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Impacts of Climate Change under the Threat of Global Warming for an Agricultural Watershed of the Kangsabati River

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Abstract**—**The effects of global warming on India vary from the submergence of low-lying islands and coastal lands to the melting of glaciers in the Indian Himalayas, threatening the volumetric flow rate of many of the most important rivers of India and South Asia. In India, such effects are projected to impact millions of lives. As a result of ongoing climate change, the climate of India has become increasingly volatile over the past several decades; this trend is expected to continue.

Climate change is one of the most important global environmental challenges, with implications for food production, water supply, health, energy, etc. Addressing climate change requires a good scientific understanding as well as coordinated action at national and global level. The climate change issue is part of the larger challenge of sustainable development. As a result, climate policies can be more effective when consistently embedded within broader strategies designed to make national and regional development paths more sustainable. The impact of climate variability and change, climate policy responses, and associated socio-economic development will affect the ability of countries to achieve sustainable development goals.

A very well calibrated Soil and Water Assessment Tool (R^2 = 0.9968, NSE = 0.91) was exercised over the Khatra sub basin of the Kangsabati River watershed in Bankura district of West Bengal, India, in order to evaluate projected parameters for agricultural activities. Evapotranspiration, Transmission Losses, Potential Evapotranspiration and Lateral Flow to reach are evaluated from the years 2041-2050 in order to generate a picture for sustainable development of the river basin and its inhabitants.

India has a significant stake in scientific advancement as well as an international understanding to promote mitigation and adaptation. This requires improved scientific understanding, capacity building, networking and broad consultation processes. This paper is a commitment towards the planning, management and development of the water resources of the Kangsabati River by presenting detailed future scenarios of the Kangsabati river basin, Khatra sub basin, over the mentioned time period.

India's economy and societal infrastructures are finely tuned to the remarkable stability of the Indian monsoon, with the consequence that vulnerability to small changes in monsoon rainfall is very high. In 2002 the monsoon rains failed during July, causing profound loss of agricultural production with a drop of over 3% in India's GDP. Neither the prolonged break in the monsoon nor the seasonal rainfall deficit was predicted. While the general features of monsoon variability and change are fairly well-documented, the causal mechanisms and the role of regional ecosystems in modulating the changes are still not clear. Current climate models are very poor at modelling the Asian monsoon: this is a challenging and critical region where the ocean, atmosphere, land surface and mountains all interact. The impact of climate change on regional ecosystems is likewise unknown. The potential for the monsoon to become more volatile has major implications for India itself and for economies worldwide. Knowledge of future variability of the monsoon system, particularly in the context of global climate change, is of great concern for regional water and food security.

The major findings of this paper were that of all the chosen projected parameters, transmission losses, soil water content, potential evapotranspiration, evapotranspiration and lateral flow to reach, display an increasing trend over the time period of years 2041-2050.

Keywords**—**Change, future water availability scenario, modeling, SWAT, global warming, sustainability.

I. STUDY AREA

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

Bankura - the western-most district of West Bengal (Fig. 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

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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.

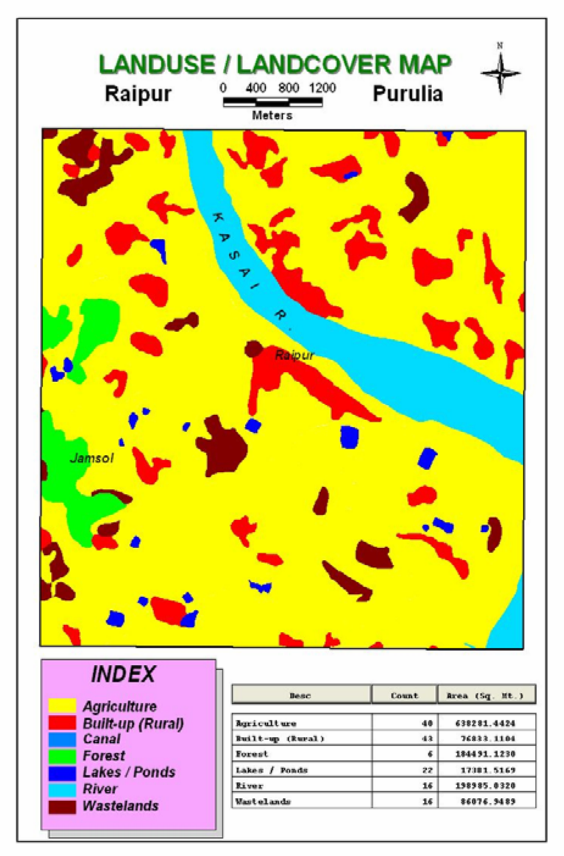

Fig. 2 Land use map of Raipur watershed of Kangsabati River, Bankura in West Bengal, India

The drainage of the district is mainly controlled by Damodar, the Dwarakeswar and the Kangsabati river (Fig 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 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.

II. RESEARCH METHODOLOGY

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 I 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.

