CarakaTani
Journal of Sustainable Agriculture
ISSN 2613-9456 (Print) 2599-2570 (Online)

Caraka Tani: Journal of Sustainable Agriculture, 38(1), 152-162, 2023
URL: https://jurnal.uns.ac.id/carakatani/article/view/64377
DOI: http://dx.doi.org/10.20961/carakatani.v38i1.64377

Analysis of the Effects of Climate Change on Cotton Production in Maharashtra State of India Using Statistical Model and GIS Mapping

Anirup Sengupta[1] and Mohanasundari Thangavel[2*]

[1]Department of Plant Science, Faculty of Agricultural and Food Sciences, University of Manitoba, Winnipeg, Canada; [2]School of Humanities and Social Sciences, Indian Institute of Technology Indore, Indore, India

[*]*Corresponding author:* mohana@iiti.ac.in

Abstract

Cotton is a prominent cash crop cultivated for fiber, edible oil and oil cake. A global environmental issue, like climate change, alters weather parameters necessary for the healthy growth and development of cotton plants, affecting fiber quality and economic yield. The study aims to illustrate the evidence of climate change in Maharashtra and assess its impact on the production of cotton in this region. The study was conducted in the state of Maharashtra, India. Geographic information system (GIS)-based models were created based on the vector data (geopolitical boundaries of the state of Maharashtra and its districts) and the corresponding raster attributes (meteorological data) to examine the changes in the patterns of distribution of temperature, rainfall and severity of drought (Standardized Precipitation Index-SPI) over the study period (1990 to 2015). Further, a statistical multiple linear regression model was developed using district-wise data on yield and climatic parameters obtained from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to estimate the relationship between the dependent variable (yield of cotton) and the independent variables (annual rainfall and annual mean temperature). GIS modeling and mapping provide evidence of changes in the spatial distribution of rainfall and temperature. Although the regression analysis seems weak, it is acceptable for natural systems because natural systems are complex and often highly variable, making it difficult to create a perfect model. The multiple linear regression model shows that such changes in climatic parameters have a significant negative impact on the economic yield of cotton.

Keywords: cotton cultivation; environmental stress; multiple linear regression; remote sensing data

Cite this as: Sengupta, A., & Mohanasundari, T. (2023). Analysis of the Effects of Climate Change on Cotton Production in Maharashtra State of India Using Statistical Model and GIS Mapping. *Caraka Tani: Journal of Sustainable Agriculture*, *38*(1), 152-162. doi: http://dx.doi.org/10.20961/carakatani.v38i1.64377

INTRODUCTION

Cotton is an important fiber crop across the world. It belongs to the genus *Gossypium* under the tribe Gossypieae of the family Malvaceae. Besides fiber, cotton is a source of edible oil and oil cake. India has around 42% of the world's area under cotton cultivation and is the second-largest producer of cotton accounting for about 26% of the world's cotton production (Cotton Corporation of India, 2021). The state of Maharashtra has the largest area under cotton cultivation in India (43.51 lakh ha in 2017 to 2018) (Cotton Advisory Board, 2019). Here, the commercially cultivated species of cotton comprises *Gossypium arboreum*, *G. herbaceum*, *G. hirsutum* and *G. barbadense* (Blaise and Kranthi, 2019).

Climate change is a serious global environmental issue resulting in rising temperatures, variability in rainfall and changes in the normal cycle of seasons (Malhi et al., 2021). The latest scientific studies reveal that the climate of the earth has significantly changed

* *Received for publication August 8, 2022*
Accepted after corrections January 15, 2023

in the last 50 years (Balasubramanian and Birundha, 2012). It has been projected by the Intergovernmental Panel on Climate Change (IPCC) that the global mean temperature would rise around 1.8 to 5.7 °C by 2100 (Masson-Delmotte et al., 2021). These changes in temperature and rainfall patterns have a serious impact on agriculture by exposing the plants to various abiotic stresses and reducing the economic yield (Palanisami et al., 2017; Karimi et al., 2018; Varga, 2021). This effect is more adverse in tropical regions consisting of developing nations like India, Pakistan, etc., (Iqbal et al., 2016).

Cotton is a perennial crop having an indeterminate growth habit. The main developmental stages of the cotton plant are: a) planting, b) plant development, c) flowering, d) boll formation and e) conditions about the end of the season (Wang et al., 2021). Due to climate change, there is a rise in average temperatures, disruptions in precipitation patterns affecting the water cycle, and frequent occurrences of extreme weather events (Ye and Grimm, 2013). Besides growth and development, it has been reported that higher temperature significantly affects fiber quality (Xu et al., 2017). Higher temperatures lead to an increased micronaire value (cross-sectional size of individual cotton fiber) that is an undesirable characteristic of cotton.

Growth and development of cotton are influenced by climate change leading to loss of yield and fiber quality mostly because of the cumulative effects of increasing temperature, reduced water availability and increased atmospheric evaporative demand (Li et al., 2021). Temperature alters boll size, boll development and maturity in cotton (Lokhande and Reddy, 2014). Another important weather parameter is rainfall, which affects cotton plants. Gwimbi and Mundoga (2010) evaluated the impact of climate change throughout the growing season of cotton in Africa and observed that production of cotton declined with the drop in precipitation and rise in temperature. On the other hand, high rainfall could lead to over-saturation and waterlogging, which further affects the growth of cotton (Adare et al., 2016). Similar observations were reported by Asaminew et al. (2017) in Ethiopia and Jans et al. (2021) in Syria and Egypt.

