Water Resources in India under Changed Climate Scenario

Pankaj Kr Roy*, Asis Mazumdar**
*Asst. Professor, S.W.R.E., Jadavpur University, Kolkata-32,
**Director & Professor, S.W.R.E., Jadavpur University, Kolkata-32

ABSTRACT:

The present study is an attempt to assess the impacts of climate change on water resources of the river basins of India which have immense importance in domestic, industrial agricultural and hydropower scenario. A distributed hydrological model developed from HEC-HMS was used on the Indian river basins using the projected daily precipitation and temperature data for the continuous daily range for the period of (2010-2040), (2041-2070) and (2071-2100) generated based on ERA-15 SRES run of PRECIS model using Met Office Hadley Centre Regional Climate Model as supplied by IITM, Pune with baseline (1961-1990) for A2, A1B and B2 scenarios without sulphur cycle with grid spacing 0.440 latitude x 0.440 longitude. The future estimation of runoff was done by HEC-HMS model and the estimated runoff was fed to the water budget equation for determination of water availability. The green water, water sequestration, virtual water and water footprint was calculated from the estimated water availability. A synthesis of proper prediction of the future scenario as regards the quantum of surplus and deficit basins for the rivers basin of India have been identified and possible notional inter basin transfer has been discussed without considering the intricacy of ecological, environmental and political constraints.

KEYWORDS: green water; HEC-HMS; river basins; virtual water; water footprint; water sequestration

I. INTRODUCTION:

The total area of India can be divided into 19 major drainage basins with varying per capita water supply. Water demand also varies substantially among basins. The Indus and the Ganga basins with 48 percent of the total population of India utilize about 57 percent of the total primary withdrawals of water resource, of which sector wise irrigation has the largest allocation. Shortage of fresh water is becoming limiting factor in the economic and social development of many countries. Under these conditions the reliable assessment of water resources is extremely important **[17]**. The Intergovernmental Panel on Climate Change estimates that up to 2 billion people may be at risk from increasing water stress by the 2050s, and that this number could raise to 3.2 billion by the 2080s, Climate change, we are told, will cause water shortages **[4]**.

Due to rapid urbanization increase in demand is projected for the industrial sector also **[29, 22]**. Because of the expected priority given to domestic use and industrial use, the water scarce basins will have to transfer water from their agriculture use. This difficult situation can be overcome if one agrees to transfer basin transfer from water surplus areas to water scarce areas.

Recent documentation provides convincing evidence on the impact on natural system by climate trends in 20th century **[13]**. The impact of climate change on water resources through increased evaporation (due to global warming) combined with regional changes in precipitation characteristic (such as total amount, variability, frequency of extremes) has the potential to affect runoff, frequency and intensity of floods and droughts, soil moisture relation, water availability for irrigation and hydroelectric power generation. Different regions can sustain populations of different sizes (i.e., with different carrying capacities, depending on climate, amount of land and water resources allocated to agro ecosystems, and the type of diet **[9, 14]**. Quantitative measure of the globalization of water resources is provided **[9, 12]**. Most of the rains in India fall within 3 to 4 months in the monsoon period. The average rainfall in the four months- June to September of the south-west monsoon is about 935 mm. The rest of the eight months receive on average only about 280 mm of rainfall **[7]**. Some even claim that almost all the annual rain falls within 100 hours **[1]**. Capturing the abundant south-west monsoon for beneficial utilization in the other period is an enormous task. This is especially true with the wide variation of spatial distribution of rain fall. The spatial variation of water availability is crucial in proper demand management. The Ganga-Brahmaputra-Meghna (GBM) system is the largest river basin in India with a catchment area of about 110 Mha, which is more than 43% of the cumulative catchment area of all the major rivers in the country.

The primary objective of this work was to analyze the spatial variation of water supply and demand across the flood prone river basins in eastern and north eastern, India. We identified basins, which are water scarce due to inadequate water supply or due to mismatches between demand and supply. We also

identified issues, which are important for meeting the food needs and their implications for future water resources development and management. Water requirements for food production exceed by far all the other water needs **[9]**.
A river basin is an ideal analytical unit for water supply and demand studies. The water availability of the Indian River basins are already comprehensively studied **[7]**. However, most of the data required for water demand estimation was collected and policy decisions taken at the administrative boundary level. Thus demand projection studies, even at sub national level use administrative boundaries as analytical units **[18]**. Therefore, the effort in this paper to assess the river runoff in the flood prone systems of eastern and north eastern river basins of India using HEC-HMS model in the continuous slices data for the period of (2010-2040), (2041-2070) and (2071-2100) for A2, A1B and B2 scenario based on PRECIS model collected from IITM, Pune with baseline (1961-1990) without sulphur cycle. This is even more important in today's increasing focus on Integrated Water Resources Management in eastern and north eastern river basins.

