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Investigation into the Effects of Climate Change for the Ajay River Basin using Hydroinformatics

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Abstract

A very exhaustive study was conducted on the Ajay River catchment under changed climate scenario from soil moisture accounting parameters. An attempt has been made to quantify the impact of climate change on the water resources of the Ajay river catchment outlet at Natunhat, West Bengal. A distributed hydrological model, HEC HMS (HEC HMS Version 2.2.2, 2000) has been exercised over the river basin under changed climate scenario. Projected data used in the model was generated in transient experiments by the Hadley Centre for Climate Prediction, U.K (Hulme and Vinar, 1995), at a resolution of 0.44° latitude X 0.44° longitude grid points, has been obtained from Indian Institute of Tropical Meteorology, Pune, India.

This paper considers input parameters of four catchments of the Ajay River basin, spread over West Bengal, Jharkhand and Bihar in eastern India namely, Natunhat and Gheropara (West Bengal), Jamtara (Jharkhand) and Sikatia (Bihar) in order to generate soil moisture relationships from 2040-2050. Water Availability status for 2040-2050 has been accomplished by computing soil moisture properties such as canopy overflow, soil infiltration and ET which have been determined and illustrated over the mentioned period of ten years.

The study uses the HadRm daily weather data to determine the control (present) and GHG (future) water availability in space and time. A total of 15 years of simulation spanning the entire Ajay River catchment has been conducted. Five years were devoted to control (present) 1997 – 2001 and the remaining 10 years (2040 – 2050) devoted to GHG (future) climate scenario. Seasonal shift of stream flow pattern, reduction of peak flow and water stressed condition have been observed.

Keywords: Hydrological Modelling, Simulation Study, Climate Change, Soil Moisture Accounting, Hydroinformatics

Introduction

The general impacts of climate change on water resources have been brought out by the Third Assessment report of the Intergovernmental Panel on Climate Change. It indicates an intensification of the global hydrological cycle affecting both ground and surface water supply. Changes in the total amount of precipitation, its frequency and intensity have also been predicted. Such changes when on the surplus side may affect the magnitude and timing of runoff but shall create drought-like situations when these are on the deficit side. Water resources will come under increasing pressure in the Indian subcontinent due to the changing climate.

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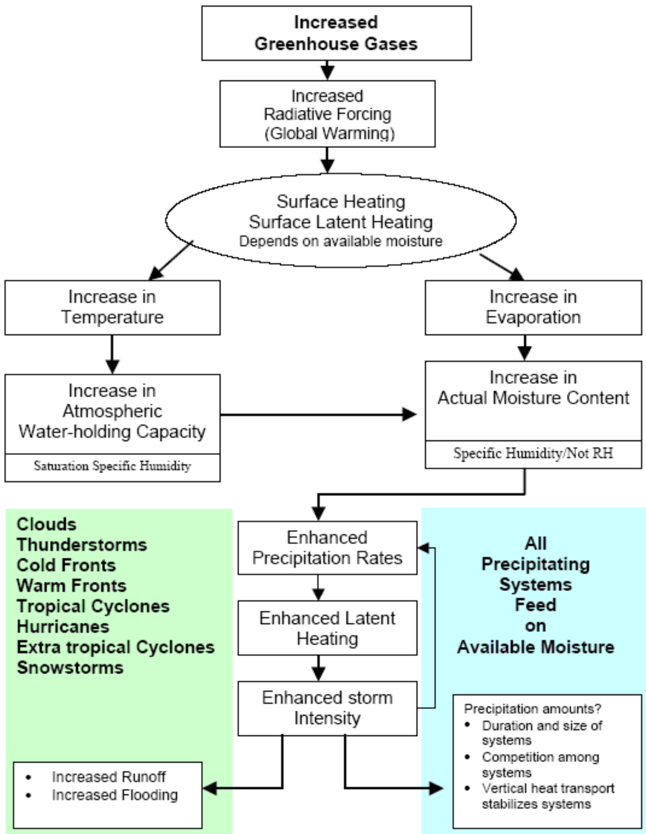
Presently, more than 45% of the average annual rainfall, including snowfall in the country, is wasted by natural runoff to the sea.



Conceptual model of the effect of greenhouse gases and global warming on the hydrologic cycle and phenomena associated with many climate extremes (source: Trenberth).

Fig 1 Conceptual model of the effect of greenhouse gases and global warming on the hydrologic cycle

Agriculture and allied activities constitute the single largest component of India's economy, contributing nearly 27% of the total Gross Domestic Product (GDP) in the year 1999-2000 (TERI. 2002). Agriculture exports accounts for 13 to 18% of total annual exports of the country (Ministry of Finance. 2002). However, given that 62% of the cropped area is still dependent on rainfall (MoEF. 2002), Indian agriculture continues to be fundamentally dependent on the weather. Climate change and variabilty are likely to worsen the existing situation by further limiting water availability. Under a changed climatic regime for any given region, the combined effect of lower rainfall and more evaporation would have dire consequences. Both these would lead to less runoff, substantially changing the availability of freshwater in the watersheds. Also, potential changes in temperature and precipitation might have a dramatic impact on the soil moisture and aridity level of hydrological zones.

Water is becoming the limiting factor for development in many parts of the world. A systematic approach is needed to communicate how water is being used and how water resource developments will affect present use patterns. In much of the world, surface water and rainfall have traditionally supplied all water demands. But as those demands increase, other sources are sought.

