XIX International Conference on Water Resources
CMWR 2012
University of Illinois at Urbana-Champaign
June 17-22, 2012

SIMULATION OF ATBARA BASIN USING A DISTRIBUTED HYDROLOGICAL MODEL AND GLOBAL DATA SETS

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Key words: Global data; ATBARA Basin; Distributed hydrological modeling; IPCC data

1 INTRODUCTION

Implementation of water management policies requires decision support tools. Modeling is one of these tools. However, in developing countries, they not only lack appropriate tools and personnel to develop and maintain water resources model, but also they do not have sufficient data to build, calibrate and validate models. For instance, rain gauge network is too sparse to produce reliable areal rainfall estimation. We should use different sources other than ground collected data.

Remote sensing is used in hydrology to estimate rainfall, surface temperature and soil moisture from satellite imagery, which can be used to determine other hydrological processes such as evapo-transpiration. Rainfall estimation from satellite imagery has been used for more than two decades (Engman, 1995). The latest technology is precipitation Radar on broad TRMM satellite, which can measure vertical structure of troposphere precipitation (Kawanishi et al, 2000). Most of these Global data are available online and free of charge, including precipitation, surface temperature, soil moisture, radiation, relative humidity, wind speed, etc. In most cases, these data are used for climatic change models. In this study, remote sensed data were analyzed and used to run a hydrologic model. The precipitation data sets used are from Intergovernmental panel on climate change IPCC data distribution center, National Institute for Environmental Studies-Japan (NIES) using model of MIROC3.2 hires and National Centre for Atmospheric Research USA (NCAR) using model of CCSM3, These models are used to predict the precipitation Globally. Global Precipitation climatology center (GPCC) V5 2.5 and ground stations rainfall data are observed data. The temporal resolution was day. In the present application, Distributed Hydrological Model (Yang, et al 2000); a physically based model with daily time step was used as it is effective for simulation of large basins. Distributed models incorporate the temporal and spatial variability of catchment conditions and meteorological inputs and allow for a better representation of the hydrological processes than other model types (Yang et al., 2002). The main objective of the present study is to set-up a hydrologic model of ATBARA basin, in both Ethiopia and Sudan using remote sensing data. Actually, this is the first step to have an integrated tool for Water Resources Management (WRM) in the whole Nile basin.

2 STUDY AREA

The Atbara Basin (Fig. 1) is 112,000 Km2; it starts 50 km north of Lake Tana passing 830 km till its mouth in the main river Nile at the Sudanese town of Atbara that lies 310 km north of Al-Khartoum town. Its major tributary is the Tekeza River, sometimes known as the Setit River, which is 608 km long and starts north of the Ethiopian Plateau near Mount Qachen. The River has been excavating a great gorge whose depth is nearly 2000 m in some parts. Tekeza River is responsible for the largest part of sediment load carried by Atbara River during the flood period.
Atbara is the last great tributaries feeding the Nile River till the end of its journey into the Mediterranean Sea. The Atbara makes a sever descent resultant from its swift flow and its massive capacity to carving leading to a remarkable decline of its water level in relation to the plan land area on both banks.

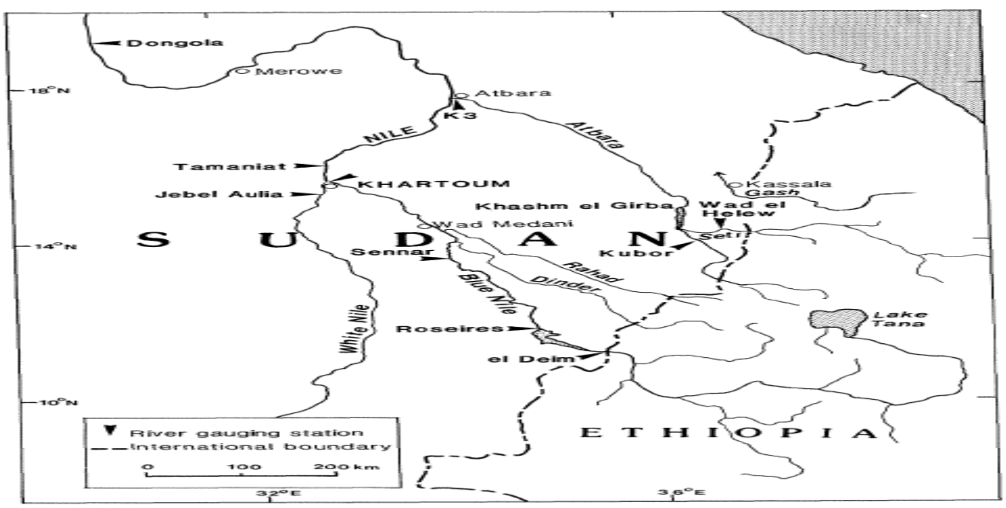

Fig. 1: Study area

3 THE DISTRIBUTED HYDROLOGICAL MODEL

3.1 Description

The development of a distributed hydrological model starts with the collection of digital geographic information related to the study area for building a digital representation of the basin.

