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Temperature extremes, moisture deficiency and their impacts on dryland agriculture in Gujarat, India

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ABSTRACT: In arid regions, water scarcity poses a serious threat to dry land agriculture. High evapo-transpiration and limited water holding capacity of the soil hampers crop production. Falling under dryland agricultural region, India's Gujarat state often experiences moisture deficiency in soil and plants. The present study analyses the adverse effects of heat waves and temperature extremes on agricultural droughts in Gujarat. Data of maximum, minimum and mean temperatures, rainfall, potential evapo-transpiration and heat waves during 2001–2010 were analysed for 8 stations on seasonal and annual time scales, and correlated with crop cycles. The results showed that most parts of Gujarat suffer from frequent droughts, either due to low rainfall or high evapo-transpiration, or both. The study also revealed that moisture deficit was acute, particularly in the years of heat wave. Heat wave events were also found responsible for moisture-stress and thermal-stress in vegetation, leading to reduced crop yield and agricultural drought.

1 INTRODUCTION

In the ensuing decades of climate change, water and food crisis is all but inevitable. In such a precarious scenario, getting into the skin of the dynamics and relationship between the various climatic parameters is the need of the hour. Correlation among these indicators can probably aid in reviewing the irrigation facilities during various crop cycles. Not only does the Crop Water Requirement (CWR) vary in one particular crop season, but the geographic location influences the correlation between different parameters which is also a vital element. A detailed study of the latter can help in implementing effective strategies for mitigating the drought impact.

According to the World Meteorological Organization (2013), both the hemispheres of the world experienced the warmest temperatures during the decade of 2001–2010. This decade also saw drought occurrences in all parts of the world, with the deadliest one being the all India drought during 2002 (also an EL-Nino year), affecting more than 300,000,000 people. Gujarat, being a chronically drought-affected region, has a probability of drought occurrence every four years. In the last decade (2001–2010), significant increase in the temperature extremes and number of heat wave days were noticed in Gujarat. During this period, Gujarat experienced four droughts in the years of 2001, 2002, 2004 and 2009, out of which except 2001 rest were El-Nino years. The impact of heat waves and temperature extremes on agriculture was not studied before in detail. In this paper, an effort has been made to understand the impact of heat waves on the occurrence of extreme temperatures, rise in evapo-transpiration rates and moisture deficit, and thereby on crop yield. The effect of heat waves and high temperature on crops can be identified not only by measuring the evapo-transpiration but also through comparison of the moisture deficit with the CWR of particular crops grown during different seasons, which will indicate the necessity of irrigation in those areas.

2 STUDY AREA

Gujarat is one of the most prosperous states of India, comprising 27 districts with a total geographical area of 196000 km². According to the report (2013) of the Agriculture and Cooperation Department, Government of Gujarat, drought-prone areas are spread over all the agro-climatic regions in the state, namely South Gujarat (heavy rain area), Middle Gujarat, North Gujarat, Bhal and Coastal Area, South Saurashtra, North Saurashtra and North West Zone. Gujarat is located near the Thar Desert in the north. Therefore, most of the land is arid. Gujarat receives rainfall during the monsoon season (June to September), which is unevenly distributed in space and time varying in the range of 300–350 mm in Kutch, within 600–700 mm in Saurashtra and North Gujarat, to more than 1,500 mm in South Gujarat. Eight stations have been selected (Figure 1) namely Ahemdabad, Baroda, Surat, Rajkot, Kutch, Banaskantha, Bhavngar and Junagarh for the study choosing one station from each climatic zone.

