ASSESSMENT OF CLIMATE CHANGE IMPACT ON THE MEGHNA RIVER BASIN USING GEOMORPHLOGY BASED HYDROLOGICAL MODEL (GBHM)

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ABSTRACT

There are several physical hydrological models to represent a river network such as the MIKE SHE, TOPMODEL, Geomorphology Based Hydrological Model (GBHM) etc. These models are different from each other based on considered aspects to represent the river basin or catchment topography. In this article a study on Surma-Meghna basin using GBHM is reported. GBHM is a fully distributed physical hydrologic model developed for simulation of regional watershed hydrology using digital elevation models (DEMs). GBHM uses the hillslope elements as the fundamental computational units. Future run-off estimation under climate change condition is also very important for Bangladesh. Such studies are also presented for Meghna-Surma basin where PRECIS simulation results are utilized to predict future rainfall and temperature values.

Keywords: *Run-off estimation, hydrological model, GBHM, PRECIS, climate change.*

1. INTRODUCTION

Understanding the behaviour of a river network is important for planning and management of the water resources. Several hydrological models have been developed by researchers to represent a river network. These models are used to estimate river network parameters by analytical solution or by numerical simulation. Discharge and run-off of a river network are among these parameters. Discharge prediction of river networks covering Bangladesh is very crucial for its people, living on one of the largest river network in the world, in order to be prepared for floods, droughts and water scarcity.

Physical hydrological models, among different types of models, are more representative and can produce more accurate output compared to other models (Refsgaard, 1996). There are several physical hydrological models such as the MIKE SHE (DHI, 1993; Refsgaard and Storm, 1995) TOPMODEL (Beven, 1989; Beven et al., 1994) and Geomorphology Based Hydrological Model (GBHM) (Yang, 2000b) that consider spatial variation. These models apply different approaches to represent the river basin or the catchment topography. A square grid based modeling system is used for topography representation in MIKE SHE where the discrete grid points are taken as the computational units. Requirement of a high computational power is a draw-back for this model since the whole catchment is considered for the simulation. On the other hand, it is assumed in

TOPMODEL that only a fraction of the total catchment area contributes to the overland flow as it becomes saturated during precipitation. So, simulation is carried out only for this area which is called source area. The model characterizes the topography using a distributed topographic index that is comprised of grid and spatial parameters. In the model, it is also assumed that areas with similar topographic indices represent similar hydrological behaviour and these areas can be aggregated into one segment. Topographic parameters are averaged over each segment to further reduce the complexity of the model.

GBHM employs area function and width function to lump the topography and divide the catchment into a series of flow intervals. Spatial parameters are averaged over each flow interval and represented by one-dimensional distribution functions. The model is also flexible in describing other spatial variability, such as land-cover and soil-type. For these reasons, GBHM can be used for complete hydrological simulations in large catchments. A comparative study among GBHM, MIKE SHE and the TOPMODEL shows that the run-off generation mechanism is more accurately addressed in GBHM compared to the other two models (Yang, 2000b). Finally, human activities for water resources assessment and management in large river basins can be incorporated in GBHM. Therefore, GBHM is considered to study the Meghna river basin that covers a large region of Bangladesh.

The article focuses on the effect of climate change on the Meghna river basin. Meteorological system is affected by the climate change. PRECIS (Providing Regional Climates for Impacts Studies) software from MetOffice can provide high resolution climate change information based on the Hadley Centre's regional climate modelling system. In this article, meteorological data predicted by PRECIS for Meghna river basin is utilized to estimate the effect of climate change in this region. Run-off of the river network is presented to show the effect of climate change as it depends on the meteorological parameters and the catchment topography of a river network.

2. STUDY AREA AND COLLECTED DATA FOR SIMULATION

GBHM was previously used to obtain hydrograph for the Seki river basin of Japan and the Chao Pharaya river basin of Thailand (Yang, 2000b). The Chao Pharaya river basin is the largest basin in Thailand in terms of both its drainage area and river length. Surma-Meghna basin, studied in this article, is the longest (669 km) river system of Bangladesh. The system also drains out one of the world's heaviest rainfall areas (e.g. about 1,000 cm at Cherapunji, Meghalaya, India). Besides, Meghna is the widest river among those that flow completely inside the boundaries of Bangladesh. Therefore, study of the Meghna river basin provides an understanding of hydrological processes for a vast region of the country. The whole basin approximately has an area of 61,021 km2.

