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Impacts of Climate Changes on Peak Flow of Upper Meghna River Basin

***Md. Mostafa Ali, **Afiya Narzis and ***Shammi Haque**

ABSTRACT

Bangladesh has been formed as the greatest deltaic plain at the confluence of the Ganges, Brahmaputra and Meghna (GBM) rivers and is highly vulnerable to climate changes according to IPCC reports (IPCC 2007 and IPCC 2014). To understand the consequences of climate changes, hydrological study of these three river basins is required. HEC-HMS is a hydrologic modeling software which includes many of the well-known and well applicable hydrologic methods to simulate rainfall-runoff processes in river basins. In this study, a semi distributed hydrological model of the Upper Meghna river basin with a drainage area of 70263 km^2 is developed using HEC-HMS. Hec-Geo HMS is used to delineate stream network and 22 sub-basins of Upper Meghna River. The model is calibrated at Bhairab Bazar station for the year of 2005 and validated against for the year of 2006. Effects of climate changes are simulated by running the model using the future precipitation data obtained from Global Climate Models (CSIRO-30 and CCCMA-31). Results from those model data are used to predict flow hydrographs for the years of 2050 and 2080. The results show that expected increase in total volume (wet period) using CCCMA-31 and CSIRO-30 precipitation will be in between 29% to 54% and 50% to 54% for the years of 2050 and 2080 respectively. The model developed in this study can be used as a tool to understand the effects of human interventions and changed climatic conditions in the basin area.

Key Words: Upper Meghna Basin, Climate Change, Hydrological Modeling, HEC-HMS, Global Climate Model.

INTRODUCTION

The exact magnitude of the changes in the global climate is still uncertain and subject of worldwide scientific studies. It has been established that human activities are leading to the alteration of the climate through global warming. Fifth Assessment Report of IPCC (IPCC, 2014) reveals that without more mitigation, global mean surface temperature might be increased by 3.7°C to 4.8°C, over the 21st century. In terms of the impact of climate change, few places in the world will experience the range of effects and the severity of changes will also occur in Bangladesh. Bangladesh is highly vulnerable to these changes because of its geographical location on the Bay of Bengal and in the delta of the Ganges, Brahmaputra and Meghna, Flat and low-lying landscape, Population density etc. Changes in future climate will have an immense impact on agricultural production, food security, ecology, biodiversity, river flows, floods and droughts, water security, human and animal health and sea level rise of Bangladesh.

*Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh; **Presidency University, Dhaka, Bangladesh; ***University of Information Technology & Sciences (UITS), Dhaka, Bangladesh.

Uncertainty remains in the prediction of future scenarios due to the diversified climate of GBM basin. Changes in climate may alter the distribution and quality of GBM river basin water resources which may lead to severe natural hazards in Bangladesh. Impacts of climate change are often evaluated by combining atmospheric and hydrologic models. It has been seen that hydrological models are better representative of river network and give more accurate results in the estimation of its parameters. Several studies have been carried out by the researcher using different hydrological models; such as, a physically based hydrological model SWAT was successfully used by Setegn (2010) for Lake Tana Basin in Ethiopia to assess the negative change in water balance in the basin. Another hydrological model named Variable Infiltration Capacity (VIC) developed by Zhang et al. (2013) was used for Huaihe River, China. The model results showed that regional flooding and regional shortage in water resources will be exacerbated under the impacts of global warming.

HEC-HMS is a widely used semi distributed physical hydrological model that simulates precipitation-runoff processes for a watershed (USACE-HEC, 2006). A few example of uses of HEC-HMS model includes: Stormwater Infrastructure Assessment for Clark County Regional Flood Control District (CCRFCD) by Forsee and Ahmad (2011), SMA Based Continuous Hydrologic Simulation of The Blue Nile Ethiopia by Bashar and Zaki (2013), and Calibration and validation of the HEC-HMS model for a river basin in Eastern India by Roy et al. (2013).

STUDY AREA

Ganges-Brahmaputra-Meghna (GBM) river basin is a transboundary river basin. It encompasses approximately 1.7 million sq. km. This area is distributed between India (64 percent), China (18 percent), Nepal (9 percent), Bangladesh (7 percent) and Bhutan (3 percent) (BWDB, 2006).