India is a large developing country with nearly 700 million rural population directly depending on climate-sensitive sectors (agriculture, forests and fisheries) and natural resources (such as water, biodiversity, mangroves, coastal zones, grasslands) for their subsistence and livelihoods. Climate change is likely to impact all the natural ecosystems as well as socio-economic systems as shown by the National Communications Report of India to the UNFCCC.

The climate change impact assessment on water resources can be best handled through simulation of the hydrological conditions that shall prevail under the projected weather conditions in an area. Such a treatment is essential because of the fact that the hydrological response is a highly complex process governed by a large number of variables such as terrain, land use, soil characteristics and the state of the moisture in the soil. The last element warrants a continuous time simulation so as to keep track of the changing moisture conditions.

The amount of water stored in the soil is fundamentally important to agriculture and is an influence on the rate of actual evaporation, groundwater recharge, and generation of runoff. Soil moisture contents are directly simulated by global climate models, albeit over a very coarse spatial resolution, and outputs from these models give an indication of possible directions of change. Gregory et al. (1997), for example, show with the HadCM2 climate model that a rise in greenhouse gas (GHG) concentrations is associated with reduced soil moisture.

The local effects of climate change on soil moisture, however, will vary not only with the degree of climate change but also with soil characteristics. The water-holding capacity of soil will affect possible changes in soil moisture deficits; the lower the capacity, the greater the sensitivity to climate changes. Climate change also may affect soil characteristics, perhaps through changes in water logging or cracking, which in turn may affect soil moisture storage properties.

Soil moisture is a key component in the land surface schemes in climate models, since it is closely related to evapotranspiration and thus to the apportioning of sensible and latent heat fluxes. It is primary in the formation of runoff and hence river-flow. Further, soil moisture is an important determinant of ecosystem structure and therein a primary means by which climate regulates (and is partially regulated by) ecosystem distribution. Soil moisture is an important regulator of plant productivity and sustainability of natural ecosystems. In turn terrestrial ecosystems recycle water vapor at the land-surface/atmosphere boundary, exchange numerous important trace gases with the atmosphere, and transfer water and biogeochemical compounds to river systems

Soil moisture is a key variable in controlling the exchange of water and heat energy between the land surface and the atmosphere through evaporation and plant transpiration. As a result, soil moisture also strongly affects the part of precipitation that runs off into nearby streams and river.

Compared to other components of the hydrologic cycle, the volume of soil moisture is small; nonetheless, it is of fundamental importance to many hydrological, biological and biogeochemical processes. Soil moisture is one of the several useful parameters that are amenable to remote sensing at global, regional and larger scales. Soil moisture is an important parameter in many diverse applications in agriculture, hydrology and meteorology. The knowledge of soil moisture content in the surface layers helps to plan agronomic operations, like irrigation scheduling, partitioning rainfall into runoff and infiltration components.

The integration of soil moisture data allows better control of the evolution of the forecasting model and improves its performance greatly. There have been at least 14 recorded floods in the 20th century in the Ajay River. The lower reaches of the river have embankments to prevent flooding. Of the districts, Burdwan accounts for a maximum of 14 deaths caused by the swirling Ajay River.

In view of the existing status of water resources and increasing demands of water for meeting the requirements of the rapidly growing population of the country as well as the problems that are likely to arise in future, a holistic, well planned long-term strategy is needed for sustainable water resources management in India. The water resources management practices may be based on increasing the water supply and managing the water demand under the stressed water availability conditions. Data monitoring, processing, storage, retrieval and dissemination constitute the very important aspects of the water resources management. These data may be utilized not only for management but also for the planning and design of the water resources structures.

This paper is a commitment towards the planning, management and development of the water resources of the Ajay River by presenting detailed future scenarios of the Ajay river basin over the mentioned time period. It starts with the calibration of the source (Jamtara in Jharkhand) and ends with the projected water availability scenario for the sink (Natunhat in West Bengal). It highlights the future soil moisture accounting parameters for the Natunhat agricultural watershed in Burdwan through the years 2040-2050.