The digital elevation model (DEM) is collected from Centre for Environmental and Geographic Information Services (CEGIS) provided by Shuttle Rudder Topography Mission (SRTM). The original DEM has a resolution of 90 m which was aggregated to 500 m. The Meghna river basin has its outlet point near Chandpur with a total area of 52,887 km2 based on DEM.

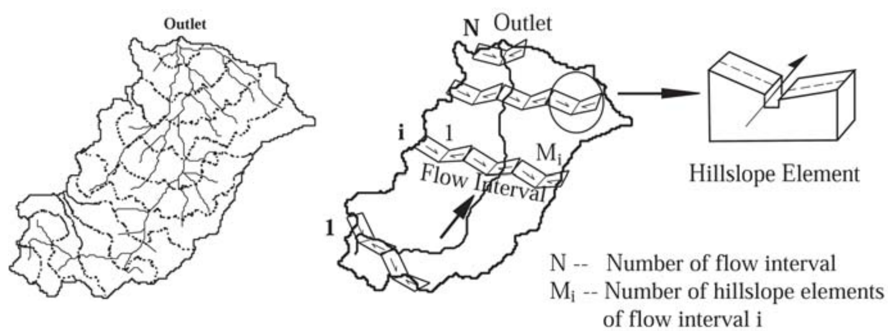
Global land use data are obtained from Global Land Cover Characteristics database of United States Geological Survey (USGS). The 24 different land use types defined in original map are merged to eight based on land property. The main land use types of this vast area are forest and agricultural land, respectfully. Monthly Global Normalized Difference Vegetation Index (NDVI) data are collected from Global Inventory Modeling and Mapping Studies (GIMMS). The daily rainfall data observed by Bangladesh Water Development Board (BWDB) are collected from Center for Environmental and Geographic Information Services (CEGIS).

3. DESCRIPTION OF GBHM

The Geomorphology Based Hydrological Model (GBHM) uses a simple distributed approach to represent a natural catchment. Here, the primary computational unit is the hillslope element that provides lateral inflow to the main stream. The topography and other spatial variables of the catchment are represented by one-dimensional functions w.r.t. the flow distance from the outlet. The catchment run-off is the integration of hillslope responses through the river routing.

3.1 Discretization Scheme

A catchment in GBHM is subdivided into a number of flow intervals following the flow distance from outlet to upper source (Yang, 2002) as shown in Figure 1. A flow interval is an area interval between two lines of equal flow distance. There can be several stream segments within each flow interval and a pair of hillslopes is considered on both side of the segment. So, the flow interval is a representation of a series of hillslope elements.



(a) **(b)** **(c)**

Figure 1: (a) Flow distance contour interval of a river network (b) discretization of a river network using flow interval and (c) hillslope element around a stream segment.

3.2 Spatial Parameters Representation

The main spatial parameters considered for run-off calculation are topography, precipitation, land cover, land use and soil type. The topography is represented using elevation, hillslope gradient and length at different grid points. An average elevation of all grids within a flow interval is considered. On the other hand, the hillslope gradient is obtained by averaging the value of the steepest gradients of all grids within the interval. The hillslope element is represented by rectangular inclined planes as shown in Figure 1(c). The hillslopes in a flow interval are assumed hydrologically similar without considering spatial variation of soil and land cover. Precipitation data recorded at gauge-points are interpolated over the catchment using Thiessen polygons.

3.3 Hillslope Hydrological Processes

The vertical plane in the hillslope response model is divided into several layers like canopy, soil surface, unsaturated zone and groundwater layer. The canopy interception ability depends on leaf-area-index of a vegetation type. Actual evapotranspiration is from the canopy water storage, root zone, surface storage and soil surface. Evapotranspiration is assumed to take place only during the 12 hours of daytime and is divided by 12 hours to convert it to an hourly potential evaporation (Yang, 2000a).

The water-flow of an unsaturated zone is described using a vertical one-dimensional Richard's equation (Yang, 2000a). On the other hand, the saturated zone is represented using mass balance equation and Darcy's law (Yang, 2000a). The surface run-off is found from the infiltration excess and saturation excess that flows through the hillslope and becomes lateral inflow into the river (Yang, 2000b).

