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IMPACT ASSESSMENT OF CLIMATE CHANGE ON WATER RESOURCES OF TWO RIVER SYSTEMS OF INDIA

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ABSTRACT *An exhaustive study was conducted as part of the National Communication (NATCOM) project undertaken by the Ministry of Environment and Forests, Government of India, to quantify the impact of climate change on the water resources of India using a hydrological model. The study uses the HadRM2 daily weather data to determine the control or present and GHG (Greenhouse Gas) or future water availability in space and time. A distributed hydrological model namely Soil and Water Assessment Tool (SWAT) has been used on major river basins of the country. The framework predicts the impact of climate change on the hydrological regime with the assumption that the land use shall not change over time and any manmade changes are not incorporated. Simulation of 12 major river major basins of the country has been conducted with 20 years of data belonging to control (present) and the remaining 20 years of data corresponding to GHG (future) climate scenario. Quantification of climate change impact has been done through the use of SWAT hydrological model. This paper presents analyses of two sample river basins namely, Godavari and Tapi. It has been observed that the impacts of climate change are not uniform and are varying across the river basins. The initial analysis has revealed that the GHG scenario may deteriorate the conditions in terms of severity of droughts and intensity of floods in various systems.*

Key words Climate change; simulation; river basin; SWAT; impact assessment.

INTRODUCTION

The general impacts of climate change on water resources have been brought out by the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001). It indicates an intensification of the global hydrological cycle and affecting both ground and surface water supply for domestic and industrial uses, irrigation, hydropower generation, navigation, in-stream ecosystems and water-based recreation. Changes in the total amount of precipitation as well as in its frequency and intensity have been predicted which shall in turn affect the magnitude and timing of runoff and soil moisture status. The impacts of climate change are also predicted to be dependent on the baseline condition of the water supply system and the ability of water resource managers to respond not only to climate change but also to population growth and changes in demands, technology, as well as economic, social and legislative conditions. The coping capacity of the societies shall vary with respect to their preparedness. Countries with integrated water-management systems may protect water users from climate change at minimal cost, whereas others may have to bear substantial economic, social and environmental costs to do the same.

Thus, 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 also comes under this category. The National Communication (NATCOM) project study (Gosain et al., 2003) was the first attempt to quantify the impact of the climate change on the water resources of the country. This paper presents detailed results of the study on two sample river basins of the country predicted to be affected with respect to drought and flood severities on account of climate change.

METHODOLOGY

The SWAT (Soil and Water Assessment Tool) water balance model has been used to carry out the hydrologic modeling of the river basins of the country. The SWAT model (Arnold et al., 1990), developed by the Agricultural Research Service, Blackland, Texas, USA, simulates the hydrologic cycle in daily time steps. The model has the capability of being used for watersheds as well as the major river basin systems. It is a distributed, continuous, daily time interval hydrological model with an ArcView GIS interface (AVSWAT) for pre- and post-processing of the input and output data.

The study determines the present water availability in space and time without incorporating any man made changes like dams, diversions, etc. The same framework is then used to predict the impact of climate change on the availability of water resources (future) by using the predicted data of a Regional Climate Model (RCM) with the assumption that the land use shall not change over time.

DATA USED FOR STUDY

The SWAT model requires the data on terrain, landuse, soil and weather for assessment of water resources availability at desired locations of the drainage basin. These data at 1:250,000 scale for the river basins have been used in the model. The following sections provide the description of data elements used and preprocessing of data, wherever required.

Digital Elevation Model (DEM)

DEM represents a topographic surface in terms of a set of elevation values measured at a finite number of points. DEM for the study areas have been generated using contours taken from 1:250,000 scale ADC world topographic map.

Stream Network Layer

There is an option in the model to use the actual stream network in the absence of large scale contour/DEM data, which has been used in the present study. This option helps in conforming to the shapes of the sub basins in the absence of large scale data availability by guiding the generated stream networks. Appropriate threshold values have been used for generating the stream networks for various river basins which primarily decide the density of the stream network and consequently the number of sub basins in each of the river basins.

Delineation of the River Basins

Automatic delineation of each of the river basins is done by using the DEM as input and the final outflow point on the river basin as the final pour/drainage point (Gosain et al., 2006). Figure 1 depicts the modeled river basins (automatically delineated using GIS). The river basins have been further divided into sub-basins depending on the selection of the threshold value.

Weather Data

The data generated in transient experiments HadRM2 by the Hadley Centre for Climate Prediction, UK, at a resolution of 0.44° x 0.44° latitude by longitude RCM grid points as shown in Fig. 1 has been obtained from Indian Institute of Tropical Meteorology (IITM), Pune, India. The daily weather data on temperature (maximum and minimum), rainfall, solar radiation, wind speed and relative humidity at all the grid locations were processed. The RCM grid has been superimposed on the sub-basins for deriving the weighted means of the inputs for each of the sub basins. The centroid of each sub basin is then taken as the location for the weather station to be used in the SWAT model. The procedure has been used for processing the control/ present (representing series 1981-2000) and the GHG (Green House Gas)/ future (representing series 2041-2060) climate data.

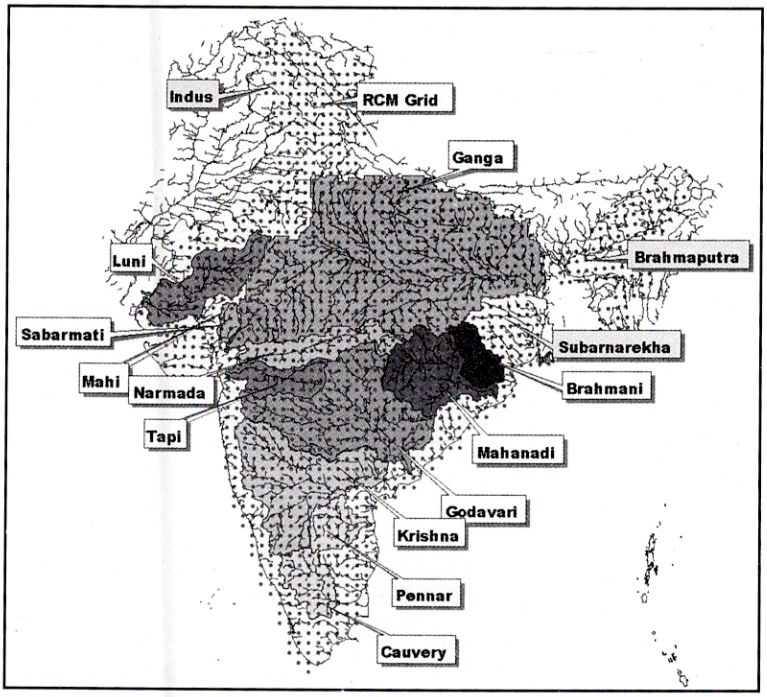

Fig. 1 The modeled river basins along with the RCM grid locations.

Land Cover/Land Use Layer

Classified land cover data produced using remote sensing by the University of Maryland Global Landcover Facility (13 categories) with resolution of 1 km grid cell size has been used (Hansen et al., 1999).