Study Area

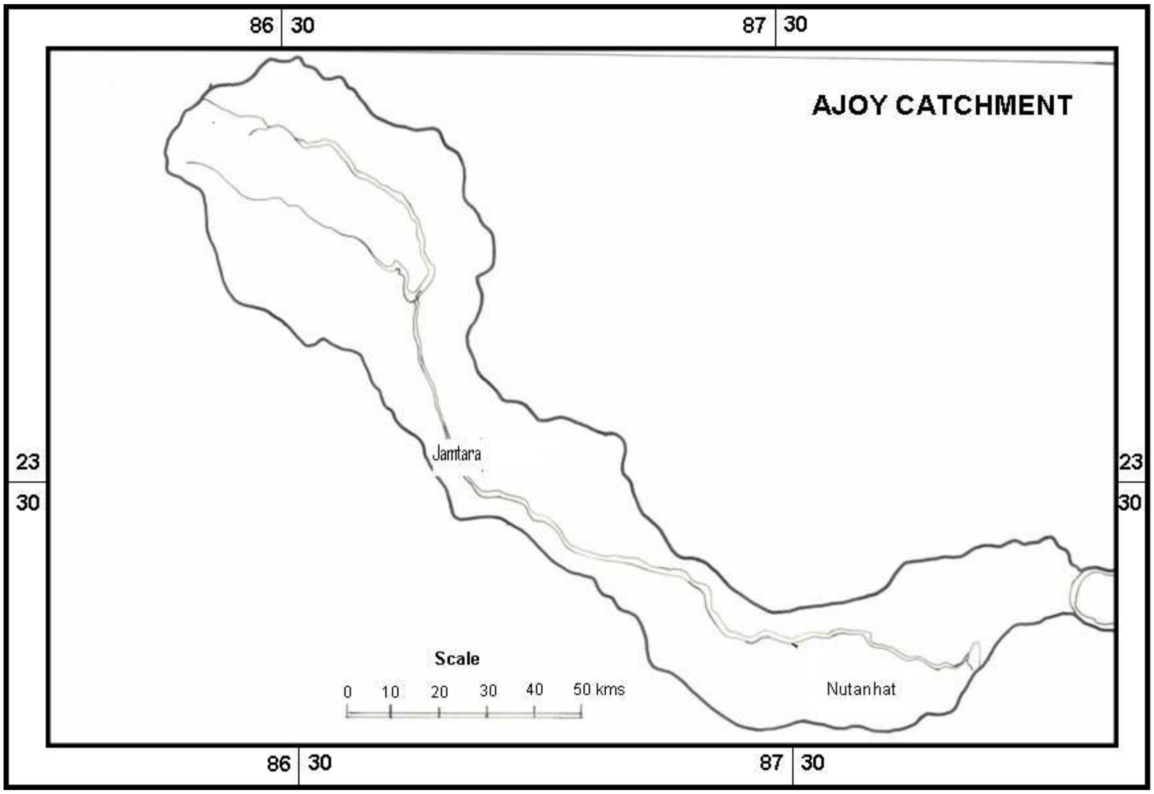


Fig 2 Ajay river catchment in Eastern India

Location & Extent

The Ajay river catchment located in the plateau of Santhal Parganas, lies between 23° 27’ to 24° 40’ N latitudes and between 86°15’ to 88°10’ E longitudes and is covered by Survey of India toposheets nos. 72L/6,7,8,10,11,12,15,16, 73I/13, 73M/1,2,5,6,7,10,11,14,15 and 79A/1 in the scale of 1:50,000 and 1:36,360. It spreads over Deoghar, Giridhi and Dumka in Jharkhand, Munger and Jamui districts of Bihar and Burdwan and Birbhum district of West Bengal. The Ajoy river emerges from the forest covered hills of Chakai block in Munger district of Bihar and flows over a length of 132km in Jharkhand, enters West Bengal near Kalipahari and flows over a length of 144 kilometers over West Bengal and falls into the Bhagirathi, which is a distributary emerging out of river Ganga, near Katwa.

It originates from a small hill about 300 metres high, south west of Munger in Bihar. Then flows through Jharkhand and enters West Bengal at Simjuri, near Chittaranjan. It first forms the border between Bardhaman District and Jharkhand and then between Bardhaman District and Birbhum District, and finally it enters Katwa subdivision of Bardhaman district at Nareng village in Ketugram police station. It then joins the Bhagirathi River at Katwa Town. Total length of the Ajay is 288 km, out of which 152 km is in West Bengal.

The important tributaries of the Ajay are Pathro and Jayanti in Jharkhand, and Tumuni and Kunur in Burdwan district of West Bengal. The upper reaches of the Ajay pass through hilly regions with latté rite soil. It is only from Ausgram in Burdwan district that the Ajay flows through alluvial plains. The Ajay valley was densely forested with sal, piyasal and palas trees till recent times when mining and other activities led to the clearing of forests.

The basin (Fig 2) lies between the latitudes 23°57' N and 24°37' N and longitudes 86°16' E and 86°57' E in the states of Bihar and Jharkhand, comprising a basin area of 2881.65 km^2 . The soils in the Ajay river basin are generally sandy and loamy sand, especially on uplands and are therefore very light at the surface. The average annual rainfall in the basin varies from 1280 to 1380 mm. The river flows over recent alluvium in the lower parts and is subject ed to spilling at amoderately high discharge. The floods of the the Ajay river are sudden, flashy and have short duration.

Physiography, Relief and Drainage

Physiographically, the area is (i) hilly and undulating land in the northwest of the catchment (ii) gently undulating and rolling uplands that are dissected by narrow valleys, depressions and interrupted by scattered and isolated hillocks covering almost the major portion of the catchment in Bihar (iii) the valley lands mostly confined along the main tributaries (iv) river terraces and flood plains in the lower catchment areas.

The drainage pattern is dendritic and sub dendritic and is parallel in the lower regions.

Geology

The common rock of Archean system of this area is gneiss with different mineralogic composition. Pegmatites are found as veins. The middle of the catchment area comprises the Gondwana system, which is dominated by sand stone, shales and clays with local coal seams. The southern portion of the catchment comprises of alluvium of the Ganga basin.

Soil

The soils encountered in the hilly region and hillrocks of the very steep slopes are yellowish brown to reddish brown, very shallow to moderate deep, light texture (skeletal). In the foot hills undulating and rolling upland of gently to moderately sloping area (especially on the upper part of the catchment) the soils are yellowish brown to yellowish red and dark brown having red mottle at places, moderately deep to very deep, coarse to fine loamy textured. In the lower convex and depression of very gently to gently sloping areas the soils are of fine loamy and fine, pale brown to grey and dark grey, with red mottles, deep to very deep; and in the river terrace and levee of very gently to gently sloping areas developed over recent alluvium; the soils are fine to coarse loamy.