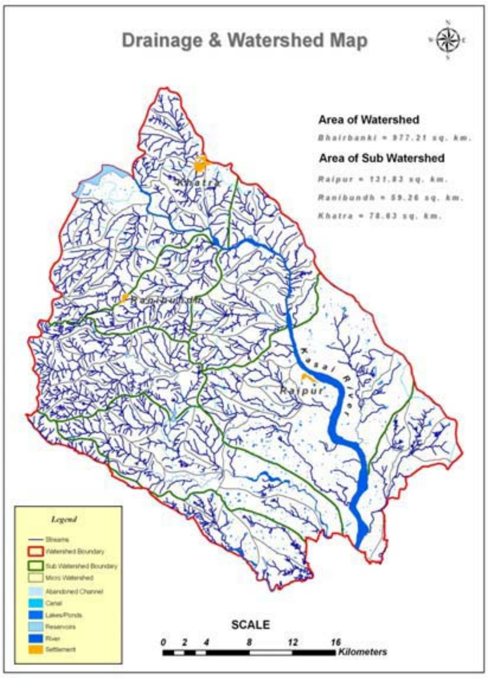

Fig. 3 Drainage and watershed map

TABLE I
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

A. 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, SWBM (the Spatial Water Budget Model, HSPF (Hydrologie Simulation Program), SWAT (Soil and Water Assessment Tool [1], PRMS (Precipitation Runoff Modeling System, and IRMB (the Integrated Runoff Model-

F.Bultot). 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 [2].

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 State Department of Agriculture (USDA), has been applied throughout the United States [2], [3]. 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. 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.

B. SWAT Model

The hydrologic components of the model have been previously validated for several watersheds [3]-[5]. Brief descriptions of some of the key model components are provided here; more detailed descriptions of the model components can be found in [3]. 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 [2] 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 [6], Penman-Monteith [7], or Hargreaves 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 [8]. The curve number is also adjusted on a daily basis according to moisture conditions in the watershed [1]. For each subbasin delineated in SWAT, the ground water flow contribution to total streamflow is simulated by creating shallow aquifer storage [1]. 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 [1]. Water routing through the channel network delineated by SWAT is performed by using either the variable storage coefficient method or the Muskingum river routing method [9].

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

- Hydrology - Surface runoff, Percolation, Lateral Subsurface Flow, Groundwater Flow, Evapo-transpiration, Snow melt and Transmission Losses
- Weather - Precipitation, Air Temperature, Solar Radiation, Wind Speed and Relative humidity.
- Sedimentation - Sediment Yield.
- Soil temperature - Daily average soil temperature is simulated at the center of each soil layer for use in hydrology and residue decay.
- Crop growth
- Nutrients - Nitrogen and Phosphorus
- Pesticides - Gleams technology for simulating pesticide transport by runoff, percolate, soil evaporation and sediment was added to SWAT.
- Agricultural Management - Tillage and residue management and Irrigation.
- 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 Fig 4 illustrates the schematic basin of Kangsabati River Catchment of SWAT model which was used for this study.

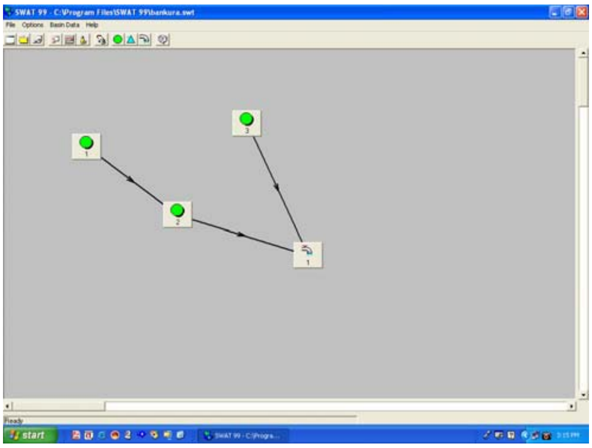

Fig. 4 Schematic representation of Kangsabati River with sub basins by the SWAT model

III. RESULTS AND DISCUSSIONS

A. Calibration Results for the Khatra Sub Basin of the Kangsabati River Located in Bankura District of West Bengal

The calibration has been performed using flow calibration hydrographs for eye inspection and also flow correlation in order to statistically represent the accuracy of the model over the Easter Indian river basin. Fig. 5 and Fig. 6 show the flow calibration and flow correlation results for the HEC HMS model over the Khatra sub basin of the Kangsabati River. The value of the coefficient of determination R^2 obtained was very nearly 1.0.

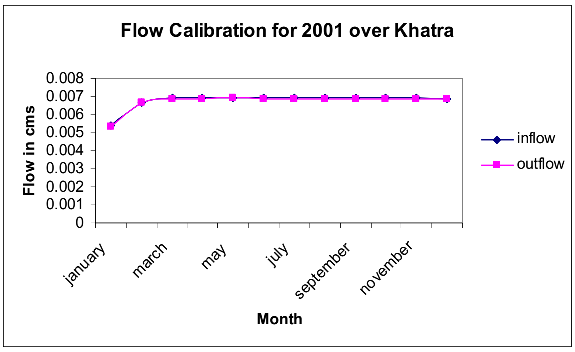

Fig. 5 Flow calibration for the year 2001 over Khatra Sub basin of the Kangsabati River in Bankura district.

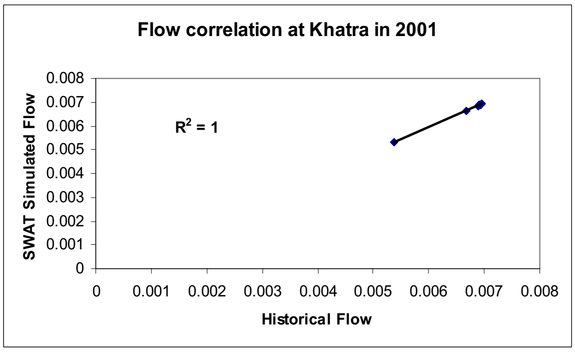

Fig. 6 Flow correlation for the year 2001 over Khatra Sub basin of the Kangsabati River in Bankura district.

