USE OF LIMITED HYDROLOGICAL DATA AND MATHEMATICAL PARAMETERS FOR CATCHMENT REGIONALIZATION OF OGUN DRAINAGE BASIN, SOUTHWEST, NIGERIA

BY

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JULY, 2018

DECLARATION

I hereby declare that this dissertation was written by me and is a correct record of my own research work. It has not been presented in any previous publication for any degree of this or any other University. All citations and sources of information are clearly acknowledged by means of references.

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CERTIFICATION

We certify that this dissertation entitled ‘‘Use of Limited Hydrological Data and Mathematical Parameters for Catchment Regionalization of Ogun Drainage Basin, Southwest State, Nigeria.’’ is the outcome of research carried out by L.A. Abegunde in the Hydrology and Climate Change Programme, Centre for Excellence in Agricultural Development and Sustainable Environment, Federal University of Agriculture, Abeokuta.

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ABSTRACT

Measurements of streamflow for long term are important for prediction, forecasting and planning of water resources for sustainable use. Scarcity and inadequacy of data needed for efficient management of water resources especially in African countries like Nigeria and also the change in climate and its variability which made flooding a recurrent decimal in the catchment of Ogun basin have necessitated the need to derive rating equations of the power type ($Q= c (h_w + a)^b$) and parabola type ($Q = c_2 (h_w + a)^2 + c_1 (h_w + a)^b + c_0$) from five gauged stations for regionalization. Stage and discharge of three hundred and sixty five days with the available rating tables for Ofiki, Oyo/Iseyin, Sepeteri, Ilaji-ile and Abeokuta stations were collected for year 2009 from Ogun-Oshun river basin development authority. Regression model was used to calculate the coefficients c, c_o, c_1, c_2, datum correction a, exponent b of the rating equations and coefficients of determination, R^2 for daily stage (h_w), daily discharge (Q) and stage-discharge for all stations. The basin maximum elevation (maxele), minimum elevation (minele), length, catchment area (CA) and slope were determined by delineating the map of the basin. Correlation matrix was used to establish relationship between model parameter (Q) and physical catchment characteristics (PCCs) for fourteen combinations and dependency was indicated for five combinations of model parameter. Piecewise regression by forward entry method was used to improve dependency given three combinations of model parameter ($Q = 10^{-8.510}(CA)^{1.343}(maxele)^{1.872}(minele)^{0.424}$) at coefficient of determination (R^2) of 99.98%. The models performance was evaluated by relative volume error (%RVE) as a measure of model adequacy. The exponent b and R^2 were used to regionalise the stations into three zones with range of b (Z_E) of 0 – 1.50 as A(Sepeteri), 1.51 – 3.01 as B(Ofiki, Oyo/Iseyin and Ilaji-ile) and 3.02 – 4.52 as C (Abeokuta) and R^2 in the range (Z_R) of 10 – 40% as I (Ofiki and Abeokuta), 41 – 70% as II (Oyo/Iseyin) and 71 – 100% as III (Sepeteri and Ilaji-ile). The zones (Z_E and Z_R) were combined to form three unitary zones A_u (IIIA, Sepeteri), B_u (IB, Ofiki, IIB, Oyo/Iseyin, and IIIB, Ilaji-ile) and C_u(IC, Abeokuta). The stations maximum discharge was calculated from the derived rating equations (power and parabola types) and the equation with three PCCs ($Q = 10^{-8.510}(CA)^{1.343}(maxele)^{1.872}(minele)^{0.424}$). The power type gave satisfactory results for four out of five stations with %RVE of -2.23, -9.00, -3.60 and -7.70 for Ofiki, Sepeteri, Oyo/Iseyin and Ilaji-ile respectively and unsatisfactory result for Abeokuta with %RVE of -22.00. The parabola type also gave satisfactory results for Ofiki, Sepeteri, Oyo/Iseyin and Abeokuta with %RVE of 0.76, -3.10, 2.60 and -4.45 respectively and unsatisfactory result of 24.56 %RVE for Ilaji-ile. The equation with three PCCs gave satisfactory results for all stations with %RVE of -0.54, -0.29, -0.23, 0.44 and 0.54 for Ofiki, Sepeteri, Oyo/Iseyin, Ilaji-ile and Abeokuta respectively. The equation with three PCCs outperformed the derived rating equations.

DEDICATION

This Dissertation is dedicated to all who have lost properties and loved ones to extreme weather conditions.

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CHAPTER ONE

1.0 INTRODUCTION

Hydrological data include hydrometric, groundwater and climatological data which provides a backbone of any type of progress in understanding and modelling of hydrological processes within a river basin (Hrachowitz *et al.,* 2013). They give information on the spatial and temporal distribution of water in its various state of occurrence in hydrological cycle. Examples of hydrometric data are streamflow and river level data. Streamflow which is synonymous with river flow is the rate at which water flows through a given river cross-section and it's usually expressed in m^3/s or l/s units. There exist various methods of measuring discharge depending on the condition at a particular site (WMO, 2008) and these methods generally involve the measurement of water level at a gauging station and subsequent application of stage-discharge relationship to derive the flow estimate.

Groundwater data is another type of hydrological data that is essential in catchment hydrology and it includes groundwater level which describes the variation in hydraulic head within an aquifer and can be measured with observation wells, piezometers, boreholes or hand-dug wells and discharge data. Groundwater discharge into streams, lakes or rivers and is measured the same way as streamflow.

Climatological data include measurements of precipitation, evaporation, temperature, radiation, wind, humidity and synoptic data which describe weather features like amount of cloud, high and low pressure areas and atmospheric circulation patterns and indices. Precipitation and evaporation data are very important in calculation of monthly dryness index (climate descriptor) which is the ratio of annual potential evapotranspiration (PET) to mean annual precipitation (MAP) (Milly, 1994).

Models are simplified systems that represent real systems and a parameter is a control device in the model. Hydrological models refer to all models describing hydrological cycle. Hydrological models can range from sand-filled boxes to complicated computer program. The first type is called scale models. In these the real system is reproduced on a reduced scale. The second type, where a number of equations stand for the real system, is termed mathematical (or symbolic) model.

Applications are known for a number of hydrologic models such as the IHACRES (Identification of unit Hydrographs And Components flows from Rainfall, Evaporation and Streamflow data), a conceptual model by Jakeman *et al.*, 1990; Sefton and Howarth, 1998; Kokkonen *et al.*, 2003, the HBV (Hydrologiska Byrans Vattenbalansavdelning) model by Bergstrom (1995); Seibert 1999; Merz and Bloschl 2004; Parajka *et al.*, 2007; Engeland and Hisdal, 2009 , the GR4J (Genie Rural a 4 parametres Journalie) model (Oudin *et al*., 2008) and TOPMODEL, topography based model (Ao *et al.*, 2006), and data driven models (Cutore *et al.*, 2007).

Mathematical models of catchments describe or incorporate aspects of the catchment structure. They provide a mechanism to generate relationships between catchment structure and response behavior. Development of these mathematical models can be based on different approaches, but catchment-hydrologic modeling is mainly based on an a priori defintion of the model structure (equations) and a subsequent estimation of the model parameters either a priori using observable landscape characteristics or through a model calibration process (Sivapalan, 2003).

The basic idea is to develop different working hypotheses that can be implemented as mathematical models of the catchment structure and find the most parsimonious one that can preserve basic response behaviour of the real system has been tested in a series of articles using a hierarchical framework in which the minimum appropriate model complexity was found for behavioural characteristics at different time-scales. The parameters of the appropriate model structure should thus relate to the dominant structural characteristics of the catchment controlling its response (Sivapalan, 2005; Son and Sivapalan, 2007).

Regardless of what approach has been chosen to arrive at a suitable model structure, mathematical models have the advantage that they provide a direct link between structure and response behaviour, and can provide one approach to the development of a viable hydrologic classification system (Wale *et al.*, 2009).

1.1 Availability of quality and quantity data

Availability of quality and quantity data is a traditional problem in hydrology and hinders the quest to advance research in this field. Extreme weather events and change in landscape have caused damages to lives and properties in recent years. Research and development have also been focused on these global phenomena. In the United States of America, the Mississippi River caused damages put at several millions of dollars when it over flew its banks, flooding some cities, towns, farmlands and major industrial installations over a distance of about 250 km and ravaging Iowa before it heaped downstream (Aderogba, 2012). The situation is worrisome in Nigeria. Current upstream and downstream flooding from the nation's major rivers and reservoirs are not consequence of climate change alone but also consequences of reservoir capacity and river channel carrying capacity losses (NAHS, 2015).

To facilitate efficient and informed management of water resources, data on flow characteristics of river systems is a prerequisite, since water resources planning and management depends on the availability of flow data. The systematic measurement of flow characteristics of rivers in a watershed is used to obtain flow statistics for each station which is extremely important for the design of engineering works, evaluation, planning and management of the water resources. However, high implementation, operation and maintenance costs of hydrological networks make it difficult for developing countries like Nigeria to have a comprehensive network in place.

This is compounded by the decline in the technical and human capacities in hydrology as noted by the reduction in the number of meteorological stations in Africa during the past thirty years (Chikodzi, 2013). Even if funds and human resources were to be made available for the extension of hydrological networks, it would take between ten to thirty years before adequate data is collected. Adequate distribution of hydrological stations will also be difficult to establish because some of the sites are remote and inaccessible. This situation makes it imperative to develop methods for predicting flow characteristics at ungauged stations. Therefore, for many practical problems extension of existing data is an important task in hydrology.

1.2 Catchment regionalization

A catchment can be defined as the drainage area that contributes water to a particular point along a channel network based on its surface topography. It also defined as an indissoluble bond of landscape, geology, climate as well as human factors, which are generally regarded as physiographic and climatic attributes or descriptors (He *et al.*, 2011). There are other important definitions of catchment, Wagener *et al.* (2010) defines it as a landscale element (at various scales) that integrates all aspects of hydrologic cycle within a defined area that can be studied, quantified and acted upon. Catchments are typically open systems with respect to both input and output of fluxes of water and other quantities (Dooge, 2003). According to Sivapalan (2005), the catchment is a self-organising system whose form, drainage network, ground and channel slopes, channel hydraulic geometrics, soils and vegetation are all a result of adaptive ecological, geomorphic and land forming processes.

Regionalisation is a process of identifying a homogenous region that can be either joint or disjoint and within which catchments have the least variance among themselves. Regionalization of model parameters by developing appropriate functional relationship between the parameters and basin characteristics is one of the potential approaches to employ hydrological models in ungauged basins (Athira *et al*., 2015). Regional analysis therefore consists of analyzing the hydrometric records of all gauged sites in a region, summarizing each record by one or two statistical values calculated from it and then finding relationship between these statistic values and numerically expressed basin characteristics (WaterNet, 2008). The catchments in such region can represent each other due to their similarity. Therefore regionalisation is often synonymously used as catchment classification though the former perhaps place more emphasis on the application side while the later is more about the theoretical basis and organising principle. Classification of catchment sets out an important foundation for regionalisation (He *et al*., 2011).

Catchments regionalisation therefore is the transfer of information of gauged catchment to ungauged catchment which is achieved by extrapolating the model parameters from gauged to ungauged sites that belong to hydrologically homogeneous regions (Sivapalan, 2005).

Research on regionalisation in hydrology has been constantly advancing due to the need for prediction of streamflow in ungauged catchments. Research focus on prediction in ungauged catchments was formally endorsed and set out by the PUB (Prediction in Ungauged Basins) Science and Implementation Plan within the IAHS (International Association of Hydrological Sciences) Bureau in 2003 (Sivapalan *et al*., 2003). Regionalisation techniques have been designed to enable estimates of statistical distribution parameters of streamflow characteristics, e.g. flood frequency distribution, low flow frequency distribution; flow duration curves etc., or rainfall-runoff model parameters to simulate continuous streamflow at ungauged catchments (Dave *et al*., 2010).

In literature, several regionalisation approaches are proposed but general conclusions on effectiveness cannot be drawn. The two probably most popular approaches are based on principles of similarity by spatial proximity and on similarity of catchment characteristics. The first approach is based on the rationale that catchments of close proximity have a similar flow regime since climatic, topographic and physiographic settings are comparable. The second approach is based on the assumption that optimised parameters representing certain catchment characteristics are also applicable in other catchments with similar characteristics (Alexander and Anthony, 2007). In this approach, the regionalisation of model parameters can be done using regression-type approaches and using other (physical) similarity approaches that transpose the parameter set of similar catchments (Oudin *et al*., 2008). In practice, collection and compilation of catchment descriptors involve, to various extents, upscaling or downscaling procedures because of the stunning degree of heterogeneity and variability in both space and time (Bloschl and Sivapalan, 1995). The similarity concept there is considered in the space of catchment descriptors that have causative links with hydrological behaviour and make regionalisation hydrologically meaningful (Gottschalk, 1985). Therefore, a proper understanding of the flow regime of rivers is essential for channel design and especially the estimation of flood discharges such structures could tolerate (Awokola and Martins, 2001).

1.3 Statement of the problem

High implementation, operation and maintenance costs of hydrological networks make it difficult for developing countries in Africa like Nigeria to have a comprehensive network in place (Chikodzi, 2013) and also inadequate funding and inconsistency in government policies that have hindered gathering of quality and quantity data within the catchment region of Ogun-Oshun river basin development authority therefore, this study is aimed to develop methods for predicting flow characteristics at ungauged stations that may be used for prediction, forecasting and efficient management of water resources in Ogun basins that are hydrologically similar for which inadequate or no stream flow data exist.

1.4 Justification for the study

Flooding of Ogun river and the release of water from Oyan Dam, its major tributary has become a recurrent decimal (2009, 2010, 2011, 2012: www.Nigerianbestforum.com) and the existing stream gauging network fall short of the originally proposed minimum density of one station for an area of 500sq.km (Tahal Consultants, 1982) which has led to shortage of quality hydrological data. Therefore, there is a need to develop methods to get data for prediction, forecasting and planning of water resources in the catchment.

1.5 The general objective

To develop a regionalization classification, based on analytically determined hydrometric parameters

1.5.1 The specific objectives

- To calculate monthly maximum discharge for each station using maximum stage from the appropriate derived equation
- To analyse the trend in daily stage and daily streamflow using polynomial regression
- To evaluate models (developed equations) performance

1.6 Study limitations

The limitations of this research work include;

- Missing data and unavailability of data were serious limiting factor to this research and this made the numbers of stations considered smaller.
- Travelling to the locations of the gauging stations was risky because most of the stations were remotely located
- The data collected from Ogun-Oshun River Basin Development Authority {OORBDA) mostly existed as raw stage readings for which rating tables were not provided in some cases.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

The availability of hydrological measurement data is restricted in both temporal and spatial respects. Therefore, for many practical problems extension of existing data is an important task in hydrology**.** Research on regionalisation in hydrology has been constantly advancing due to the need for prediction of streamflow in ungauged catchments. There are two types of studies that use regionalisation techniques for ungauged catchments. One type estimates parameters of streamflow statistics, flood quartiles in most cases. The other type estimates parameters of a rainfall-runoff model for simulating continuous streamflow or estimates continuous streamflow without using a model. Almost all methods applied to the latter can be applied to the former. Regardless of the type of hydrological model used to derive rainfall and runoff relationships, estimation of model parameters and prediction in ungauged catchments are particularly difficult and are always associated with considerable uncertainties. Estimation of streamflow statistics in ungauged catchments is also an issue that is always encountered when engineering design is needed for hydraulic structures. Research focus on prediction in ungauged catchments was formally endorsed and set out by the PUB (Prediction in Ungauged Basins) Science and Implementation Plan within the IAHS (International Association of Hydrological Sciences) Bureau in 2003 (Sivapalan *et al*.,2003). Regionalisation techniques have been designed to enable estimates of statistical distribution parameters of streamflow characteristics, e.g. flood frequency distribution, low flow frequency distribution, flow duration curves etc., or rainfall-runoff model parameters to simulate continuous streamflow at ungauged catchments.

2.2 Rainfall-run-off model

A run-off model is a mathematical model describing the rainfall-runoff relations of a rainfall catchment area, drainage basin or watershed (Wikipedia, 2016). Rainfall-runoff models are developed and applied to test theories and to improve our understanding of hydrological processes. Rainfall-runoff models hold parameters that cannot be measured either because they represent several physical processes or because the parameters in the models cannot be measured at the same scale with which they are applied. These parameters therefore need to be determined by means of calibration. All calibration methods need stream flow data to compare the predictions with. It is now recognized that the stream flow data availability is not improving world-wide (Takeuchi, 2002). United Kingdom with the network of 1,400 flow gauging stations is extensive but still insufficient to cover the entire network of rivers (Sefton and Howarth, 1998). Rainfall-runoff modelling approaches are various and there is a plethora of models. Beven (2001) mentioned his attempt to draw an exhaustive list of rainfall-runoff models nearly twenty five years ago and his abandoning of the task when he reached 100 models (Marechal, 2004). Therefore it is very difficult if not impossible to have a classification system, but the most commonly used system classifies the models as metric, physically-based and conceptual (Beck, 1960).

Metric models treat the catchment as a single unit and relate its output (the flow Q (t)) to its input (the rainfall I (t)) where t is the time, through an operator Φ and are usually lumped. It is mainly empirical approach for the fact that a great amount of information is held in measured data that the model can from extract the measured data to conduct predictions.

Physically-based models should be a true representation of the physical processes. They are developed following the bottom-up approach (Sivapalan *et al*., 2003) or appropriate spatial and temporal scale to address the needs (Sivapalan *et al*., 2003) and are based on a priori perception of the importance of the various physical processes and how they interact. Beven (2001) argued that it is not currently possible to build this true representation and that empiricism has to be introduced. He mentioned these models as almost deductive. It has been reported in the literature by Perrin *et al*., (2001) that due to their large number of parameters to calibrate, physically-based models were overparameterised.

Conceptual models are lumped or semi-distributed. Semi-distributed models recognise that in a catchment, areas can have similar hydrological behaviour and react in the same way. The aim is thus to define these areas and to group them together to simplify the computation. Conceptual models are capable means of narrowing down future states of hydrological variables for a given area. Simple conceptual models are useful in the generation of synthetic sequences of hydrological data for facility design, for water resources planning and management, and for use in forecasting (Xu, 2009). It is within the realms of prediction that rainfall-runoff models, capable of simulating flow in areas that are ungauged, are best suited (Alexander and Anthony, 2007). Rainfall-runoff models have been used very successfully in estimating runoff at small and large catchments under different climate regimes. Usually, rainfall-runoff models use rainfall and other climate data (e.g., temperature and/or potential evaporation) to estimate runoff (Marechal, 2004).

2.3 Flood frequency analysis

Flood frequency analysis indicates the catchment characteristics, water availability and possible extreme hydrological conditions like floods and droughts at various locations of any river system(Guru and Jha, 2015) while low-flow statistics indicate the probable availability of water in streams during times when conflicts between water supply and demand are most likely to arise. One of the documents that support the use of flood frequency analysis and provide guidelines for it in Bulletin 17B; 'Guidelines for determining flood flow frequency analysis' (USGS, 1982) which promote a consistent approach to flood frequency estimation in United States. A principal feature of Bulletin 17B is the recommendation of log-pearson type III as standard statistical distribution for fitting flood data series. Odunuga and Raji (2014) used Gumbel probability distribution method and tested the method with Log Pearson Type III to ascertain the best fitting statistical measure for hydrological fluxes within the lower Ogun river basin using Chi Square. A limitation of the log-Pearson Type III distribution is that the number of year of observation (N) must be at least ten (Ries *et al.*, 1998).

In literature several regionalisation approaches are proposed but general conclusions on effectiveness cannot be drawn. The two probably most popular approaches are based on principles of similarity by spatial proximity and on similarity of catchment characteristics. The first approach is based on the rationale that catchments of close proximity have a similar flow regime since climatic, topographic and physiographic settings are comparable. The second approach is based on the assumption that optimised parameters representing certain catchment characteristics are also applicable in other catchments with similar characteristics. In this approach, the regionalisation of model parameters can be done using regression-type approaches and using other (physical) similarity approaches that transpose the parameter set of similar catchments (Oudin *et al.*, 2008). The regression-type approach is most widely tested in regionalisation studies and is also selected for this study. Besides this, regionalisation by use of default parameter set is tested as an alternative to spatial proximity approaches. The approach is commonly referred to as the classical approach of regionalisation and has applications in various climatic and physiographic settings.

