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AN ASSESSMENT OF METEOROLOGICAL DROUGHTS IN MAHARASHTRA: A CASE STUDY OF OSMANABAD DISTRICT (2004-2013)

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ABSTRACT
The present research work is associated with meteorological drought assessment ofOsmanabad district of Maharashtra. With the help of surfer 10 GIS software, 10 years of average annual temperature and total rainfall gridded Indian Meteorological Department's (IMD) data (extension 1^{O} x 1^{O}) wasgraphically represented and analyzed to find out the water scarcity areas in Maharashtra state in general and Osmanabad district in particular. The temperature zones were analyzed by employing 30 years of IMD's temperature data with the help of climatograph devised by E.N. Munns. While water budget analysis was carried out by using 102 years of annual mean rainfall and potential evapotranspiration data. Besides that by calculating Thornwaite's total moisture index (TMI), month-wise aridity of the study area was evaluated. Hence, the study helps to pinpoint the areas of severe meteorological droughts, which later on due to improper irrigation practices and mismanagement of water resources converted into water scarcity areas called as droughts prone areas. The western part and the far eastern side of the Maharashtra state received high annual total rainfall, which is up to 800 mm, as compared to central Maharashtra. Particularly, the eastern part of Sangli district, Osmanabad district, Latur, Bid, Jalna, Nanded, and Parbhani district were continuously received average annual temperature above 26^{O}C and total annual rainfall below 100 mm. Hence, high average annual temperature and low total annual rainfall created the water deficiency, which ultimately responsible for drought situation in above-mentioned districts.

KEYWORDS: *Meteorological droughts; GIS; Temperature zones; Water budget; Total moisture index.*

INTRODUCTION
More than one-half of the terrestrial earth is vulnerable to drought each year. Because drought is a recurring phenomenon and typical for the majority of world zones, the most productive lands of all continents can lose millions of tons of agricultural production annually. The immediate consequences of 623 Bulletin of the American Meteorological Society drought include water-supply shortages, destruction of ecological resources, and losses of agricultural production, resulting in famine, human suffering, death, and abandonment of whole geographic regions (Felix 1997). A drought can be as damaging as a flood, but affects a whole region and not just the low lying parts. A meteorological drought occurs when there is little rain compared with normal, in terms of the degree of variability at the place. Persistence is a related feature of drought perhaps due to positive feedbacks in the atmosphere prolonging a random dry period into a drought. (Linacre and Geerts 1997).Drought can be defined as a condition of abnormally dry weather

resulting in a serious hydrological imbalance, with consequences such or losses of standing crop. And the shortage of water needed by people and livestock (Alexander 1993). The water balance is maintained through continuous processes of evaporation, condensation, and precipitation, whereas interruption in this cycle creates the hazardous problems like droughts and floods. In thecase of anagrarian country like India droughts and floods reduces the agricultural production and ultimately adversely affected the country's economy. Hence, the effective design and management of an irrigation system require accurate estimation of crop evapotranspiration. The knowledge of the exact amount of water required by different crops in a given set of climatic conditions of theregion is of great help for theplanning of irrigation schemes, irrigation scheduling and also for mid-term planning in case of mid-season drought. (Hajare et al. 2009). No instrument has yet been perfected to measure the water movement from the earth to the atmosphere (Thornthwaite1948). Evapotranspiration is computed using the method devised by thornthwaite and Mather (1957) this method computes the PET. Then adjust it to estimate actual evapotranspiration (www.michigen.gov.).Sir Dudley explains that evapotranspiration means the combined evaporation from the soil surface and transpiration from plants (Dudley1961). The water surplus areas and deficit areas are identified with the help of total evapotranspiration from the earth to the atmosphere and precipitation over the earth.

The high surface temperatures and low rainfall amounts during the pre-monsoon and monsoon seasons of 2009 lead to an increase in aerosol optical depth AOD as compared to those in 2008 and 2010 responsible for droughtsover a tropical urban site (Vijayakumar et al. 2012). The drought had always been a recurring phenomenon hitting the economy and creating famine conditions in ancient, medieval and Mughal India and British India. The state of Maharashtra is not free from drought. A vast tract of the rain shadow areas has been under the influence of drought from time to time. The review committee has identified about 35% of the geographical area of the state as drought prone (Gaikwad 2003). Out of the total geographical area of India, an almost one-sixth area with 12% of the population is drought prone; the areas that receive an annual rainfall up to 60 cm are the most prone. A drought prone area is defined as one in which the probability of a drought year is greater than 20%. A chronic drought-prone area is one in which the probability of a drought year is greater than 40% (Negi 2016).Drought impacts vary from region to region, but the overall issues are similar and Maharashtra State is indicative of the rest of the Drought Prone Area of the country (Udmale et al. 2014).The All-India rainfall trend is in fact indicative of no trend while the Northeast Homogeneous Regions shows a significant decrease. Furthermore, a significant decrease in rainfallis to be observed over Himachal Pradesh, Madhya Pradesh, Maharashtra and the Southern Peninsular region, and a significant increase over West Bengal, Punjab, Haryana, Coastal Karnataka, North Interior Karnataka. There have been 21 All-India drought years during the last century, of which 13 were linked to El Ninõ (Tyalagadi et al. 2015).In thecase of India, there is a substantial increase of arid region in Gujarat and, a decrease of arid region in Haryana. There is also the increase in asemi-arid region in Madhya Pradesh, Tamil Nadu and Uttar Pradesh due to theshift of climate from dry sub-humid to semi-arid. Likewise, the moist sub-humid pockets in Chhattisgarh, Orissa, Jharkhand, Madhya Pradesh and Maharashtra states have turned dry sub-humid to a larger extent (Raju et al. 2013).The Maharashtra government has declared a "drought-like condition" in 14,708 of the state's 43,000 villages. This means the drought covers 34% of the state. The region of Marathwada has been worst-hit, with a drought-like condition declared in every single village. As many as 8,522 villages in the region have been impacted. This accounts for 58% of the drought area in the state. North Maharashtra, which includes NashikJalgaon&Osmanabad districts, follows next with 4,869 villages impacted. This accounts for 33% of the drought area (Kakodkar 2015).The 2012 drought in Maharashtra's Marathwada region was mainly the result of lack of good water governance and poor operation of watershed development and irrigation projects. A policy that restrains sugar cane cultivation and modernises all types of water resource development works will go a long way in ensuring that a situation as in 2012-13 is not repeated (Purandare 2013).Agriculture (e.g., rain-fed cropping and livestock) is the major income activity of over 64% of the Maharashtra state's population. The most instant impact of thedrought is found on theeconomy of farmers besides that various social impacts, environmental impacts were also observed. The government provided various mitigation measures, but the level of satisfaction amongst farmers was low. It is expected frompolicymakersthat they have to develop more appropriate drought adaptation policies in India (Udmaleet al. 2014, pp-250-269).