B. Sensitivity Analysis

A sensitivity analysis was done to study the effects of these various parameters on the runoff from the study area. The parameters chosen for the sensitivity analysis were – curve number, Manning's n, slope, lateral flow (days), and average slope length. SWAT 2000 is a watershed scale model developed to model land surface processes on large watersheds. Application of this model to this particular field site changed the influence of these parameters on the total runoff. The sensitivity results presented here are for the field scale application of this model.

The sensitivity analysis was carried out using two year model runs with the same input data used in the calibration study. The values of the parameters obtained during calibration were used as a 'baseline' and the changes in the runoff were plotted against the percentage changes in these parameters. During the sensitivity analysis it was apparent that several of these parameters modified the shape of the output hydrograph without affecting the total runoff. The changes in the standard deviation of the runoff were also studied in an attempt to quantify this behavior.

C. Soil Water Content Analysis

Soil Water Content: The amount of soil water is usually measured in terms of water content as percentage by volume or mass, or as soil water potential. Water content does not necessarily describe the availability of the water to the plants, nor indicates, how the water moves within the soil profile. The only information provided by water content is the relative amount of water in the soil.

Soil water dynamics can be thought of as comparable to a sponge. When a sponge is saturated by soaking it in water when it is lifted out of the water any excess water will drip off it. This is equivalent to drainage from the macropores in the soil. Once the sponge has stopped dripping it is at field capacity.

When the sponge is squeezed it is easy to get the first half of the water out. This first squeeze is equivalent to draining the sponge to the stress point and the water is removed like the RAWC (readily available water-holding capacity). Squeezing the second half of the sponge out is much harder. This is like draining the sponge to permanent wilting point. The total water squeezed out of the sponge from when it stopped dripping is the TAWC (Total Available Water-Holding Capacity). But no matter how hard the sponge is squeezed there is no way to get all the water out of it. The water left is the equivalent to the hygroscopic water found in soil.

This sponge analogy is similar to how plant roots find getting moisture from the soil. From field capacity to the stress point it is easy to get the water. From the stress point to the permanent wilting point plants find it much harder to draw water from the soil and their growth is stunted. Below the permanent wilting point no further water can be removed and the plant dies.

D. Khatra Subbasin

The projected soil water content over the years 2042-2050 for the Khatra sub basin is displayed in Figure 7 to figure 12. It is observed that the soil water content will decrease over the above mentioned time period.

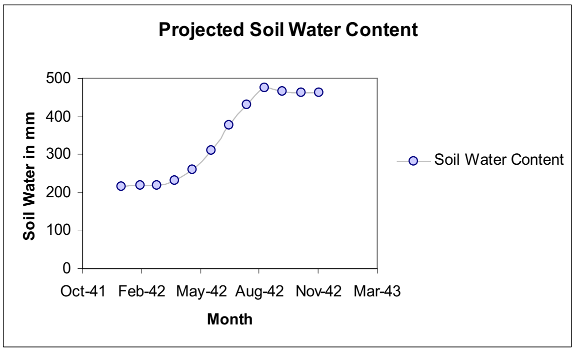

Fig. 7 Projected Soil Water Content for the year 2042 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

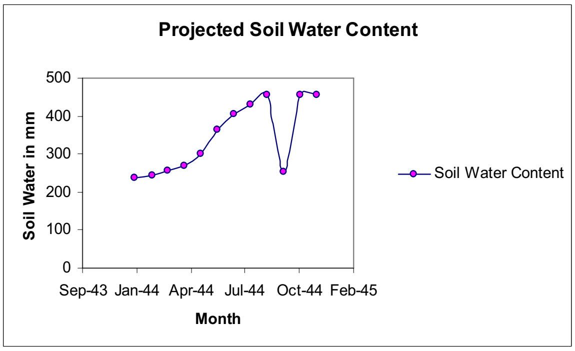

Fig. 8 Projected Soil Water Content for the year 2044 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

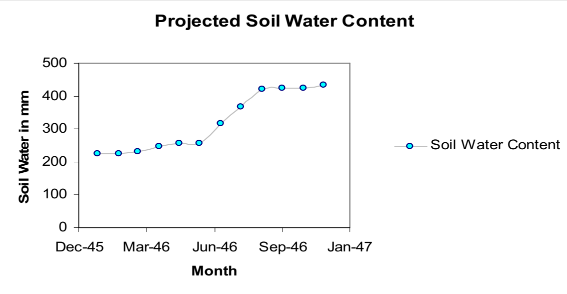

Fig. 9 Projected Soil Water Content for the year 2046 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

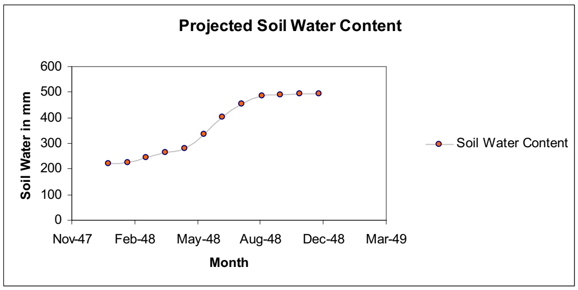

Fig. 10 Projected Soil Water Content for the year 2048 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