Various studies report on the effectiveness of the classical approach, but in Merz and Bloschl (2004) and Oudin *et al.* (2008) the approach is out performed by the spatial proximity approach. Zhang and Chiew (2009) found that the spatial proximity approach performs slightly better than the physical similarity approach, while in Wale *et al.* (2009) the opposite was found. Sefton and Howarth (1998) used sixty catchments in England and Wales and defined relationships with correlation coefficients varying between 0.37 and 0.80, where the selection of the relationships was based on statistical significance and hydrologic plausibility. Relationships were satisfactorily validated at two additional catchments and it was stated that relationships were robust enough to produce daily flows. For thirteen sub-catchments in the Coweeta catchment in North Carolina in the USA, Kokkonen *et al.* (2003) described that encouraging results were achieved in reconstructing daily flows. It is reported that elevation, slope and mean over land flow distance are the most dominating characteristics that affect the hydrologic behaviour in these sub-catchments. In the same work it is stated that the application of multiple regression analysis does not account for model parameter dependencies and a high significance of regression does not guarantee a set of parameters to have good predictive power. Seibert (1999) used three catchment characteristics (i.e. Catchment area, forest and lake percentages) of eleven Swedish catchments to relate to HBV (Hydrologiska Byrans Vattenbalansavdelning) model parameters. Relationships were found for six out of thirteen model parameters, whereas the physical premise of some of these relationships only weakly relate to the physical basis of the hydrologic model.

Awokola *et al.* (2013) investigated the trends of variations in daily stage and discharge of seven gauging stations located in the 9,900km^2 Osun Drainage Basin (South West, Nigeria). Linear regression models for all stations show the expected strong positive association of stage and discharge. In Nigeria and other developing countries, there are problems of data inadequacy- frequent data gaps and non-existence of data at development sites and these issues create serious design and project management problems (Sonuga, 1990). When no flow records are available anywhere in the catchment, in many aspects, even a site which has only several years of record must be evaluated as if it were an ungauged catchment, because the information usually requires augmentation. Even when models are constructed, they will require additional site specific parameters to be defined for each application site (Beven, 2000; Awokola, 2001). The derivation of relationships between hydrological variables is of great importance for the transfer of information from the few-gauged rivers to the many other rivers with hydrologically similar catchments for which no stream flow data exist. There is need for an approach to ascertain the actual changes in hydrological response of a particular catchment within a drainage basin, which can reveal land transformations and interactions that occurred in the past.

The ‘region of influence’ (ROI) approach adopted by Burn (1990) is limited to measures which do not rely on actual flow data.

2.4 Prediction in ungauged basins

Prediction is concerned with estimating the frequency of occurrence, in the future, of events of any given magnitude, without reference to the times at which they would occur. Forecasting is concerned with what will be happening at a stated point of time in the future, such as discharge tomorrow, or runoff in the coming month. Prediction in ungauged basins (PUB) is concerned with both prediction and forecasting.

Drainage basin is defined as the area of land where surface water from precipitation or glaciers drain to a body of water such as stream, river or lake and finally converges to the outlet which is at the lowest elevation of the basins.

A basin is said to be ungauged if there is no record of a variable of interest, or has not been measured at a required resolution or for the length of period required for model calibration and other purposes. There are also other categories of ungauged basins e.g. sites on a river which is gauged different locations upstream or downstream or gauged on some tributaries rather than the main river. Even sites which have only few years of record or have half hazard records has to be dealt with in some aspects, as if it were an ungauged basin because information contained in it has to be augmented (WaterNet, 2008). Prediction in ungauged basin (PUB) was launched in 2003 by International Association of Hydrological Science (IAHS). A decade (2003-2012) was dedicated by the body to resolve the challenging issues of limited or unavailability of hydrological data in ungauged basins. Sivapalan *et al.*, 2003 defines PUB as the prediction or forecasting of hydrological responses of the ungauged or poorly gauged basins and its associated uncertainty.

2.5 Catchment characteristics

Hydrological characteristics of a catchment are broadly classified into physiographic (e.g. catchment area, slope, elevation, land use and land cover), soil and climatic (e.g. rainfall, evaporation, temperature). Catchment attributes used for regionalization purposes should characterize the factors that drive the hydrological response of a catchment and should also be derivable from existing and readily available data sources, such as topographical maps (Kokkonen *et al.*, 2003). According to Mwakalila (2003), methods which are used to quantify the catchment attributes usually include topographical indices, geology and soil index, climate indices, and vegetation cover indices. Croke and Norton (2004) collected catchment attributes on soil covers and physiographic characteristics, since their study focused on predicting hydrologic responses to land cover changes due to agricultural intensification in gauged and ungauged basins.

The use of remotely sensed data with the integration of Geographic Information System technology provides a strong and analytical framework for assessing land use/land cover inventory, annual rate of change and evaluating the emerging environmental response at the periphery of a fast growing city. The importance of geospatial information to be generated from such an endeavour cannot be over emphasized as Adeniyi and Omojola (1999) submitted that information based on urban land use changes can shed more light on the growth process, since physical changes in the distribution of urban land uses are direct indications of social and economic changes. Awoniran (2012) observed that land use changes occur at the periphery of large urban concentration where urbanization and industrialization pressures frequently result in loss of prime agricultural lands and tree cover. Also, Oyinloye *et al. (*2004) observed that land use and land cover are dynamic phenomena that are characterized by seasonal changes, particularly in south-western Nigeria where farming is both intensive and extensive. These often result in unprecedented changes in the hydrological balance of the area, increase in the risk of floods and landslides, air and water pollution among others.

In general, the most widely used attributes by researchers in continuous streamflow regionalisation are catchment area, elevation, slope of basins or channels, and mean annual or daily rainfall and temperature.

2.6 Methods of catchment regionalisation

2.6.1 Spatial proximity method of regionalisation: This is also called geographical distance-based, it is the most known and clear basis to classify catchments though geographical neighbouring catchments do not necessarily share similar hydrological responses and behaviour (He *et al.*, 2005; Merz and Bloschl, 2004; Oudin *et al.*, 2008, 2010; Parajka *et al.*, 2005; Seibert, 1999). Oudin, 2008 concluded that physical and climatic characteristics are relatively homogeneous within a region, so that neighbouring catchment should behave similarly. Bloschl, (2005) also reported that catchments that are close in a geographical space is assumed to behave similarly based on the premise that hydrological response is likely to vary gradually and smoothly in space and hence spatial proximity is a reasonable indicator for catchment similarity. Merz and Bloschl (2004) transfer the average value of model parameters from the immediate upstream and down- stream neighbouring catchments in Austria and found this approach outperforms kriging or regression method. Randrianasolo *et al.* (2011) use model parameters transferred from neighbouring catchments for ensemble forecast at ungauged catchments in France and show it can provide reasonably good forecasts at the target catchments neighbouring catchments as direct discharge donors for updating forecasts in addition to the use of their model parameters, but find rather poor performance. Merz and Bloschl (2004) found that the regressions between model parameters and catchment attributes performed not as well as other methods but it was not clear whether this was due to the catchment attributes being poor hydrological indicators at the regional scale or due to the problems with the linearity assumption of the multiple linear regressions used. Studies by various authors (Yadav *et al.,* 2007; Zhang *et al*., 2008; Bulygina *et al*., 2009; Winsemius *et al*., 2008; Palanisamy *et al*., 2014) used regressive relationship between streamflow characteristics and physical catchment characteristics as proposed by Chiang *et al.* 2002 (a & b). Advanced remote sensing techniques were also used for regionalization. For instance, Sun *et al.* (2012) used satellite radar altimetric observations of river water level at basin outlet to calibrate the hydrologic models in ungauged basins.

2.6.2 Physical similarity method of regionalisation: The physical similarity method consists of transferring hydrological information from gauged (Donor) catchments that are similar to the ungauged catchments in terms of catchment descriptors (Oudin *et al*., 2008) i.e. the physiographic and climatic attributes. Target catchments refer to poorly gauged with some past hydrometric data, completely ungauged or pseudo- ungauged regarded as ungauged for research purpose catchments that require information to be transferred from donor catchments. Donor catchments are gauged catchments identified to be similar to target catchments. The similarity concept here is considered in the space of catchment descriptors that have causative links with hydrological behaviour and make regionalisation hydrologically meaningful (He *et al*., 2011). If the donor catchment has sufficient physical similarity to the target catchment, the set of hydrometric model parameters can be transposed (McIntyre *et al*., 2005). Since a number of regionalisation techniques are developed based on hydrological distances in the space of physiographic and climatic descriptors, it is necessary to reflect on the subject of hydrological similarity and catchment classification. Many studies can be found in literatures that aim at defining hydrological similarities. For example, Bloschl and Sivapalan (1995) explore similarities in association with dimensional analysis from a scaling point of view. McDonnell and Woods (2004) suggest a catchment classification scheme needs to include descriptions of fluxes, storages, and response times as explanatory variables. Wagener et al. (2007) view hydrological similarity as a joint functional response based on catchment structural and climatic characteristics and a physically meaningful classification is to map them into a functional space. Hydrological similarity integrates the model based similarity measure and the measure based on physiographic-climatic descriptors. It is a promising approach because it minimizes influence of unsuitable or poorly calibrated models (possibly due to unreliable input data or model structure), and at the same time, it selects donor catchments in a way that they do not have physiographic-climatic characteristics that deviate too far from the target catchments (He *et al.,* 2011).

2.6.3 Regression method of regionalisation: This approach establishes a relationship between the optimised parameter values, catchment climate and physical attributes (Chikodzi, 2013). Parameter values are then estimated for the ungauged catchment from its attributes and the relationship identified. The regression method is also referred to as the classical approach of regionalisation and has applications in various climatic and physiographic settings. This is the most tested in regionalisation studies. Studies on the effectiveness of the regression approach by Merz and Bloschl (2004) and Oudin *et al.* (2008) reported that regression approach is outperformed by the spatial proximity approach whereas in Wale *et al.* (2009) the opposite was found. Wagener and Wheater (2006) reported on statistical regionalisation while again a number of different is physical catchment characteristics (PCCs) are selected. Results from that work with a simple conceptual model structure are satisfying although it is stated that the approach is unlikely to be robust because of the small number of catchments. Also Awokola *et al.* (2013) used daily stage, daily discharge and information from rating tables from seven gauged stations in Osun drainage basin of southwest Nigeria to develop a regionalisation protocol and found expected strong association of stage and discharge with linear regression models for all stations.

2 .7 Hydrological classification of catchment

Hydrologic classification is the process of systematically arranging streams, rivers or catchments into groups that are most similar with respect to characteristics of their flow regime. This process has frequently been applied by hydrologists seeking to extend insights gained from well-gauged regions to ungauged or sparsely gauged regions or rivers (Bates, 1994). Consequently, by dividing a study area into homogeneous groups that are considered to exhibit similar hydrologic characteristics, records may be extrapolated with more precision, and regionalisation models based on catchment characteristics may be used with greater confidence (Olden *et al.*, 2009). The grouping approaches used by Mosley (1981), Natural Environmental Research Council, 1975 and Hall and Minns (1999) encompassed geographical areas by plotting the residuals from an overall regression equation and by defining subjectively the boundaries of the homogeneous regions. Hermanovsky and Pech (2013) grouped catchments based on the seven identified conditionally optimal subset of catchment descriptors i.e. climatic (mean annual potential evaporation and ratio of mean annual evaporation to mean annual potential evaporation), soil (porosity and loam soils) and land cover (greenness factor, fraction of urban areas and fraction of grassland). Awokola *et al.* (2013) identified three hydrometric zones within Osun basin using coefficient of determination (r^2) for daily-stage and daily-discharge i.e. Zone I, Zone II and Zone III with coefficients of determination within the range of 0 - 6 %, 7 - 10.5 % and 11 - 22 % respectively. The work of Awokola *et al*, 2013 also used the values from exponential equation from daily-stage and daily-discharge for another classification into A, B, C with values in the range of 1.3 - 1.7, 2.2 - 2.3 and 4.0 - 4.7 respectively to finally form three unitary zones.

The work of Alexander Peter and Anthony Fionda (2007) classified ungauged catchments in Scotland using a Region Of Influence regionalisation method to group selected catchments by Q95 (% MF) i.e. the 95^{th} percentile of the mean flow as a percentage of mean flow. Four groups of four catchments were established, which covered Q95 (%MF) 5 - 7%, 7 - 9%, 9 - 11% and 11- 13%.

2.8 Outliers in data series

Several researchers have given various definitions of outliers in data series or sample population. According to Panagiota and Panayotis (2010) an outlier is an observation that lies an abnormal distance from other values in a random sample from a population. The most used test for detection of outlier is Grubbs-Beck test (USGS, 1982) .The problem of outliers is of major concern when dealing with extreme events. In statistics, an outlier is a single observation “far away” from the rest of the data that can lead to unrealistic conclusions, especially when considering extrapolation to high enough quantiles of the variables analyzed (Panagiota and Panayotis, 2010). The cause of a faulty observation may be a mistake, but a general assumption is made that all mistaked have been eliminated. Other possibilities include faulty equipment, inaccurate recording or transcription. So we may encounter an observation whose deviation from the mean will be greater than the expected. The practitioners and researchers are often tempted to omit the outliers from the available data samples, because this choice allows one to proceed with the statistical analysis using simpler and well-behaved distributions. The decision to reject an outlier (observation) should be based on experience and must not be made lightly. The rejection of outliers on a purely statistical basis is and remains a dangerous procedure. Its very existence may be a proof that the underlying population is, in reality, not what it was assumed to be (Laio *et al.*, 2010). The most used test for detection of outlier is Grubbs-Beck test.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The study area

The study area is the Ogun basin under Ogun-Oshun River Basins Development Authority.

3.1.1 Location: The Ogun River Basin occupies 23,700 km^2 and lies between latitudes 6°26'- 9°10'N and longitudes 2°28'E and 4°8'E (Figure 1). The Ogun River major drainage system in Southwest, Nigeria rises in the Iganran hills 503m east of Shaki in the northwestern part of Oyo state and flows southward for approximately 410km before discharging into Lagos Lagoon and a part of it about 0.2% falls within the Republic of Benin to the west. The main tributary is Oyan which rises to the west of Shaki and incorporates the Ofiki River. The Oyan dam is situated in Abeokuta North Local Government area of Ogun State which is 20 km north west of Abeokuta.

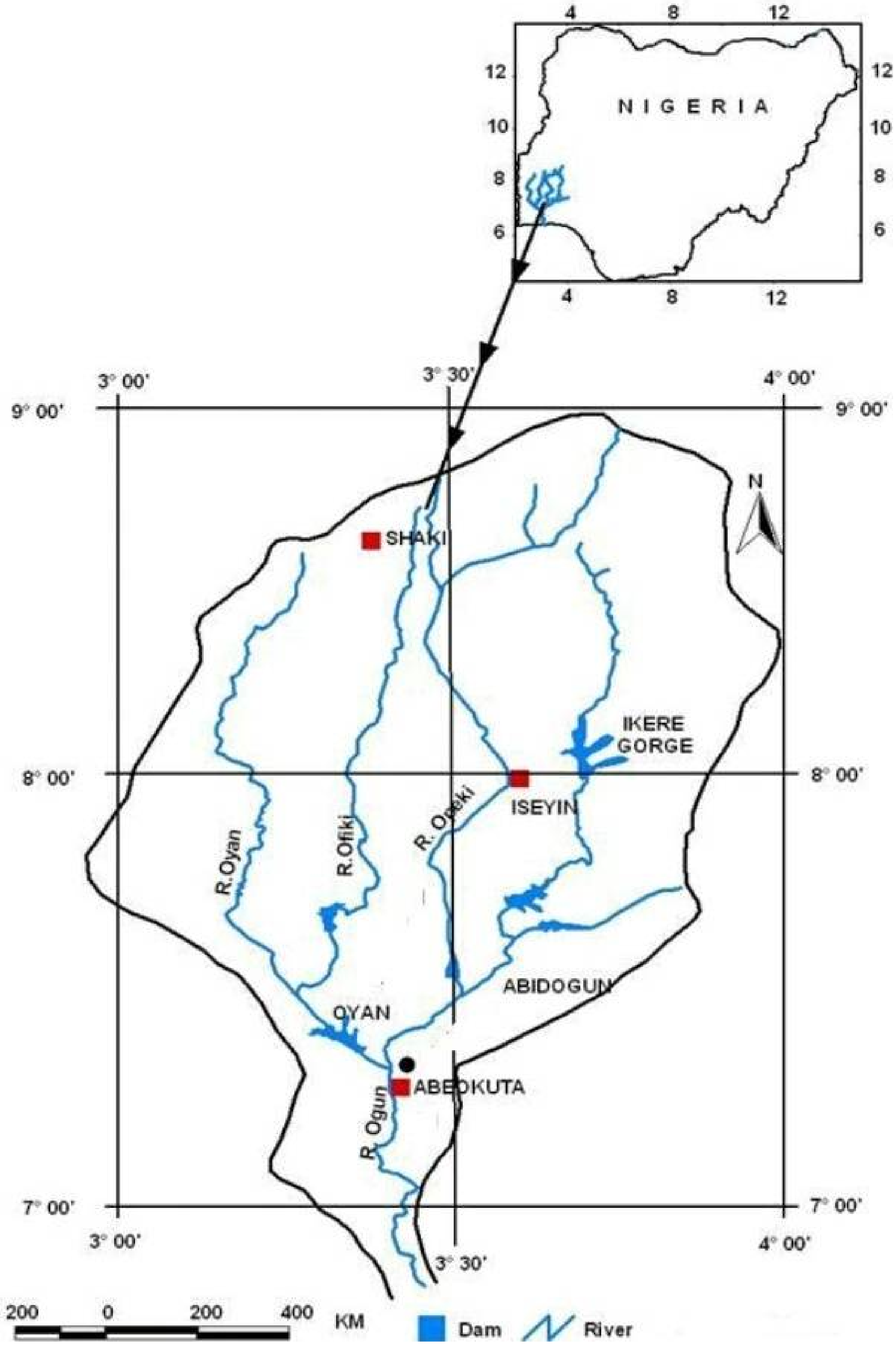

Figure 1: Map of Ogun drainage basin

Source: Oke *et al*., 2015

3.1.2 Climate: The climate of the area is influenced by two air masses, namely; Tropical maritime and the Tropical continental air masses. The tropical maritime air mass, which is warm and wet, originates from the Atlantic Ocean. The tropical continental air mass is warm, dry and dusty and originates from the Sahara desert. Hence, the climate of the area is similar to that of the other coastal regions of the tropical West Africa with tropical sub-equatorial climate. The mean daily maximum temperature for February is 31.4^{o}C in the south and as pattern is its seasonal distribution. The rainy season begins earlier in the south, usually commencing in March, and continues until late October or early November and the mean annual rainfall ranges between 900 mm in the North to 2000 mm towards the south. The total potential evapotranspiration is estimated at between 1600 mm and 1900 mm (Oke *et al*., 2015). The two major vegetation zones that can be identified on the watershed are the high forest vegetation in the north and central part, as well as swamp/mangrove that cover the southern coastal and floodplains proximate to the Lagos lagoon.

3.1.3 Physiography: The Ogun River is subdivided into Upper Central and Lower Basin areas for the context of the physiographic details. The Upper Central Ogun River constitutes the main body of the basin and it includes the Oyan Ofiki river system – the major tributary of the Ogun River. The Confluence of the Oyan and Ogun rivers marks the boundary between the Upper Central Basin to the north and the Lower Basin to the south. Abeokuta is the second major town in the basin after Lagos and it is located immediately downstream of Ogun Oyan confluence. The Central Basin is approximately 200 km long and 140 km wide at its extreme points, with a catchment area of about 20000 sq km, draining to the Lower Ogun. The topography in the north ranges in elevation from 370 m to the highest point at 572 m, located west of Saki (Akanni, 1992). The relief is generally low, with the gradient in the north-south direction. The Ogun, Oyan, and Ofiki rivers all appear to have a reasonably uniform gradient of 1m per km to the Ogun – Oyan confluence. The gradient is determined by the Basement Complex Formation on which the rivers have formed their beds. Development of the river system on the crystalline basement is largely controlled by the pattern of foliated rocks and by jointing on the more resistant rocks.

The Lower Ogun basin is the part of the basin downstream of the Ogun – Oyan confluence. It is a narrow strip about 100 km long from north to south and of an average width of 24 km. Its total area is approximately 3700 sq.km.

The gradient of the Ogun River in the Lower Ogun Basin changes dramatically form 1m per km to 0.1 m per km downstream of the Ogun – Oyan confluence, which also marks the boundary between the Basement Complex and Sedimentary Formations. In the Lower Basin the Ogun River flows sluggishly in alluvial bed, causing flood plain inundations during the rainy season.

