	**MARE**
Power model $Q = 102.461h^{1.2249}$	**0.9697**	**0.9847**	**0.9679**	**6.40**	**-0.0356**	**0.086**	**0.9936**
Polynomial model $Q = 104.58h^3 - 581.01h^2 + 1204.1h - 683.11$	**0.9723**	**0.9861**	**0.9722**	**5.95**	**0.0008**	**1.818**	**1.0006**
ANOVA model for regression $Q = 148.048h - 56.051$	**0.9663**	**0.9830**	**0.8107**	**6.56**	**0.0004**	**0.0009**	**1.0005**

The calibrated models of Imo River at Obigbo gauging station were capable of reproducing the observed streamflow's for the study catchments reasonably well.From the model evaluation parameters, the three models are good, but the polynomial model is the best and better than others, followed by the power model.Okoro and Uzoukwu (2013) describe the power model method which include the use of streamflow models for regional water resources allocation.

The polynomial model presented here is slightly different from the approach adopted in developing streamflow regression models in Nwaogazie and Okah (2003) work which has to do with selecting flow depth at upstream Otamiri River at Nekede hydrological station as the independent variable and streamflow discharge of Imo River at downstream Obigbo station as the dependent variable. This arrangement was also reversed by selecting streamflow depth of Imo River at downstream Obigbo hydrological station as the independent variable and streamflow discharge of Otamiri River at upstream Nekede station as the dependent variable. It is slightly different from my work as I used the stage and discharge measurement of Imo river at the various gauging stations to provide models.

From Table 4.134 which is the one–way ANOVA F-Test, the calculated value of F at 5% level of significance is 2.0525E-05. Since the calculatedvalue is less than the table value (F critical) of 3.31583,the hypothesis holds true that there is no significant difference between the three streamflow models of Imo River at Obigbo gauging station. From Tables 4.135 through 4.137 which represent the Variance Ratio Test or Snedecor's F distribution (F-Test), the calculated values of F are less than the table values (critical values) of F. Hence the hypothesis that the difference of two samples is not significant at 5% level holds true.

From Figure 4.69 which is the comparison of the streamflow models verified for Imo River at Obigbo gauging station using graph, there is no significant difference in the three streamflow models calibrated for Imo

River at Obigbo. From Table 4.138 which represent the T-test, the observed value of t is less than the critical value of t which is in the acceptance region for both one-tail and two-tail tests. and thus we conclude that the difference in streamflow rate in the power model and polynomial model of Imo River at Obigbo gauging station is insignificant.

From Table 4.139 the observed value of t is less than the critical value of t using table of t-distribution for 10 degrees of freedom which is in the acceptance region and thus we accept the conclusion that the difference in streamflow rate in the power model and ANOVA model for regression of Imo River at Obigbo gauging station is insignificant. From Table 4.140 the observed value of t is less than the critical value of t using table of t-distribution for 10 degrees of freedom. We conclude that the difference in the streamflow rate in the polynomial model and ANOVA model for regression of Imo River at Obigbo gauging station is insignificant.

The rainfall and hydrological conditions in Imo River should make it possible to exploit, with good chances of success for an annual rainfall crop, the alluvial plains of the Imo River and its tributaries. However, to be able to cultivate all year round, irrigation is necessary. The irrigation potential in this region is high and easy to develop, though the construction of dams is necessary for storage of water. Hence the streamflow models of Imo River developed at the various streamflow gauging stations are useful for water resources planning and allocation of water to the various water using sectors in that part of Southern Nigeria.

4.15 Applications of the Streamflow Models

The streamflow models developed for Cross River at Afikpo North L.G.A. streamflow gauging station and River Niger at Onitsha streamflow gauging station were used to produce Flow Duration Curves which are also known as discharge-frequency curves or the cumulative frequency curves. Flow Duration Curves are highly useful in the planning and design of water resources projects. For hydropower studies, the flow duration curve serves to determine the potential for firm power (primary power) generation. The firm power is normally computed on the basis of flow available 90 to 97 per cent of the time for a run-of-the river plant. The flow duration curve is also useful in flood control studies and in the design of drainage systems.

The streamflow model (power-law model) developed for Ikpoba River in Benin City is applied in the determination of reservoir storage capacity in Benin City. To determine the capacity for any uniform rate of demand of water, mass curve becomes useful, although the required storage capacity reservoir can also be obtained by calculations.