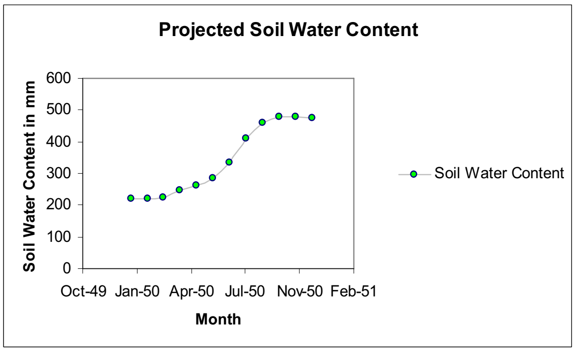

Fig. 11 Projected Soil Water Content for the year 2050 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

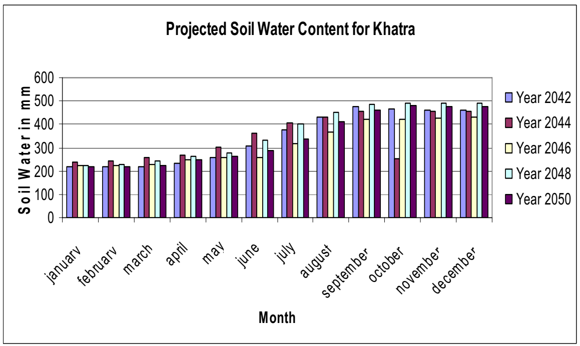

Fig. 12 Projected Soil Water Content for Khatra Sub basin of Kangsabati River in Bankura, West Bengal for the years 2042-2050

E. Evapotranspiration

The projected evapotranspiration over the years 2042-2050 for the Khatra sub basin is displayed in Figure 13 to figure 18.

It is observed that the evapotranspiration will increase over the above mentioned time period.

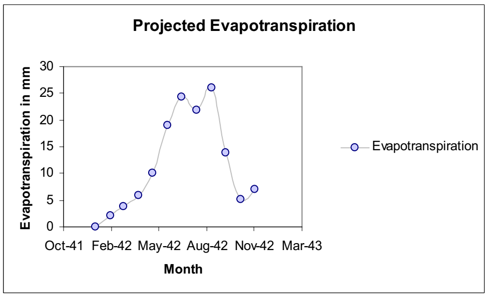

Fig. 13 Projected Evapotranspiration for the year 2042 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

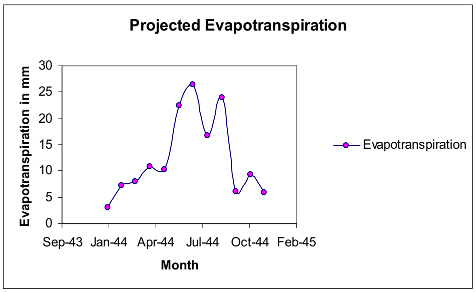

Fig. 14 Projected Evapotranspiration for the year 2044 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

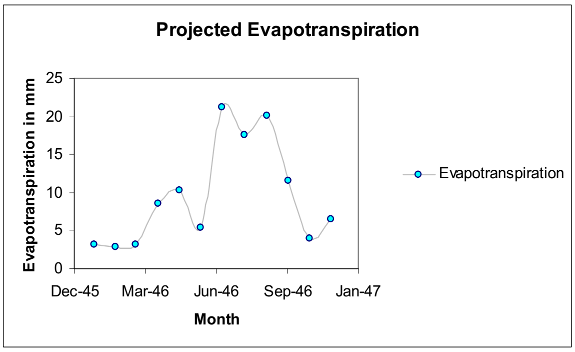

Fig. 15 Projected Evapotranspiration for the year 2046 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

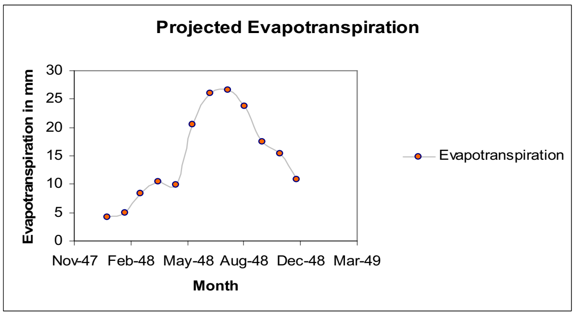

Fig. 16 Projected Evapotranspiration for the year 2048 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

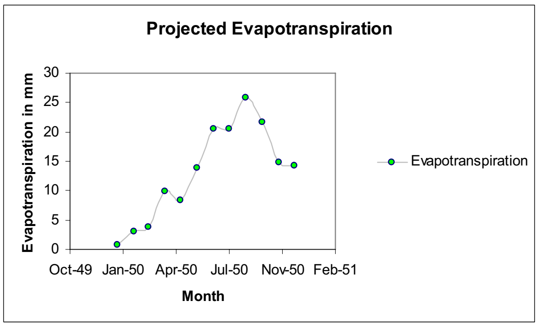

Fig. 17 Projected Evapotranspiration for the year 2050 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