II. MATERIALS AND METHODS:

HEC-HMS MODELLING

The hydrologic simulation package HEC-HMS has been used for the evaluation of hydrologic impact of climatic variability on water resources of ten important eastern and north eastern river basins in India **[32]**. The HEC-HMS (HEC-HMS, Version 2.2.2., 2000) is the US Army Corps of Engineers' hydrologic modelling system and was developed by the Hydrologic Engineering Centre (HEC). The hydrologic model simulates the precipitation-runoff and routing processes, both natural and controlled. The use of model requires input of daily/hourly rainfall, soil condition at the micro-watershed level and hydro-meteorological data. Monthly precipitation observations were used from the most recent version of the Global Historical Climatology Network **[34]**. The historical data for the basins will be used for the calibration and validation **[27]**. Figure 1 depicts the spatial variation of the maximum values of the different indicators found in the baseline scenario. The use of the model requires input of daily rainfall, soil condition and hydro meteorological data. Potential evapotranspiration has been calculated by using Thornthwaite Method. The "Thornthwaite (1948) method" , based on knowledge of the temperature and latitude, is traditionally used to calculate **[6]**.

Daily rainfall data and stream flow data for a period of thirty years (January 1961 to December 1990) for the river basins of eastern and north eastern India were used for the calibration and validation. Calibration factors for CTL were calculated using the entire 2000-yr integration **[6]**. The calibration error, expressed as a percent difference of simulated discharges with respect to observed discharges, were found to lie within the range of 0.2% to 20% for all the eastern and north eastern river basins **[26]**.

The future projection of climatic variables was collected from the PRECIS climatic model, future groundwater was estimated from **[10]** groundwater recharge model and future land use as well as soil characteristics was collected **[15].** Future trend of industry was estimated based on the trends proposed by **[5]** whereas Future trend of forest cover was estimated based on the trends proposed by **[33]**. The trends proposed in **[25]** were applied to the local population of river basins to estimate the trends of population change over 2010 to 2100 time slice. The grid spacing in PRECIS is 0.440 latitude x 0.440 longitudes. Because of the irregularity in station distribution, gridding is needed to reduce regional bias in area-averaged precipitation **[11]**. MODRAT through Watershed Modeling System was used for drainage delineation using GIS, Maps or building the modeling tree based input parameters. The study by **[8]** did not take a grid-based approach.

Using the results of this analysis some basins were identified that are to be scared in the projected scenario for A2, A1B and B2 for the period of 2010 to 2100 generated at IITM, Pune using Met Office Hadley Centre Regional Climate Model PRECIS. The future estimation of runoff was done by HEC-HMS model and the estimated runoff was fed to the water budget equation for determination of water availability. The green water, water sequestration, virtual water and water footprint was calculated from the estimated water availability.

III. RESULTS AND DISCUSSION:

River Runoff:

Runoff is a dynamic part of long term water reserves, and serves as a characteristic of potential renewable water resources, not only of rivers proper but also of lakes, reservoirs and glaciers. The total global runoff averages (excluding the ice flow of Antarctica) 44,500 km3 per year **[17]**. River Runoff of eastern and north eastern river basins in India in three different scenario (A2, A1B and B2) were estimated by using HEC-HMS Model directly derived from daily meteorological data from PRECIS, 2040 and 2070 from monthly climatic data predicted by pattern scaling approach **[28]**. It is not hard to identify quantitative relationships between total runoff and climatic factors **[17]**.

Table 1 depict that the A2 and B2 scenario is more vulnerable than A1B in 2040, A2 was most vulnerable in 2070 and A2 and A1B scenario was found to be more vulnerable than B2 in 2100. If different basins are compared, Ganga Downstream and Brahmaputra in A2, Mahanadi in A1B and B2 was found to be more vulnerable than any other basins if river runoff is an indicator of watershed status.

Note.1: Climatic Vulnerability Scale for River Runoff

-70 and below: Completely Invulnerable (CI)
-26 to -70: Invulnerable (I)
-6 to -25: Semi-Invulnerable (SI)
-5 to +5: Non-Vulnerable (NV)
+6 to +25: Semi-Vulnerable (SV)
+26 to +70: Vulnerable (V)
+70 and above: Highly Vulnerable (HV)

Table 1. Vulnerability scale of River Runoff in basin wise in three different scenarios for the period of 2040, 2070 and 2100.

