

Crop Water Demand under Climate Change Scenarios for Western Rajasthan

R.K. Goyal, Anurag Saxena, P.C. Moharana and C.B. Pandey

Central Arid Zone Research Institute, Jodhpur 342 003, India

Received: December 2012

Abstract: Climate change due to greenhouse effect is expected to cause major changes in natural eco-system of some of the areas. The change in climate is likely to profoundly influence hydrological cycle viz. precipitation, evapotranspiration, soil moisture, etc. Evapotranspiration (ET) being the major component of hydrological cycle will affect crop water requirement and future availability of water resources. The most visible signature of climate change is rise in temperature by few degrees varying over different regions. Temperature being principle source of energy, will have major effect on ET and consequently on water demand. The study has been conducted for hot arid zone of western Rajasthan. Penman-Monteith model was used for the estimation and sensitization of ET. Study suggests that as small as 1°C rise in temperature from normal will enhance the annual ET demand from minimum of 35 mm for Ganganagar district to maximum of 96 mm for Jaisalmer district. Enhanced ET would primarily be a consequence of higher air and land surface temperature. The increase in ET demand will have a direct bearing on total water demand for irrigation. The rise in temperature by 1°C will cause an additional annual water demand of 1570.9 Mm³ for the entire western Rajasthan based on net irrigated area of 31,64,512 ha. The total available utilizable ground water for western Rajasthan is 3516.9 Mm³ and rise of 1°C in normal temperature will put additional stress of 44% on existing groundwater resources based on present land use pattern. An attempt has been made in the present study to estimate the water demand under climate change scenario for the hot arid zone of western Rajasthan.

Key words: Evapotranspiration, water resources, global warming, climate change.

Global climate change has emerged as a major scientific and political issue in last two decades. Global warming issue was first discussed in United Nations Conference on Environment and Development (UNCED) at Rio de Janeiro, during 3-14 June, 1992 and reported a rise by few degrees in average annual temperature worldwide. There are sufficient evidences to show that earth's temperature has risen by more than 0.5°C since 1880 and continues to rise at a 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 going on worldwide to understand/predict the effects

of global warming on the various aspects of ecosystem (Ravindranath and Sukumar, 1996; Liu *et al.*, 1997; Mendelsohn and Dinar, 1999; Mathauda *et al.*, 2000; Roos *et al.*, 2002; Mall *et al.*, 2004). The main reason for global warming is increase in concentration of greenhouse gases in the atmosphere. The important greenhouse gases are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and tropospheric ozone (O₃). 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, ET, soil moisture, etc. (Nemec and Schaake, 1982; Gleick, 1986; Bultot *et al.*, 1988). ET being the major component of hydrological cycle will affect crop water requirement and future planning and management of water resources. Following the approach of Martin *et al.* (1989) and Rosenberg *et al.* (1989), an attempt has been made in the present study to understand the implications of global warming

*E-mail: rkgoyal24@rediffmail.com

on the water demand of western hot arid zone of Rajasthan.

Materials and Methods

Study area

The Indian hot arid region is situated between 22°30' and 32°05' N latitudes and from 68°05' to 75°45' E longitudes, covering western part of Rajasthan (19.6 Mha, 69%), north-western Gujarat (6.22 Mha, 21%) and south-western part of Haryana and Punjab (2.75 Mha, 10%). The majority of the hot arid zone falls under north-western part of Rajasthan covering 12 districts (Fig. 1). Rainfall distribution in the region is highly uneven over space and time (CV>60%). The region receives low rainfall (<100 mm to 500 mm), has high ET and high temperature regime. Groundwater is deep and often brackish. The western-central area is devoid of drainage system and surface water resources are meager. Due to low and erratic

rainfall, replenishment of water resources is also very poor. With vast variations in rainfall and ground water availability, the differences in access/availability of water are also apparent. While average annual rainfall of Rajasthan state is 531 mm; it is 318 mm for the western parts of Rajasthan.