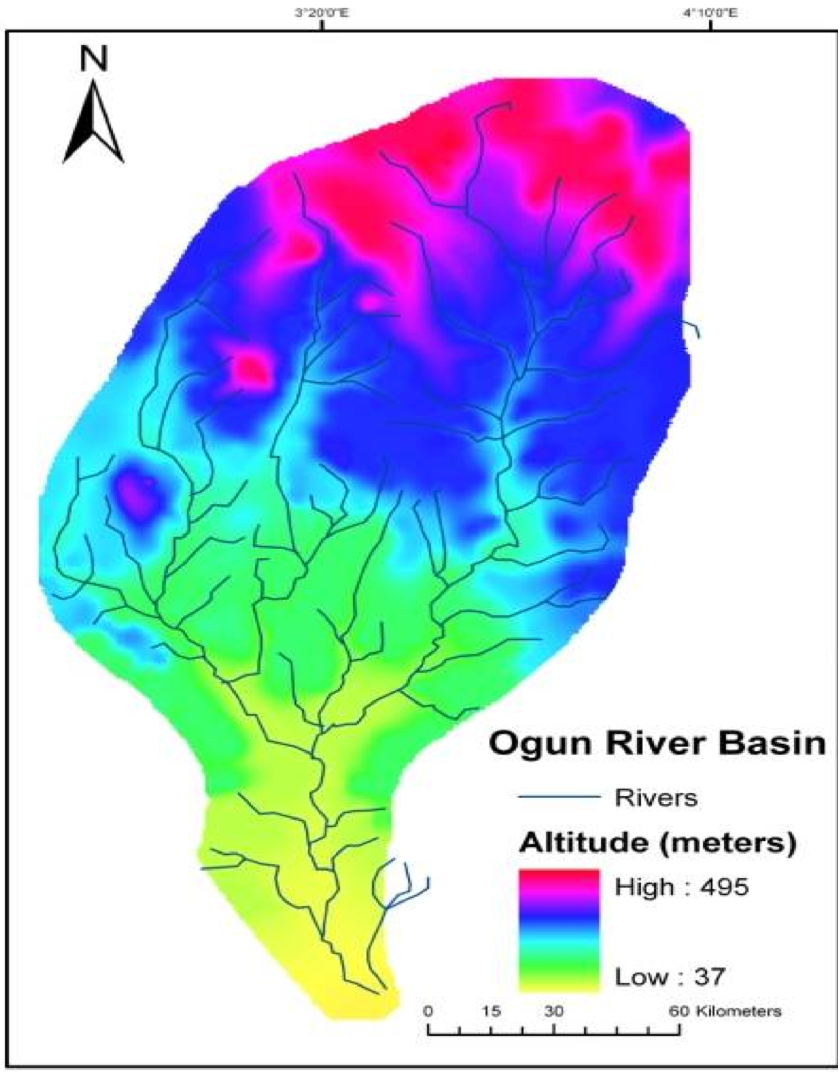

Figure 2: Map showing the altitude of Ogun drainage basin

Source: Oke *et al*., 2015

3.1.4 Geology: The geology of the study area is described as a rock sequence that starts with the Precambrian Basement. The foliation and joints on these rocks control the course of the rivers, causing them to form a trellis drainage pattern, particularly to the north of the study area. The overlying sedimentary rock sequences are from Cretaceous to Recent; the oldest of them, the Abeokuta Formation, consists of grey sandstones intercalated with clay. It is overlain by Ewekoro Formation, which typically contains thick limestone layers at its base. Overlying the Ewekoro Formation is the sand of the Ilaro Formation, which is overlain by the Coastal Plain Sands (Jones and Hockey, 1964).

About 9 km upstream of Abeokuta town there is a sharp change in land gradient, changing the river morphology from fast flowing to slow moving and leading to the formation of alluvial deposits overlying the sedimentary formation of Ewekoro, Ilaro and Coastal Plain Sands in sequence towards the Lagos lagoon.

The Upper Central Ogun Basin is composed of crystalline rocks of the Basement Complex consisting mainly of folded gneiss, schist and quartzite complexes which belong to the Older Intrusive Rocks series. The Lower Ogun Basin is composed of sedimentary formations which were deposited in the Cretaceous Basin which extends from the Volta River in the west to the Cross River Basin in the East, attaining a maximum thickness of about 2,100m. The Recent deposits, Coastal Plain Sands, Ilaro and Abeokuta Formations all have potential for groundwater development. The Ewekoro Formation is considered an aquiclude because of its insignificance in groundwater exploitation. However, the occurrence of groundwater in the upper basin crystalline rocks depends on the extent of weathering and jointing. Meanwhile the Basement Complex constitutes a favorable environment for dam construction (Tahal Consultants, 1982).

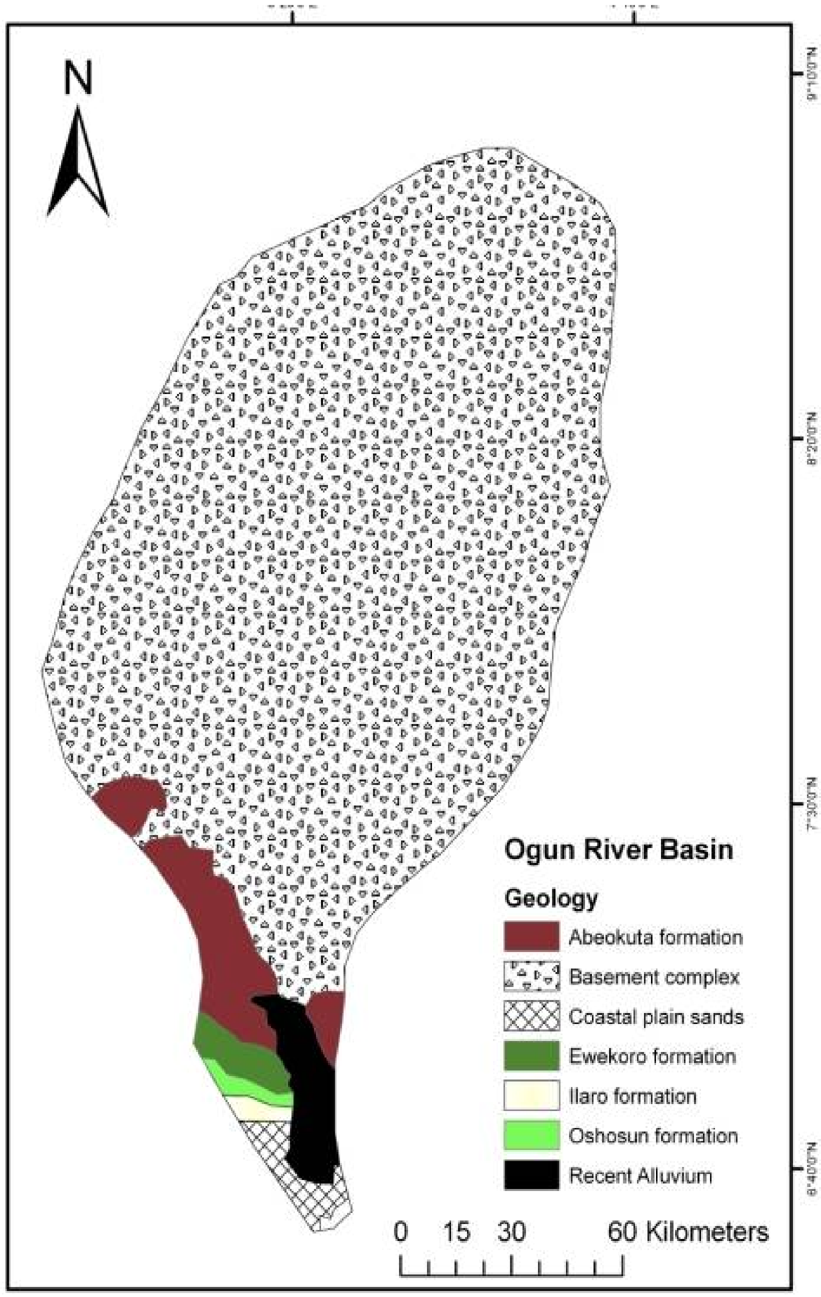

Figure 3: Map of geology of Ogun drainage basin

Source: Oke *et al*., 2015

There are 23 stream gauging stations in the Ogun River Basin (Tahal Consultants, 1982). They are monitored by Ogun, Oyo and Osun State Water Corporations. Rating tables are available for some of gauging stations. The available daily stage data for the selected stations were subjected to statistical analysis. All daily stage data for the selected stations and the chosen period (2009) were used with the available rating tables for each station to derive the rating equations. The derived equations could be used to predict discharge values for the range of daily stage available and the monthly maximum discharge for each station was calculated using the maximum stage and appropriate derived equation. The trend in daily stage and stream flow was analysed using the polynomials.

3.2 Data sources

The data sets used in this study were obtained from both primary and secondary. The primary data source was field observation while the secondary data sources include Land cover classifications from the Forestry Monitoring and Evaluation coordinating Unit (FORMECU), Google Earth images of 2015 from the Google Earth and hydroclimatic data from Ogun–Oshun River Basin Development Authority (OORBDA). The daily stage and daily discharge data were collected for all the study locations and climatic data was collected for only a location because of lack of meteorological station at the other four locations at the hydrometeorological division, a sub-section of hydrogeology at the OORBDA National Headquarters along Alabata road, Abeokuta, Ogun state. The Authority (OORBDA) has been collecting, processing and analysing streamflow data on many of the rivers under its area of operation (Ogun, Osun, Oyo and Lagos States). Feasibility studies report on Ogun Basin (volumes two and seven) were collected from Ogun – Oshun River Basin Development Authority. The feasibility studies reports contain information on the number of gauging stations, their location and the record of gauge readings of more than thirty years though not of the recent years.

The stage information was used with the available rating tables at Ogun-Oshun River Basin Development Authority to derive rating equation.

3.3 Data screening

The following findings were observed after collecting gauge reading records and the availability rating tables for discharge conversion:

- There are missing records for many stations. Enquires revealed that data were missing for periods of strikes, political instability, faulty instruments, lack of money to pay the local gaugers or whenever there was change in staff handling gauge readings. This happened because all gauging stations were read manually.
- The records were in some cases not supported with rating tables. Such records could not be used, so they were discarded.
- Continuous records of stages were available for varying length of years for different stations, many of which were not supported with rating tables that would enable discharge conversion. As a result of this, some stations were considered.

Data for twenty three stations were screened and only five were found suitable for the analysis because of the researcher's preference for recent records especially data taking in this twenty first century.

3.4 Validation of data

The researcher worked closely with the staff and the gauge readers of OORBDA for a period of five weeks i.e. a week at each of the five selected stations. The gauge readings that were taken by the researcher alongside OORBDA staff during the validation exercise were plotted against the readings recorded by the staff of ORBDA to obtain a linear relationship as equation of the form $y = ax + b$

Where;

$y = Q$, dependent variable,

$x_i = H$, independent variables,

b_i = regression coefficients which are constants that represent the rates of change of one variable (y) as a function of change in the other variables (x_i).

3.5 Sampling techniques

3.5.1 Discharge measurements

Discharge is defined as the volume rate of flow of water, usually expressed in cubic metres per second (m^3/s).The water flow velocity and cross sectional area at each station are measured. The basic instrument used by OORBDA for measurement is the current meter. To measure the cross sectional area of the river, two components were used: the water level and the river bed profile. The river bed profile was mapped by a hydrographer, while stationary at each of several points in the cross section of the stream. The water level is read directly from the gauge erected at the station. The vertical velocities are taken at 2 points i.e. 0.2 and 0.8 depths, taking the mean of these two points as the mean velocity in vertical. The cross section is remapped when the flow regime is suspected to have changed. The final stage is development of the stage-discharge curve or rating curve for gauging station which is used to estimate the volume of flow.

3.6 Data analysis

3.6.1 Choice of software

ArcView 3.2a version was used for the delineation of the study location from the map, clipping of the image to the study area and preparation of images for analysis.

Google Earth pro is internet based software used for downloading an internet image representing the study area which served as a referenced image and a complementary to field observation. The statistical analyses were done with SPSS version 21.0 and Microsoft Excel 2007 with XLSTAT software packages

3.6.2 Test for outliers

The Grubbs-Beck test was used to check the presence of outliers in the studied measurement series. This was done with XLSTAT trial version 2016 on Microsoft Excel 2007 statistical package. The data were used with outliers based on Gumbel (1960) and Laio *et al.,* (2010)

3.6.3 The physical basis of the Grubbs-Beck test

The random variable Y equals to natural logarithm from the value of the studied random variable X that is normally distributed.

$$y_i = \ln x_i \qquad i= 1, 2,\ldots N \qquad (1)$$

Where

y_i = individual random variable Y

x_i = individual random variable X

This test statistics consider elements x_i of the measurement series to be outliers, the value of which exceed the values of lower X_D or upper X_G limit of confidence interval of the test assumed for significance level $\alpha = 0.10$. The lower X_D and upper X_G limits are calculated as follows:

$$X_D = exp\,(\bar{y} - K_N s_y) \qquad (2)$$

$$X_G = exp\,(\bar{y} + K_N s_y) \qquad (3)$$

Where

$\bar{y}$ - Mean value from values y_i of random variable Y,

s_y – Mean deviation from values y_i of random variable Y,

$$K_N = -3.62201 + 6.28446.N^{0.25} - 2.49835.N^{0.5} + 0.491436.N^{0.75} - 0.037911.N \quad (4)$$

N – Size of measurement series.

The presence of outliers is an indicator that the data population is non –homogeneous.

3.7. Equations that were used for models and their physical basis

Two types of algebraic equations that are commonly fitted to stage-discharge data are:

1. Power type equation which is the most commonly used:

$$Q = c\,(h + a)^b \quad (5)$$

Where;

Q = discharge (m^3/s)

h = measured water level (m)

a = water level (m) corresponding to Q = 0

c = coefficients derived for the relationship corresponding to the station characteristics

2. The parabola equation

$$Q = c_2(h_w + a)^2 + c_1(h_w + a)^b + c_0 \quad (6)$$

Where:

H = stage (m) before deduction of value at datum

h_w = measured water level (m)

a = water level (m) corresponding to Q = 0

c_i = coefficients derived for the relationship corresponding to the station characteristics

Taking logarithms, the power type equation results in a straight line relationship of the form:

$$\text{Log}(Q) = \log(c) + b\log(h + a) \qquad (7)$$

i.e the form;

$$y = a + bx \qquad (8)$$

That is, if a set of discharge (Q) and the effective stage (h + a) are plotted on a double log scale, they will represent a straight line. Coefficients A and B of the straight line fit are functions of a and b. Since values of a and b can vary at different depths owing to changes in physical characteristics at different depths, one or more straight lines will fit the data on a double log plot.

3.7.1 Determination of datum correction (a)

The datum correction (a) corresponds to that value of water level for which the flow is zero. From equation (6) it can be seen that for Q = 0, (h + a) = 0 which means:

a = - h. Using Johnson method which is described in the WMO Operational hydrology manual on stream gauging (Report No. 13, 1980). This procedure is based on expressing the datum correction “a” in terms of observed water levels. This is possible by elimination of coefficients b and c from the power type equation between gauge and discharge. From the median curve fitting the stage discharge observations, two points are selected in the lower and upper range (Q_1 and Q_3) whereas the third point Q_2 is computed from $Q_2^2 = Q_1 Q_3$, such that:

$$\frac{Q_1}{Q_2} = \frac{Q_2}{Q_3} \qquad (8)$$

If the corresponding gauge heights for the above discharges are h_1, h_2 and h_3, then using the power type, it gives:

$$\frac{c(h_1+a)}{c(h_2+a)} = \frac{c(h_2+a)}{c(h_3+a)} \qquad (9)$$

This yield;

$$a = \frac{(h_2^2 - h_1 h_3)}{(h_1 + h_3 - 2h_2)} \qquad (10)$$

3.7.2 Determination of rating curve coefficients

A least square method was employed for estimating the rating curve coefficients. From the power type equation, taking a and b as the estimates of the constants of the straight line fitted to the scatter of points in double log scale, the estimated value of the logarithm of the discharge was obtained as:

$$\breve{Y} = a + bX \quad (11)$$

The least square method minimises the sum of square of deviations between the logarithms of measured discharges and the estimated discharges obtained from the fitted rating curve. Considering the sum of square error as E, then

$$E = \sum_{i=1}^{N}(Yi - \hat{Y}i)^2 = \sum_{i=1}^{N}(Yi - a - bXi)^2 \quad (12)$$

Here *i* denote the individual observed point and N is the total number of observed stage discharge data.

Since this error is to be minimum, the slope of partial derivatives of this error with respect to the constants must be zero, In other words:

$$\frac{\partial E}{\partial a} = \frac{\partial(\sum_{i=1}^{N} Yi - a - bXi)^2)}{\partial a} = 0 \quad (13)$$

And

$$\frac{\partial E}{\partial b} = \frac{\partial(\sum_{i=1}^{N} Yi - a - bXi)^2)}{\partial b} = 0 \quad (14)$$

This results in two algebraic equations of the form:

$$\sum_{i=1}^{N} Yi - aN - b\sum_{i=1}^{N} Xi = 0 \quad (15)$$

and

$$\sum_{i=1}^{N}(XiYi) - a\sum_{i=1}^{N} Xi - b\sum_{i=1}^{N}(Xi)^2 = 0 \quad (16)$$

All the quantities in the above equations are known except $\alpha\, and\, \beta$. Solving equations (15& 16) yield;

$$b = \frac{N\sum_{i=1}^{N}(XiYi)-(\sum_{i=1}^{N}Xi)(\sum_{i=1}^{N}Yi)}{N\sum_{i=1}^{N}(Xi)^2-(\sum_{i=1}^{N}Xi)^2} \qquad (17)$$

and

$$a= \frac{\sum_{i=1}^{N}Yi-b\sum_{i=1}^{N}Xi}{N} \qquad (18)$$

The value of coefficients c and b of power type equation was then finally obtained as:

$$b = \beta \text{ and } c = 10^{\alpha} \qquad (19)$$

3.7.3 Determination of rating coefficients a, b, and c using the least-square parabola

The least squares parabola having the form;

$$y = a + bx + cx^2 \qquad (20)$$

Equation (17) was fitted using normal equations;

$$\sum y = an + b\sum x + c\sum x^2 \qquad (21)$$

$$\sum xy = a\sum x + b\sum x^2 + c\sum x^3 \qquad (22)$$

$$\sum x^2 y = a\sum x^2 + b\sum x^3 + c\sum x^4 \qquad (23)$$

3.8 Determination of elevation

The shape files of the basin were downloaded from Forestry Monitoring and Evaluation Coordinating Unit (FORMECU). The shape files were opened in ArcView 3.2a and the spotheight shape file was used to create the contour lines, the elevation for the mouth, mid-point and head of each streamlet of each of the rivers in the study location. The distance between the minimum and maximum elevation of each river was recorded as L (length) in metre.

3.8.1 Determination of slope

Slope was calculated with the formula;

$$\text{Slope, } S = \frac{H_{max} - H_{min}}{L} \qquad (24)$$

where;

H_{max} = Highest elevation in metre

H_{min} = Lowest elevation in metre

L = Distance between the highest elevation and lowest elevation in metre

3.9 Correlation analysis

Relations between equation parameter and PCCs were established through a correlation matrix using SPSS 21.0 version. Out of a total of fourteen combinations, dependency was indicated for five combinations of model parameter and catchment characteristics. Multiple linear regression analysis was applied to improve on the simple linear relation by adding PCCs using a method of forward entry in which the established relationships are extended by adding PCCs to the relationships until the last added PCC does not significantly contribute.

3.9.1 Regression equations

Multiple linear-regression analysis has been used by the United States Geological Survey (USGS) and other researchers throughout the United States and elsewhere to develop equations for estimating streamflow statistics for ungauged sites. In regression analysis, a streamflow statistic (the dependent variable) for a group of data-collection stations is statistically related to one or more physical or climatic characteristics of the drainage areas for the stations (the independent variables). This leads to an equation that can be used to estimate the statistic for sites where no streamflow data are available. Equations can be developed by use of several different regression analysis models. The various algorithms use different methods for minimizing differences between the values of the dependent variable for the stations used in the analysis and the corresponding values provided by the resulting regression equation. Choice of one algorithm over another depends on the characteristics of the data used in the analysis and on the underlying assumptions for use of the algorithm. Equations obtained by use of regression analysis take the general form

$$Y_i = b_o + b_1 x_1 + b_2 x_2 + \cdots + b_n x_n + \varepsilon_i \qquad (25)$$

Y_i is the estimate of the dependent variable for site i,

X_1 to X_n are the n independent variables,

b_o to b_n are the n + 1 regression model coefficients,

ε_i is the residual error (difference between the observed and estimated value of the dependent variable) for site i.

The following assumptions were used for regression analysis according to…;

(1) equation 12 adequately describes the relation between the dependent and the independent variables,

(2) the mean of the residual error (ε_i) is zero,

(3) the variance of the ε_i is constant and independent of the values of Xn,

(4) the εi are normally distributed, and

(5) the εi are independent of each other .

Regression analysis results were evaluated to assure that these assumptions met. Streamflow and basin characteristics used in hydrologic regression usually are log-normally distributed; therefore, transformation of the variables to logarithms was done to satisfy regression assumption 2.

Transformation results in a model of form

$$\log Y_i = b_o + b_1 \log X_1 + b_2 \log X_2 + \cdots b_n \log X_n + \varepsilon_1 \qquad (26)$$

The algebraically equivalent form when logarithms base 10 are used in the transformations and the equation is retransformed to original units is

$$Y_1 = 10^{b_o}(X_1)^{b_1}(X_2)^{b_2} \dots (X_n)^{b_n} \quad (27)$$

3.9.2 Evaluation of model performance

The regional model is established to predict streamflow from ungauged catchment. It is therefore necessary to assess the model by comparing the predicted and observed discharges from the gauged test catchment. Since in this study the number of gauged catchments is limited to five, it is not possible to carry out a formal validation process with independent catchments. Instead, the validation of the regional model is done by estimating the maximum discharge of each of the stations for the year considered and comparing it with maximum discharge from rating tables for the five gauging stations. This is a modification of the approach used by Perera (2009). The measures of model adequacy include (1) the coefficient of determination, otherwise known as the adjusted R- squared (R^2_{adj}) which is a measure of the proportion of the variation in the dependent variable that is explained by the independent variables, adjusted for the number of stations and the number of independent variables used in the analysis and (2) the relative volume error (%) which is calculated as;

$$RVE\ (\%) = \frac{(\text{Predicted} - \text{Observed})}{\text{Observed}} \times 100 \quad (28)$$

The result of R^2 greater than 0.6 and RVE smaller than +10 or -10% is considered satisfactory according to Wale *et al*. (2009).

