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# Climate Change and its Impact on the Kangsabati Basin Using Swat Model

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**ABSTRACT:** This paper attempts to quantify the effect of climate change over the Kangsabati basin in Bankura, West Bengal. A very well calibrated ($R^2 = 0.9968$, NSE = 0.91) physically distributed hydrological model, Soil and Water Assessment Tool (SWAT) uses futuristic climatic data from HadRM2 in order to predict the future water availability scenario of one of Bengal's most physically diversified regions.

SWAT predicts the impact of land management practices on water, sediment and agricultural chemical yields in complex watershed with varying soil, landuse and management conditions over long periods of time.

General Circulation Models are widely accepted as the primary tool used for analysis of potential increased green house gases and more recently, aerosols. Two outputs of these models are temperature and precipitation. Water availability in the basin under changed climate scenario was evaluated using the projected daily precipitation for 2041–2050 as supplied by IITM, Pune. There work is based on the model HadRM2, the Regional Model of Hadley Centre for Climatic Prediction, UK at a resolution of 0.44° latitude *X* 0.44° longitude.

**Keywords:** SWAT Model, Climate Change, Water Availability Projected Scenarios.

## INTRODUCTION

Although India occupies only 3.29 million $km^2$ geographical area, which forms 2.4% of the world's land area, it supports over 15% of the world's population. The population of India as on 1 March 2001 stood at 1,027,015,247 persons. Thus, India supports about 1/6th of world population, 1/50th of world's land and 1/25th of world's water resources. India also has a livestock population of 500 million, which is about 20% of the world's total livestock population. More than half of these are cattle, forming the backbone of Indian agriculture. The total utilizable water resources of the country are assessed as 1086 $km^3$.

Water resources of a country constitute one of its vital assets. India receives annual precipitation of about 4000 $km^3$. The rainfall in India shows very high spatial and temporal variability and paradox of the situation is that Mousinram near Cherrapunji, which receives the highest rainfall in the world, also suffers from a shortage of water during the non-rainy season, almost every year. The total average annual flow per year for the Indian rivers is estimated as 1953 $km^3$. The total annual replenishable groundwater resources are assessed as 432 $km^3$. The annual utilizable surface water and groundwater resources of India are estimated as 690 $km^3$ and 396 $km^3$ per year, respectively. With rapid growing population and improving living standards the pressure on our water resources is increasing and per capita availability of water resources is reducing day by day. Due to spatial and temporal variability in precipitation the country faces the problem of flood and drought syndrome. Over-exploitation of groundwater is leading to reduction of low flows in the rivers, declining of the groundwater resources, and salt water intrusion in aquifers of the coastal areas. Over canal-irrigation in some of the command areas has resulted in waterlogging and salinity. The quality of surface and groundwater resources is also deteriorating because of increasing pollutant loads from point and non-point sources.

Several factors influence India's future water supply and demand. These include spatial variation and future growth of the population, urbanization and income, and associated changes in dietary preferences, on the crop-consumption side; growth in crop yield, cropping intensity and groundwater use, and contribution to production from rain-fed agriculture, on the crop-production side; and future growth in other factors

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such as domestic, industrial and environmental water demand, and internal and international trade. These factors need to be carefully assessed in future water supply and demand projections. India, with a population of slightly more than one billion, is projected to become the most populated country in the coming decades (UN, 1999).

The population of India is expected to stabilize around 1640 million by the year 2050. As a result, gross per capita water availability will decline from ~ 1820 $m^3$/yr in 2001 to as low as ~1140 $m^3$/yr in 2050. Total, water requirement of the country for various activities around the year 2050 has been assessed to 1450 $km^3$/yr. This is significantly more than the current estimate of utilizable water resource potential (1122 $km^3$/yr) through conventional development strategies. Therefore, when compared with the availability of ~ 500 $km^3$/yr at present, the water availability around 2050 needs to be almost trebled.

