IMPACT OF CLIMATE CHANGE ON RUNOFF OF THE MAJOR RIVER BASINS OF INDIA USING GLOBAL CIRCULATION MODEL (HADCM3) PROJECTED DATA

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ABSTRACT:

The effects of climate change on hydrological regimes have become a priority area for water and catchment management strategies. The terrestrial hydrology driven by monsoon rainfall plays a crucial role in shaping the agriculture, surface and ground water scenario in India. Thus, it is imperative to assess the impact of the changing climatic scenario projected under various climate change scenario towards the hydrological aspects for India. Runoff is one of the key parameters used as an indicator of hydrological process. A study was taken up to analyse the climate change impact on the runoff of river basins of India. The Global Circulation Model (GCM) output of Hadley centre (HADCM3) projected climate change data was used. Scenario for 2080 (A2 scenario indicating more industrial growth) was selected. The runoff was modeled using the Curve Number (CN) method in spatial domain using satellite derived current Landuse/cover map. The derived runoff was compared with the runoff using normal climatic data (1951-1980). The results showed that there is a decline in the future climatic runoff in most of the river basins of India compared to normal climatic runoff. However, significant reduction was observed for the river basins in the eastern region viz: lower part of Ganga, Bahamani-Baitrani, Subarnrekha and upper parts of the Mahanadi. The mean runoff reduction during 4 months (June- September) were 66 mm, 110 mm, 120 mm and 113 mm for Brahmaputra-Barak Subarnrekha, Subarnarekha and Brahmini-Baitrani basin, respectively in comparison to normal climatic runoff. Overall seasonal (June to September) runoff reduction was high for Subarnrekha basin (54.1 %). Rainfall to runoff conversion was high for Brahmaputra-Barak basin (72 %), while coefficient of variation for runoff was more for Mahanadi basin (1.88). Study indicates that eastern India agriculture will be affected due to shortage of surface water availability.

1. INTRODUCTION

Information about the extent, spatial distribution and temporal variation of runoff at regional scales is essential to understand its influence on regional hydrology, as well as conservation and development of land resources. Conventional techniques of runoff measurement are useful, however in most cases such measurements are very expensive, time consuming and difficult. Therefore, rainfall-runoff models are commonly used for computing runoff. The Soil Conservation Service (SCS, 1985) curve number method, which is a versatile and widely used approach for quick runoff estimation and also relatively easy to use with minimum data and give adequate results (USDA, 1986; Schulze et al., 1992; SCS, 1972; Chatterjee et al., 2001; Bhuyan et al., 2003) was used. Generally, this model is well suited for small watershed of less than 250 km^2, as it requires details of soil physical properties, land use and vegetation condition (Ponce and Hawkins, 1996; Sharma et al., 2001). Therefore, so far it has been used mostly as lumped (taking the average value of the study area) model at watershed scale (Miloradov and Marjanovic, 1991; Rao et al., 1996; Kumar et al., 1997; Pandey et al., 2002; Nayak and Jaiswal, 2003). But, advances in computational power and the growing availability of spatial data from remote sensing techniques have made it possible to use hydrological models like SCS curve number in spatial domain with satellite remote sensing data and Geographic Information System (GIS) (Moglen, 2000). In the present study SCS model was used to estimate runoff at National scale and results were analyzed at 10 km spatial and monthly temporal scales during normal climatic (1951-1950) and projected climatic scenario (2080 projections from HADCM3).

2. STUDY AREA

The water resources of India drain from 17 major drainage basins (Fig. 1).

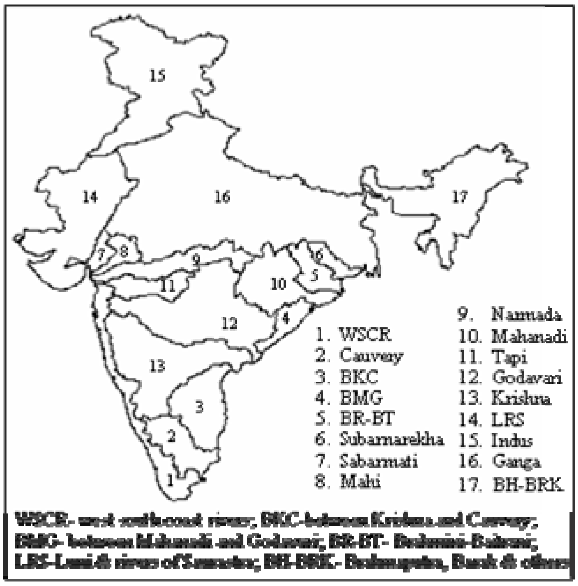

Figure 1. Major River Basins of India (Study Area)