The present research work is associated with an assessment of meteorological variables behind the drought conditions in Osmanabad district of Maharashtra. The average annual temperature and total annual rainfall gridded data of IMD (extension 1^{O} x 1^{O}) were analysed in order to find out the water scarcity areas in Maharashtra state in general and Osmanabad district in particular.The water surplus and deficit months of Osmanabad district were identified by using 102 years of annual mean precipitation and Potential Evapotranspiration data.Besides thatby calculating month wise Total Moisture Index (TMI), aridity of the study area was evaluated. Hence, the study helps to pinpoint the areas of severe meteorological droughts,which is needed to prepare concrete plans to reduce the severity of future droughts conditions.

MATERIALS AND METHODS

The present research work is mainly based secondary sources of data. The data is collected from Indian Meteorological Department, Pune, India water portal website, Censusmaps, District Census Handbook, Socio-Economic Review of Osmanabad District, Gazetteers, Website of Municipal Corporation and available published and unpublished material, the internet, Books.

In order to investigate the various meteorological variables behind drought situation, a number of methods were employed. For the temperature zone analysis with the help of average temperature of 30 years (IMD) climatographdevised by E.N. Munnswas employed. The water budget analysis was carried out by using water budget graph. With the help of surfer 10 GIS software,10 years of gridded IMD data (extension 1^{O} x 1^{O}) of average annual temperature and total rainfall data wasgraphically represented and analysed. In order to compute the average annual temperature and total annual rainfall from daily gridded IMD data, asystematic sampling technique is employed. With the help of this technique, the temperature and rainfall of four days (days- 7^{th}, 14^{th} 21^{st}, 28^{th}) from each individual month were counted.

The water scarcity monthswererecognizedby using TMI devised by Thornthwaite, which is represented as-