CHAPTER FOUR

4.0 RESULTS

4.1 Results of data validation

Table 1 shows the list of gauging stations, name of river, location, station identity number and catchment area in squared kilometre considered for this study. The daily stage and daily discharge of seven days at all the five study locations were monitored and recorded by the Researcher and the staff of OORBDA. The stage and discharge data taken by the Researcher were plotted against that of the data taken by the OORBDA staff. All the stations showed positive trend for both daily stage and daily discharge. The coefficient of determination obtained for all the stations were above 0.95 (95%) and are shown on Table 2 with each station's linear equation

Table 1: List of gauging stations, river name, location, station identity and catchment area

Serial Number	River Name	Location	Station Identity	Catchment Area(km^2)
1	Ogun	Ofiki Town	21	770
2	Ogun	Sepeteri	36	1190
3	Ogun	Oyo/Iseyin	20	5740
4	Ogun	Ilaji-ile	70	1610
5	Ogun	New bridge,Lafenwa	Og. 5	21,030

Table 2: Linear equation for stage and discharge for validation period at stations

Station Name	Data	Linear Equation,	R^2
Ofiki	Stage, H(m)	H_R=1.017H_A - 0.026	0.967
	Discharge, Q(m^3/s)	Q_R=1.017Q_A – 0.1	0.971
Oyo/Iseyin	Stage, H (m)	H_R=1.022H_A – 0.053	0.986
	Discharge, Q(m^3/s)	Q_R=0.99 Q_A – 0.454	0.991
Sepeteri	Stage, H (m)	H_R=0.953H_A – 0.057	0.989
	Discharge, Q(m^3/s)	Q_R=1.036Q_A– 0. 415	0.990
Ilaji-ile	Stage, H (m)	H_R=0.994H_A – 0.000	0.987
	Discharge, Q(m^3/s)	Q_R= 0.983H_A - 0000	0.994
Abeokuta	Stage, H (m)	H_R=0.938H_A + 0.152	0.983
	Discharge, Q(m^3/s)	Q_R=0.934Q_A + 1.071	0.986

H_R and Q_R are the dependent variables and stage and discharge recorded by Researcher

H_A and Q_A are the independent variables and stage and discharge recorded by Authority

4.2 Development of regionalization protocol

4.2.1 Derivation of rating equation and type of equation derived

The rating equations were derived for the five stations in both power and parabola types in Table 3 with exponent of 1.49, 1.66, 1.76, 1.99 and 4.22 for stations 36, 21, 70, 20 and Og.5 respectively.

4.2.2 The derived daily-stage, daily-discharge and stage-discharge equations with R^2

Table 4 shows the equation of line of daily stage, daily discharge and rating equation for daily stage-discharge relation with coefficient of determination in percentage. The daily stage and stage-discharge for all the five stations are significant with their coefficient of determination at $p \leq 0.01$ while the discharge for stations 21 and are non-significant but are significant for the rest of the stations.

Table 3: The derived rating equations and type

Station Identity	Derived rating Equations (m^3/s)	Type
21	$Q_{21} = 3.29H^{1.66}$	Power
	$Q_{21} = 1.78H^2 + 1.82H – 0.311$	Parabola
36	$Q_{36} = 8.02H^{1.49}$	Power
	$Q_{36} = 5.88H^2 – 1.48H +3.55$	Parabola
20	$Q_{20} = 5.87H^{1.99}$	Power
	$Q_{20} = 6.12H^2 – 0.07H – 0.61$	Parabola
70	$Q_{70} = 2.36H^{1.76}$	Power
	$Q_{70} = 9.28H^2 – 18.25H + 9.63$	Parabola
Og. 5	$Q_{og.5} = 0.62H^{4.22}$	Power
	$Q_{og.5} = 82.51H^2 – 371.54H + 430.42$	Parabola

Table 4: The derived daily-stage, daily-discharge and stage-discharge equations with R^2

Station	Stage-Discharge	Equation	Coefficient of Determination (R^2)
21	Stage (m)	$H= -6E\text{-}05D^2+0.024D-0.511$	62.6%
	Discharge (m^3/s)	$Q=-0.0000D^2+0.152D-5.461$	49.7%
	Stage-Discharge	$Q = 3.29H^{1.66}$	99.8%
36	Stage (m)	$H = 1E\text{-}10D^4-3E\text{-}07D^3+0.000D^2-0.008D+1.154$	78.8%
	Discharge (m^3/s)	$Q = -1E\text{-}0.8D^4+5E\text{-}0.6D^3-0.000D^2+0.054D+8.229$	11.7%
	Stage-Discharge	$Q = 8.02H^{1.49}$	96.1%
20	Stage (m)	$H = 4E\text{-}09D^4-3E\text{-}06D^3+0.000D^2-0.045D+2.333$	76.7%
	Discharge (m^3/s)	$Q = 1E\text{-}07D^4-9E\text{-}05D^3+0.022D^2-1.526D+37.92$	77.7%
	Stage-Discharge	$Q = 5.87H^{1.99}$	95.3%
70	Stage (m)	$H = -2E\text{-}09D^4+9E\text{-}07D^3-0.000D^2+0.006D+0.461$	94.4%
	Discharge (m^3/s)	$Q = -1E\text{-}08D4+5E\text{-}06D^3-0.000D^2+0.012D+0.930$	94.0%
	Stage-Discharge	$Q = 2.36H^{1.76}$	88.7%
Og.5	Stage (m)	$H = -2E\text{-}09D^4+1E\text{-}06D^3-0.0000D^2+0.006D+1.969$	92.3%
	Discharge (m^3/s)	$Q = -5E\text{-}07D^4+0.0000D^3-0.048D^2+2.648D-15.79$	72.4%
	Stage-Discharge	$Q = 0.62H^{4.22}$	99.8%

Q = Discharge

H = Stage

D = Day

4.2.3 Zonal classification of stations based on coefficient of determination, R^2

The stations were grouped into three based on their R^2 range in Table 5 and mapped on Figure 4. The zone I, II and III were classified with R^2 range of 10 to 40%, 41 to 70% and 71 to 100% respectively. The station 36 was zoned I, station 21 was zoned II and stations 20, 70 and Og.5 were zoned III.

4.2.4 Classification of stations based on exponent of derived equations

Table 6 and Figure 5 show the zonal classification of gauged stations based on exponent of derived rating equation. The exponent range of 0 to 1.50 as A, 1.51 to 3.01 as B and 3.02 to 4.52 as C. Station 36 was zoned A, stations 20,21,70 were zoned B and Og.5 as C.

4.2.5 Regionalization of the catchment into unitary zones

The zonal classifications based on coefficient of determination and exponent of derived rating equation were jointly grouped into unitary zones A_u, B_u, C_u with station 36 under joint zone IIIA and A_u unitary zone, stations 20, 21, 70 under joint zones IB, IIB, IIIB and B_u unitary zone and Og.5 as IC and C_u unitary zone shown on Table 7 and on map with Figure 6.

Table 5: Zonal classification of stations based on coefficient of determination, R^2

Station Identity	R^2 Range	Zone (Z_R)
36	10 -40%	I
21	41 – 70%	II
20, 70, Og.5	71 – 100%	III

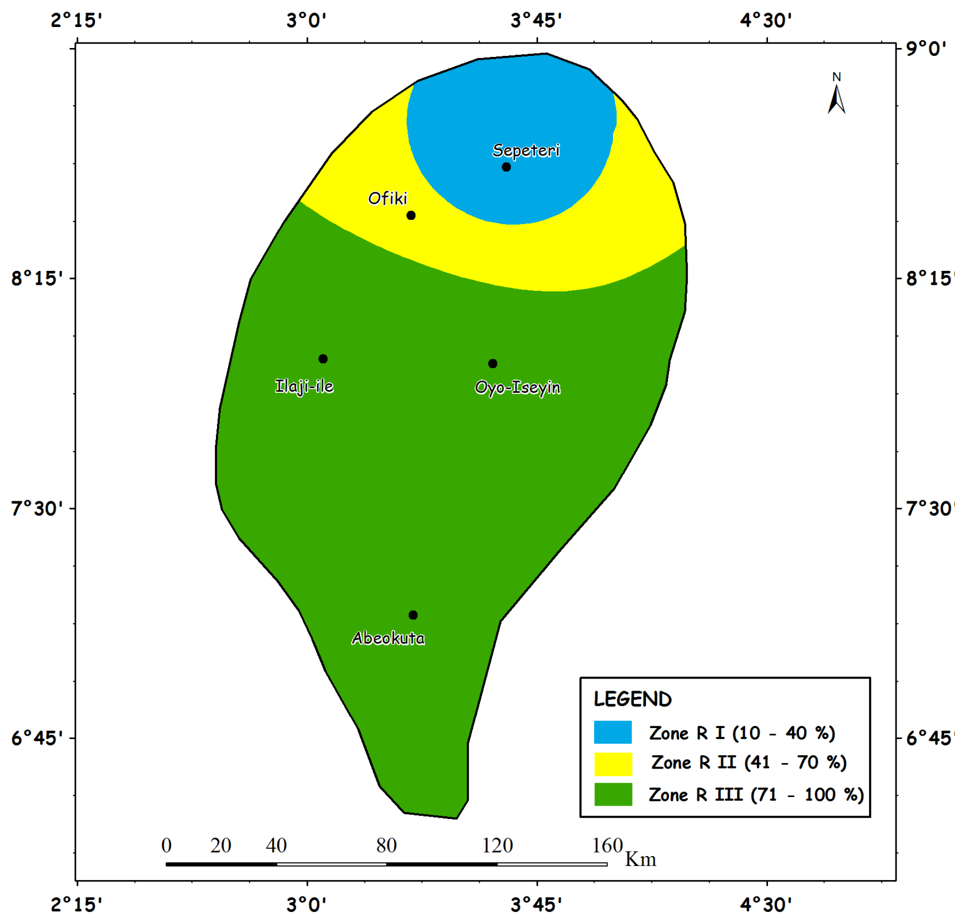

Figure 4: Regionalised catchments based on R^2 (Z_R)

Table 6: Classification of stations based on exponent of derived equations

Station Identity	Exponent Range	Zone (Z_E)
36	0 – 1.50	A
20, 21, 70	1.51 – 3. 01	B
Og.5	3.02 – 4.52	C

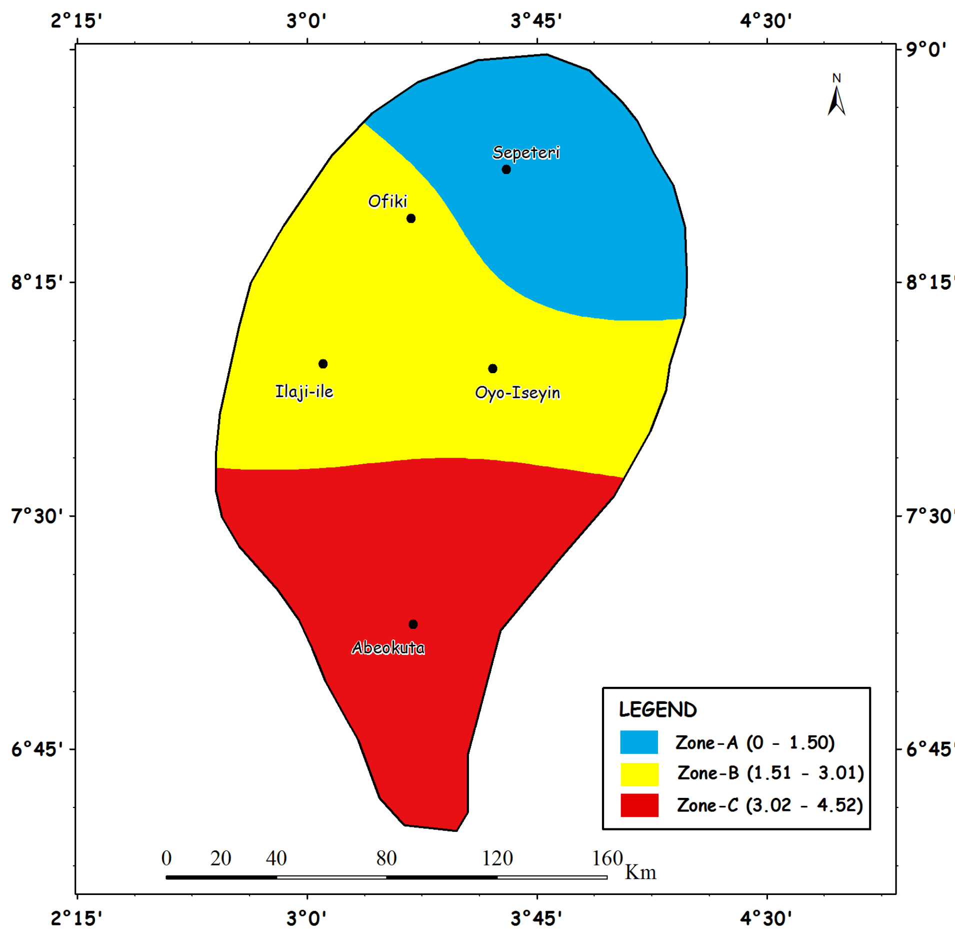

Figure 5: Regionalised catchments based on exponents (Z_E)

Table 7: Regionalization of the catchment into unitary zones

Station Identity	Zone (Z_R)	Zone (Z_E)	Joint Zones	Unitary Zones
36	III	A	IIIA	A_u
20	I	B	IB	
21	II	B	IIB	B_u
70	III	B	IIIB	
Og.5	I	C	IC	C_u

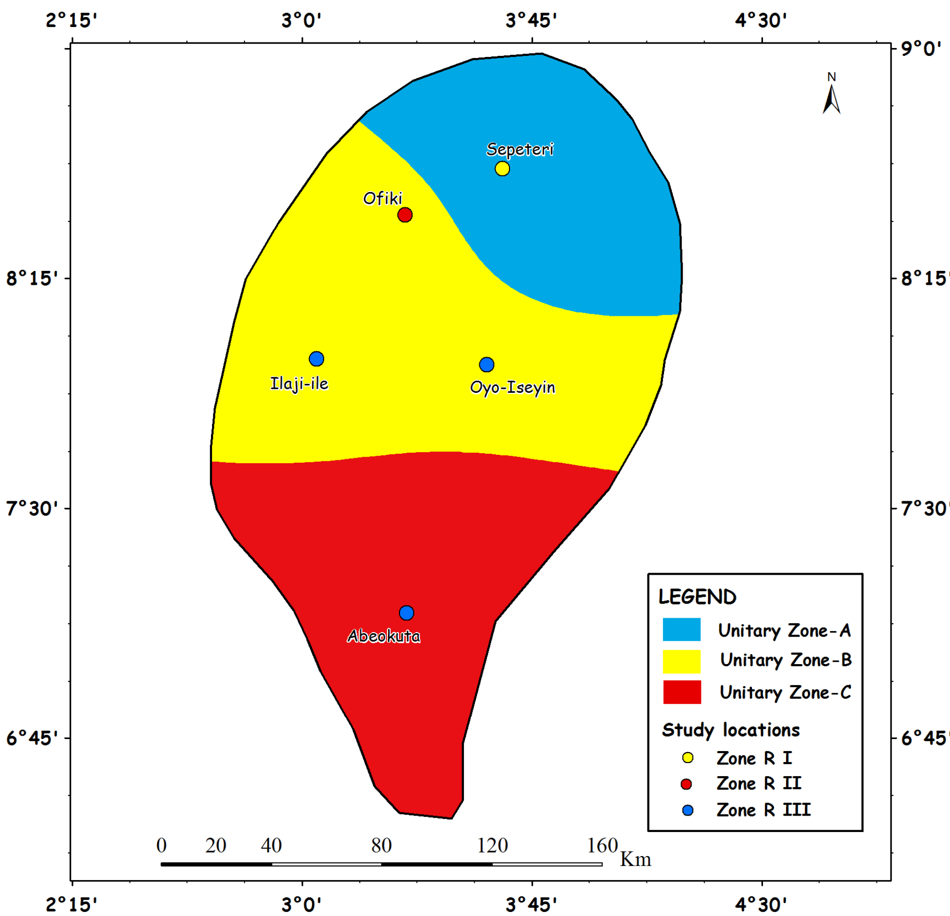

Figure 6: Map showing regionalised catchments

4.3 Result of monthly maximum discharge calculated from the derived equations

The monthly maximum discharge calculated from the derived equations i.e. the power type and parabola type is shown in Table 8. The monthly maximum discharges (m^3/s) calculated from the power type equation range from 17.96 to 297.94 with percentage accuracy of 77.9% to 97.8%. The relative volume error in percentage for stations 21, 36, 20, 70 and Og.5 are – 2.23, - 9.00, - 3.60, - 7.70 and - 22.00 respectively for the power type equation and 0.76, - 3.10, 2.06, 24.56 and – 4.45 respectively for the parabola type equations.

Table 8: Monthly maximum discharge calculated from the derived equations

S/N	Station ID	H_{max} (m)	$Q_{tabulated}$ (m^3/s)	Derived equation					
				Power type			Parabola type		
				$Q_{calculated}$ (m^3/s)	% accuracy	% RVE	$Q_{calculated}$ (m^3/s)	% accuracy	% RVE
1	21	2.78	18.37	17.96	97.8	- 2.23	18.51	100.8	0.76
2	36	1.97	24.20	22.03	91.0	- 9.00	23.45	96.9	- 3.10
3	20	3.74	83.05	80.06	96.4	- 3.60	84.76	102.1	2.06
4	70	2.05	9.04	8.35	92.4	- 7.70	11.26	124.6	24.56
5	Og.5	4.32	382.2	297.94	77.9	-22.00	365.20	95.6	- 4.45

H_{max} is the monthly maximum stage recorded at each station

$Q_{tabulated}$ is the monthly maximum discharge corresponding to the monthly maximum stage at each station

$Q_{calculated}$ is the monthly maximum discharge estimated from the derived equations

% accuracy is the $Q_{calculated}$ divided by $Q_{tabulated}$ multiplied by 100

% RVE is the percentage relative volume error

4.4 Trend of daily stage and daily streamflow at stations

The daily stage and daily streamflow were plotted to show how it varied over the period of one year. The trends were shown as well to reveal the relationship of the time. The estimated R^2 explained 62.6% of variations in daily stage, 49.7% variations in daily discharge at station 21, 78.8% variation in daily stage, 11.7% variation in daily discharge for station 36, 76.7% variation in daily stage, 77.7% variation in daily discharge for station 20, 94.4% variation in daily stage, 94.0% variation in daily discharge for station 70 and 92.3% variation in daily stage and 72.4% variation in daily discharge for station Og.5. The results are shown on Table 9 and Figures 7 to 16.