There are very few studies delineating climate change on a regional scale using modern geographic information system (GIS) techniques and studying its impact on the economically important cash crops. The present study attempts to illustrate the changes in annual rainfall, mean temperature, and evapotranspiration over a period of 25 years from 1990 to 2015 using remote sensing and GIS techniques and further statistically analyzes its impact on the productivity of cotton in Maharashtra, India. This would further help in developing sustainable strategies for management of our agroecosystems as well as promote climate-smart farming (Vyankatrao, 2017) for a better future.

MATERIALS AND METHOD

Study area

The study area (Figure 1) is the state of Maharashtra in India, comprising 36 districts extending between 15.37° to 22.6° N latitude and 72.36° to 80.54° E longitude, having an area of 307,713 km^2. Maharashtra state is surrounded by Gujarat and Madhya Pradesh in the north, Karnataka in the south, Chhattisgarh in the east, and the Arabian Sea in the west. Nasik, Dhule, Jalgaon, Ahmednagar, Pune, Satara, Sangli, Solapur, Kolhapur, Prabhani, Beed, Nanded, Osmanabad, Buldhana, Akola, Amaravati, Yeotmal, Wardha, Nagpur, Chandrapur, Jalna, Latur and Gadchiroli are some of the significant districts for cotton production (Nikam et al., 2022). The soil of this region is of residual type since it is derived from the basalts underneath. It is black in color and popularly known as '*regur*' or black-cotton soil (Bhattacharyya et al., 2013). The soil is clayey in nature, rich in iron whereas nitrogen and organic matter are critical; it has a high moisture retention capacity. The region is divided into 9 agro-climatic zones (Adhav et al., 2021): South Konkan, North Konkan, Western Ghat zone, Sub Montane zone, Western Maharashtra plain zone, Western Maharashtra scarcity zone, Central Maharashtra plateau zone, Central Vidarbha zone and Eastern Vidarbha zone.

Collection of data

Database of Global Administrative Areas (GADM), Terra Climate, and Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) data have been used to develop the geo-climatic informatics of the state of Maharashtra. Secondary data based on the official statistics published by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) on the district-wise yearly yield of cotton in Maharashtra, monthly precipitation and temperature for the period 1990 to 2015 have also been used in this study. Annual precipitation is the sum of monthly precipitations and annual temperature is the mean of average monthly temperatures for a year. The tabular data used in this study were sourced from the online repositories of ICRISAT and Climate Engine. The dataset obtained was analyzed using Microsoft Excel, STATA and QGIS 3.18.3. Table 1 illustrates the variables and their corresponding data sources used in the present study.

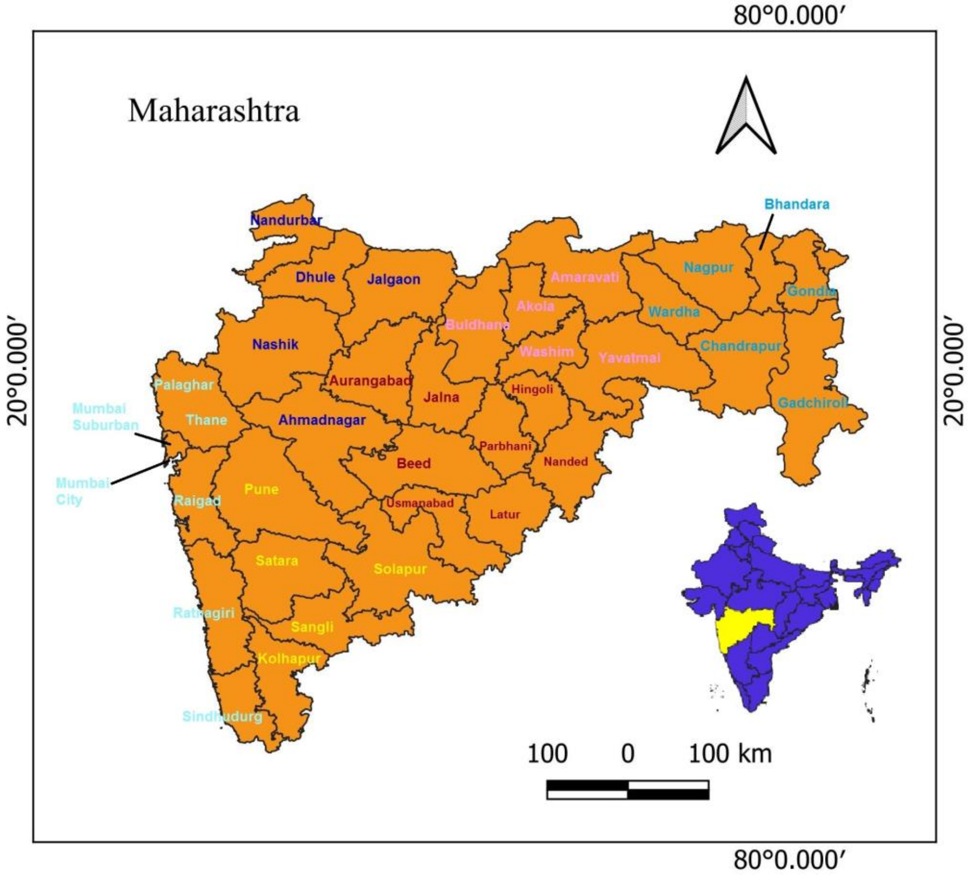


Figure 1. Study area: Maharashtra, India; location map (blue) depicts the geographical position of Maharashtra (yellow) in India

