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IMPACT OF CLIMATE CHANGE ON WATER RESOURCES AVAILABILITY AND CROP PRODUCTIVITY IN INDIA

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Abstract *Worldwide agriculture contributes about 14% of greenhouse gas emissions with land use change and forest adding another 19%. There is growing recognition that agriculture is already affecting, and being affected by climate change. Future global food supply will depend on how well agriculture adopts to climate change. The apparent impacts of the global climate change in India include erratic monsoon, high intensity floods, increased frequency of draughts, decreasing crop yields among others. Rapid industrial development, growing urbanization and the increasing demand for irrigation water to feed the burgeoning population of India are already placing immense pressure on existing water resources. There is a direct link between the rise in global temperature and damage to eco-systems. Trends indicate that agricultural productivity in India will decline up to 25 percent which could be as much as 50 percent in rainfed agriculture. Small and marginal farmers with small land holdings will be more vulnerable to climate change. This paper provides an overview of the impact of various climatic factors on water resources availability and crop productivity. A brief discussion on mitigation/ adaptation strategy towards sustainable crop production under climate change has also been provided as a way forward.*

1. INTRODUCTION

The pace and impact of climate change in terms of heavy floods and drought, change in precipitation pattern, increased temperature, increase in carbon dioxide and rise in sea level etc. across India has been well acknowledged (World Bank, 2008). These changes could impact socio-economic activities with serious implication on the welfare of human being into long run. Escalating population pressure, rapid urbanization and industrialization, deforestation, unlimited waste production are leading enormous pressure on our natural resources and has led to qualitative and quantitative degradation of land, water, air, forests, bio-diversity and bio-resources. The associated problems like shrinking farm size, depleting natural resources, increased biotic and abiotic stress and regional variability are further exacerbating the situation.

In India, agriculture plays and important role in country's economy contributing around 18.5% of GDP. Close to 70 percent of population depends upon agriculture. Consequently, agriculture development has important implications in alleviating poverty, especially in rural India.

Agriculture is one of the most vulnerable sectors to the anticipated climate change. Despite the technological advances in the 'Green Revolution' during 1960s, climatic factors have significant impact on the agricultural productivity. Agriculture in India is extremely diverse in the range of crops grown and livestock raised. While climate change clearly affects agriculture, climate is also affected by agriculture, which contributes 13.5% of all human induced green house gas emissions globally. Developing countries like India, whose economy is agriculture based, is likely to suffer more from the impacts of climate change due to their geographic location, greater agriculture share in their economies and limited ability to adopt to climate change.

Globally, a significant amount of modeling and research has been done by experts on the impacts of climate variability and change, with an emerging consensus that climate change will have a negative impact on development patterns and growth potential. The most recent findings of Working Group I1 of the Intergovernmental Panel on Climate Change (IPCC) reinforces these broad conclusions (World Bank, 2008). Table1 provides an overview of the key findings of the IPCC's Working Group I1 report (IPCC 2007). The report concludes with high confidence (90% probability) that "climate change is projected to impinge on the sustainable development of most developing countries of Asia, as it compounds the pressures placed on natural resources and the environment that are associated with rapid urbanization, industrialization, and economic development".