The general impacts of climate change on water resources have been identified by the Third Assessment report of the Inter-governmental Panel on Climate Change, (IPCC, 2001). Changes in the total amount of precipitation as well as in its frequency and intensity have also been predicted, which shall inturn affect the magnitude of runoff and soil moisture status.

Thus, the climate change impacts are going to be most severe in the developing world, because of their poor capacity to cope with and adapt to climate variability. India falls in this category. The general philosophy of the implications of climate change on water resources of India has been discussed by Lal (2001). A general projection of the water resource demand for 2050 has been worked out by Central Water Commission, without consideration for the possible impact of climate change (Thatte, 2000).

General Circulation Models are widely accepted as the primary tool used for analysis of potential increased green house gases and more recently, aerosols. Two ouputs of these models are temperature and precipitation. Water availability in the basin under changed climate scenario was evaluated using the projected daily precipitation for 2041–2060 as supplied by IITM, Pune. There work is based on the model HadRM2, the Regional Model of Hadley Centre for Climatic Prediction, UK at a resolution of 0.44° latitude $X$ 0.44°.

Indians should be concerned about global climate change since this phenomenon might have substantial adverse impacts on them. Not all possible consequences of climate change are yet fully understood, but the three 'main' categories of impacts are those on agriculture, sea level rise leading to submergence of coastal areas, as well as increased frequency of extreme events. Each of these pose serious threats to India.

Climate change is a human-induced stress (at least in part) that is generally not yet taken into account. An annual mean global warming of 0.4 to 0.8°C has been reported since the late 19th century. The Regional Impacts of Climate Change: An (Assessment of Vulnerability. A Special Report of IPCC Working Group II eds Watson, R.T., Zinyowera, M.C. and Moss, R.H., Cambridge University Press, UK, 1998, pp. 517). In India, the analysis of seasonal and annual air temperatures, using the data for 1881 to 1997 has shown a warming trend of 0.57°C per hundred years (Pant, G.B. and Kumar, K.R., *Climates of South Asia*, John Wiley, UK, 1997, pp. 320).

Substantial increases in greenhouse gases are likely in the future as a consequence of which global mean surface temperature is expected to increase by between 1.4°C and 3°C for low emission scenarios and between 2.5°C and 5.8°C for high-emission scenarios by 2100 with respect to 1990. Lal. (Lal, M., Climate change—Implications for India's water resources. *J. India Water Res. Soc.*, 2001, 21, 101–119) states that globally averaged global mean sea level is likely to rise by 0.14 to 0.80 m from 1990 to 2100.

## STUDY AREA

Bankura—the western-most district of West Bengal (Figure 1) may be described having the most varied physiographic features. The district can be geologically divided in three categories according to the height of a total land area of 384496 hectares. High hilly region/Hard rock area region consists of Khatra and Ranibandh covering 176915 hec. Most of these parts don't have the irrigation facility and full of grits. Uneven Lands/Hard rock ring area lands are also gritty but when irrigated, covers 150611 hec. The drought prone area shares the area of 118370 hec., the hilly area stretches over a part of 21432 hec. and 12676 hec. suffers as flood prone. According to soil texture, 60207 hec. is Clay area, 81944 hec. is loamy-clay area and the rest is described as sandy-clay area. The drainage of the district is mainly controlled by Damodar, the Dwarakeswar and the Kangsabati river (Figure 1) along with their network of tributaries. They have in general south-easterly flow. The Kangsabati or the Kasai is the third largest river in the district, which rises in the hilly terrain of Jhalda block in the