4.15.1 Application of the streamflow model of Cross River at Afikpo North L. G. A. gauging station in Hydropower Electricity Generation

Mean monthly water levels (stages) were calculated from the daily streamflow records of Cross River at Afikpo North L.G.A. streamflow gauging station. Then with the help of the calibrated streamflow model of Cross River at Afikpo North L.G.A. streamflow gauging station, the predicted mean monthly flows (discharges) were computed and then tabulated in Table 4.148.

Calibrated streamflow model (power model) of Cross River at Afikpo North L.G.A. streamflow gauging station is $Q = 37.814h^{\mathbf{2.5883}}$

therefore,

$Q_{\text{(Cross River in June 2016)}} = 37.814\ (4.05)^{\mathbf{2.5883}} = 1{,}412.30\ m^3/s$

$Q_{\text{(Cross River in July 2016)}} = 37.814(5.15)^{\mathbf{2.5883}} = 2{,}630.41\ m^3/s$

$Q_{\text{(Cross River in Aug. 2016)}} = 37.814\ (7.63)^{\mathbf{2.5883}} = 7{,}275.97\ m^3/s$

$Q_{\text{(Cross River in Sept. 2016)}} = 37.814\ (9.28)^{\mathbf{2.5883}} = 12{,}076.94\ m^3/s$

$Q_{\text{(Cross River in Oct. 2016)}} = 37.814\ (8.36)^{\mathbf{2.5883}} = 9{,}217.20\ m^3/s$

$Q_{\text{(Cross River in Nov, 2016)}} = 37.814\ (5.59)^{\mathbf{2.5883}} = 3{,}252.21\ m^3/s$

$Q_{\text{(Cross River in Dec.2016)}} = 37.814\ (3.79)^{\mathbf{2.5883}} = 1{,}189.45\ m^3/s$

$Q_{\text{(Cross River in Jan 2017)}} = 37.814\ (2.94)^{\mathbf{2.5883}} = 616.42\ m^3/s$

$Q_{\text{(Cross River in Feb. 2017)}} = 37.814\ (2.53)^{\mathbf{2.5883}} = 417.88\ m^3/s$

$Q_{\text{(Cross River in Mar, 2017)}} = 37.814\ (2.38)^{\mathbf{2.5883}} = 356.74\ m^3/s$

$Q_{\text{(Cross River in Apr, 2017)}} = 37.814\ (2.33)^{\mathbf{2.5883}} = 337.66\ m^3/s$

$Q_{\text{(Cross River in May 2017)}} = 37.814\ (3.28)^{\mathbf{2.5883}} = 818.26\ m^3/s$

Table 4.148: Mean monthly streamflow data of Cross River at Afikpo North L.G.A. gauging station

Months	Mean monthly stage (m)	Predicted mean monthly discharge m^3/s
June 2016	4.05	1,412.30
July 2016	5.15	2,630.41
Aug. 2016	7.63	7,275.97
Sep. 2016	9.28	12,076.94
Oct. 2016	8.36	9,217.20
Nov. 2016	5.59	3,252.21
Dec. 2016	3.79	1,189.45
Jan. 2017	2.94	616.65
Feb. 2017	2.53	417.88
Mar. 2017	2.38	356.74
Apr. 2017	2.33	337.66
May 2017	3.28	818.26

The computations of flow duration curve of Cross River at Afikpo North L.G.A. gauging station are tabulated in Table 4.149.

Table 4.149: Computations for Flow Duration Curve for Cross River at Afikpo North L.G.A. streamflow gauging station

Months	Predicted mean monthly discharge m^3/s	Discharge arranged in descending order m^3/s	Rank m	Percentage of time discharge equaled or exceeded $\frac{m}{n} \times 100$ %
June 2016	1,412.30	12,076.94	1	8.33
July 2016	2,630.41	9,217.20	2	16.67
Aug.2016	7,275.97	7,275.97	3	25.00
Sep. 2016	12,076.94	3,252.21	4	33.33
Oct. 2016	9,217.20	2,630.41	5	41.67
Nov. 2016	3,252.21	1,412.30	6	50.00
Dec. 2016	1,189.45	1,189.45	7	58.33
Jan. 2017	616.65	818.26	8	66.67
Feb. 2017	417.88	616.65	9	75.00
Mar. 2017	356.74	417.88	10	83.33
Apr. 2017	337.66	356.74	11	91.67
May 2017	818.26	337.66	12	100.00

The flow duration curve is obtained by plotting discharge (flow) as the ordinate and the percent of time as abscissa as shown in Figure 4.73.