As such whole Rajasthan state is categorized as the driest and water scarcest state in the country. The annual per capita water availability in the state is below 1000 m³ since 1991 (Narain *et al.*, 2006). Increasing pollution by large and small industrial units, unregulated mining and over-extraction of water from deep wells also add to the poor water quality problem. Rapid urbanization and industrialization make such existing differences even more glaring. Under scenario of water scarcity further reduction in availability of water due to global warming will seriously affect the agricultural production. Rajasthan's

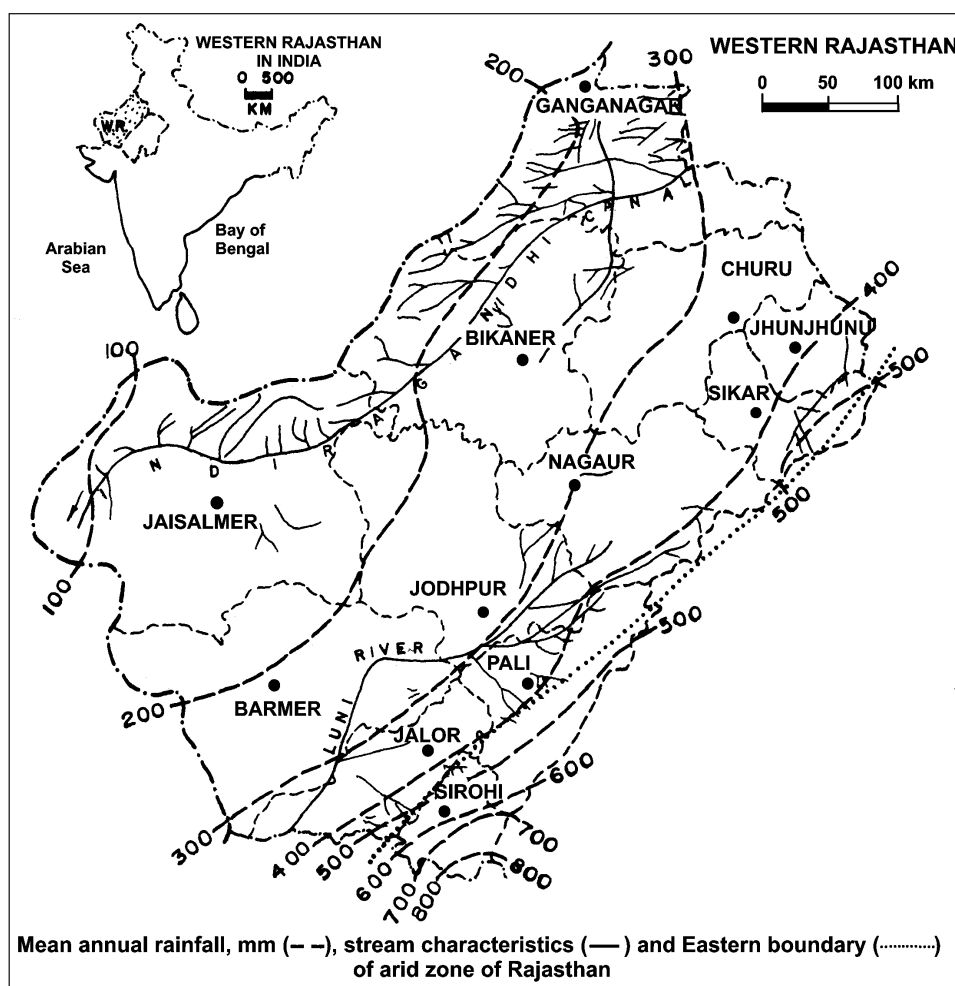


Fig. 1. Western hot arid Rajasthan - physiography.

economy is primarily agricultural and over 60% of the State's population is dependent on agriculture. Agriculture contributes about one-fourth to the State's Gross Domestic Product. Growth of the agriculture sector therefore has an important impact on State's economy and more importantly on the lives of people dependent on agriculture. Any adverse effect of global warming on agriculture will have serious implications for Rajasthan.

Data used

About 35 years (1973-2008) weekly meteorological data of all the 12 districts of western Rajasthan have been used as reference point for the study. The selected period accommodates all typical climatic events 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. As specific data for climate change for the western Rajasthan are not available, therefore, the most visible signature of climate change i.e. temperature has been used for the sensitization. An expected rise in temperature from +1 to +2°C (Pant and Kumar, 1997) from normal values has been used in the analysis. The average maximum temperature varies from 22.8°C to 41.6°C. Change in CO₂ concentration and precipitation is not considered in the present study as this is indirectly related to the changes in other meteorological parameters.