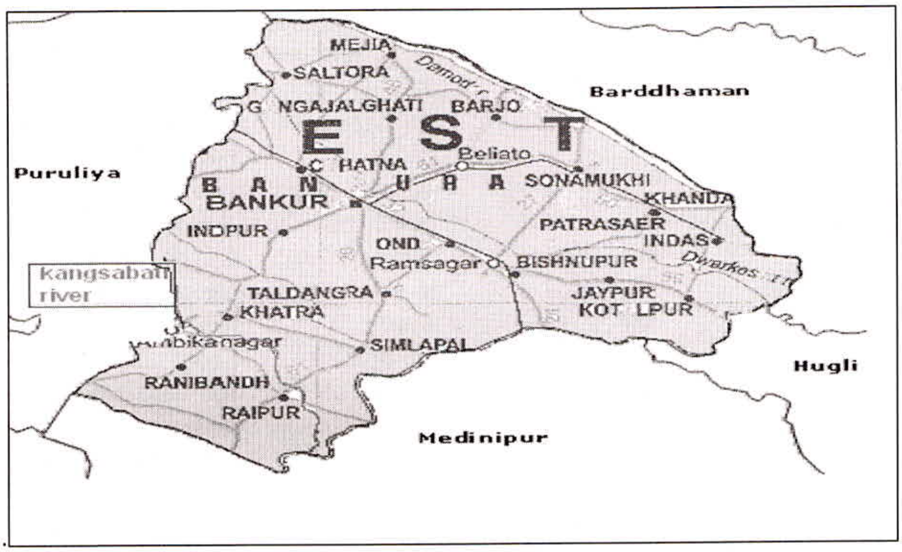


**Fig. 1:** Kangsabati River in Bankura, West Bengal, India

adjoining district of Purulia and enters Bankura district in Khatra block. Therefore, it flows south-easterly for a distance of about 56 km, across the southern part of the district and enters Midnapur district at the south-east corner. All the rivers are seasonal, hence the district is drought prone.

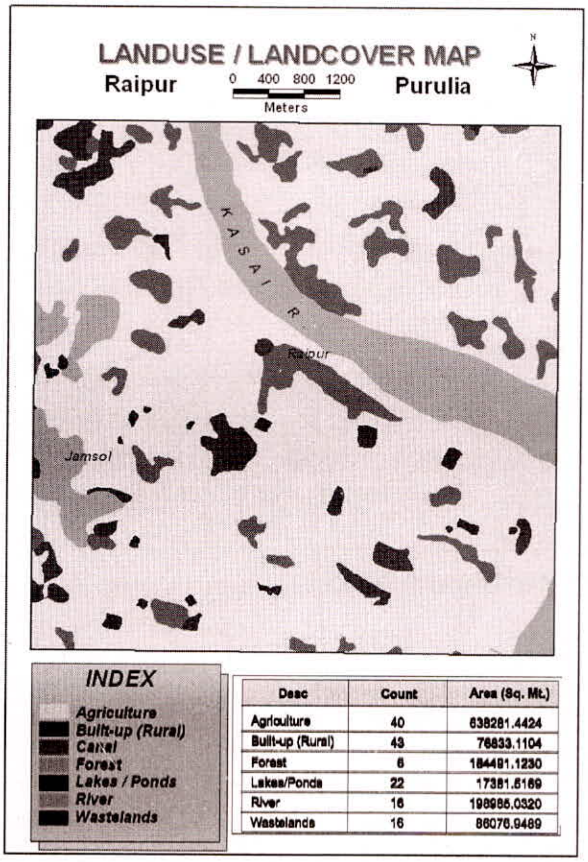
## RESEARCH METHODS

Several maps like watershed and sub-watershed boundaries, drainage networks, land use/cover and soil texture are required besides rainfall and other hydrological data Various parameters of SWAT model such as stream length, average slope length, drainage density, erosion control practice factor (P), soil erodability factor (K), available water holding capacity, bulk density, and saturated hydraulic conductivity have been computed using cartography generated topographical maps or thematic cartographic maps. The model requires average main channel depth and width for determining the losses from each sub-watershed. Table 1 displays the different sets of data used with their sources. The Raipur sub-basin of the Kangsabati River in the Bankura region of West Bengal was chosen for the futuristic study.