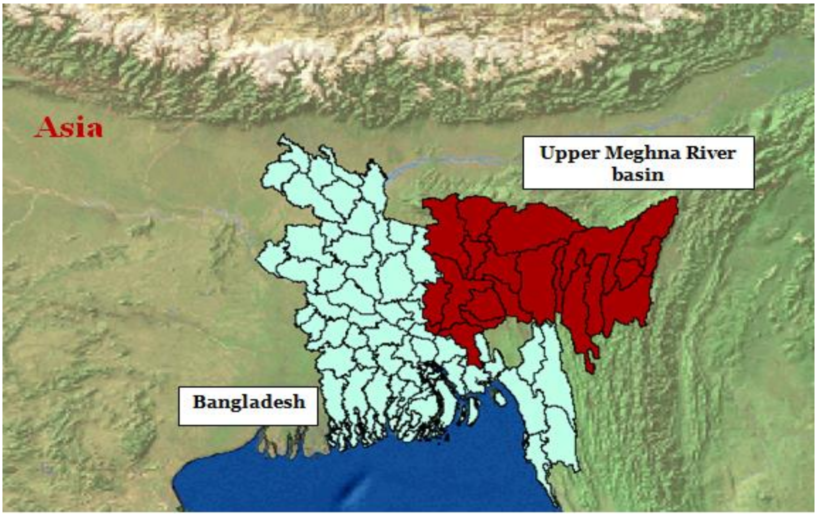

Fig 1. Upper Meghna River Basin (Brown Colored Area)

Bangladesh has been formed as the greatest deltaic plain at the confluence of the Ganges, Brahmaputra and Meghna rivers and their tributaries. The Meghna River is one of the most important rivers in Bangladesh, one of the three that forms the Ganges Delta. Meghna River is hydrographically referred to as Upper Meghna down to Chandpur district in Bangladesh and the associated basin is known as Upper Meghna basin. The study area (colored area) is shown in Fig. 1. According to the Joint River Commission Bangladesh (JRCB, 2011), the Upper Meghna Basin occupies total area of 82,000 km^2. 47000 km^2 (57% of total area) and 35000 km^2 (43% of total area) are contributed by India and Bangladesh respectively as shown in Fig. 1. About 0.4% of the area of Southeast Asia is covered by study area of this project. Average annual rainfall and average annual discharge of the basin are 4900 mm and 4600 m^3/sec respectively (AQUASTAT, 2011). The basin is less than 5% of the total GBM basin, but the total area is more than half of the country and discharge is nearly 20% (BWDB, 2006).

Overview of HEC-HMS

HEC-HMS is a widely used semi distributed physical hydrological model that simulates precipitation-runoff processes for a watershed (USACE-HEC, 2006). The program is a generalized modeling system capable of representing different watershed. Specific capabilities include the ability to specify losses and precipitation volumes for each sub-basin within a watershed, methods to transform precipitation excess to direct runoff, stream routing options, and parameter optimization techniques. In HEC-HMS, User-Specified Unit Hydrograph, Clarks UH, Snyders UH, SCS UH, ModClark and Kinematic Wave methods are available to simulate the process of direct runoff excess precipitation on a watershed as transformation of precipitation excess into point runoff. Among them, SCS UH method has been selected for this study. The Bounded Recession, Constant Monthly, Linear Reservoir, Nonlinear Boussinesq and Recession models are available to simulate the process of base flow. Recession Baseflow method is used in this analysis. To model channel flow, Muskingum, Modified Plus Method, Kinematic Wave, Lag, Muskingum-Cunge and Straddle Stagger are available. Muskingum method is used to route flow hydrograph for this study. To calculate loss, SCS curve number method is selected for which curve number for each subbasin is generated by ArcGIS.

METHODOLOGY

Data Collection

To delineate watershed and river network of Upper Meghna River Basin, Digital elevation model (DEM) and stream network of the study area (resolution- 30s) are collected from the Hydro SHEDS webpage of U.S. Geological Survey (USGS). Land use and soil data are used to generate Curve number grid for each sub basin. The resolution of soil data and land use data are 1:5,000,000 and 1000 m respectively. The reference system is WGS1984.