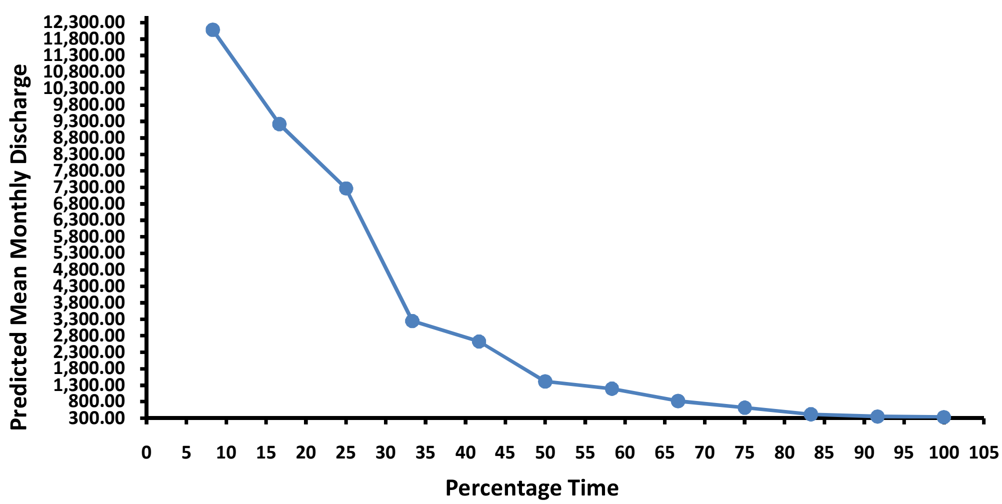


Figure 4.73: Flow duration curve for Cross River at Afikpo North L.G.A streamflow gauging station

The discharge available 90 to 97 % of the time is used for estimating the firm power. 95 % dependable flow is adopted here. From flow duration curve the magnitude of the flow available 95 % of the time is 347.60m^3/s. Available head is 2.0m. Assuming an overall efficiency of 80 % for the turbine-generator system, the firm power (P) for a run-of-the river plant is calculated as follows:

$$P = \eta\, g\, Q\, H \qquad . \qquad . \qquad . \qquad (4.3)$$

Substituting the values in Equation 4.3

$$P = 0.80 \times 9.81 \times 347.60 \times 2.0$$

$$P = 5,455.93\text{kw}$$

where, P = firm power

η = the overall efficiency of the scheme

g = acceleration due to gravity = 9.81 m^3/s

Q = dependable flow

H = available head

4.15.2 Application of the streamflow model of River Niger at Onitshagauging station in hydropower electricity generation

Streamflow model of River Niger at Onitsha streamflow gauging station is used in hydropower electricity generation in Onitsha, Anambra State. The mean monthly water levels (stages) were calculated from the daily streamflow records of River Niger at Onitsha streamflow gauging station. Then with the help of the calibrated streamflow model of River Niger at Onitsha streamflow gauging station, the predicted mean monthly flows (discharges) were computed and then tabulated in Table 4.150.

The calibrated streamflow model (power model) of River Niger at Onitsha streamflow gauging station is $Q = 206.74\ (h)^{\mathbf{1.8456}}$

Therefore,

$Q_{\text{(River Niger in January 2001)}} = 206.74(3.78)^{\mathbf{1.8456}} = 2{,}382.27\ m^3/s$

$Q_{\text{(River Niger in February 2001)}} = 206.74\ (3.33)^{\mathbf{1.8456}} = 1{,}903.92\ m^3/s$

$Q_{\text{(River Niger in March 2001)}} = 206.74\ (3.13)^{\mathbf{1.8456}} = 1{,}698.25\ m^3/s$

$Q_{\text{(River Niger in April. 2001)}} = 206.74\ (3.07)^{\mathbf{1.8456}} = 1{,}638.65\ m^3/s$

$Q_{\text{(River Niger in May 2001)}} = 206.74\ (3.37)^{\mathbf{1.8456}} = 1{,}946.34\ m^3/s$

$Q_{\text{(River Niger in June 2001)}} = 206.74\ (4.05)^{\mathbf{1.8456}} = 2{,}732.40\ m^3/s$

$Q_{\text{(River Niger in July 2001)}} = 206.74\ (5.32)^{\mathbf{1.8456}} = 4{,}520.30\ m^3/s$

$Q_{\text{(River Niger in August 2001)}} = 206.74\ (7.42)^{\mathbf{1.8456}} = 8{,}352.99\ m^3/s$

$Q_{\text{(River Niger in September 2001)}} = 206.74\ (9.68)^{\mathbf{1.8456}} = 13{,}670.48\ m^3/s$