Research Methods

A distributed hydrological model, HEC HMS (HEC HMS Version 2.2.2, 2000). has been executed on the river basin under changed climate scenario. Projected data used in the model was generated in transient experiments by the Hadley Centre for Climate Prediction, U.K (Hulme and

Vinar, 1995), at a resolution of 0.44° latitude X 0.44° longitude grid points has been obtained from Indian Institute of Tropical Meteorology, IITM Pune, India.

The HEC – HMS is the US Army Corps of Engineers' hydrologic modeling system and was developed by the Hydrologic Engineering Centre (HEC). A total of seven methods are available in the model for estimating the losses including SCS Curve and SMA methods. Different methods are adapted depending on the availability of data. The program computes direct runoff both by traditional empirical Unit Hydrograph Model and conceptual model (Kinematic Wave Model). The model requires inputs of daily rainfall, soil condition and other hydro meteorological data. Daily rainfall data and stream flow data for a period of five years 1998-2000 was used to calibrate and validate the model (Fig 3).

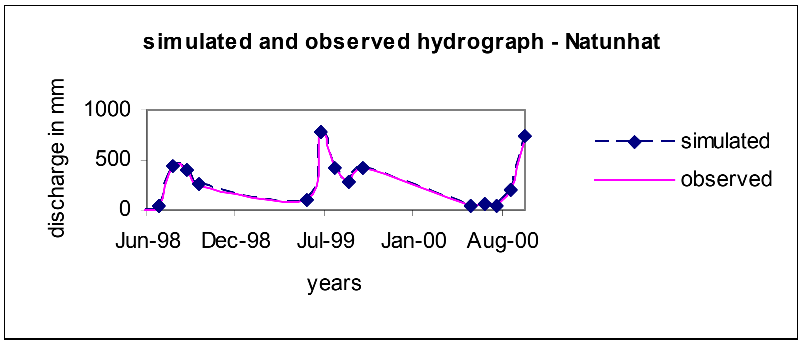
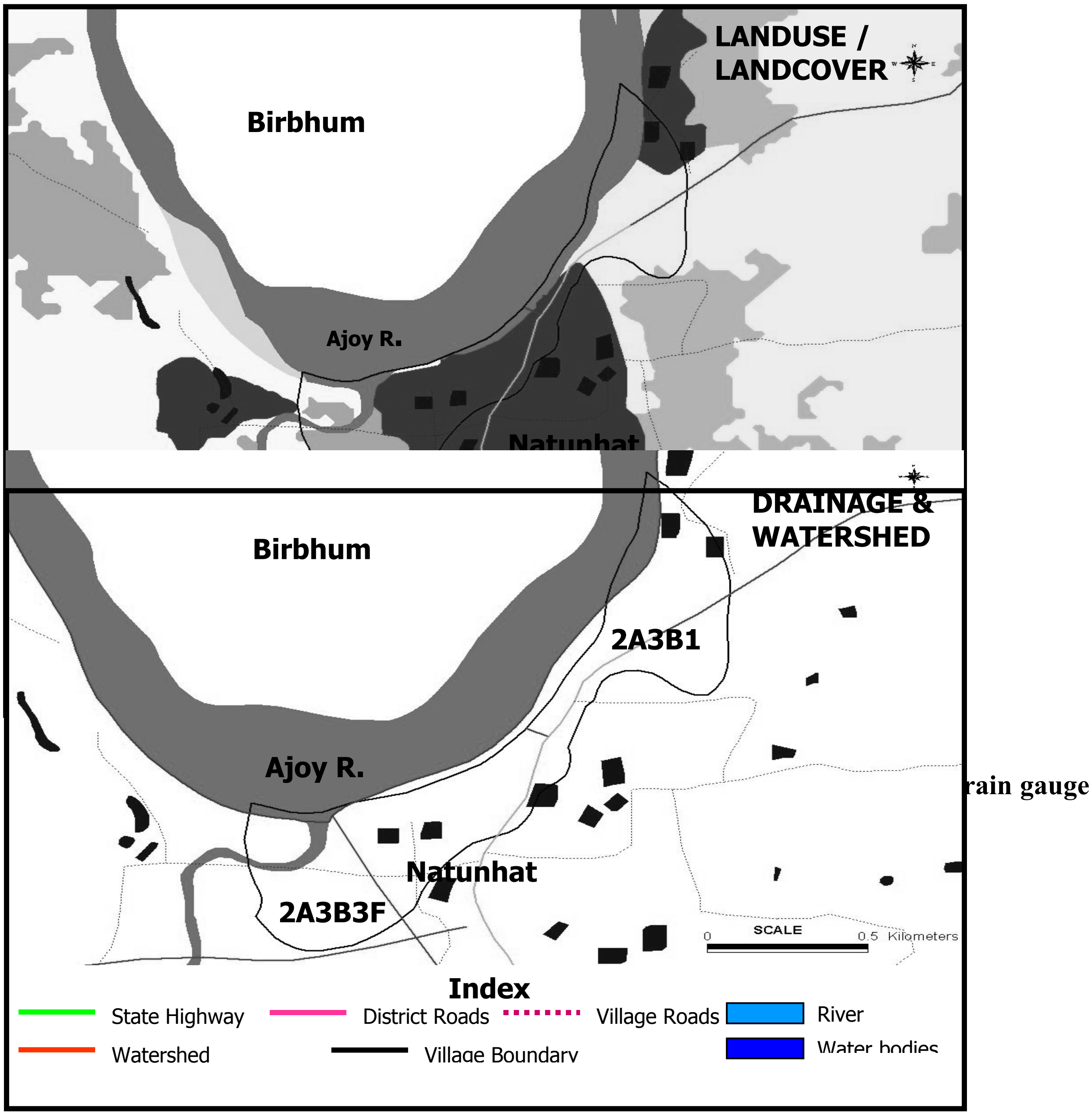