River Runoff	Scenarios								
	A2			A1B			B2		
Year	2040	2070	2100	2040	2070	2100	2040	2070	2100
Ganga -Upstream	SV	SV	V	SI	SV	SV	SV	SI	SI
Ganga Downstream	V	HV	HV	CI	V	V	SV	I	I
Mahanadi	SV	SV	SV	SV	SV	SV	SV	SI	SI
Brahmani	I	HV	V	I	SV	V	SV	I	I
Brahmaputra	V	HV	HV	I	SV	V	SV	CI	I
SurmaImphal	V	V	HV	CI	SV	V	SV	CI	I

Water Availability:

The water availability (WA) was calculated as per the water budget equation **[31]** which states that,

$$\text{Water Availability (m}^3\text{/capita/year)} = \left(\frac{P-(Q+E+G+T)}{p}\right) \ldots.(1)$$

The equation 1 can be rearranged as,

$$= \left(\frac{P-(Q+ET+L_c)}{p}\right) \ldots.1(A))$$

Where P = Precipitation volume, Q = runoff volume, E = Evaporation volume, G = Groundwater outflow volume, T = Transpiration volume, ET = Potential Evapo-Transpiration, L = Basin Loss, p = Population of the sampling region. Evaporation (E) and Transpiration (T) could be collectively represented as Evapo-Transpiration (ET) and Groundwater outflow could be replaced by Basin Loss coefficient. The unit of water availability is taken as cubic meter/capita/year. Global circulation models (GCMs) have been used previously to investigate water availability **[6]**.

Note 2: Climatic Vulnerability Scale for Water Availability and Related Indicators

70 and above: Completely Invulnerable (CI)
26 to 70: Invulnerable (I)
6 to 25: Semi-Invulnerable (SI)
+5 to -5: Non-Vulnerable (NV)
-6 to -25: Semi-Vulnerable (SV)
-26 to -70: Vulnerable (V)
-70 and below: Highly Vulnerable (HV)

Table 2. Vulnerability scale of Water Availability in basin wise in three different scenarios for the period of 2040, 2070 and 2100

Water Availability	Scenarios								
	A2			A1B			B2		
Year	2040	2070	2100	2040	2070	2100	2040	2070	2100
Ganga - Upstream	SV	SV	SV	SV	V	V	SV	SV	V
Ganga Downstream	HV	HV	HV	HV	HV	HV	HV	HV	HV
Mahanadi	SV	SV	V	SV	V	SI	SV	V	SI
Brahmani	HV	HV	HV	V	V	SI	HV	HV	HV
Brahmaputra	HV	HV	HV	HV	HV	HV	HV	HV	HV
SurmaImphal	HV	HV	HV	HV	HV	HV	HV	HV	HV

A2 is found to be more vulnerable in the year 2100 and showed a continuous degradation of the watershed status but for B2 and A1B improvement was observed in 2100. It can be said that Gini co-efficient may have direct relation with vulnerability but inverse relation with water availability. Since, population factor plays an important role in deciding vulnerability and calculating Gini co-efficient so both can be co-related with each other. Gini co-efficient is a measure of inequality of distribution **[16]**. Thus, Gini co-efficient is concluded to be maximum for A2 scenario in the year 2100, which contributes to inequality with the other scenario. Gini co-efficient is calculated for each water use **[30]**. Ganga Downstream, Brahmaputra and SurmaImphal showed high vulnerability towards climate change among all the river basins of East and North East India in all the three scenarios. Mahanadi was found to have a similar vulnerability in A2 and B2 but not in A1B scenarios which represent positive status for the river based on water availability (Table 2).

Virtual Water Availability:

Virtual water is defined as the volume of water used in the production of a commodity, good or service, but not necessarily contained within, a unit mass of agricultural and industrial goods **[9, 21]**. Virtual water has a number of advantages apart from the strategic one of solving the current and growing water problem of the region **[3]**. On a dark Monday afternoon in November 1992, during a routine SOAS seminar, somebody used the term 'virtual' water to describe the same concept **[4]**. The globalization of (virtual) water resources may prevent malnourishment, famine, and conflicts, its long- term effects on the coupled human natural system remain poorly investigated **[12]**.