Table 1. List of variables and data sources

Variables	Data source	Format of data vector/raster	Period
District-level map of Maharashtra	- GADM (https://gadm.org/)	Vector	_
Maximum and minimum temperature (°C)	- Terra Climate (http://climateengine.org/data) - ICRISAT [District-wise] (http://data.icrisat.org/dld/src/crops.html)	Raster	1990-2015
Precipitation (mm)	- Terra Climate (http://climateengine.org/data) - ICRISAT [District-wise] (http://data.icrisat.org/dld/src/crops.html)	Raster	1990-2015
Standardized Precipitation Index (SPI)	- CHIRPS (http://climateengine.org/data)	Raster	1990, 2015
Yield of cotton (kg ha^{-1} $year^{-1}$)	- ICRISAT [District-wise] (http://data.icrisat.org/dld/src/crops.html)	Raster	1990-2015

GIS modeling

The raster data from Terra Climate were extracted by clipping with vector mask layer of the state of Maharashtra obtained from GADM (Version 3.6). The single grey bands obtained were replaced with pseudocolors for better observations and understanding. Accordingly, maps were drawn to illustrate the changes in climatic parameters over the duration of the study (1990 to 2015). The study also adopts the SPI formulated by McKee et al. (1993), to assess the regions affected by drought stress over this period. The software package QGIS 3.18.3 has been used to process all the information as per the requirements.

Multiple linear regression model

Multiple linear regression is used to predict the relationship between a continuous dependent variable and two or more independent variables (Uyanık and Güler, 2013). The independent variables are either continuous or categorical (dummy). It is a useful tool to study the effects or impacts of changes, i.e. it denotes the rate of changes in the dependent variable corresponding to the changes in the independent variables (Kang and Zhao, 2020). The model assumes that: (1) there should be normal distribution of the regression residuals, (2) the relationship between the dependent variable and the independent variables is linear, (3) the residuals are homoscedastic and approximately rectangular-shaped and (4) there is the absence of multicollinearity that is, independent variables are not too highly correlated.

This study takes into account two major climatic factors that affect the yield of cotton namely annual rainfall and annual mean temperature. District-wise yearly yield of cotton was taken as the dependent variable while annual rainfall and annual mean temperature were chosen to be the independent variables. A multiple linear regression model was formulated following the ordinary least squares procedure, expressed in Equation 1.

$$\text{yield} = f(\text{annual rainfall, annual mean temperature}) \quad (1)$$

Where yield (kg ha^{-1} year^{-1}) is the district-wise annual yield of cotton, annual rainfall is the sum of monthly rainfall of a district for a year (mm), and annual mean temperature is the average of the mean monthly temperatures of a district for a year (°C).

Softwares, including Microsoft Excel and STATA, were used to run the model and descriptive statistics. It is evident that even when the independent variables are zero there can be some amount of cotton yield due to irrigation and other factors. Thereafter, the model needs a constant. Hence, it becomes Equation 2.

$$\text{yield} = \alpha_0 + \alpha_1(\text{rainfall}) + \alpha_2(\text{temperature}) \quad (2)$$

Where α_0 is the constant; α_1 and α_2 are the contribution coefficients to be estimated; rainfall is the annual rainfall; temperature is the annual mean temperature; and yield is the district wise yield of cotton per year.

RESULTS AND DISCUSSION

Climatic variability affecting cotton production was explored using GIS-based models. Temperature is an important parameter regulating plant growth and development. The optimum range of temperature needed for biochemical and metabolic activities in plants is called the thermal kinetic window (TKW) (Burke et al., 1988). Temperatures above or below the TKW result in stress that limits plant growth and yield. The TKW for cotton growth is 23.5 to 32 °C (Zafar et al., 2018), with an optimum temperature of 28 °C (Sawan, 2017). Fruit retention decreases rapidly if exposed to a temperature of 40 °C or more for long (Luo et al., 2014). Figure 2 illustrates the changes in the spatial distribution of temperature in Maharashtra across the study period (1990 to 2015) by taking into account images of 1990, 2000, 2010 and 2015 obtained from Terra Climate data. It was observed that the regions experiencing a maximum temperature within the TKW range were gradually declining from 1990 to 2015.

Besides temperature, rainfall is an important factor governing the yield of crops. For perennial cash crops like cotton, the optimum annual rainfall should be 850 to 1050 mm (Sawan, 2013). Rainfall less than 550 mm or greater than 1200 mm has a serious impact upon the growth and development of the crop (Sawan, 2018). In course of time, the rainfall has become erratic (Figure 3). In some parts, there is scarcity of rain leading to moisture stress while in others there are excessive downpours resulting in water logging (Rana et al., 2014; Sreenath et al., 2022). Prolonged dry spells hamper the vegetative growth and maturity of cotton plants whereas excessive rainfall also impairs pollination, flowering and boll opening and reduces fiber quality (Iqbal et al., 2016).