Fig 3: Simulated and Observed Hydrograph at Natunhat 1998-2000

Application of Geographical Information System

The boundary of the basin , stream network and contours of the Ajay river basin at Natunhat were mapped using Survey of India toposheets at scales of 1:50,000 and 1: 250,000 for extracting the geomorphological parameters using ERDAS Imagine software.(Figs 4 and 5)



Simulation of Soil Moisture Accounting

A soil moisture accounting (SMA) algorithm was developed by the Hydrologic Engineering Center for the Hydrologic Modeling System (HEC-HMS). SMA method allows for long-term continuous simulation of hydrologic processes that occur and change over time in a watershed.

The HEC-HMS SMA model (Fig 4) is patterned after Leavesley's Precipitation-Runoff Modeling System (1983) and is described in detail in Bennett (1998). SMA model parameters were determined by calibration with observed data ranging from 1997-2001.In this iterative process, parameter values are proposed, the model is exercised with these parameters and precipitation inputs. The resulting computed hydrograph is compared with an observed hydrograph for the same period, in this case 1997-2001.

The HEC HMS SMA methodology has been used to generate projected soil moisture accounting parameter graphs (Figs 5-9) for the projected period 2041-2050 for soil evapotranspiration, canopy overflow, canopy evapotranspiration and soil infiltration of the Ajoy river catchment, Jamtara guage to provide a more precise and realistic water availability accounting.