## MODEL SELECTION

In recent years, a number of conceptual watershed models have been developed to assess the impacts of changes in land use, land cover, management practices, or climatic conditions on water resources and water quality at watershed scales. Examples of continuous watershed simulation models reported in the literature include CREAMS (a field scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems; Knisel, 1980), SWBM (the Spatial Water Budget Model; Luijten, 2000), HSPF (Hydrologie Simulation Program: Johanson *et al.,* 1984), SWAT (Soil and Water Assessment Tool; Arnold *et al.,* 1993), PRMS (Precipitation Runoff Modeling System; Leavesley *et al.,* 1983), and IRMB(the Integrated Runoff Model-F.Bultot; Bultot and Dupriez, 1976). These models generally operate on a daily time step, are computationally efficient, and often lump many detailed processes that occur over short time steps into simplifying approximations (Binger, 1996).

The most appropriate model for this scale of watershed and for long-term analysis is the Soil and Water Assessment Tool (SWAT Version, 2000). SWAT, a semi-distributed watershed model developed by the United States Department of Agriculture (USDA), has been applied throughout the United States (Cho *et al.,* 1995; Bingner, 1996; Arnold *et al.,* 1998, 1999; Peterson and Hamlett, 1998; Srinivasan *et al.,* 1998; Arnold *et al.,* 1999; Neitsch *et al.,* 2001). The equations in SWAT focuses on a soil water balance. SWAT simulates the water balance, along with plant growth, sediment erosion and transport, nutrient dynamics, and pesticides. The model permits the incorporation of management practices on the land surface, including fertilizer application, livestock grazing, and harvesting operations. Neitsch (2001) details the full capabilities of the SWAT model. There are hundreds of parameters in SWAT. Some of these parameters vary by subbasin, land use, or soil type, which increases the number of parameters substantially.



| Desc | Count | Area (Sq. Mt.) |
|---|---|---|
| Agriculture | 40 | 638281.4424 |
| Built-up (Rural) | 43 | 76833.1104 |
| Forest | 6 | 184491.1230 |
| Lakes/Ponds | 22 | 17381.6169 |
| River | 16 | 198986.0320 |
| Wastelands | 16 | 86076.9489 |

**Fig. 2:** Land use map of Raipur watershed of Kangsabati river, Bankura in West Bengal, India

## SWAT MODEL

The hydrologic components of the model have been previously validated for several watersheds (Arnold and Allen, 1996; Arnold *et al.,* 1998, 1999; Saleh *et al.,* 2000). Brief descriptions of some of the key model components are provided here; more detailed descriptions of the model components can be found in Arnold *et al.,* 1998, Neitsch *et al.,* 2001b, and Jha, 2002. For modeling purposes in SWAT, a watershed is partitioned into a number of subbasins. Each subbasin delineated within the model is simulated as a homogeneous area in terms of climatic forcing, but with additional subdivisions within each subbasin to represent different soils and land use types. Each of these individual land use areas is referred to as a hydrologic response unit, or HRU (Binger, 1996) and is assumed to be spatially uniform in terms of soil, land use, topographic, and climatic data. A daily water budget is computed for each HRU based on precipitation, runoff, ET, percolation, and return flow from subsurface and ground water flow. Subdivision of a watershed into HRUs allows the model to reflect differences in ET for various crops and soils, using the Priestly-Taylor (1972), Penman-Monteith (Monteith, 1965), or Hargreaves (1975) methods. The SCS runoff curve number is used to estimate surface runoff from daily precipitation, with curve number values based on soil type, land use, and land management conditions (Rallison and Miller, 1981). The curve number is also adjusted on a daily basis according to moisture conditions in the watershed (Arnold *et al.,* 1993). For each subbasin delineated in SWAT, the ground water flow contribution to total streamflow is simulated by creating shallow aquifer storage (Arnold *et al.,* 1993). Percolation from the bottom of the root zone is recharge to the shallow aquifer. A recession constant is used to lag flow from the aquifer to the stream (Arnold and Allen, 1996). Water routing through the channel network delineated by SWAT is performed by using either the variable storage coefficient method (Williams, 1969) or the Muskingum river routing method (Overton, 1966).