$Q_{\text{(River Niger in October 2001)}} = 206.74\ (10.43)^{\mathbf{1.8456}} = 15{,}659.22\ m^3/s$

$Q_{\text{(River Niger in November 2001)}} = 206.74\ (5.91)^{\mathbf{1.8456}} = 5{,}488.66\ m^3/s$

$Q_{\text{(River Niger in December 2001)}} = 206.74\ (3.48)^{\mathbf{1.8456}} = 2{,}076.17\ m^3/s$

Table 4.150: Mean monthly streamflow data of River Niger at Onitsha gauging station

Months	**Mean monthly stage (m)**	**Predicted mean monthly discharge m^3/s**
January 2001	3.76	2,382.27
February 2001	3.33	1,903.92
March 2001	3.13	1,698.25
April 2001	3.07	1,638.65
May 2001	3.37	1,946.34
June 2001	4.05	2,732.40
July 2001	5.32	4,520.30
August 2001	7.42	8,352.99
September 2001	9.69	13,670.48
October 2001	10.43	15,659.22
November 2001	5.91	5,488.66
December 2001	3.49	2,076.17

Computation for Flow Duration Curve (FDC) for River Niger at Onitsha streamflow gauging station is shown in Table 4.151.

Table 4.151: Computation for Flow Duration Curve (FDC) for River Niger at Onitsha streamflow gauging station

Months	Predicted mean monthly discharge (flow) m^3/s	Discharge (flow) arranged in descending order m^3/s	Rank m	Percentage of time discharge equaled or exceeded $\frac{m}{n}x100$ %
Jan. 2001	2,382.27	15,659.22	1	8.33
Feb. 2001	1,903.92	13,670.48	2	16.67
Mar. 2001	1,698.25	8,352.99	3	25.00
Apr. 2001	1,638.65	5,488.66	4	33.33
May 2001	1,946.34	4,520.30	5	41.67
Jun. 2001	2,732.40	2,732.40	6	50.00
Jul. 2001	4,520.30	2,382.27	7	58.33
Aug. 2001	8,352.99	2,076.17	8	66.67
Sep. 2001	13,670.48	1,946.34	9	75.00
Oct. 2001	15,659.22	1,903.92	10	83.33
Nov. 2001	5,488.66	1,698.25	11	91.67
Dec. 2001	2,076.17	1,638.65	12	100.00

The flow duration curve is obtained by plotting discharge (flow) as the ordinate and the percent of time as abscissa as shown in Figure 4.74.

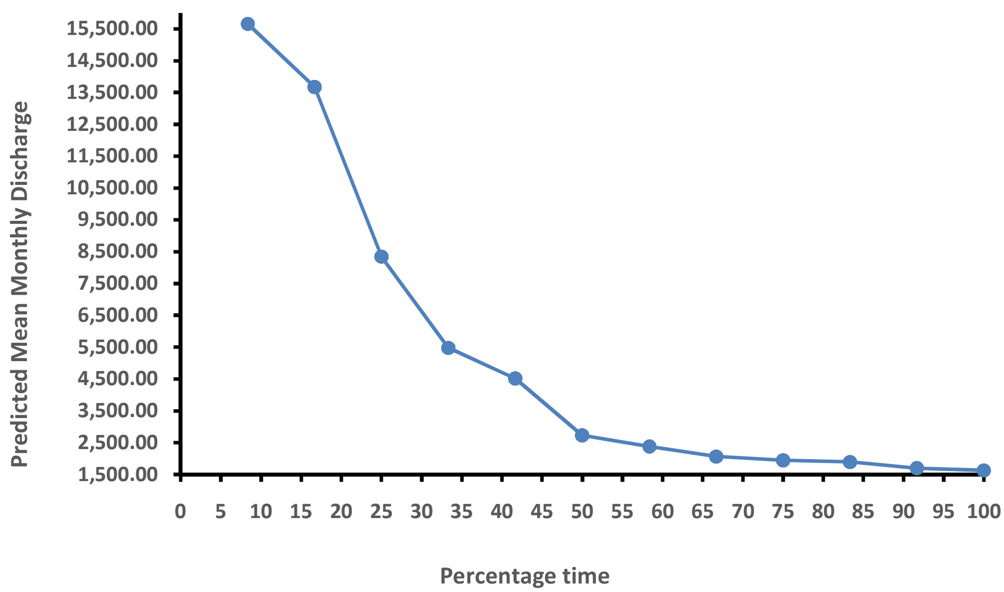


Figure 4.74: Flow duration curve for River Niger at Onitsha streamflow gauging station