Estimation of evapotranspiration

The selection of a particular model for the estimation of ET depends upon the type of meteorological data available for the given region and the accuracy desired in the computation of water needs. There are several models described by Eagleson (1978), Viessman *et al.* (1977), Doorenbos and Pruitt (1977) for the estimation of reference evapotranspiration (ET_o). FAO recommended the universal adoption of the Penman-Monteith combination method for estimation of ET_o . 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_o can be expressed as

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

where,

ET_o = reference ET (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 vapor pressure (kPa)

e_a = actual vapor pressure (kPa)

$e_s - e_a$ = saturation vapor pressure deficit (kPa)

Δ = slope of vapor pressure curve (kPa°C⁻¹)

γ = psychrometric constant (kPa°C⁻¹) = 0.665 × 10⁻³.P

P = atmospheric pressure (kPa)

Results and Discussion

Weekly ET_o was calculated using above described Penman-Monteith equation. Sensitivity of ET was studied by varying temperature within a range as described earlier while keeping other parameters constant. The normal average annual ET of the western Rajasthan varied from minimum of 1502 mm for Nagaur to maximum of 2177.2 mm for Barmer (Table 1). According to Irving (1993), the greatest threat from climatic changes is by increase in evaporative losses and water demands caused by higher temperature. Globally ET trends are projected for +5% to +10% increase due to rise in temperature by +2 to +5°C (Schneider *et al.*, 1990). Wetherald and Manabe (1981) found that global evaporation changes by 3% when temperature changes by 1°C. Similarly, Budyko (1982) suggests a 5% increase in ET demand for each degree Celsius rise in temperature.

Table 1. Annual evapotranspiration demand under global warming

District	Evapotranspiration (mm)				
	Normal	1°C rise in temp.	Net increase in ET (mm)	2°C rise in temp.	Net increase in ET (mm)
Barmer	2177.2	2224.9	47.7	2272.7	95.5
Bikaner	2009.7	2055.0	45.3	2100.5	90.8
Churu	1702.2	1737.4	35.2	1772.8	70.6
Ganganagar	1632.4	1667.5	35.1	1702.8	70.4
Hanumangarh	1973.4	2018.2	44.8	2063.0	89.6
Jaisalmer	2064.0	2160.0	96.0	2256.0	192.0
Jalor	1905.0	1970.0	65.0	2040.0	135.0
Jhunjhunu	1819.0	1883.0	64.0	1950.0	131.0
Jodhpur	2002.0	2045.8	43.8	2089.9	87.9
Nagaur	1502.0	1583.0	81.0	1669.0	167.0
Pali	2071.6	2117.4	45.8	2163.5	91.9
Sikar	1528.0	1569.0	41.0	1611.0	83.0

Table 1 presents the future scenario of annual ET demand in response to expected change in temperature. As small as 1°C rise in normal temperature will enhance the ET from minimum of 35 mm for Ganganagar district to highest of 96 mm for Jaisalmer district. Spatial distribution of enhanced ET demand has been processed in GIS and presented in Fig. 2. Enhanced ET would primarily be a consequence of higher air and land surface temperature.

The increase in ET demand will have a direct bearing on total water demand for irrigation. The rise in temperature by 1°C will cause an additional annual water demand of 1570.9 Mm³ for the entire western Rajasthan based on net irrigated area of 3.16 Mha (Table 2). The total available utilizable ground water for western Rajasthan is 3516.9 Mm³ and rise of 1°C in normal temperature will put additional stress of 44% on existing groundwater resources based on present land use pattern.