$$TMI = 100 [P / PE - 1]$$

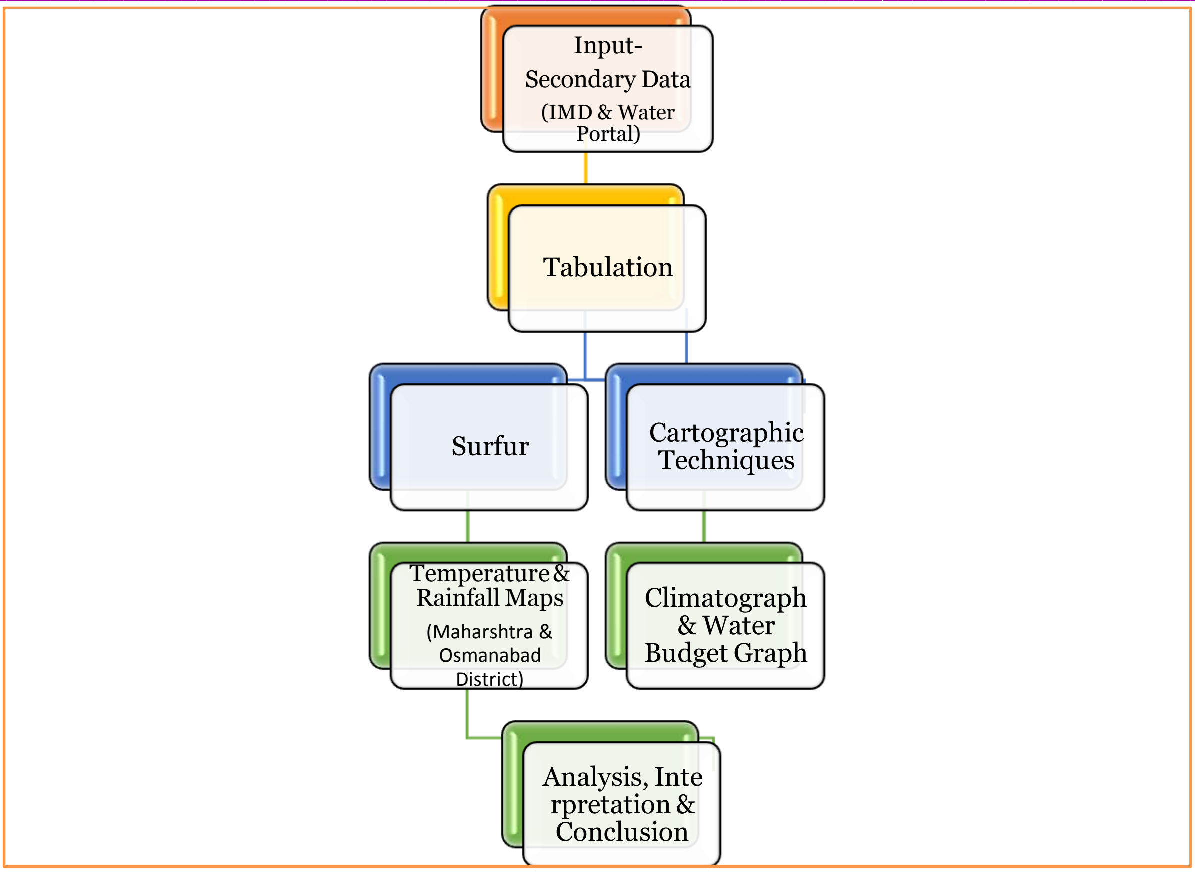
Where,

TMI= Total Moisture Index

P= Precipitation

PE= Potential Evapotranspiration

The values of the index correspond to the humidity or aridity of an area. If the value of the index is positive then the atmospheric condition is humid and the negative index value represents dry climate conditions(Thornthwaite1948).



STUDY AREA

The State of Maharashtra is divided into four major regions viz; Konkan, Western Maharashtra, Marathwada, and Vidarbha. Generally, the Marathwada region is known as a low rainfall region and frequently experiencing drought conditions. Therefore, the Marathwada region experienced drought after every six to ten years, while the year 2012 has also been declared as a drought year for this region. The Osmanabaddistrictis one of the districts from eight districts of Marathwada region located in the southern part of Marathwada region, which lies between 17^{O} 37' to 18^{O} 45' North latitude and 75^{O} 15' to 76^{O} 50' East longitudes.

Osmanabad district has 8 towns, 8 tahsils, and 733 villages spread over Paranda (96), Bhum (96), Washi (54) ,Kalamb (94), Osmanabad (127),Tuljapur (123),Lohara (47) and Umarga (96). The district is divided into two sub-divisions of Osmanabad and Bhumand 8 tahsils for administrative purposes. Osmanabad sub-division includes Osmanabad; Tuljapur; Umarga and Loharatahsils and Bhum sub-division includesBhum; Kalamb; Paranda and Washitahsils(http://www.censusindia.gov.in/2011census). It is located about 600 meters above the sea level. The total area of the district is 7512.4 sq km out of which 241.4 km is an urban area. Ternariverflows through the district while part of Manjara River also falls under the district.

Analyzing Meteorological Variables

Average Annual Temperature and Total Annual Rainfall (2004-2013)

The average temperature of 2004 denotes that most of the eastern Maharashtra have acomparativelyhigh average temperature, which is more than 27^{O}C throughout the year. Western Maharashtra has received more than 26^{O}C average annual temperature. The study area (Osmanabad District) received average annual temperature between 26.4^{O}C to 26.8^{O}C. The total rainfall figures for Maharashtra state indicates that western Maharashtra received maximum total annual rainfall (based on sample days selected) ranges between 140 mm to 520 mm from east to west. The most eastern part of Maharashtra state also received total rainfall ranges between 80 mm to 260 mm. whereas, the NW part of the study area received total annual rainfall between 20 mm to 40 mm and SE part received total annual rainfall between 40 mm to 60 mm. hence, the study area has received average annual temperature above 26^{O}C and total annual rainfall below 60 mm, which indicates that there is great water deficiency with hot climatic conditions. In 2006, thesame kind of temperature trends was observed in the entire Maharashtra state as well as in the study area as it observed in 2005. But there is variation in the rainfall trends in case of Maharashtra

