Groundwater Scenario under Changing Climate: Rajasthan

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Abstract: One of the primary threats from climatic changes is because of increase in evaporative losses and water demands caused by higher temperature. The increase in water demand due to increase in evaporative losses will have direct bearing on water resources. Ground water is the major source of irrigation. Change in crop water requirement due to increased evapotranspiration is likely to affect groundwater resources of any region. This paper analyzes likely effects of climate change on evapotranspiration demand (or crop water requirement) and consequently on the groundwater resources of Rajasthan state. FAO Penman-Monteith model (1998) was used to estimate evapotranspiration (ET). The average annual ET demand for the State of Rajasthan is estimated as 1701 mm. One percent increase in temperature (or $\leq 0.42°C$) over the prevailing temperature would enhance the annual evapotranspiration demand by 11.7 mm, which indicated requirement of additional annual water demand of 718 mcm for the net irrigated area of 61,345 km^2 and 2,245 mcm for the total cropped area of 1,92,302 km^2 in the State. In comparison to the total available utilizable ground water of 11,159 mcm in Rajasthan, these additional requirements would put stress of 6.43% to 22.16% with land use pattern remaining unaffected. Increase in temperature by 1% will reduce number of safe districts from 6 to 3 and bring additional districts in the category of 'critical' and 'overexploited'. An increase in temperature by 2-3% over normal temperature (i.e. 0.82–1.24°C) will reduce the category of 'safe' zone district into 1, remaining 31 districts will be mostly in the category of 'overexploited'. The paper also discusses groundwater resource scenario of Rajasthan and its probable effect due to climate change.

INTRODUCTION

Global warming issue was first discussed in Rio de Janeiro in year 1992 and reported a rise by few °C in average annual temperature worldwide. There are sufficient evidences to show that the earth's temperature has risen by more than 0.5°C since 1880 and continues to rise at faster rate (Martinez-Austria, 1994). Another most visible evidence of global warming is rise in sea-level which could be up to 1 m over next hundred years (Schneider, 1989; Houghton et al., 1990). Keeping in view the evidence of global warming, the World Meteorological Organization (WMO) formed the Intergovernmental Panel on Climatic Change (IPCC) in 1988, which called on different experts organized into working groups to analyze the possible effects of this phenomenon. Since the formation of IPCC, various studies are undertaken worldwide to understand/predict the effect of global warming on the various aspects of ecosystem (Ravindranath and Sukumar, 1996; Mendelsohn and Dinar, 1999; Mathauda et al., 2000; Roos et al., 2002; Mall et al., 2004 and others). The main reason for global warming is considered as increase in concentration of greenhouse gases in the atmosphere. The major sources of these gases are combustion of fossil fuels, agriculture and land use changes (Singh and Kumar, 1997). Global warming due to greenhouse effect is expected to cause major changes in climate of some areas. The change in climate is likely to have a profound effect on hydrological cycle viz. precipitation, evapotranspiration, soil moisture etc (Nemec and Schaake, 1982; Gleick, 1986; Bultot et al., 1988 and others). Evapotranspiration (ET) being the major component of hydrological cycle will affect crop water requirement. The present study deals with the likely effect of global warming on crop water requirement and subsequently on groundwater resources of Rajasthan.

MATERIAL AND METHODS

Study Area and Climate of Region

The study has been conducted for the Rajasthan state, which is the largest state in Indian Union, with an area of 3,42,239 km^2 and is situated between 23°3′ N and 30°12′ N latitudes and 69° 30′ E and 78° 17′ E longitudes (Fig. 1). The western and northern boundaries of the State are shared by the eastern boundaries of Pakistan. The rest of the boundaries in the north, east and south are marked by the other Indian states (DST, 1994). Physiographically, Rajasthan stretches in two of India's major physiographic divisions, namely the Great Plains and the Central Highlands. The area lying west of the *Aravallis* known as Western Sandy Plains occupies the western part of the Great Plains, while the area east of *Aravallis* falls in northern part of the Central Highlands. The climate of Rajasthan west of the *Aravallis*, as of other desert and semi-desert regions, is characterized by great extremes of temperatures and long periods of severe drought accompanied by high wind velocity and low relative humidity. The winter is quite cold, at many places, the temperature falls below freezing point, and frost occurs. On the other hand, the heat during summers is intense and scorching. The arid region in western Rajasthan is hottest region in India. East and south of the *Aravallis*, there is a considerable variation in rainfall and temperature distribution.

