A Comparative Modelling Study in Blue Nile basin

Mona Hussien Mohamed Ahmed

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for examination/acceptance by the UNESCO Chair in Water Resources a thesis/dissertation entitled: ***A comparative modelling study in Blue Nile basin***, in fulfilment/partial fulfilment of the requirements for the degree of M.Sc.

Name:Kamal El din E. Bashar

(SUPERVISOR)

Date ______________

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I**, Mona Hussien Mohamed**, declare that, this thesis is my own original work and that it has not been presented and will not be presented to any other university for a similar or any other degree award.

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ACKNOWLEDGEMENT

I would like to thank **Dr. Kamal Bashar** for his advices, guidance and supervision of this thesis..

I wish to record my thanks to **NBI** staff for sponsoring me to get my degree.

I extend my thanks to all, who help me and encourage me to complete this thesis,

Colleagues, **friends especially Muna Musnad**, and all the staff of **UCWR**.

FIRST OF ALL I thank MY **GOD** who be beside me.

DEDICATION

To my lovely daughters ***Reyan, Mariam****,*

To the memory of ***my father*** *and* ***my mother***

To all my family…….,

ABSTRACT

Flow forecasting is needed for many aspects of water resources management, operation of hydrologic structures and flood hazard – are just some of the aspects.

The objective of the study is to try in a comparative mannar to apply several rainfall- runoff models to Eldiem station catchment of the Blue Nile in an attempt to forecast flows at the outlet of the catchment for its importance in operation and management aspects of Sudan work resources.

Several models are applied for forecasting flow of Blue Nile river at El Diem station. These models are the ones grouped in GFFS (Galway flow forecasting system). These models are applied in simulation mode.

In addition the soil moisture accounting model developed by HMS as a semi distributed model is also used.

A comparison based on model efficiency is made for the applied models, higher efficiency is obtained by LPM model, and therefore the model is recommended to be used for forecasting river flow at El Diem in the Sudan-Ethiopia border.

الخلاصة

التنبؤ بكمية مياه التصرف أهمية كبيرة في تشغيل المنشأت الهايدرولوكية وتوزيع المياه وكمية مياه الفيضان لأخذ الإحتياطات اللازمة.

الهدف من هذة الدراسة مقارنة عدة أنمذجة رياضية تختص بحساب التصرف بمعرفة كمية الامطار الساقطةوكميةالجريان عند محطة الديم علي النيل الأزرق.

في هذة الدراسة طبقت الأنمذجة التي جمعت في برنامج كمبيوتر في جامعة قولوي بالإضافة HEC-HMS

أستخدمت في هذة الدراسة بيانات لستة سنوات 1990-1996 لتطبيق تلك الأنمذجة الرياضية

تمت مقارنة نتائج هذة الأنمذجة الرياضية علي قدرتها لحساب كمية التصرف أقرب إلي التي قيست في المحطة بوسطة القياسين. فوجد النموذج الرياضي LPM هو الأفضل لحساب كمية التصرف ويمكن من خلال تطبيق هذا الإنموذج للتنبؤ بكمية الجريان في النيل الأزرق عند الحدود السودانية-الإثيوبية وتقدير كمية مياة الفيضان الداخلة للسودان وعمل الإحتيطات اللازمة.

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CHAPTER ONE

1.0 Introduction

The relationship between the rainfall and runoff has been a theme of hydrological research for many years and considerable processes had made the development of mathematical Rainfall-Runoff transformation models possible. These models have been developed for widely different purposes ranging from real time flow forecasting to long predictions for large river basins. Adoption of a model for simulating a given catchment is always depending on many factors such as catchment characteristics, meteorological factors, appropriation of the model for the catchment, etc.

The main purpose of using simulation models has been to assess the effect of water management measures on the components of water balance equation. Many of these models have been developed to determine and predict lumped or average physical parameters over the watershed. As such they are referred to as lumped models. Such models don’t account for distributed aspect of topography, soil type, pattern and change in vegetation type. Other models which are based on physical relationships are called physically based hydrologic models.

Hydrological models are divided broadly into two groups; deterministic models seek to simulate the physical processes in catchment involved in transformation of rainfall to stream flow whereas stochastic models describe the hydrological time series of the several measured variables such as rainfall, evaporation and stream flow involving statistical methods.

1.1 The study area

The Nile is one of the longest rivers in the world. Its catchment area is about 2.9 million sq kilometers up to the Northern border of Sudan. The catchment area can be divided into three sub-catchment namely, the Equatorial lakes plateau, the Ethiopian plateau, and the Sudan plains. These subcatchments exhibit a wide variety of climate, geology, topography, vegetation and drainage pattern.

One of the main characteristics of the Ethiopian plateau subcatchment is that it is very efficient in draining rain water problems such as sediment and floods.

The river Nile has two major tributaries, the White Nile and the Blue Nile. The main source of the White Nile is Lake Victoria while the Blue Nile and its tributaries (Eldender and Alrahad) originate from Lake Tana in Ethiopia. Fig. (1.1) shows the location of the Blue Nile and its tributaries. Both rivers follow long and complex routes before they converge near Khartoum, the capital of Sudan.

The Blue Nile River is the major tributary in the Nile basin system; it contributes to the system in flood season 600-750 Mm3/day. It originates from Lake Tana and run down through the catchment in steep gorge until it reaches the Diem gauge station at the Sudan- Ethiopia borders.

The Blue Nile has a catchment area of 324,530 Km^2. The greater part of this catchment is located in Ethiopia.

The rain begins early on Ethiopia highlands but the maximum flows reach Khartoum in the mid of August. The watershed receives average annual rainfall varies from 625mm in dry and low regions to 2140mm. Inside the Sudan the river collects flow from more tributaries such as, the Dinder and the Rahad. The head streams of both tributaries rise on the Ethiopian plateau.

There are about 16 rainfall gauging stations in the Ethiopian plateau Figure (1.2) shows the catchment boundary and the distribution of the rain gauge stations.

In this study only the catchment area up to El Diem station on the main stream of the Blue Nile (at the border between Sudan and Athiopia) is considered. The Blue Nile watershed was delineated using DEM-based delineation in the Watershed Modelling System (WMS). The delineated watershed is shown in Fig. (1.2).

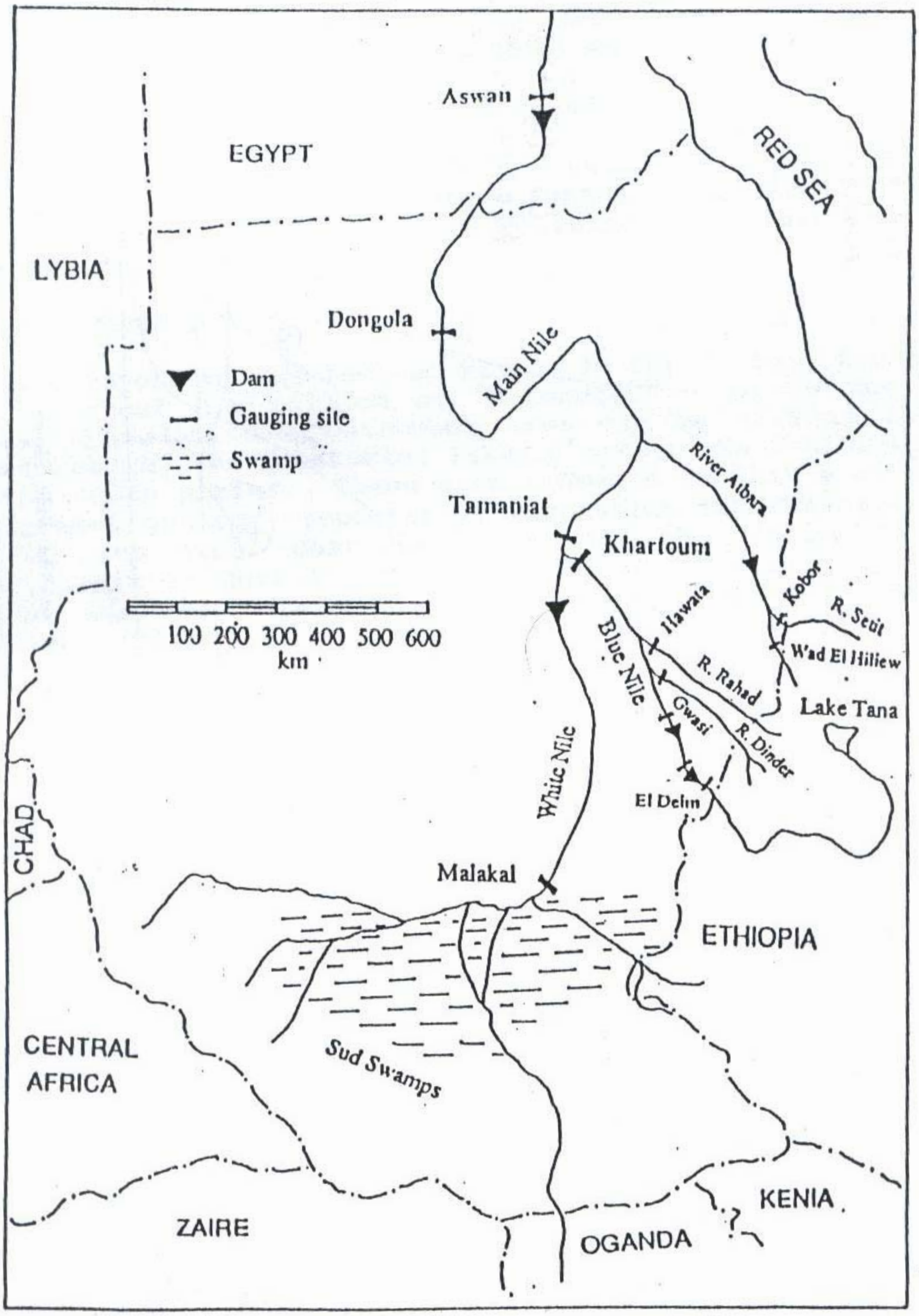


Fig. (1.1) Location of Blue Nile and El Diem station

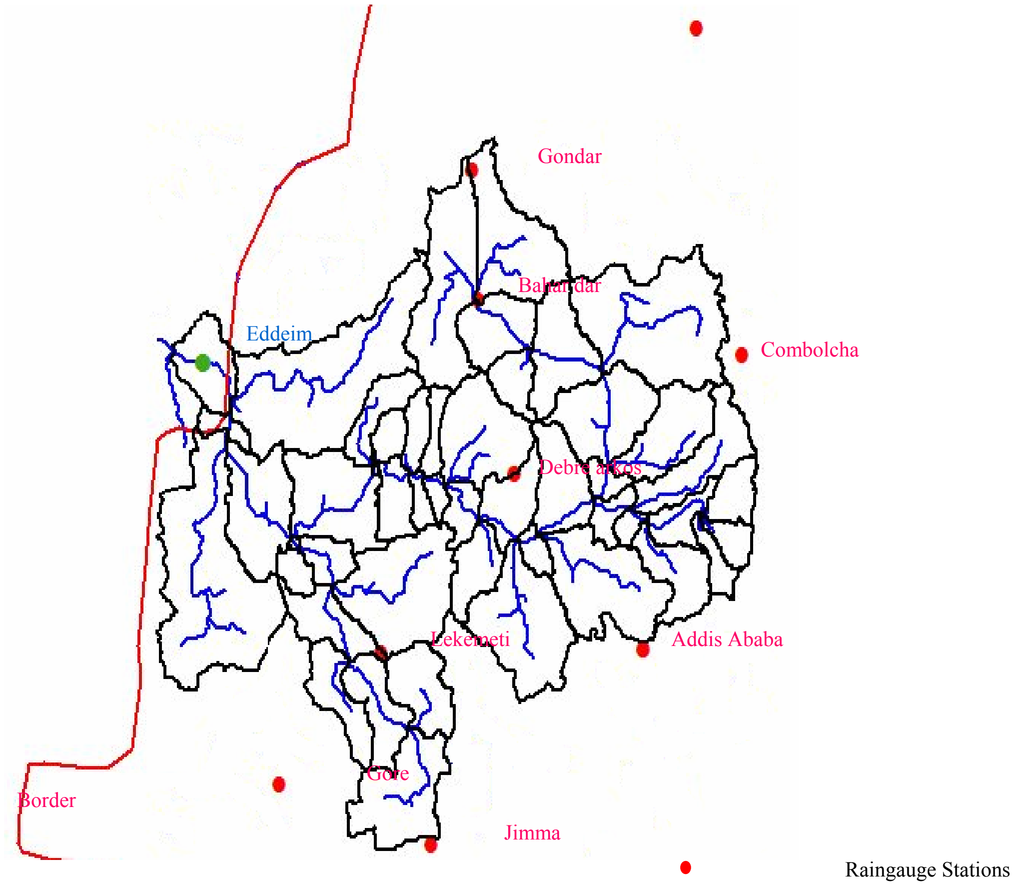


Fig. (1.2) Delineated watershed up to El Diem and rainfall stations **(Bashar,K.E and Zaki, A.F**,(2004), SMA based continuous hydrologic simulation of the Blue Nile)

1.2 Statement of the problem

River flow analysis is very essential for the planning, design and operation. The flow regime of the Blue Nile River and the rapid and huge amount of flood increase the importance of adopting a forecasting model that can represent as closely as possible the actual physical process occurring in the catchment and give an acceptable output to forecast the flow and extension of discharge data series in the catchment.