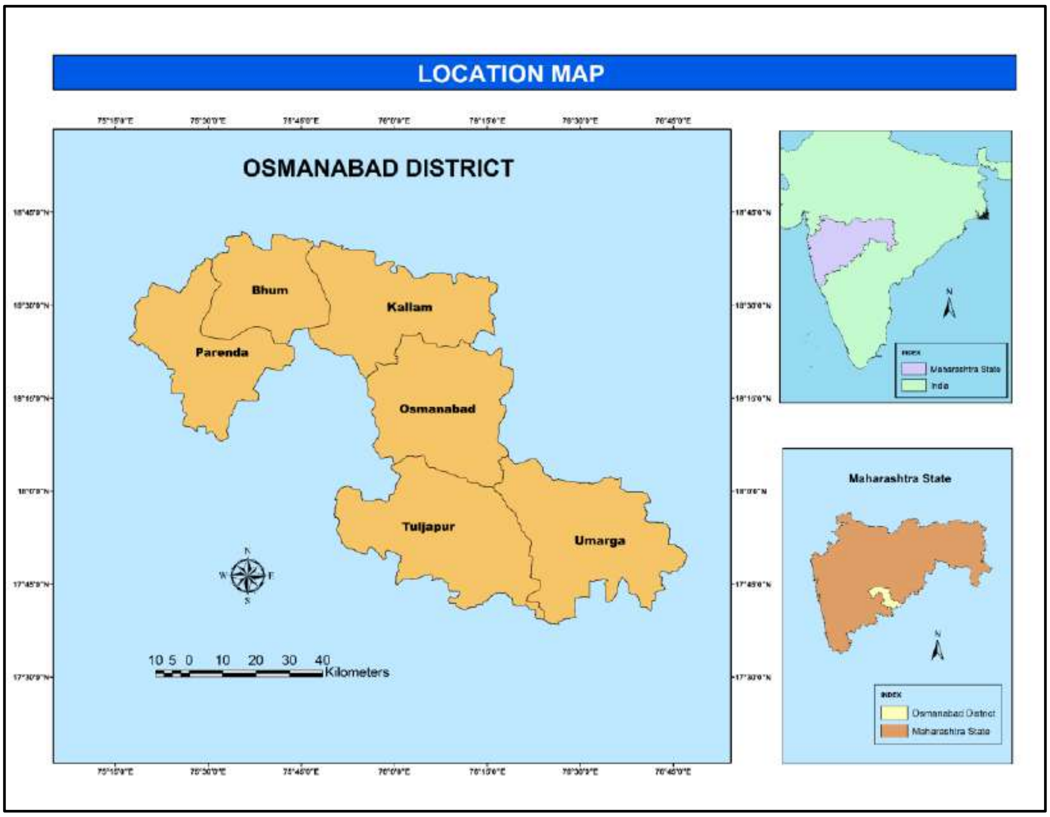
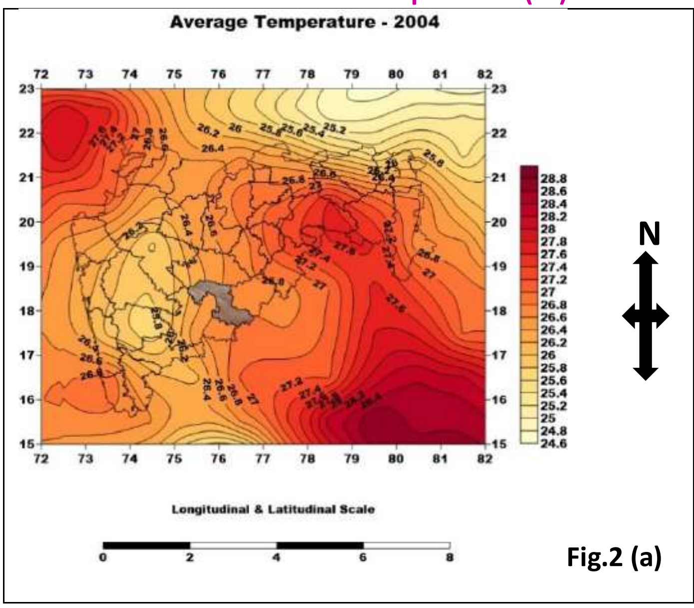


Fig. 1

Mean Temperature (^{o}C) and Total Rainfall (mm)- 2004 and 2005



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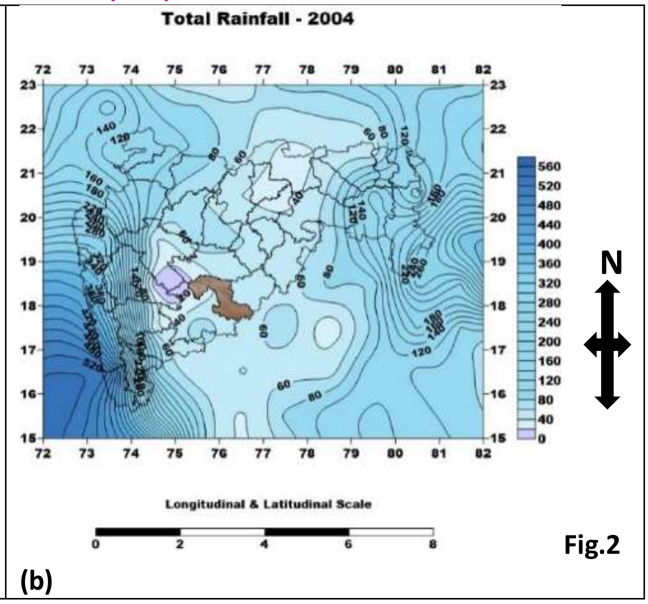

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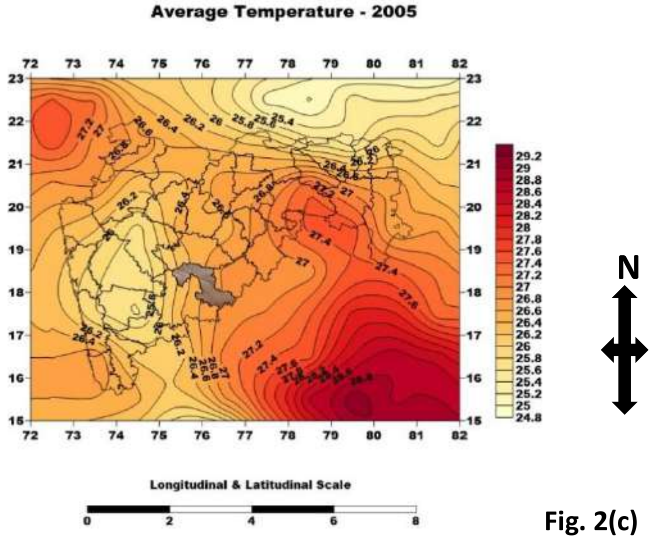

Fig. 2(c)