Soil Layer

Soil map adopted from FAO Digital Soil Map of the World and Derived Soil Properties with a resolution of 1:5,000,000 has been used (FAO, 1995).

HYDROLOGIC MODELING OF THE RIVER BASINS

The AVSWAT distributed hydrologic model has been used. The basins have been sub-divided using the threshold values adapted to divide the basin into a reasonable number of sub-basins so as to account for the spatial variability. After mapping the basins for terrain, land use and soil, each of the basins has been simulated imposing the weather conditions predicted for control and GHG climate.

Control Climate Scenario

Each of the river basins has been simulated using the SWAT model firstly by using generated daily weather data by the HadRM2 control climate scenario (1981-2000). Although the SWAT model does not require elaborate calibration, yet, in the present case, any calibration was not meaningful since the simulated weather data is being used for the control period which is not the historical data corresponding to the recorded runoff. The SWAT model has been used on various Indian catchments of varied sizes and it has been observed that the model performs very well without much calibration (Gosain et al., 2004). Presently, the model has been used with the assumption that every river basin is a virgin area without any manmade change incorporated, which was reasonable for making the initial national communication to the United Nations Framework Convention on Climate Change - UNFCCC (the basic objective of this study).

The model generates detailed outputs on flow at sub-basin outflow points, actual evapotranspiration and soil moisture status at daily interval. Further sub-divisions of the total flow into components such as surface and subsurface runoff, recharge to the ground water can be made on daily basis.

GHG Climate Scenario

The model has then been run on each of the basins using GHG climate scenarios (for the years 2041–2060) data but without changing the land use. The outputs of these two scenarios have been made available at the basin level for all the basins modeled (Gosain et al., 2006). Detailed analyses have been performed on two of the river systems, namely Godavari and Tapi to demonstrate the impacts at the sub-basin level.

Summary Results of River Basins Modeled

Figure 2 shows the plot of the percent change in water balance components from the Control to GHG climate scenarios for the 12 river basins. It can be observed that the impacts are different in different catchments. A close examination of the figure reveals that the increase in rainfall due to climate change is not resulting always in an increase in the surface runoff as may be generally predicted. For example, in the case of Cauvery river basin an increase of 2.7% of rainfall has been observed but the runoff has in fact reduced by about 2% and the actual evapotranspiration has increased by about 7.5%. On the contrary, a reduction in rainfall in Narmada has resulted in increase in the runoff, which is again contrary to the usual expectation. It is important to note that these inferences have become possible because of the fact that daily computational time step has been used in the distributed hydrological modeling framework that has been able to simulate the natural processes in a realistic manner so as to represent the complex spatial and temporal variability inherent in the natural systems. Due to paucity of space, Fig. 2 presents only three major components (that too aggregated over time and space) of the water balance.

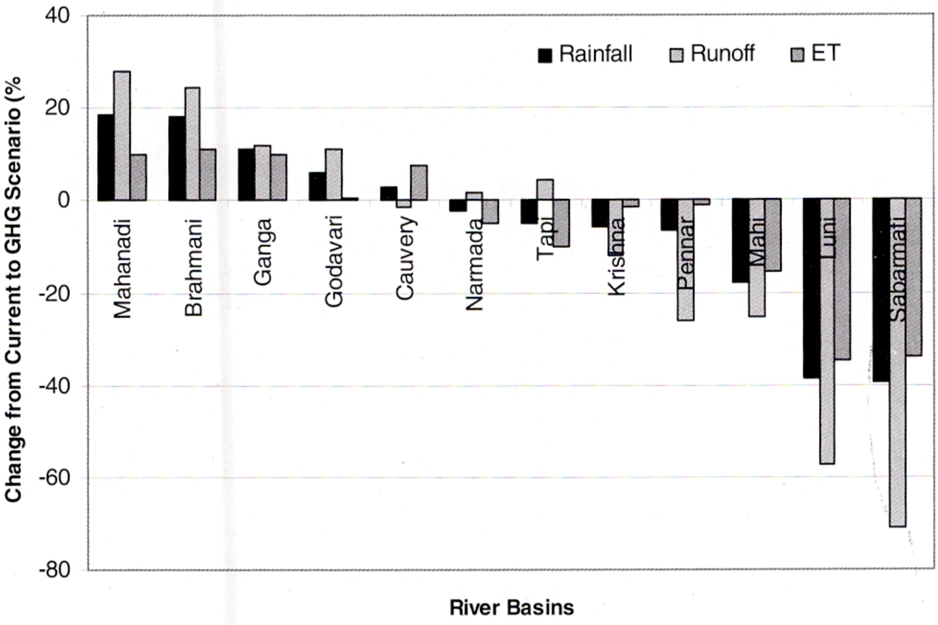

Fig. 2 Percent change in mean annual water balance for control and GHG climate scenarios.

Detailed Results of Two River Basins

Results for two of the river basins, one with resulting drought conditions i.e., the Tapi basin and the other one with pronounced flood conditions i.e., the Godavari basin, are discussed below in detail.

TAPI RIVER BASIN

Tapi river basin has been sub-divided into 21 sub-basins as depicted in Fig. 3. The water yield has been simulated by the SWAT model over the Tapi basin for control and GHG scenarios as given in Table 1.

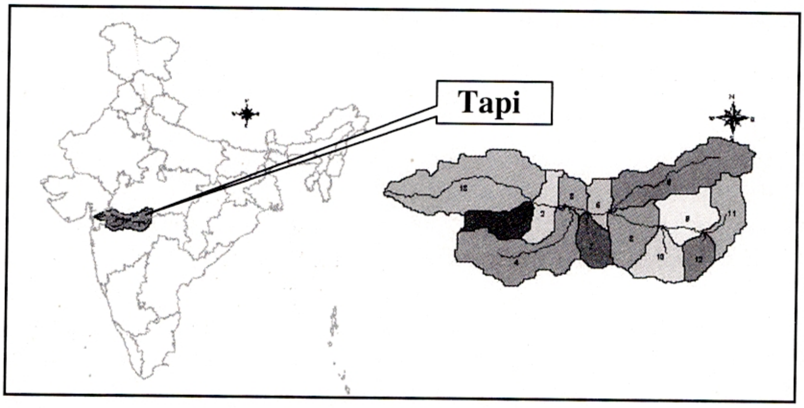

Fig. 3 Tapi river basin and its sub-basins.

The variation in mean annual water balance components from current to GHG scenario show that there has been reduction in the annual precipitation, yet there is a marginal increase in the annual water yield as revealed in Table 1. However, there is a decrease in actual evapotranspiration.

Table 1 Annual water balance components (mm) for Tapi basin.