Precipitation and discharge data of daily interval are collected for 1990, 2005 and 2006 time period. To run the model, rainfall data of eight rain gage stations (Joydebpur, Lakhsam, Netrokona, Sylhet, Narayanganj, Sreemangal, Moulvibazar and Narshindi) which are located within Bangladesh are used as boundary condition. Also, rainfall data of Meghalaya, Silchar and Agartala station (within India) are collected from NASA (Prediction of Worldwide Energy Resource). Discharge data at Bhairab Bazar are collected for the year of 2005 and 2006 from BWDB. They are used for calibration and validation of model. Percentage change in Rainfall of 2050 and 2080 for two Global climate models, CSIRO-30 and CCCMA-31 are collected from Climate Wizard which is an online database source according to the latitude and longitude of the rainfall stations. Table 1 represents the data sources for this study.

Table 1: Data Sources for the Proposed Study

Data	Source
DEM	HydroSHEDS (source: http://hydrosheds.cr.usgs.gov/index.php)
Stream Network	HydroSHEDS
Land use map	GlobCover (source: http://due.esrin.esa.int/globcover/)
Soil data map	FAO (source: http://www.fao.org/climatechange/54273/en/)
Precipitation	BWDB & NASA
Discharge	BWDB
Percentage change in Rainfall	Climate Wizard Website (source: http://www.climatewizard.org/)

Schematization of Basin Model:

The whole basin was subdivided into twenty-two sub basins. Basin model (as shown in Fig. 2) with sub-basins and river network shape files are created through Arc hydro tools and Hec-GeoHMS in ArcGIS 9.3. The process of delineating watershed is also referred as terrain pre-processing. Output files from terrain pre-processing are used to create input files for Hec-HMS models using HEC-GeoHMS. It is required to define the project for Upper Meghna Basin, extracting the basin characteristics, merging the sub basins, create schematic map for the output and to specify basin parameters using HEC-GeoHMS.

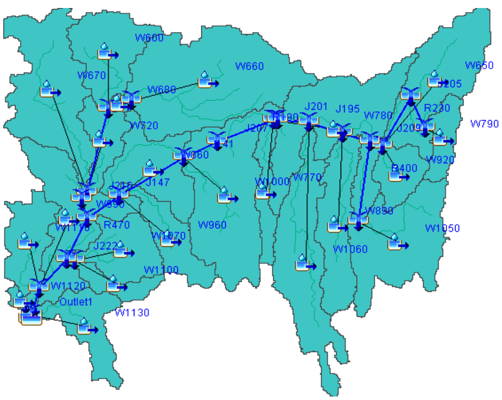

Fig 2. Basin Model

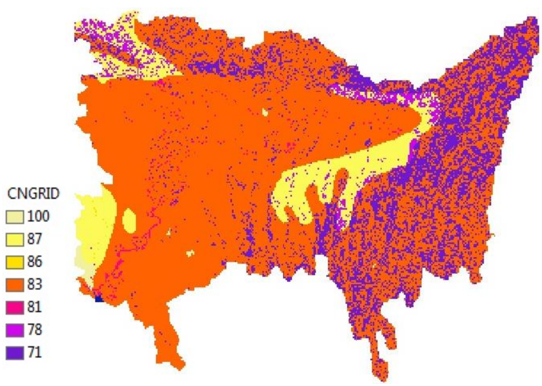

Fig 3. CN Grid for study area

CN Grid Generation

Curve numbers for sub basins are generated by merging soil and land use data through HEC-GeoHMS which is shown in Fig 3. The main objective is to create polygons that have both soil and land use information. First, reclassify method is used to reclassify the land use data into four types: water, medium residential, forest and agriculture. The reclassified land use grid is converted into a polygon feature class.

Then, the attribute table of soil data is populated with soil group, PctA, PctB, PctC, and PctD as Soil group for each polygon is necessary to extract CN grid. For each polygon in a soil clip, PctA will define what percentage of area within the polygon has soil group A; PctB will define what percentage of area within the polygon will have soil group B and so on. For easement of work, only one soil group is assigned to each polygon. More than one soil group for each polygon is avoided. In this study, soil group C or soil group D is selected for each polygon. After merging soil and land use data, a look up table (as shown in Table 2) is prepared which store curve numbers for corresponding soil groups of each land use category. Using the look up table and soil_landuse_merge feature, curve number grid is generated. Curve number for each sub basin is added in the sub basin file. The SCS curve number values are found to be ranged from 71 to 100.