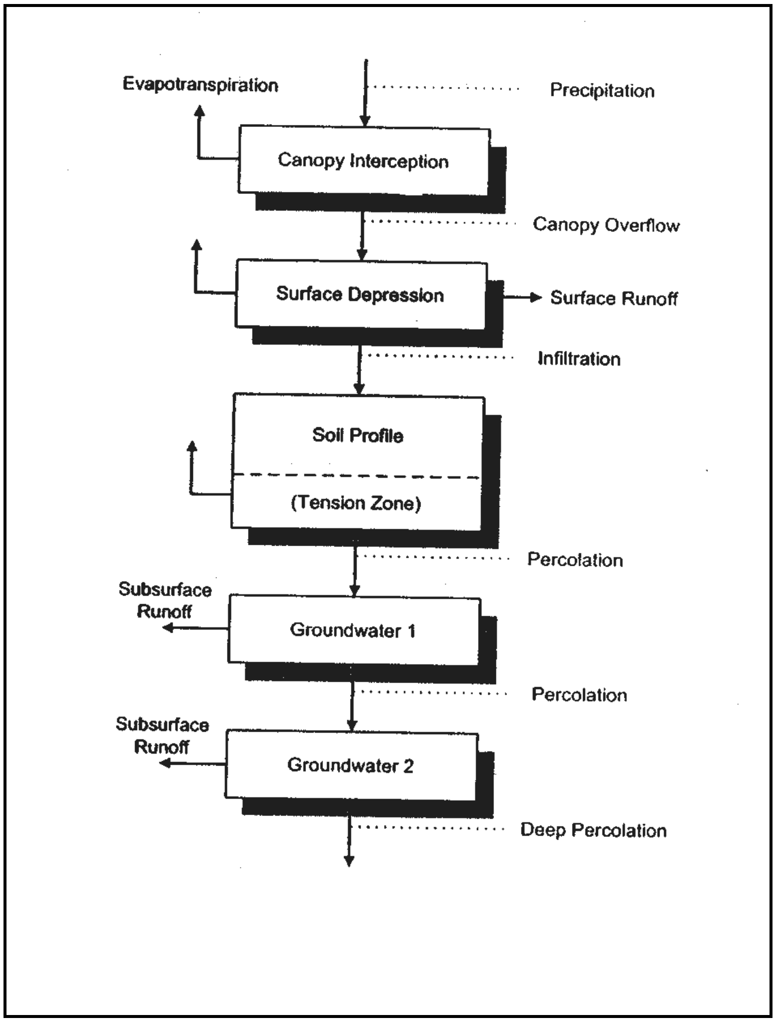


Fig 6 Conceptual View of the Soil Moisture Accounting Method

Results and Discussion

Projected Flows for Natunhat

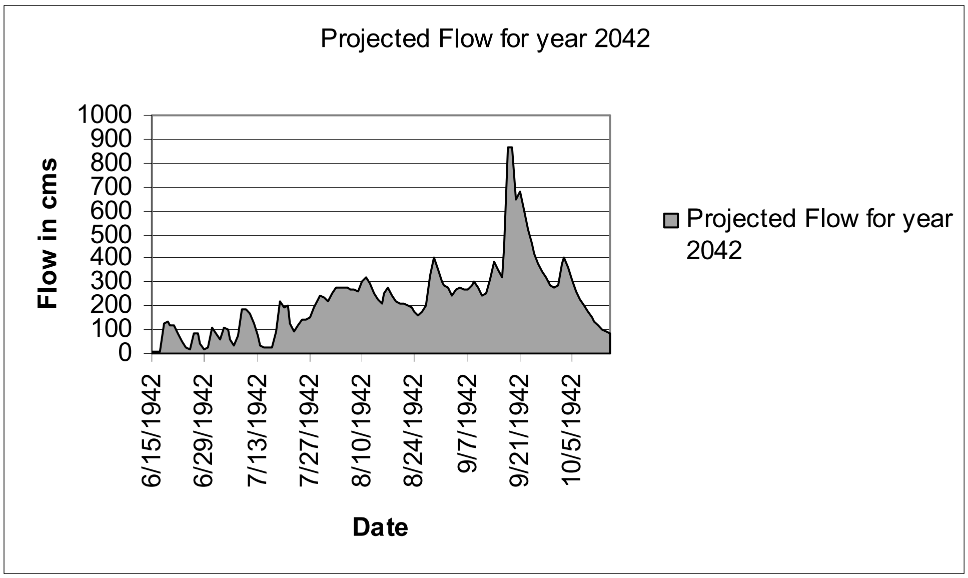


Fig 7 Projected Flow for year 2042 for Natunhat watershed of Ajoy River catchment in West Bengal

Figs 7 to 11 display the projected flow in cms from the Natunhat watershed of the Ajay catchment in West Bengal from the years 2042 till 2050. Natunhat was selected as the sink of the study area.

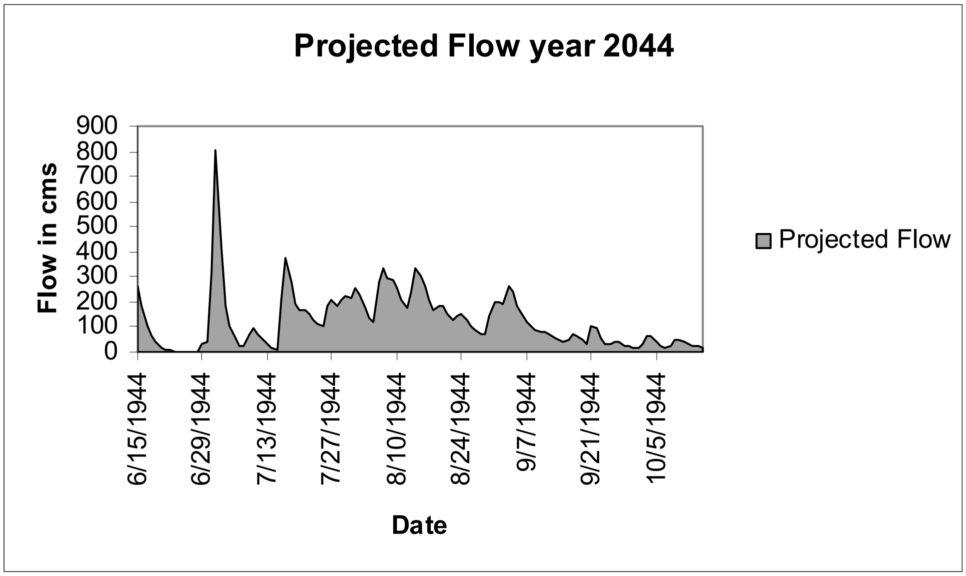


Fig 8 Projected Flow for year 2044 for Natunhat watershed of Ajay River catchment in West Bengal

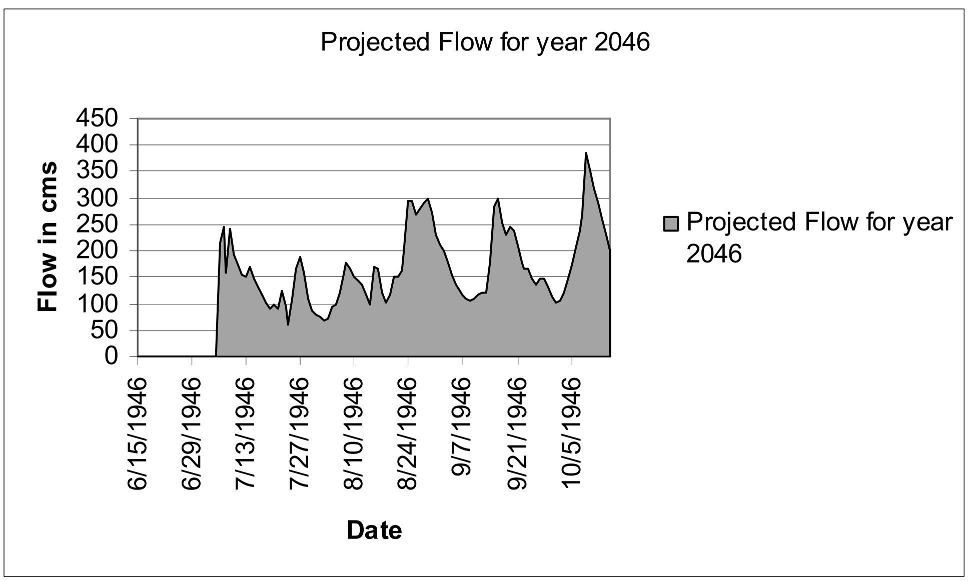


Fig 9 Projected Flow for year 2046 for Natunhat watershed of Ajay River catchment in West Bengal