Control Scenario				GHG Scenario			
Year	Precipitation	ET	Water Yield	Year	Precipitation	ET	Water Yield
1981	1120.92	464.81	532.56	2041	874.63	469.56	286.63
1982	1120.92	579.35	381.85	2042	526.01	480.57	73.61
1983	544.43	481.92	95.96	2043	789.29	592.50	169.97
1984	992.07	539.25	376.67	2044	1334.47	639.37	634.00
1985	941.83	529.78	387.80	2045	1113.01	625.55	451.90
1986	801.61	516.32	246.63	2046	1067.17	533.39	496.96
1987	840.96	589.66	232.94	2047	718.20	438.62	267.77
1988	830.13	588.92	228.49	2048	916.36	540.46	336.40
1989	1088.32	544.22	507.15	2049	770.53	474.06	283.04
1990	834.49	565.17	225.68	2050	922.27	539.42	361.82
1991	1060.59	571.63	464.91	2051	683.90	480.00	182.47
1992	1029.38	747.77	267.99	2052	883.31	497.11	350.37
1993	1056.78	785.50	207.39	2053	907.61	532.78	345.15
1994	883.72	635.80	263.64	2054	1193.42	573.99	578.05
1995	712.46	574.69	149.21	2055	955.27	546.74	389.62
1996	759.00	495.34	229.64	2056	689.99	579.20	153.41
1997	1073.12	652.56	380.37	2057	750.58	471.29	206.40
1998	1019.29	674.57	310.57	2058	765.31	515.63	232.87
1999	924.75	540.38	364.72	2059	687.08	515.59	148.66
2000	1066.54	679.91	370.10	2060	1135.63	539.51	549.25
Average	928.6	587.88	311.21		884.2	529.27	324.92

The monthly average precipitation, actual evapotranspirarion and water yield as simulated by the model over the total Tapi basin for control and GHG scenarios has been depicted in Fig. 4.

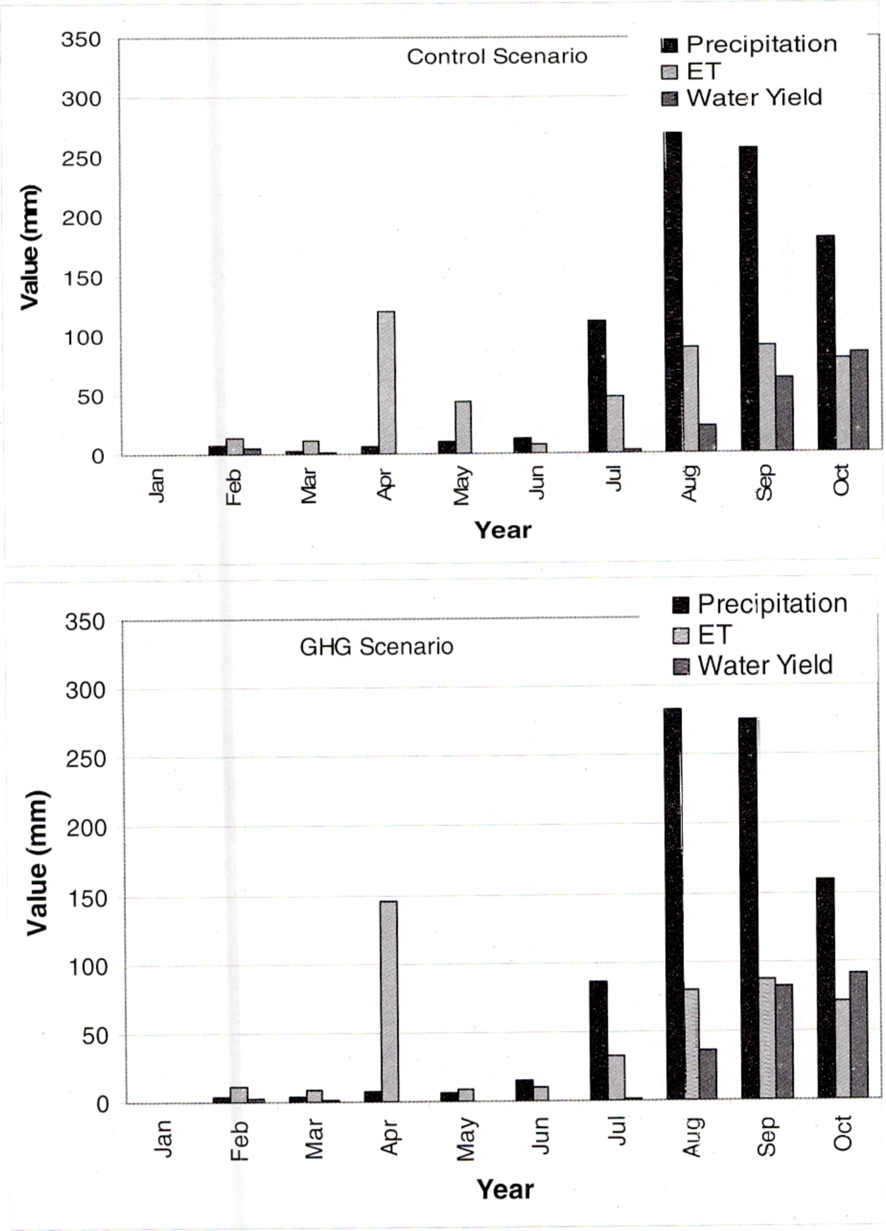

Fig. 4 Mean monthly water balance components for control and GHG scenarios for Tapi.

Figure 5 shows the variation in mean monthly water balance components from control to GHG scenario, both in terms of change in individual values of these components as well as percentage of change over control.