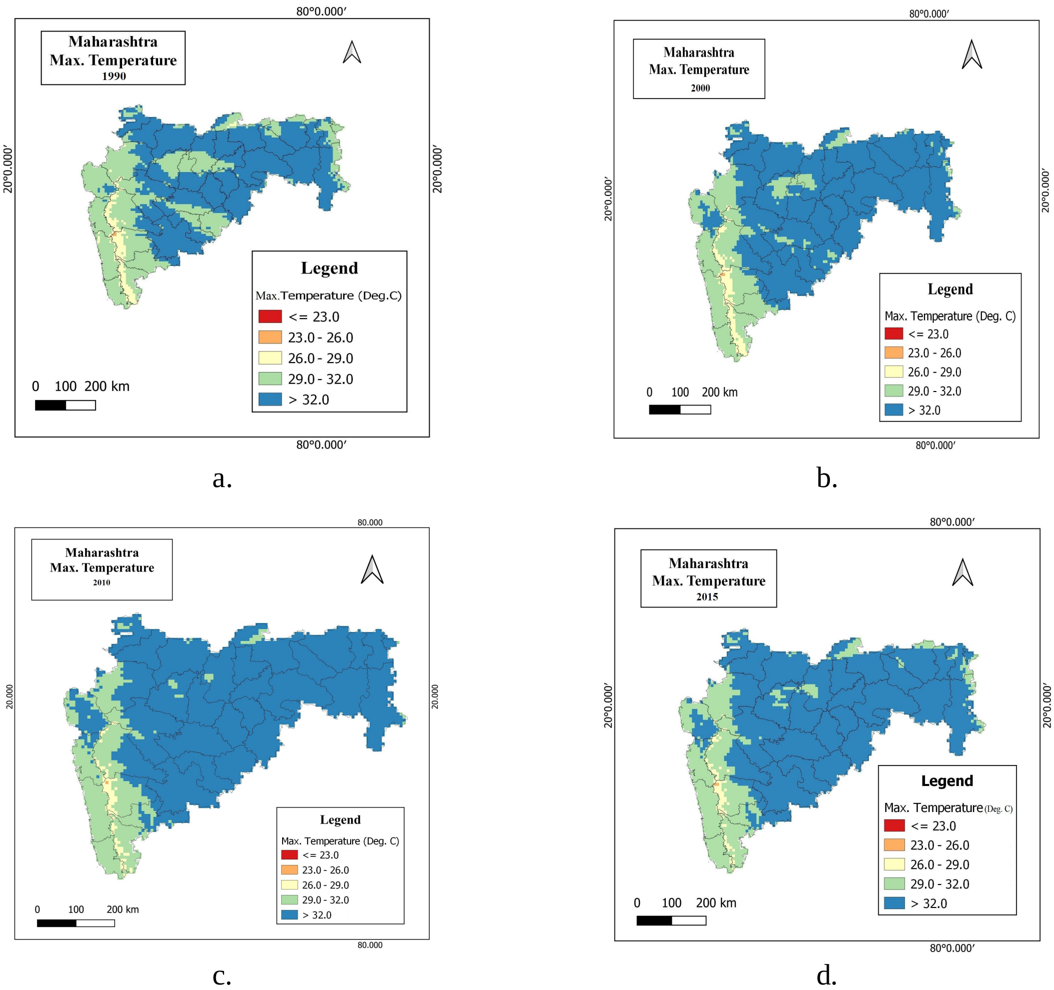


Figure 2. Spatial distribution of annual maximum temperature (a) 1990; (b) 2000; (c) 2010; (d) 2015