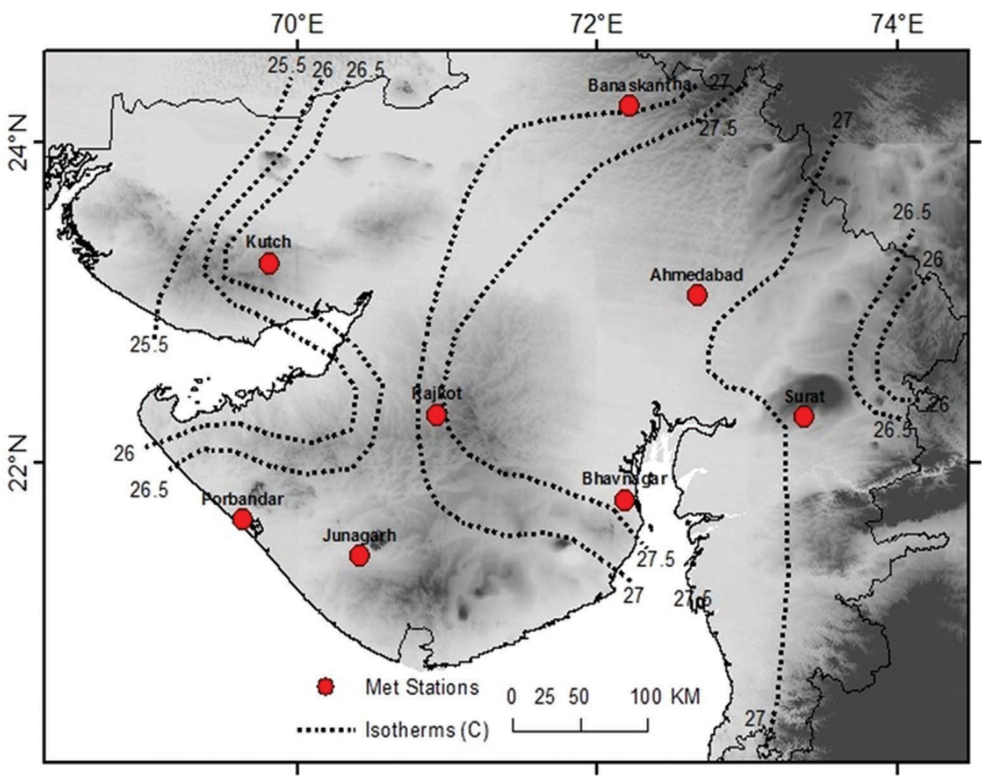

Figure 1. Location map of Gujarat state, India. Topography shown in the background.

3 DATA AND METHODOLOGY

3.1 *Data source*

- Rainfall: District-wise monthly rainfall data from Indian Meteorological Department (IMD), Pune from 2001–2010.
- Temperature: Monthly mean maximum temperature data from IMD, 2001–2010.
- Heat Wave: Severe Heat Wave data and Medium Heat Wave data for Gujarat was obtained from IMD from 1981–2010.
- El Nino: World Meteorological Organisation (WMO).
- Crop Water Requirement (CWR): Food and Agricultural Organization of the United Nations (FAO) 1998, Indian Council of Agricultural Research (ICAR).

3.2 *Methodology*

Gujarat in general falls in the category of high Potential Evapo-Transpiration (PET) zone with annual PET rates varying from 1500 mm to 2000 mm (IMD Science Report No.36). Evapo-transpiration is one of the major hydrological components for determining the water budget and is indispensable for the calculation of a reliable recharge and groundwater flow analysis. Calculation of PET by Thornthwaite's (1948) method was done with the help of open access software (National Institute of Hydrology, IIT Roorkee, GUI Interface was used). The MDI is usually determined on the basis of annual precipitation and annual PET as adapted by Thornthwaite and Mather in 1955. In this article, the monthly MDI for dryland stations in India based on normal data has been worked out. Cumulative MDI values of all the months (June to September) of the Kharif (monsoon) season was computed using the Thornthwaite's equation to correlate with the crop yield and heat wave data using the formula: **MDI = (P – PET)/PET*100** where, P = Precipitation (in millimeters) and PET = Potential evapo-transpiration (in millimeters). The calculated values for CWR for the major Kharif crops (having maximum percentage of area under cultivation) in each district of Gujarat for the entire season was obtained from Indian Council of Agricultural Research (2012) which used the formula: **ET crop = $K_c \times ET_o$** Since the values for ET_o are normally measured or calculated on daily basis (mm/day), an average value for the total growing season has to be determined, and then multiplied with the average seasonal crop factor K_c. The CWR data for each of the crops was then compared with the MDI values to understand the imbalance between the two and the need for immediate irrigation facilities. Pearson's correlation coefficient (R) values were calculated. Comparison was made between the two values of heat wave and MDI, between heat wave and crop yield, and between MDI and crop yield. The comparisons were done by taking the average of R values for each of the stations separately as there are spatial variations in terms of types of crops grown, moisture deficit and crop water requirement.