Through the long- range transport and globalization of virtual water, international trade is modifying the dependence of human societies on their regional water balance **[9, 14]**. Virtual Water was calculated from the data of industrial demand of the two river basins. Virtual water flows among nations are obtained **[23]**. If percentage annual demand for raw water from the industries of a location, were, say, V and annual water availability in m3 of the same location was WA, then amount of annual virtual water (VW) in m3/year can be expressed as,

$$VW = \sum f\,(V_m x WA_m)/m \quad m = 1 \text{ to } 12 \ldots\ldots..(2) \text{ and where, } V = f\,(V_h, V_m)$$

where, m is month and V_h and V_m is the high consumer and medium consumer of water respectively representing large and small scale industries which need water as raw material for production. The equation 2 implies that more the amount of virtual water more is the number of water-dependant industry available in the region. Industrial richness of a region can be well expressed by the amount of virtual water consumed in the region.

Table 3. Vulnerability scale of virtual water availability in basin wise in three different scenarios for the period of 2040, 2070 and 2100

Virtual Water Availability	Scenarios								
	A2			A1B			B2		
Year	2040	2070	2100	2040	2070	2100	2040	2070	2100
Ganga - Upstream	SV	SV	SV	HV	SV	SV	SV	V	SV
Ganga Downstream	HV	V	HV	V	V	V	HV	HV	HV
Mahanadi	SV	SV	SV	SV	SV	SI	N	SV	N
Brahmani	HV	HV	HV	V	V	SV	HV	HV	HV
Brahmaputra	HV	HV	HV	HV	V	V	HV	HV	HV
SurmaImphal	HV	HV	HV	V	HV	HV	HV	HV	HV

A2 was found to be most vulnerable scenario where 2010 and 2070 both time period show large scale degradation when availability of virtual water in East and North East India was compared. Brahmani, Brahmaputra and SurmaImphal catchment was found to receive the highest reduction of virtual water in A2 and B2 scenario of climate change. But in A1B, only SurmaImphal was found to have the maximum negative change in total available virtual water. The results implied that industrial concentration will increase in South of East India and in North East and which, in turn, will reduce the availability of virtual water (Table 3). The globalization of water may allow for a disproportionate demographic growth in water- poor geographic areas, which would heavily depend on "flows" of virtual water from other regions of the world **[12]**.

Water Footprint:

The water footprint (WF) is defined as an indicator of water consumption that looks at both direct and indirect water use of a consumer or producer **[2]**. The water footprint represents the per capita consumption of fresh water in the manufacturing as well as service industries or producers and the consumers of their produce. The concept of 'water footprint' provides an appropriate framework of analysis to find the link between the consumption of animal products and the use of the global water resources. The water footprint is defined as the total volume of freshwater that is used to produce the goods and services consumed by an individual or community **[9]**.The water footprint of a location could be calculated in the following manner,

If, f = percentage of annual supply of fresh water of a location,

and f_i = percentage of annual supply of fresh water to the manufacturing as well as service industries or producers of the location for maintaining their service and development of the products.

And p_c = numbers of consumers for the produce of the same location,

Then, Availability of Fresh Water = (WAxf) …..(3)

Again, by using Equation.3, Fresh Water supplied to manufacturing and service industries for maintaining the development and servicing of their products can be calculated as,

= (WAxf) x f_i ……..(4)

and from Equation.4, water footprint(WF) in m3/capita/year can be calculated as,

WF = [(WA x f)+{ (M, mmWA x f) x f_i] / p_c

Or, WF = (WAx f) [{(1 + fi)}/ pc]…..(4(A))

From Equation-4(A), it can be observed that WF is inversely proportional to number of consumers. So WF can indicate the beneficial effects of industries as well as wastage of water. If water footprint of a region is less than the footprints of other regions of the catchment, then the region is said to be efficiently managing their water resource as more consumers are utilizing the industrial production and services of the region. But very low footprint of water can also imply the low supply of fresh water for direct as well as indirect use of water by the population living in the catchment. So, a very low footprint of water is also not a good indicator of optimal management of water availability.

Table 4. Vulnerability scale of water footprint in basin wise in three different scenarios for the period of 2040, 2070 and 2100

Water Footprint	Scenarios								
	A2			A1B			B2		
Year	2040	2070	2100	2040	2070	2100	2040	2070	2100
Ganga - Upstream	V	V	V	HV	SV	SV	V	V	V
Ganga Downstream	HV	HV	HV	V	V	V	HV	HV	HV
Mahanadi	N	SV	SV	SV	SV	SV	V	SV	SV
Brahmani	HV	HV	HV	V	V	V	HV	V	V
Brahmaputra	HV	HV	HV	V	V	V	HV	HV	HV
SurmaImphal	HV	HV	HV	V	V	V	HV	HV	HV

Similar to virtual water availability, A2 was the most vulnerable scenario where continuous reduction of availability of virtual water per capita per year was observed. In B2 and A1B scenario the same parameter showed an increasing trend. Although the increasing population in A2 the rate of which is greater than the other two scenarios can reduce the per capita availability due to increase in demand, the lower availability of water was identified as the main cause for showing such trend. Ganga (Downstream), Brahmaputra and SurmaImphal were found to be more vulnerable than any other basins for all the three scenarios. Although Brahmani features in the list of most vulnerable rivers of East and North East India in A2 and A1B scenarios, it is not that affected in B2 scenario. The increase in industry along with increase in population enforced the model to predict similar reduction of the parameter in A1 scenario (Table 4).