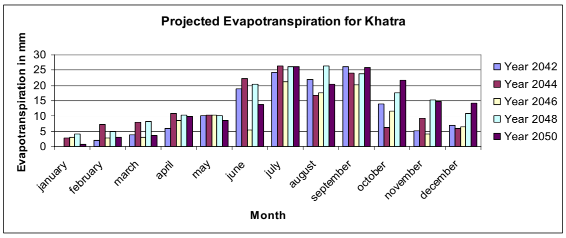

Fig. 18 Projected Evapotranspiration for Khatra Sub basin of Kangsabati River in Bankura, West Bengal for the years 2042-2050

F. Potential Evapotranspiration Analysis

The projected potential evapotranspiration over the years 2042-2050 for the Khatra sub basin is displayed in Figure 19 to figure 24. It is observed that the potential evapotranspiration will decrease over the above mentioned time period.

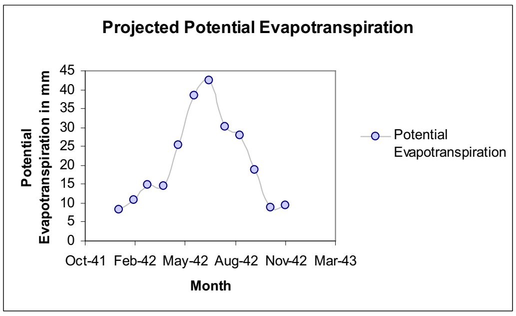

Fig. 19 Projected Potential Evapotranspiration for the year 2042 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

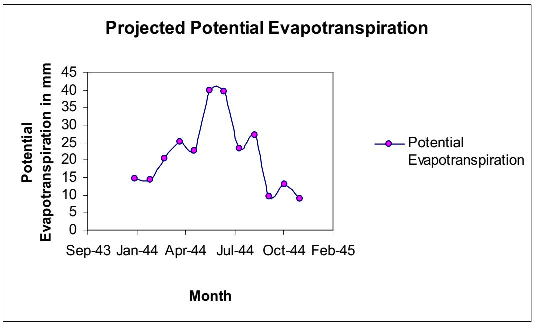

Fig. 20 Projected Potential Evapotranspiration for the year 2044 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

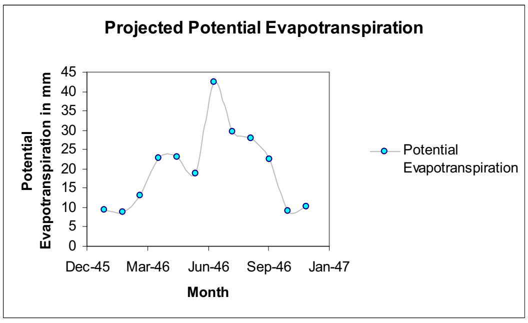

Fig. 21 Projected Potential Evapotranspiration for the year 2046 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

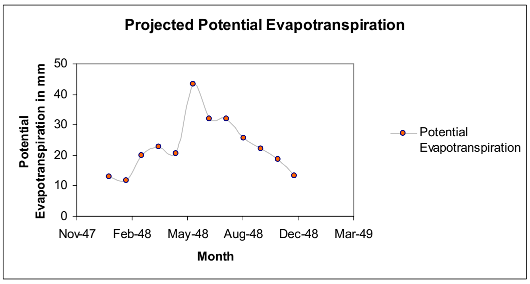

Fig. 22 Projected Potential Evapotranspiration for the year 2048 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

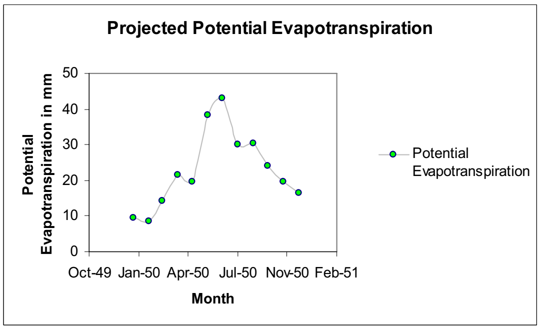

Fig. 23 Projected Potential Evapotranspiration for the year 2050 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

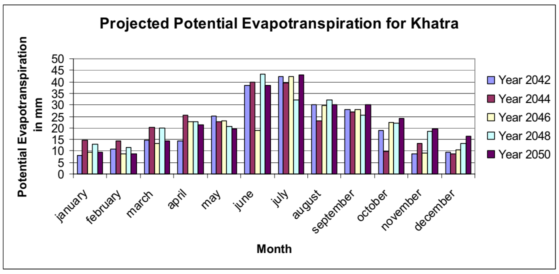

Fig. 24 Projected Potential Evapotranspiration for Khatra Sub Basin of Kangsabati River in Bankura , West Bengal for the years 2042-2050

G. Stream Flow Analysis

Lateral Subsurface Flow. Lateral subsurface flow, or interflow, is streamflow contribution which originates below the surface but above the zone where rocks are saturated with water. Lateral subsurface flow in the soil profile (0-2m) is calculated simultaneously with redistribution. A kinematic storage model is used to predict lateral flow in each soil layer. The model accounts for variation in conductivity, slope and soil water content.

Stream Flow. The projected lateral flow to reach over the years 2042-2050 for the Khatra sub basin is displayed in Figure 25 to figure 30. It is observed that the lateral flow to reach will increase over the above mentioned time period.