SWAT is a river basin or watershed scale model developed by the USDA Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. SWAT is a continuous time model operating on daily time step. The sub-basin components of SWAT can be placed into eight major divisions-hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides and agricultural management:

1. *Hydrology*—Surface runoff, Percolation, Lateral Sub-surface Flow, Groundwater Flow, Evapotranspiration, Snow melt and Transmission Losses.
2. *Weather*—Precipitation, Air Temperature, Solar Radiation, Wind Speed and Relative Humidity.
3. *Sedimentation*—Sediment Yield.
4. *Soil temperature*—Daily average soil temperature is simulated at the centre of each soil layer for use in hydrology and residue decay.
5. Crop growth.
6. *Nutrients*—Nitrogen and Phosphorus.
7. *Pesticides*—Gleams technology for simulating pesticide transport by runoff, percolate, soil evaporation and sediment was added to SWAT.
8. *Agricultural Management*—Tillage and residue management and Irrigation.
9. *Routing component*—Channel flood routing, Channel sediment routing, Channel nutrient and pesticide routing, Reservoir Routing, Reservoir water balance and routing, Reservoir sediment routing, Reservoir nutrient and pesticides.

In Figure 3, illustrates the schematic basin of Kangsabati River Catchment of SWAT model which was used for this study.

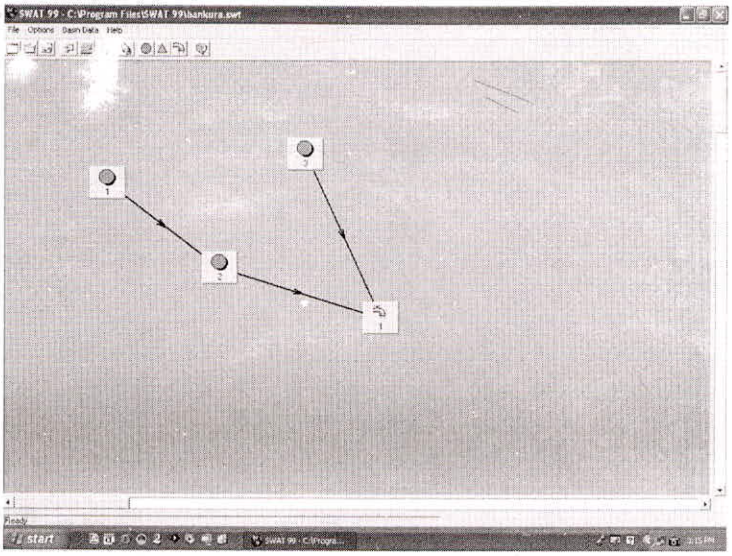


**Fig. 3:** Schematic representation of Kangsabati River with sub-basins by the SWAT model

**Table 1:** Details of Various Data Sets Used in the Present Study

| *Type of Data* | *Source of Data* |
|---|---|
| Survey of India Topographical sheet | Survey of India |
| Thematic Maps: Soils, Slope | National Bureau of Soil Survey and Land Use Planning |
| Agricultural Report | All India Soil and Land Use Survey |
| PS Maps | Directorate of Land Use and Land Records |
| DPMS Series | National Thematic Mapping Organization |

## RESULTS AND DISCUSSIONS

A very well calibrated SWAT model ($R^2 = 1$) was exercised over Bankura, Kangsabati river catchment to generate a futuristic water availability scenario for the year 2050. Figures 4 and 5 illustrate the streamflow and correlation curves used for the calibration process.