4. METEOROLOGICAL DATA PREDICTION USING PRECIS

PRECIS (Providing Regional Climates for Impact Studies) v1.8 is used for climate modeling of the Meghna river basin (PRECIS, 2010). PRECIS is developed by the Hadley Centre, UK which is physical model to help generate high-resolution climate change information for Bangladesh. The PRECIS simulation domain includes Bangladesh and south Asia that has 88×88 grid points with a 50 km horizontal resolution. The SRES A1B scenario of IPCC was used to derive the lateral boundary conditions of the simulation using three dimensional ocean-atmospheric coupled model (HadCM3Q) to generate prognostic variables over the simulated domains. This information was used to generate diagnostic variables such as rainfall using PRECIS model all over the domain. The regional climate model dynamically downscaled the data of the Global Climate Model (GCM) with a resolution of 50km from 250km from 1951 to 2100 over the study area.

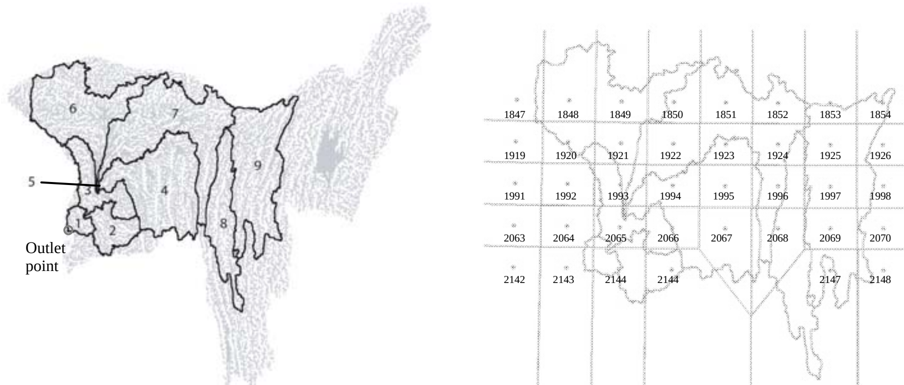
The minimum, the maximum and average temperatures are used to calculate the temperature distribution throughout the day. The temperature is considered to vary linearly in four segments on a particular day from the minimum to the maximum temperatures of that day and the next day. The time-span of these segments are determined in such a way that the average temperature of daily distribution matches the average temperature of the day.

5. RESULTS AND DISCUSSION

A grid-based Digital Elevation Model (DEM) is used for run-off estimation of Meghna river basin. At first the DEM is projected to UTM (Universal Transverse Mercator). The flow direction is then determined by finding the steepest downslope direction from each cell of the grid. Number of cells contributing water to each cell is calculated and the river network is delineated. The location of the cell having the maximum flow accumulation value i.e. the cell to which maximum number of cells contributes water is considered as the outlet point for the river basin. The river basin is then constructed by determining the cells or areas that contribute flow to the outlet point. The whole catchment area is then subdivided into nine sub-catchments and numbered using Pfafstetter basin numbering system (Verdin, 1996). Figure 2(a) shows the Meghna basin with the sub-basins used for run-off calculation. The outlet point of this basin is at Chandpur district as shown in the figure.

Separate grids for slope, distance from outlet and flow-direction are generated for each subcatchment. Different sub-basin parameters like interval-length, bed slope, width, depth, and roughness are recorded. Rain-fall data, other spatial input data (land-use, soil-type), NDVI data and grids containing other information like hill-slope length, and cell-area are also prepared.

Meteorological data are estimated for discrete points of the basin using PRECIS software. These discrete points can be considered as virtual meteorological stations shown in Figure 2(b). The figure also shows the coverage area under each station determined using Thiessen polygons. Average daily rainfall predicted by PRECIS is equally distributed over 24 hours of that day. And a linear change of temperature is considered throughout the day.



(a) (b)

Figure 2: (a) Meghna River Basin with its sub-basins and (b) considered meteorological stations for PRECIS (dots with numbers) with coverage area determined using Thiessen Polygon.

The hydrological simulation is carried out with an hourly time step for the years 1991, 2021, 2051 and 2081. Even though PRECIS provides predicted meteorological data, the software also provides data from the past based on its database. The average rainfall over the study area for 1991 according to PRECIS is shown in Figure 3. The observed rainfall data for the same year of three stations situated in Bancharampur, Muradnagar, and Nabinagar are also shown in the figure. Comparing the PRECIS data with the observed rainfall data in the diagram it is evident that the PRECIS data reflects the observed rainfall pattern throughout the year. Moreover, the values are of the same order.