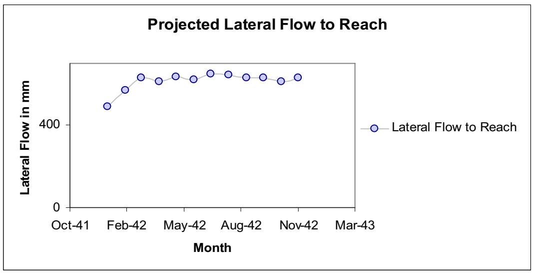

Fig. 25 Projected Lateral Flow to Reach for the year 2042 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

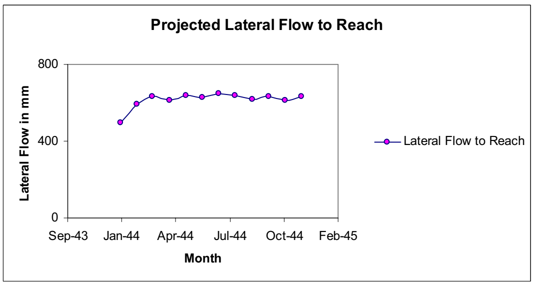

Fig. 26 Projected Lateral Flow to Reach for the year 2044 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

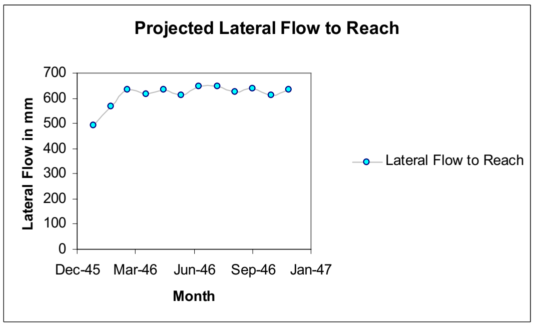

Fig. 27 Projected Lateral Flow to Reach for the year 2046 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

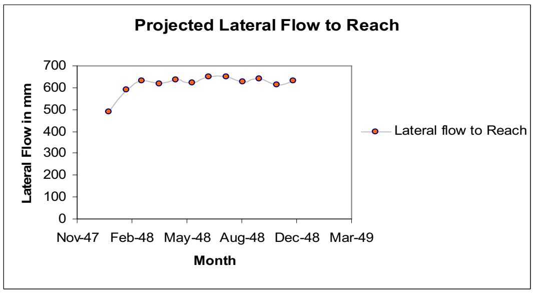

Fig. 28 Projected Lateral Flow to Reach for the year 2048 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

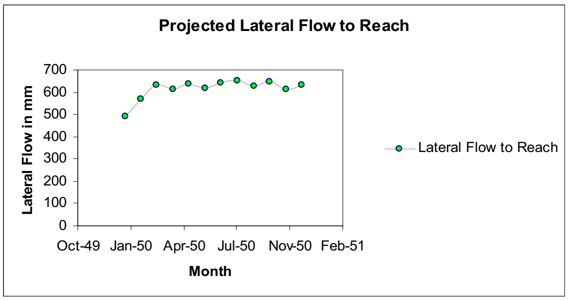

Fig. 29 Projected Lateral Flow to Reach for the year 2050 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

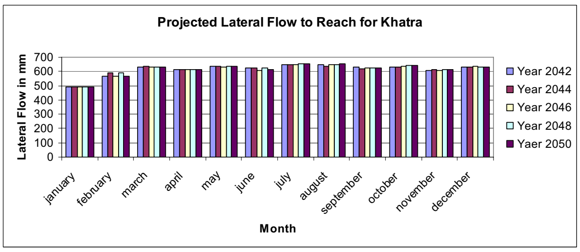

Fig. 30 Projected Lateral Flow to Reach for Khatra Sub Basin of Kangsabati River in Bankura , West Bengal for the years 2042-2050

H. *Transmission Losses Analysis*

Transmission Losses. Transmission losses are losses of surface flow via leaching through the streambed. This type of loss occurs in ephemeral or intermittent streams where groundwater contribution occurs only at certain times of the year, or not at all. SWAT uses Lane’s method described in Chapter 19 of the SCS Hydrology Handbook to estimate transmission losses. Water losses from the channel are a function of channel width and length and flow duration. Both runoff volume and peak rate are adjusted when transmission losses occur in tributary channels.

Transmission Losses: The projected transmission losses over the years 2042-2050 for the Khatra sub basin are displayed in Figure 31 to figure 36. It is observed that the transmission losses will decrease over the above mentioned time period.