Table 1. Working Group I1 of IPCC: Summary of Rural Impacts

South Asia	**Agriculture/food supply**	**Freshwater resources**
(concluded with medium to high confidence)[a] • Crop yields could decrease up to 30% in central and South Asia by the mid-21st century. • Endemic morbidity and mortality are expected to rise due to diarrhea disease primarily associated with floods and droughts. • Increases in coastal water temperature would exacerbate the abundance and toxicity of cholera in South Asia. The largest number of people affected by sea level rise will be in the heavily populated large deltas of Asia & Africa. • Glacier melt in the Himalayas is projected to increase flooding and rock avalanches from destabilized slopes, and affect water resources within the next two to three decades. This will be followed by decreased river flows as glaciers recede. • Freshwater availability, particularly in large river basins, is projected to decrease, which, along with population growth and increasing demand arising from higher standards of living, could adversely affect more than a billion people by 2050.	*(concluded with medium to high confidence)*[a] • At mid to high latitudes, and where local average temperature increases anywhere from 1°C to 3^0C, crop productivity is projected to increase slightly depending on the crop. Past that point, crops will see declines in yield in some regions. At lower latitudes, especially seasonally *dry* and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1-2^0C), which would increase risk of hunger. • Globally, the potential for food production is projected to go up as long as local average temperature rise does not exceed 3°C; above this, it is projected to decrease. • In the frequency of droughts and floods are projected to affect local production negatively, especially in subsistence sectors at low latitude.	*(concluded with either high or very high confidence)*[a] • By mid-century, while average river runoff and water availability at high latitudes and in some wet tropical areas are projected to increase by 10-40%, at mid-latitudes and in the *dry* tropics they will decrease by 10-30%. Some o f these *dry* regions are already water-stressed areas. The extent of drought-affected areas will likely to increase. • Heavy precipitation events, which are very likely to increase in frequency, will augment flood risk. • In the course o f the century, water supplies stored in glaciers and snow coverage are projected to decline. This will reduce water availability in regions supplied by melt water from major mountain ranges, which are home to more than 1 billion people. • Sea level rise is expected to exacerbate inundation, storm surge, erosion, and other coastal hazards, thus threatening vital infrastructure, settlements, and facilities that support the livelihood of island communities.

(a) Very high confidence implies that the statement has at least a *9* out o f 10 chance o f being correct; high confidence implies an 8 out o f 10 chances; and medium confidence a **5** out o f 10 chance.

2. IMPACT OF CLIMATIC FACTORS ON AGRICULTURAL PRODUCTIVITY

The key climate change components impacting crop productivity are – (1) Rising temperatures (2) Changing water resources availability, and (3) Increasing carbon dioxide concentration in the atmosphere. As per the IPCC report (2007,a) moderate to medium increase in mean temperature (1-3^0C) along with CO_2 increase and rainfall changes, are expected to benefit crop yields at high latitude. However, in low latitude regions moderate temperature increase (1-2^0c) are likely to have negative yield impacts for most of cereals, but warming (more than 3^0c) would have negative impacts in all regions (IPCC.2007,b). Surface air temperature for the period of 1901-2000 indicates a significant warming of 0.4^0c during the period of 100 years. The spatial distribution of temperature change indicating a significant warming trend has been observed along the west cost, central India and interior peninsula and over north east India. However, cooling trend has been observed in north-west and some parts of southern India, but past 130 years records do not show any specific long term trend in the frequencies of large scale droughts or floods in summer monsoon season. Soil moisture is dependent of interaction of temperature increase and changing rainfall patterns. Evaporation and precipitation both increase with rise in temperature. The resulting net effect on water availability would depend on dominating force. The following is a brief on the impact of some important climatic factors on water resources availability and crop productivity in India.

2.1 Temperature

National Institute of Hydrology (2007) has studied the temperature variability and trends in some river basins of India, Table 2 shows a season wise summary of trends and magnitude of different temperature variables. A higher rate of warming /cooling has been observed in some pockets in the large basin like Ganga. The trends of change in temperature suggest that majority of the basins except Sabarmati and Luni and other small rivers have experienced an increasing trend in mean annual temperature over the last century, while two basins namely Sabarmati and Luni have experienced cooling trends. The range of increase in mean annual temperature in warmer basins varied between 0.40^0c to 0.64^0c per 100 years and for the cooler basins, it varied between 0.15 to 0.44^0c per 100 years.

A comparison of magnitude of warming and cooling trends of different river basins indicate that Narmada basin experienced maximum warming, while Sabarmati river basin has sown the largest cooling trend. Seasonal analysis of different variables show that the maximum change in T max and T mean were observed in the post monsoon, while T_{min} experienced maximum change in the monsoon season. The majority of basins have shown increasing trend in T range in the range of 0.09 to 1.78 ^{0}c /100 years. Both T max and T min have shown increasing trend in the above areas. These study findings can be used in planning and implementation of strategies for development.

Climate change scenarios over India to predict change in temperature and temporal and spatial variability of the monsoon rain fall projected that mean surface temperature may rise between 3.5^0C and 5.5^0C by 2080 (Lal, 2002). It is also projected that surface warming is higher in winter than during summer monsoon. Spatial distribution marked that north India may experience an annual mean surface warming of 3^0C in winter.