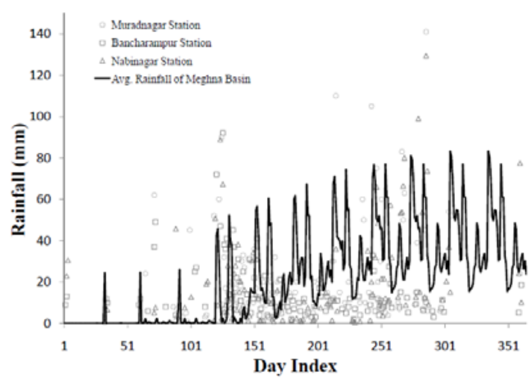
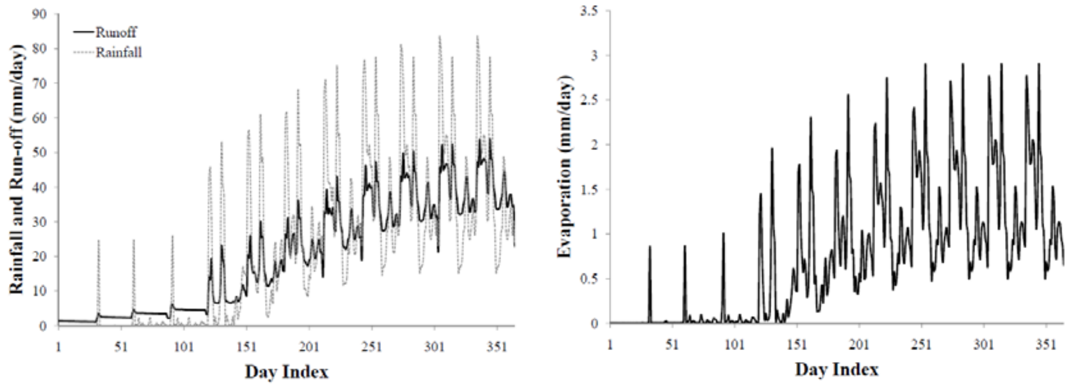


Figure 3: Comparison of the observed rainfall data of three stations with the average rainfall of the Meghna basin according to PRECIS for the year 1991

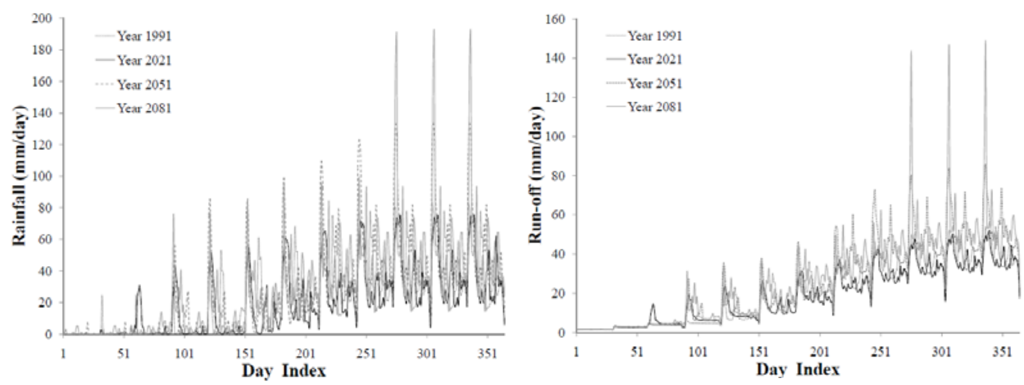
Figure 4 shows the average daily rainfall given by PRECIS, calculated run-off and calculated evaporation for the total catchment in 1991. As expected the run-off and evaporation increases with the increasing rainfall. Moreover, the run-off gradually changes with the rainfall whereas the evaporation changes instantaneously. A small fraction of rainfall is evaporated while most of it contributes to the run-off.



(a) **(b)**

Figure 4: (a) Run-off variation with the rainfall (b) corresponding evaporation throughout 1991

The effect of climate change, reflected by the meteorological data, on run-off is shown in Figure 5. More rainfall for later years result increased run-off.



(a) **(b)**

Figure 5: The effect of climate change on run-off (a) rainfall for different years and (b) corresponding run-off.

6. CONCLUSIONS

The article presents a study on rainfall-run-off relation of Meghna river basin using Geomorphology Based Hydrological Model (GBHM). PRECIS predicts more rainfall for future years resulting increased run-off for the Meghna river basin. The result from this study will be used for discharge calculation of the river basin.

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