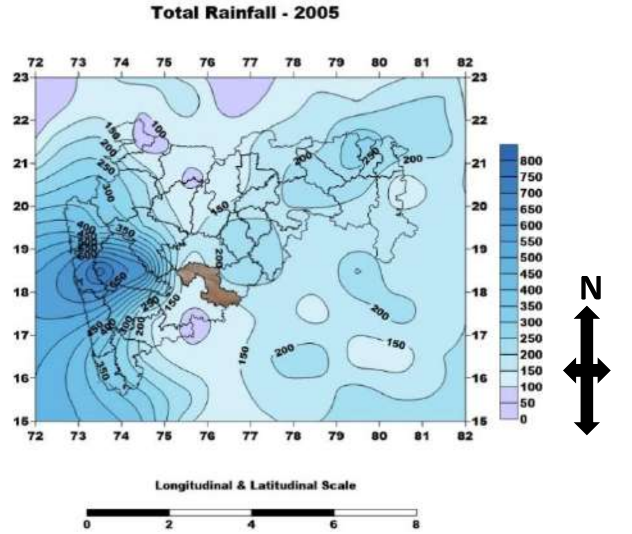

Fig. 2(d)

Source: IMD, Pune gridded Data

Mean Temperature (^{o}C) and Total Rainfall (mm)- 2006 and 2007

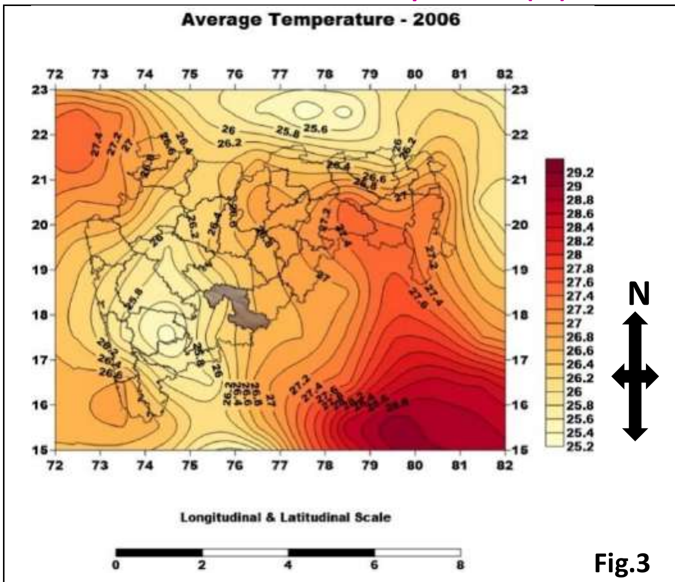

Fig.3

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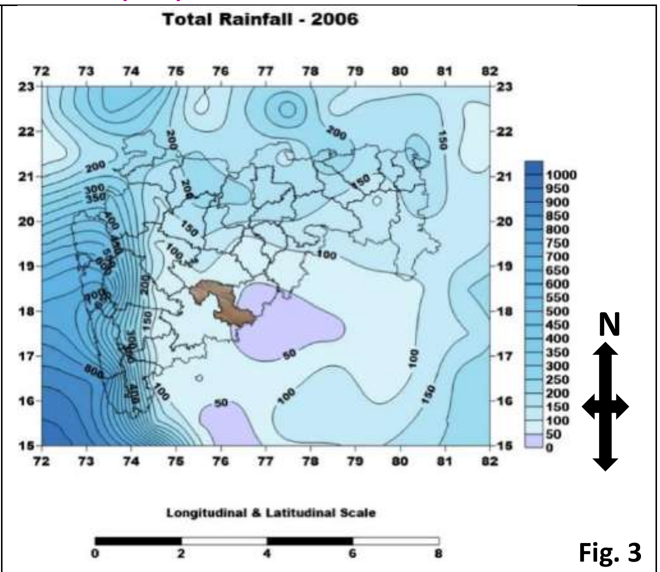
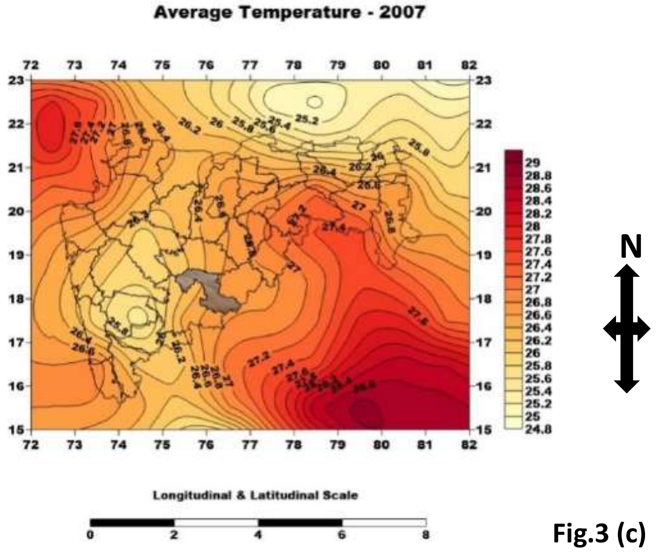


(b)