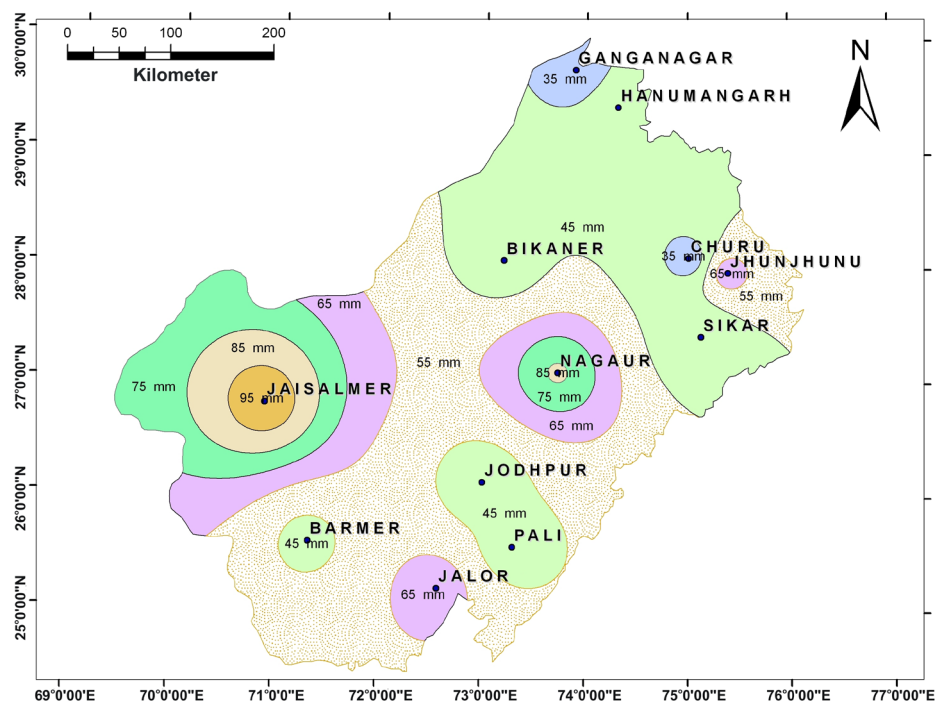


Fig. 2. Spatial distribution of enhanced ET demand under 1°C rise in temperature.

Table 2. Additional annual water requirement for irrigation under global warming by 1°C in western Rajasthan

District	Total area (ha)	Total cropped area (ha)	Total irrigated area (ha)	Net annual groundwater availability (Mm ³)	Additional water requirement for irrigation (Mm ³) (+1°C scenario)
Barmer	2817332	1650376	150540	249.8049	71.81
Bikaner	3035589	1465305	228355	197.6075	103.44
Churu	1385889	1140803	58115	197.6883	20.46
Ganganagar	1092960	906759	786859	198.8341	276.19
Hanumangarh	970315	882697	549853	194.6094	246.33
Jaisalmer	3839154	467391	90745	52.5923	87.12
Jalor	1056602	740878	202153	423.6140	131.40
Jhunjhunu	591682	609659	242584	243.0369	155.25
Jodhpur	2256405	1227843	176571	393.1304	77.34
Nagaur	1764383	1365402	294800	628.1586	238.79
Pali	1233079	582884	112059	413.3910	51.32
Sikar	774244	671578	271878	324.5240	111.47
Total	20817634	11711575	3164512	3516.9914	1570.92

Since western Rajasthan is not blessed with good perennial river system, any increase in water demand requires careful planning for future water resource development. More emphasis is needed to develop technologies for reducing water losses from 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 crop 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 conflicts 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 44% or more simply due to temperature rise of 1°C - well within the range of expected change. Therefore, a relatively small decrease in water availability can readily produce drought conditions. 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 regional and global level. These effects are independent of the increased biological and natural ecosystem demand 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 greenhouse gases produced by various human activities and on other hand effective measures are needed to increase water use efficiency and reduce water losses.

References

- Allen, R.G., Pereira, L.S., Raes, Dirk and Smith Martin 1998. *Crop Evapotranspiration*. FAO Irrigation and Drainage Paper 56 Rome, 300 p.
- Budyko, M.I. 1982. *The Earth's Climate: Past and Future*. International Geophysics Series, New York, Academic Press.
- Bultot, F., Dupriez, G.L. and Gellens, D. 1988. Estimated annual regime of energy balance components, evapotranspiration and soil moisture for a drainage basin in case of a CO₂ doubling. *Climate Change* 12: 39-56.
- Doorenbos, J. and Pruitt, W.O. 1977. *Crop Water Requirements*. FAO Irrigation and Drainage Paper 24 Rome, 144 p.
- Eagleson, P.S. 1978. Climate, soil, and vegetation. *Water Resource Research* 15: 705-776.
- Gleick, P.H. 1986. Methods for evaluating the regional hydrologic impacts of global climatic changes. *Journal of Hydrology* 88: 97-116.
- Houghton, J.T., Jenkins, G.J. and Ephraums, J.J. 1990. *Climate Change: The IPCC Scientific Assessment*. Cambridge University Press, Cambridge.