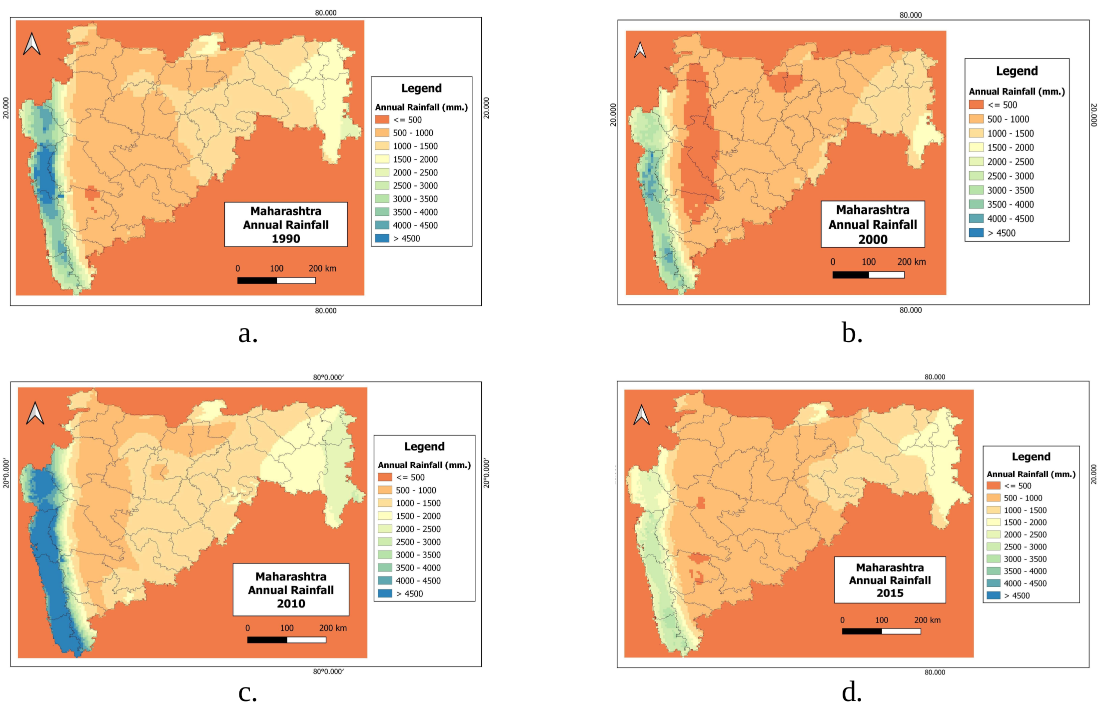


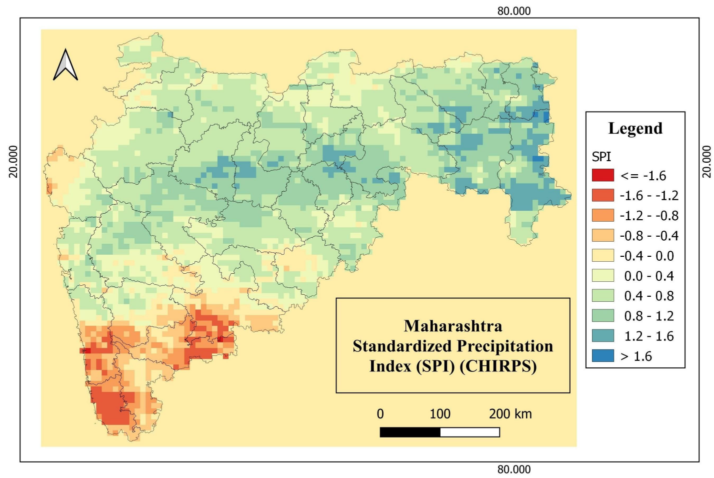
Figure 3. Spatial distribution of annual rainfall (a) 1990; (b) 2000; (c) 2010; (d) 2015

The increasing global temperature and subsequent changes in rainfall patterns have led to the occurrence of droughts, which is highly detrimental to agriculture (Nath et al., 2017; Kalubarme et al., 2019). Crops experience moisture stress, which hinders their growth and proliferation thereafter reducing the economic yield (Sahito et al., 2015). Thus, the incidence of drought is an important criterion to evaluate the effects of climate change (Mukherjee et al., 2018; Javadinejad et al., 2021). In this study, the SPI has been used to analyze the distribution and severity of droughts in the study area. Table 2 indicates the scale of moisture stress as devised by McKee et al. (1993). Besides, increasing temperatures cause high evapotranspiration resulting in increased atmospheric water vapor, which leads to erratic heavy rainfall (Tabari, 2020) that further damages the crop, especially during the flowering and boll development stage.

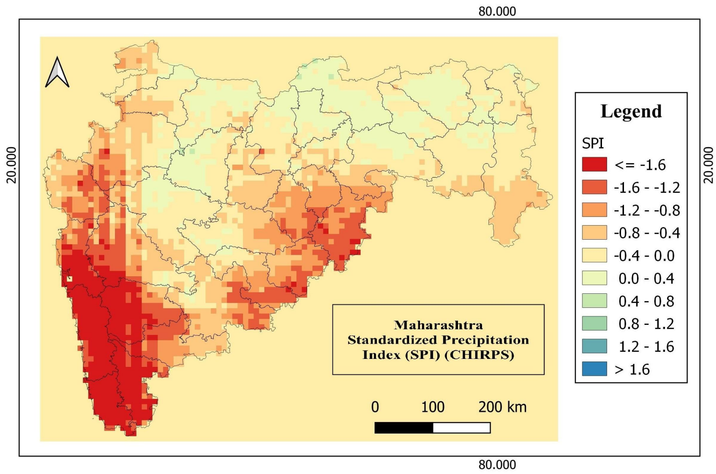
Table 2. SPI classification scheme

SPI value	Precipitation regime
≥ 2.0	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
$\leq$ -2.0	Extremely dry

Figure 4 reflects that in 2015 much larger areas of the state witnessed severe moisture stress as compared to that in 1990. This further justifies the above argument on changes in temperature and rainfall patterns over the period 1990 to 2015. Statistical analysis of yield and climate data using multiple linear regression reveals the extent of the threat to the production of cotton from such variability in climatic factors.



a.



b.

Figure 4. Maps showing areas facing moisture stress in Maharashtra using the SPI in (a) 1990; (b) 2015

Table 3. Model outputs: Relevance of the equation ANOVA[a]

Model	Sum of squares	df	MS	F
Regression	2043913.3	2	1021956.65	69.14
Residual	10331640	699	14780.6009	
Total	12375553.3	701	17654.1417	

Note: (a) dependent variable = yield of cotton

Table 4. Model's output summary[a]

Number of observations	R^2	Adjusted R^2	Root MSE
702	0.1652	0.1628	121.58

Note: (a) dependent variable = yield of cotton, MSE = mean squared error

Table 5. Model outputs: Regression coefficients

Model	Non standardized coefficient		Standardized coefficient	t	P-value
	A	Standard error	Beta		
Rainfall	-0.0682259	0.0059835	-0.39843	-11.4024	< 0.001
Temperature	-21.65355	4.78016	-0.15829	-4.52988	< 0.001
Constant	834.7237	128.1763		6.51231	< 0.001

Table 3 delineates the model output, which shows that the F value is about 69.14 and significant at $P < 0.001$. Hence, the null hypothesis (H_0) is rejected. Therefore, there exists a statistically significant relationship between the dependent and the independent variables.