The discharge available 90 to 97 % of the time is used for estimating the firm power. 95 % dependable flow is adopted here. From flow duration curve the magnitude of the flow available 95 % of the time is 1674 m^3/s. Available head is 3m. Assuming an overall efficiency of 80 % for the turbine-generator system, the firm power (P) for a run-of-the river plant is calculated as follows:

$$P = \eta \, g \, Q \, H \qquad . \qquad . \qquad . \qquad \text{(Eqn. 4.3)}$$

Substituting the values in Equation 4.3

$$P = 0.80 \times 9.81 \times 1674 \times 3$$

$$P = 39{,}412.66 \text{ kw}$$

where, P = firm power

η = the overall efficiency of the scheme

g = acceleration due to gravity = 9.81 m^3/s

Q = dependable flow

H = available head

4.15.3 Application of the streamflow model of Ikpoba River at Benin City in the determination of storage capacity of reservoir

To obtain the storage requirement of a reservoir proposed at Ikpoba River gauging site in Benin city by calculation method, the mean monthly discharge of Ikpoba River is computed from January 1999 to December 2000 and the values are tabulated in Table 4.152. The calculation of the minimum storage capacity of the proposed reservoir for Ikpoba River at Benin City streamflow gauging site having a demand rate of 35 m^3/s is shown in Table 4. 153.

Table 4.152: Mean monthly streamflow of Ikpoba River at Benin City gauging station

S/n	Month / Year	Measured mean monthly stage (m)	Predicted mean monthly discharge $Q = 5.166x^{1.847}$ (power model) (m^3/s)
1	Jan. 1999	2.77	33.92
2	Feb. 1999	2.74	33.24
3	Mar. 1999	2.72	32.79
4	Apr. 1999	2.70	32.35
5	May 1999	2.75	33.47
6	Jun. 1999	2.82	35.06
7	Jul. 1999	2.87	36.21
8	Aug. 1999	3.53	53.08
9	Sep. 1999	4.04	68.10
10	Oct. 1999	3.85	62.30
11	Nov. 1999	3.65	56.46
12	Dec. 1999	2.90	36.92
13	Jan. 2000	2.63	30.82
14	Feb. 2000	2.73	33.02
15	Mar. 2000	2.64	32.13
16	Apr. 2000	2.78	34.14
17	May 2000	2.96	38.34
18	Jun. 2000	3.07	41.01
19	Jul. 2000	3.51	52.52
20	Aug. 2000	3.86	62.60
21	Sep. 2000	3.96	65.63
22	Oct. 2000	3.87	62.90
23	Nov. 2000	3.52	52.52
24	Dec. 2000	2.83	35.29

Table 4.153: Calculation of the minimum storage capacity of the proposed reservoir for Ikpoba River at Benin City streamflow gauging site

Month	**Predicted mean monthly discharge m^3/s**	**Demand or outflow m^3/s**	**Deficit m^3/s**	**Surplus m^3/s**	**Cumulative deficit m^3/s**	**Cumulative surplus m^3/s**	**Remark**
1	2	3	4	5	6	7	8
Jan. 1999	33.92	35	1.08				The highest value of cumulative surplus is 130.86 m^3/s. Hence the required storage capacity is 130.86 m^3/s.
Feb. 1999	33.24	35	1.76				
Mar. 1999	32.79	35	2.21		9.22		
Apr. 1999	32.35	35	2.65				
May 1999	33.47	35	1.53				
Jun. 1999	35.06	35		0.06			
Jul. 1999	36.21	35		1.21			
Aug. 1999	53.08	35		18.08			
Sep. 1999	68.10	35		33.10		103.13	
Oct. 1999	62.30	35		27.30			
Nov. 1999	56.46	35		21.46			
Dec. 1999	36.92	35		1.92			
Jan. 2000	30.82	35	4.18				
Feb. 2000	33.02	35	1.98				
Mar. 2000	32.13	35	2.87		9.89		
Apr. 2000	34.14	35	0.86				
May 2000	38.34	35		3.33			
Jun. 2000	41.01	35		6.01			
Jul. 2000	52.52	35		17.52			
Aug. 2000	62.60	35		27.60		130.86	
Sep. 2000	65.63	35		30.63			
Oct. 2000	62.90	35		27.90			
Nov. 2000	52.52	35		17.52			
Dec. 2000	35.29	35		0.35			

The required minimum storage capacity is 130.86 m^3/s.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Water resources are essential renewable resources that are the basis for existence and development of a society. Proper utilization of these resources requires assessment and management of the quantity of the water resources both spatially and temporally. Most water resources investigations require the knowledge of total volume of water that have to be dealt with over long periods of time. For design or regulatory purposes, it is necessary to know how often the discharge of a river may be less than or greater than a given value. Also, if a river is being considered for a water–supply source, it is necessary to know how much water can be obtained. Assessment of Streamflow Relationship Models of Selected Rivers in Southern Nigeria facilitates informed water management decision making process and policies for productive and accountable water management in the region.