The annual rainfall in the state varies significantly. The general trend of isohytes is from northwest to southeast. There is a very rapid and marked decrease in rainfall in west of the Aravalli range making western Rajasthan the most arid part. Based on rainfall data of 1901 to 2002 the average annual rainfall of the western arid region has been worked out as 317 mm and that of rest of eastern Rajasthan is 680 mm with overall average rainfall of 554 mm in the state. The yearly total rainfall is highly variable at different places all over the state and it is most erratic in the western half with frequent spells of drought. The coefficient of variation (CV) of rainfall varies between 30 and 50%. The southwest monsoon, which has its beginning in the last week of June in the eastern parts, may last till mid-September. Pre-monsoon showers begin towards the middle of June and post-monsoon rains occasionally occur in October. In the winter season also, there is sometimes, a little rainfall associated with the passing western distribution over the region. At most places, the highest normal monthly rainfall is during July and August. The number of rainy days varies widely in different places, ranging from 10 to 40. Every alternate year is drought year for the state. The overall probability of drought for the state is 47%.

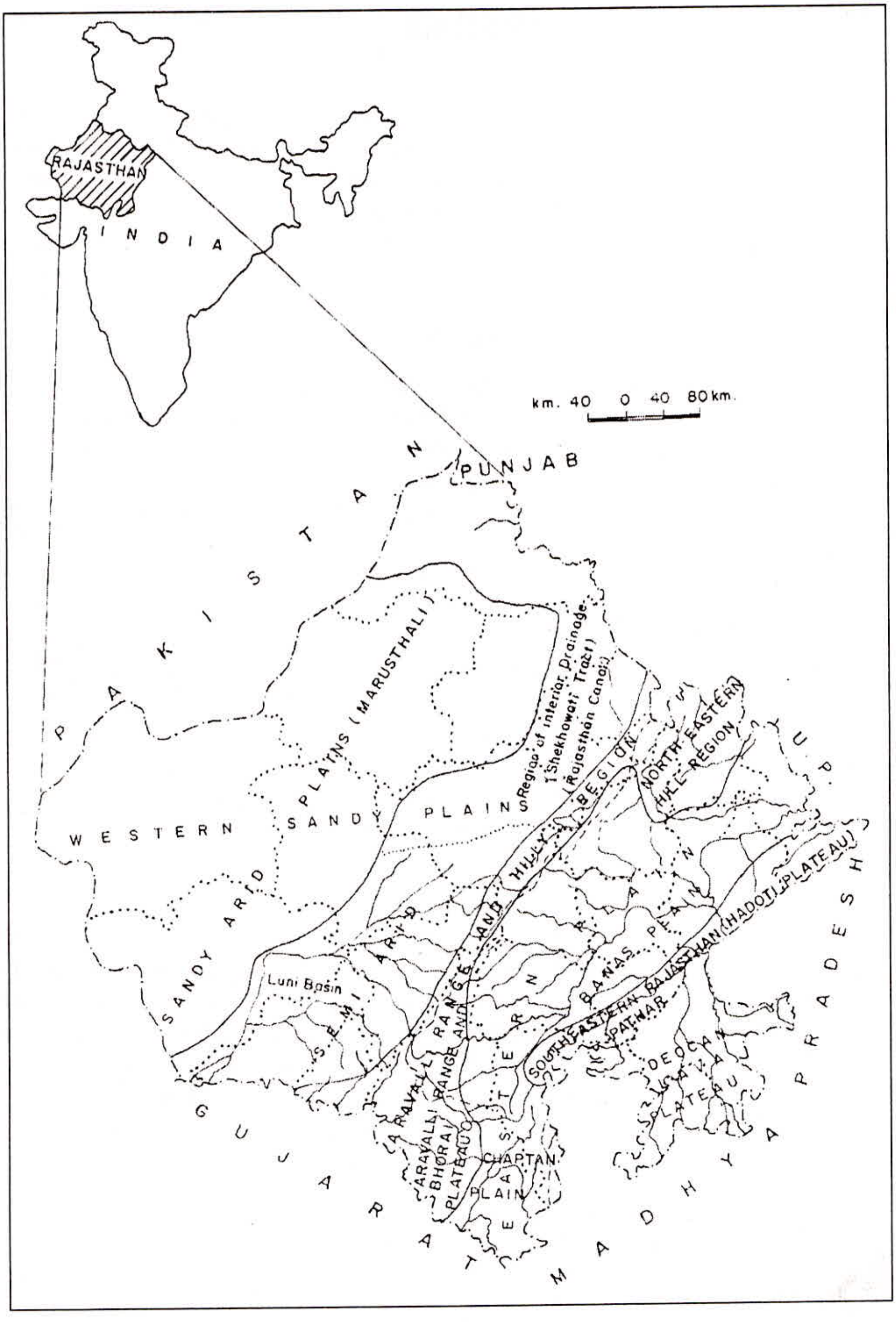

Fig. 1. Physiography and drainage of Rajasthan.

The state presently consists of 32 districts. The total cropped area of the state is 1,92,302 km^2 (56.12% of total area) which includes double cropped area also (DES, 2002). The total irrigated area is 61,345 km^2 (31.9% of total cropped area or 17.9% of total area of Rajasthan state. The major sources of irrigation are wells and tubewells (70.77%). The total annual groundwater availability is 11,159 mcm as against total annual water demand (draft) of 11,626 mcm (GoR, 2002). The overall groundwater stage of development for the whole state is 104%, which is categorized as 'over exploited' as per hydrological water balance (Table 1). Presently out of total 32 districts, 14 districts are in the category of overexploited, four are in critical zone, eight are in semi critical zone and remaining six are in safe category.

Climate Change and Evapotranspiration (ET)

Increase in temperature effects ET primarily by increasing the capacity of air to hold water vapour. As per general circulation models (GCMs) with different scenarios of greenhouse gases emission, the globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over a period of 1990 to 2100. Rosenberg et al. (1989) calculated expected change in temperature ranging between –4 to +10° C by the end of present century. Decreased cloudiness and increased solar radiation (R_n) would increase ET. An increase in cloudiness (caused by increased ET) will have the opposite effects. Net radiation is directly affected by dust contents of the