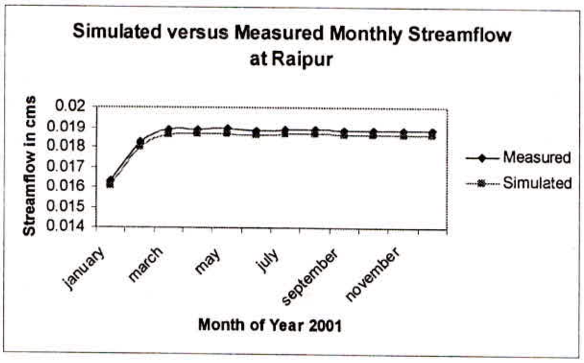


**Fig. 4:** Flow Correlation at Raipur sub-basin of Kangsabati River for the Year 2001

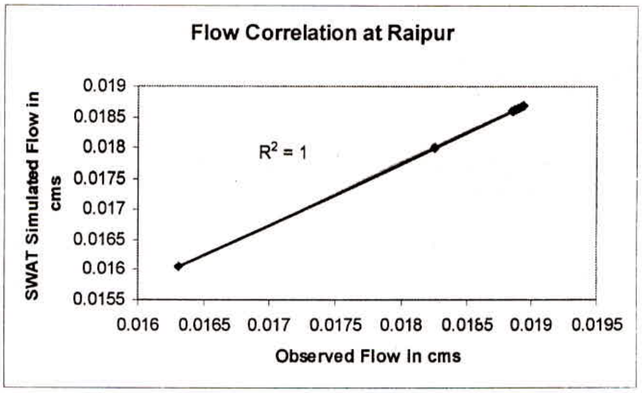


**Fig. 5:** Flow Correlation at Raipur subbasin of Kangsabati River for the Year 2001

### Projected Scenarios for Raipur—Kangsabati Watershed for the Year 2050 Using Swat Model

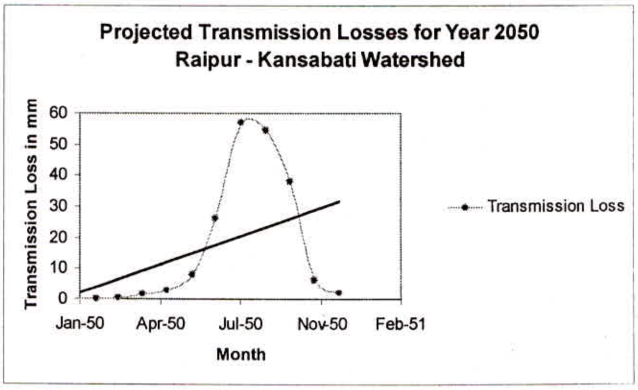


**Fig. 6:** Projected Transmission Losses for the year 2050 for Raipur watershed of the Kangsabati River in Bankura, West Bengal, India

Figure 6 represents the transmission losses which is the water that seeps into the stream channels and recharges the shallow aquifer. The transmission losses are seen to increase which also means that the water percolating past the root zone will also increase and recharge shallow aquifer (Figures 7 and 8). It also follows that the amount of water in the soil will also increase (Figure 9).

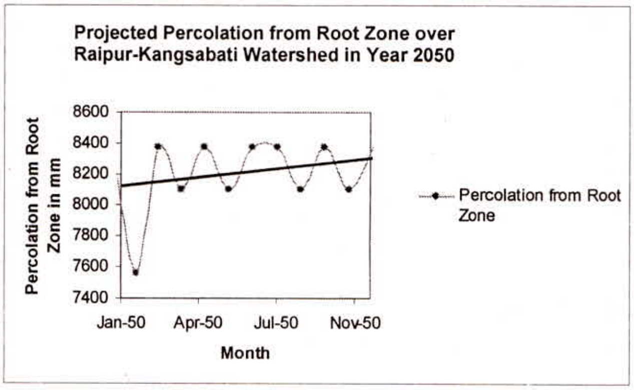


**Fig. 7:** Projected Percolation for the year 2050 for Raipur watershed of the Kangsabati River in Bankura, West Bengal, India