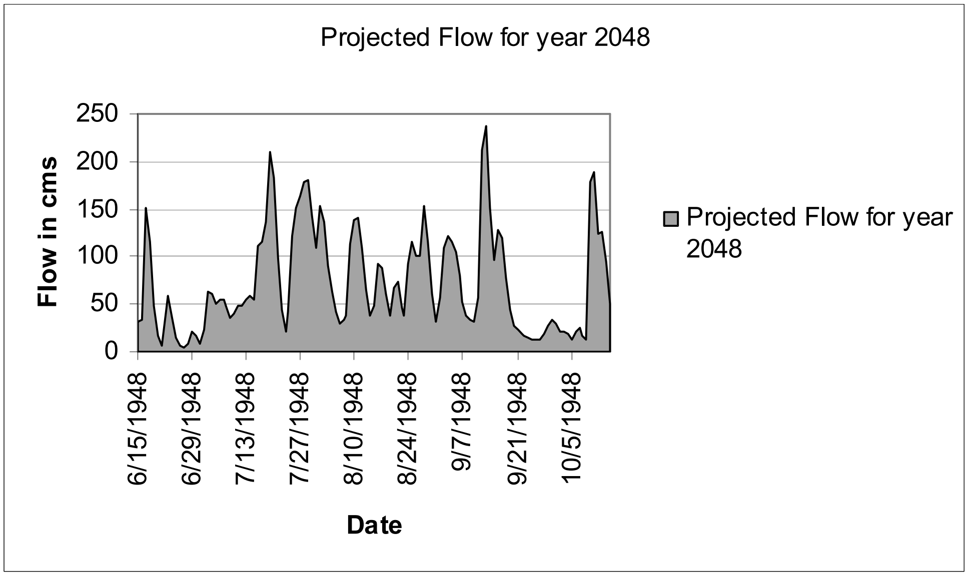


Fig 10: Projected Flow for year 2048 for Natunhat watershed of Ajay River catchment in West Bengal

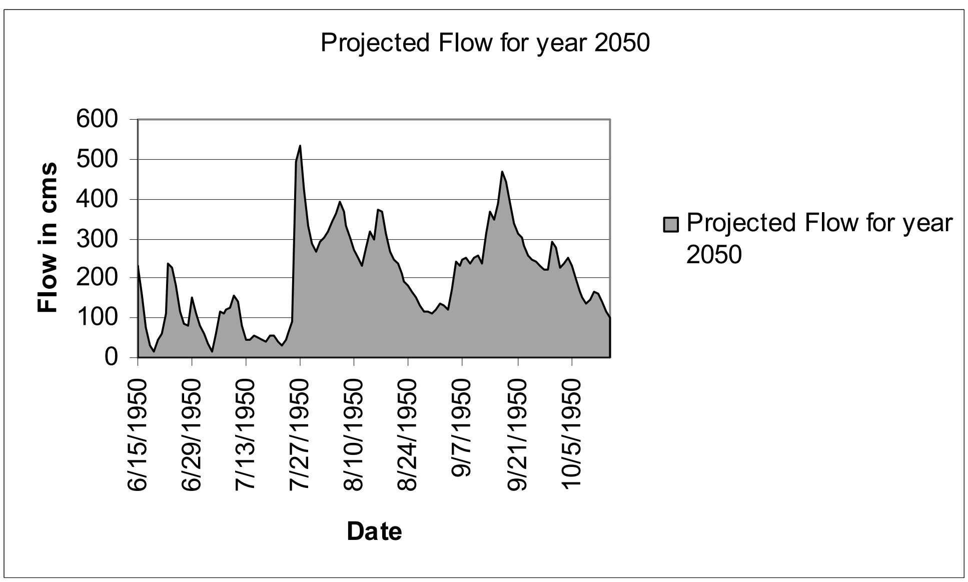


Fig 11: Projected Flow for year 2050 for Natunhat watershed of Ajay River catchment in West Bengal

Figs 12 and 13 illustrate the projected groundwater and soil storage at Natunhat. It is observed that the soil storage and the groundwater storage increase over the mentioned time frame.

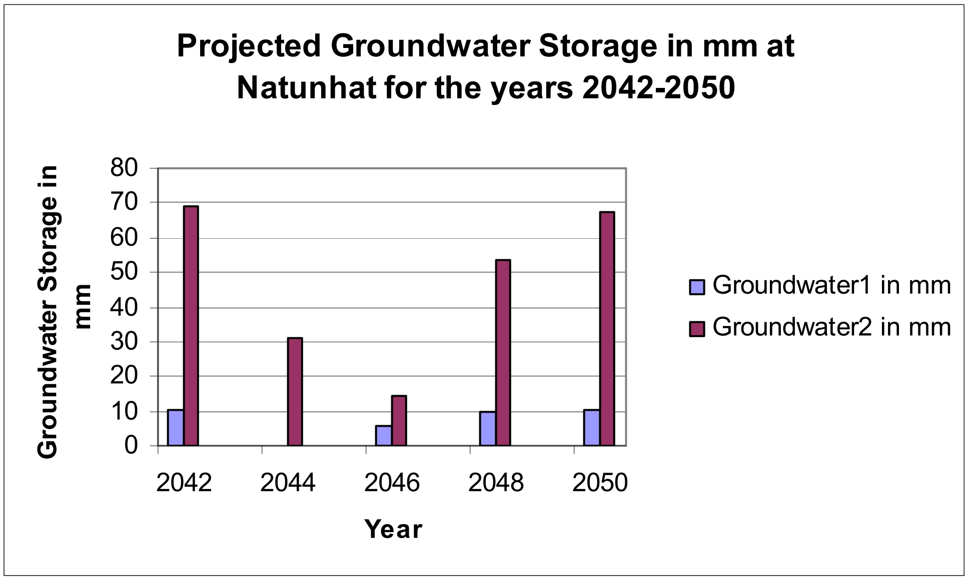


Fig 12: Projected groundwater storage in mm at Natunhat watershed of the Ajay River catchment in West Bengal