atmosphere, which in turn depends upon the wind velocity and vegetation. The vapour pressure deficit of the air measures its dryness. Saturation pressure increases exponentially with increasing temperature. If all other factors remain unchanged, warming should cause drier air and hence more ET. However, actual vapour pressure may also change in response to increased ET. The process of vapour removal depends to a large extent on wind and air turbulence, which transfers large quantities of air over the evaporating surface. Higher wind speed can increase or decrease ET, depending on other climatic factors particularly humidity and the plant/crop characteristic such as stomatal resistance. An increase in wind velocity could also result in higher dust content in the atmosphere, which in turn leads to lower incoming solar radiations.

Data Used

The most visible and measurable effect of climate change is change in temperature at regional and global level. The specific data for climate change for the state of Rajasthan are not available; therefore, the present study has been conducted with reference to increase in temperature alone within a likely range of 1 to 3% from normal temperature. Although climate change, beside temperature, is associated with changes in other climate parameters like humidity, wind velocity, duration of sunshine hours, evapotranspiration or crop water requirement is most sensitive to change in temperature. So changes in temperature alone is considered in the present study. Change in CO_2 concentration and precipitation is not considered in the present study as this is indirectly related to the changes in other meteorological parameters.

To obtain normal representative values of meteorological parameters for the study area i.e. Rajasthan, the whole state has been divided into seven sub-climatic zones, i.e. (i) Arid western plains, (ii) Northwestern plains, (iii) Flood prone eastern plains, (iv) Humid southern plains, (v) Sub-humid southern plains and *Aravallis* hills, (vi) Semi-arid eastern plains and (vii) Humid Southeastern plains. One representative meteorological station for which sufficient data are available has been selected in each climatic zone. 30 years (1973-2002) weekly meteorological data of selected stations from seven zones has been used as reference point for the study. The selected period accommodate all typical climatic features of Rajasthan including droughts and good rainfall years. To decrease the discreteness of climatic parameters, weekly averages over different years were used in the analysis. Maximum possible sunshine hours (N) and radiation (R_a) have been interpolated for given range of latitudes and time from the standard tables. Psychrometric constant (γ) depends upon atmospheric pressure which in turn depends on altitude. The value of 'γ' was estimated as 0.064506 based on the average elevation of 370 m of the state (Goyal, 2001).