As a guide in the procedure for deriving streamflow models, a review of literatures in related topics was carried out. Seven rivers in the Southern Nigeria were selected for the study. Streamflow data were collected from Federal Ministry of Water Resources, Anambra-Imo River Basin Development Authority and Benin-Owena River Basin River Basins Development Authority. Statistical method of least squares (regression analyses) was used to develop streamflow mathematical models (Power, Polynomial models, and ANOVA model for regression). The models were tested and it was discovered that they represent the actual field or measured data (observed data) very well. Several model performance measures such as Nash–Sutcliffe model efficiency, mean absolute relative error, percentage bias, root mean square error or standard error of estimateand mean of residue or mean absolute error were used for model evaluation and the results were very satisfactory.

To show the importance of this work, the size / capacity of water storage reservoir was designed for Ikpoba River at Benin City, Edo State. Hydropower electricity generations were designed for Cross River at Afikpo North L.G.A. in Ebonyi State and River Niger at Onitsha in Anambra State.

5.2 Recommendations

Based on the results of this research, the following recommendations are made:

i. The Federal and State Ministries of Agriculture and Water Resources, River Basin Development Authorities, Research Institutes, Universities, Polytechnics and other related organizations in Nigeria should make available long periods of streamflow records (50 - 100 years) which will assist in reliable/precise and more accurate model development for solving the country's water resources problems.

ii. This study which was limited to selected rivers in the Southern Nigeria should be extended to other rivers in the country having similar characteristics with the rivers studied. This will help in water resources planning and management in Nigeria.

iii. Government should sponsor continuous stream gauging activities that will keep current data updated, for the primary reason of keeping up with environmental changes, such as the present day global warming effect that has caused overflow of rivers banks, flooding of cities/regions and imbalance of supply and demand of water.

iv. Old hydrological stations installed by the River Basins should be properly equipped and made functional, while new ones should be installed to enhance collection of streamflow data and other records for research and planning.

4.3 Contributions to Knowledge

The contributions are summarized as follows:

Three new models for streamflow prediction in the seven selected rivers were developed using annual maximum streamflow measurements as part of its contributions to knowledge. In addition, other contributions include:

i. Derivation of power–law equation, polynomial equation and ANOVA linear regression equation for streamflow modelling using annual maximum streamflow measurements.
ii. This work has succeeded in providing the Southern Nigeria with set of well-defined models as shown in Table 4.145 [summary of streamflow (power-law) models], Table 4.146 [summary of streamflow (polynomial) models] and Table 4.147 [summary of streamflow (ANOVA) models] for the seven selected rivers.
iii. These models have provided the lacking streamflow information required by water resources engineers for effective water resources planning, control, and management in the Southern Nigeria as demonstrated in the applications of the streamflow models.
iv. This work gives an understanding of the hydrology of Southern Nigeria which is paramount in the development of the region. Development will not be feasible without an in-depth knowledge of the location, direction and other properties of

flow of rivers through an articulated inventory. To achieve this development, there is need for a clear understanding of the region’s hydrological processes as it relates water distribution and movement over time. The availability of water from various sources is estimated by a good knowledge of hydrology of the places and the knowledge of hydrology of Southern Nigeria is one of the key ingredients in decision-making processes where water is involved in the region (Southern Nigeria).

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APPENDIX A

Extension of Streamflow Record of Imo River at Umuopara Gauging Station using Linear Regression Analysis

The annual maximum streamflow measurements including their transformed logarithmic values of Imo river at Umuopara streamflow gauging station is shown in Table 4.154.