Table 2. Trends and magnitude of changes in different temperature variables (^{0}C/100 year) for different river basins

#	River basins	T_{mean}					T_{max}					T_{min}					T_{range}					H_{max}	H_{min}
		S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S5	S5
1	Indus (lower)	0.39	0.30	-0.04	0.87	0.50	1.03	0.75	0.53	1.13	1.39	-0.21	-0.18	-1.00	0.22	-0.33	1.81	0.92	1.19	1.09	1.78	0.71	-0.13
2	Gange	0.63	0.19	0.02	0.92	0.44	1.00	0.58	0.68	1.17	0.90	0.36	0.05	-0.63	0.77	0.04	0.52	0.58	0.95	0.35	0.72	0.60	0.49
3	Brahamni & Subarn	0.84	0.02	0.03	0.73	0.40	0.59	0.08	0.54	0.83	0.54	1.13	0.33	-0.28	0.79	0.29	-0.33	0.06	0.77	0.13	0.28	0.27	1.10
4	Mahanadi	0.62	0.29	0.34	0.99	0.61	1.09	0.51	0.85	1.30	1.10	0.92	0.78	-0.09	0.91	0.38	0.25	0.60	1.05	0.41	0.68	0.69	0.67
5	Tapi	0.47	0.49	0.19	0.72	0.46	0.46	0.33	0.30	0.58	0.43	0.39	0.38	0.04	0.65	0.37	0.21	-0.22	0.26	-0.14	0.09	-0.06	0.74
6	Narmada	0.60	0.75	0.31	1.00	0.64	0.50	0.58	0.44	0.85	0.58	0.71	1.05	0.13	1.02	0.59	-0.20	-0.26	0.32	-0.24	-0.02	0.19	1.11
7	Mahi	0.10	0.55	0.24	0.50	0.47	0.13	0.40	0.52	0.34	0.36	0.15	0.73	0.24	0.74	0.50	0.02	-0.20	0.12	-0.40	-0.04	-0.19	0.30
8	Sabarmati	-1.30	-0.10	0.06	-0.94	-0.44	-0.43	0.01	0.22	-0.24	-0.03	-2.11	-0.08	0.00	-1.52	-0.77	1.80	0.22	0.27	1.43	0.87	0.47	-2.22
9	Luni & others	-0.39	-0.33	0.08	-0.37	-0.15	0.60	0.01	0.41	0.35	0.44	-1.34	0.44	-0.17	-0.88	-0.62	2.08	0.62	0.63	1.38	1.17	-0.47	-0.94
10	All NW&C basins	0.44	0.19	0.09	0.64	0.35	0.92	0.46	0.60	1.02	0.81	0.04	0.08	-0.44	0.40	-0.05	0.87	0.59	0.93	0.67	0.84	0.34	0.18

S1: Winter S2: Pre-monsoon S3: Monsoon S4: Post-Monsoon S5: Annual

Source: Preliminary Consolidated Report on Effect of Climate Change on Water Management

2.2 Rainfall

NIH (2007) has studied seasonal and annual trend of change in rainfall, rainy days, heaviest rain and relative humidity over the last century for 9 river basins. Majority of river basins have shown increasing trend both in annual rainfall and relative humidity. The magnitude of increased rainfall varied from 2-19% of mean per 100 year with maximum increase in Indus followed by Tapi river basin and more than 3% in Ganga basin (Table 3).

Maximum increase in rainfall was observed in the post monsoon season followed by pre monsoon season. There were least variations in the monsoon rainfall during the last century and winter rainfall has shown decreasing trend. Most of the river basins have experienced decreasing trend in annual rainy days. The heaviest rain of the year has increased by 9-27 mm per 100 years, being maximum increase in Brahamani and Subarna rekha river basins.

Increase in heaviest rainfall and reduction of number of rainy days together have reflected the possibility of increasing floods. The projected scenario for rainfall for different seasons by 2020s, 2050s and 2080s is given in Table 4. Projection of the increase in rainfall is 7-10%, decrease in winter precipitation is 5-25% and an increase of 10-15% average rainfall by 2080 has been suggested.