Table 2: Look up Table for Creating Curve Number

Description	A	B	C	D
Water	100	100	100	100
Medium residential	57	72	81	86
Forest	30	58	71	78
Agricultural	67	77	83	87

Meteorological and Time Series Data

For each sub-basin, names of rainfall station, depth weights and time weights are added manually. Depth weights are calculated in GIS by the method of Thiessen polygon. Time series data of 11 precipitation gage stations are prepared as DSS files through HEC-DSSVue. Rainfall data of daily time interval with metric unit system is used as a time-series data.

Model Parameters Calibration and Validation

The hydrological model is calibrated against the observed data at Bhairab Bazar station for the year of 2005 and validated for the year of 2006 at the same station. Though, hydrologic model is usually calibrated for longer periods, as an initial project and due to unavailability of the observed data of low flow months (December to April), only high flow months (May to November) are selected as a calibration period. The validation is also done for the same period of year 2006. Therefore, with this model, impacts of climate changes on low flows cannot be modeled or predicted.

The final calibrated parameters are shown in Table 3. Observed and simulated hydrographs for the years of 2005 and 2006 are shown in Fig. 5 and Fig. 6. Moreover, Different statistical parameters, e.g., NSE, RSR and PBIAS (according to Moriasi et al., 2007), for calibration and validation graphs are calculated and shown in the figures. The statistical parameters are within the permissible limits as specified according to Moriasi et al., 2007. In addition, observed and simulated flows for the years of 2005 and 2006 are plotted and shown in Fig. 7 and Fig. 8. Correlation parameter R^2 for both plots are also calculated and shown in the figures. The values of R^2 for calibration and validation are found as 0.876 and 0.829 which show that the calibration and validation are quite satisfactory.

Table 3: Final Calibrated Parameters

Elements	Parameters	Initial	Final
For all Sub basins	Lag time, t_p	18.86	144
	Peaking coefficient, C_p	0.5	0.22
	Initial Discharge	10	100
	Recession constant	0.11	0.91
	Initial Abstraction, I_a	0	0.15488 to 0.15509
For all Reaches	Muskingum K	6	24
	Muskingum X	0.45	0.45