4 RESULTS AND DISCUSSIONS

In this article, relationships amongst heat wave, moisture deficit, and crop yield are explored in both spatial and temporal scales. The results have been discussed in the following sections.

4.1 *Influence of heat wave on crop yield*

Heat waves raise the land-surface and air temperature and thereby affect the crop production as crops exposed to extreme heat may die quickly due to lack of moisture and excessive evapo-transpiration. It was observed that in the last decade (2001–2010) number of heat waves increased in Gujarat remarkably in comparison to previous three decades (1971–2000), and the number of heat wave days was highest in the year 2010 (Table 1). Number of heat wave days was remarkably high particularly in the drought years of 2002, 2004, 2009 and 2010 resulting in severe damage to crop health and significant reduction in crop yield.

Table 1. Year-wise number of heat wave days during 2001 to 2010.

Stations	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Ahmedabad	1	9	0	7	0	0	0	0	0	19
Baroda	0	7	6	11	2	0	0	0	2	12
Surat	1	7	4	8	3	0	4	0	3	10
Rajkot	3	7	0	12	0	1	0	0	2	9
Kutch	0	7	0	6	0	0	0	0	1	10
Banaskantha	0	5	2	13	0	0	0	2	0	18
Bhavnagar	3	2	0	5	1	0	0	0	0	11
Junagarh	1	3	2	6	5	1	2	0	9	2
Average	1	6	2	9	1	0	1	0	2	11

4.2 *Impact of heat wave on temperature, rainfall and moisture availability*

Heat waves cause rise in temperature during the summer but impact of heat waves continue also in the monsoon season (June–September), particularly in the month of June. Due to delayed monsoon and low rainfall, moisture deficiency is already high particularly in the drought years. Heat waves further aggravate the condition.

Strong correlations are also noticed between Heat Wave and MDI in seven out of eight stations with Junagarh being the only exception (Table 2) which indicates an increase in moisture deficit due to increase in heat wave. It can also be observed that in five out of eight stations (Ahmadabad, Rajkot, Kutch, Banaskantha and Bhavnagar) the average rainfall amount is very low compared to the average potential evapo-transpiration rate resulting in high moisture deficit.

It is noticed that the impact of heat wave on crop yield is negative for most of the stations. The correlation is found to be strongest ($R = -0.58$) for the Ahmedabad station but positive for Surat, Rajkot and Junagarh. For other stations, the negative impact of heat waves on crop yield is definite but low in comparison to Ahmedabad station (Table 2). For these stations, smaller correlation is most likely due to attenuation of the heat-wave impact by the overlapping positive impact of monsoon-rainfall on the crops.

4.3 *Relationship between moisture deficit and crop yield*

Adequate supply of moisture is crucial for the growth of crops. Heat waves cause moisture-stress and thermal-stress affecting vegetation health (Kogan 1995; Bhuiyan 2008; Bhuiyan and Kogan 2010) resulting reduced crop production. Various crops have different CWR, and if that is not met either by rainfall or by irrigation then moisture-stress develop in crops affecting their health, growth and ultimately production. Analysis in the present study shows that except Surat, at all other locations moisture was deficient during 2001–2010 (Table 2). Irrespective of drought or non-drought years, except Baroda and Junagarh which can be managed with irrigation water, the other areas show very high value of moisture deficit. During droughts, areas like Ahmedabad remain highly vulnerable as it suffers from excessive moisture deficit for cultivation of the main crop Cotton having high CWR. The other areas with very high moisture deficit have gradually adapted to drought-resistant crops like *Bajra* (Pearl Millet) and Groundnut, which have less crop water requirement (Table 2).