These basins are namely, Indus, Ganga, Brahmputra including Barak & others (BH-BRK), Luni and rivers of Saurastra (LRS), Sabarmati, Mahi, Narmada, Brahmani-Baitrani (BR-BT), Mahanadi, Godavari, Rivers between Mahanadi and Godavari (BMG), Tapi, Krishna, Rivers between Krishna & Cauvery (BKC), Cauvery, West and South coast rivers (WSCR) and Subarnarekha.

3. DATA AND ANALYSIS

3.1 Land Use/Cover

Land use/cover map was generated over India using IRS-WiFS data with 35 land cover types were generated (P K Joshi et al., 2006). The SPOT sensor (operates in four spectral bands red, blue, NIR and SWIR regions) 10 day composite NDVI images were downloaded from internet (www.free.vgt.vito.be). Multi-date SPOT NDVI data was used to prepare NDVI profiles of various land cover classes. An attempt has been made by studying the NDVI profiles to stratify the different vegetation classes keeping in mind hydrological requirements (canopy, flow to retardance etc.) of land cover classes. Hydrological land cover map is presented in Fig. 1. NDVI profiles were used to discriminate the cultivated areas into good, fair and poor categories.

3.2 Hydrological Soil Group (HSG)

Soil texture map was used from Survey of India (SOI, 1978**)**. There are fourteen soil textures over India. Soil textures were used to prepare HSG map considering the soil infiltration and drainage characteristics (SCS, 1972). Area under different hydrological soil groups (A to D; high to low infiltration) were calculated and validated with the reported area. In the present study, area under different soil groups were found 9%, 51%, 17% and 23% (percentage calculated considering total 319 Mha area) for the A, B, C and D groups of soils, respectively. While, the reported areas are 11%, 54%, 16% and 19% (percentage calculated considering total 328 Mha area) for the A, B, C and D type of soils, respectively (Dhruvnarayan, 1993).

3.3 Antecedent Moisture Condition (AMC)

Daily rainfall data has been downloaded from NOAA Climate Prediction Centre (CPC) site ftp.cpc.ncep.noaa.gov/fews/S.Asia for the year 2004 and 2007. The AMC is determined by cumulative last five days daily rainfall. The AMC is used as index of wetness in a particular area. Three levels are used:

AMC- I: Lowest runoff potential. The soils are dry enough for satisfactory cultivation (rainfall < 35 mm)

AMC- II: Average condition (rainfall between 35 to 52.5 mm)

AMC- III: Highest runoff potential. The area is practically saturated from antecedent rains (rainfall > 52.5 mm)

4. METHODOLOGY

4.1 SCS Model

The SCS model developed by United States Department of Agriculture (USDA) computes direct runoff that requires rainfall (antecedent soil moisture condition), soil, land cover and the curve number (CN), which represents the runoff potential of the land cover soil complex (SCS, 1972). This model involves relationship between land cover, hydrologic soil class and antecedent soil moisture to assign curve number. Following layers were prepared for CN based runoff calculation: Since, standard table for CN values (ranges from 1 to 100), considering land use/cover and HSG are given for AMC-II (Vandersypen et al. 1972). Following conversion formulas were used to convert CN from AMC-II (average condition) to the AMC-I (dry condition) and AMC-III (wet condition) (SCS, 1972):

For dry condition (AMC-I):

$$\mathrm{CN(AMC\text{–}I)} = \frac{4.2 * \mathrm{CN(AMC\text{–}II)}}{10 - 0.058 * \mathrm{CN(AMC\text{–}II)}} \tag{1}$$

For wet conditions (AMC-III):

$$\mathrm{CN(AMC\text{–}III)} = \frac{23 * \mathrm{CN(AMC\text{–}II)}}{10 + 0.13 * \mathrm{CN(AMC\text{–}II)}} \tag{2}$$