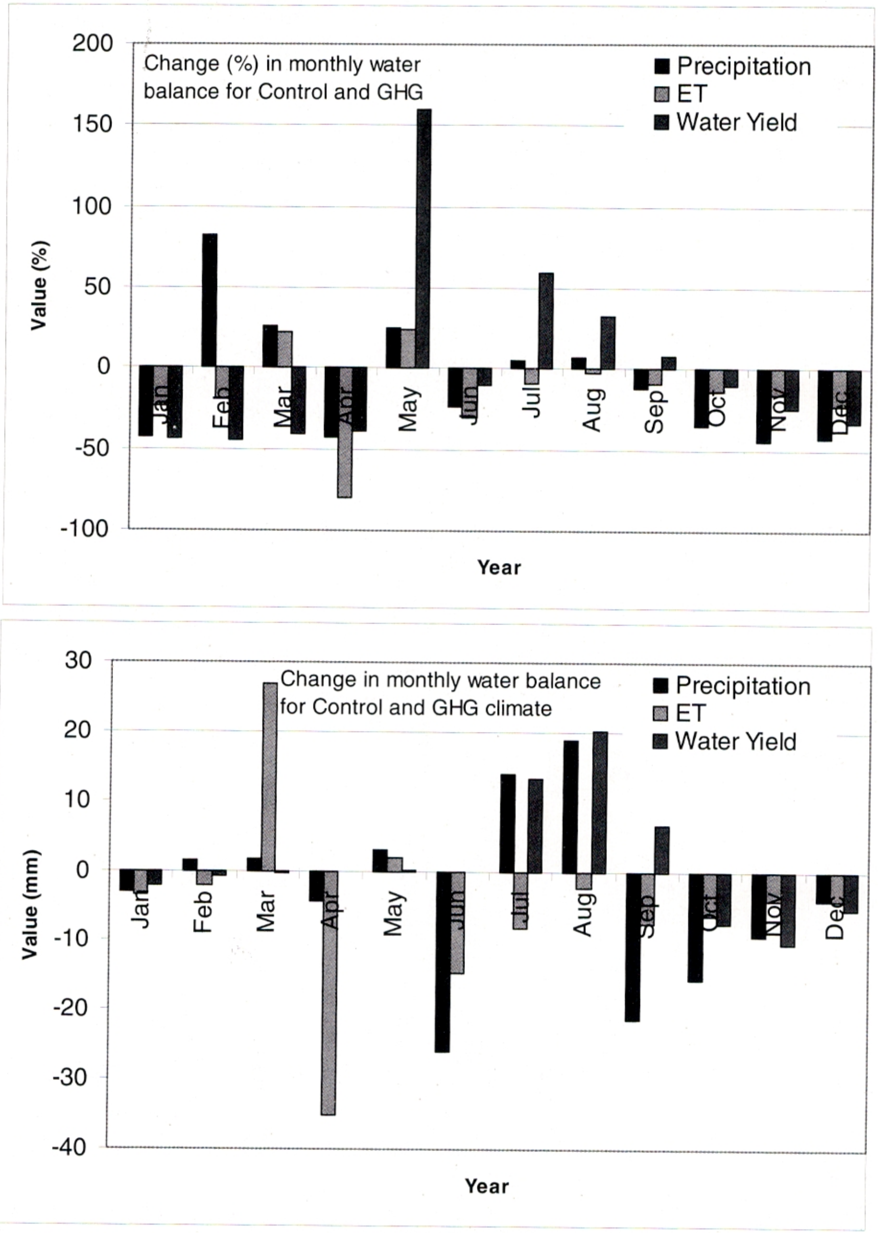

Fig. 5 Difference in mean monthly water balance components from control to GHG for Tapi

It may be observed that increase in precipitation has been predicted in almost half the months of the year, while in the remaining months decrease in precipitation has been predicted (Fig. 5). The magnitude of this increase/ decrease in precipitation over Tapi has been variable over various months. The monsoon months exhibit maximum variation in terms of absolute quantities whereas the corresponding increase/decrease in percentage has been pronounced for the non-monsoon months (Fig. 5). There has been appreciable increase in water yield for the months of July to

September. There has been reduction in evapotranspiration predicted in almost all the months but for the months of March and May.

On the annual basis it may be observed (Table 1) that there has been reduction in the annual precipitation, yet there is a marginal increase in the annual water yield. However this might be attributed to a decrease in actual evapotranspiration.

Tapi Sub-basin Analysis

Analysis has also been performed to evaluate the impact of climate change across the 13 sub-basins of Tapi river basin (Fig. 3). Figure 6 presents the annual average precipitation, actual evapotranspiration and water yield as simulated by the model over the sub-basins of the Tapi basin for control and GHG scenarios.

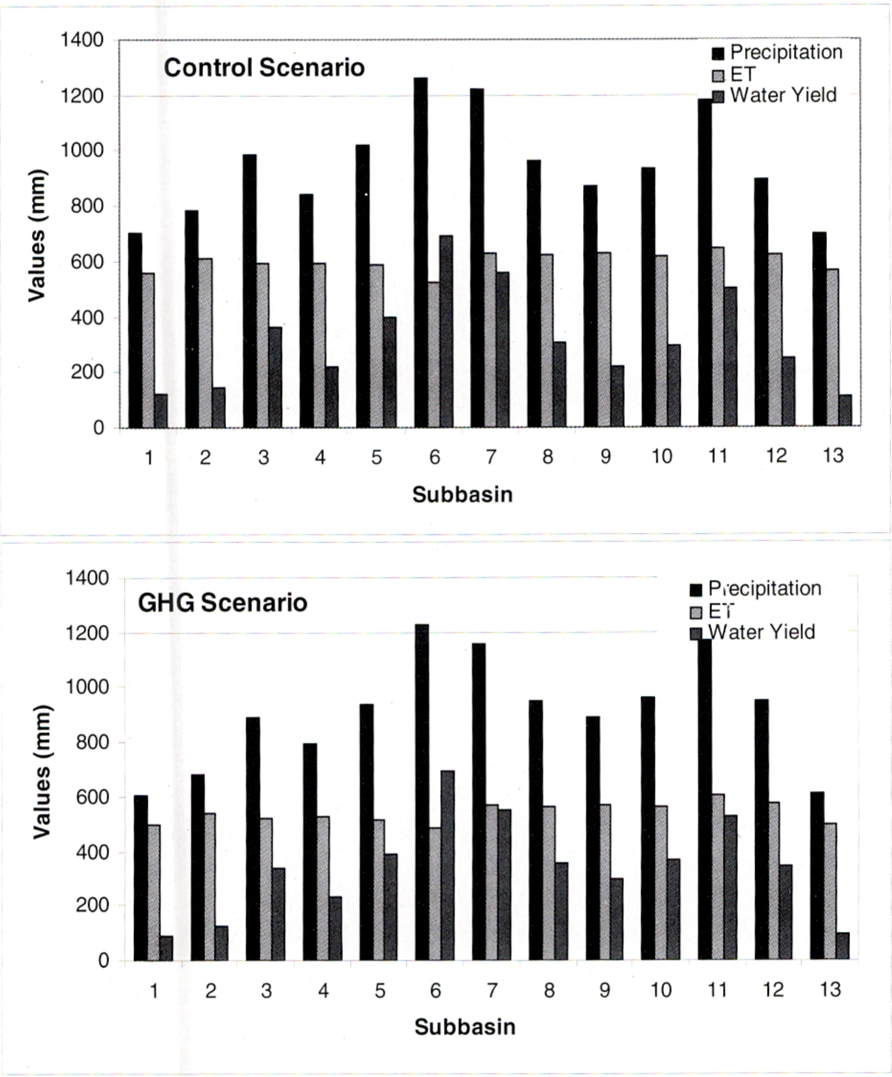

Fig. 6 Sub-basin water balance components for control and GHG for Tapi.

Variation in mean annual water balance components from control to GHG scenario, both in terms of change in individual values of these components as well as percentage of change over control is shown Fig. 7.