Fig. 3



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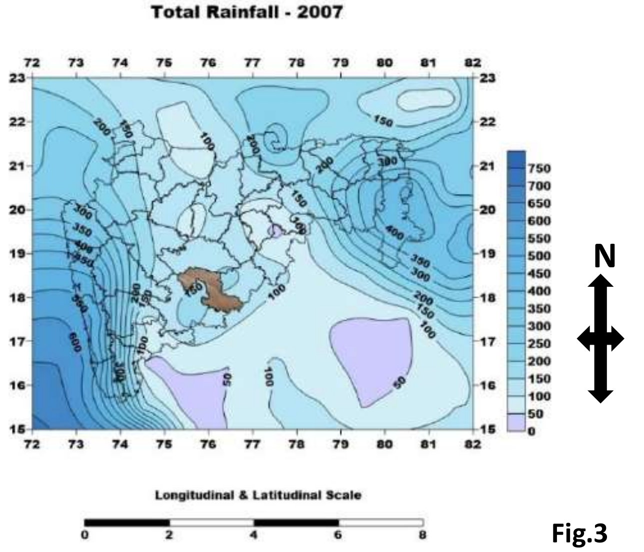
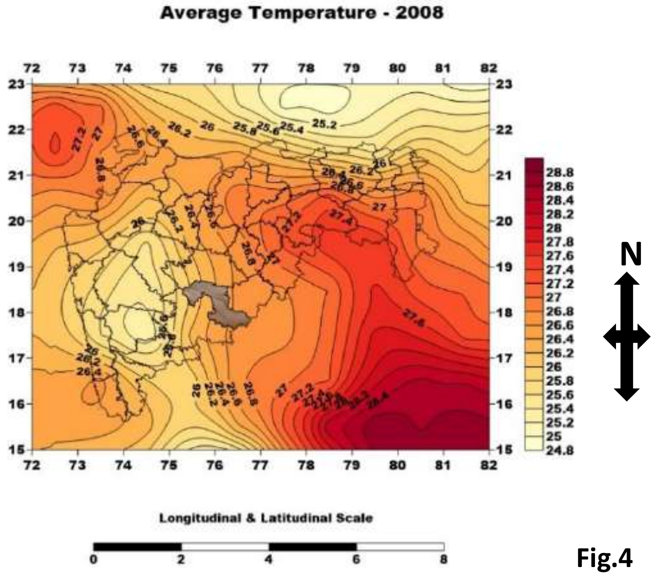


Fig.3 (d)

Source: IMD, Pune gridded Data

Mean Temperature (^{o}C) and Total Rainfall (mm)- 2008 and 2009



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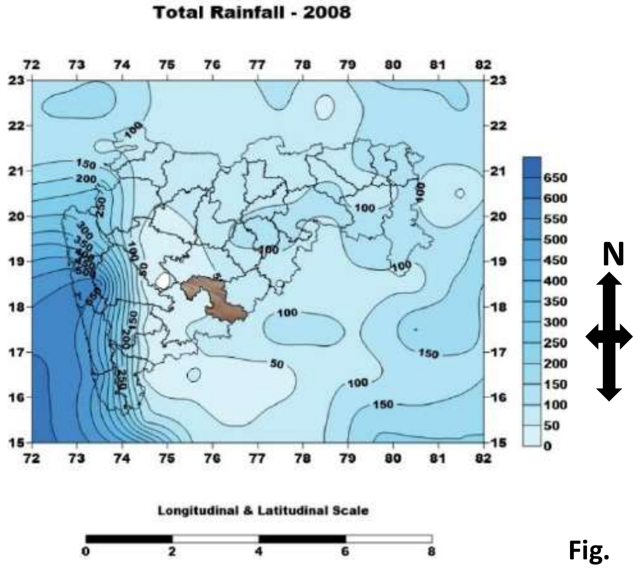
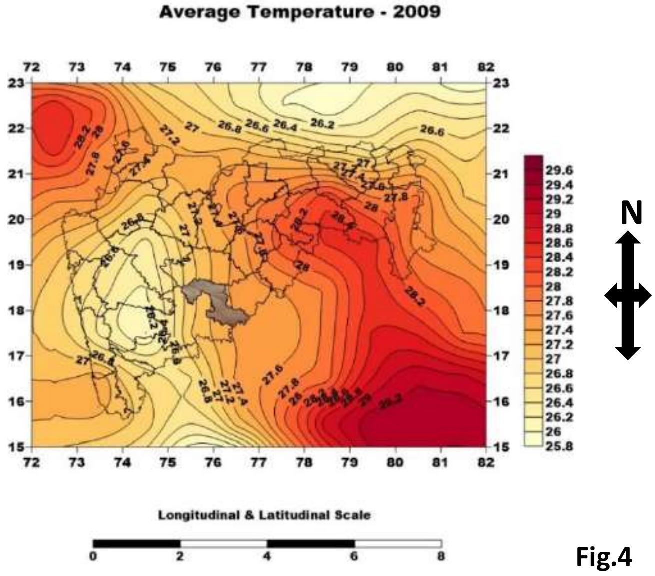


Fig. 4 (b)