Table 9: Trend of daily stage and daily streamflow at stations

Station	Stage-Discharge	Equation	Coefficient of Determination (R^2)
21	Stage (m)	$H= -6E\text{-}05D^2+0.024D-0.511$	62.6%
	Discharge (m^3/s)	$Q=-0.0000D^2+0.152D-5.461$	49.7%
36	Stage (m)	$H = 1E\text{-}10D^4-3E\text{-}07D^3+0.000D^2-0.008D+1.154$	78.8%
	Discharge (m^3/s)	$Q = -1E\text{-}0.8D^4+5E\text{-}0.6D^3-0.000D^2+0.054D+8.229$	11.7%
20	Stage (m)	$H = 4E\text{-}09D^4-3E\text{-}06D^3+0.000D^2-0.045D+2.333$	76.7%
	Discharge (m^3/s)	$Q = 1E\text{-}07D^4-9E\text{-}05D^3+0.022D^2-1.526D+37.92$	77.7%
70	Stage (m)	$H = -2E\text{-}09D^4+9E\text{-}07D^3-0.000D^2+0.006D+0.461$	94.4%
	Discharge (m^3/s)	$Q = -1E\text{-}08D4+5E\text{-}06D^3-0.000D^2+0.012D+0.930$	94.0%
Og.5	Stage (m)	$H = -2E\text{-}09D^4+1E\text{-}06D^3-0.0000D^2+0.006D+1.969$	92.3%
	Discharge (m^3/s)	$Q = -5E\text{-}07D^4+0.0000D^3-0.048D^2+2.648D-15.79$	72.4%