A comparative study whereby several models can be used and their performances evaluated is of high value for both research and application.

In this study several lumped and physically based models were used in an attempt to select a model that best reproduce the flow of the Blue Nile.

1.3 Objectives

The main objective is to apply different rainfall–runoff modeling techniques in the Blue Nile River, including system types conceptual and semi distributed models in a comparative manner.

The specific objectives include:

a. Application of system type models which include SLM, LPM, LVGEM, ANN and MOCT.
b. Application of the SMAR model as a candidate conceptual model to the Blue Nile.
c. Application of the HEC-HMS as a candidate model for semi distributed case.
d. Comparative analysis to select a suitable model for forecasting flows in the Blue Nile.

1.4 Outline of present study

The first chapter gives an introduction to the hydrological models and overview of the problem, the objectives and a layout of the thesis.

The 2nd chapter gives a brief theoretical background as well as literature review.

Chapter three is dedicated for discussing methods and material of the research including a short description of the models applied in the study

Chapter four is reserved for the application, results and discussions.

Chapter five gives the study output in form of conclusion and recommendations.

CHAPTER TWO
Literature review

2.0 Introduction

A catchment model is a set of mathematical abstractions (equations) describing relevant phases of the hydrologic cycle with the objective of simulating the conversion of precipitation into runoff. The technique of catchment modeling is applicable to catchments of any size.

A typical catchment modeling application consists of the following:

- Selection of model type
- Model formation and construction
    - * Theoretical and empirical evidence
    - * Assumptions to reduce the problem
- Model testing (calibration, verification and validation)
    - * Determination of the model parameters using regression, optimization techniques, etc.
- model application
    - * testing the model for different catchments (data)

2.1 Types of hydrologic models

Hydrologic models may be classified into two categories namely, physical models and mathematical models

2.1.1 Physical models

Physical models include scale models which represent the system on a reduced scale such as a hydraulic model of a dam spillway and analog models which use another physical system having properties similar to those of the prototype.

2.1.2 Mathematical models

Mathematical models represent the system in mathematical form. The system operation is described by a set of equations linking the input and the output variables. These variables may be functions of space and time and time and they may be also being probabilistic or random variables. Mathematical model can be either deterministic or probabilistic, linear or non-linear, time variant, lumped or distributed, continuous or discrete, analytical or numerical and event driven or continuous process.

2.2 History of the rainfall-runoff modelling

The necessity for estimating river flow from measurable causative factors, principally rainfall, has perhaps provided the most important driving force in developing hydrology as discipline of science. As early as the seventeen century a little known French, Pierr Perraualt (Dooge1959) quantitatively showed that the rainfall and snowmelt were sufficient to maintain flow in the river seine. Mulvaney (Dooge1973) attempted to relate the storm peak of river flow with rainfall records by what is known as the rational method that still finds the application in the design of urban storm drainage network in parts of the world. Then a plethora of models have been developed for different purposes, mainly to simulate and forecast the runoff from watershed.

A model is mathematical or physical description, which represents physical, biological or social system. All models simplify the complexity of the real world by selectively exaggerating the fundamental aspects of the system at the expense of incidental detail.

The simplest model that reflects the systems behavior in an adequate way and addresses the question raised is the best model.

2.3 Purpose of hydrologic Modeling

The fundamental objective of hydrological Modeling is to provide reliable information for water resources management. Some general purposes of hydrological Modeling are listed below:

- Hydrological models are largely applied to predict extreme event, such as flood and flows.
- Hydrological models may be used in interpolation and extrapolation of a hydrological data series i.e. they may involve the filling in or the replacing of the missing records.
- A well-structured hydrological model promotes an improved understanding of, and provides in sight into physical, chemical and biological processes involved in the hydrological system (Fleming 1975).
- A well-structured hydrological model merges the component of the system, resulting in a catchment view on the behavior of the entire system (Decoursey 1991).
- Hydrological models are applied to make decisions in relation to design, planning, operation and management of water related structures (Schulze 1998).

2.4 General structure of Rainfall-Runoff models

General characteristic of most of the Rainfall-Runoff models is dividing of the catchment to several zones, mainly vertically ordered. These zones are computed with help of the linear cascade model (O`Connor, 1976). The simplified structure of these models is displayed in Figure (2.1) below. For computation of processes running in each of the reservoirs shown in this figure (filling or drainage), many equations (model techniques) are applied.

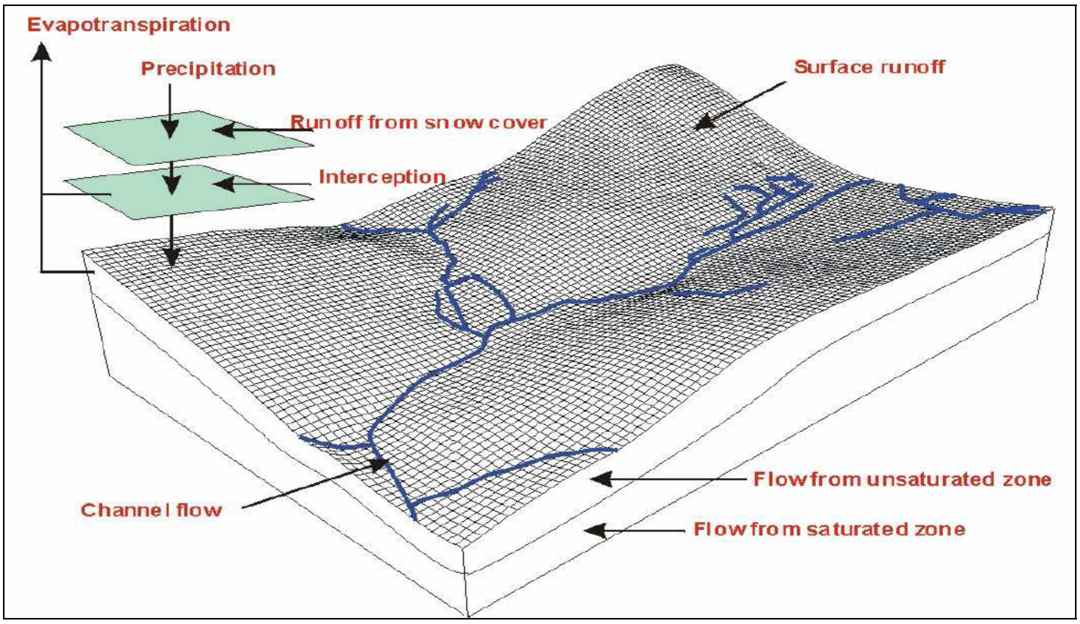


Fig. (2.1) General structure of rainfall-runoff models

Precipitation (both rain and snow) is entered into the models in form of time series from meteorological stations or sometimes meteorological radars (as an area rain). For estimation of the snow precipitation influence methods of temperature index, degree-day method or energy balance are applied.

Evapotranspiration (include interception) in form of actual evapotranspiration and interception are computed from time series from climatologic stations if they are available. It is also possible to derive actual evapotranspiration from potential evaptranspiration (there are a lot of equations based on climatologic data).

Surface runoff from the catchment is commonly obtained from methods of the unit hydrograph (UH) and various modifications (Clark`s,..).
Subsurface flow in the unsaturated zone – it is mostly the most important component of runoff concentration. Several methods are available, Soil Conservation Service Curve Number), e.g. SCS CN method, which is used for runoff volume computation in dependence on hydrologic parameters of the soil, initial condition (saturation) or soil land use. Some other methods are Green-Ampt or SMA (Soil Moisture Accounting).

Base flow –in dependence on concrete model, mostly applied are methods based on linear cascade model (Oconnor, 1976), exponential decrease (Chow et al., 1988).

Open channel flow –rainfall-runoff models apply methods together often called hydrologic routing. There is Muskingum-Cunge method, Lag method or transport diffusion equation. These methods are mainly based on a solution of basic equations of open channel flow (continuity and momentum equations). (Feldman, 2000).

2.3 Type of hydrological models:

For the various hydrological problems a wide range of hydrological models has been developed .Models can be linear or non-linear and can be described as conceptual or empirical .Finally they can be lumped or distributed depending on whether or not the spatial distribution of hydrological variables within the catchment is considered. At present there many type of hydrological models can be distinguished on the basic of their function, structure, level of spatial dis-aggregation and simulation process.

2.3.1 Functional classification of models

As rule hydrological models have a scientific basis and provide insight into and explanation of the nature of hydrological system (Dooge 1986).The use of hydrological models can be divided into tow different categories (Oconnell 1991) .

2.3.1.1Descriptive Models: concerns prediction on the effect of engineering measures, examples includes the rational method, the unit hydrographic method and the Stanford water model.

2.3.1.2Descriptive Modeling: Is concerned with the question of enhancing our scientific understanding of the catchment system for instance the Kinematics wave model and the SHE model.

2.3.2 Structural classification of models

Modeling of catchment behavior in the quantitative sense deals with reconstructing the past rainfall-runoff behavior and forecasting future runoff behavior from design rainfall. Three type of model structure can be defined, deterministic, stochastic and conceptual models

2.3.2.1 Deterministic models:

They are physically based and account for all physical processes, storage and interaction for set of initial and boundary conditions a deterministic model lead to a unique definable output, meaning that there is only one possible answer for any input (Wagenet 1988).

Deterministic models could be defined in another way. Abbott and Refsgard (1996) classified deterministic models to description of the considered area. The classification was based on whether the model gives a lumped or distributed description and whether the description of hydrological processes is physically based, conceptual or lumped. Their deterministic were introduced. System or empirical models (black box models), lumped model (Grey box models) and physical-based models (white box models).

2.3.2.2 System models

Sherman (1932), who postulated the concept of unit hydrograph for a catchment, established the instance to systems theory later, clork(1945) refined shaman s idea to the instantaneous unit hydrograph, which opened up the flood dates of systems approach from other disciplines to hydrological research. Regrettably, the techniques and models carried over from other disciplines like communication and electrical engineering were quite inappropriate and often reflect the classic black box syndrome. As result, prior to model inter-comparison studies instigated by WOM (1975) practical hydrologists were usually bewildered and often poorly served the proliferation of techniques and models suggested for river for flow forecasting. Regardless of these unfortunate difficulties, the development of system concepts in hydrology were firmly established by the pioneer9ing work of Snyder(1955),Nash (1957),Eagles et al(1965) and many others.

Following the inspirational leads, further work on system theoretic, rainfall-runoff modeling continued unabated and resulted in many useful extension and generalizations examples, such as the nonlinear Voltaire models introduced by Amorocho and Oconnor (1976) and the concept of geomorphologic unit hydrograph proposed Rodriduez, Itrurbe and valdes(1979).