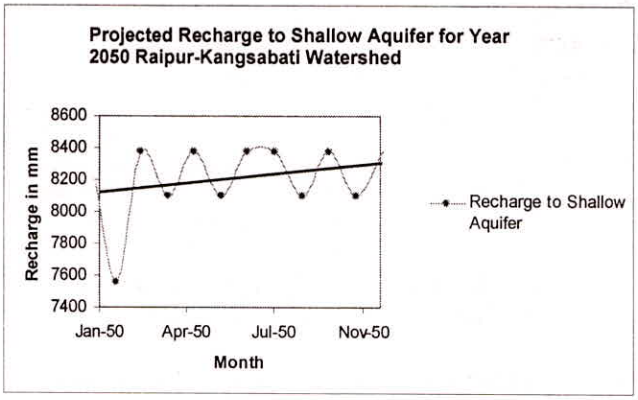


**Fig. 8:** Projected Recharge to shallow aquifer for the year 2050 for Raipur watershed of the Kangsabati River in Bankura, West Bengal, India

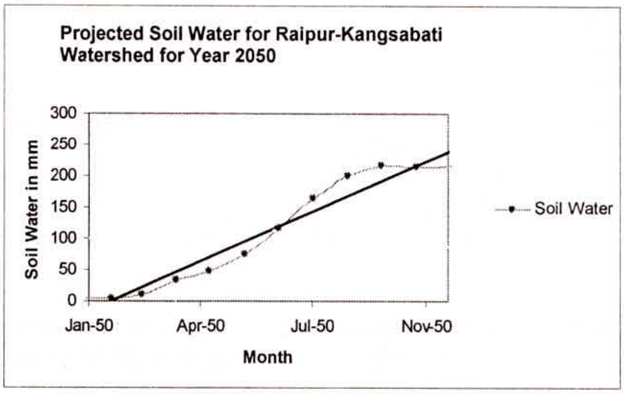


**Fig. 9:** Projected Soil Water relationship for the year 2050 for Raipur watershed of the Kangsabati River in Bankura, West Bengal, India

Figures 10 and 11 illustrate the projected evapotranspiration from the soil profile and projected the potential evapotranspiration over the Raipur watershed for the year 2050 which are seen to increase.

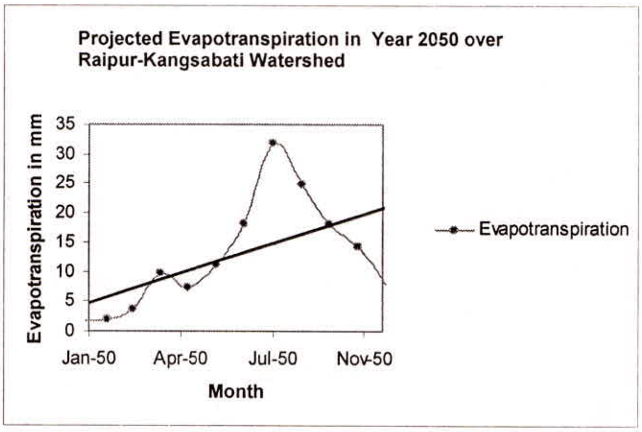


**Fig. 10:** Projected Evapotranspiration for the year 2050 for Raipur watershed of the Kangsabati River in Bankura, West Bengal, India

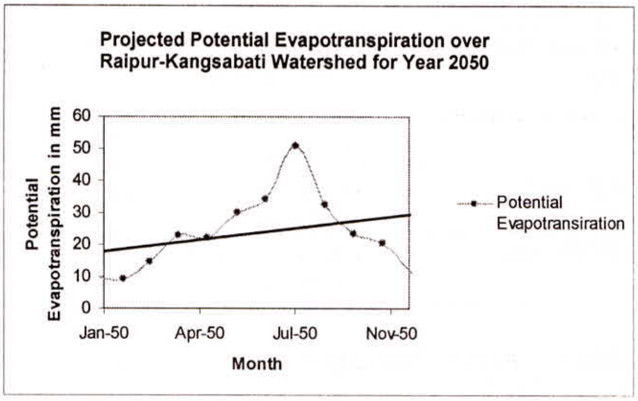


**Fig. 11:** Projected Potential Evapotranspiration for the year 2050 for Raipur watershed of the Kangsabati River in Bankura, West Bengal, India

The water yield is the amount of water that leaves the sub basin and contributes to streamflow at the sub basin outlet. It is the sum of the surface runoff, lateral flow in root zone and ground water flow less the transmission losses in channels within the sub basin. The water yield is seen to decrease as illustrated in Figure 12.