Green Water Availability:

The green water is defined as the amount of water consumed for agricultural production of a location.

Agriculture currently accounts for approximately 69% of total water use and 89% of consumptive water use in the world **[17]**.

The green water footprint refers to the rainwater consumed **[23]**. The calculation of green water could be performed by the following way,

If, g= percentage contribution of soil moisture to total available water of the catchment,

Then, green water, GW in m3/year could be expressed as,

GW = f (g xWA) ……..(6)

The amount of green water generally represents the agricultural productivity of a region. But a very large amount of green water will also indicate saturated catchments not conducive for crop production as too much consumption of water may rot the plant. So, very large amount of green water compared to other regions of the catchment is also not good for the watershed. Only, a moderate consumption of green water will indicate a healthy watershed. In recent years, there have been various attempts to assess global water consumption in agriculture at high spatial resolution **[2, 17]** made a global estimate of green and blue water consumption.

Table 5. Vulnerability scale of green water availability in basin wise in three different scenarios for the period of 2040, 2070 and 2100

Green Water Availability	Scenarios								
	A2			A1B			B2		
Year	2040	2070	2100	2040	2070	2100	2040	2070	2100
Ganga - Upstream	SV	V	V	V	SV	SV	SV	SV	SV
Ganga Downstream	V	HV	HV	HV	V	V	V	HV	V
Mahanadi	SV	SV	SV	SI	N	SV	SV	SV	SV
Brahmani	SV	HV	HV	V	V	V	V	HV	V
Brahmaputra	V	HV	HV	HV	V	V	V	HV	V
SurmaImphal	V	HV	HV	HV	HV	V	V	HV	V

A2 scenario was found to be more susceptible than the other two scenarios to the changes induced by global warming where a degrading trend was observed from 2040 to 2100 but in A1B scenario improvement of soil moisture was observed from 2040 to 2100. In the B2 scenario the trend show deterioration in 2070 from 2040 but in 2100 the water holding capacity of the soil gets improved. If the basins of East and North East India were compared, Ganga Downstream, Brahmaputra and SurmaImphal showed the most deterioration but in A1B scenario SurmaImphal was found to be most susceptible to the climate changes. Erosion of soil, rampant land use change due to industrial growth can be contributed to the reduction of vegetation and soil moisture from the Ganga Downstream. The mountain topography of the North East is conducive for less soil moisture capacity. But the pinus and cycus species of the region can hold the soil water for a long time with their large roots. The large change in green water can be contributed to the large scale loss of vegetation predicted for the A2 scenario. In the other two scenarios the reduction of rainfall can be the cause for reduction of soil moisture (Table 5).

Water Sequestration:

The water sequestration capacity (WSC) of a region is defined as the maximum amount of water possible for consumption by the plant species in a location **[24]**.

The Water Sequestration Capacity of a region could be defined as the amount of green water available per square kilometer of vegetation **[24]**. The WSC could be calculated in the following manner,

Let, percentage of soil moisture in an area of A km^2 is s,

Let, basin area of the same region be A sqkm and percentage of vegetated area of that region is av,

Then, WSC in m3/sqkm/year can be calculated as,

WSC = WAx{s/(Ax av)} ……(5)

Table 6. Vulnerability scale of Water Sequestration in basin wise in three different scenarios for the period of 2040, 2070 and 2100

Water Sequestration	Scenarios								
	A2			A1B			B2		
Year	2040	2070	2100	2040	2070	2100	2040	2070	2100
Ganga - Upstream	SV	V	V	HV	V	V	SV	V	SV
Ganga Downstream	V	HV	HV	V	HV	V	V	HV	V
Mahanadi	SV	SV	SV	SV	SV	CI	SV	SV	SV
Brahmani	V	V	V	V	V	CI	V	V	SV
Brahmaputra	V	HV	HV	HV	HV	HV	V	HV	V
SurmaImphal	V	HV	HV	V	HV	HV	V	HV	V

The amount of water available per square unit area of vegetation was found to show a continuous degradation in A2 scenario and for both A1B and B2, but 2070- 2100 showed positive changes in the latter two scenarios which were conducive to increase in water productivity. Ganga Downstream, Brahmaputra and SurmaImphal was found to be more sensitive to climate changes than any other basins of East and North East India in A2 and B2 scenario although the severity of change is more in A2 than in B2. In A1B scenario, however, Brahmaputra becomes the most vulnerable to climate change where the severity was similar to A2 scenario.