Estimation of Evapotranspiration

There are several models described by Eagleson (1970), Viessman et al. (1977), Doorenbos and Pruitt (1977) and others for the estimation of reference evapotranspiration (ET_0). FAO recommended the universal adoption of the Penman-Monteith combination method for estimation of reference evapotranspiration. The reference crop is defined as hypothetical crop with an assumed height of 0.12 m having the surface resistance of 70 s m^{-1} and albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height and actively growing and adequately watered (Allen et al., 1998). The recommended method is said to overcome shortcomings of the previous FAO Penman method and provides results that are more consistent. According to Penman-Monteith combination equation, ET_0 can be expressed as

$$ET_0 = \frac{0.408\Delta\,(R_n - G) + \gamma \dfrac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma\,(1 + 0.34u_2)} \qquad (1)$$

where ET_0 = reference evapotranspiration (mm day^{-1}); R_n = net radiation at the crop surface (MJ m^{-2} day^{-1}); G = soil heat flux density (MJ m^{-2} day^{-1}); T = mean daily temperature at 2 m height (°C); u_2 = wind speed at 2 m height (m s^{-1}); e_s = saturation vapour pressure (kPa); e_a = actual vapour pressure (kPa); $e_s - e_a$ = saturation vapour pressure deficit (kPa); Δ = slope of vapour pressure curve (kPa°C^{-1}); γ = psychrometric constant (kPa°C^{-1}) = $0.665 \times 10^{-3}.P$; and P = atmospheric pressure (kPa).

Evapotranspiration V/s Water Resources

About 84 per cent of the total population in Rajasthan lives in rural areas and 78 per cent of the rural population depends on agriculture. Out of total available surface and ground water, about 85% is being used for agriculture. Table 1 presents projected water demand of Rajasthan for various sectors. Agriculture continues to be the major sector of water demand even in coming four decades. Water, as such and also as carrier of large amount of nutrients, is required in a large measure for the successful growth of the plants. The metabolic activity of cells and plants is closely related to their water content.

The total quantity of water required by different crops/plants for the essential physiological functions are less than 1% of the total water absorbed. Most of the water entering the plant is lost in transpiration and evaporation from the soil surface. However, failure to replace the water lost by plant in transpiration and evaporation from soil surface results in the loss of turgidity, cessation of growth and eventual death of plant from dehydration. Hence, for successful crop production evaporation demand of soil

Table 1. Projected sectoral water demand for Rajasthan (billion cubic metre)

Purpose/Year	*2005*	*2015*	*2045*
Domestic	2.6(6.5%)	3.2(7.1%)	4.7(8.2%)
Livestock	0.9(2.2%)	1.1(2.4%)	1.3(2.3%)
Irrigation	35.9(89.5%)	40(88.7%)	49.1(86.0%)
Others	0.7(1.7%)	0.8(1.8%)	2(3.5%)
Total	40.1	45.1	57.1

* Figures in parenthesis indicate % of total water demand.

Source: Report of expert committee on integrated development of water resources, Government of Rajasthan, June 2005.

surface and transpiration demand of plant/crop must be satisfied. So to meet the evapotranspiration demand, about 84-85% of total water resources is being used. Thus, evapotranspiration demand has direct bearing on the total water demand.

RESULTS AND DISCUSSION

The greatest certain threat from climatic changes is by increase in evaporative losses and water demands caused by higher temperature (Irving, 1993). Globally evapotranspiration trends are projected for +5% to +10% increase due to increase in temperature by +2 to +5°C under equivalent doubling of atmospheric CO_2 from pre-industrial level (Schneider et al., 1990). Wetherald and Manabe (1981) found that global evaporation changes by 3% when temperature changes by 1 °Celsius. Similarly, Budyko (1982) suggests a 5% increase in evapotranspiration demand for each degree Celsius rise in temperature. Enhanced evapotranspiration would be primarily a consequence of higher air and land surface temperature. Even in tropics, where temperature increase are expected to be smaller than elsewhere, the increased rate of loss of moisture from plants and soil could be considerable (Rind et al., 1989; Parry, 1990). Lal and Chander (1993) studied the effects of greenhouse warming on the water resources of the Indian subcontinent and suggested a rise in annual mean surface temperature of 2.0-3.5°C over the Indian subcontinent by the year 2090. According to them warming would be most pronounced over the northwestern India.