2.3.2.3 Conceptual models

Conceptual rainfall-runoff (CRR) models were introduced in hydrology to improve the black box, system theoretical approach which depends mainly on some general, yet flexible relationships between input and data without much physics within the system. Conceptual models are generally designed to conceptually account for the soil moisture phase of the hydrologic cycle at basin scale. The primary approach is to transform rainfall to steam flow through a number of interconnected mathematical function, each representing a certain component of the hydrologic (e.g. Crawford and linsley 1986 Burnash et al 1973).CRR models have generally been aver useful and successful approach in simulating runoff catchment in different part of the world for the last three decades(WMO) However, because the basin-scale hydrologic processes are lumped at a point, CRR ignores spatial variability of meteorological variables. So CRR are limited in assessing the effect of land use and other changes in basin hydrology (e.g. Abbort, 1992 Gan and Biftu. 1996). Their applicability are limited to area where runoff has been measured for some years and in places where on significant changes in catchment condition have occurred over the period of simulation since model parameters that are calibrated ,are assumed to remain constant.

2.3.3 Model classification by spatial distribution

There are many ways of classifying hydrological models, which apply to the definition of catchment characteristics or hydrological processes. Based on the spatial distribution, hydrological models may be grouped as either lumped or distributed.

2.3.3.1 Distributed models

As result of civilization and industrialization, we have upset the equilibrium of many aspects of our environment, including the water cycle. Recently environment protection, sustainable development and climate change are becoming issues of major concern to the nations across the word. Besides the emission of green house gases to the atmosphere, politicians and scientists are also intercede in the implications of land use changes, agricultural practices forestation or deforestation, etc, to our environment and to the world climate .NASA of USA has monitoring our environment through its global earth observation program (EOS).Many scientists are using various models to simulate the potential impact of various anthropogenic action to out mother earth .Impact of use changes manifested through hydrological processes such as evaporation, runoff and soil moisture which all vary spatially. Therefore in order to effectively study, the impact of land use change, surface water and ground water exploitation, climate change, and subsurface migration of industrial and agricultural chemicals, on our river basins, there has been a trend to wards developing fully distributed, physically based hydrologic models. For the last tow decades different causal models have been building with an attempt to fill in the gap of lumped models. A good example is the European Hydrological system-System Hydrologic European model (SHE), developed by abbot et al ,in 1986, which unfortunately has little real world application since its data requirements often far exceed what is available.

As an improvement to lumped conceptual models, A merman (1965) developed extension of lumped non-linear synthesis model based on ‘unit source’ areas in which the catchment is broken down into a system of sub-area of relatively homogeneous soils, topography and land use. A similar approach, known as ‘hydrological response zone’, was adopted by England and Stephenson (1970) to account for spatial variability across the watershed. However these models do not allow for the interaction between sub-area and the resulting runoff was estimated by summing up the contributions from the individual elements.

Beven and Kirkbl(1979) also developed physically based model which takes which into account the distributed effects of the channel network topology and dynamic contribution area .Based on the concept of unit sources proposed by, American (1965) semi distributed hydrologic model have evolved recently as spatially distributed hydrologic data become more readily through remote sensing (e.g.HYDROTEL of for et al.,1986; Top model of Beven et al.,1987; and SLURP model of kite1995) .

Without spatially distributed hydrologic information retrievable from many spaces plot forms launched recent years, distributed or semi-distributed hydrologic models would have little or no practical application. Remotely sensed data initially collected from truch mounted and airborne sensors and later from space platforms have been used for wide ranges of applications in water resources problem. Kite and Pietroniro . Kite and pietroniro (1996) provide an excellent model and indicates the likely development in this aspect. Studies also indicated potential benefits of using satellite data the migration of flood damage improved planning of hydropower production, and irrigation (e.g.Castruccio et al, 1980).

Even through there is potential to review spatially distributed hydrologic information from satiated data, other than mapping of land cover and snow extent, the current of remotely sensed data in hydrologic modeling is very limited. According to kite and pietroniro (1996) reasons for limited use of remotely sensed information in hydrologic models are such as lack universally applicable operational method of deriving hydrological variables from remotely sensed information of different resolutions from different platforms, and insufficiency education and training .

It is our goal investigates and develops a suitable hydrologic model for rainfall-runoff modeling .One of these models HEC-hms that is based on GIS to drive spatial attributes and parameters. The model will be designed to maximize the applicability of spatially distributed hydrologic information retrievable from the above space platforms. In addition the model will accommodate topographic information to derive from digital elevation model DEM using a raster a vector geographic information system (GIS).

2.3.3.1.1 HEC-HMS 3.1.0

The model is known as the Hydrologic Engineering centre, Hydrologic Modeling system (HEC-HMS). The U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC) was formed in 1964 to institutionalize the technical expertise that subsequently became known as hydrologic engineering. The cadre of engineers that had come to the USACE following World War II was approaching retirement age, and there was concern that their expertise that had evolved from the on-going unprecedented Corps water resources development activities would dissipate and be difficult to restore. HEC was established in the USACE Sacramento District within the Engineering Division. Principals involved included: Albert Cochran, HQUSACE Hydrology and Hydraulics Chief, who formed and sold the idea of an HEC; Emilio Gomez, Sacramento District Chief of Engineering Division; and Roy Beard, then the District Reservoir Control Chief and subsequently HEC founding Director. HEC immediately set to work organizing and presenting training courses, the first of such kind in the Corps, and initiating development of what later became to be the well-known family of HEC software. Early software packages were HEC-1 (watershed hydrology), HEC-2 (river hydraulics), HEC-3 (reservoir analysis for conservation), and HEC-4 (stochastic stream flow generation program). Within ten years after establishment, the technical field of planning analysis, the application of analytical methods to planning activities closely associated with hydrologic engineering, was added to the HEC mission. By that time, the permanent staff had risen to about 30 engineers and computer specialists. HEC staff is about that same size today.

In its history, HEC went through a series of organizational reporting realignments, but has for the most part, maintained generally the same scope of activities, staff, support to the field ethic, and output products. HEC moved from under the Sacramento District Engineering Chief to reporting to the District Commander, and by the early 1970s, had successively been realigned to report to the South Pacific Division Commander, then to HQUSACE Director of Civil Works, and then finally became an organization within the Water Resources Support Center (WRSC). HEC remained assigned to WRSC for about twenty years until WRSC was dissolved in 2000 to be replaced by the Institute for Water Resources (IWR), then a sister organization to HEC within WRSC. Today, HEC is one of six organizations within IWR - two Centers and four divisions. IWR reports to the Deputy Director of Civil works and is classified as a Civil Works Support Office.

Over the years, HEC developed and published a number of technical methods documents addressing the full range of hydrologic engineering and planning analysis technologies. The format and content for technical short courses evolved early on and continues to be a mainstay of the HEC program. The family of software has grown to over twenty major programs that are supported by a library of utility programs, recent additions including GIS support. HEC is perhaps best known for these nationally and internationally renowned hydrologic engineering programs.

HEC is organized into an Executive Office and three divisions: Hydrology and Hydraulics Technology; Water Resource Systems; and Water Management Systems. Staffs in all divisions undertake training, methods documentation, research and development, technical assistance and special projects. Notable recent achievements include: development of the NexGen family of successor HEC software (HEC-RAS, HEC-HMS, HEC-FDA, and HEC-ResSim); providing leadership in establishing risk analysis as the foundation technology for flood damage reduction planning and analysis; and development and deployment of the Corps Water Management System (CWMS), the real-time forecasting and decision-support system that is used 24/7 in execution of the USACE Civil Works water resource water control management mission.

2.4 Previous studies

Prof. Gamal .M. Abdo used flow forecasting models developed at university college in Galway, the multiple input-single output models, namely, simple linear model and linear perturbation model for forecasting the flow in Nile River at Khartoum, Tamaniat, and Dongla. Both models were tested in simulation mode in non-parametric form under the constraints of general difference equation form (linear transfer function model). The study conclude that the LPM has higher efficiency and recommended to use for flood forecast along the river.

Rainfall –runoff modeling using artificial neural networks techniques at Blue Nile catchment

By Antar, Mamdouh A.; Elassiouti, Ibrahim; Allam, M.N.,

This study used an artificial neural network (ANN) to simulate rainfall-runoff for Blue Nile, they classified the catchment into seven subcatchments, and the mean areal precipitation over the subcathments was computed as a main input to the ANN model.

The results of the ANN model were compared with one of physical distributed rainfall-runoff models that apply hydraulic and hydrologic fundamental equations in a grid base. The results show that the ANN technique has great potential in simulating the rainfall-runoff process adequately.

River flow forecasting using time series analysis for Blue Nile at El Diem station by Manal Yousif Ahmed

This study used time series analysis to predict the future values of the flows and to generate synthetic flows. Annual and monthly trend analysis was performed on historical data. ARMA model was fitted to the historical data. The results showed complete agreement between the observed and generated flows.

Flow forecasting on the Blue Nile using lumped & conceptual models by Elgaily Mohamed Ahmed (2004)

This study used several models in GFFS software in single input –single output form and also tests the use of multiple input-single output and areal rainfall estimation by Thesien polygon method and their effects in reducing the problem of peak reproduction. Results shows that no significant difference between the two cases (single input & multiple inputs) and the problem of failure of models to produce the peak can be attributed to either the areal rainfall estimation or rating curve.

CHAPTER TREE

Methodology

3.0 Introduction

This chapter discussed the methodology used in the study. The different mathematical developments of the models are discussed. Method for testing model efficiency is also outlined. The discussion is grouped into three main sections reflecting the three broad grouping of the models namely the linear system type, conceptual and physical semi distributed models.

3.1 Linear models

This category assumes linear relationship in the transformation process of rainfall to runoff. This include SLM, LPM and LVGFM

3.1.1 The Simple Linear Model (SLM)

The input-output relationship for lumped, linear, time invariant system expressed in terms of a series of pulses or mean values over successive short intervals T can be conveniently obtained from the response to unit pulse of duration T which is a convenient expression of the operation of the system. The discrete linear input-output relationship is expressed in terms of sampled pulse response which can be written after incorporating the model error term as

$$y_t = \sum_{j=1}^{m} x_{t-j+1} h_j + e_t \tag{3.1}$$

Where h_j refers to the j^{th} ordinate of the pulse response, m is the memory length which implies that the effect of any input x last only through m intervals of duration T and e_t is the model error term or residual.

Equation (3.1) can be written in matrix form as

$$Y = X\hat{H} + E \tag{3.2}$$

Where Y is an (n,1) column vector of the output series, X is an (n,m) matrix of input series, $\hat{H}$ is an (m,1) column vector of the pulse response ordinate and E is an (n,1) column vector of the model errors.
In identifying the operation of the system the input and output series are assumed to be known and $\hat{H}$ must be determined. If the objective function is to minimize the sum of squares of model errors, the optimum value of $\hat{H}$ can be determined directly by method of ordinary least squares as

$$\hat{H} = \left(X^T X\right)^{-1} X^T y \tag{3.3}$$

Equation (3.3) gives the non-parametric form of the pulse response of a single input single output linear model known as the SLM.

Several constraints can be applied to the SLM form such as the gain factor and volumetric constraints, shape constraints, smoothing by ridge regression and parameterization of the model. Of these constraints only the parameterization by gamma and linear transfer functions will be considered.

3.1.1.1 Parametric modelling- The Linear Transfer Function Model

The operation of a single input-single output of a linear, time invariant system in a discrete form is governed by transfer function model defined by a linear difference equation of the form

$$\sum_{j=0}^{r} \alpha_j y_{t-j} = \sum_{j=1}^{s} \omega_j x_{t-b-j+1} \tag{3.6}$$

where the α_j's are the autoregressive parameters with $\alpha_0 = 1$, the ω_j's are the moving average parameters and b is the pure time delay restricted to integer values only. Equation (3.6) can be written explicitly for y as

$$y_t = \sum_{j=1}^{r} \delta_j y_{t-j} + \sum_{j=1}^{s} \omega_j x_{t-b-j+1} \tag{3.7}$$

In this form the current values of y depends on the previous values of y and x and can be viewed and analysed as algebraically equivalent to two input-single output linear system. The parameters of the model can be obtained by method of ordinary least squares.

3.1.1.1.2 Parametric modelling-The Gamma Function Model

Constraint to the shape and volume of the estimated pulse response functions is obtained by parametric modelling where a solution is sought within the constraint of an assumed model form. Based on prior knowledge of the system behaviour the response function is represented by a suitable mathematical equation involving only a few parameters.

The parameters must be estimated by optimization through a search in the space of reasonable parameter values.