Potential maximum retention for a given soil is related to the curve number. Losses due to infiltration, detention storage and interception were considered as initial abstractions. Vandersypen et al. (1972) developed the following relationship between initial abstractions and potential maximum retention for Indian conditions; for black soil region (AMC-I) and for all other regions:

$$I_a = 0.3 * S \tag{3}$$

Where I_a = initial abstractions and S = potential maximum retention. For black soil region (AMC-II and AMC-III):

$$I_a = 0.1 * S \tag{4}$$

SCS, 1972 has shown the derivation of equation of runoff from the water balance equation under the critical assumption that the ratio of the actual runoff to the potential runoff (rainfall less initial abstraction) is equal to the ratio of the actual retention to the potential retention.

$$Q = \frac{\left(P - I_a\right)^2}{\left(P + I_a - S\right)^2} \tag{5}$$

Where P = rainfall and Q = runoff

The methodology for runoff estimation using SCS model is shown in Fig. 2.

HSG and land cover class were combined to generate Hydrological Soil Cover Complex. Considering the established curve numbers for different combinations of HSCC, a base CN map was prepared for AMC-II. Antecedent moisture condition maps were prepared considering the summation of last five days rainfall. Daily changes in the AMC condition and its distribution due to variation in the rainfall estimate were used to modify base CN map for AMC-I and AMC-III using the formulas presented in equation 1 and 2, respectively. These modified CN maps were used to estimate initial abstractions (taking into account black cotton soil), which covers losses due to interception, infiltration and detention storage. Finally, monthly runoff maps were prepared. Above-mentioned procedure to develop monthly spatial runoff was translated in the GIS environment using an Arc Macro Language (AML).

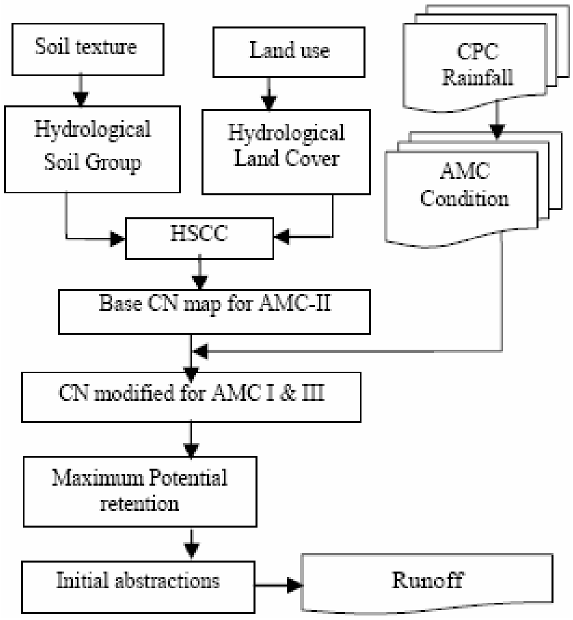

Figure 2. Methodology for Runoff Estimation

5. RESULTS AND DISCUSSION

Soil conservation service model using inputs like soil, landuse etc. were used to model runoff pattern using for the normal climatic (1951-1980) and projected (GCM HADCM3-2080; A2 Scenario) rainfall conditions. In this section results for SCS model estimated runoff for major river basins of India are presented.

5.1 Normal Climatic Runoff

It was observed that runoff concentration was high for Brahmaputra-Barak (BH-BRK) and West-south coast river (WSCR) basins during the monsoon period (June to September; Fig.3) as well as for annual period. Month-wise highest total runoff values considering all the basins were of 403 mm (BH-BRK), 535 mm (WSCR), 328 mm (WSCR) and 226 mm (Subarnarekha) for June, July, August and September months, respectively. Highest and lowest seasonal mean total runoff of 1323 mm and 13 mm were obtained for BH-BRK and BKC basins, respectively, whereas, coefficient of variation was highest for Subarnarekha (3.1) and lowest for BKC (0.2) for total monsoon season runoff. The runoff pattern from June-September typically matched well with the advancement of monsoon system. The runoff in the northern and central region became low for October-December period, whereas it was significant in the southern basins like Cauvery. This could be re-treating southwest monsoon and the north-east monsoon.