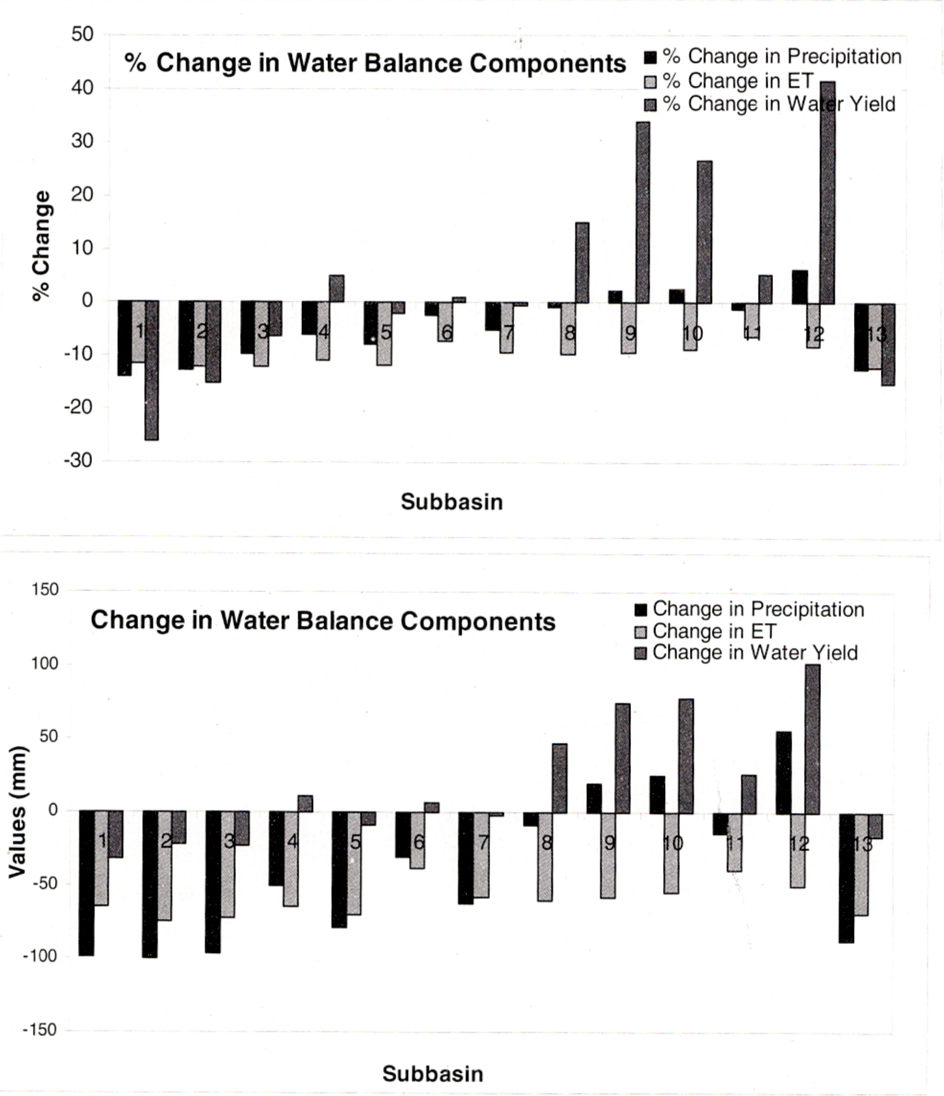

Fig. 7 Sub-basinwise mean annual difference in water balance components from control to GHG for Tapi.

It may be observed that the trend over various sub-basins of Tapi is different in terms of the identified components of the water balance. There are three sub-basins that show increase in precipitation while there are seven sub-basins out of thirteen that show increase in water yield in a range of a fraction to about 40%. The evapotranspiration has reduced across the sub-basins of Tapi in the range of 7 to 12% (Fig. 7).

Drought Analysis of Tapi Basin

Drought indices are widely used for the assessment of drought severity by indicating relative dryness or wetness effecting water sensitive economies. The Palmer Drought Severity Index (PDSI) is one such widely used index that incorporates information on rainfall, land-use, and soil properties in a lumped manner (Palmer 1965). The Palmer index categorize drought into different classes. PDSI value below 0.0 indicates the beginning of drought situation and a value below -3.0 as severe drought condition.

Recently, a soil moisture index has been developed (Narasimhan and Srinivasan, 2002) to monitor drought severity using SWAT output. This formulation has been employed in the present study to focus on the agricultural drought where severity implies cumulative water deficiency. With this in mind, weekly information has been derived using daily SWAT outputs which in turn have been used for subsequent analysis of drought severity. The soil moisture index has been computed for all the sub-basins of river Tapi.

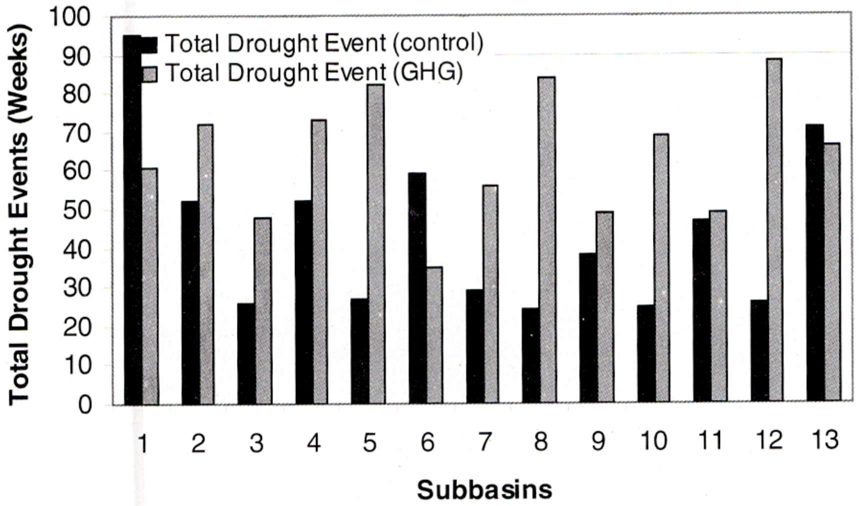

Fig. 8 Number of drought weeks in sub-basins of Tapi for current to GHG scenarios.

Figure 8 depicts the number of drought weeks in the sub-basins of Tapi consisting of the weeks with SMI of less than or equal to -3.0, for both current and GHG scenarios. The SMI for GHG scenario has been computed using the soil moisture deficit ratio parameters of current scenario. It may be observed from Fig. 8 that the numbers of drought weeks have considerably increased during GHG scenario barring about three sub-basins.

Water Yield Analysis for Tapi

Lastly, the impact of the climate change on the dependability of the water yield of the river system has been analyzed with respect to four arbitrarily selected levels of 25, 50, 75 and 90%. Figure 9 depicts the flow duration curves for the Control and GHG scenario. Table 2 shows the values corresponding to the levels of 25, 50, 75 and 90%. It may be noticed that the flow for all the dependable levels has decreased for the GHG scenario over the corresponding control flow magnitude but there has been appreciable decrease in the medium flows.

Table 2 Dependable flow at 25, 50, 75, 90% level for control and GHG scenario for Tapi.