Water sequestration as discussed earlier is actually availability of soil moisture per square unit area of vegetation. The reduction in area of vegetation as predicted in A2 scenario can be the reason for the scenario becoming the most susceptible one to climate change. The IPCC Second Assessment Report noted that data and analyses of extremes related to climate change were sparse **[21]**. The reason for loss of water due to reduced rainfall predicted for the eastern and north east India by the PRECIS model can be attributed to the reduction of water sequestration in B2 scenario. As rainfall change is moderate for the A1B scenario, increase of sequestration is predicted by the model in the said scenario (Table 6).

IV. CONCLUSION:

River runoff is a function of precipitation, landuse, soil type and topography etc. Again water availability largely depends on river runoff. Larger runoff will imply lesser availability of water in the catchment. In eastern India the problem of runoff largely causes the increase in soil erosion. Forest or vegetation can detain the runoff, absence of which may allow water to drain out of the basin with significantly small recharge. In north eastern India high slope causes runoff to increase but dense forest cover helps the catchment to hold the surface runoff.

But in the future as considered in A2 scenario, the vegetation will slowly but rampantly vanish due to growth in industry and shortage of land to accommodate this growth. A disintegrated regionalized world was considered in the said scenario without any restrictions of emission law. So it can be estimated that destruction of vegetation and change in vegetation will be rampant and increase the deterioration of soil structure and water holding capacity of the basin.

In B2 scenario, a world with strict implementation of emission law was considered but with no cooperation or interconnectivity between the countries. The simulation estimated from such scenarios will predict little less increase of runoff than the A2 scenario.
Gini co-efficient is having direct relationship with river runoff as well as vulnerability. Thus Gini co-efficient is also observed to be maximum for A2 & B2 scenario, A2 scenario, A1B scenario in 2040, 2070 and 2100 respectively. But, water availability shows the just reverse relationship with Gini co-efficient as the population plays a crucial role in determining both the water availability and Gini co-efficient and water availability is inversely related with population. Lorenz curve is the cumulative proportion of water used by the cumulative proportion of global population **[30]**.

Gini co-efficient is calculated by, G= $1 - 2\int_0^1 L(x)dx$

Since water footprint is inversely related to number of consumer, indicating the beneficial effects of industries shows the probability of Gini co-efficient to be high.

In A1B, however an integrated world with moderate restrictions on emission and medium growth in industry was predicted. The runoff in such conditions will represent catchment response due to normal climate. Using the climate change experiments generated for the Fourth Assessment of the Intergovernmental Panel on Climate Change, some aspects of the changes in the hydrological cycle that are robust across the models was studied **[20]**.

V. ACKNOWLEDGEMENT:

There are number of organizations who we would like to thank to NATCOM-II Project: MoEF/GoI/UNDP-GEF/ Winrock International India for generating data in different scenarios to the Indian Institute of Tropical Meteorology, Pune using Met Office Hadley Center regional climate model PRECIS.

COMPETING INTEREST:

Authors have declared that no competing interests exist.

AUTHORS' CONTRIBUTION:

This work was carried out in collaboration between all authors. PKR designed the study, performed the MODEL analysis and wrote the first draft of the manuscript. AM managed the analyses of the study, corrected the draft manuscript and formed the final manuscript and managed the literature searches. All authors read and approved the final manuscript.

REFERENCE:

[1] Agrawal, A. (1998). Coping with dry spells and drought years – India's traditions in water harvesting, Stockhlom Water Front, No.1-2, May 1998. Stockholm, Sweden.
[2] Aldaya, M., Martínez-Santos, P., Llamas, M. (2009). Incorporating the water footprint and virtual water into policy: Reflections from the mancha occidental region, Water Resources Management, Spain.
[3] Allan, J.A. (1998). Virtual water: A strategic resource. Global solutions to regional deficit. Groundwater 36 (4), 545-546
[4] Barnaby W. (2009). Do Nations go to war over water? Nature, 458: 282-283
[5] Bernstein, L., Roy, J., Delhotal, K.C., Harnisch, J., Matsuhashi, R., Price, L., Tanaka, K., Worrell, E., Yamba, F., Fengqi, Z. (2007). Industry. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel, on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
[6] Burke, E.J., Brown, S.J., Christidis, N. (2006). Modelling the recent evolution of global drought and projections for the 21st century with the Hadley Centre climate model, Journal of Hydrometeorology, 7 , 1113-1125.