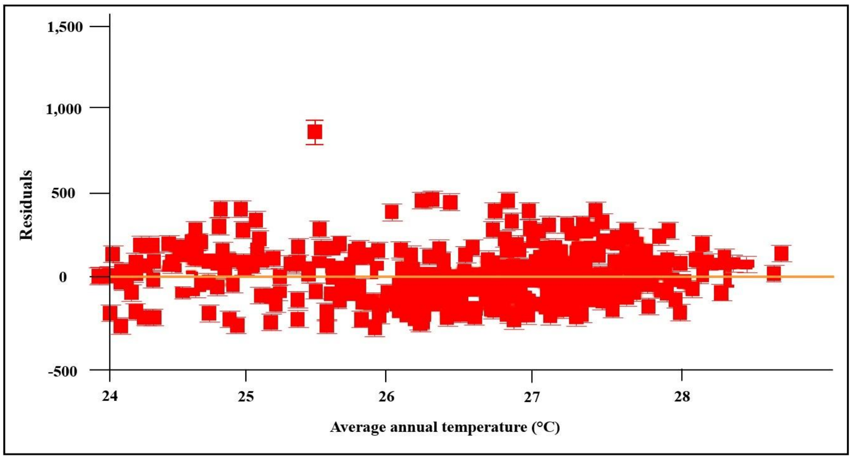
From Table 4, the value of the multiple correlation coefficients is 0.4043. $R \approx 0.40$ indicates that the data set to be well adjusted to the model so far as the study is concerned. The value $R \approx 0.17$ depicts that the independent variables explain around 17% of the variability of the model. The adjusted value of $R \approx 0.16$ infers the robustness to be about 16% even if another sample from the same population is considered.

Table 5 presents that the last column implies that all coefficients are significant at a probability level of < 0.001%. Therefore, there is a significant contribution of the independent variables for the explanation of the variability of the model. The standardized coefficients of "rainfall" and "temperature" contribute negatively to the explanation of yield variability with an approximate relative weight of 40% and 16%, respectively. As per the non-standardized coefficients (A), the regression line can be reconstructed in Equation 3.

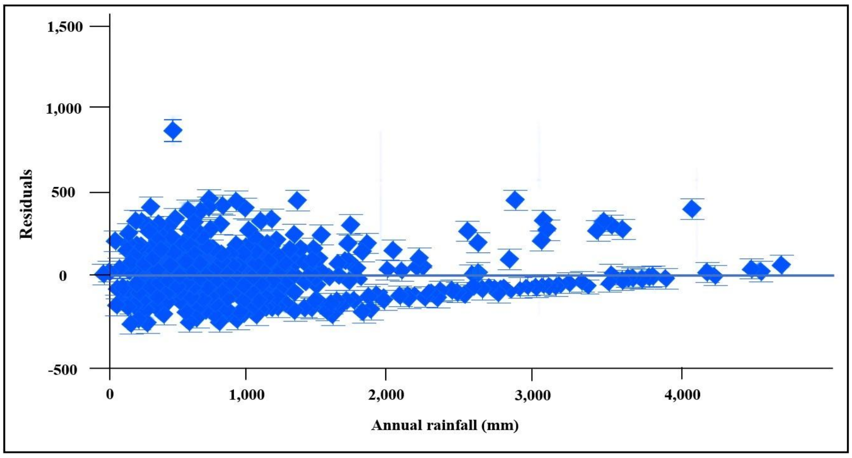
$$\text{Yield} = 834.7237 - 0.0682259\ (\text{rainfall}) - 21.65355\ (\text{temperature}) \quad (3)$$

The model output confirms the results of the previous studies on factors affecting yield variability of cotton. Similar observations were noted by Nadiruzzaman et al. (2021) in Bangladesh, Ali et al. (2022) in Pakistan and Arshad et al. (2021) in China. Although the regression analysis appears to be weak, it is still valid for natural systems as natural systems are intricate and often highly variable, making it hard to devise an ideal model. The residual plots for temperature and rainfall also reveal that the residual values are symmetrical to the origin and close to the line of zero, which suggests that the model fits perfectly (Figure 5a and b). It is to be noted that the model explains more than 40% of yield variability and production, technology explains the rest.

Innovations such as drought-tolerant varieties, no-till technology, and others are highly required. Hence, it is important to consider climate as an integral part of modern agricultural research, especially on cash crops.



a.



b.

Figure 5. Residual plot of (a) Average annual temperature; (b) Annual rainfall

CONCLUSIONS

GIS modeling and mapping provide evidence of changes in the spatial distribution of rainfall and temperature. The statistical analysis reflects that temperature rise of 1% may cause 16% decrease in yield of cotton. Again, only 1% increase in rain may result in 40% decrease in yield. This is because precipitation variability increases with the rise in temperature, which reduces the economic yield of the crop. Hence, it is important to monitor the climate variability, minimize anthropogenic factors like pollutants, and promote climate-smart agricultural practices to ensure optimum crop production.

ACKNOWLEDGEMENT

The authors are grateful to Indian Institute of Technology Indore, for helping them with technical assistance and research facilities.

REFERENCES

Adare, Z. M., Srinivas, A., Rao, V. P., Prakash, T. R., & Thatikunta, T. R. (2016). Association of weather variables with yield and yield components of cotton (*Gossypium hirsutun* L.) at reproductive phenophase. *African Journal of Agricultural Research*, *11*(29), 2555–2561. https://doi.org/10.5897/ajar2016.11090

Adhav, C. A., Chandel, B. S., Bhandari, G., Ponnusamy, K., & Ram, H. (2021). Socio-economic vulnerability to climate change–Index development and mapping for districts in Maharashtra, India. http://dx.doi.org/10.2139/ssrn.3854297

Ali, M. A., Hassan, M., Mehmood, M., Kazmi, D. H., Chishtie, F. A., & Shahid, I. (2022). The potential impact of climate extremes on cotton and wheat crops in Southern

Punjab, Pakistan. *Sustainability*, *14*(3), 1609. https://doi.org/10.3390/su14031609