Table 3. Trends and magnitude of changes in rainfall (% of mean/Year), rainy days (% of mean/Year) and heaviest (% of mean/Year) for different river basins

#	River basins	Rain					Rainy days					Heavy Rain
		S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S5
1	Indus(lower)	3.51	22.53	13.93	46.91	19.03	-16.71	14.64	0.57	11.58	5.96	22.16
2	Ganga	0.25	10.02	1.74	13.68	3.16	-16.82	2.02	-2.31	6.80	-3.96	9.31
3	Brahamani & Subarn.	-19.31	19.76	2.32	10.57	3.40	-29.59	9.53	-3.96	-3.94	-5.80	27.03
4	Mahanadi	-9.33	-0.27	-5.31	10.53	-4.70	-22.34	2.67	-5.34	-9.96	-9.83	16.60
5	Tapi	-24.46	-12.21	11.11	0.13	9.62	-34.01	-10.44	-0.66	0.26	-1.01	18.16
6	Narmada	2.74	-9.58	8.18	-8.04	6.92	-9.52	-17.54	-1.05	-5.80	-1.89	18.47
7	Mahi	6.04	-63.58	6.29	61.86	6.98	-18.63	-66.00	-2.37	29.97	-2.45	11.81
8	Sabarmati	42.60	-22.44	0.09	93.61	2.07	10.93	-57.91	-4.50	41.08	-0.76	15.11
9	Luni &others	-10.49	2.58	-1.12	86.52	4.94	-39.49	-15.44	-3.40	57.44	-5.42	15.05
10	All NW & C basins	-2.02	5.54	2.87	31.28	5.18	-21.86	-3.29	-5.30	14.93	-3.23	14.17s

S1: Winter; S2: Pre-monsoon; S3: Monsoon; S4: Post-Monsoon; S5: Annual

Source: Preliminary Consolidated Report on Effect of Climate Change on Water Management

Table 4. Climate change projections for the Indian sub-continent

Scenarios		Increase in temperature (^{0}C)	Change in rainfall (%)
2020s	Annual	1.00-1.41	2.16-5.97
	Winter	1.08-1.54	(-)1.95-4.36
	Monsoon	0.87-1.17	1.81-5.10
2050s	Annual	2.23-2.27	5.36-9.34
	Winter	2.54-3.18	(-)9.22-3.82
	Monsoon	1.81-2.37	7.18-10.52
2080s	Annual	3.53-5.55	7.48-9.90
	Winter	4.14-6.31	(-)24.83-4.50
	Monsoon	2.91-4.62	10.10-15.18

Source: Preliminary Consolidated Report on Effect of Climate Change on Water Management

2.3 Carbon dioxide

Higher carbon dioxide level has a positive impact on crop yields by stimulating plant photosynthesis and reducing water loss via plant respiration. The carbon fertilization effect is strong for C3 plants such as rice, wheat, soybean, legumes and most trees, which have lower photosynthesis efficiency. C4 plants like maize, sugarcane, sorghum and many grasses these effects are smaller. IPCC report suggested that yield may increase by 10-25% for C3 crop plants and 0-10% for C4 crop plants when CO2 levels reach 550 ppm (2007 b). Higher carbon dioxide generally causes plants to grow larger, but this is not necessarily beneficial because they may be less nutritious with low protein content. Carbon dioxide makes some plants more water use efficient meaning production of more grain or material on less water. This is of advantage in water scare conditions and areas.

2.4 Water Resources

One of the most pronounced effects of climate change is the increase in heavy rainfall with more intensity. As it is projected that number of wet days will decrease and monsoon rain will increase. A combination of increase in rainfall intensity and reduction in number of wet days suggest the possibility of increasing severity of floods. One of the consequences of field flooding during the crop growing season is reduced crop production due to low oxygen level in soil, susceptibility of roots for diseases, low nutrients supply etc. Amount of moisture in soil is affected by change in rainfall, runoff and evaporation. Drought frequency is also projected specially in tropical region. In the both situations tolerant crops /varieties are required to avoid the detrimental effects. Another projection indicated an increase the monsoon rainfall – suggesting increasing the area under crops like rice; while reduction in rainfall in winters suggests growing of less water requiring crops like Pulses, Oilseeds, etc.