A digital elevation model (DEM) is used to define the target area, and the target basin is subdivided into a number of fundamental units for hydrological simulation. The catchment parameters related to topography, land use and soil are then calculated for each simulation unit. As shown in Figure 2, geographical information system (GIS) defines the general structure of the hydrological model.Fig.2 shows the general structure of the hydrological model.

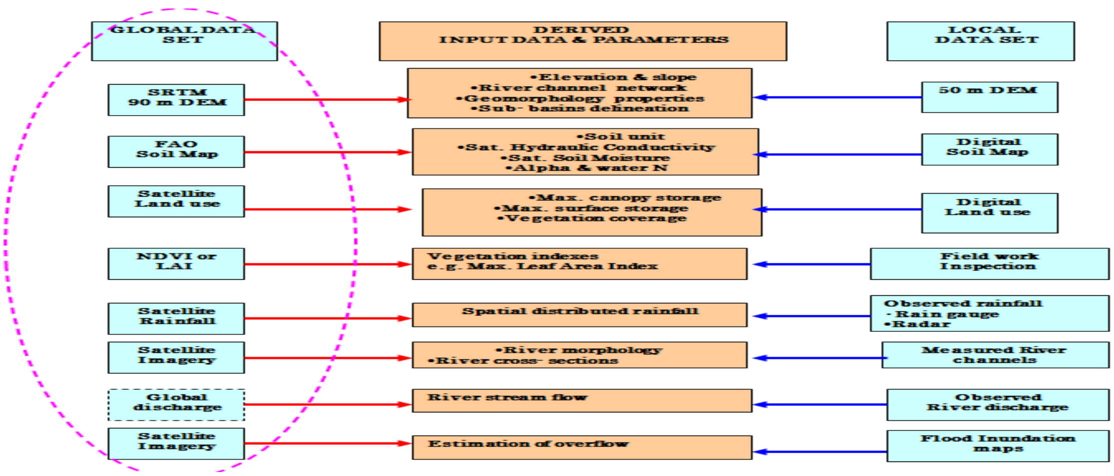

Figure 2.Usage of global data sets and local observations

3.2 Data Preparation

The geographic information used for the construction of a distributed hydrological model includes topography, land cover, soil, and geological maps. The digital data of elevation, land use and geological conditions were obtained from satellite data. Moreover, the data that includes climatic conditions; particularly precipitation and temperature were obtained from Research centers as global data sets. Discharge is strongly affected by the precipitation and temperature. So, precipitation, temperature and Evaporation are the forcing climatic data.

3.2.1 Topography

The topography data used for building model is from HYDRO1K. HYDRO1K is a geographic database developed to provide comprehensive and consistent global coverage of topographically derived data sets, including streams, drainage basins and ancillary layers derived from the USGS' 30 arc-second digital elevation model of the world (GTOPO30). HYDRO1k provides a suite of geo-referenced data sets, both raster and vector, which are of value for all users who need to organize, evaluate, or process hydrologic information on a continental scale. It has a spatial resolution approximately 1000 meters. Fig. 3 shows the elevation map for ATBARA Basin as extracted from the HYDRO1K database.

3.2.2 Land use

A digital land-use map is available in the Global Land Cover Facility (GLCF) which is a NASA-funded member of the earth science Information partnership at the University of Maryland at 1 Km resolution and 25 different types of land cover. Land use in ATBARA basin is dominated by Barren or Sparsely Vegetated which covers 68.38%. Fig. 4 shows different types of land use in ATBARA Basin as extracted from NASA Satellite database.