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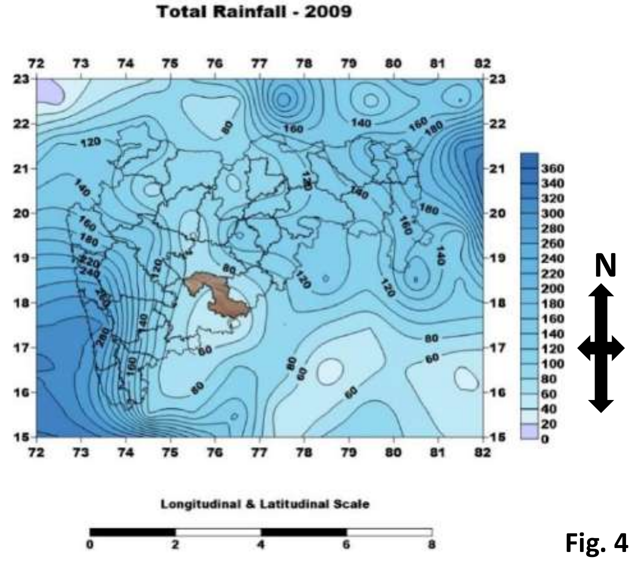
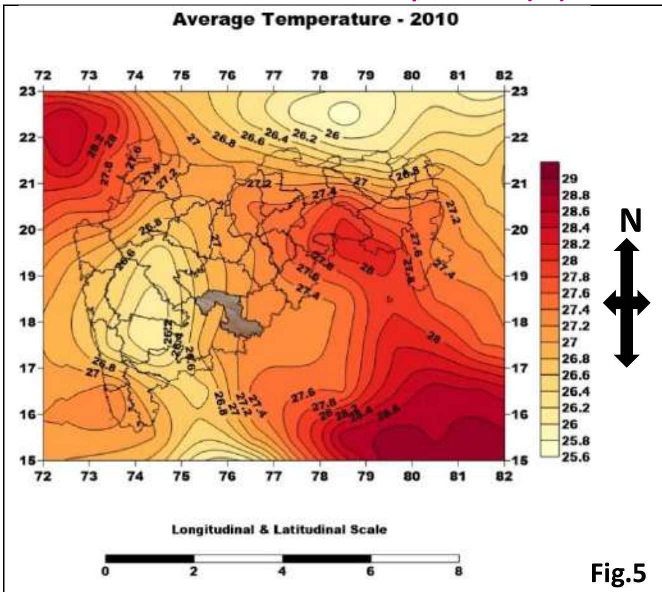


Fig. 4 (d)

Source: IMD, Pune gridded Data

Mean Temperature (°C) and Total Rainfall (mm)- 2010 and 2011



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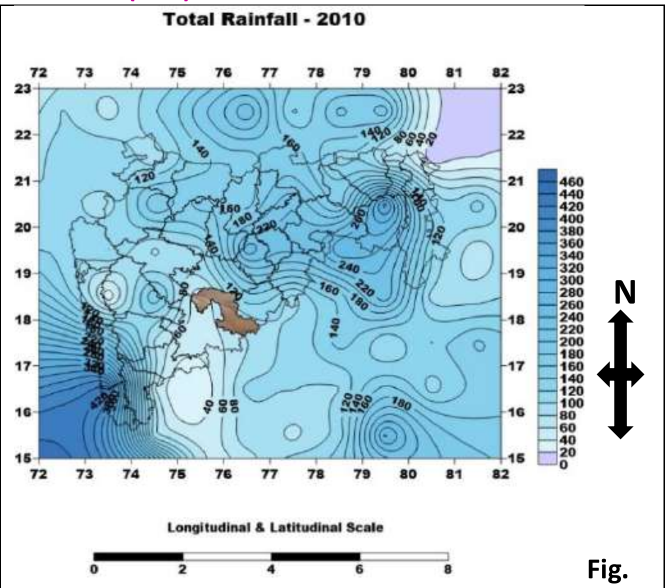
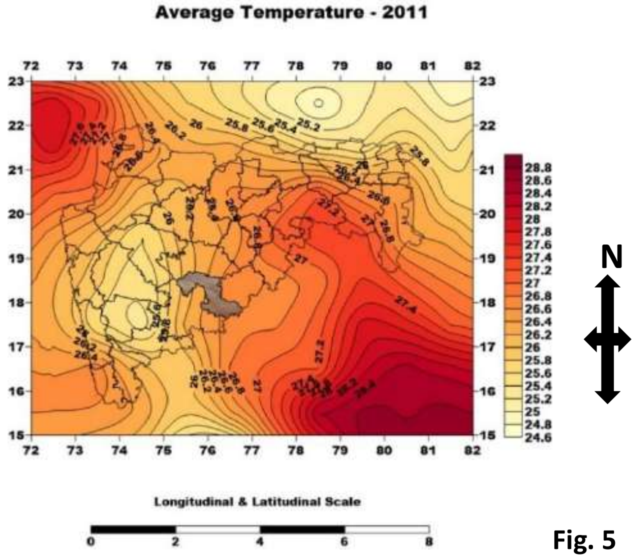


Fig. 5 (b)



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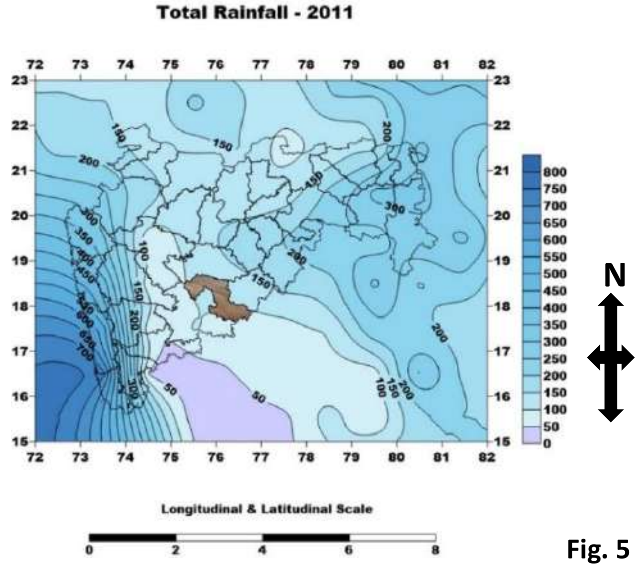