The lateral flow is the water flowing laterally within the soil profile that contributes to the stream flow. This is observed to increase over the year and cause an increase in the surface flow for the year 2050 over Raipur Watershed of the Kangsabati River in Bankura (Figures 13 and 14 respectively).

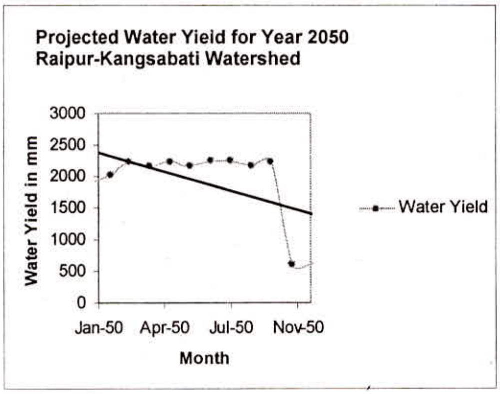


**Fig. 12:** Projected Water yield for the year 2050 for Raipur watershed of the Kangsabati River in Bankura, West Bengal, India

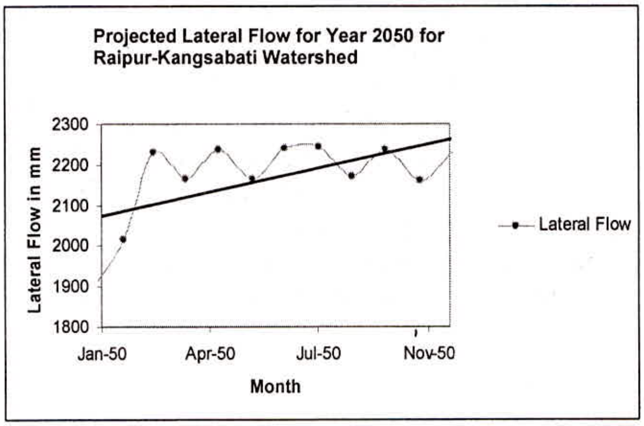


**Fig. 13:** Projected Lateral Flow for the year 2050 for Raipur watershed of the Kangsabati River in Bankura, West Bengal, India

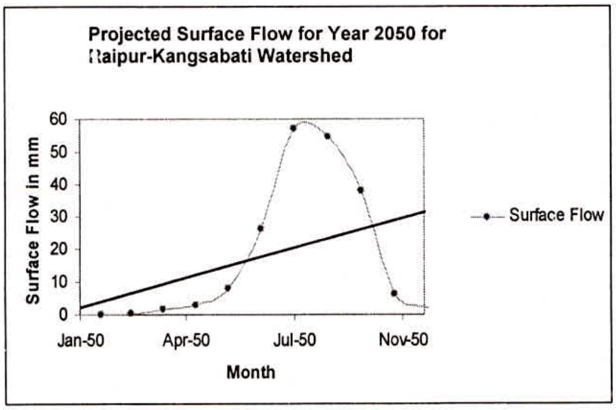


**Fig. 14:** Projected Surface Flow for the year 2050 for Raipur watershed of the Kangsabati River in Bankura, West Bengal, India

## CONCLUSIONS

A study was conducted to evaluate the impact of climate change on the Raipur watershed of the Kangsabati river in Bankura, West Bengal, India. The Soil and Water Assessment Tool was used to generate the projected scenarios for the year 2050.

It was observed that recharge to shallow aquifer and percolation past the root zone depth increases thereby improving soil water content of soil profile. The transmission losses increased, resulting in an increase in lateral flow to the reaches of the river and the surface flow. The evapotranspiration and potential evapotranspiration are also seen to increase.

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