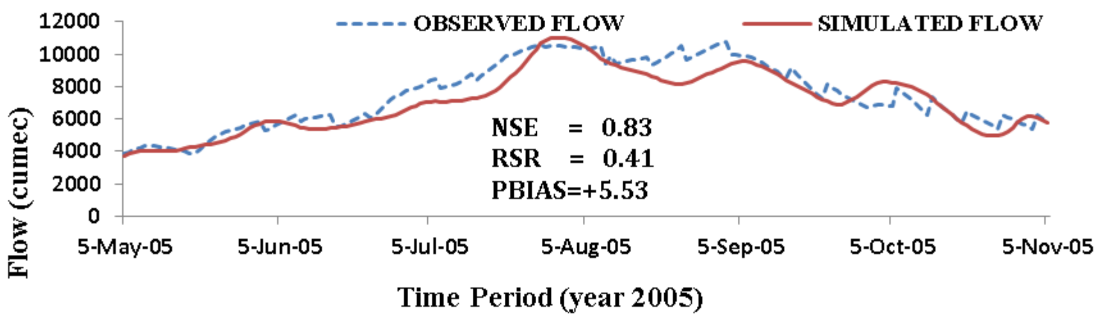

Fig 5. Calibration graph at Bhairab Bazar

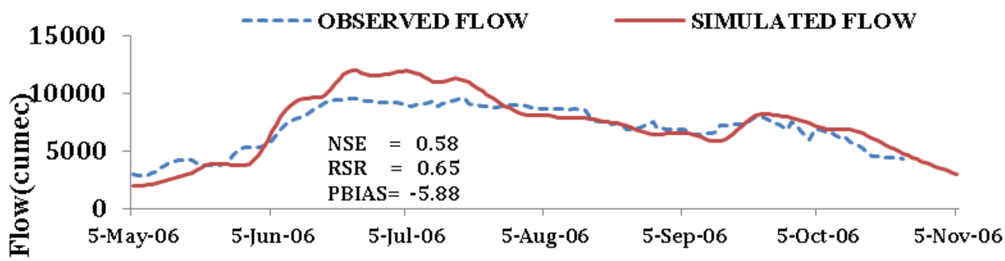

Fig 6. Validation graph at Bhairab Bazar

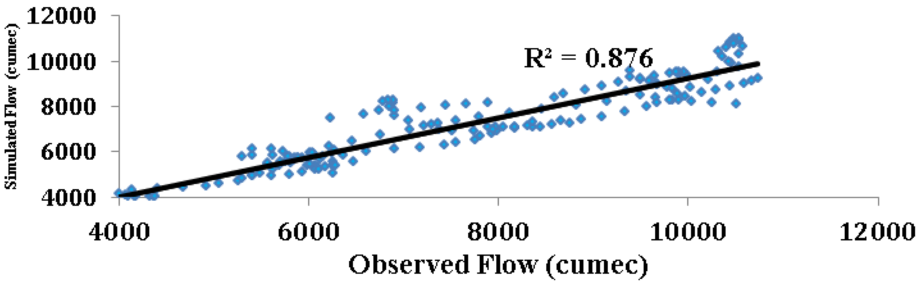

Fig 7. Graphical representation of simulated and observed flow of 2005

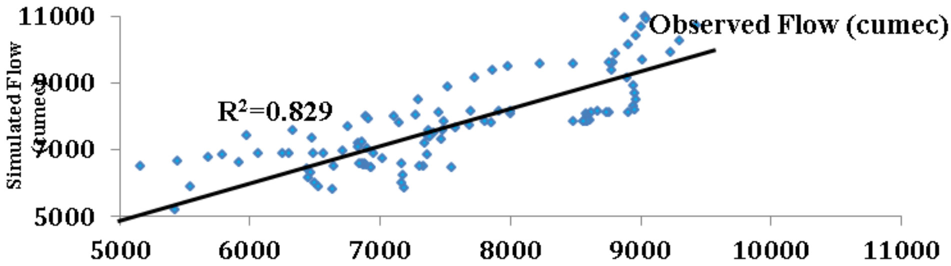

Fig 8. Graphical representation of simulated and observed flow of 2006

RESULTS AND DISCUSSION

Generation of Rainfall Hyetographs

Using the percentage change in rainfall, magnitudes of precipitation for 11 rainfall gage stations are calculated. These data are collected from Climate Wizard which is an online database containing 16 GCM model results. Among those 16 GCM results, nine GCM models have been primarily selected specially for Bangladesh based on skill criteria. However, for this study, only two GCM model results, i.e., CCCMA-31 and CSIRO-30 with A1B scenario and baseline period 1961-1990, are selected. Percentage changes in rainfall have been added or subtracted from the base rainfall data of 1990. It gives precipitation values of 2050 and 2080 which are shown in Fig 9 and Fig 10. For both models, similar rainfall hyetographs for remaining 10 stations are generated to predict future runoff of 2050 and 2080 at Bhairab Bazar station which are not shown in here due to space limitations but can be found in Haque and Narzis, 2014.