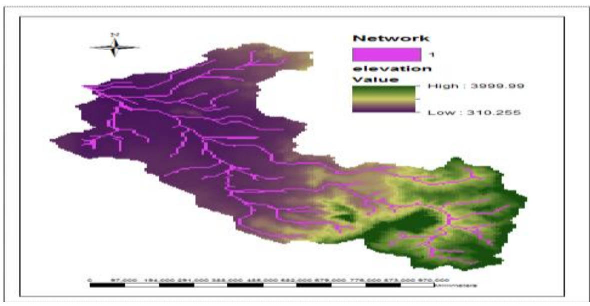

Figure 3: Elevation map

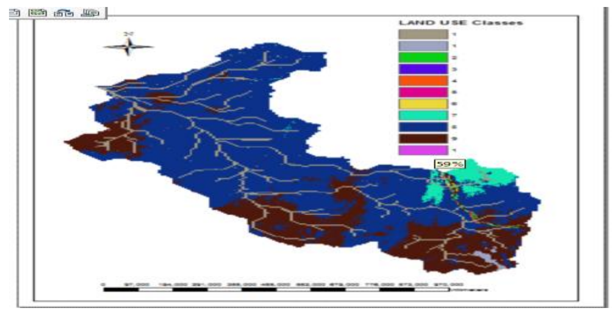

Figure 4.Land use types

3.2.3 Soil

The soil map used is from FAO world soil classification with a scale of 1:25.000.000. The FAO soil classification defines 30 major soil groups, and their physical and chemical properties, texture and slope. The vertical distribution of the saturated hydraulic conductivity of the topsoil is assumed to decrease exponentially from Ks1 near the soil surface to Ksg for groundwater at the bottom of the topsoil. Ks1 and Ksg are parameters that require calibration. Fig. 5 shows different types of soil in ATBARA Basin.

3.2.4 Precipitation

There are 4 datasets of rainfall used in this study: rain gauge data, GPCC global dataset, AR4 GCM datasets using model of MIROC3.2 hires and CCSM3. The simulation period is the flood season starting from 15June 2001 to 15October 2001 and 2002 for calibration and validation respectively. Fig.6 (a, b) show the locations of stations for global data set and ground data respectively.

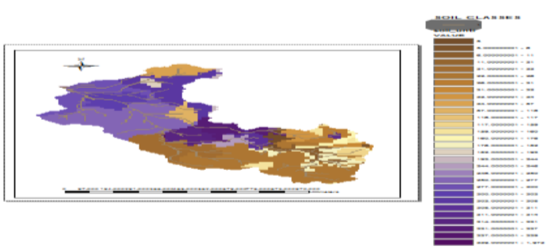

Figure 5: Soil map

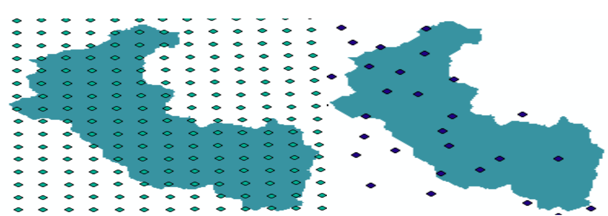

Figure 6. (a, b): Distribution of Global Data set and ground data Stations

3.3 Running Distributed Hydrological Model

In order to use satellite rainfall data, a grid-based hydrological model is used in this study, which is modified from the geomorphology-based hydrological model (GBHM) (Yang et al., 2002). Unfortunately, grid-based distributed hydrological models usually cannot run at high resolution for practical applications due to their heavy computational requirement. A sub grid parameterization scheme is necessary when a hydrological model uses a large-sized computational grid. In this study, the grid size in the hydrological model is 4000 m. The spatial heterogeneity inside a 4000 m grid is considered in the hydrological model. Figure 7 shows the concept of the sub grid parameterization used in the grid-based distributed hydrological model.

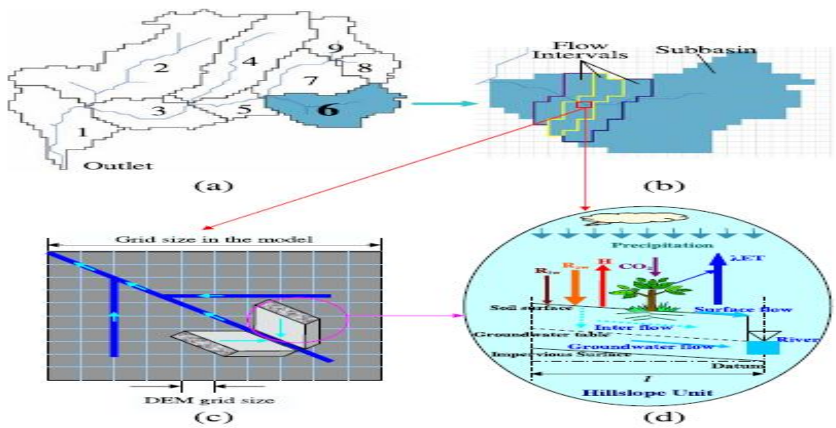

Figure 7.Concept of the grid-based hydrological model

4 RESULTS AND DISCUSSION

4.1 Rainfall data analysis

A comparison of precipitation datasets used is needed to understand model response to variation in precipitation estimation and as they come from different places with different measuring systems and estimation algorithms. The comparison of estimation methods requires the definition of a set of reference values of error criteria in order to evaluate the agreement between the estimates and the reference values. The rainfall was estimated for each sub-basin of the study area for all data sets, using Thiessen polygon method.