4.4 *Spatial pattern*

Although the areas apart from Ahmedabad, Baroda and Surat have adapted to cultivation of drought-resistant crops, they still suffer from moisture deficiency (Table 2) due to erratic monsoon behaviour and inconsistent rainfall patterns. The impact of moisture deficiency on crop yield is evident in the negative values of R between MDI and crop yield at all the stations (Table 2). Among all the stations, the highest negative correlation is found for Rajkot. This clearly indicates that moisture stress leads to decrease in crop yield, and the effect of

Table 2. Major Kharif crops, crop-water requirement, average P, PET and correlation among different variables at selected stations in Gujarat.

Stations	Kharif crops	CWR (mm)	Avg. P (mm)	Avg. PET (mm)	Avg. MDI* (Cum.)	MDI & CY (R)	HW & CY (R)	HW & MDI (R)
Ahmedabad	Cotton	600–700	754.9	1138.23	−223.65	−0.1	−0.58	0.41
Baroda	Cotton	600–700	968.11	880.71	−38.72	−0.15	−0.29	0.69
Surat	Rice	900–2500	1579.49	471.39	170.94	−0.44	0.27	0.33
Rajkot	Groundnut	450–600	691.21	1002.53	−230.88	−0.61	0.29	0.32
Kutch	*Bajra*	350–400	434.65	687.33	−291.08	−0.5	−0.1	0.33
Banaskantha	*Bajra*	350–400	642.04	967.71	−255.51	−0.24	−0.07	0.28
Bhavnagar	Groundnut	450–600	628.19	778.4	−248.59	−0.42	−0.09	0.69
Junagarh	Groundnut	450–600	1004.07	342.9	−23.72	−0.27	0.37	0.07

Bajra: (Pearl Millet); MDI (Cum.): Cumulated values of MDI (%) for four monsoon months.

moisture deficiency is not restricted to the period of heat waves but may persist even in the successive months.

5 CONCLUSIONS

The study has revealed that in the semi-arid state of Gujarat during 2001 to 2010, number of heat wave days have increased remarkably compared to the earlier decades, which has increased the PET. Comparatively higher PET than rainfall further resulted in moisture deficit in different districts across Gujarat. A positive relationship between heat wave and moisture deficit, and negative correlations between moisture deficit and crop yield, and also between heat wave and crop yield could be observed indicating a strong association among them. Through the analysis and comparison of the water requirement for major crops of Gujarat with moisture deficit, it is found that during the monsoon season the crops require additional water through irrigation. If the CWR is not met then that may lead to huge loss of crops. In certain instances where the CWR is low like *Bajra*, groundnut, etc, vegetation can resist the thermal stress. However, crops with higher water requirement are more susceptible to heat stress and usually bear the maximum damage in the events of monsoon failure, eventually leading to agricultural drought. The present study has found that moisture deficit was profound especially in the years of heat wave. Moisture-stress along with thermal-stress in vegetation is responsible for reduced crop yield and agricultural drought. Since heat wave influences both moisture-stress and thermal-stress, it emerges as a critical factor for triggering agricultural drought especially in drylands. Thus, considering only the rainfall deviations from the normal may not be effective or sufficient for drought mitigation in a country like India, where the government declares a drought solely based on arrival of the monsoon and the amount of rainfall. The facilities for irrigation should be extended to the areas where average rainfall is less than the evapo-transpiration. Due to the impact of high temperature, normal rainfall may also be not sufficient for the water requirements of the major crops in each district. In areas of high rainfall also, strategies to avoid crop loss can be adopted by shifting cultivation from crops with high CWR to drought resistant crops as the instances of heat waves have substantially increased recently. Air Temperature and its impact should also be studied and incorporated in policy making along with assessment of precipitation deficit for early drought monitoring and preparedness.

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