Weekly reference evapotranspiration was calculated using above described Penman-Monteith equation. Sensitivity of ET_0 has been studied by increasing temperature from 1 to 3% as described earlier while keeping other parameters constant. The normal average annual evapotranspiration of the Rajasthan state is estimated as 1701 mm. As small as 1% increase in temperature (≤0.42°C based on normal maximum temperature of Rajasthan) will enhance the evapotranspiration demand by 11.7 mm on annual basis. It will cause an additional annual water demand of 718 mcm and 2,245 mcm for the whole state based on net irrigated area (61,345 km^2) and total cropped area (1,92,302 km^2) respectively. As per 2001 records, the total available utilizable ground water for whole Rajasthan is 11,159 mcm and increase of 1% in temperature will put additional stress of 6.43–22.16% on existing groundwater resources based on present landuse pattern. Increase in temperature by 1% will reduce number of safe districts from 6 to 3 and bring additional districts in the category of 'critical' and 'overexploited'. Similarly, an increase in temperature by 2-3% from normal data (i.e. 0.82–1.24°C) due to increased concentration of greenhouse gases will leave only one district in the category of 'safe' zone and remaining 31 districts will be mostly in the category of 'overexploited' (Table 2). The satellite data

Table 2. District-wise present status (2002) of cropped area and stage of groundwater development in Rajasthan State

Districts	*Total area (Km^2)*	*Total cropped area (Km^2)**	*Total irrigated area (Km^2)*	*Net annual groundwater availability (mcm)*	*Existing gross groundwater draft (mcm)*	*Stage of groundwater development (%)*	*Category of ground water development under increased temperature scenario*			
							Present	*1%*	*2%*	*3%*
Ajmer	8,423	4,233	949	314	349	111	OE	OE	OE	OE
Alwar	7,829	7,849	4,568	912	1112	122	OE	OE	OE	OE
Banswara	5,065	2,748	476	163	39	24	S	S	S	S
Baran	6,997	4,514	2,317	495	321	65	S	SC	SC	SC
Barmer	28,173	16,504	1,505	250	256	102	OE	OE	OE	OE
Bharatpur	5,071	5,626	2,741	514	480	93	C	C	OE	OE
Bhilwara	10,475	4,096	1,198	427	452	106	OE	OE	OE	OE
Bikaner	30,356	14,653	2,284	198	145	73	SC	C	OE	OE
Bundi	5,819	3,443	2,015	356	231	65	S	SC	SC	C
Chittorgarh	10,357	4,758	1,083	460	519	113	OE	OE	OE	OE
Churu	13,859	11,408	581	198	117	59	S	S	SC	SC
Dausa	3,405	3,150	1,563	269	295	110	OE	OE	OE	OE
Dholpur	3,009	1,587	549	237	246	104	OE	OE	OE	OE
Dungarpur	3,856	1,283	132	93	71	76	SC	SC	SC	SC
Ganganagar	10,930	9,068	7,869	199	134	67	SC	OE	OE	OE
Hanumangarh	9,703	8,827	5,499	195	165	85	SC	OE	OE	OE
Jaipur	11,055	8,150	4,226	684	1016	148	OE	OE	OE	OE
Jaisalmer	38,392	4,674	907	53	40	75	SC	C	OE	OE
Jalore	10,566	7,409	2,022	424	827	195	OE	OE	OE	OE
Jhalawar	6,322	4,170	1,240	398	381	96	C	C	OE	OE
Jhunjhunu	5,917	6,097	2,426	243	420	173	OE	OE	OE	OE
Jodhpur	22,564	12,278	1,766	393	661	168	OE	OE	OE	OE
Karauli	5,052	2,705	913	413	341	83	SC	C	C	C
Kota	5,211	3,880	2,059	404	221	55	S	S	SC	SC
Nagaur	17,644	13,654	2,948	628	842	134	OE	OE	OE	OE
Pali	12,331	5,829	1,121	413	330	80	SC	SC	C	C
Rajsamand	4,551	915	109	154	144	93	C	C	C	C
S.Madhopur	4,994	3,179	1,261	385	312	81	SC	SC	C	C
Sikar	7,742	6,716	2,719	325	345	106	OE	OE	OE	OE
Sirohi	5,179	1,668	508	266	247	93	C	C	C	C
Tonk	7,180	4,673	1,529	415	269	65	S	SC	SC	SC
Udaipur	14,621	2,559	266	284	299	105	OE	OE	OE	OE
TOTAL	3,42,648	1,92,302	61,346	11,159	11,626	104	OE	OE	OE	OE