4.1.1 Rainfall estimation error

The visual interpretation of global data was complemented by statistical analysis. Error (residual) and absolute error between global data sets and rain gauge precipitation data for simulation period are calculated. If rain gauge values are Z (t), and estimate values are Θ(t), the error is calculated as e(t) = Z(t) - Θ(t). For each of these quantities, the minimum, the maximum, the mean, the median and the standard deviation were compared. The results are presented in Tables 1-1, 1-2 and 1-3.

	GPCC Data set	Gauge	Error
Mean	2.016	2.896	1.68
Minimum	0.0	0.0	-27.36
Maximum	52.56	27.36	52.56
Median	0.0	0.0	0.0
Standard deviation	0.0004075	0.0014021	0.00039

Table 1.1 : Statistical analysis of GPCC data set

	MIROC3.2 hires Model	Gauge	Error
Mean	2.424	2.896	2.135
Minimum	0.0	0.0	-27.3
Maximum	114.4	27.36	114.4
Median	0.0	0.0	0.0
Standard deviation	0.00027	0.001402	0.00027

Table 1.2 : Statistical analysis of MIROC3.2 model data set

	CCSM3 model	Gauge	Error
Mean	1.73568	2.896	-8.227
Minimum	-27.3	0.0	-31.256
Maximum	59.832	27.36	1
Median	0.0	0.0	-5.456
Standard deviation	0.00037	0.001402	0.00426

Table 1.3 : Statistical analysis of CCSM3 data set

4.2 Comparison Model Results

Semi-automatic model calibration and validation were carried out at ATBARa_k3 flow gauging stations (Figure 1). It is a multi objective function optimization task. This was done in order to ensure a good calibration for the whole study area which is a vast watershed, because calibration at downstream gauging station (ATBARA_k3) gave good results at that particular site in 2001 and 2002 in validation. The criteria for model performance was checked with the Nash-Sutcliffe's model efficiency (Ns) and coefficient of determination (R2) and root-mean-square error (RMSE) based on the observed and simulated daily stream flows over the calibration and validation periods. The hydrograph of observed and simulated at ATBARA gauging station are shown in Figure 8-1, 8-2, 9-1, 9-2, 10-1, 10-2, 11-1 and 11-2. Performance criteria are shown in Table 2, 3 and 4.

	Calibration	**Validation**
Ns	**0.57**	**0.37**
R2	**0.70**	**0.62**
RMSE	**1596**	**1086**

Table 2: Model performance with rain gauge data in ATBARA station

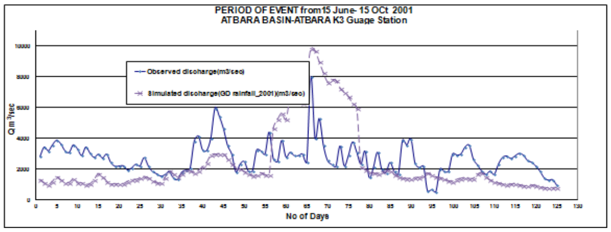

Figure 8.1 Rain gauge Calibration at ATBARA station

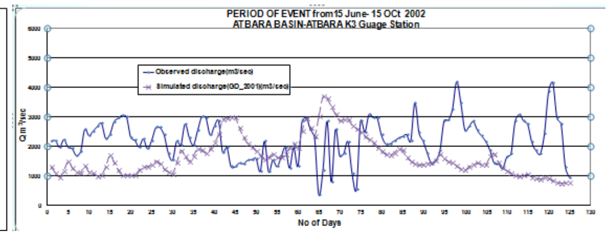

Figure 8.2 Rain gauge Validation at ATBARA station

	Calibration	Validation
Ns	**0.31**	**0.42**
R2	**0.60**	**0.64**
RMSE	**1572**	**1088**