The most popular impulse response function is given by

$$h(t) = \frac{1}{k\Gamma(n)} e^{-\frac{t}{k}} \left(\frac{t}{k} \right)^{n-1} \tag{3.4}$$

Where $\Gamma(n) = \int_0^\infty e^{-x} x^{n-1} dx$ is the gamma function of n.

The equation of the SLM for single input-single output will be

$$y_t = G_f \sum_{j=1}^{m} x_{t-j+1} h_j + e_t \tag{3.5}$$

Where h_j is given by equation (3.4) and G_f is the gain factor.

For multiple input-single output system under the constraints of the gamma function impulse response the parameters n, nk and G_f must be found or each input.

3.1.2 The Linear Perturbation Model (LPM)

The LPM concept was developed and explored by Nash and Barsi (1983) in the context of rainfall-discharge modeling.

Assuming that in any one year in which the rainfall exactly follows the seasonal expectation, the discharge hydrograph will similarly follow its expectation, and other years departures from the seasonal expected values in rainfall and discharge will be linearly related. The model is therefore a marriage between two well established concepts, one in time series analysis (i.e, seasonal component identification) and the other in deterministic systems analysis (i.e classical unit hydrograph identification), Kachroo et al., 1988.

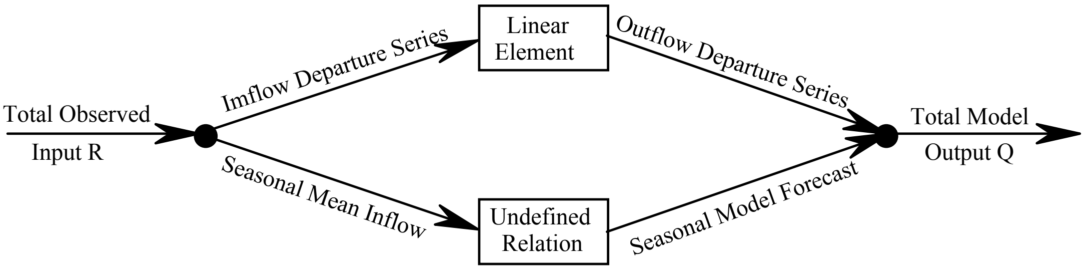
The seasonal means of output (similarly for input) on date d are obtained in the calibration period by:

$$q_d = \frac{1}{L}\sum_{r=1}^{L} q_{d,r} \tag{3.3}$$

Where L is the number of years in the calibration period and $q_{d,r}$ is the output on date d for the rth year of calibration data. In practice, the q_d so obtained may be smoothed e.g. by Fourier smoothing and the resulting seasonal mean of output (as input) is the simplest model, and is called the seasonal model (SM), Garrick, et al. 1978.

For large rivers, forecasts of discharge are seldom obtained from rainfall alone. When concentration time permits, forecasts of the discharges at downstream points are usually based on observed discharges at points further upstream, either on the main river or its tributaries. Forecasting problem then becomes mainly one of the channel systems with some corrections for rainfall on the intervening catchment. The linear perturbation concept can be applied to this situation, which is essentially a multiple-input, single-output system, Liang & Nash, 1988.

LPM structure reduces reliance on the linearity assumption of the SLM and gives substantial weight to the observed seasonal behavior of the catchment. A schematic diagram of the LPM model is represented in Fig. (3.1) below.



Fig(3.1) Schematic representation of LPM

3.1.3 Linearly varying gain factor model (LVGFM)

This model was proposed by Ahsan and O`connor (1994) for the single input to single output case. It involves only the variation of the gain factor with the selected index of the prevailing catchment wetness without varying the shape (i.e. the weight) of the response function. The model allows for a variable gain factor linearly related to an index of the soil moisture state z_i. The gain factor G_i is given by

$$G_i = a + bz_i \tag{3.4}$$

Where a and b are constants.

The overall operation of the LVGFM has the mathematical form

$$Q_i = G_i \sum_{j=1}^{m} R_{i-j+1} B_j + e_i \tag{3.5}$$

Where G and B are estimates of the gain factor and pulse response ordinates respectively of the auxiliary simple linear model (SLM).

Figure 3.2 shows the schematic diagram of the concept of LVGFM.

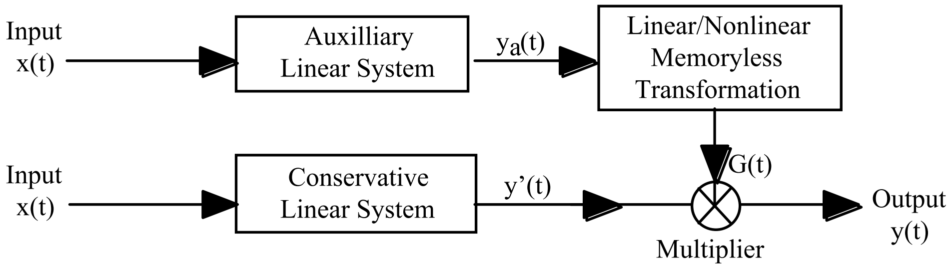


Fig.(3.2): Schematic diagram of the LVGFM (Ahsan & O`connor,1994)

3.2 Conceptual models

Conceptual models are generally designed to conceptually account for the soil moisture phase of the hydrologic cycle at basin scale. The primary approach is to transform rainfall to steam flow through a number of interconnected mathematical functions, each representing a certain component of the hydrologic.

3.2.1 SMAR model

The Soil Moisture Accounting and Routing model (SMAR) is mainly divided into two components:

- water balance component
- routing component

Its water balance component being based on layer water balance model proposed by Nash and Sutcliffe in 1969. The SMAR model is lumped conceptual rainfall-evaporation-runoff model.

The routing component simulates the attenuation and the diffusive effects of the catchment by routing the various generated runoff components which are the outputs from the water balance component.

As can be seen in the schematic diagram of the SMAR model Fig. (3.3) the model has nine parameters which are listed in table (3.1) below. Five of which control the overall operation of the water budget component, while the remaining four parameters control the operation of the routing component.

Table (3.1) The SMAR parameters

Parameter	Description
Z	The combined water storage depth capacity of the layers (mm)
T	A parameter (less than unity) that converts the given evaporation series to the model-estimated potential evaporation series.
C	The evaporation decay parameter, facilitating lower evaporation rates from the deeper soil moisture storage layers
H	The generated *'direct runoff'* coefficient
Y	The maximum infiltration capacity depth (mm)
n	The shape parameter of the Nash gamma function *'surface runoff'* routing element; a routing parameter
nK	The scale (lag) parameter of the Nash gamma function *'surface runoff'* routing element; a routing parameter
g	The weighting parameter, determining the amount of generated *'groundwater'* used as input to the *'groundwater'* routing element.

K_g	The storage coefficient of the *'groundwater'* (linear reservoir) routing element; a routing parameter

To estimate potential evaporation the pan evaporation values are multiplied by a ratio T. Evaporation from the top layer proceeds at potential rate on demand. On exhaustion of the first layer, evaporation will proceed at C times the remaining potential from the 2nd layer. The evaporation will then proceed at C^2 times the remaining potential from the 3rd layer on exhaust of the 2nd layer and so on. Where C is a constant.

The total storage capacity given by Z is a parameter to be optimized. The fraction given by H` of the excess rainfall contributes to the generated runoff (r_1). Any thing in excess of the infiltration capacity (Y) of the soil will also contribute to the generated runoff (r_2). The remaining rainfall restores each layer to its full capacity. Any remaining rainfall contributes to generated runoff (r_3).

The routing components of the model are achieved through Nash (1957) gamma function which is given by:

$$u(t) = \frac{e^{-1/k}(t/k)^{n-1}}{k\Gamma N} \qquad (3.6)$$

To accommodate the groundwater component a new parameter (G) divides generated runoff into two parts the fraction of G (r_g) determine the groundwater component, (1-G) joins r1 and r2 to yield the overall surface runoff (r_s) which is routed via the Nash cascade model. The groundwater component is routed through a single linear reservoir. The output is finally added up to the estimated total discharge.

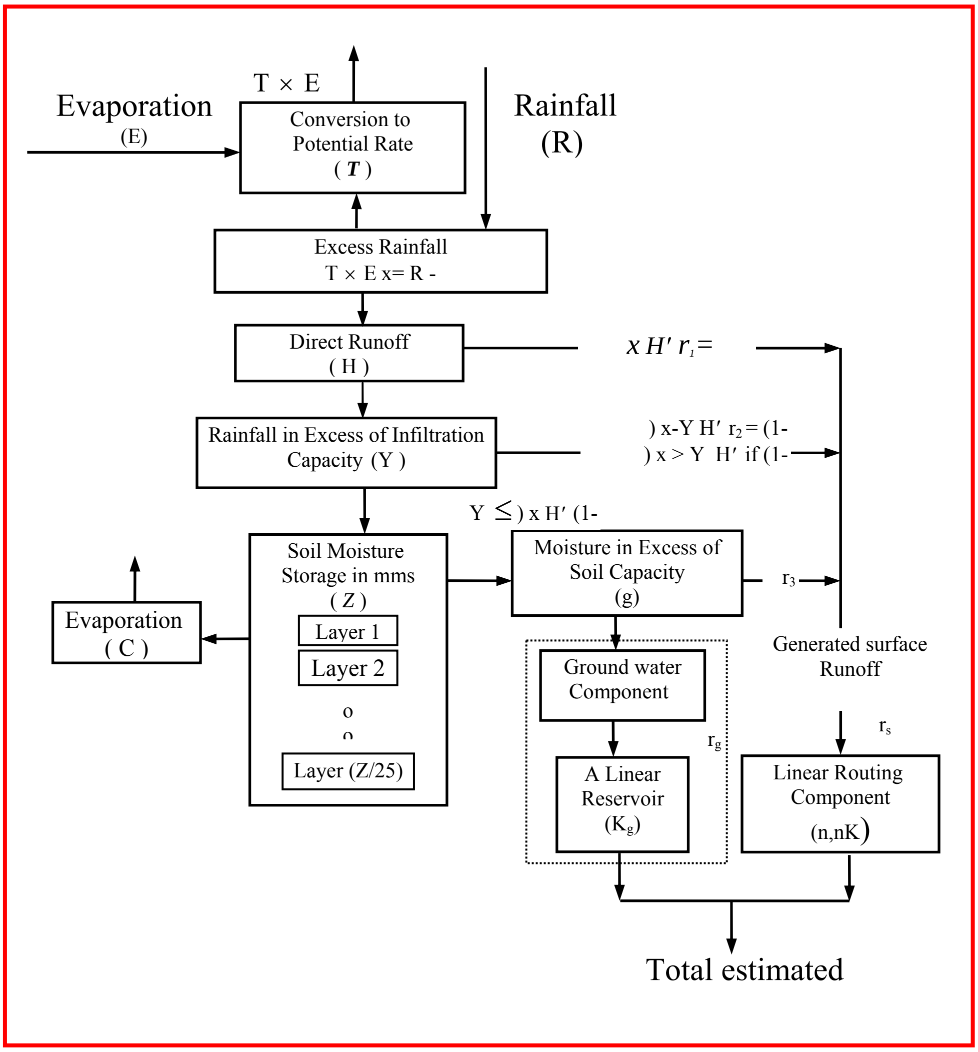


Fig (3.3) Schematic diagram of SMAR model

3.2.3 Artificial Neural Network model (ANN)

Artificial neural network system functions as parallel distributed computing networks. Their most basic characteristic is architecture. The initial development of artificial neural system was in 1943 when Mcculloch and Pitts outlined the first formal elements to perform logic operations. Scientist and technologist are interested in opportunities that are opened by the massively parallel computation networks in the area of artificial intelligence, computational theory, modeling and simulation and others.

The type of ANN model used in GFFS is the multi layer feed forward network which is considered to be very powerful in function modeling. It consists of an input layer, output layer and only one hidden layer located between the input and the output layers. The number of neurons in the input layer equals the number of the elements in the external input array to the network. There is only one neuron for the single output in the output layer.

In the context of the ANN as a basic rainfall-runoff model, instead of using the rainfall series as input the ANN used a form of antecedent rainfall index comprising a weighted sum of the current and immediately previous rainfall values as single external input to the network. ANN used the output series of the SLM as an auxiliary model so the ANN effectively enhances the output of the SLM by means of a suitable non-linear transformation (Shamseldin, 1997).