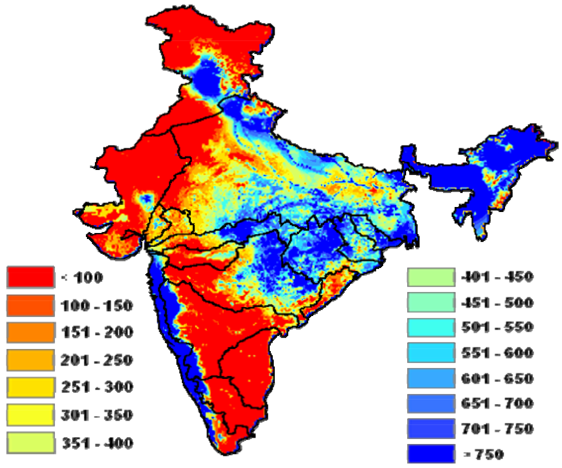

Figure 3. Total Seasonal (June to September) Runoff for Normal Climatic Year (1951-1980)

Total annual runoff was high for BH-BRK (1514 mm) and low for (75 mm) for LRS basin. Overall rainfall to runoff conversion over India considering monsoon season was of 48.3 %. This low and high runoff in different basins was because of low/high rainfall occurrence and curve number pattern in these basins.

5.2 Projected Climatic Runoff

Runoff modelling was extended using the HADCM3 (GCM) projected rainfall for the A2-scenario. High runoff concentration was observed for BH-BRK, WSCR, Narmada and Godavari basins (Fig. 4). Monthly high runoff has been obtained for BH-BRK (337 mm), WSCR (490 mm), Narmada (272 mm) and WSCR (149 mm) basins for June, July, August and September months, respectively. Total seasonal runoff was high for WSCR (1173 mm) and low for BKC (7 mm), whereas, coefficient of variation varies from 0.25 (BKC) to 1.81 (Mahanadi). Overall rainfall to runoff conversion over India considering monsoon season was of 42.8 %. Total annual runoff was high for WSCR (1307 mm) and low for (66 mm) for LRS basin.

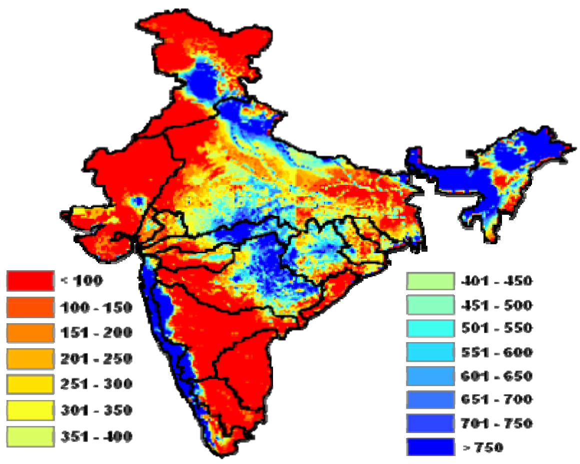

Figure 4. Total Seasonal (June to September) Runoff for the Projected Climatic Year (2080; A2 scenario)

5.3 Comparison Between Normal and Projected Runoff

Runoff analysis results indicate less projected runoff in most of the river basins in comparison to the normal climatic runoff (Fig. 5). Maximum reduction of runoff was observed in the basins located in the eastern regions like lower part of the Ganga, brahmini-Baitrani, Subarnarekha, lower part of the Mahanadi basins. Total seasonal (June to September) difference between normal and projected runoff varies from –17.3 mm (Indus) to 360.7 mm (Subarnarekha), whereas annual runoff difference were ranging from –78.3 mm (BKC) to 393.6 mm (Subarnarekha). Overall seasonal and annual reductions in the total runoff for the projected climate, over India, were of 23.2 Mha, and 20.8 Mha, respectively. Major reductions in total annual runoff were of 8.7 Mha (Ganga), 6.5 Mha (BH-BRK) and 3.3 Mha (Mahanadi). Basin-wise reported total annual runoff (Rao, 1975) were compared with the model-estimated runoff for normal climatic and projected climate (2080; A2 scenario) and presented in Table 1.