Dependable flow (cumecs)	25%	50%	75%	90%
Control	1075	106.7	0.2778	0.0523
GHG Scenario	994.9	39.85	0.1194	0.0414

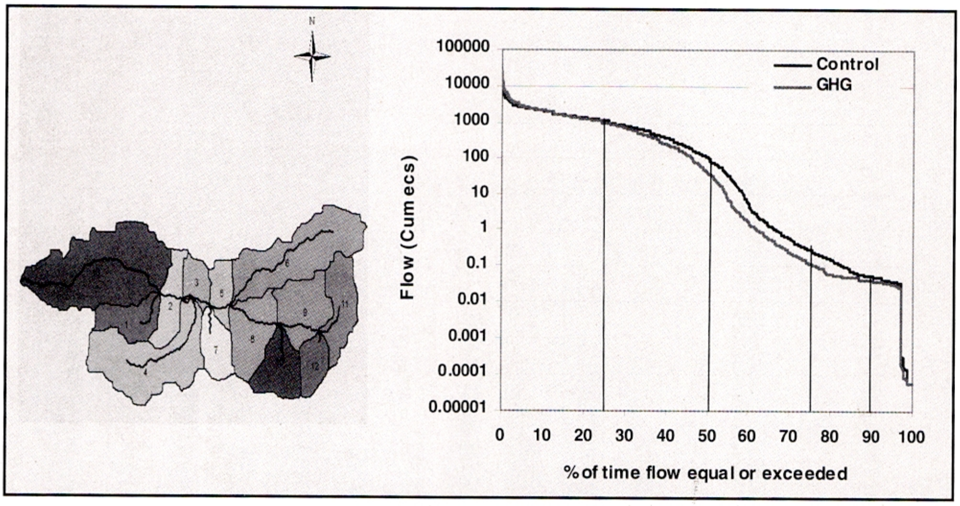

Fig. 9 Tapi and flow duration curve at outlet.

GODAVARI RIVER BASIN

The Godavari river basin has been divided into 27 sub-basins as shown in Fig. 10. An area of 3,00,033 km^2 covering Godavari basin has been modeled. The annual average precipitation, actual evapotranspirarion and water yield as simulated by the model over the total Godavari basin for control and GHG scenarios has been depicted in Fig. 11. The corresponding values of the same have also been presented in Table 3. The year numbers used here are only representative and should not be taken as actual. A close examination reveals that this river basin is expected to receive marginally (about 5%) higher level of precipitation in GHG Scenario. This increase in precipitation is predicted to result in an increase water yield by about 10% but the evapotranspiration has not changed much (Table 3).

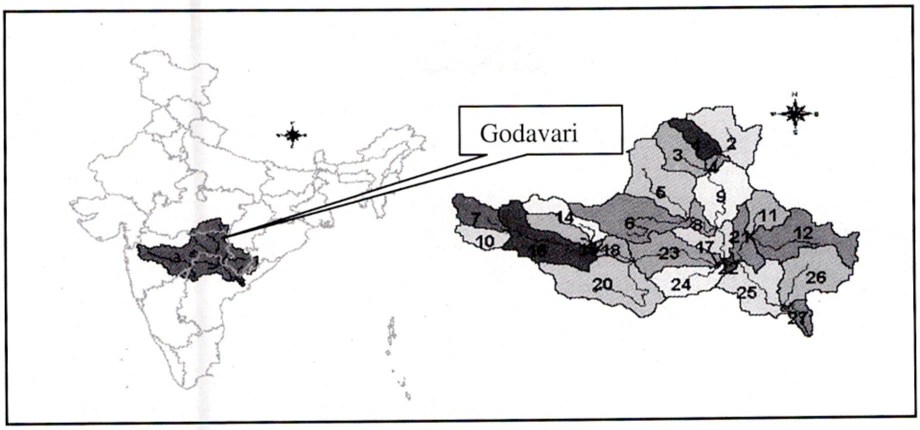

Fig. 10 Godavari river basin and its sub-basins.

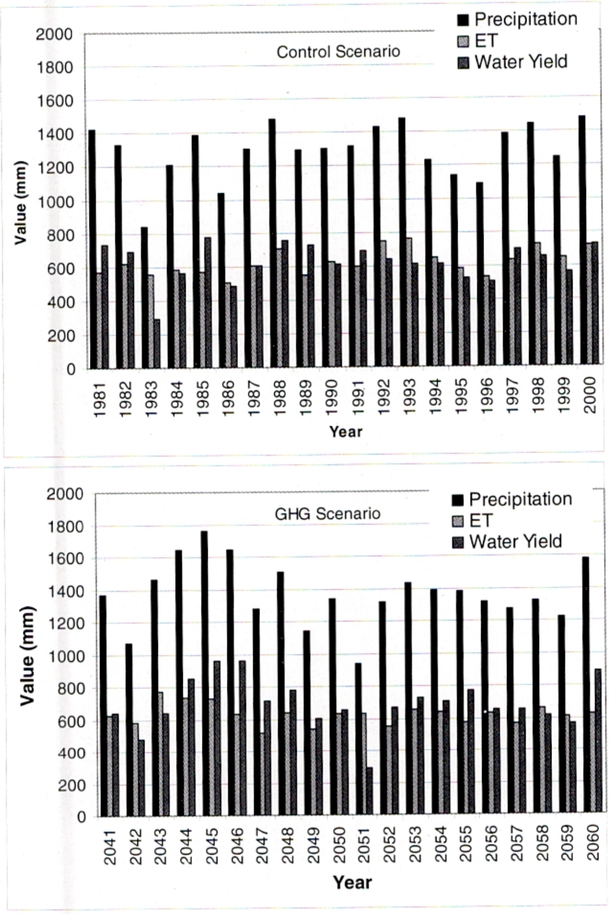

Fig. 11 Annual water balance components for control and GHG scenarios.

Table 3 Annual water balance components (mm) for Godavari basin.

Control Scenario				GHG Scenario			
Year	Precipitation	ET	Water Yield	Year	Precipitation	ET	Water Yield
1981	1426.50	570.48	735.92	2041	1368.68	628.67	637.16
1982	1332.74	619.85	689.96	2042	1068.52	580.56	481.35
1983	842.94	554.86	290.98	2043	1460.83	772.69	637.35
1984	1211.36	585.24	560.75	2044	1643.28	735.72	853.43
1985	1388.36	569.90	776.36	2045	1757.42	729.40	963.32
1986	1038.19	507.16	487.54	2046	1645.80	632.89	957.13
1987	1303.69	607.36	604.34	2047	1279.37	513.58	710.95
1988	1478.57	705.04	752.38	2048	1508.26	643.60	780.29
1989	1297.52	549.01	724.27	2049	1140.96	540.34	607.20
1990	1301.38	623.87	612.62	2050	1334.79	634.86	652.35
1991	1315.87	601.14	687.14	2051	934.74	632.72	289.57
1992	1430.83	750.85	643.42	2052	1318.14	554.07	667.42
1993	1478.41	758.28	608.89	2053	1429.15	656.73	729.79
1994	1231.01	644.15	608.78	2054	1388.82	640.40	706.11
1995	1136.41	585.91	525.39	2055	1380.37	575.78	769.17
1996	1090.73	533.44	501.95	2056	1318.93	629.11	657.19
1997	1385.05	630.08	698.71	2057	1274.61	567.42	657.05
1998	1445.94	723.44	658.32	2058	1320.49	659.57	617.54
1999	1243.53	645.99	564.56	2059	1221.96	613.27	567.46
2000	1477.47	716.86	724.10	2060	1577.22	623.88	887.15
Average	1292.83	624.15	622.82		1368.62	628.26	691.45

The monthly average precipitation, actual evapotranspiration and water yield as simulated by the model over the total Godavari basin for control and GHG scenarios has been depicted in Fig. 12. Variation in mean monthly water balance components from control to GHG scenario, both in terms of change in individual values of these components as well as percentage of change over control is shown in Fig. 13. It may be observed that increase in precipitation has been predicted in about half the months of the year. The increase in precipitation has been more during the monsoon period but for the month of June. The consequent increase in water yield has also been predicted over these months (Fig. 13).