For a neuron either in the hidden or in the output layer, the received inputs y_i are transformed to its output y_{out} by a mathematical transfer Function of the form

$$y_{out} = f(\sum_{i=1}^{M} w_i y_i + w_o) \qquad (3.7)$$

Where f () denotes the transfer function, w_i is the input connection pathway weight, M is the total number of inputs (which usually equals the number of neurons in the preceding layer), and w_o is the neuron threshold (or bias), i.e. a base-line value independent of the input.

3.2 Semi- distributed models

3.2.1 HEC-HMS model

Hec-hms is a numerical model that includes a large set of methods to simulate watershed, channel and water-control structure behavior, thus predicting flow stage and timing. The HEC-hms methods which are summarized in table (3.2) represent:

- Watershed precipitation and evaporation, these describe the spatial and temporal distribution of rainfall on and evaporation from watershed.
- Runoff volume, these address question about the volume of precipitation that falls on watershed: how much infiltration on previous surface, how much runs off of the impervious surface and when does it run off.
- Direct runoff, including overland flow and interflow: these methods describe what happens as water that has not infiltration or been

stored on the watershed moves over or just beneath the watershed surface.

- Base flow: these simulate the slow subsurface drainage of water from a hydrologic system into the watershed`s channels.
- Channel flow: these so-called routing methods simulate one-dimensional open channel flow, thus predicting time series of downstream flow, stage, or velocity given upstream hydrographs.

Table (3.2) Summary of simulation methods included in HEC-HMS

category	Method
precipitation	User-specified hyetograph User-specified gage weighting Inverse-distance-squared gage weighting Gridded precipitation Frequency-based hypothetical storms Soil conversation service hypothetical storm
Runoff volume	Initial and constant rate SCS curve number (CN) Deficit and constant rate Soil moisture accounting (SMA) Gridded SMA
Direct runoff	User specified unit hydrograph Clark`s UN SCS UN Kinematic wave User specified s-graph
Base flow	Constant monthly Exponential recession Linear reservoir
Routing	Lag Modified pulse Muskingum Muskingum-cunge confuence

The hydrologic modeling system (HMS) is physically-based distributed parameter model. HMS simulates the hydrologic processes, such as vertical soil moisture flow, evapotranspiration (ET), infiltration, overland flow, channel flow and groundwater flow within a river basin. HMS includes SMA method which counts on rainfall depths and evapotranspiration rate, as inputs to define the rainfall, runoff, storage and losses relationships. There are five storage zones simulated as shown in figure (3.5). For the simulation of water movement through the various storage zones, initial storage condition in terms of percentage of the filled portion of each zone, and the transfer rates, such as the maximum infiltration rate, are required (Fleming and neary, 2004).

According to the SMA algorithm, evapotranspiration is only assumed to take place during dry periods and from canopy interception storage then from surface depression storage and then from the soil profile storage. On the other hand, soil percolation will start only when the tension zone capacity is fulfilled. According to Fig. (3.5) the outflow form the groundwater layer 2 storage as percolation will be considered as a loss from the system.

Excess rainfall transform to direct runoff by using Clark unit hydrograph technique.

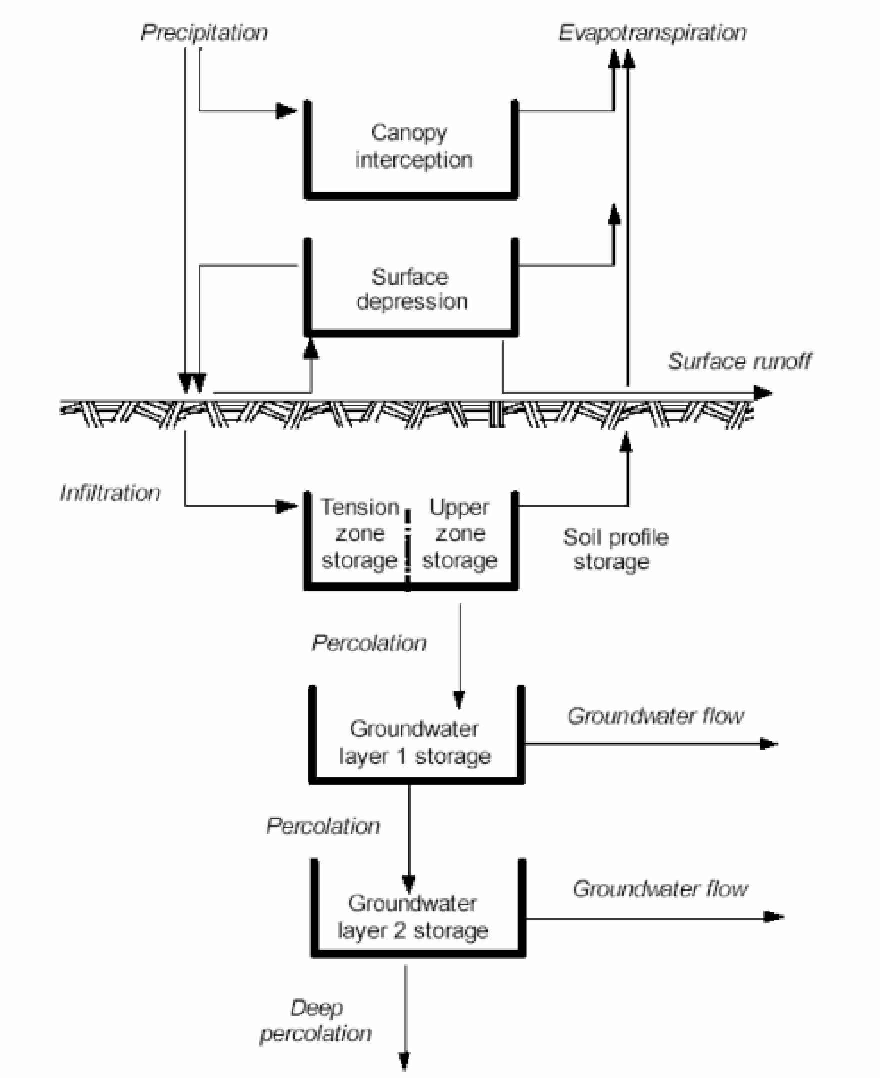


Fig.(3.5)Schematic diagram of HMS/SMA algorithm(HEC-2000)

3.2.1.1 Calibrating the HEC-HMS models

In this study, manual calibration method was adopted to determine a practical range of the parameter values preserving the hydrograph shape, minimum error in peak discharges and volumes.

The whole 12 parameters needed for the SMA were taken into consideration in the simulation, the maximum infiltration rate, maximum soil depth, percolation rate and ground water components had influence on the simulated discharges,

3.3 The model efficiency criteria

The performance of a model must be judged on the extent to which it satisfies its practical objectives (accuracy). Efficiency criteria express model accuracy which can be used for models comparison. Was used to judge on the similarity and consistency between the observed and estimated hydrograph.

Nash & Sutcliffe (1970) defined model efficiency as:

$$R^2 = \frac{F_0 - F}{F_0} \qquad (3.7)$$

Where F_0 is the initial variance associated with the mean value of discharges in the calibration period; and F is the residual variance computed by comparing the observed and forecasted discharges. This is a use full criterion provided that the estimate of the mean is consistent. Efficiency ($R^{2)}$ can be written as:

$$R^2 = \frac{\sum (y - \bar{y})^2 - \sum (y - \tilde{y})^2}{\sum (y - \bar{y})^2} \qquad (3.11)$$

Where

$\hat{y}$: Estimated flow discharges by the model

y: observed flow discharges

$\bar{y}$: mean of y in the calibration period.

CHAPTER FOUR

Application, results and analysis

4.0 Introduction

The previous chapter discussed the methods and materials used in this study with a complete mathematical background of the models to be used. This chapter goes on to discuss the application of these models and results obtained and continue to do some comparative studies based on the results.

4.1 Data preparation

The data used in this study comprises rainfall, runoff and evapotranspiration**.**

4.1.1 Rainfall

The rainfall data is available for eight gauge stations from 1990-1996. All stations are located in Ethiopia. Table (4.1) shows stations name, % of missing data and mean annual rainfall. The data was collected from the FRIEND/Nile study in the area.

Table (4.1) Names and locations of the rainfall guage stations

N	Name	% Missing	Mean annual rainfall (mm)
1	Mekele	42	674
2	Gondar	23	672
3	Bahar Dar	17	1288
4	Combolcha	22	1040
5	Debre Markos	27	1366
6	Jimma	40	1692
7	Gore	51	1724
8	Addis Ababa	10	1200

4.1.1.1 Areal rainfall

The average depth of rainfall over the area is very important to set the rainfall data. Arithmetic mean method is used to determine the mean depth of rainfall on the catchment. The areal arithmetic mean is given by:

$$X_i = \frac{\sum_{s=1}^{n} X_{i,s}}{n} \qquad (4.1)$$

Where

$X_{i,s}$ is measured rainfall value observed and recorded at rainfall station s for day i and n is the number of rainfall stations in the catchment that have record in day i.

The daily data of the eight stations on the catchment summed and divided by eight.

4.1.2 Discharge

Discharge data was available since 1964. This study used only seven years of daily data 1990- 1996 concurrent with the available rainfall data. Table 4.2 shows the available record at eddeim station with some statistics. The flow data is collected from Ministry of Irrigation and Water Resources and cross checked with that collected from the FRIEND/Nile Study.

Eddeim station is located at border between Sudan and Ethiopia in territorial area of the Sudan (Figure (1.1)). The catchment area behind the gauging station is 254230 km2.

The total recorded data available is for 33 years with only 2% missing. The missing part is mainly in the year 1988 (very wet year). It has along term mean annual value of 195 mm (about 570000 cumecs or 49.25 milliard m^3/day)

Table 4.2: Flow data and its statistics in main gauge station at Eddeim

Station	Start year	No. of years	% missing	Mean 10^9 m^3/d	Std	CV
Eddeim	1964	33	2	49.25	1886.5	1.265

The % missing within the period 1990 to 1996 was found to be very small. All the missing data is during the recession period which is well defined. The missing entries are filled by interpolation.

4.1.3 Evaporation data

Limited amounts of climatic data are available for estimation of potential evaporation in the basin. Data are available on minimum and maximum daily temperature, wind speed, sunshine hours and relative humidity.

Data on all parameters that are required in Penman calculations are available for only five years of early nineties.

Penman- Monteith potential evaporation data are collected from FRIEND/Nile Study in the area. The mean annual evaporation over the catchment was found to be 1400 mm

4.2 The Catchment Hydrologic Diagram

The catchment hydrologic diagram presents the expected variation through the year of rainfall, potential evaporation and discharge. Figure 4.1 gives an idea about the water balance of the basin. From the figure one can see that the effective rainy season (rainfall exceeds potential evaporation) can be considered from May to September. It can also be seen that the peak of the rainfall occurs on average three weeks before the peak of the flow. The flow hydrograph starts to pick up in two weeks time after the start of the effective rainy season.