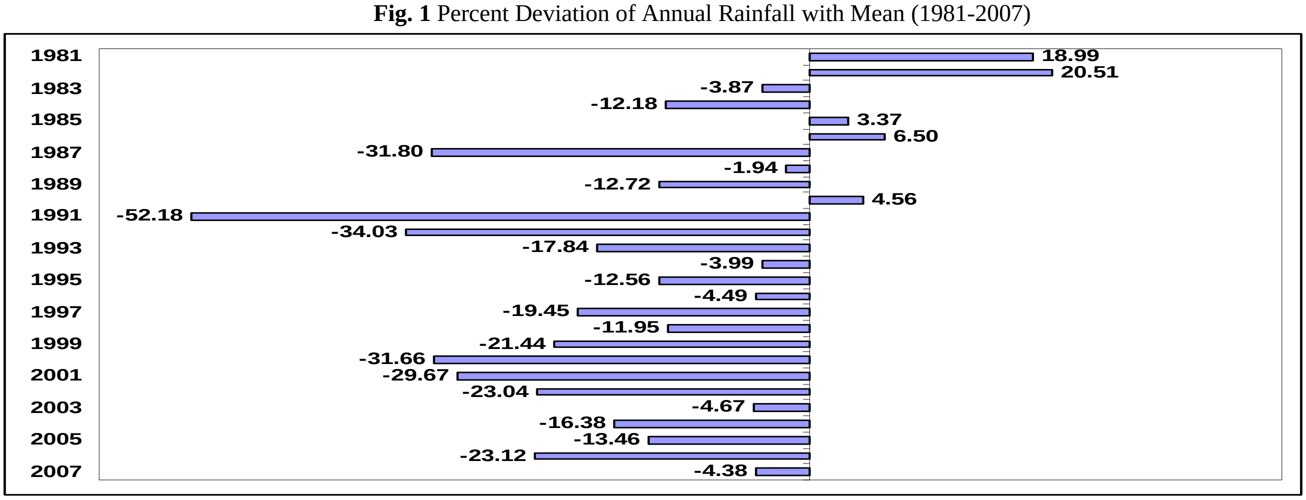
2.5 Diseases and Pests

Increased concentration of carbon dioxide and temperature benefits weeds more than crop plants. Many insect pests and crop diseases thrive well due to humidity increase and warming allow higher survival rate of pathogens and parasites. In such a situation, disease and pest resistant varieties should be adopted for maximizing profitability.

3. IMPACTOF CLIMATE CHANGE IN GHAGHRA –GOMTI RIVER BASIN A CASE STUDY

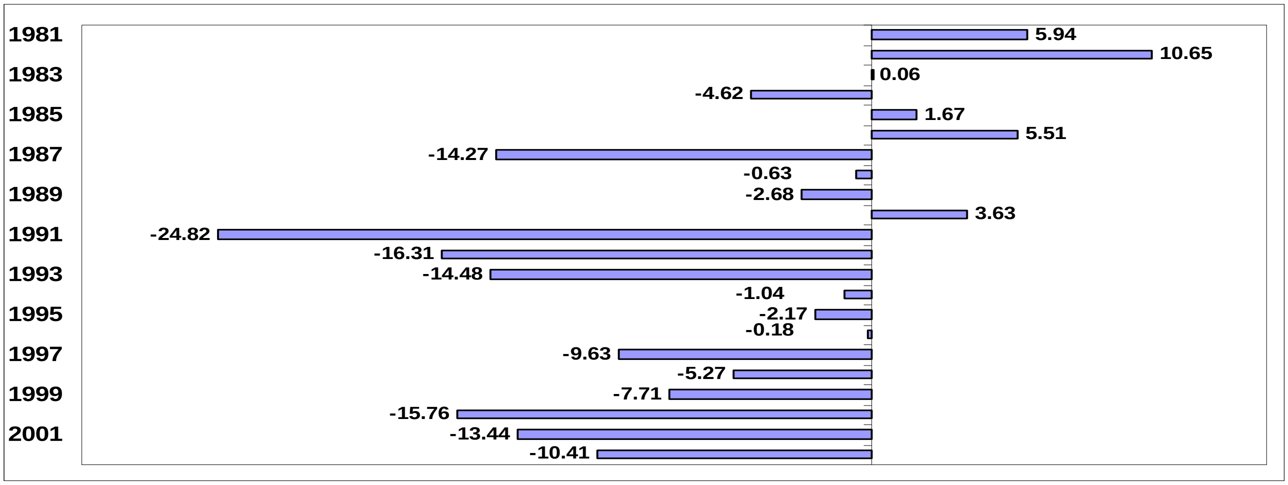
In Ghaghra-Gomti Basin (GGB) of India, a decadal pattern of annual rainfall and number of wet days were studied from 1901-2007. Study reflected that decadal rainfall was below normal during the decades 1901-1910, 1981-1990, 1991-2000 and 2001-2007. The detailed annual analysis indicated that the GGB has been experiencing below normal rainfall consistently since 1987 with exception of year1990, when it was +4.56% above normal rainfall (Fig. 1). In the study it was found that the pattern of temporal variation of number of wet days in basin was almost the same as that of quantity of rainfall (Fig. 2). The study has also indicated that there has been marked decrease in rainfall pattern since 1987 onwards.