[7] Central Water Commission (CWC). (1998). Water Statistics of India, Delhi, India: Central Water Commission.

[8] Chapagain, A.K., Hoekstr, A.Y. (2004). The water footprints of Morocco and the Netherlands', Value of Water Research Series No. 21, UNESCO-IHE, New York.

[9] Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G., Gautam, R. (2006). The water footprint of cotton consumption: An assessment of the impact of the worldwide consumption of cotton products on the water resources in the cotton producing countries. Ecological Economics 60 (1), 186-203.

[10] Crosbie, R. (2007). The Hydrological Impacts of Climate Change on Groundwater, Water for a Healthy Country, National Research Flagship, CSIRO, Australia.

[11] Dai, A., Fung, I.Y., Delgenio, A.D. (1997). Surface observed global land precipitation variation during 1900-88. Journal of Climate, 10, 2943-2962.

[12] D'Odorico, P., Laio, F., Ridolfi, L. (2010). Does globalization of water reduce societal resilience to drought?, Geophys. Res. Lett. 37, L13403, doi: 10.1029/2010GL043167, 2-5.

[13] Easterling, D.R., Meehl, G. A., Parmesan, C., Changnon, S.A., Karl, T.R., Mearns, L.O. (2000). Climate extremes: observations, modelling, and impacts. Science 289 (5487), 2068-2074.

[14] Falkenmark, M.J., Rockstrom, J., Savenjie, H. (2004). Balancing Water for Humans and Nature, (Earthscan, London, UK).

[15] Fischer, G., Shah, M., Velthuizen, H.V. (2002). Climate Change and Agricultural Vulnerability, International Institute for Applied Systems Analysis, United Nations.

[16] Gini, C. (1921). Measurement of inequality of incomes, Economic journal 31, 124-126.

[17] Gleick, P. (1993). Water Crisis: A Guide to the World's freshwater Resources(Oxford University Press), New York, USA.

[18] Government of India (GOI). (1999). Report of the National Planning Commission Integrated Water Resources Development, India: Government of India.

[19] HEC-HMS, Version 2.2.2. (2000). Hydrologic Simulation Package, Technical Reference Manual, US Army Corps of Engineers, Hydrologic Engineering Centre

[20] Held, I.M., Soden, B.J. (2006). Robust responses of the hydrological cycle to global warming, Journal of Climate, 19, 5686-5699.

[21] Hoekstra,A.,Chapagain, A. (2008). Globalization of water (Wiley-Blackwell). Intergovernmental Panel on Climate Change (IPCC) (2007), Summary for policymakers. In S. Solomon et al. (Eds.): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC, Cambridge Univ. Press, New York.

[22] International Water management Institute (IWMI). (2000). World Water Supply and Demand 1995 to 2025, Draft Report prepared for World water Vision. Colombo, Sri Lanka: International Water Management Institute.

[23] Konar, M., Dalin, C., Suweis, S., Hanasaki, N., Rinaldo, A., Rodriguez-Iturbe, I. (2011), Water for food: The global virtual water trade network, Water Resour. Res., 47, W05520, doi:10.1029/2010WR010307.

[24] Majumder, M. (2010). Watershed Modeling of River Damodar with the Help of Neural Network and Genetic Algorithm, PhD Thesis, School of Water Resources Engineering, Jadavpur University, Kolkata, India

[25] Nakicenovic, N., Swart, R. (2007). Population Projections. Special Report on Emissions Scenarios. http://www.grida.no/publications/other/ipcc_sr/?src=/Climate/ipcc/emission/014.htm (accessed 30 August 2009).

[26] Roy, P.K., Mazumdar, A. (2005). Hydrologic Impacts of Climatic Variability on Water Resources of Damodar River Basin in India, International Association of Hydrological Science (IAHS) Red Book, UK-295, 147-156.