Q = Discharge

H = Stage

D = Day

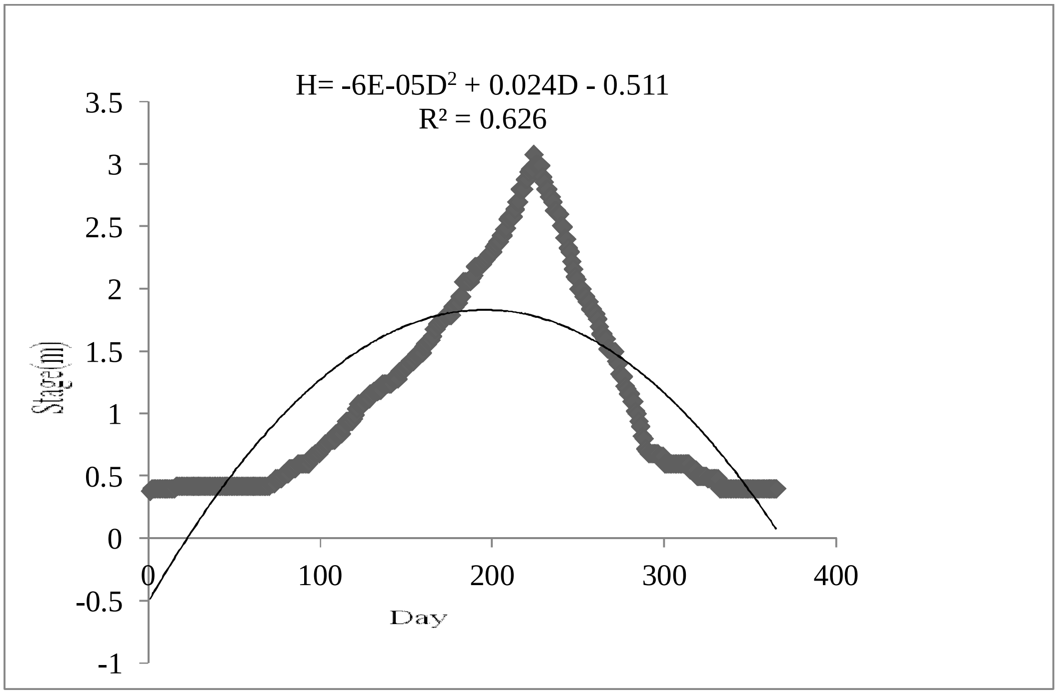

Figure 7: Daily stage at Ofiki station

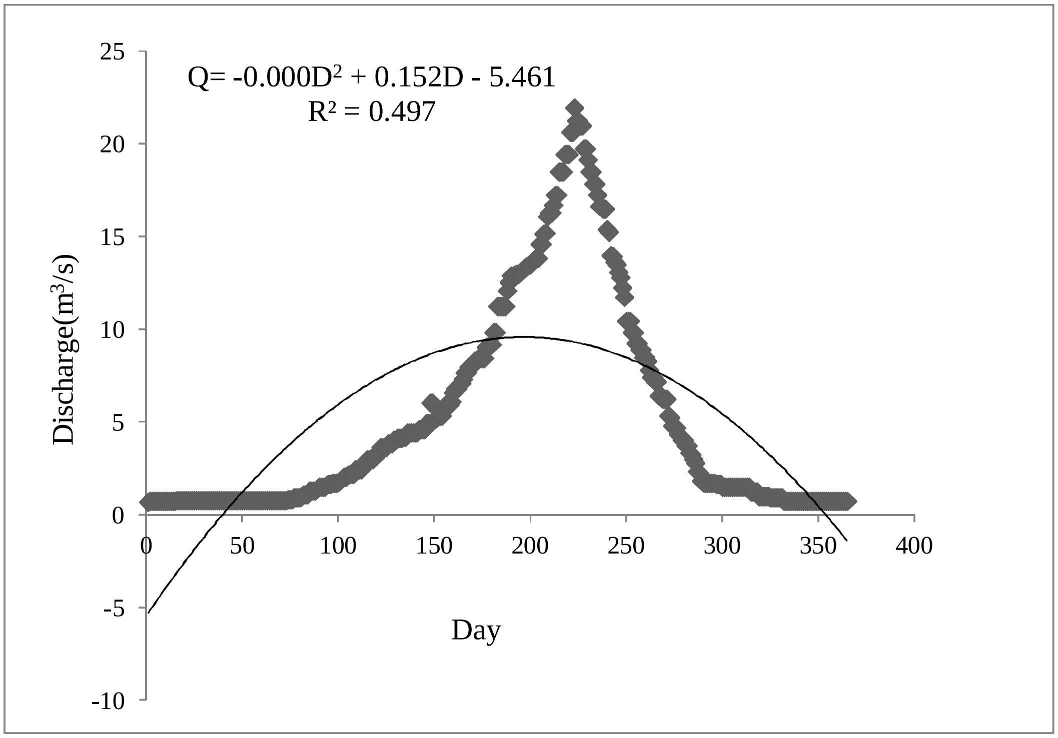

Figure 8: Daily discharge at Ofiki station

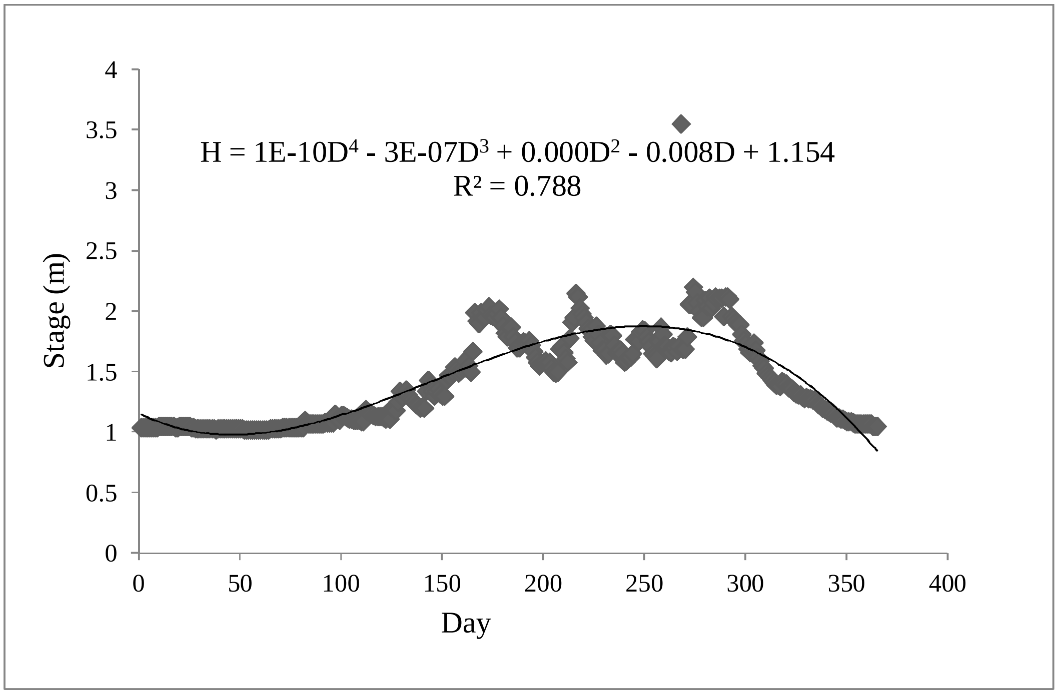

Figure 9: Daily stage for Sepeteri station

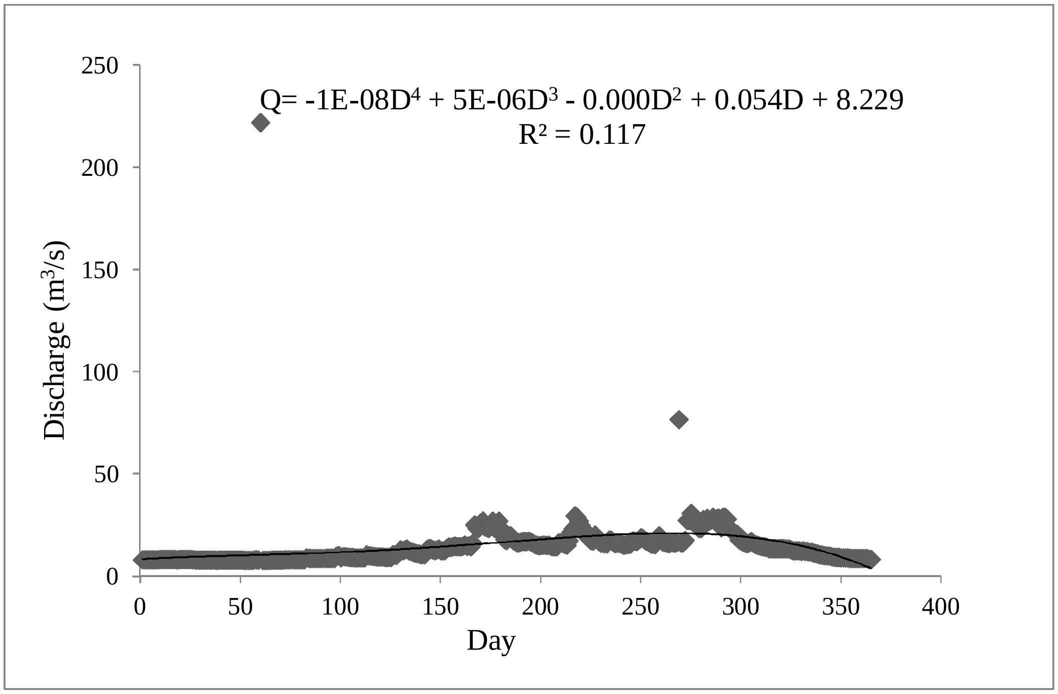

Figure 10: Discharge for Sepeteri station

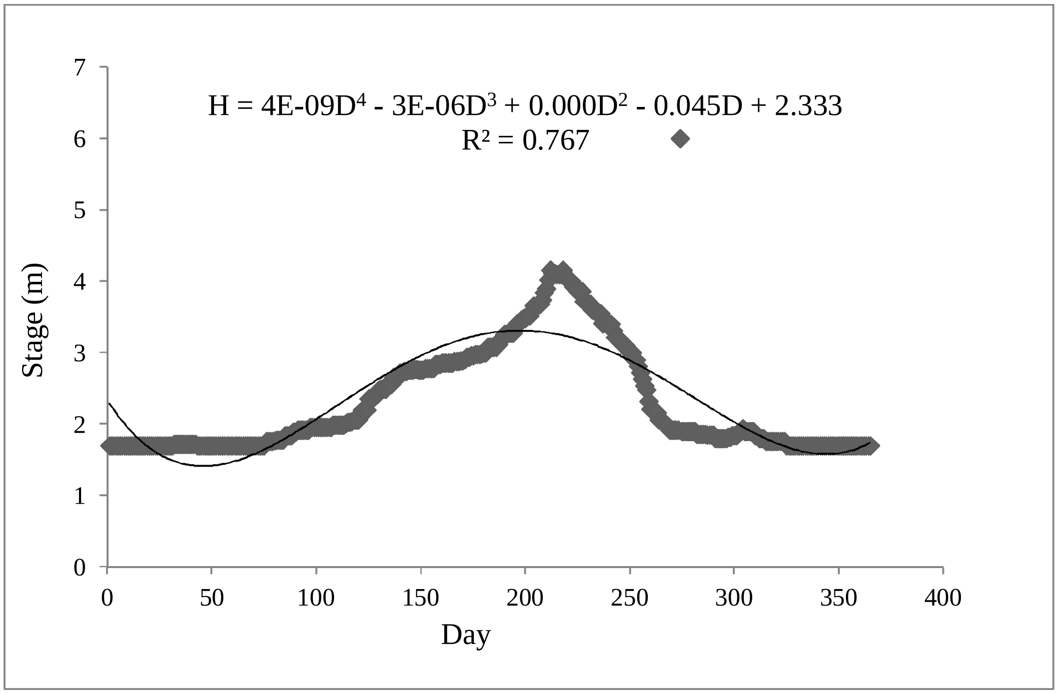

Figure 11: Plot of daily stage at Oyo/Iseyin

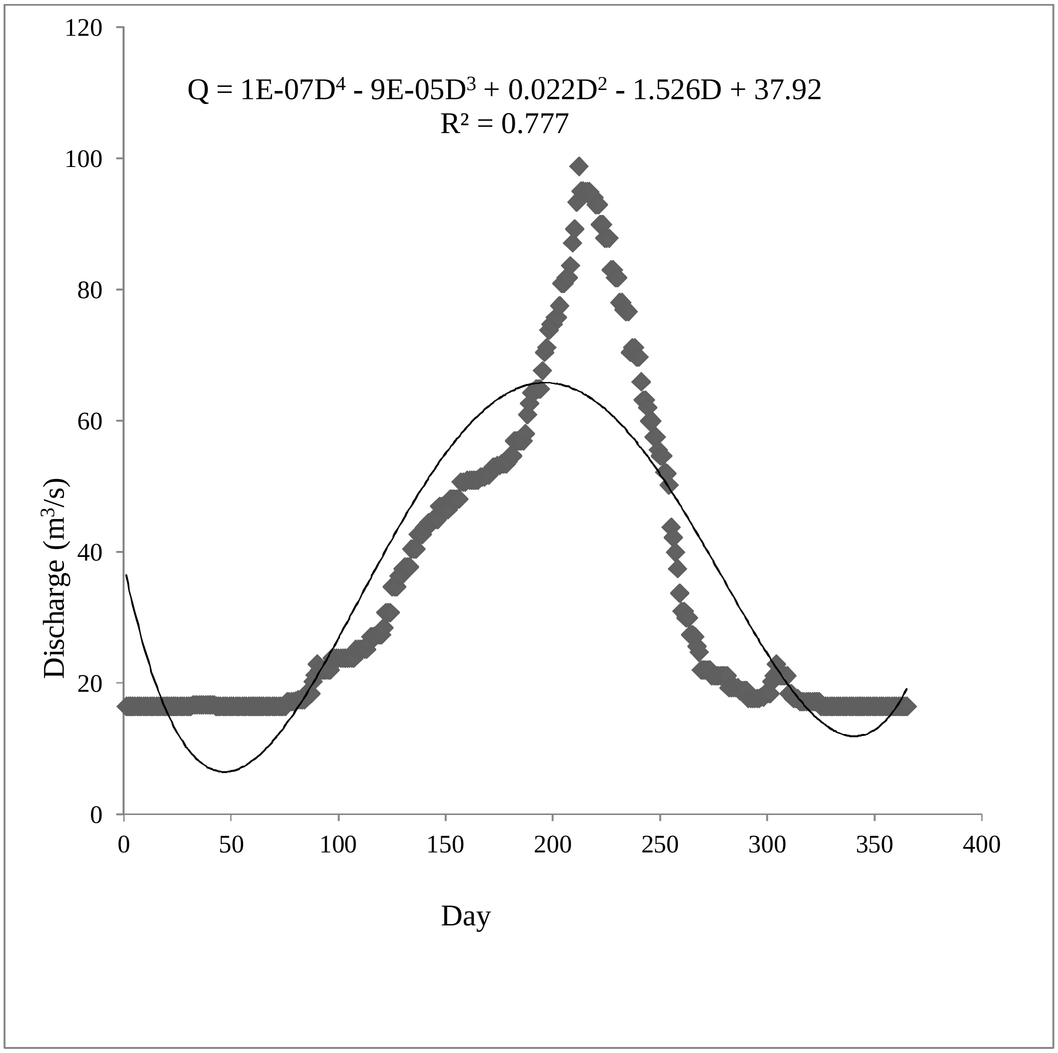

Figure 12: Discharge at Oyo/Iseyin

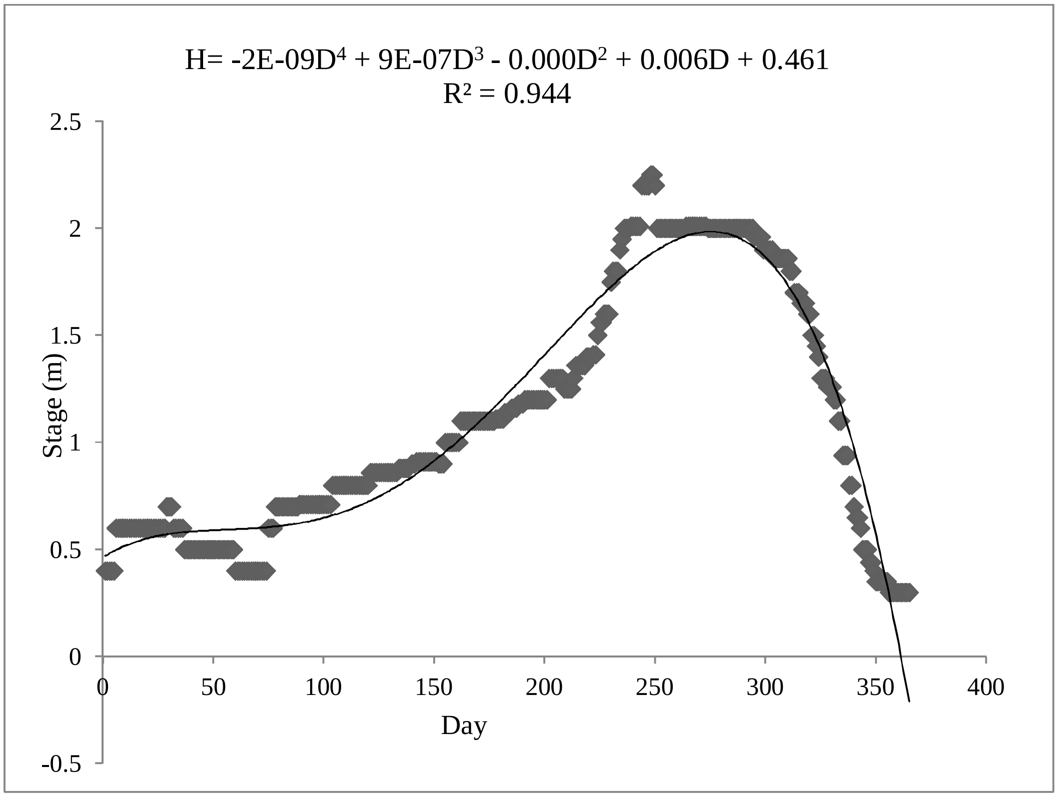

Figure 13: Daily stage at Ilaji-Ile station

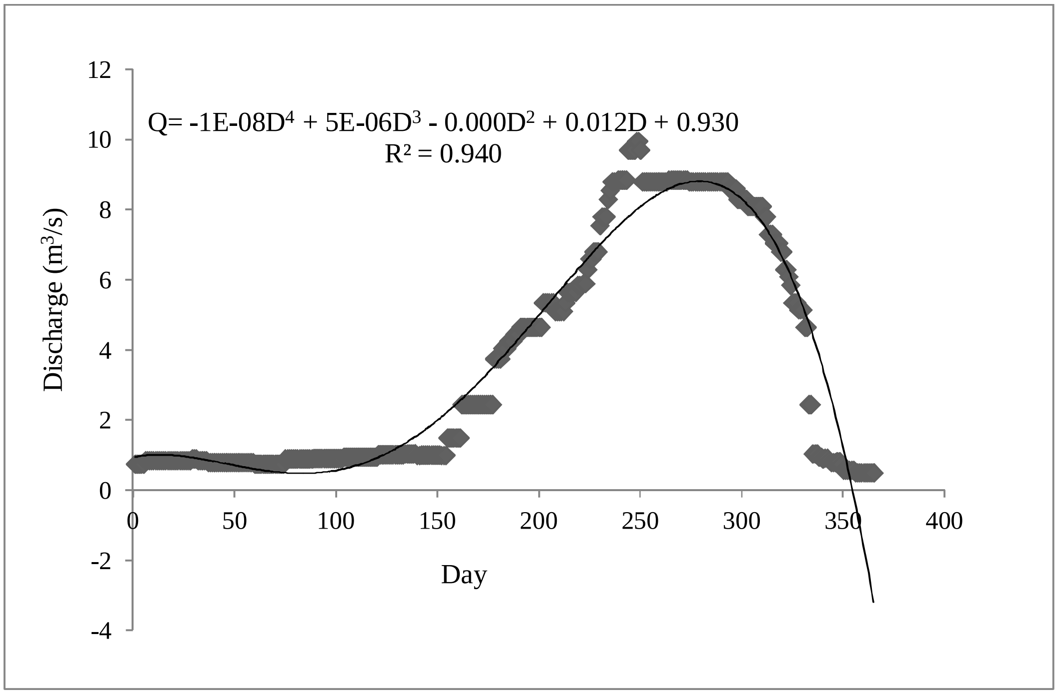

Figure 14: Daily discharge at Ilaji-Ile

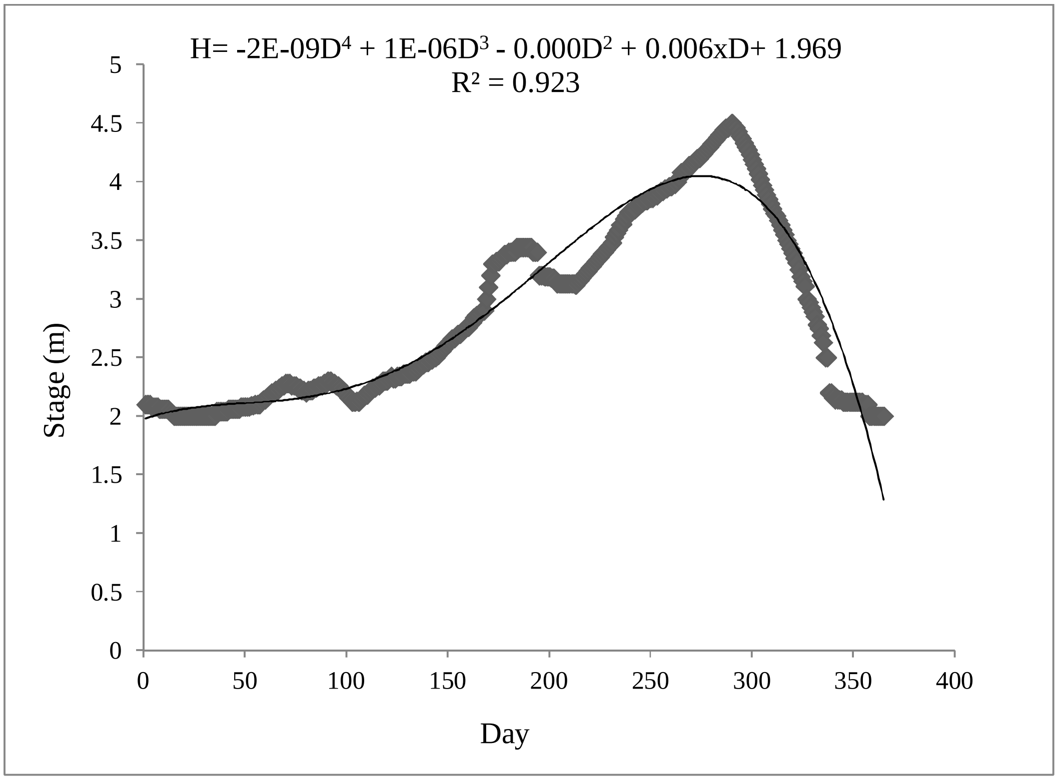

Figure 15: Daily stage at New Bridge, Abeokuta station

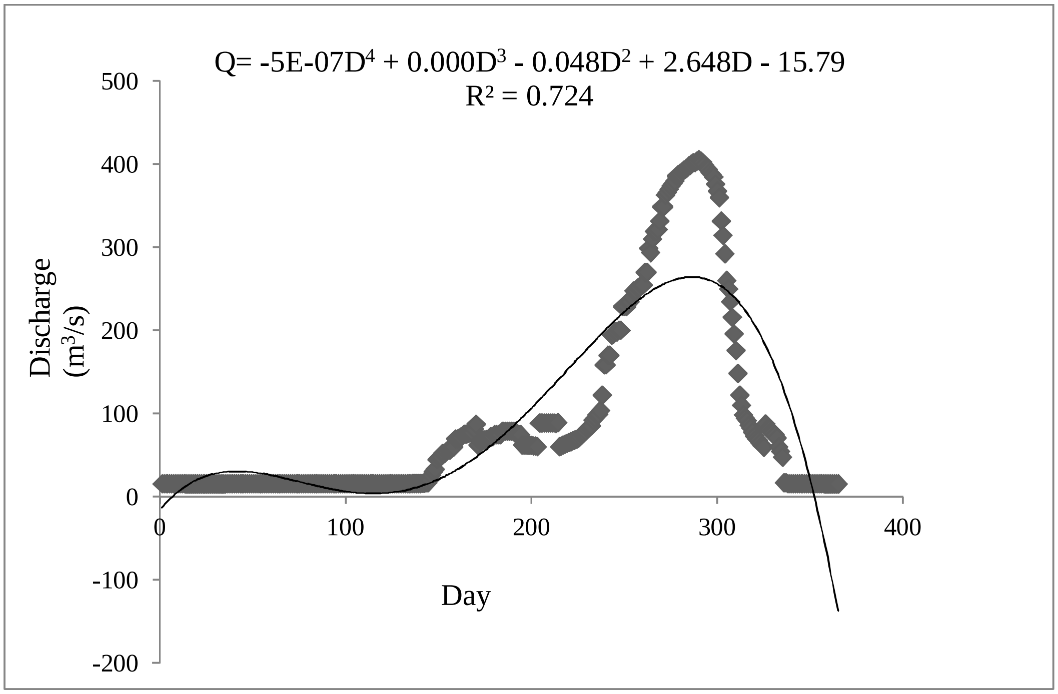

Figure 16: Daily discharge at New Bridge, Abeokuta station

4.5 Result from regionalization with multiple catchment characteristics

Land use type for the whole of Ogun river drainage basin is shown on Figure 17. The land use type was grouped into twenty-two types through unsupervised classification with their percentage land mass in Table 10 with the land use types that are greater than or equal to 1% as distributed forest as 4.38%, extensive smallholder rainfed agriculture as 6.13%, grassland as 6.42%, intensive smallholder rainfed agriculture and urban as 1.09. These were later considered as the dominant land use types.

Table 11 showed the physical and climatic characteristics of the catchment that were used percentage of dominant land use types in the regionalisation of the five catchments. The climatic data for Abeokuta weather station was used as a representative of the climate of the whole study location. The correlation between flow (Streamflow) and catchment characteristics that were significant at 5% are presented on Table 12. The correlation between the model parameter, percentage land use types and climate indicators was not possible (see appendix for the table of Correlation matrix). The statistical characteristics for the regression equation of model parameter, Log Q was given on Table 13. The model is significant at 5% with adjusted coefficient of determination of 99.98%.

The model performance was further evaluated with percentage relative volume error. All the five stations gave satisfactory result with – 0.54% for Ofiki, - 0.29% for Sepeteri, - 0.23% for Ilaji-ile and – 0.54% for Abeokuta (Table 14).

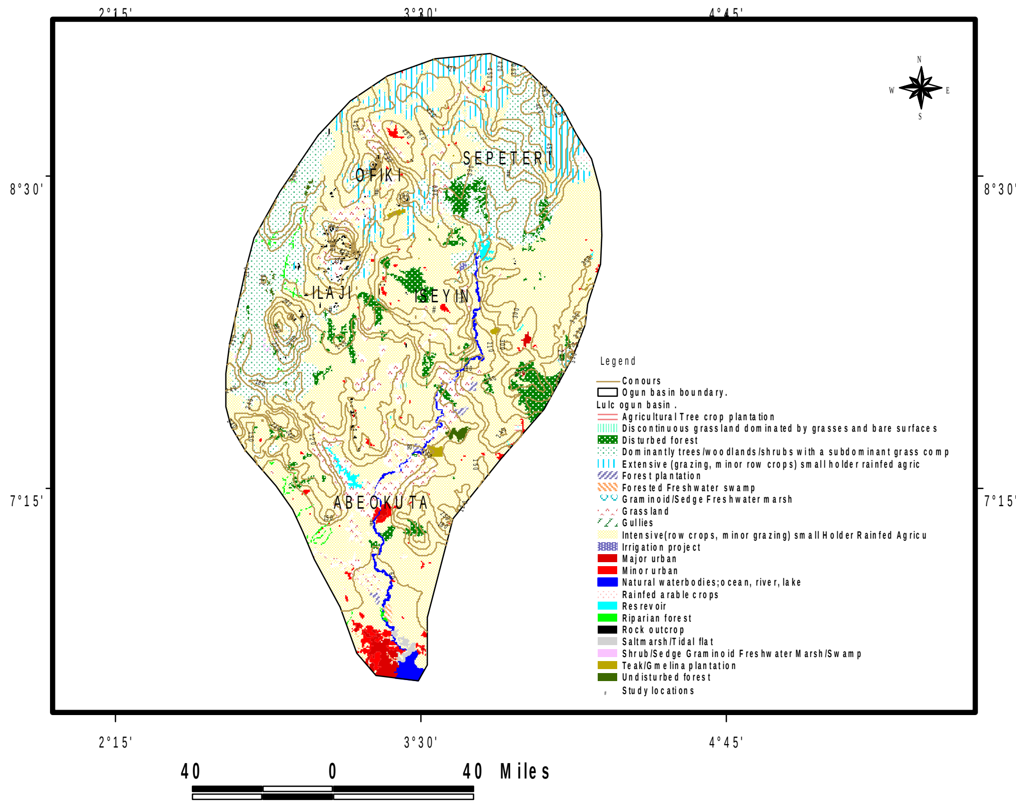

Figure 17: Land cover types and contour map obtained from the drainage shape file of Nigeria which was derived from 1995 Landsat TM images

Table 10: Percentage land use and land cover types

S/N	Land use type	Land use (%)
1	Agricultural tree crop	0.04
2	Distributed grass	0.02
3	Disturbed forest	4.38
4	Trees/woodland	19.13
5	Extensive smallholder rainfed agriculture	6.13
6	Forest plantation	0.19
7	Forested freshwater swamp	0.10
8	Graminoid/sedge freshwater marsh	0.05
9	Grassland	6.42
10	Gullies	0.02
11	Intensive smallholder rainfed agriculture	60.51
12	Irrigation project	0.03
13	Urban	1.09
14	Natural waterbodies like ocean, lakes, river	0.21
15	Rainfed arable crop	0.02
16	Reservoir	0.36
17	Riparian forest	0.31
18	Rock outcrop	0.36
19	Salt marsh/ tidal flat	0.15
20	Shrub/sedge graminoids	0.03
21	Teak/gmelina	0.22
22	Undistributed	0.21

Table 11: Selected physical catchment characteristics physical and climate characteristics of the catchment

Station name	Minimum elevation(m)	Maximum elevation(max)	Length (m)	Slope	Area (km^2)	MAP (mm)	MAT(^oC)
Ofiki	210	420	62541	0.0034	770	1189.9	26.7
Oyo/Iseyin	90	270	79892	0.0023	1190	1189.9	26.7
Sepeteri	300	450	34660	0.0043	5740	1189.9	26.7
Ilaji-ile	150	360	111348	0.0019	1610	1189.9	26.7
Abeokuta	90	240	103727	0.0014	21,030	1189.9	26.7

MAP (mm) – mean annual precipitation

MAT (^{o}C) – mean annual temperature

Table 12: Shows the correlation between flow characteristics and catchment descriptors

Catchment characteristics	Model parameter Q(m^3/s)
Stage(m)	0.826
Slope	-0.624
Maximum elevation(m)	-0.196
Minimum elevation(m)	-0.626
Catchment area (km^2)	0.997

Correlation between flow and catchment characteristics.

Only correlation coefficients significant at the 5% significance level are presented.

Table 13: Statistical characteristics for the regression equation LogQ

$\log Q = \beta_0 + \beta_1 \log CA + \beta_2 \log maxele + \beta_3 \log minele$					
	Coefficients	p-value	t_{cal}	Std error	R^2
β_0	-8.510	0.002	-335.208	0.025	99.98%
B_1	1.343	0.001	601.512	0.002	
B_2	1.872	0.002	385.610	0.005	
B_3	0.424	0.006	109.702	0.004	

$\log Q = -8.510 + 1.343 \log CA + 1.872 \log maxele + 0.424 \log minele$

$Q = 10^{-8.510} (CA)^{1.343} (maxele)^{1.872} (minele)^{0.424}$

Table 14: Evaluation of model performance

Station name	Minimum elevation (m)	Maximum elevation (m)	Area (km^2)	$Q_{tabulated}$ (m^3/s)	$Q_{calulated}$ (m^3/s)	% accuracy	($Q_{calulated}$ (m^3/s) - $Q_{tabulated}$ (m^3/s))/N	% RVE
Ofiki	210	420	770	18.37	18.27	99.51	0.1	- 0.54
Sepeteri	300	450	1190	24.2	24.13	99.71	0.07	- 0.29
Oyo/Iseyin	90	270	5740	83.05	82.86	99.77	0.19	- 0.23
Ilaji-ile	150	360	1610	9.04	9.00	99.56	0.04	- 0.44
Abeokuta	90	240	21,030	382.2	380.13	99.46	2.07	- 0.54

CHAPTER FIVE

5.0 DISCUSSIONS

One of the major constraints to water resources development in developing countries like Nigeria is the lack of basic data for planning, management and design. The role of hydrometric data collection has been regrettably either been under played or ignored by the respective authorities or agencies under them as a result of inadequate funding and man-power.

Data used for development of regionalisation protocol and empirical model for data scarce region were subjected to Grubbs-beck test for detection of outliers according to Laio *et al*. (2010) after scrutinizing the way the raw records were taken as readings from gauge stations, before being converted to discharges using rating tables. This was beneficial in that high level of confidence was then imparted on the data before being used though the outliers were left because they were considered to be true observations. The presence of outliers in the raw data did not bear any direct relationship with other tests because the criteria upon which they were based are quite different.

The predictive function of ungauged basins is enhanced in the case of hydrologically clearly separated physical regional classes (Solin, 2005). Therefore, rating equations were derived with one model parameter (streamflow) and one catchment characteristic (stage) for the five stations in both power and parabola forms using linear regression analysis (Parajka *et al*., 2005; Booij *et al*., 2007; Awokola *et al*., 2013). The derived daily–stage and daily-discharge equations for the five stations were used with their corresponding coefficient of determination and range of exponent for numeral and alphabetic grouping respectively into three (i.e. R^2 into

Zones I, II, III and range of exponent into A, B, C). These two groupings were later combined into three distinct hydrometric zones, A_u, B_u and C_u after the work of Awokola *et al*. (2013) and NERC (1975). This regionalisation protocol can be used to understand and perhaps quantitatively predict how a change in catchment characteristic will affect its hydrological response especially in catchments with scarce data that are similar with the model catchment hydrologically (Mwakalila, 2003).

Only Oyo/Iseyin with positive coefficient for both daily stage and daily discharge showed increasing trend to positive infinity at both ends thus has global minimum while Sepeteri gave negative coefficients for both daily stage and daily discharge thus decreasing trend to negative infinity at both ends with global maximum. Ofiki, Ilaji-ile and Abeokuta gave positive coefficients for stage and negative coefficients for discharge thus decrease to negative infinity at both ends.

Slope, minimum and maximum elevations calculated from the delineated map of the study area after the work of Palanisamy *et al*., 2014 and were negatively related to the discharge in line with the work of Merz and Bloschl, 2004. Stage and catchment area were positively correlated.

A model with percentage relative volume error (%RVE) smaller than + 10% and

– 10% and a coefficient of determination (R^2) of greater than 60% is said to be satisfactory according to *Wale et al.* (2009). Therefore, the derived rating equations of power type gave satisfactory results for the five stations while the equations derived in parabola form were satisfactory for four stations but were unsatisfactory for Abeokuta station in respect of percentage relative volume error. This implies that there might be problem of overestimation with the model for Abeokuta despite the fact that the model gave a good coefficient of determination of 77%.

The regionalised model with multiple catchment characteristics outperformed the models with only one catchment characteristics (Wale *et al*., 2009). This confirms the assumption made by Perera (2009) that the use of multiple physical catchment characteristics will give better relation than the use of only one.

5.1 Conclusion

The main objective of this study is the use of limited data and mathematical parameters to enhance prediction of streamflow in ungauged catchment. Therefore, the research has been executed using classical approaches of regionalisation techniques and the following conclusion made;

- A regionalisation protocol that was based on hydrometric parameters was developed for hydrological catchment classification
- The monthly maximum discharges for each station calculated from derived power equations were more satisfactory than ones calculated from parabola type
- Only Oyo/Iseyin gave a positive coefficient of the function for both daily stage and daily discharge while Sepeteri gave negative coefficient of the function for both daily stage and daily discharge. Ofiki, Ilaji-ile and Abeokuta gave positive coefficients for discharge and negative for stage.
- The model with multiple physical catchment characteristics outperformed the other two model types derived with only one characteristics of the catchment flow.

5.2 Recommendation

To further enhance the result of the regionalisation, the following recommendations are made;

- It is observed that the weather stations are not well distributed within the study location to represent the distinct climatic features of each station. As such the use of remote sensing data on regional scale should be explored.
- An open access hydrometric database with quality hydrometeorological data sshould be made available on internet because the process of writing and transferring data from hydrological year book or station's meteorological forms is cumbersome and often lead to error
- The use of rating equations with multiple catchment characteristics is recommended against the use of rating equations developed from only one characteristic.

5. 3 Contributions to knowledge

1. I have been able to develop regionalized classification rating based on analytically determined hydrometric parameters for the study locations.

2. I was able to estimate flow into the catchment using only one flow characteristic and physical catchment characteristics from geospatial data.

3. The regionalized protocols were mapped.

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APPENDIX

APPENDIX 1: Raw data of daily stage (m) and discharge (m^3/s) for the year 2009 for the five gauging stations considered in the study

Stage for Ofiki

S/N	JANUARY	FEBRARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1	1.7	1.72	1.7	1.92	2.11	2.78	3.08	4.11	3.2	6	1.9	1.7
2	1.7	1.72	1.7	1.92	2.2	2.78	3.08	4.11	3.16	1.9	1.9	1.7
3	1.7	1.72	1.7	1.92	2.2	2.78	3.08	4.1	3.16	1.9	1.9	1.7
4	1.7	1.72	1.7	1.92	2.2	2.78	3.08	4.1	3.1	1.9	1.9	1.7
5	1.7	1.72	1.7	1.92	2.36	2.78	3.08	4.1	3.1	1.9	1.9	1.7
6	1.7	1.72	1.7	1.92	2.36	2.84	3.12	4.06	3.04	1.9	1.84	1.7
7	1.7	1.72	1.7	1.96	2.36	2.84	3.18	4.06	3	1.9	1.84	1.7
8	1.7	1.72	1.7	1.96	2.42	2.84	3.21	4	3	1.9	1.8	1.7
9	1.7	1.72	1.7	1.96	2.42	2.86	3.26	4	2.91	1.86	1.8	1.7
10	1.7	1.72	1.7	1.96	2.48	2.86	3.26	3.92	2.9	1.86	1.8	1.7
11	1.7	1.72	1.7	1.96	2.49	2.86	3.28	3.92	2.81	1.86	1.76	1.7
12	1.7	1.7	1.7	1.96	2.49	2.86	3.28	3.86	2.72	1.86	1.76	1.7
13	1.7	1.7	1.7	1.96	2.49	2.86	3.28	3.86	2.63	1.86	1.76	1.7
14	1.7	1.7	1.7	1.96	2.56	2.86	3.36	3.86	2.54	1.85	1.76	1.7
15	1.7	1.7	1.7	1.96	2.56	2.88	3.41	3.72	2.48	1.85	1.76	1.7
16	1.7	1.7	1.7	1.96	2.56	2.88	3.42	3.72	2.32	1.85	1.76	1.7
17	1.7	1.7	1.76	1.96	2.66	2.88	3.46	3.68	2.21	1.85	1.76	1.7
18	1.7	1.7	1.76	1.99	2.66	2.89	3.48	3.68	2.21	1.8	1.76	1.7
19	1.7	1.7	1.76	1.99	2.66	2.89	3.48	3.6	2.16	1.8	1.76	1.7
20	1.7	1.7	1.76	1.99	2.72	2.91	3.52	3.6	2.16	1.8	1.76	1.7
21	1.7	1.7	1.77	1.99	2.72	2.94	3.52	3.56	2.06	1.8	1.7	1.7
22	1.7	1.7	1.78	1.99	2.74	2.94	3.58	3.55	2.06	1.8	1.7	1.7
23	1.7	1.7	1.78	1.99	2.74	2.96	3.66	3.55	2.03	1.8	1.7	1.7
24	1.7	1.7	1.78	2.01	2.76	2.96	3.66	3.41	2	1.82	1.7	1.7

25	1.7	1.7	1.78	2.03	2.76	2.98	3.68	3.42	1.98	1.82	1.7	1.7
26	1.7	1.7	1.84	2.03	2.76	2.98	3.68	3.42	1.92	1.84	1.7	1.7
27	1.7	1.7	1.84	2.04	2.77	2.98	3.74	3.4	1.92	1.84	1.7	1.7
28	1.7	1.7	1.84	2.06	2.77	2.99	3.84	3.4	1.92	1.84	1.7	1.7
29	1.7		1.84	2.06	2.76	3	3.9	3.31	1.92	1.88	1.7	1.7
30	1.7		1.89	2.06	2.76	3	4.02	3.22	1.92	1.9	1.7	1.7
31	1.7		1.89		2.76		4.16	3.22		1.94		1.7
SUM	**52.7**	**47.82**	**54.27**	**59.31**	**79.26**	**86.64**	**106.84**	**112.3**	**74.54**	**57.58**	**53.18**	**52.7**
AVERAGE	**1.7**	**1.71**	**1.75**	**1.98**	**2.56**	**2.89**	**3.45**	**3.74**	**2.48**	**1.86**	**1.77**	**1.7**

DISCHARGE FOR OFIKI TOWN(2009)