Table 4.154: Transformed logarithmic of streamflow measurements of Imo River at Umuopara gauging station

S/n	Year	Annual Maximum Stage (m)	Log Annual Maximum Stage	Annual Maximum Discharge (m^3/s)	Log Annual Maximum Discharge
1	1978	5.66	0.7528	270.00	2.4314
2	1979	4.54	0.6571	158.40	2.1998
3	1980	3.95	0.5966	118.00	2.0719
4	1983	5.53	0.7427	223.00	2.3483
5	1984	3.22	0.5079	126.20	2..1011
6	1985	4.83	0.6839	194.40	2.2887
7	1986	3.00	0.4771	115.00	2.0607
8	1987	5.19	0.7152	223.20	2.3487
9	1988	1.32	0.1206	42.85	1.6320

With the aid of the computer program in linear regression (EXCEL), using Table 4.154 as input resulted in the linear equations shown in Figure 4.75

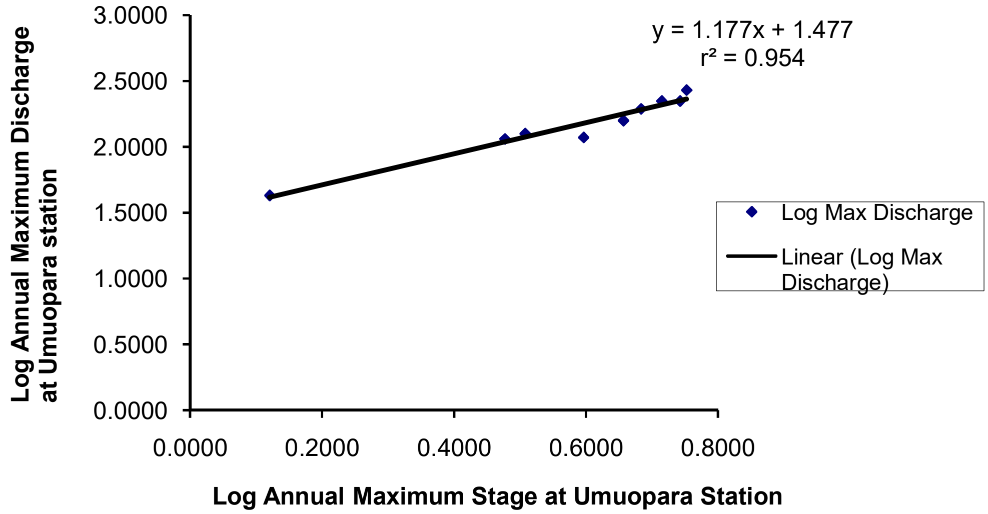

Figure 4.75: Plot of the transformed logarithmic of streamflow measurements of Imo River at Umuoparagauging station

The relation between the stage (h) and the corresponding discharge (Q) can be expressed as:

$$Q = k\,(h)^{b}$$

The above exponential function is transformed to a straight line by taking logarithms of the variables:

$$\underbrace{\text{Log } Q}_{y} = \underbrace{\text{Log } k}_{a} + \underbrace{b \ \text{Log}}_{b \ \ x}$$

The plot of log Q versus log h on a linear graph paper gives a straight line as shown in Figure 4.62.

The equation of the straight line fit for the annual maximum discharge and annual maximum stage curve Figure 4.62 is:

$$y = 1.177x + 1.477: \quad r^2 = 0.954.$$

This derived equation is used to calculate annual maximum stage values in 1981 and 1982. Since the equation of the straight line fit is:

$$y = 1.177x + 1.477$$

which implies that $\log Q = 1.177 \log h + 1.477$

In 1981: $\text{Log } 258.2 = 1.177\log h + 1.477$

$$2.412 = 1.177\log h + 1.477$$

$$2.412 - 1.477 = 1.177\log h$$

$$0.935 = 1.177\log h$$

$$\log h = \frac{0.935}{1.177} = 0.794$$

H = Antilog of 0.794 =6.23m

Stage (h) = 6.23m

In 1982: $\text{Log } 187.50 = 1.177\log h + 1.477$

$$2.273 = 1.177\log h + 1.477$$

$$2.273 - 1.477 = 1.177\log h$$

$$0.796 = 1.177\log h$$

$$\log h = \frac{0.796}{1.177} = 0.676$$

h=Antilog of 0.676 =4.75m

Stage (h) = 4.75m

In 1982: $\text{Log } Q = 0.465 \log 4.75 + 1.301$

$$\text{Log Q} = 0.315 + 1.301$$

$$\text{Log Q} = 1.616$$

$$Q = \text{Antilog of } 1.616 = 41.27m^3/s$$

Extension of Streamflow Record of Imo River at Ndimoko Gauging Station using Linear Regression Analysis

Table 4.155 shows the annual maximum streamflow measurements including the transformed logarithmic values of Imo River at Ndimoko streamflow gauging station.