Arshad, A., Raza, M. A., Zhang, Y., Zhang, L., Wang, X., Ahmed, M., & Habib-Ur-rehman, M. (2021). Impact of climate warming on cotton growth and yields in China and Pakistan: A regional perspective. *Agriculture*, *11*(2), 97. https://doi.org/10.3390/agriculture11020097

Asaminew, T. G., Araya, A., Atkilt, G., & Solomon, H. (2017). Modeling the potential impact of climate change on cotton (*Gossypium hirsutum*) production in Northeastern Semi-Arid Afar and Western Tigray Regions of Ethiopia. *Journal of Earth Science & Climatic Change*, *8*(3), 1–7. https://doi.org/10.4172/2157-7617.1000390

Balasubramanian, M., & Birundha, V. D. (2012). Climate change and its impact on India. *The IUP Journal of Environmental Sciences*, *6*(1), 31–46. Retrieved from https://scholar.google.com/scholar?hl=id&as_sdt=0%2C5&q=Climate+Change+and+Its+Impact+on+India+Balasubramanian&btnG=

Bhattacharyya, T., Pal, D. K., Mandal, C., Chandran, P., Ray, S. K., Sarkar, D., … & Nimkhedkar, S. S. (2013). Soils of India: Historical perspective, classification and recent advances. *Current Science*, *104*(10), 1308–1323. Retrieved from https://www.jstor.org/stable/24092506

Blaise, D., & Kranthi, K. R. (2019). Cotton production in India. *Cotton Production*, 193–215. https://doi.org/10.1002/9781119385523.ch10

Burke, J. J., Mahan, J. R., & Hatfield, J. L. (1988). Crop-specific thermal kinetic windows in relation to wheat and cotton biomass production. *Agronomy Journal*, *80*(4), 553–556. https://doi.org/10.2134/agronj1988.00021962008000040001x

Cotton Advisory Board. (2019). *Cotton sector*. Retrieved from http://ministryoftextiles.gov.in/sites/default/files/Textiles-Sector-Cotton-Sep19.pdf

Cotton Corporation of India. (2021). *National cotton scenario*. Retrieved from https://cotcorp.org.in/national_cotton.aspx

Gwimbi, P., & Mundoga, T. (2010). Impact of climate change on cotton production under rainfed conditions: Case of Gokwe. *Journal of Sustainable Development in Africa*, *12*(8), 59–69. Retrieved from https://scholar.google.com/scholar?hl=id&as_sdt=0%2C5&q=Impact+of+climate+change+on+cotton+production+under+rainfed+conditions%3A+case+of+Gokwe&btnG=

Iqbal, M. A., Ping, Q., Abid, M., Kazmi, S. M. M., & Rizwan, M. (2016). Assessing risk perceptions and attitude among cotton farmers: A case of Punjab Province, Pakistan. *International Journal of Disaster Risk Reduction*, *16*, 68–74. https://doi.org/10.1016/j.ijdrr.2016.01.009

Jans, Y., Von Bloh, W., Schaphoff, S., Müller, C., & Jans, Y. (2021). Global cotton production under climate change-implications for yield and water consumption. *Hydrology and Earth System Sciences*, *25*(4), 2027–2044. https://doi.org/10.5194/hess-25-2027-2021

Javadinejad, S., Dara, R., & Jafary, F. (2021). Analysis and prioritization the effective factors on increasing farmers resilience under climate change and drought. *Agricultural Research*, *10*, 497–513. https://doi.org/10.1007/s40003-020-00516-w

Kalubarme, M., Acharya, M., & Shukla, S. H. (2019). Monitoring drought and its impact on agriculture using drought indices and geo-informatics technology in Patan District, Gujarat. *International Journal of Environment and Geoinformatics*, *6*(2), 153–162. https://doi.org/10.30897/ijegeo.554465

Kang, H., & Zhao, H. (2020). Description and application research of multiple regression model optimization algorithm based on data set denoising. *Journal of Physics: Conference Series*, *1631*, 012063. https://doi.org/10.1088/1742-6596/1631/1/012063

Karimi, V., Karami, E., & Keshavarz, M. (2018). Climate change and agriculture: Impacts and adaptive responses in Iran. *Journal of Integrative Agriculture*, *17*(1), 1–15. https://doi.org/10.1016/S2095-3119(17)61794-5

Li, N., Yao, N., Li, Y., Chen, J., Liu, D., Biswas, A., … & Chen, X. (2021). A meta-analysis of the possible impact of climate change on global cotton yield based on crop simulation approaches. *Agricultural Systems*, *193*, 103221. https://doi.org/10.1016/j.agsy.2021.103221

Lokhande, S., & Reddy, K. R. (2014). Quantifying temperature effects on cotton reproductive efficiency and fiber quality. *Agronomy Journal*, *106*(4), 1275–1282. https://doi.org/10.2134/agronj13.0531

Luo, Q., Bange, M., & Clancy, L. (2014). Cotton crop phenology in a new temperature regime. *Ecological Modelling*, *285*, 22–29. https://doi.org/10.1016/j.ecolmodel.2014.04.018

Malhi, G. S., Kaur, M., & Kaushik, P. (2021). Impact of climate change on agriculture and its mitigation strategies: A review. *Sustainability*, *13*(3), 1318. https://doi.org/10.3390/su13031318

Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., ... & Zhou, B. (2021). Climate change 2021: The physical science basis. *Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change*, *2*. Retrieved from https://www.ipcc.ch/report/ar6/wg1/

McKee, T. B., Nolan, J., & Kleist, J. (1993). The relationship of drought frequency and duration to time scales. *Proceedings of the 8th Conference on Applied Climatology*, *17*(22), 179–183. Retrieved from https://climate.colostate.edu/pdfs/relationshipofdroughtfrequency.pdf