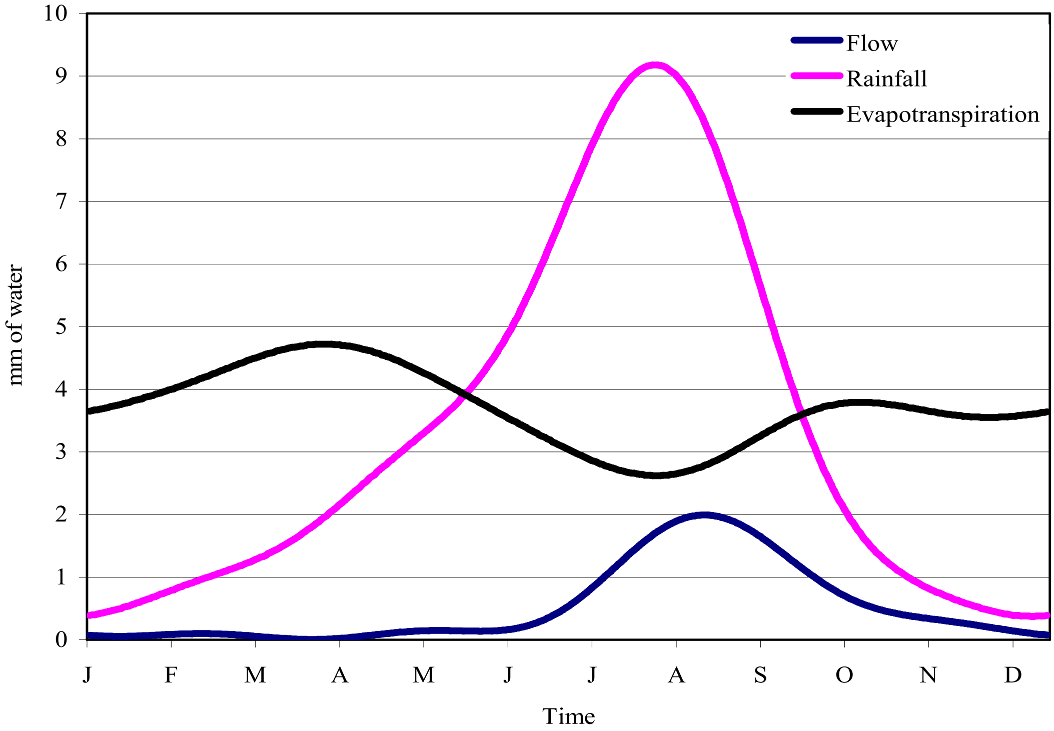


Figure (4.1) Hydrologic Diagram of the Deim Catchment

4.2 Data preparing

The models to be applied require that all the data should be written in UCG format. UCG format is and ASCII file format developed by the University Collage Galway for use with their models.

All the sets of data were prepared in this format ready for use in the models.

4.3 Applications of models

For application of rainfall-runoff models it is customary to split the data into two parts; one major part in which the models are calibrated and some few years in which the models are verified.

In the current study the data is splitted into two periods, one major part comprise five years (1826 days) used for calibrating the models and the other part comprising two years (731 days) used for verification.

It should be noted that both periods contain both normal and extremely wet years.

4.3.1 Application of simple linear model (SLM)

The hypothesis of the SLM is the assumption of a linear time-invariant relationship between the rainfall and the discharge. This model can be applied in two forms, Parametric and non parametric forms.

To apply SLM model a memory length is required. This parameter is obtained by trail and error and watching closely the fit between the observed and estimated discharges.

4.3.1.1 Non-parametric form (NPSLM)

In this model a simple relationship is assumed between the input (rainfall) and the output (discharge). The model is calibrated on daily data using ordinary least squares (OLS). The memory length (number of pulse response ordinates) is chosen by trial and error.

Table (4.3) below displays the results obtained using SLM in non-parametric form. A model efficiency of 77.8% was obtained during the calibration period and 76.0% was obtained during the verification period.

Table (4.3) Results of SLM in non-parametric form

catchment	Memory length	calibration			verification		
		start	No.days	R^2	start	No. days	R^2
El diem	60	1/1/1990	1826	77.8	1/1/1995	731	76.0

Figure (4.2) shows the scatter diagram of the observed and estimated discharges. It is clear that the model under estimated the peaks.

4.3.1.2 Parametric form (PSLM)

The rainfall was converted to runoff by using a runoff coefficient as a transfer function. Parameters used in SLM includes the memory length which chosen by trial and error.

Table (4.4) Results of SLM in parametric form

catchment	Memory length	calibration			verification		
		start	No. days	R^2	start	No. days	R^2
El diem	N.A	1/1/1990	1826	98.2	1/1/1995	731	97.3

Table (4.4) above shows the results of application of SLM in parametric form. It can be seen that the model accounted for about 98.2% of the initial variance.

The observed and simulated results using PSLM are shown in figure (4.3). From the figure it can be seen that the model under estimates the peak flows. This can be due to the model structure lacking seasonal component.

4.3.2 Application of linear perturbation model (LPM)

This model exploits the seasonal information inherent in the observed rainfall and discharge series. When the rainfall and the discharge values depart from their respective seasonal expectation, these departures series are assumed to be related by a linear time-invariant system. Hence the LPM structure reduces reliance on the linearity assumption of the SLM and gives substantial weight to the observed seasonal behaviour of the catchment.

4.3.2.1 Non-parametric form (NPLPM)

In order to use the information contained in the observed seasonal variation of the hydrograph Nash and Barsi (1983) suggested the use of linear perturbation model LPM.

The Linear Perturbation Model (LPM) was applied as follows to the catchment under consideration using the daily data.

- Seasonal mean rainfall and seasonal mean discharge were calculated for the period of calibration. Smoothing was done by the method of unconstrained Fourier analysis with four harmonics.

- The smooth seasonal mean values (x_d, y_d) were then subtracted from the corresponding observed series for the period of calibration to get the perturbations R and Q.
- The pulse response function for the catchment was estimated by method of ordinary least squares.
- The resulting pulse response is convoluted with the corresponding rainfall perturbation to obtain the estimated discharge perturbations
- The final estimated discharge series of the LPM is calculated by adding the seasonal mean discharge to the estimated outflow perturbation series
- The sum of square difference between observed and estimated discharges is obtained and the model efficiency is computed.

The result of fitting the non parametric LPM is presented in table T4.5. A model efficiency of 92.2% was obtained during the calibration period and 91.4% was obtained for the verification period. This fact indicates the importance of increasing the dependence on observed seasonal behavior of the catchment especially in large rivers.

Table (4.5) Results of NPLPM

catchment	Memory length	calibration			verification		
		start	No.days	R^2	start	No. days	R^2
El diem	60	1/1/1990	1826	92.2	1/1/1995	731	91.4

4.3.2.2 Parametric form (PLPM)

To apply this model needs to choose pure lag And the moving average order which they choosen as 1and 2 respectively.

Table (4.6) Results of PLPM

catchment	pure lag	calibration			verification		
		start	No.days	R^2	start	No. days	R^2
El diem	1	1/1/1990	1826	98.6	1/1/1995	731	97.2

Table (4.5) above shows the results of application of the PLPM. It can be seen that the model provided high performance 98.6%.

The observed and simulated results are shown in Fig (4.2). From the figure can be seen that the model over estimates the peak flows this can be due to measuring of the observed discharges in this period or may be for estimating areal rainfall.

4.3.3 Application of linearly varying gain factor model (LVGFM)

The result of fitting the LVGFM is presented in table 4.7. A model efficiency of 91.9% was obtained during the calibration period and 87.4% was obtained for the verification period. The improved performance over the SLM can be attributed to the gain factor parameter.

Table (4.7) summary of the results obtained with the LVGFM

Catchment	**Memory length**	**Calibration**			**Verification**		
		Start	**No. days**	**R^2**	**Start**	**No. days**	**R^2**
Eddeim	60	1/1/1990	1826	91.9	1/1/1995	731	87.4

Figure ??? shows the scatter of the observed and estimated discharges. It is clear from the diagram that the model fairly accurately reproduced the observed discharge in its full range. Figure AF5 of the annexes shows the time series plots of the observed and estimated discharges using the LVGFM. There is a considerable amount of initial variance accounted for by considering variable gain factor model.

4.3.4 Application of SMAR

The Soil Moisure Accounting and Routing model needs evaporation data in addition to rainfall and runoff data because it is based on layer water balance. The model has 9 parameters five of which control the overall operation of the water budget component, while the remaining four parameters control the operation of the routing component. The starting values of the parameters which were chosen manually were listed in table (4.8) below.

Table (4.8) Starting values of the 9 parameters.

T	H	Y	Z	C	G	N	NK	Kg
0.9	0.5	100.0	50.0	0.75	0.75	1.0	5.0	100.0

The SMAR model is applied to the catchment under consideration on daily data. The optimization is done under constrained conditions and all possible alternatives of Rosenbrock, Simplex and generic algorithm are used. The results of the application are shown in table 4.9. A model efficiency of 92.0% was obtained during the calibration period and 91.3% was obtained for the verification period.

Table (4.9) Results oF the SMAR

Catchment	**Memory length**	**Calibration**			**Verification**		
		Start	**No. days**	**R^2**	**Start**	**No. days**	**R^2**
Eddeim	60	1/1/1990	1826	92.0	1/1/1995	731	91.3

Figure ??? shows the visual display of the scatter of the observed and estimated discharges. It can be seen that this model is successful in reproducing the observed discharge.

4.3.4 Application of MOCT

This model used the outputs of any other three models to give an improved discharge series by using simple average method, weighted average method or artificial neural networks method.

4.3.4.1 By using the simple average method (SAM)

This method is computing the discharge series by computing the simple arithmetic mean of the outputs of three models. The models chosen to apply this model are SLM, LPM, and ANN.

Table (4.9) Results of MOCT-SAM

model	Calibration (R^2)%	Verification (R^2)%
LPM	96.38	95.15
ANN	92.17	91.17
SLM	78.01	75.95
SAM combined	93.14	92.12

4.3.4.2 Weighted Average Method (WAM)

This method is used multiply the values of the results discharges of the chosen three models by weights and summed it to give the new estimated discharge series. The values of three the weights used in this model were 0.0474, 0.1811, and 0.8664.

Table (4.10) Results of MOCT-WAM

model	Calibration (R^2)%	Verification (R^2)%
LPM	96.38	95.15
ANN	92.17	91.17
SLM	78.01	75.95
WAM combined	97.92	95.36

4.3.4.3 Artificial Neural Network Method (ANN)

no. of models = 3

no. of neural network weights =16

Table (4.11) Results of MOCT-ANN

model	Calibration (R^2)%	Verification (R^2)%
Model no. 1	96.38	95.15
Model no. 2	92.17	91.17
Model no. 3	78.01	75.95
NNM combined	96.91	95.66

4.3.5 Application of HEC-hms model

The total area of the Blue Nile catchment including lake Tana and its basin is 324,530 Km^2. In this paper, only the catchment of the Blue Nile till Eddeim station on the main stream of the Blue Nile (at the border between Sudan and Ethiopia) is considered. The catchment area behind the gauging station is 254,230 km^2. The Blue Nile watershed was delineated using DEM-based delineation in the Watershed Modelling System (WMS) (Nelson, 2004). The DEM of the Blue Nile and the delineated watershed are shown in Fig. (4.2) and (4.3).