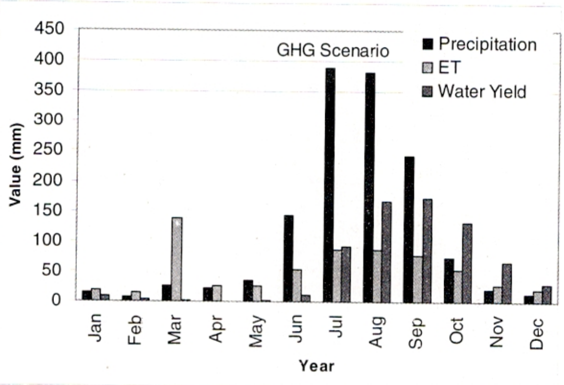

Fig. 12 (a) Mean monthly water balance components for GHG scenario.

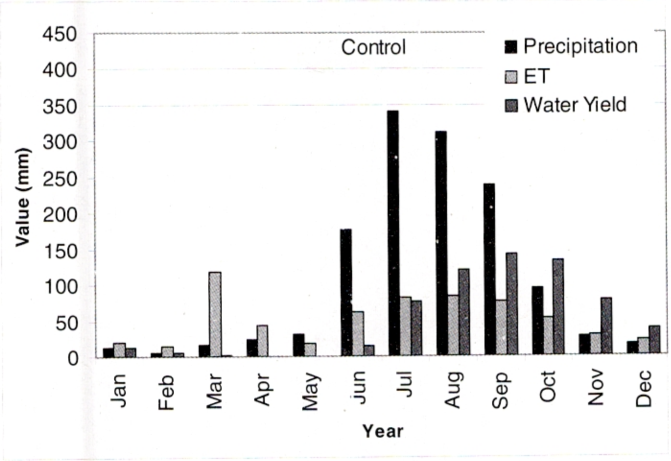

Fig. 12 (b) Mean monthly water balance components for control GHG scenario.

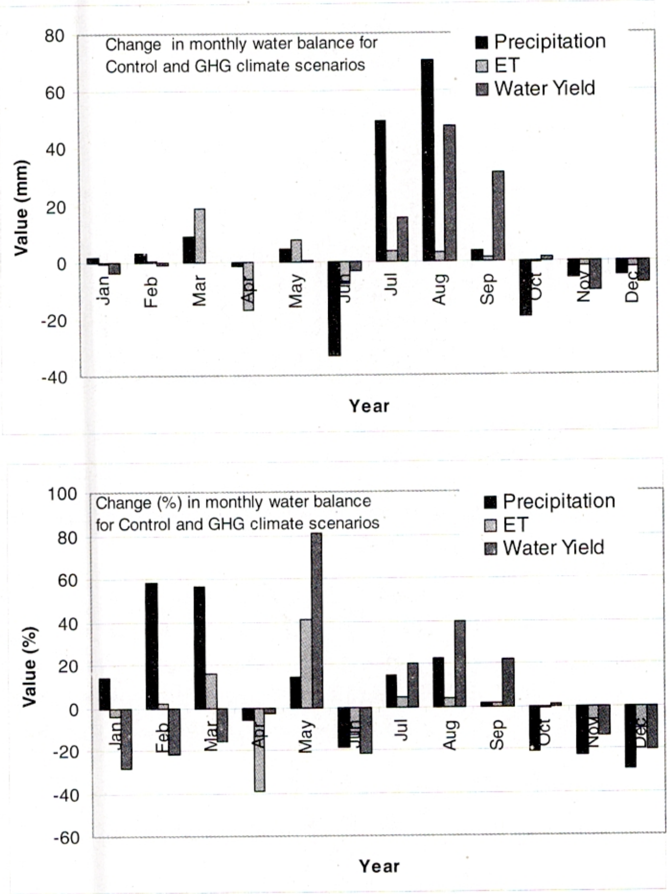

Fig. 13 Difference in mean monthly water balance components from control to GHG for Godavari basin.

Sub-basin Analysis for Godavari Basin

Analysis has also been performed to evaluate the impact of climate change across 27 sub-basins of the Tapi basin (Fig. 10). Figure 14 presents the annual average precipitation, actual evapotranspirarion and water yield as simulated by the model over the sub-basins of the Godavari basin for control and GHG scenarios.

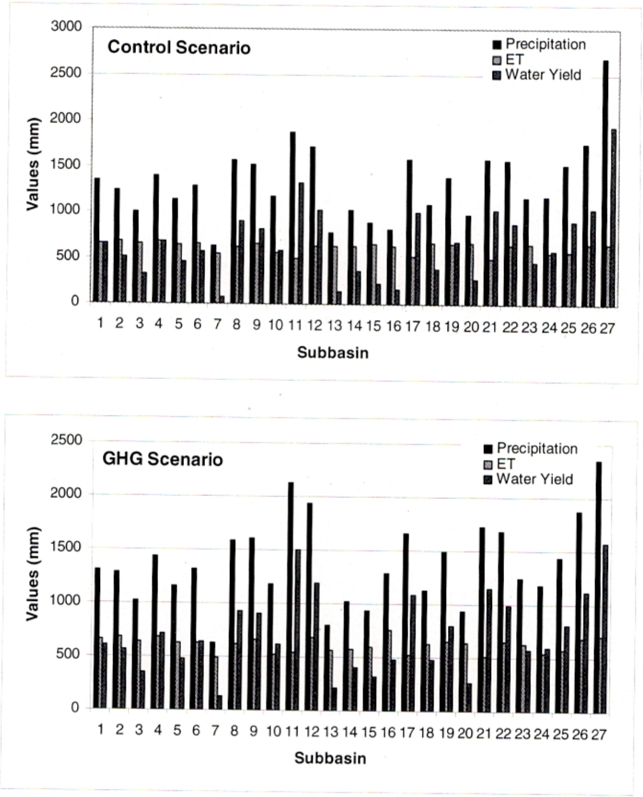

Fig. 14 Sub-basin water balance components for control and GHG scenarios for Godavari.

The analyses over the sub-basins have revealed increase in precipitation over most of the sub-basins of Godavari. Increase is in general about 10% of the control value. The corresponding increase in water yield has been variable over the sub-basins and is varying between 10% to about 60% over the sub-basins. The actual evapotranspiration has been predicted to decrease in majority of the sub-basins upto about 10%.

Drought Analysis for Godavari

Although there has been a prediction for the increase in the precipitation in the Godavari river basin, however, the drought analyses of the river basin reveals a very dismal picture for the future. Figure 15 presents the total number of drought weeks experienced in each of the sub-basins of Godavari basin during the control and GHG period of 20 years.