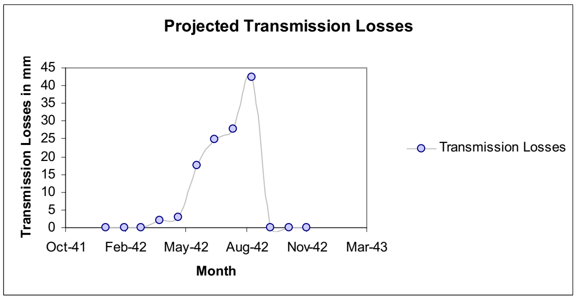

Fig. 31 Projected transmission losses for the year 2042 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

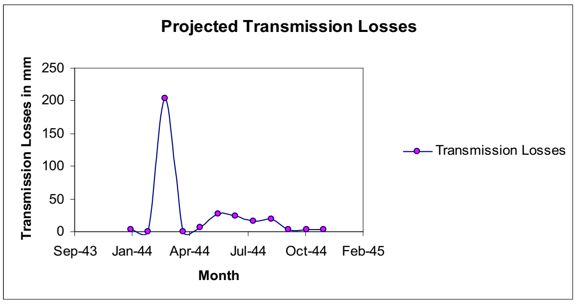

Fig. 32 Projected transmission losses for the year 2044 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

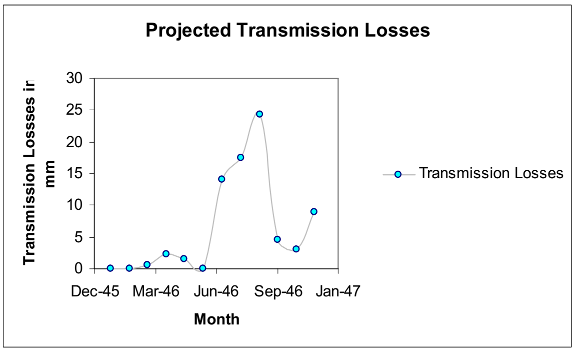

Fig. 33 Projected Transmission Losses for the year 2046 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

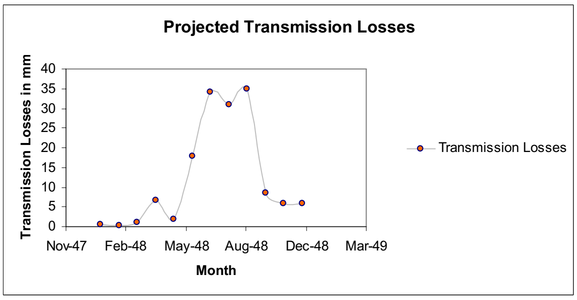

Fig. 34 Projected transmission losses for the year 2048 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

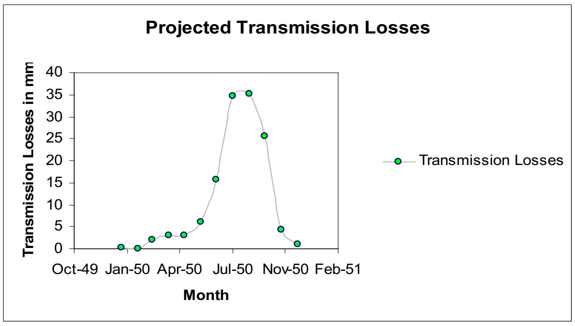

Fig. 35 Projected Transmission Losses for the year 2050 for Khatra Sub Basin of Kangsabati River in Bankura, West Bengal

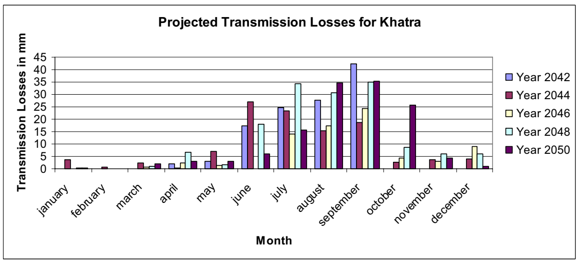

Fig. 36 Projected Transmission Losses for Khatra Sub basin of Kangsabati River in Bankura , West Bengal for the years 2042-2050

I. *Reliability and Limitations*

One of the major limitations to large area hydrological modelling is unavailability of data to account for spatial variability associated with rainfall. For example, during this study data, from only 4 rainfall stations were used. There is no rain gauge station in the upper areas of the basin having long-term records. For each subbasin, SWAT assigns rainfall from the nearest rain gauge station. This would decrease the accuracy of simulations. The Hargreaves and Samani method estimated the PET in an acceptable order of magnitude in the wet months with respect to the long term observed pan evaporation data around the lower part of the basin. However, the spatial variation was not correctly represented in the simulated data with respect to the ET map prepared by Farah (2001).

Due to the unavailability of long-term data, the original weather generator inside the SWAT was used to estimate temperature. This could be the reason for poor spatial variations of simulated potential evapotranspiration values. The Hargreaves and Samani method estimates the potential evapotranspiration as a function of extraterrestrial radiation and air temperature, SWAT makes a broad assumption that roughly 20% of the extraterrestrial radiation is lost while passing through the atmosphere under cloudless skies. Using this assumption, the maximum possible solar radiation at a particular location on the earth's surface is calculated. This could be a reasonable assumption in the wet months. But in the dry months, this percentage can be lower than the assumed value. This could probably be the reason for relative under estimations of PET in the dry period.

The SWAT weather generator corrects the estimated daily solar radiation, minimum and maximum temperature by adjusting those according to the wet and dry condition of the day. The modified weather generator, introduced in this study, estimates the accurate monthly total rainfall but it is incapable of preserving the statistics such as skewness. Therefore in simulated rainfall data, wet and dry day sequences could be different from the real rain falls on the area. This would affect the generation of solar radiation and temperature, hence affecting the potential evapotranspiration. This problem of poorly generated rainfall as well as the statistical properties closer to the observed or real rainfalls on the ground could be achieved by incorporating a model such as Brtlett-Lewis which has proven capabilities of generating daily rainfall data closer to observed rainfall as well as the statistics of them.