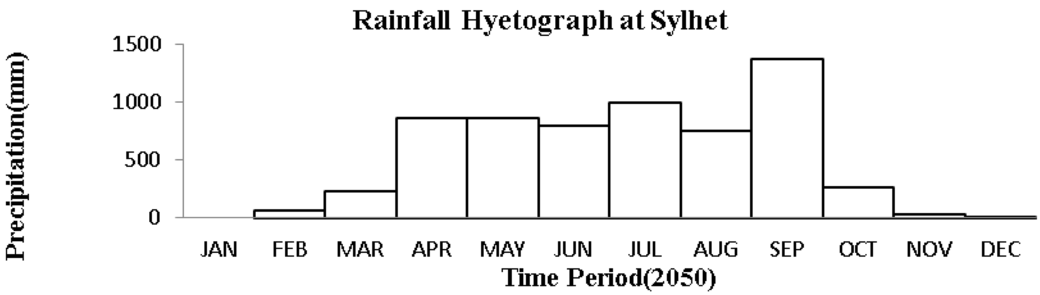

Fig 9. Rainfall Hyetograph at Sylhet for the year of 2050

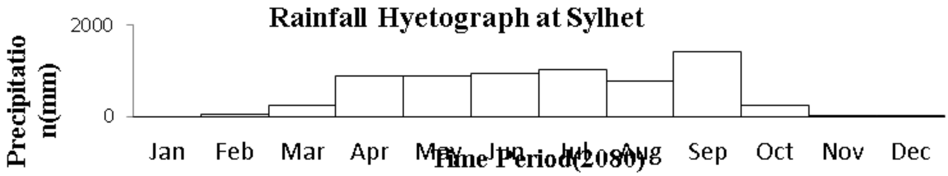

Fig 10. Rainfall Hyetograph at Sylhet for the year of 2080

Comparison of Flow Hydrographs of 2050 and 2080 using both GCM Model Results

The flow hydrographs at Bhairab Bazar station for the years of 2050 and 2080 are generated from the calibrated model using the precipitations of two GCM model results as specified in the above section. The hydrographs are shown in Fig. 11 and Fig. 12

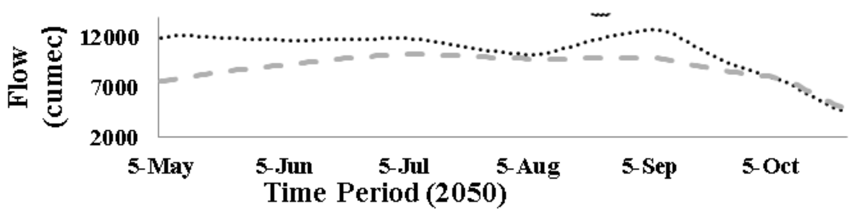

Fig 11. Flow Hydrographs at Bhairab Bazar in 2050

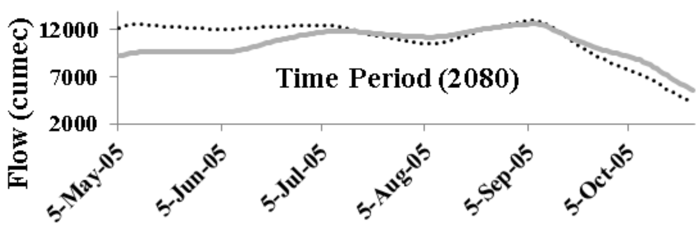

Fig 12. Flow Hydrographs at Bhairab Bazar in 2080

Changes in Peak Outflow at Bhairab Bazar Station

Percent changes in total volume and Peak Outflow are calculated with respect to the latest available observed data (2006) and are shown in Table 4. The results show that expected increase in total volume (wet period) using CCCMA-31 and CSIRO-30 precipitation will be in between 29%-54% and 50% -54% for the years of 2050 and 2080 respectively. Moreover, peak flows at Bhairab Bazar station will be increased by 34% and 36.81% for the year of 2050 and 7.98% and 32.76% for the year of 2080 using CCCMA-31 and CSIRO-30 model results respectively. In addition, the occurrence of the peak will be lagged by 45 to 48 days for the years of 2050 and 2080 compared to the occurrence of the peak (18th July, 2006) for the year of 2006.

Table 4: Percent Change in Total volume and Peak Outflow

Year	GCM Models	Total Volume of Outflow		Peak Outflow		Date of occurrence of peak	
		Value (MM)	Percent Change (%)	Value (cumec)	Percent Change (%)	Date	Lag (days)
2050	**CCCMA-31**	1864.08	53.84	12724.5	34	06 September	48
	CSIRO-30	1857.10	29.30	12990.75	36.8	03 September	45
2080	**CCCMA-31**	3197.41	57.58	10253.5	7.98	06 September	48
	CSIRO-30	2953.26	49.89	12606.3	32.76	06 September	48

CONCLUSION

Hydrological model of Upper Meghna river basin using HEC-HMS is successfully developed in this study. Model parameters are calibrated and validated and the model is then used to evaluate climate change scenario for the year of 2050 and 2080. The results show that expected increase in total volume (wet period) with CCCMA-31 and CSIRO-30 will be in between 29%-54% and 50% -54% and the peak flows will be in between 34%-36.81% and 7.98%-32.76% for the years of 2050 and 2080 respectively. As observed flow data at Bhairab Bazar was not available for dry period, the model is calibrated mainly considering the flows for wet period. Several studies can be made using this model in future. These includes, but not limited to, effects of land use on flow, effects of any upstream development such as construction of dam, urbanization etc.

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