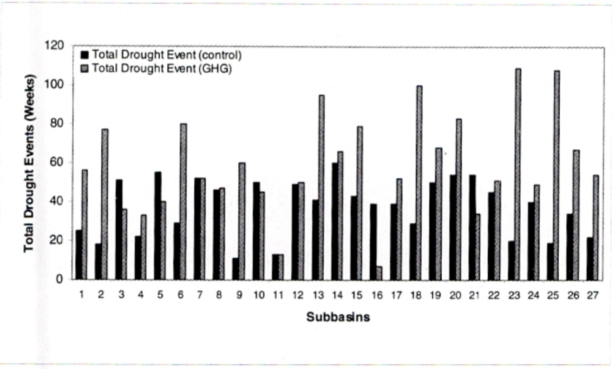

Fig. 15 Total drought weeks in sub-basins of Godavari.

It may be observed that there is no definite trend across the sub-basins of Godavari basin. There are some sub-basins that are predicted to be under higher stress level in the GHG Scenario whereas there are a few sub-basins which also predict improvement of drought conditions in GHG Scenario. However, it may be noted that the order of magnitude of the deterioration is much higher than that of the improvement.

Flood Analysis for Godavari Basin

The two of the worst affected sub-basins in Godavari (sub-basins 21 and 25) have been analyzed for flood severity (Fig. 16).

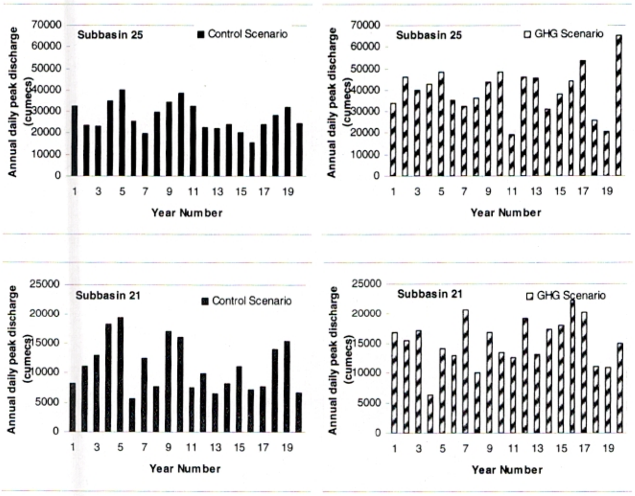

Fig. 16 Annual maximum daily peak discharges for Godavari sub-basin for control and GHG scenarios.

Taking sub-basin 21 into consideration, the annual maximum peak has exceeded from the present level of below 20000 cumecs under control scenario to a maximum level of about 23000 cumecs under GHG scenario. In the GHG scenario there have been three years when the peak level of 20000 cumecs has been surpassed. Similarly, in the sub-basin 25, the maximum peak of under 40000 cumecs under the control scenario has been enhanced to around 65000 cumecs under GHG scenario. There is only one year in twenty years duration when the peak level of 40000 cumecs (maximum peak) under the control scenario has been touched whereas under the GHG scenario this level has been predicted for more than half of GHG 20 years

Water Yield Analysis for Godavari Basin

The impact of the climate change on the dependability of the water yield of the river system has been analyzed with respect to four arbitrarily selected levels of 25, 50, 75 and 90%. Figure 17 depicts the flow duration curves for the Control and GHG scenario. Table 4 shows the values corresponding to the levels of 25, 50, 75 and 90%. It may be noticed that the flow for the dependable level of 25% and 75% has increased whereas that of 50% and 90% has reduced.

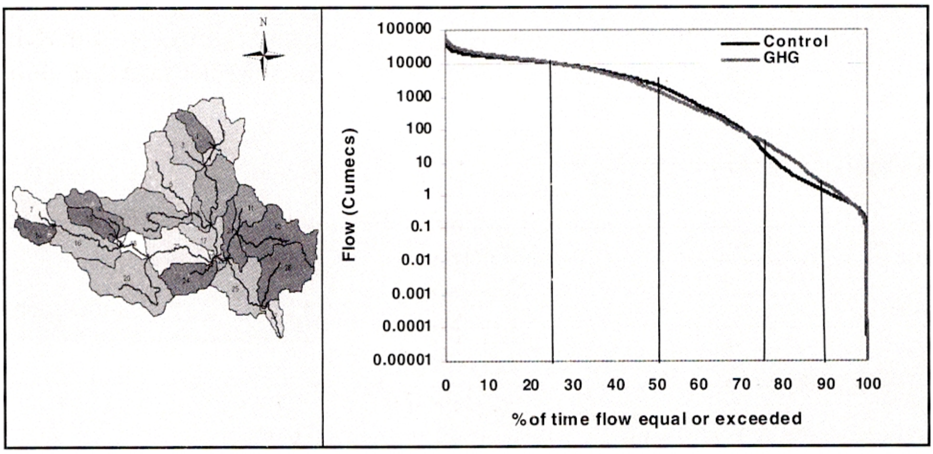

Fig. 17 Flow duration curve for Godavari river for control and GHG scenarios.

Table 4 Dependable flow at 25, 50, 75, 90% level for control and GHG scenario.

Dependable flow (cumecs)	25%	50%	75%	90%
Control	10660	2381	24.55	1.293
GHG Scenario	11050	1574	45.69	2.103

GAPS AND FUTURE DIRECTIONS OF STUDIES

In the present study, the 'hot spots' have been identified only with respect to the natural boundaries in the form of sub-basins of the river systems. Before the adaptation issues are addressed, it will be imperative to qualify these hot spots further by qualifying these geographic areas with respect to population and ecosystems they inhabit (Gosain and Rao, 2004).

The identification of hot spot areas requires a consistent framework for vulnerability assessment. Such a framework is desirable to integrate all other information generated by many other groups engaged in impact assessment within their domains, such as, agriculture, forestry, health etc. A standard set of criteria is required to evaluate level of environmental stress and susceptibility of a region. It is recommended that the criteria for environmental stress be subdivided into indicators related to the quantity of water and its quality. Susceptibility is to be broken into indicators reflecting the capacity of individuals or ecosystems to cope with climate change as well as their ability to manage water resources in the face of adverse conditions due to climate change. The coping up capacity is a function of financial resources, strong management institutions, and many other factors.

Another gap which shall be required to be addressed is the institutional capacity building at various levels. The creation of unified framework and its maintenance shall be a gigantic task which can be achieved only through major policy restructuring of the institutions at different level of management.

CONCLUSIONS

It has been an exhaustive study to quantify the climate change impacts on water resources wherein the water balance simulation modeling approach has been used to maintain the dynamics of hydrology and thereby make assessments of vulnerability which are more authentic and reliable. Usefulness of such handling has been proved by the fact that the results of the GHG scenarios have been dictated by temporal variability at daily level as well as the spatial state of the land mass in terms of its moisture conditions and landuse.

The study has revealed that under the GHG scenario the conditions may deteriorate in terms of severity of droughts in some basins and enhanced intensity of floods in other basins of the country. However, there is a general overall reduction in the quantity of the available runoff under the GHG scenario. There are definite climate change impacts that may induce additional stresses and shall need various adaptation strategies to be taken up. The strategies may range from change in land use, cropping pattern, to water conservation, flood warning systems etc.

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