Table 4.155: Transformed logarithmic of streamflow measurements of Imo River at Ndimoko streamflow gauging station

S/n	Year	Annual Maximum Stage (m)	Log Annual Maximum Stage	Annual Maximum Discharge (m^3/s)	Log Annual Maximum Discharge
1	1978	3.02	0.4800	25.00	1.3979
2	1979	2.59	0.4133	18.20	1.2601
3	1980	3.30	0.5185	27.50	1.4393
4	1981	3.14	0.4969	24.40	1.3874
5	1982	3.16	0.4997	22.20	1.3464
6	1983	3.14	0.4969	24.50	1.3892
7	1984	3.00	0.4771		
8	1985	2.95	0.4698		
9	1986	2.79	0.4456		
10	1987	3.56	0.5514		
11	1988	3.52	0.5465		

With the aid of the computer program in linear regression (EXCEL), using Table 4.155 as input resulted in the linear equation shown in Figure 4.76.

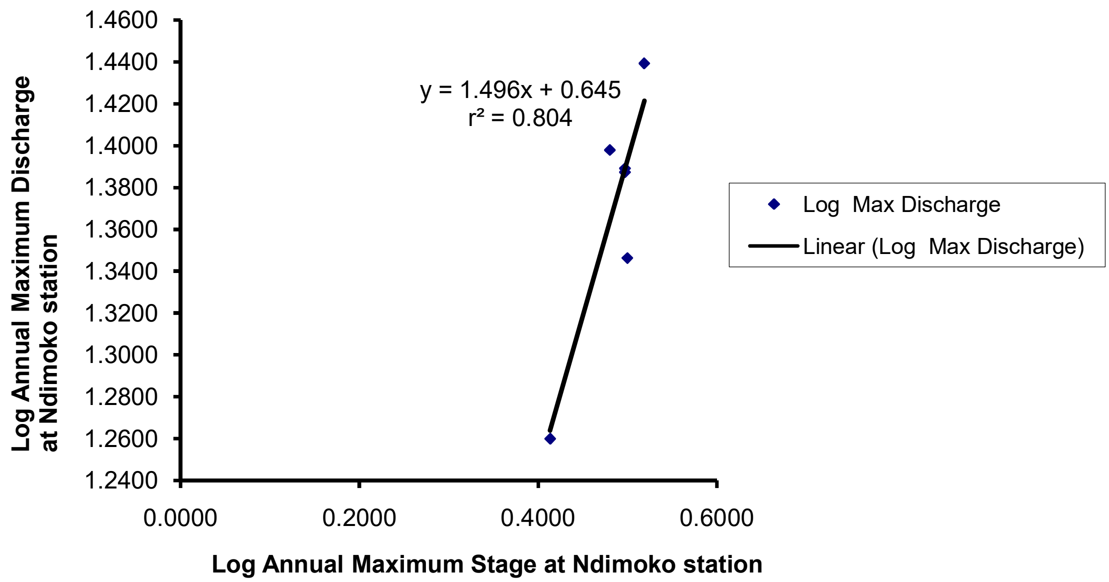

Figure 4.76: Plot of the transformed logarithmic of streamflow measurements of Imo River at Ndimoko streamflow gauging station

The equation of the straight line fit is: $y = 1.496\,x + 0.645$: $r^2 = 0.804$.

This derived equation is used to calculate annual maximum discharge values in 1984 to 1988. Since the equation of the straight line fit is:

$y = 1.496\,x + 0.645$ which implies that $\log Q = 1.496 \log h + 0.645$

In 1984: $\text{Log } Q = 1.496 \log 3.0 + 0.645$

$\text{Log } Q = 0.714 + 0.645$

$\text{Log } Q = 1.359$

Q = Antilog of 1.359 = 22.84m^3/s

In 1985: Log Q = 1.496 log 2.95 + 0.645

Log Q = 0.703 + 0.645

Log Q = 1.348

Q = Antilog of 1.348 = 22.28m^3/s

In 1986: Log Q = 1.496 log 2.79 + 0.645

Log Q = 0.667+ 0.645

Log Q = 1.312

Q = Antilog of 1.312 = 20.49m^3/s

In 1987: Log Q = 1.496 log 3.56 + 0.645

Log Q = 0.825 + 0.645

Log Q = 1.470

Q = Antilog of 1.470 = 29.51m^3/s

In 1988: Log Q = 1.496 log 3.52 + 0.645

Log Q = 0.818 + 0.645

Log Q = 1.463

Q = Antilog of 1.463 = 29.02m^3/s

APPENDIX B

Samples of the Data collected from the Federal Ministry of Water Resources and River Basins Development Authorities