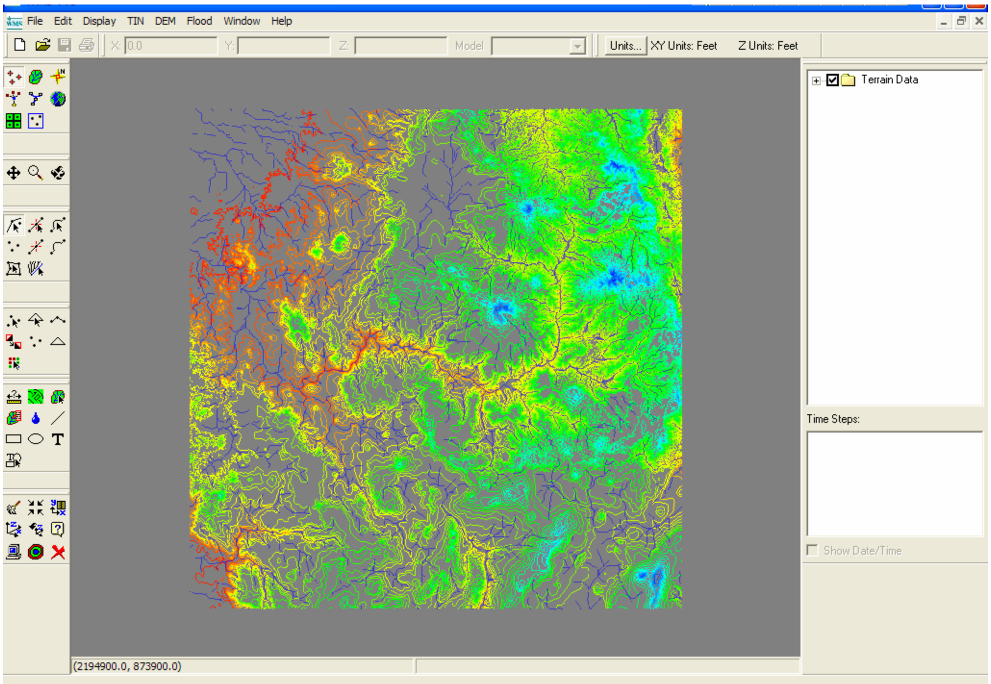
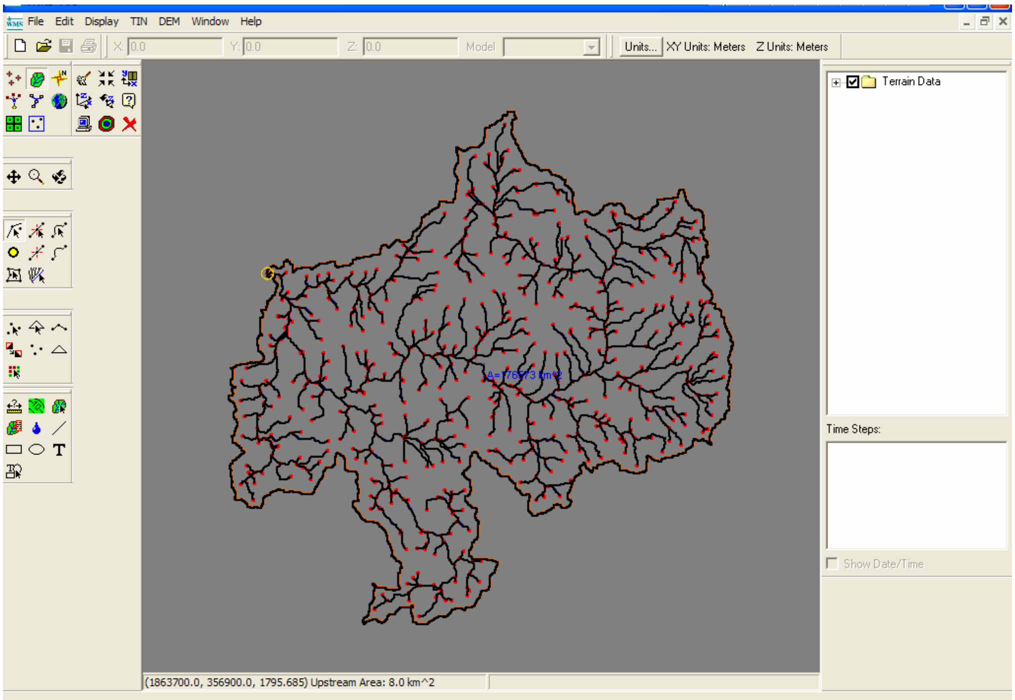


Fig. (4.2) DEM of the Blue Nile Watershed up to Eddeim

Daily rainfall and evaporation records are available for the Blue Nile watershed for the period 1/1/1990 to 31/12/1996. Furthermore, daily flow discharges record at Eddeim station were made available for the same period for comparison needs with the simulated flow discharges by HMS.

In this study, 5 years were devoted to calibration and 2 years to validation. The beginning and ending dates of the calibration and validation simulations represent inactive meteorological and hydrological conditions in order to minimize the error in setting the initial conditions. The calibration stage covered the period 1/1/1990-31/12/1994 including different levels of floods (low, moderate and high flooding cases). The verification stage focused on the period 1995-1996 which represents one low and high flood year.



(1863700.0, 356900.0, 1795.685) Upstream Area: 8.0 km^2

Fig. (4.3) Delineated Watershed of the Blue Nile up to Eddeim

4.3.5.1 Model Calibration

Rainfall Losses: SMA Parameters Definition

HMS has the capabilities to process automated calibration in order to minimize a specific objective function, such as sum of the absolute error, sum of the squared error, percent error in peak, and peak-weighted root mean square error. However, in many cases, the resulted automated parameters are not reasonable and practical. In this study, manual calibrated method was adopted to determine a practical range of the parameter values preserving the hydrograph shape, minimum error in peak discharges and volumes.

The whole 12 parameters needed for the SMA were taken into consideration in this simulation. The maximum infiltration rate and the maximum soil depth as well as the percolation rates and groundwater components had significant influence on the simulated flow discharges. The remaining parameters were adjusted to match the simulated and observed peak flows, volumes, time to peaks and hydrograph shape. The 12 parameters needed for the SMA were estimated as shown in Table (1). While adjusting parameter values during model calibration, the wet period of the year were weighted more heavily, ensuring that the model would accurately simulate, to some extent, the high flooding period in each simulated year.

Table (4.12) SMA parameters for Blue Nile watershed simulation

Parameter	**Value**
Canopy Storage Capacity	1.0 mm
Surface Storage Capacity	1.0 mm
Soil Storage Capacity	2.0 mm
Soil Tension Storage Capacity	0.5 mm
Soil Maximum Infiltration Rate	0.6 mm/hr
Soil Maximum Percolation Rate	0.6 mm/hr
Groundwater 1 Storage Capacity	55.0 mm
Groundwater 1 Max. Percolation Rate	0.8 mm/hr
Groundwater 1 Storage Coefficient	7000 hours
Groundwater 2 Storage Capacity	50 mm
Groundwater 2 Max. Percolation Rate	0.8 mm/hour
Groundwater 2 Storage Coefficient	6000 Hours

The evaporation model used in conjunction with the SMA algorithm takes into account evaporation and transpiration. To model transpiration, the rooting depth was determined to be the maximum depth of the soil profile.

Excess Rainfall Transformation: Transform and Base flow Parameters

Excess rainfall was transformed to direct runoff using the Clark unit hydrograph technique. In this method, the processes of translation and attenuation of excess rainfall dominate the movement of flow through a watershed. Translation is the movement of flow down gradient through the watershed in response to gravity. Attenuation results from the frictional forces and channel-storage effects that resist the flow, (Straub et al., 2000).

The translation of flow throughout the watershed is based on time-area curve, which expresses the curve of the fraction of watershed area contributing runoff to the watershed outlet as a function of time since the start of excess rainfall. The time-area curve is bounded in time by the watershed time of concentration. On the other hand, attenuation of flow can be represented with a simple, linear reservoir for which storage is related to outflow. The two parameters HMS/Clark parameters are the time of concentration and the storage coefficient and are set for the Blue Nile as 160 and 650 hours, respectively. These parameters were derived from WMS.

4.4 Results of models

Models applied are the GFFS models namely, SLM, LPM, ANN, LVGFM, MOCT, SMAR and HEC-hms.

Table (4.13) below shows a summary of the results for calibration and verification.

Fig. (4.4) to fig. (4.14) shows the observed and estimated discharges by the models.

Table (4.13) Results of GFFS models

model	Efficincy criteria R%		G.F	IVF	MSE
	Calib.	Verfic.			
PSLM	98.2	97.3	0.152	0.99	7.5E+4
NPSLM	77.8	76.0	0.137	0.86	80.3E+4
NPLPM	92.2	91.4	0.153	0.98	28.4E+4
PLPM	98.6	97.2	0.150	0.998	6.3E+4
LVGM	91.5	87.2	0.490	0.99	34.4E+4
SMAR	92.0	91.3	0.149	1.01	29.04E+4
NNM	97.4	96.6	0.155	0.97	10.02E+4
MOCT					
By SAM	96.2	94.7	0.153	0.98	16.4E+4
By WAM	97.5	96.7	0.150	0.97	9.8E+4
By NNM	96.9	96.1	0.152	0.99	11.8E+4
HEC-hms	80.0	64.9	0.145	0.81	71.3E+4

In terms of the model efficiency in table above higher performance index is provided by PLPM as compared to the others, but the model isn't represent closely the actual physical processes occurring within the catchment, there is over estimate and under estimate in many periods.
The simulated flows as an output of HMS based on the mentioned parameters are compared to the observed ones for calibration period.
Fig. (4.14) below show the scatter diagram of the observed and estimated discharges. From fig. (4.14) below it can be noticed that the model produced a relatively reasonable results.

The Nash-Sutcliffe (1970) coefficient of efficiency (R^2) which used to judge the model performance was computed by eq. (3.11). The estimated value of the coefficient was computed by HEC-hms as 0.80 which may be satisfactory to judge on similarity and consistency between the observed and estimated hydrograph shape.

From fig (4.14) below it is clear that the model produced relatively over estimated flows.