Table 3: Model performance with GPCC data in ATBARA station

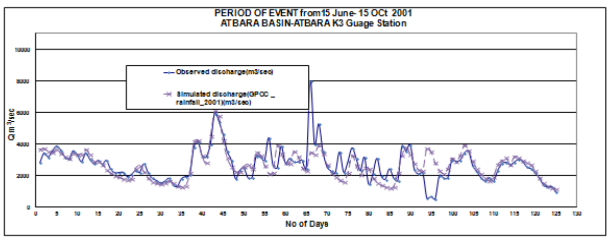

Figure 9.1 GPCC Data set Calibration at ATBARA station

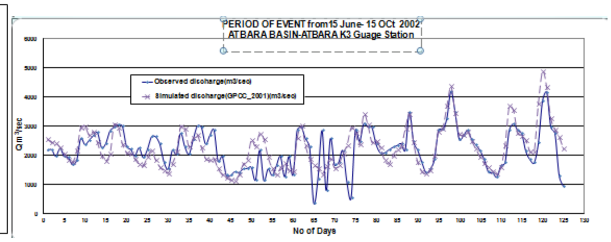

Figure 9.2 GPCC Validation at ATBARA station

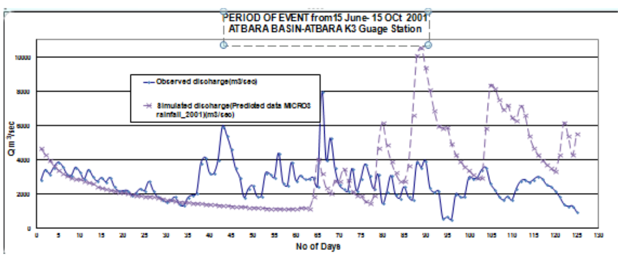

Figure 10.1 : MICRO3_hires Calibration

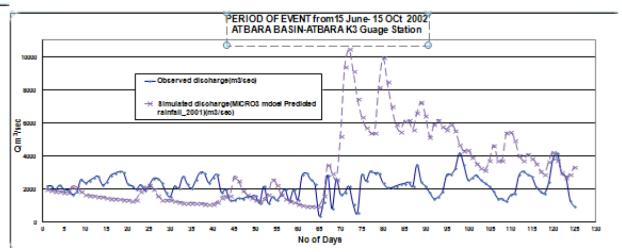

Figure 10.2 : MICRO3_hires Validation

	Calibration	Validation
Ns	**0.79**	**0.93**
R2	**0.82**	**0.93**
RMSE	**2544**	**2332**

Table 4: Model performance with MICRO3_Hires Model data in ATBARA_k3 station

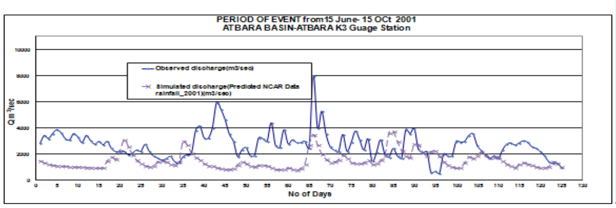

Figure 11.1 CCSM3 Calibration

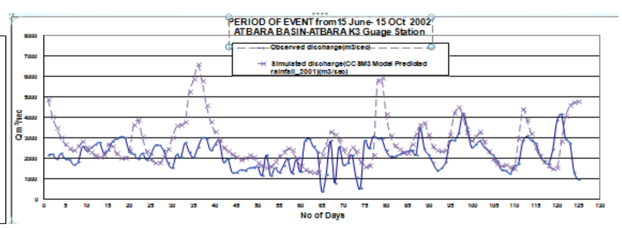

Figure 11.2 CCSM3 Validation

	Calibration	Validation
Ns	**0.44**	**0.93**
R2	**0.64**	**0.93**
RMSE	**1247**	**1032**

Table 5 : Model performance with CCSM3 Model data in ATBARA_k3 station

4.3 Discussion

Besides general problem related to flow gauging stations, modeling approach, each precipitation dataset has its own characteristics. GPCC dataset gave a minimum error of precipitation related to ground gauges which results in simulated flow. The model predicted well peak flow, but failed to predict a good base flow. The overestimation precipitation of MICRO3_Hires Model dataset at the end of flood season affects the final stream flow. However, this data gave acceptable results compared to other global datasets. The simulated hydrograph using CCSM3 Model data set does not show a good stream flow. The model performance was very low because of the values of precipitations during the flood season have a big error related to ground rain gauges. Hence, this model is not good enough to simulate stream flow. In conclusion, Hydrograph derived from ground data has very poor matching with observes hydrograph due to limited number of ground stations. On the other hand, GPCC is satellite data while MICRO3 and CCSM3 are global climate modeling, GPCC is the best even better than ground stations.

5 ACKNOWLEDGEMENT

The research is part of the PhD work of the first author which is supported by a grant from the Ministry of Higher Education, Egypt to conduct his study at E-JUST. The authors thank E-JUST for covering all the expenses of the conference fees and accommodation for the first author to attend the conference.

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