An overall weakness of the SWAT model is the use of equations that have parameters that are not directly measured by using data. For example, the curve number equation, although often employed to estimate runoff volumes, is highly uncertain because of the use of a parameter i.e, the curve number that has been determined empirically for different land uses. In addition, the MUSLE, which is employed for soil-erosion simulation, is also uncertain because of the number of parameters in the equation that are set from qualitative information e.g., soil type. Although efforts have been made to incorporate more process-based equations, some of the basic processes modeled by SWAT still have room for improvement.

The first specific shortcoming is in the model's simulation of snowmelt for flow volumes. The difficulty in simulating snowmelt has been documented in previous work with SWAT Peterson and Hamlett (1998). In addition, our model's overestimation of flows in the summer may be caused by underestimating evapotranspiration. The Penman–Monteith equation, which is used to estimate evapotranspiration, requires significant data, including, but not limited to, solar radiation, wind speed, soil characteristics, and canopy cover characteristics. Because only precipitation and temperature were available as input data, the other meteorological data needed for this calculation were obtained by using a weather generator in SWAT. Considerable uncertainty exists in weather generation, even though the parameters for the weather generator were set for an area in upstate New York. As a result, considerable uncertainty exists in the final evapotranspiration values determined by SWAT. In sediment erosion modeling, the SWAT model cannot capture floodplain erosion, which is shown in its inability to simulate the January 1996 flood event in the Cannonsville Reservoir and its surrounding watershed, in which floodplain erosion and snowmelt erosion were both experienced.

The MUSLE algorithm is designed to simulate erosion occurring because of the runoff produced during a storm event. Reference [3] stated that SWAT does not simulate detailed event based flood and sediment routing. Reference [10] believed that the model was best developed to evaluate management impacts on long-term erosion and sedimentation [3]. As a result, it would be inappropriate to apply the model in an attempt to evaluate particular flooding events, especially those in which floodplain erosion occurred. In addition to floodplain erosion, snowmelt erosion during the spring and winter months is difficult to model using the MUSLE, which is employed by SWAT. The original USLE was developed to simulate erosion caused by sheet flow runoff. As a result, even the MUSLE, which was adapted by replacing the rainfall energy used in the USLE with a runoff factor, has difficulty with snowmelt erosion. This outcome is shown by the model's inability to capture the sediment load at Beerston in January 1996. The January 1996 event was characterized by heavy rains falling on an existing snowpack. The SWAT erosion algorithms are currently designed to reduce sediment erosion calculated by the MUSLE when snowpack exist. These predictions are a function of snowpack depth and are unrelated to surface runoff or soil temperature.

However, in the case of heavy rains and high amounts of snowmelt such as those experienced in January 1996, assuming that erosion was minimal may not be accurate. Although the snowpack existed, the heavy rains most likely accelerated snowmelt and caused considerable soil erosion that was not captured by the SWAT algorithms. Another cited limitation in SWAT is the sediment routing routine, which has relatively simplistic equations [3]. Currently, the sediment transport routine uses a stream power equation that calculates the maximum transportable sediment load, given the stream velocity. However, this equation does not consider sediment transport characteristics, such as bottom shear stress, which determines whether erosion or deposition will occur, given flow velocities. Pursuing a refinement of these equations to incorporate more representative processes in the stream channel may be beneficial.

Finally, the simulation of the Town Brook watershed illustrates a possible limitation in the model when modeling small watersheds. In this case, SWAT did not perform as well for Town Brook, which was one of the smallest subwatersheds in the Cannonsville system 3% of the total area, as it did on larger watersheds. This outcome may have occurred because parameters had to be adjusted on a basin wide basis. Although these parameter adjustments seemed to be accurate for the system as a whole, they may not have been representative for a small area such as Town Brook. Because of Town Brook's size, the response of the subwatershed to precipitation events is more sensitive, and timing of the events is crucial for model performance. Consequently, errors that may be averaged out on larger basins would be quite apparent on small basins because the input data and parameters have been set on a large scale. Although the SWAT model has limitations, it is still a viable model for simulating water balance and sediment transport on large watersheds. Previous efforts have illustrated calibrated models that were used to investigate management options and understand crop growth. The model is capable of continuously simulating flow and sediment transport in a semi distributed fashion for analyzing the impact of different sub watersheds on a receiving water body.

One of the major limitations to large area hydrologic modelling is the spatial variability associated with precipitation. There are more than 8000 rain gage locations in the U.S. with more than 30 years of daily precipitation data. There are, on average, two or three gages per county, which leaves several kilometres between gages. This can cause considerable errors in runoff estimation if one gage is used to represent an entire sub watershed or even if an attempt is made to "spatially weight" precipitation for a watershed. Also, the data files are difficult to simulate and contain considerable days of missing record.

Weather generators can be extremely useful when measured data is unavailable and management scenarios are being compared. Daily weather generator parameters are available for generating weather sequences at a point. However, spatially correlated generator required for large area hydrologic simulations have not been developed. The physical processes driving large area weather phenomenon are not fully understood and many technical obstacles need to be overcome before spatially correlated rainfall generation is possible.

SWAT does not simulate detailed event based flood and sediment routing. It was developed to predict agricultural management impacts on long term (hundreds of years) erosion and sedimentation rates. The model operates on a daily time step, although a shorter and more flexible time increment would be a major enhancement to the model.

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