Mukherjee, S., Mishra, A., & Trenberth, K. E. (2018). Climate change and drought: A perspective on drought indices. *Current Climate Change Reports*, *4*, 145–163. https://doi.org/10.1007/s40641-018-0098-x

Nadiruzzaman, M., Rahman, M., Pal, U., Croxton, S., Rashid, M. B., Bahadur, A., & Huq, S. (2021). Impact of climate change on cotton production in Bangladesh. *Sustainability*, *13*(2), 574. https://doi.org/10.3390/su13020574

Nath, R., Nath, D., Li, Q., Chen, W., & Cui, X. (2017). Impact of drought on agriculture in the Indo-Gangetic Plain, India. *Advances in Atmospheric Sciences*, *34*, 335–346. https://doi.org/10.1007/s00376-016-6102-2

Nikam, V., Ashok, A., & Pal, S. (2022). Farmers' information needs, access and its impact: Evidence from different cotton producing regions in the Maharashtra state of India. *Agricultural Systems*, *196*, 103317. https://doi.org/10.1016/j.agsy.2021.103317

Palanisami, K., Reddy, K. K., Raman, S., & Mohanasundari, T. (2017). Policy options for better implementation of micro irrigation: Case study of India. In *Micro Irrigation Engineering for Horticultural Crops* (pp. 37-50). Florida, United States: Apple Academic Press. Retrieved from https://scholar.google.com/scholar?hl=id&as_sdt=0%2C5&q=Policy+Options+for+Better+Implementation+of+Micro+Irrigation%3A+Case+Study+of+India&btnG=

Rana, A., Foster, K., Bosshard, T., Olsson, J., & Bengtsson, L. (2014). Impact of climate change on rainfall over Mumbai using distribution-based scaling of global climate model projections. *Journal of Hydrology: Regional Studies*, *1*, 107–128. https://doi.org/10.1016/j.ejrh.2014.06.005

Sahito, A., Baloch, Z. A., Mahar, A., Otho, S. A., Kalhoro, S. A., Ali, A., … Ali, F. (2015). Effect of water stress on the growth and yield of cotton crop. *American Journal of Plant Sciences*, *6*(7), 1027–1039. https://doi.org/10.4236/ajps.2015.67108

Sawan, Z. M. (2013). Applied methods for studying the relationship between climatic factors and cotton production. *Agricultural Sciences*, *4*(11), 37–54. https://doi.org/10.4236/as.2013.411a005

Sawan, Z. M. (2017). Cotton production and climatic factors: Studying the nature of its relationship by different statistical methods. *Cogent Biology*, *3*(1), 1292882. https://doi.org/10.1080/23312025.2017.1292882

Sawan, Z. M. (2018). Climatic variables: Evaporation, sunshine, relative humidity, soil and air temperature and its adverse effects on cotton production. *Information Processing in Agriculture*, *5*(1), 134–148. https://doi.org/10.1016/j.inpa.2017.09.006

Sreenath, A. V., Abhilash, S., Vijaykumar, P., & Mapes, B. E. (2022). West coast India's rainfall is becoming more convective. *Npj Climate and Atmospheric Science*, *5*, 36. https://doi.org/10.1038/s41612-022-00258-2

Tabari, H. (2020). Climate change impact on flood and extreme precipitation increases with water availability. *Scientific Reports*, *10*, 13768. https://doi.org/10.1038/s41598-020-70816-2

Uyanık, G. K., & Güler, N. (2013). A study on multiple linear regression analysis. *Procedia - Social and Behavioral Sciences*, *106*, 234–240. https://doi.org/10.1016/j.sbspro.2013.12.027

Varga, A. (2021). Climate change and its impact on agriculture. *Acta Horticulturae et Regiotecturae*, *24*(s1), 50–57. https://doi.org/10.2478/ahr-2021-0010

Vyankatrao, N. P. (2017). Impact of climate change on agricultural production in India: Effect on rice productivity. *Bioscience Discovery*, *8*(4), 897–914. Retrieved from https://scholar.google.com/scholar?hl=id&as_sdt=0%2C5&q=Impact+of+climate+change+on+agricultural+production+in+India%3A+effect+on+rice+productivity&btnG=

Wang, S., Li, Y., Yuan, J., Song, L., Liu, X., & Liu, X. (2021). Recognition of cotton growth period for precise spraying based on convolution neural network. *Information Processing in Agriculture*, *8*(2), 219–231. https://doi.org/10.1016/j.inpa.2020.05.001

Xu, B., Zhou, Z. G., Guo, L. T., Xu, W. Z., Zhao, W. Q., Chen, B. L., … & Wang, Y. H. (2017). Susceptible time window and endurable duration of cotton fiber development to high temperature stress. *Journal of Integrative Agriculture*, *16*(9), 1936–1945. https://doi.org/10.1016/S2095-3119(16)61566-6

Ye, L., & Grimm, N. B. (2013). Modelling potential impacts of climate change on water and nitrate export from a mid-sized, semiarid watershed in the US Southwest. *Climatic Change*, *120*, 419–431. https://doi.org/10.1007/s10584-013-0827-z

Zafar, S. A., Noor, M. A., Waqas, M. A., Wang, X., Shaheen, T., Raza, M., & Rahman, M. U. (2018). Temperature extremes in cotton production and mitigation strategies. *Past, Present and Future Trends in Cotton Breeding*, *4*, 65–91. https://doi.org/10.5772/intechopen.74648