Date	January	Febrary	March	April	May	June	July	August	September	October	November	December
1	0.7	0.79	0.79	1.5	3.45	5.35	9.85	17.25	13.65	4.82	1.5	0.75
2	0.75	0.79	0.79	1.5	3.65	5.35	11.25	17.25	13.5	4.7	1.5	0.75
3	0.75	0.79	0.79	1.5	3.65	5.35	11.25	18.5	13.1	4.7	1.5	0.75
4	0.75	0.79	0.79	1.62	3.65	5.65	11.25	18.5	12.8	4.35	1.5	0.75
5	0.75	0.79	0.79	1.67	3.65	5.95	11.25	18.5	12.25	4.25	1.5	0.75
6	0.75	0.79	0.79	1.67	3.85	5.95	11.25	19.45	11.75	4.05	1.5	0.75
7	0.75	0.79	0.79	1.71	3.85	5.95	12.1	19.45	10.45	4.05	1.5	0.75
8	0.75	0.79	0.79	1.71	3.85	6.1	12.55	19.45	10.45	3.75	1.5	0.75
9	0.75	0.79	0.79	1.71	4.05	6.61	12.9	20.65	10.45	3.75	1.5	0.75
10	0.75	0.79	0.79	1.75	4.05	6.8	12.9	20.65	9.85	3.35	1.5	0.75
11	0.75	0.79	0.79	1.85	4.15	6.8	12.95	21.95	9.85	3.25	1.25	0.75
12	0.75	0.79	0.79	1.95	4.15	7	13	21.25	9.25	3	1.25	0.75
13	0.75	0.79	0.79	2.05	4.15	7.1	13	21.25	9.25	2.8	1.25	0.75
14	0.75	0.79	0.79	2.05	4.2	7.32	13.1	20.99	8.9	2.35	1.25	0.75
15	0.75	0.79	0.83	2.15	4.2	7.68	13.2	20.99	8.9	2.25	1	0.75
16	0.79	0.79	0.83	2.2	4.45	7.68	13.3	19.75	8.5	1.85	1	0.75
17	0.79	0.79	0.83	2.2	4.45	7.98	13.4	19.75	8.5	1.75	1	0.75
18	0.79	0.79	0.94	2.2	4.45	7.98	13.45	19.15	8.3	1.71	1	0.75
19	0.79	0.79	0.94	2.45	4.45	8.16	13.5	18.5	7.8	1.71	1	0.75
20	0.79	0.79	0.94	2.45	4.45	8.3	13.65	18.5	7.44	1.71	1	0.75
21	0.79	0.79	0.94	2.45	4.45	8.3	13.75	17.85	7.44	1.71	0.94	0.75
22	0.79	0.79	1	2.45	4.62	8.45	13.85	17.85	7.2	1.71	0.94	0.75
23	0.79	0.79	1.1	2.75	4.62	8.45	13.85	17.25	7.2	1.71	0.94	0.75
24	0.79	0.79	1.1	2.8	4.62	8.45	14.6	16.65	6.43	1.67	0.94	0.75
25	0.79	0.79	1.1	3	4.62	8.45	14.6	16.65	6.43	1.67	0.94	0.75
26	0.79	0.79	1.3	3	4.94	9.05	15.15	16.5	6.25	1.67	0.94	0.75
27	0.79	0.79	1.3	3	4.94	9.05	15.2	16.5	6.25	1.5	0.94	0.75
28	0.79	0.79	1.3	3	6.05	9.2	16.1	15.4	6.25	1.5	0.75	0.75
29	0.79		1.3	3.09	6.05	9.2	16.3	15.25	5.35	1.5	0.75	0.75

30	0.79		1.4	3.21	5.15	9.85	16.3	14	5.25	1.5	0.75	0.75
31	0.79		1.5		5.2		16.7	13.95		1.5		0.75
SUM	**23.84**	22.12	**29.71**	**66.64**	**136.06**	**223.51**	**415.5**	**569.58**	**268.99**	**81.79**	**34.83**	**23.25**
AVERAGE	0.77	0.79	0.96	2.22	4.39	7.45	13.4	18.37	8.97	2.64	1.16	0.75

Stage for Sepeteri

S/N	JANUARY	FEBRARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1	1.04	1.03	1.02	1.07	1.12	1.43	1.79	1.78	1.65	2.2	1.68	1.25
2	1.04	1.03	1.02	1.08	1.11	1.47	1.87	1.91	1.77	2.16	1.62	1.23
3	1.04	1.03	1.02	1.08	1.12	1.46	1.87	1.95	1.76	2.07	1.59	1.22
4	1.04	1.03	1.02	1.08	1.11	1.5	1.79	2.15	1.75	2	1.55	1.2
5	1.04	1.03	1.02	1.08	1.2	1.54	1.75	2.12	1.83	1.95	1.53	1.19
6	1.04	1.03	1.03	1.08	1.19	1.52	1.7	2.03	1.85	1.95	1.49	1.18
7	1.04	1.02	1.03	1.15	1.18	1.49	1.7	1.98	1.84	2.09	1.47	1.17
8	1.04	1.03	1.03	1.11	1.25	1.51	1.73	1.95	1.79	2.04	1.45	1.16
9	1.04	1.03	1.03	1.1	1.34	1.53	1.75	1.91	1.75	2.11	1.43	1.16
10	1.05	1.03	1.03	1.14	1.29	1.59	1.74	1.86	1.71	2.03	1.41	1.14
11	1.05	1.03	1.03	1.14	1.33	1.53	1.74	1.84	1.65	2.07	1.39	1.12
12	1.05	1.03	1.04	1.13	1.35	1.55	1.76	1.79	1.63	2.12	1.39	1.12
13	1.05	1.03	1.04	1.12	1.31	1.5	1.72	1.76	1.61	2.1	1.38	1.11
14	1.05	1.03	1.04	1.11	1.28	1.67	1.67	1.88	1.75	2.11	1.42	1.11
15	1.05	1.03	1.04	1.11	1.27	1.99	1.62	.81	1.87	2.11	1.41	1.1
16	1.05	1.03	1.04	1.1	1.25	1.92	1.58	1.74	1.81	1.96	1.4	1.09
17	1.05	1.03	1.04	1.1	1.23	1.9	1.55	1.68	1.72	2.12	1.37	1.09
18	1.04	1.03	1.04	1.1	1.22	1.99	1.57	1.68	1.71	2.12	1.37	1.09
19	1.04	1.03	1.04	1.1	1.2	1.95	1.58	1.64	1.67	2.1	1.36	1.08
20	1.05	1.03	1.04	1.09	1.21	1.95	1.59	1.65	1.66	1.96	1.33	1.07
21	1.05	1.02	1.04	1.09	1.2	2.01	1.57	1.81	1.71	1.94	1.32	1.07
22	1.05	1.02	1.04	1.19	1.34	2.04	1.58	1.8	1.7	1.91	1.31	1.07
23	1.05	1.02	1.1	1.17	1.43	1.97	1.53	1.72	1.67	1.89	1.31	1.07
24	1.05	1.02	1.08	1.16	1.39	1.96	1.5	1.66	1.71	1.89	1.29	1.07
25	1.05	1.02	1.07	1.15	1.34	1.95	1.49	1.67	3.55	1.81	1.28	1.07
26	1.04	1.02	1.07	1.14	1.3	1.98	1.5	1.68	1.69	1.76	1.29	1.07
27	1.04	1.02	1.07	1.13	1.34	2.02	1.69	1.65	1.69	1.73	1.28	1.07
28	1.03	1.02	1.07	1.13	1.36	1.95	1.71	1.58	1.79	1.69	1.28	1.07
29	1.03		1.07	1.13	1.32	1.88	1.66	1.59	2.06	1.66	1.27	1.05
30	1.03		1.07	1.13	1.3	1.82	1.61	1.62	2.06	1.69	1.27	1.05
31	1.03		1.07		1.3		1.58	1.62		1.74		1.05
Sum	**32.34**	28.75	32.39	33.49	39.18	52.57	51.49	55.51	54.41	61.08	41.94	34.59
average	1.04	1.03	1.04	1.12	1.26	1.75	1.66	1.79	1.81	1.97	1.4	1.12

Daily Discharge (m^3/s) for Sepeteri (2009)

S/N	JANUARY	FEBRARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1	8.1	7.95	7.8	8.7	9.45	13.55	17.6	17.5	16	30.8	16.3	11.5
2	8.1	7.95	7.8	8.85	9.3	14.3	19.8	21.6	17.3	30	15.7	11.2
3	8.1	7.95	7.8	8.85	9.45	14.2	19.8	23.4	17.2	27.5	15.4	11.05
4	8.1	7.95	7.8	8.85	9.3	14.5	17.6	29.5	17.1	25.65	15	10.7
5	8.1	7.95	7.8	8.85	10.7	14.8	17.1	29	18	23.4	14.7	10.55
6	8.1	7.95	7.95	8.85	10.55	14.6	16.5	27.1	18.9	23.4	14.5	10.35
7	8.1	7.8	7.95	9.9	10.35	14.5	16.5	24.75	18.45	27.8	14.3	10.2
8	8.1	7.95	7.95	10.2	11.5	14.5	16.8	23.4	17.6	27.2	14.1	10.05
9	8.1	7.95	7.95	9.15	13	14.7	17.1	21.6	17.1	28.5	13.55	10.05
10	8.25	7.95	7.95	9.75	12.5	15.4	17	19.35	16.6	27.1	13.55	9.75
11	8.25	7.95	7.95	9.75	13	14.7	17	18.45	16	27.5	13.55	9.45
12	8.25	7.95	8.1	9.6	13.5	15	17.2	17.6	15.8	29	13.55	9.45
13	8.25	7.95	8.1	9.45	12.5	14.5	16.7	17.2	15.6	28	13.5	9.3
14	8.25	7.95	8.1	9.3	12.15	16.2	16.2	20.25	17.1	28.5	13.55	9.3
15	8.25	7.95	8.1	9.3	11.85	25.2	15.7	17.8	19.8	28.5	13.55	9.15
16	8.25	7.95	8.1	9.15	11.5	23.4	15.3	17	17.8	23.85	13.55	9
17	8.25	7.95	8.1	9.15	11.2	23.4	15	16.3	16.7	29	13.5	9
18	8.1	7.95	8.1	9.15	11.05	26.1	15.2	16.3	16.6	29	13.5	9
19	8.1	7.95	8.1	9.15	10.7	27.2	15.3	15.9	16.2	28	13.5	8.85
20	8.25	7.95	8.1	9	10.85	24.3	15.4	16	16.1	23.85	13	8.7
21	8.25	7.8	8.1	9	10.7	23.85	15.2	17.8	16.6	22.95	12.55	8.7
22	8.25	7.8	8.1	10.55	13	23.4	15.3	17.7	16.5	21.6	12.5	8.7
23	8.25	7.8	9.15	10.2	13.55	24.75	14.7	16.7	16.2	20.7	12.5	8.7
24	8.25	7.8	8.85	10.05	13.55	27	14.5	16.1	16.6	20.7	12.5	8.7
25	8.25	7.8	8.7	9.9	13	23.4	14.5	16.2	76.7	17.8	12.15	8.7
26	8.1	8.1	8.7	9.75	12.5	24.75	14.5	16.3	16.4	17.2	12.5	8.7
27	8.1	8.1	8.7	9.6	13	27	16.4	16	16.4	16.8	12.15	8.7
28	7.95	7.95	8.7	9.6	13.5	23.4	16.6	15.3	17.6	16.4	12.15	8.7
29	7.95	222	8.7	9.6	12.55	20.25	16.1	15.4	27.4	16.1	11.85	8.25
30	7.95		8.7	9.6	12.5	17.9	15.6	15.7	27.4	16.4	11.85	8.25
31	7.95		8.7	9.426667	12.5		15.3	15.7		17		8.25
sum	**252.6**	**222**	**254.7**	**282.8**	**364.75**	**590.75**	**503.5**	**588.9**	**589.75**	**750.2**	**404.55**	**290.95**
Average	**8.148387**	**7.928571**	**8.216129**	**9.426667**	**11.76613**	**19.6916**	**16.2419**	**18.9967**	**19.658333**	**24.2**	**13.485**	**9.3854838**

DAILY STREAM OBSERVATION FOR OYO/ISEYIN (m)

S/N	JANUARY	FEBRARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1	1.7	1.72	1.7	1.92	2.11	2.78	3.08	4.11	3.2	6	1.9	1.7
2	1.7	1.72	1.7	1.92	2.2	2.78	3.08	4.11	3.16	1.9	1.9	1.7
3	1.7	1.72	1.7	1.92	2.2	2.78	3.08	4.1	3.16	1.9	1.9	1.7
4	1.7	1.72	1.7	1.92	2.2	2.78	3.08	4.1	3.1	1.9	1.9	1.7
5	1.7	1.72	1.7	1.92	2.36	2.78	3.08	4.1	3.1	1.9	1.9	1.7
6	1.7	1.72	1.7	1.92	2.36	2.84	3.12	4.06	3.04	1.9	1.84	1.7
7	1.7	1.72	1.7	1.96	2.36	2.84	3.18	4.06	3	1.9	1.84	1.7
8	1.7	1.72	1.7	1.96	2.42	2.84	3.21	4	3	1.9	1.8	1.7
9	1.7	1.72	1.7	1.96	2.42	2.86	3.26	4	2.91	1.86	1.8	1.7
10	1.7	1.72	1.7	1.96	2.48	2.86	3.26	3.92	2.9	1.86	1.8	1.7
11	1.7	1.72	1.7	1.96	2.49	2.86	3.28	3.92	2.81	1.86	1.76	1.7
12	1.7	1.7	1.7	1.96	2.49	2.86	3.28	3.86	2.72	1.86	1.76	1.7
13	1.7	1.7	1.7	1.96	2.49	2.86	3.28	3.86	2.63	1.86	1.76	1.7
14	1.7	1.7	1.7	1.96	2.56	2.86	3.36	3.86	2.54	1.85	1.76	1.7
15	1.7	1.7	1.7	1.96	2.56	2.88	3.41	3.72	2.48	1.85	1.76	1.7
16	1.7	1.7	1.7	1.96	2.56	2.88	3.42	3.72	2.32	1.85	1.76	1.7
17	1.7	1.7	1.76	1.96	2.66	2.88	3.46	3.68	2.21	1.85	1.76	1.7
18	1.7	1.7	1.76	1.99	2.66	2.89	3.48	3.68	2.21	1.8	1.76	1.7
19	1.7	1.7	1.76	1.99	2.66	2.89	3.48	3.6	2.16	1.8	1.76	1.7
20	1.7	1.7	1.76	1.99	2.72	2.91	3.52	3.6	2.16	1.8	1.76	1.7
21	1.7	1.7	1.77	1.99	2.72	2.94	3.52	3.56	2.06	1.8	1.7	1.7
22	1.7	1.7	1.78	1.99	2.74	2.94	3.58	3.55	2.06	1.8	1.7	1.7
23	1.7	1.7	1.78	1.99	2.74	2.96	3.66	3.55	2.03	1.8	1.7	1.7
24	1.7	1.7	1.78	2.01	2.76	2.96	3.66	3.41	2	1.82	1.7	1.7
25	1.7	1.7	1.78	2.03	2.76	2.98	3.68	3.42	1.98	1.82	1.7	1.7
26	1.7	1.7	1.84	2.03	2.76	2.98	3.68	3.42	1.92	1.84	1.7	1.7
27	1.7	1.7	1.84	2.04	2.77	2.98	3.74	3.4	1.92	1.84	1.7	1.7
28	1.7	1.7	1.84	2.06	2.77	2.99	3.84	3.4	1.92	1.84	1.7	1.7
29	1.7		1.84	2.06	2.76	3	3.9	3.31	1.92	1.88	1.7	1.7
30	1.7		1.89	2.06	2.76	3	4.02	3.22	1.92	1.9	1.7	1.7
31	1.7		1.89		2.76		4.16	3.22		1.94		1.7
SUM	**52.7**	**47.82**	**54.27**	**59.31**	**79.26**	**86.64**	**106.84**	**112.3**	**74.54**	**57.58**	**53.18**	**52.7**
AVERAGE	**1.7**	**1.71**	**1.75**	**1.98**	**2.56**	**2.89**	**3.45**	**3.74**	**2.48**	**1.86**	**1.77**	**1.7**

DAILY DISCHARGE FOR OYO/ISEYIN

S/N	JANUARY	FEBRARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1	16.5	16.7	16.5	22.05	28.5	48.1	57	95.1	62.1	21.15	21.15	16.5
2	16.5	16.7	16.5	22.05	30.8	48.1	57	95.1	60	21.15	21.15	16.5
3	16.5	16.7	16.5	22.05	30.8	48.1	57	95	60	21.15	21.15	16.5
4	16.5	16.7	16.5	22.05	30.8	48.1	57	95	57.6	21.15	21.15	16.5
5	16.5	16.7	16.5	22.05	34.75	48.1	57	95	57.6	21.15	21.15	16.5
6	16.5	16.7	16.5	22.05	34.75	50.7	58.1	94.1	55.6	21.15	18.45	16.5
7	16.5	16.7	16.5	23.85	34.75	50.7	61	94.1	54.7	21.15	18.45	16.5
8	16.5	16.7	16.5	23.85	36.35	50.7	62.7	93	54.7	21.15	17.7	16.5
9	16.5	16.7	16.5	23.85	36.35	51	64.35	93	52.25	19.35	17.7	16.5
10	16.5	16.7	16.5	23.85	37.5	51	64.35	90	52	19.35	17.7	16.5
11	16.5	16.7	16.5	23.85	37.75	51	64.9	90	50.25	19.35	17.2	16.5
12	16.5	16.5	16.5	23.85	37.75	51	64.9	87.9	43.8	19.35	17.2	16.5
13	16.5	16.5	16.5	23.85	37.75	51	64.9	87.9	42.25	19.35	17.2	16.5
14	16.5	16.5	16.5	23.85	40.5	51	67.7	87.9	40	18.9	17.2	16.5
15	16.5	16.5	16.5	23.85	40.5	51.5	70.5	83.1	37.5	18.9	17.2	16.5
16	16.5	16.5	16.5	23.85	40.5	51.5	71.2	83.1	33.75	18.9	17.2	16.5
17	16.5	16.5	17.2	23.85	42.7	51.5	73.9	81.9	31	18.9	17.2	16.5
18	16.5	16.5	17.2	25.2	42.7	51.8	74.8	81.9	31	17.7	17.2	16.5
19	16.5	16.5	17.2	25.2	42.7	51.8	74.8	78.1	30	17.7	17.2	16.5
20	16.5	16.5	17.2	25.2	43.8	52.25	75.8	78.1	30	17.7	17.2	16.5
21	16.5	16.5	17.3	25.2	43.8	53	75.8	77	27.4	17.7	16.5	16.5
22	16.5	16.5	17.5	25.2	44.5	53	77.6	76.7	27.4	17.7	16.5	16.5
23	16.5	16.5	17.5	25.2	44.5	53.25	81	76.7	27.1	17.7	16.5	16.5
24	16.5	16.5	17.5	26.1	45	53.25	81	70.5	25.65	17.9	16.5	16.5
25	16.5	16.5	17.5	27.1	45	53.5	81.9	71.2	24.75	17.9	16.5	16.5
26	16.5	16.5	18.45	27.1	45	53.5	81.9	71.2	22.05	18.45	16.5	16.5
27	16.5	16.5	18.45	27.2	47	53.5	83.7	69.8	22.05	18.45	16.5	16.5
28	16.5	16.5	18.45	27.4	47	53.85	87.2	69.8	22.05	18.45	16.5	16.5
29	16.5		20.25	27.4	46.5	54.7	89.3	66	22.05	20.25	16.5	16.5
30	16.5		21.25	27.4	46.5	54.7	93.4	63.2	22.05	21.15	16.5	16.5
31	16.5		22.95		46.5		98.85	63.2		22.95		16.5
Sum	**511.5**	**464.2**	**539.9**	**735.55**	**1243.3**	**1545.2**	**2230.55**	**2491.4**	**1240.75**	**603.25**	**532.75**	**511.5**
Average	**16.5**	**16.57857**	**17.4161**	**24.5183**	**40.1064**	**51.5066**	**71.9532**	**83.0466**	**39.288333**	**19.45967**	**17.758333**	**16.5**