- Irving, M. Minitzer 1993. *Confronting Climate Change: Risk, Implications and Responses*. Cambridge University Press. 382 p.
- Liu, G., Ding, J., Liu, G.D. and Ding, J. 1997. Applying the BP neural networks to study effects on water resources in Yalongjiang and Jialingjian river catchments due to variations of climate factors. *China Environmental Science* 17(5): 414-417.
- Mall, R.K., Lal, M., Bhatia, V.S., Rathore, L.S., Singh, Ranjeet and Singh, R. 2004. Mitigating climate change impact on soybean productivity in India: A simulation study. *Agricultural and Forest Meteorology* 121: 113-125.
- Martin, P., Rosenberg, N.J. and McKenney, M.S. 1989. Sensitivity of evapotranspiration in wheat field, a forest and a grassland to change in climate and direct effect of carbon dioxide, *Climate Change* 14: 117-151.
- Martinez-Austria, P. 1994. Efficient use of irrigation Water. *Efficient Water Use* Montevideo, UNESCO/ROSTLAC. 379 p.
- Mathauda, S.S., Mavi, H.S., Bhangoo, B.S. and Dhaliwal, B.K. 2000. Impact of projected climate change on rice production in Punjab (India). *Tropical Ecology* 41(1): 95-98.
- Mendelsohn, R. and Dinar, A. 1999. Climate change, agriculture, and developing countries: Does adaptation matter? *World Bank Research Observer* 14(2): 277-293.
- Narain Pratap, Khan, M.A. and Singh, G. 2006. Potential for water conservation and harvesting against drought in Rajasthan. Working paper No. 104, Drought series: paper 7, IWMI. 23 p.
- Nemec, J. and Schaake, J. 1982. Sensitivity of water resources system to climate variation. *Hydrological Science Journal* 27: 327-343.
- Pant, G.B. and Kumar, K.R. 1997. *Climate of South Asia*. John Wiley & Sons Ltd., West Sussex, U.K. 320 pp.
- Ravindranath, N.H. and Sukumar, R. 1996. Impacts of climate change on forest cover in India. *Commonwealth Forestry Review* 75: 76-79.
- Roos, M., Burt, C.M. and Anderson, S.S. 2002. Suggested research on the effect of climate change on California water resources. *Proceedings of the USCID-EWRI Conference on Energy, Climate, Environment and Water -Issues and Opportunities for Irrigation and Drainage*, San Luis Obispo, California, USA.
- Rosenberg, N.J., McKenney, M.S. and Martin, P. 1989. Evapotranspiration in greenhouse warmed world: A review and a simulation, *Agricultural and Forest Meteorology* 47: 303-320.
- Schneider, S.H. 1989. *Global Warming: Are We Entering The Greenhouse Century?* San Francisco, Sierra Club Books
- Schneider, S.H., Gleick, P.H. and Mearns, L.O. 1990. Prospects for climate change. In *Climate Change and US Water Resources* (Ed. P.E. Waggoner), pp 41-47. John Wiley and Sons, New York.
- Singh, P. and Kumar, N. 1997. Impact assessment of climate change on the hydrological response of a snow and glacier melt runoff dominated Himalayan river. *Journal of Hydrology* 193: 316-350.
- Viessman, Warren, J.R., Knapp, John W., Lewis, Garry, L. and Harbaugh, Terence E. 1977. Hydrologic Abstractions. In *Introduction to Hydrology* (Ed. Thomas Y. Crowell), pp. 704, Harper & Row Publisher Inc., New York.
- Wetherald, R.T and Manabe, S. 1981. Influence of seasonal variation upon the sensitivity of a model climate. *Journal of Geophysics Research* 86(C2): 1194-1204.