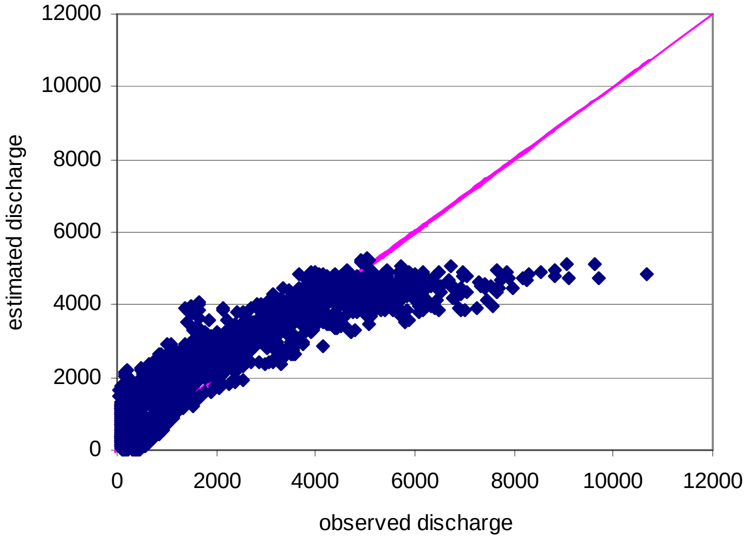


Fig. (4.4) Results of NPSLM model

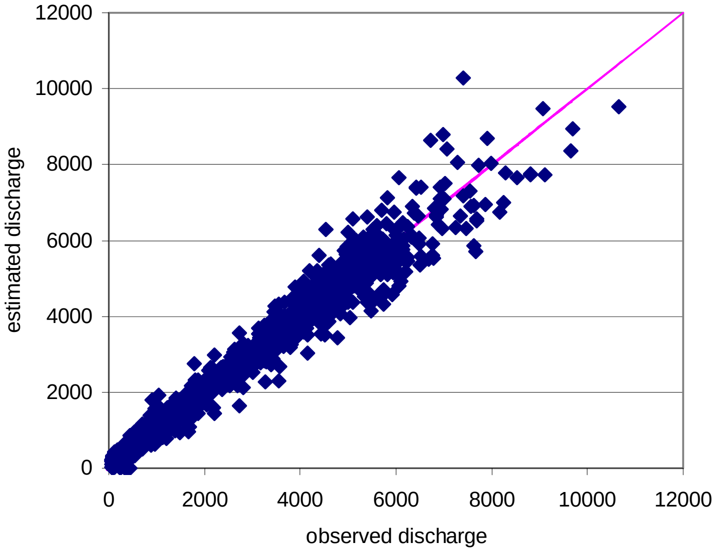


Fig. (4.5) Results of PSLM model

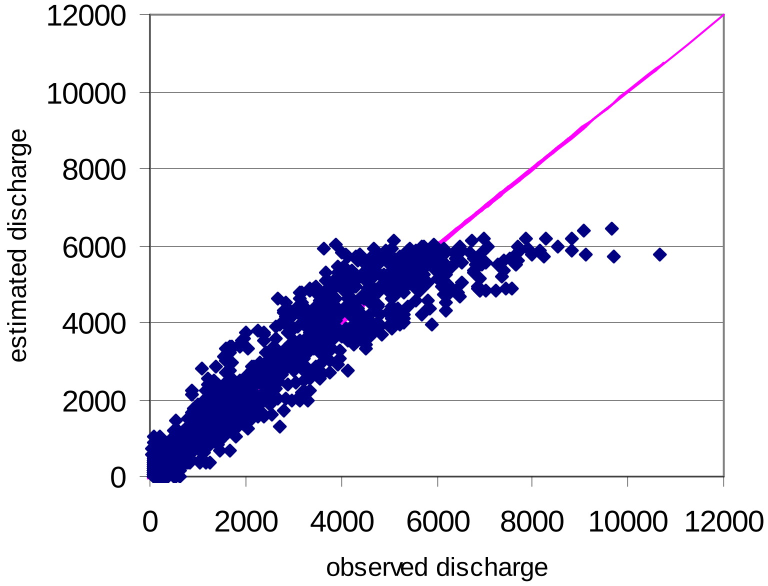


Fig. (4.6) Results of NPLPM model

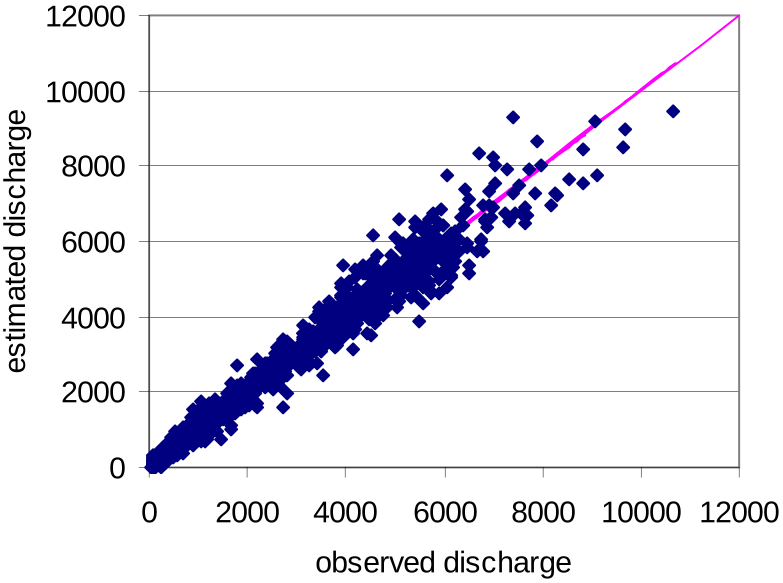


Fig. (4.7) Results of PLPM model

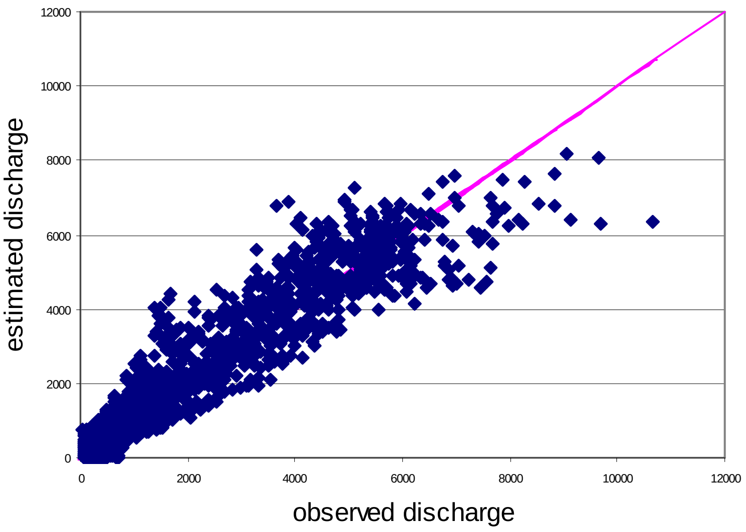


Fig. (4.8) Results of LVGFM model

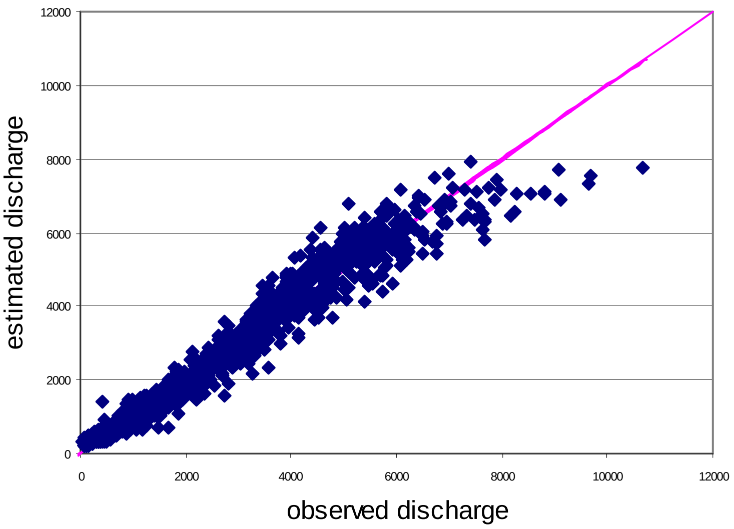


Fig. (4.9) Results of ANN model

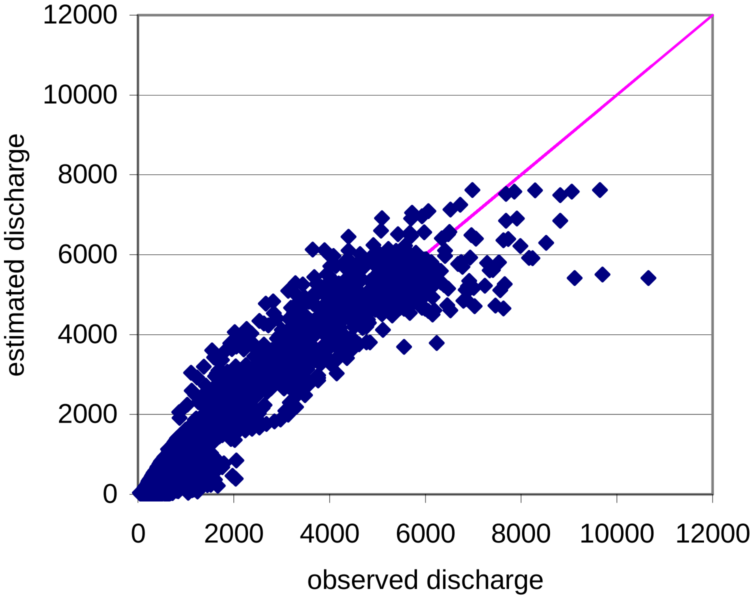


Fig. (4.10) Result of SMAR model

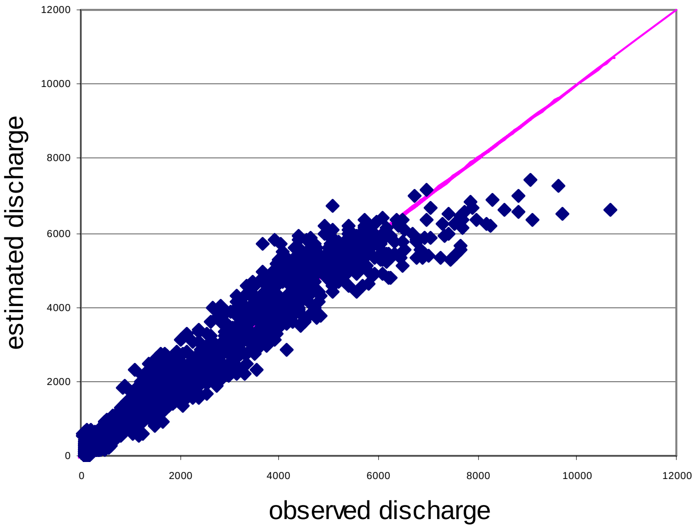


Fig. (4.11) Results of MOCT by SAM

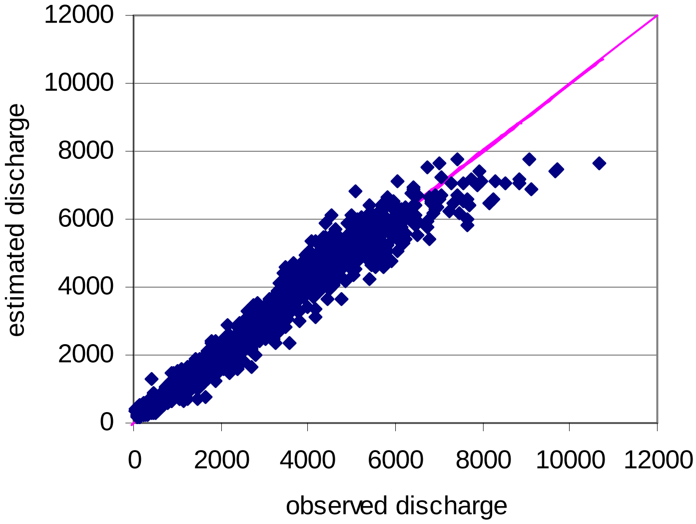


Fig. (4.12) Results of MOCT by WAM

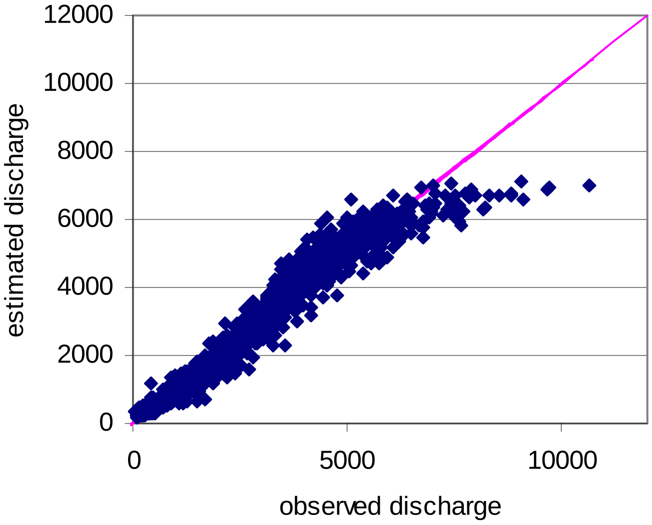


Fig. (4.13) Results of MOCT by ANN

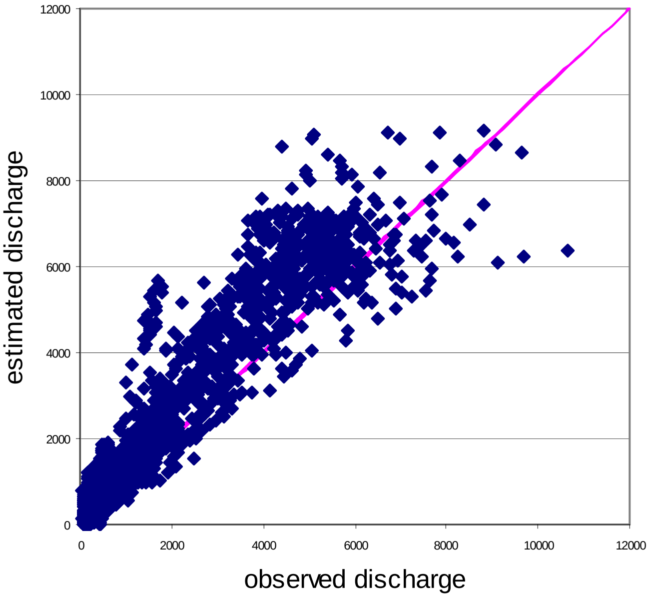


Fig. (4.14) Results of Hec-hms model

Chapter five

Conclusion and Recommendations

5.1 Conclusion

Data sets of daily time span for a period of 7 years (1990-1996) comprising rainfall, runoff and evaporation were collected, processed and used in this study to calibrate several models and estimate discharges which compared with the observed ones in El Diem station.

The models applied are namely; SLM (parametric and nonparametric), LPM (parametric and nonparametric), SMAR, LVGM, ANN, MOCT (SAM, WAM and NNM), in addition to the HEC-HMS.

Results showed that the LPM consistently performed better than all the other models by accounting for more than 90% of the initial variance but the model failed to reproduce accurately the high observed discharges in some occasions however it is not that severe failure.

PSLM ranked second in its in performance but it under estimated the high flows.

These results also indicate that simple models, involving fewer parameters or weights to be evaluated, and relying on simple mathematical procedures (e.g. the ordinary least squares solution), are often better in discharge forecasting than models which involve a significantly higher number of parameters or weights to be evaluated relying on complex procedures such as SMAR and HEC-HMS models.

However, the purpose of modeling dictate which type of model should be used. Those simple models (black box ones) lack completely any physical representation. On the other hand parameters of SMAR and HEC-HMS have physical meaning and can be related to catchments characteristics.

The performance of the conceptual models is not that bad compared to the black box ones.

5.2 Recommendations

- The overall results demonstrate the potential of the PLPM model as a simple forecasting tool to forecast flows in the Blue Nile as early flood warning and the quantity of water for irrigation purposes.
- More hydrological data are needed to take into account the hydrological, soil characteristics and climatic change for better and accurate modeling of the hydrological processes in the catchment.
- Further study is needed to analyze the model performance and attribute the accounting for the initial variance to model components. This kind of studies helps understanding the rainfall-runoff relations and the process that should be considered seriously.

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