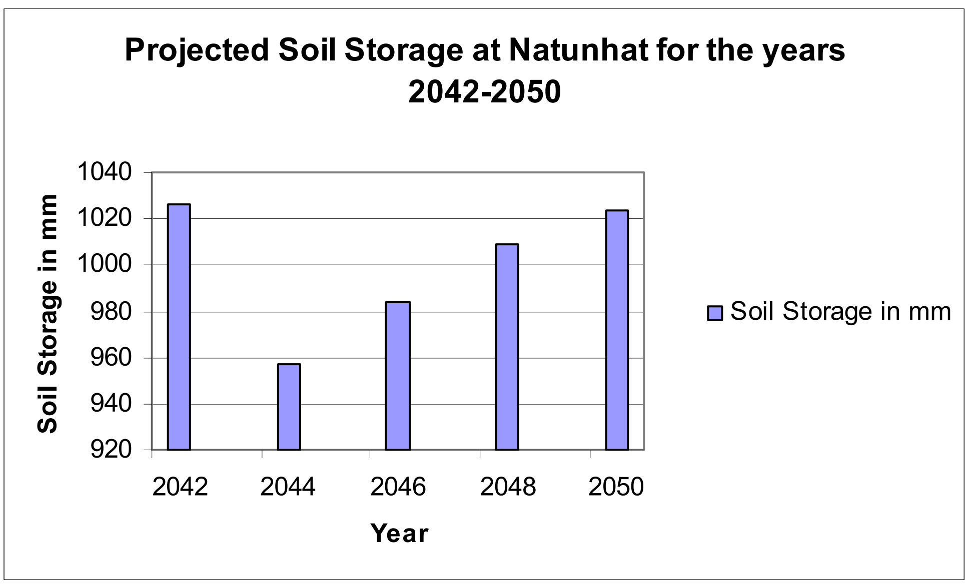


Fig 13: Projected soil storage in mm at Natunhat watershed of the Ajay River catchment in West Bengal

Conclusions

After an exhaustive study on the hydrology scenario of Natunhat watershed in West Bengal of the Ajay river catchment through soil moisture accounting parameters, it is seen that climate change threatens to affect the parameters studied.

Climate is an integral part of ecosystems and organisms have adapted to their regional climate over time. Climate change has the potential to alter ecosystems and the many resources they provide to society. Variation of properties such as soil ET, soil infiltration, canopy ET and its overflow over 2041-50 have proved to have a considerable control over the future water availability scenario as illustrated in the projected scenarios under changed climate conditions.

Over the years 2041-50, soil ET and canopy overflow are seen to decrease whereas soil infiltration decreases and canopy ET increases. The stream flow and its peak, are seen to display decreasing trends from 2041-50. The reduction in the water availability can be attributed to the decrease in the number of rainy days coupled with increasing demand in agricultural, industrial and domestic sector in the changed climate scenario.

These predicted climate change impacts may induce additional stresses and shall need various adaptation strategies to be taken up. The strategies may range from change in land use, cropping pattern to water conservation, flood warning systems, etc. and need rigorous integrated analysis before paving way into policy decisions.

In the case of an agricultural watershed like Natunhat, parameters such as canopy overflow, precipitation, discharge, soil and surface ET decreasing will naturally be harmful for agriculture. As a rule plant ET increases as temperature. Net result could be slightly higher agricultural water requirements. The whole subject of potential crop ET and water requirements is an important area of investigation for researchers.

Acknowledgement
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References

Army Corps of Engineers U.S.-HEC-HMS, *Technical Reference Manual.*

Army Corps of Engineers U.S.-HEC-HMS. *User's Manual.*

Brady, N. C. (1984). The nature and properties of soils.9th edition, New York: Macmillan*,*

Brutsaert, W. (1982). Evaporation into the atmosphere: theory, history and applications. Holland: D. Reidel publishing Company.

Burgy, R. H. and Pomeroy, C.R. (1958). Interception losses in grassy vegetation. *Transactions of the American Geophysical Union. Vol.39, 1095-1100.*

Childs, E. C. (1969) An introduction to the physical basis of soil water phenomena. *Wiley,UK.*

Chow,V. T, et al. (1988). Applied Hydrology*,* Mc Graw –Hill, Inc., New York.

Horton, R. E. (1933). The role of infiltration in the hydrologic cycle. *Transactions of the American Geophysical Union,14, 446-460.*

Huff, F. A. (1970). Spatial distribution of rainfall rates. *Water Resources Research, 6, 447-454.*

Mather, J. R. (1972). The Climate Water Budget , *Lexington Books.*

Mintz, Y. & G. K. Walker. (1992). A global monthly climatology of soil climatology of soil moisture and water balance. *Climate Dynamics,8,13-27..*

Mole, F.J., Soil moisture availability for transpiration. *Water Resources Research ,6, 1161, 1968.*

Smith, K.J., A longterm assessment of the Penman and Thornwaite potential evaporation formulae. *Journal of Hydrology, 2, 277-290. 1965.*

S. Dhar, P. K. Roy & A. Mazumdar. (2006). An Assessment of the future water availability of Ajoy river catchment with special emphasis on soil moisture accounting. Map India*.*