[27] Roy, P.K., Roy, D., Mazumdar, A. (2004). An Impact assessment of Climate Change and Water Resources Availability of Damodar River Basin, Hydrology Journal, 27(3-4), 53-70

[28] Rupa Kumar, K., Krishna Kumar, K., Prasanna, V., Kamala, K., Deshpande, N.R., Patwardhan, S.K., Pant, G.B. (2003). Future climate scenarios. In Climate Change and India: Vulnerability Assessment and Adaptation (eds Shukla, P. R., Subodh K. Sharma, Ravindranath, N. H., Amit Garg and Sumana Bhattacharya),Universities Press, Hyderabad, 2003, 69–127.

[29] Seckler, D., Upali, A., Molden, D., Silva, R.D., Barker, R. (1998). World Water Supply and Demand, 1995-2025: IWMI Research Report 19, Colombo, Sri Lanka: International Water management Institute.

[30] Seekell, D.A., D'Odorico, P., Pace, M.L. (2011). Virtual water transfers unlikely to redress inequality in global water use, Environm. Res. Lett. 6, (2011), doi: 10.1088/1748-9326/6/2/024017

[31] Subramanya, K. (1994). Engineering Hydrology, Tata McGraw Hill Publishing Company Limited, New Delhi 2, 60-90.

[32] SWRE. (2010). Water Resources-National and Regional Impacts of Climate Change (eastern and north eastern region)-Project enabling

activities for preparation of India's Second National Communication to the UNFCCC bearing contract number IND0264.05-25/2007-08/WII-675 submitted to NATCOM Project Management Cell, MoEF/UNDP/GEF/WII by Jadavpur University, Kolkata, India.

[33] Watson, R.T., Nobal, I.R., Bolin, B.N., Ravindranath, N.H., Verardo, D.J., David, J.D. (2000). Land Use, Land Use Change and Forestry (ed.), IPCC, Cambridge University Press, UK, 375.

[34] Zhang, X., Zwiers, F.W., Hegerl, G.C., Lambert, F.H., Gillett, N.P., Solomon, S., Stott, P.A., Nozawa, N.P. (2007). Detection of human influence on 20th-century precipitation trends, Nature, 448, 461-466

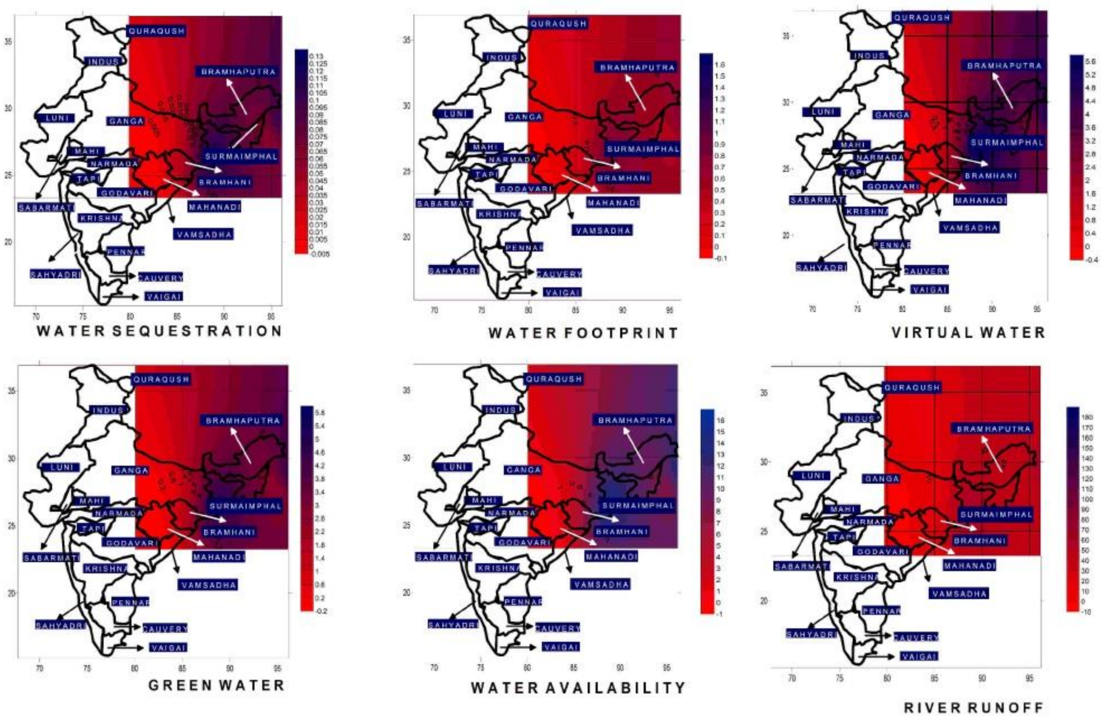

Fig.1. Different Indicators of Eastern and North Eastern River