The accuracy of the input data required to estimate CN is vital for accurate runoff calculations. Hence, area under different HSG types, calculated in the present study, were confirmed with the reported HSG area. In the present study, area under different soil types have been found 8.3%, 51.5%, 17% and 23.2% (percentage calculated considering total 313 Mha area) for the A, B, C and D type of soils, respectively. While, the reported areas were 11.1%, 53.7%, 16.8% and 18.4% (percentage calculated considering total 328 Mha area) for the A, B, C and D type of soils, respectively (Dhruvnarayan 1993).

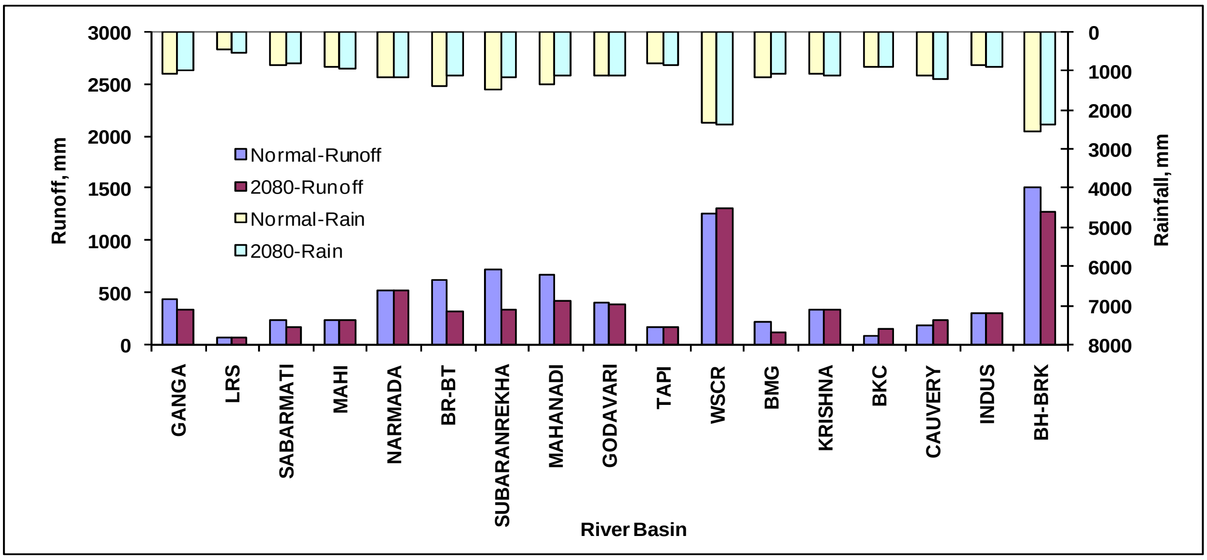

Figure 5. Major River Basin-Wise Comparison of Rainfall and Runoff Considering Normal and Projected Climate Scenarios

River Basin	Reported (1975) Mha-m	Estimated Normal (1951-1980) Mha-m	Estimated Projected (2080; A2 scenario) Mha-m
Ganga	55.0	37.6	29.60
LRS	1.2	5.4	2.12
Sabarmati	0.4	1.4	0.39
Mahi	1.2	2.0	0.83
Narmada	4.0	5.0	5.14
BR-BT	4.4	3.8	1.66
Subarnarekha	-	2.7	0.98
Mahanadi	7.1	8.8	6.14
Godavari	11.5	13.2	12.16
Tapi	2.0	2.7	1.18
WSCR	22.7	11.2	18.39
BMG	1.7	2.6	0.60
Krishna	5.8	8.5	8.7
BKC	2.5	7.9	2.5
Cauvery	1.9	4.7	1.9
Indus	7.7	10.0	10.2
BH-BRK	59.7	23.3	34.8

Table 1: Reported and Estimated Runoff for Different Major River Basins of India

CONCLUSION

SCS model has been used to estimate runoff over mainland of India using normal (1951-1980) and projected climatic (2080; A2 scenario) rainfall along with other inputs like soil and hydrological land cover. This model gives quick estimate of generated runoff in a particular location with reasonably good accuracy. Rainfall to runoff conversion was high (48.3 %) for normal year as compared to low (42.8 %) for the projected climate scenario. Runoff results indicate less projected runoff in most of the river basins in comparison to the normal climatic runoff. Maximum reduction of runoff was observed in the basins located in the eastern regions like lower part of the Ganga, Brahmini-Baitrani, Subarnarekha, lower part of the Mahanadi basins.

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