Fig. 1 Percent Deviation of Annual Rainfall with Mean (1981-2007)



(Source: Ground Water Management, Uttar Pradesh, Proce. SWaRA)

Fig. 2 Percent Deviation of Annual No. of Wet Days with Mean (1981-2002)



(Source: Ground Water Management, Uttar Pradesh, Proce. SWaRA)

The Ghaghra- Gomti Rivers are perennial in nature, but do not follow the same pattern through out the year or even do not remain at a high stage over the monsoon season. It is only spell of sever rains may be several hours or few day that generates large run off in the catchments.

The Sai River has gone in the worst position in view of flow; where one can travel across the river bed. All the irrigation schemes constructed on this river almost have gone dry, which effected the irrigation and ultimately crop yields (Fig. 3).

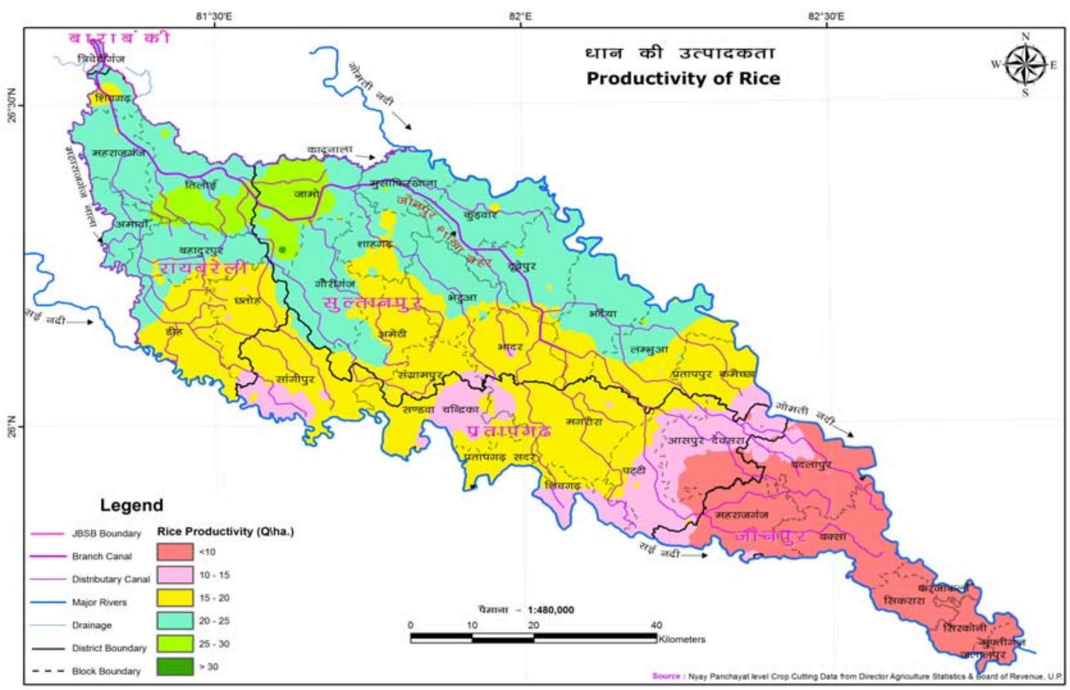


Fig. 3. Productivity of Rice in the Jaunpur Branch Sub-basin

Other rivers of GGB have some flow as they receive water from their sources and base flow although in reduced quantum. This is the direct impact of decrease in rainfall pattern, as after 1987, the decreased rainfall resulted in the lowering groundwater level and drastic reduction in flow of rivers. Unavailability of surface water has forced the farmers to use groundwater for irrigation purpose which led to overexploitation of this resource.

3.1 Temperature

Warming generally causes faster growth, causing reduction in crop reproductive period and reducing crop yields. In the months of January-February 2006, above normal temperature (4-6 degree C) over the Gangetic plains at the time of flowering and dough stage reduced yields by 10-15 percent. This can be managed by early planting to avoid the heat stress. Moderate increase in temperature will decrease yields of rice, wheat, corn, bean, ground nut etc. and also could have significant effect on quality fruits, vegetables, medicinal and aromatic plants etc. Increased temperature affects the crop plants and its productivity in several ways. Efficiency of fertilizer application is reduced because it gets leached after field application. This requires more nutrient supply to maintain the soil fertility status. As it is expected that in future , night temperature are expected to continue to rise, which is critical to plants specially in reproductive period of growth because warm nights increase the respiration rate and reduce the photosynthesis, captured during the day time. In the high temperature grain setting failure is very often because of mortality of pollen grain and failure of pollination process and can suffer even under well watered condition, causing yield reduction.

4. MITIGATION/ ADAPTATION STRATEGIES: WAY FORWARD