* Total cropped area includes area sown more than once, i.e. double cropped area also. S – Safe zone (< 65%); SC – Semi Critical (65%-85%); C – Critical (85%-100%); and OE – Over Exploited (>100%)

Source: GOR, 2002.

of Rajasthan by IRS 1A/1B and LISS for 1992-93 shows a total wetland area of 3,450 km^2 (i.e. average exposed area of all natural and manmade water bodies) which includes 1,239 km^2 ha as natural and 2,210 km^2 as man-made wetland area. Increase in evaporation due to global warming will cause additional annual water loss of 40.4, 80.7 and 121 mcm for 1, 2 and 3% increase in temperature, respectively (Table 3).

Table 3. Likely effect of global warming on water resources of Rajasthan

Category of groundwater development stage	*No. of districts under different groundwater zone*			
	Present status (2002)	*Temperature increase*		
		1%(0.4°C)	*2%(0.8°C)*	*3%(1.2°C)*
Safe zone (< 65%)	6	3	1	1
Semi critical zone (65%-85%)	8	6	6	5
Critical zone (85%-100%)	4	7	5	6
Over exploited zone (>100%)	14	16	20	20
Total	32	32	32	32
Additional groundwater demand based on irrigated area alone (mcm)		718	1,436	2,154
Additional groundwater demand based on total cropped area (mcm)		2,250	4,500	6,750
Addition water loss as evaporation from wetlands (mcm)		40	81	121

Globally, projected increase in temperature/evapotranspiration demand is coupled with increase in precipitaion by almost same magnitude. However, it is projected that shift will be more towards extreme events. The area with higher rainfall is likely to have more rainfall and area with less rainfall will have lesser rainfall. Some of the most pronounced year to year variability in extreme weather events such as droughts in many parts of Asia has been linked to El Niòo events. At least half of the severe failures of Indian summer monsoon since 1871 have been occurred during El Niòo years (Webster et al., 1998). In the event of enhanced warming, higher frequency of drought conditions in some part of the India is projected.

Since this state is not blessed with good perennial river systems, any increase in water demand requires careful planning for future water resource development. More emphasis is needed to develop technologies for reducing water losses in reservoirs, conservation of rainwater and development of such crop varieties that require less water. So it is high time for the planners/users/water resources managers to think in term of expected water demand due to global warming and its likely effect on water resources of Rajasthan. The availability of water has direct bearing on the type of crops to be grown and will determine the economy of the state.

CONCLUSIONS

Water will continue to be a vital resource in arid and semi-arid regions of the world, and conflict over its access and possession are likely to worsen in water stressed regions such as Rajasthan. Even without changes in other parameters water availability can be decreased by 10% or more simply owing to temperature increase of 2°C (≈4.8% increase over mean maximum temperature of the state i.e. 41.6°C)–well within the range of expected change. Globally average precipitation is projected to increase, but at regional scale both increases and decreases are projected. In terms of changes in rainfall over India, no clear trend of increase or decrease in average annual rainfall over India have been observed (Lal, 2001). In view of current uncertainties, no useful prediction about regional patterns of rainfall can be made at this point of time. However, it is clear that in some regions, a relatively small decrease in water availability can readily produce drought conditions. In India, for example, lower than average rainfall in 1987 reduced food grain production from 152 to 134 million tonnes, lowering food buffer stock from 23 to nine million tonnes. Increase in risk and intensity of drought, especially in drought prone regions like Rajasthan, represent potentially the most serious impact of climate change on agriculture both at a regional and global level. These effects are independent of the increased demands from both human users and natural ecosystem that will occur at the same time.

A precautionary approach to the problem of global warming is warranted on the basis of its potential impact and the scale of the response that is necessary if that impact is to be avoided. On one hand intensive and global measures are needed to curb the concentration of greenhouse gases produced by various human activities and on other hand effective measures are needed to increase water use efficiency and reduce losses.

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