DAILY STEAM OBSERVATION OF OYAN RIVER AT ILAJI- ILE

S/N	JANUARY	FEBRARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1	0.4	0.6	0.4	0.71	0.86	0.9	1.14	1.3	2.2	2	1.86	0.94
2	0.4	0.6	0.4	0.71	0.86	0.9	1.14	1.36	2.2	2	1.86	0.94
3	0.4	0.6	0.4	0.71	0.86	0.9	1.14	1.36	2.2	2	1.86	0.94
4	0.4	0.6	0.4	0.71	0.86	1	1.16	1.36	2.2	2	1.86	0.8
5	0.4	0.6	0.4	0.71	0.86	1	1.16	1.36	2.25	2	1.86	0.8
6	0.6	0.5	0.4	0.71	0.86	1	1.16	1.36	2.25	2	1.86	0.7
7	0.6	0.5	0.4	0.71	0.86	1	1.18	1.4	2.2	2	1.8	0.65
8	0.6	0.5	0.4	0.71	0.86	1	1.18	1.4	2	2	1.8	0.65
9	0.6	0.5	0.4	0.71	0.86	1	1.18	1.4	2	2	1.7	0.6
10	0.6	0.5	0.4	0.71	0.86	1	1.2	1.41	2	2	1.7	0.5
11	0.6	0.5	0.4	0.71	0.86	1.1	1.2	1.41	2	2	1.7	0.5
12	0.6	0.5	0.4	0.71	0.86	1.1	1.2	1.5	2	2	1.65	0.5
13	0.6	0.5	0.4	0.71	0.86	1.1	1.2	1.56	2	2	1.65	0.44
14	0.6	0.5	0.4	0.8	0.88	1.1	1.2	1.56	2	2	1.65	0.44
15	0.6	0.5	0.4	0.8	0.88	1.1	1.2	1.6	2	2	1.6	0.4
16	0.6	0.5	0.6	0.8	0.88	1.1	1.2	1.6	2	2	1.6	0.35
17	0.6	0.5	0.6	0.8	0.88	1.1	1.2	1.6	2	2	1.5	0.35
18	0.6	0.5	0.6	0.8	0.88	1.1	1.2	1.75	2	2	1.5	0.35
19	0.6	0.5	0.7	0.8	0.89	1.1	1.2	1.8	2	2	1.45	0.35
20	0.6	0.5	0.7	0.8	0.9	1.1	1.2	1.8	2	2	1.4	0.35
21	0.6	0.5	0.7	0.8	0.9	1.1	1.3	1.8	2.01	2	1.3	0.35
22	0.6	0.5	0.7	0.8	0.91	1.1	1.3	1.9	2.01	1.96	1.3	0.3
23	0.6	0.5	0.7	0.8	0.91	1.1	1.3	1.95	2.01	1.96	1.3	0.3
24	0.6	0.5	0.7	0.8	0.91	1.1	1.3	2	2.01	1.96	1.26	0.3
25	0.6	0.5	0.7	0.8	0.91	1.1	1.3	2	2.01	1.96	1.26	0.3
26	0.6	0.5	0.7	0.8	0.91	1.1	1.3	2	2.01	1.9	1.26	0.3
27	0.6	0.5	0.7	0.8	0.91	1.11	1.3	2.01	2.01	1.9	1.2	0.3
28	0.6	0.5	0.7	0.8	0.91	1.11	1.25	2.01	2.01	1.9	1.2	0.3
29	0.7		0.7	0.8	0.91	1.11	1.25	2.01	2.01	1.9	1.1	0.3
30	0.7		0.71	0.8	0.91	1.11	1.25	2.01	2.01	1.9	1.1	0.3
31	0.7		0.71		0.91		1.25	2.01		1.86		0.3
SUM	**17.9**	**14.5**	**16.92**	**22.83**	**27.37**	**31.74**	**37.74**	**51.59**	**61.6**	**61.2**	**46.14**	**14.9**
AVERAGE	**0.58**	**0.52**	**0.55**	**0.76**	**0.88**	**1.06**	**1.22**	**1.66**	**2.05**	**1.97**	**1.54**	**0.48**

DISCHARGE FOR ILAJI- ILE

S/N	JANUARY	FEBRARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1	0.75	0.85	0.75	0.91	1.02	1	4.05	5.35	9.7	8.8	8.1	1.04
2	0.75	0.85	0.75	0.91	1.02	1	4.05	5.65	9.7	8.8	8.1	1.04
3	0.75	0.85	0.75	0.91	1.02	1	4.05	5.65	9.7	8.8	8.1	1.04
4	0.75	0.85	0.75	0.91	1.02	1.5	4.25	5.65	9.7	8.8	8.1	0.95
5	0.75	0.85	0.75	0.91	1.02	1.5	4.25	5.65	9.95	8.8	8.1	0.95
6	0.85	0.8	0.75	0.91	1.02	1.5	4.25	5.65	9.95	8.8	8.1	0.9
7	0.85	0.8	0.75	0.91	1.02	1.5	4.45	5.85	9.7	8.8	7.8	0.92
8	0.85	0.8	0.75	0.91	1.02	1.5	4.45	5.85	8.8	8.8	7.8	0.92
9	0.85	0.8	0.75	0.91	1.02	1.5	4.45	5.85	8.8	8.8	7.3	0.85
10	0.85	0.8	0.75	0.91	1.02	1.5	4.65	5.9	8.8	8.8	7.3	0.8
11	0.85	0.8	0.75	0.91	1.02	2.45	4.65	5.9	8.8	8.8	7.3	0.8
12	0.85	0.8	0.75	0.91	1.02	2.45	4.65	6.3	8.8	8.8	7.05	0.8
13	0.85	0.8	0.75	0.91	1.02	2.45	4.65	6.6	8.8	8.8	7.05	0.82
14	0.85	0.8	0.75	0.95	1.04	2.45	4.65	6.6	8.8	8.8	7.05	0.82
15	0.85	0.8	0.75	0.95	1.04	2.45	4.65	6.8	8.8	8.8	6.8	0.75
16	0.85	0.8	0.9	0.95	1.04	2.45	4.65	6.8	8.8	8.8	6.8	0.58
17	0.85	0.8	0.9	0.95	1.04	2.45	4.65	6.8	8.8	8.8	6.3	0.58
18	0.85	0.8	0.9	0.95	1.04	2.45	4.65	7.55	8.8	8.8	6.3	0.58
19	0.85	0.8	0.9	0.95	1.05	2.45	4.65	7.8	8.8	8.8	6.1	0.58
20	0.85	0.8	0.9	0.95	1	2.45	4.65	7.8	8.8	8.8	5.85	0.58
21	0.85	0.8	0.9	0.95	1	2.45	5.35	7.8	8.85	8.6	5.35	0.58
22	0.85	0.8	0.9	0.95	1.01	2.45	5.35	8.3	8.85	8.6	5.35	0.5
23	0.85	0.8	0.9	0.95	1.01	2.45	5.35	8.55	8.85	8.6	5.35	0.5
24	0.85	0.8	0.9	0.95	1.01	2.45	5.35	8.8	8.85	8.6	5.15	0.5
25	0.85	0.8	0.9	0.95	1.01	2.45	5.35	8.8	8.85	8.3	5.15	0.5
26	0.85	0.8	0.9	0.95	1.01	2.45	5.35	8.8	8.85	8.3	5.15	0.5
27	0.85	0.8	0.9	0.95	1.01	3.75	5.1	8.85	8.85	8.3	4.65	0.5
28	0.85	0.8	0.9	0.95	1.01	3.75	5.1	8.85	8.85	8.3	4.65	0.5
29	0.9		0.9	0.95	1.01	3.75	5.1	8.85	8.85	8.3	2.45	0.5
30	0.9		0.91	0.95	1.01	3.75	5.1	8.85	8.85	8.1	2.45	0.5
31	0.9		0.91		1.01		5.1	8.85		8.1		0.5
SUM	**26**	**21.8**	**25.67**	**27.98**	**31.61**	**67.7**	**147**	**221.3**	**271.3**	**260**	**191.1**	**21.88**
AVERAGE	**0.84**	**0.81**	**0.83**	**0.93**	**1.02**	**2.26**	**4.74**	**7.14**	**9.04**	**8.67**	**6.37**	**0.71**

DAILY STREAM LEVEL OBSERVATION FOR NEW BRIDGE ,ABEOKUTA

S/N	JANUARY	FEBRARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1	2.1	2	2.14	2.3	2.32	2.66	3.4	3.12	3.81	4.2	3.97	2.63
2	2.1	2	2.16	2.3	2.34	2.66	3.4	3.14	3.82	4.22	3.93	2.5
3	2.1	2	2.18	2.28	2.32	2.68	3.44	3.16	3.82	4.24	3.89	2.5
4	2.08	2	2.2	2.28	2.32	2.7	3.44	3.18	3.84	4.26	3.85	2.2
5	2.08	2.04	2.2	2.26	2.34	2.7	3.44	3.2	3.84	4.28	3.81	2.2
6	2.08	2.04	2.22	2.26	2.34	2.72	3.44	3.22	3.86	4.3	3.77	2.16
7	2.08	2.04	2.22	2.24	2.34	2.74	3.44	3.24	3.86	4.32	3.73	2.14
8	2.06	2.04	2.24	2.22	2.36	2.76	3.44	3.26	3.86	4.34	3.71	2.14
9	2.06	2.04	2.26	2.2	2.36	2.76	3.44	3.28	3.88	4.36	3.67	2.14
10	2.06	2.04	2.26	2.18	2.36	2.78	3.44	3.3	3.88	4.38	3.63	2.14
11	2.06	2.06	2.28	2.16	2.36	2.8	3.4	3.32	3.9	4.4	3.59	2.12
12	2.06	2.06	2.28	2.14	2.38	2.84	3.4	3.34	3.92	4.42	3.55	2.12
13	2.04	2.06	2.28	2.12	2.38	2.86	3.4	3.36	3.92	4.44	3.5	2.12
14	2.02	2.06	2.26	2.12	2.38	2.86	3.2	3.38	3.94	4.46	3.47	2.12
15	2	2.06	2.26	2.13	2.4	2.88	3.2	3.4	3.94	4.46	3.43	2.12
16	2	2.06	2.26	2.12	2.42	2.9	3.2	3.42	3.96	4.48	3.39	2.12
17	2	2.08	2.24	2.14	2.44	2.9	3.19	3.44	3.96	4.5	3.35	2.12
18	2	2.08	2.24	2.16	2.44	3	3.19	3.46	3.98	4.48	3.31	2.12
19	2	2.08	2.22	2.18	2.46	3.1	3.19	3.48	3.98	4.46	3.25	2.12
20	2	2.08	2.22	2.18	2.46	3.2	3.18	3.53	4	4.43	3.19	2.12
21	2	2.08	2.2	2.2	2.48	3.3	3.18	3.56	4.03	4.39	3.15	2.1
22	2	2.09	2.22	2.22	2.48	3.3	3.16	3.59	4.08	4.37	3.11	2.1
23	2	2.09	2.22	2.24	2.5	3.32	3.13	3.63	4.08	4.33	3	2.1
24	2	2.1	2.22	2.24	2.5	3.32	3.13	3.64	4.09	4.3	2.97	2
25	2	2.1	2.24	2.26	2.52	3.34	3.13	3.68	4.11	4.27	2.93	2
26	2	2.1	2.24	2.26	2.54	3.36	3.13	3.71	4.14	4.23	2.89	2
27	2	2.12	2.26	2.28	2.56	3.38	3.13	3.74	4.14	4.19	2.85	2
28	2	2.14	2.26	2.3	2.58	3.38	3.13	3.74	4.16	4.15	2.78	2
29	2		2.26	2.3	2.6	3.4	3.13	3.76	4.18	4.11	2.75	2
30	2		2.28	2.3	2.62	3.4	3.13	3.76	4.2	4.07	2.69	2
31	2		2.28		2.64		3.13	3.8		4.02		2
SUM	**62.98**	**57.74**	**69.3**	**66.57**	**75.54**	**90**	**101.38**	**106.84**	**119.18**	**133.86**	**103.74**	**66.25**
AVERAGE	**2.03**	**2.06**	**2.24**	**2.22**	**2.44**	**3**	**3.27**	**3.45**	**3.97**	**4.32**	**3.35**	**2.14**

DISCHARGE FOR NEW,BRIDGE,ABEOKUTA

S/N	JANUARY	FEBRARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1	15.86	15.76	15.9	16.05	16.07	52.5	75	88.5	196	370	260.5	48
2	15.86	15.76	15.91	16.05	16.09	52.5	75	89.5	198.5	374	250	17
3	15.86	15.76	15.93	16.03	16.07	54.5	79	60.5	198.5	377	235	17
4	15.84	15.76	15.95	16.03	16.07	56.5	79	61.5	200.5	380	216	15.95
5	15.84	15.8	15.95	16.01	16.09	56.5	79	62.5	200.5	385.9	196	15.95
6	15.84	15.8	15.97	16.01	16.09	58.5	79	63.5	229	387.7	176	15.91
7	15.84	15.8	15.97	15.99	16.09	60	79	64.5	229	389.5	148.6	15.9
8	15.82	15.8	15.99	15.97	16.11	70	79	65.5	229	391.31	122.5	15.9
9	15.82	15.8	16.01	15.95	16.11	70	79	66.5	234.5	393.11	110.5	15.9
10	15.82	15.8	16.01	15.93	16.11	71	79	67.5	234.5	394.91	99	15.9
11	15.82	15.82	16.03	15.91	16.11	72.5	75	68.5	240	396.72	95	15.88
12	15.82	15.82	16.03	15.9	16.13	74.5	75	69.5	248	398.52	92.05	15.88
13	15.8	15.82	16.03	15.88	16.13	75.5	75	70.5	248	400.32	86	15.88
14	15.78	15.82	16.01	15.88	16.13	75.5	62.5	72.5	251.5	402.13	83	15.88
15	15.76	15.82	16.01	15.89	16.15	76.5	62.5	75	251.5	402.13	78	15.88
16	15.76	15.82	16.01	15.88	16.18	77.5	62.5	77	255	403.91	73	15.88
17	15.76	15.84	15.99	15.9	16.2	77.5	62	79	255	405.73	70	15.88
18	15.76	15.84	15.99	15.91	16.2	82	62	82	270	403.91	68	15.88
19	15.76	15.84	15.97	15.93	16.22	87.5	62	84.05	270	402.13	65	15.88
20	15.76	15.84	15.97	15.93	16.22	62.5	61.5	85.5	299	399.42	62	15.88
21	15.76	15.84	15.95	15.95	16.24	67.5	61.5	92.5	293.7	395.82	60	15.86
22	15.76	15.85	15.97	15.97	16.24	67.5	60.5	95	310.5	394.02	88	15.86
23	15.76	15.85	15.97	15.99	17	68.5	89	99	319.5	390.4	82	15.86
24	15.76	15.86	15.97	15.99	17	68.5	89	99.5	319.5	387.7	80.9	15.76
25	15.76	15.86	15.99	16.01	20.14	69.5	89	104	322	385	79	15.76
26	15.76	15.86	15.99	16.01	26.12	70.5	89	122.5	332	376	77	15.76
27	15.76	15.88	16.01	16.03	30.4	72.5	89	159	349	368	75	15.76
28	15.76	15.9	16.01	16.05	33.44	72.5	89	159	349	360	71	15.76
29	15.76		16.01	16.05	45.14	75	89	170.5	363	332	60.5	15.76

30	15.76		16.03	16.05	47.48	75	89	170.5	366	314.5	55	15.76
31	15.76		16.03		48.3		89	194.5		292.5		15.76
SUM	**489.54**	**443.02**	**495.56**	**497.13**	**640.07**	**2070.5**	**2365**	**2919.55**	**8062.2**	**11854.29**	**3362.55**	**525.87**
AVERAGE	**15.79**	**15.82**	**15.99**	**15.97**	**20.65**	**69.02**	**76.29**	**94.18**	**268.4**	**382.4**	**108.47**	**16.96**

APPENDIX 2: Outlook of selected output of Grubbs test for outliers

Stage (m) for Oyo/ Iseyin station

XLSTAT 2016.06.35837 - Grubbs test for outliers - Start time: 30/10/2016 at 20:51:51 / End time: 30/10/2016 at 20:51:58
Data: Workbook = my project analysis (version 1).xlsb / Sheet = Sheet4 / Range = Sheet4!$P$3:$P$368 / 365 rows and 1 column
Alternative hypothesis: Two-sided
Significance level (%): 5
Iterations: Maximum: 1
Run again:

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Stage	365	0	365	1.700	6.000	2.316	0.752

Grubbs test for outliers / Two-tailed test:

G (Observed value)	4.899
G (Critical value)	3.778
p-value (Two-tailed)	0.000
alpha	0.05

99% confidence interval on the p-value:
] 0.000, 0.000 [

Test interpretation:
H0: There is no outlier in the data
Ha: The minimum or maximum value is an outlier
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The risk to reject the null hypothesis H0 while it is true is lower than 0.02%.

Outliers:

Stage	G	G(Critical value)	p-value	Step
6.000	4.899	3.778	0.000	1

Discharge (m^3/s) for Oyo/Iseyin station

XLSTAT 2016.06.35837 - Grubbs test for outliers - Start time: 30/10/2016 at 20:54:03 / End time: 30/10/2016 at 20:54:08
Data: Workbook = my project analysis (version 1).xlsb / Sheet = Sheet4 / Range = Sheet4!$S$3:$S$368 / 365 rows and 1 column

Alternative hypothesis: Two-sided
Significance level (%): 5
Iterations: Maximum: 1
Run again:

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Discharge	365	0	365	16.500	98.850	34.660	23.217

Grubbs test for outliers / Two-tailed test:

G (Observed value)	2.765
G (Critical value)	3.778
p-value (Two-tailed)	0.001
alpha	0.05

99% confidence interval on the p-value:
] 0.001, 0.001 [

Test interpretation:

H0: There is no outlier in the data

Ha: The minimum or maximum value is an outlier

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The risk to reject the null hypothesis H0 while it is true is lower than 0.12%.

Outliers:

Discharge	G	G(Critical value)	p-value	Step
98.850	2.765	3.778	0.001	1

Stage (m) for Ofiki station

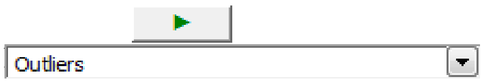
XLSTAT 2016.06.35837 - Grubbs test for outliers - Start time: 02/10/2016 at 22:42:20 / End time: 02/10/2016 at 22:42:31 / End time: 02/10/2016 at 22:4

Data: Workbook = my project analysis.xlsx / Sheet = Sheet1 / Range = Sheet1!$Q$3:$Q$368 / 365 rows and 1 column

Alternative hypothesis: Two-sided

Significance level (%): 5

Iterations: Maximum: 1



again:

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Stage	365	0	365	0.380	3.080	1.141	0.796

Grubbs test for outliers / Two-tailed test:

G (Observed value)	2.435
G (Critical value)	3.778
p-value (Two-tailed)	< 0.0001
alpha	0.05

99% confidence interval on the p-value:

] 0.000, 0.000 [

c

s

Test interpretation:

H0: There is no outlier in the data

Ha: The minimum or maximum value is an outlier

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The risk to reject the null hypothesis H0 while it is true is lower than 0.01%.

Outliers:

Stage	G	G(Critical value)	p-value	Step
3.080	2.435	3.778	< 0.0001	1

Appendix 3.

Correlations

		Qms	Stagem	Grassland	ISRA	Urban	DF	Treeswoodland0	ESRA	CatchmentareaKm	Slope	Maxelem	Minelem	MAPmm	MATC
Qms	Pearson Correlation	1	.826	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.997[**]	-.624	-.196	-.626	.[a]	.[a]
	Sig. (2-tailed)		.085	.	.	.	.	.	.	.000	.261	.753	.258	.	.
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Stagem	Pearson Correlation	.826	1	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.840	-.627	.028	-.945[*]	.[a]	.[a]
	Sig. (2-tailed)	.085		.	.	.	.	.	.	.075	.257	.965	.016	.	.
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Grassland	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.		.	.	.	.	.	.	.	.	.	.	.
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5
ISRA	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.			.	.	.	.	.	.	.	.	.
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Urban	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.		.	.	.	.	.	.	.	.	.
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5

DF	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.	.		.	.	.	.	.	.	.	.
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Treeswoodland0	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.	.	.		.	.	.	.	.	.	.
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5
ESRA	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.	.	.	.		.	.	.	.	.	.
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5
CatchmentareaKm	Pearson Correlation	.997[**]	.840	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	1	-.674	-.253	-.647	.[a]	.[a]
	Sig. (2-tailed)	.000	.075	.	.	.	.	.	.		.212	.681	.238	.	.
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Slope	Pearson Correlation	-.624	-.627	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	-.674	1	.626	.624	.[a]	.[a]
	Sig. (2-tailed)	.261	.257	.	.	.	.	.	.	.212		.258	.261	.	.
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Maxelem	Pearson Correlation	-.196	.028	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	-.253	.626	1	-.128	.[a]	.[a]
	Sig. (2-tailed)	.753	.965	.	.	.	.	.	.	.681	.258		.838	.	.
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Minelem	Pearson Correlation	-.626	-.945[*]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	-.647	.624	-.128	1	.[a]	.[a]

	Sig. (2-tailed)	.258	.016	.	.	.	.	.	.	.238	.261	.838		.	.
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5
MAPmm	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.	.	.	.	.	.	.	.	.		.
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5
MATC	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.	.	.	.	.	.	.	.	.	.	
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

a. Cannot be computed because at least one of the variables is constant.

Appendix 4: Coefficients of regression model

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-8.536	.000		.	.	-8.536	-8.536
	logCA	1.340	.000	1.227	.	.	1.340	1.340
	logMaxele	1.866	.000	.474	.	.	1.866	1.866
	logminele	.438	.000	.224	.	.	.438	.438
	logH	.040	.000	.010	.	.	.040	.040

a. Dependent Variable: logQ