Climate change over last few decades has endangered food security in India. Impacts are diversified and need to be addressed through public-private partnerships among communities, local government and states. There are two fold approaches to mitigate the climate stress – firstly by reducing greenhouse gas emissions, the main culprits of climate change and secondly, by adopting measures to mitigate adverse impacts of climate change. Water harvesting and conservation both in agriculture and domestic sectors has to be a national priority. Use of drip and sprinkler irrigation systems, mulching and bed plantation, construction of small tanks and check-dams are some of the conventional measures for water conservation and harvesting. In Alwar region of Rajasthan for example, barren lands have been converted into lush fields adopting these measures. Dried up rivers got rejuvenated by making ‘Johads’, - small earthen check dams.

Temperature and rainfall are the two major factors affecting crop-productivity in Uttar Pradesh State of India. The main cropping pattern is rice-wheat based system in terms of area coverage, water consumption and farm income in both the sub-basins of Jaunpur and Immamganj Branch which falls in Tarai region. In both the sub-basins rain-fed pulse crops such as lentil and pigeon pea are grown on considerable area. Improvement in land drainage is a pre-requisite for achieving the crop diversification. Vertical drainage in the form of pumping groundwater is a cost effective measure to lower the high water table. Also, the aquifer has storage properties and can be operated as inter-seasonal and multi-annual water storage facilitating supply of water in periods of scarcity. Thus further development of groundwater is an important strategy to achieve crop diversification.

With unpredictable weather, farmers will have to change crop management practices, grow drought tolerant crop varieties. One adaptive measure to sustain wheat productivity would be introduction of longer duration and early planting varieties. Building capacities by designing climate proof investment, resource mobilization, promoting insurance and agribusiness are other majors to protect against risk of production loss due to calamities like droughts, pest attack, and floods.

Farmers need to be advised as regards the crop planting/ sowing dates for avoiding crop exposure to adverse condition as high temperature or limited water or low rainfall periods. In future, however predicting planting dates for avoiding stress condition will be a challenging task. The study findings and recommendations of the study carried by the World Bank (2008) has suggested four interrelated strategies that would help lower the exposure to climate risks and build adaptive resilience: (a) Strengthening climate information systems and mechanisms and related management tools to match current and future needs; (b) Fostering climate-resilient reforms in agriculture and water resource management; (c) Supporting the management of climate risks with economic mechanisms, and (d) Improving institutional capacities and linkages among sectoral programs.

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