Fig. 5
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Source: IMD, Pune gridded Data

Mean Temperature (°C) and Total Rainfall (mm)- 2012 and 2013

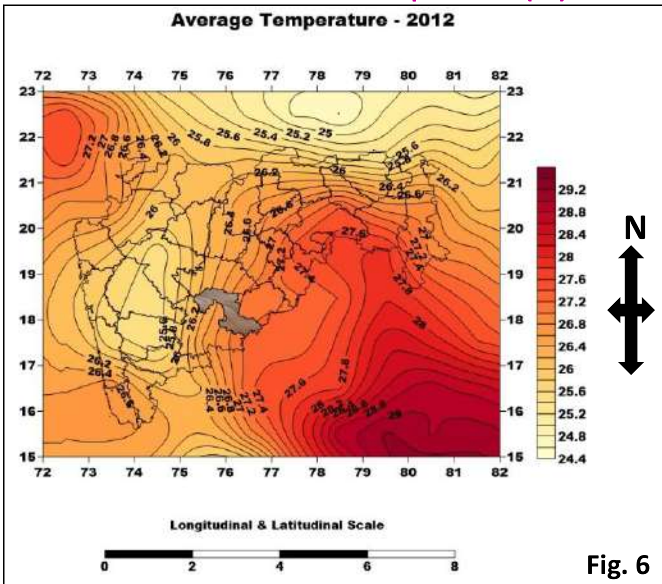

Fig. 6
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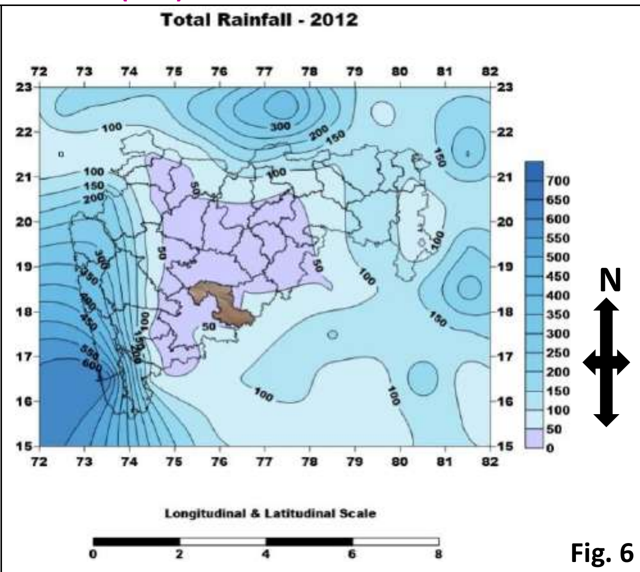

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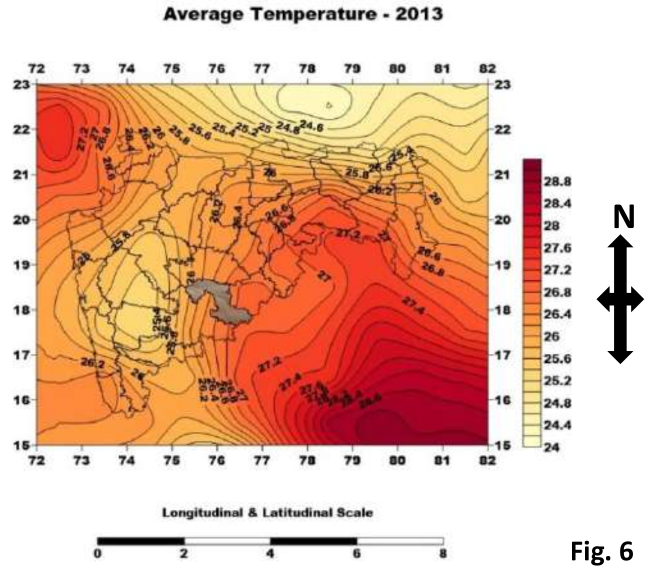

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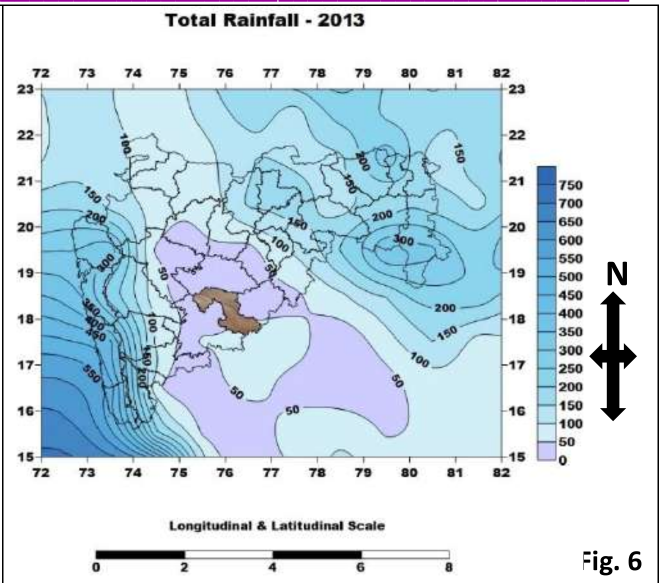


Fig. 6

(d)

state in which western part received total annual rainfall between 200 mm to 750 mm, which is more than last year. While, the study area have received average annual temperature between 26.2^{O}C to 27^{O}C and total annual rainfall between 100 mm to 150 mm.

The observation of the rainfall and temperature figures for the rest of eight years made it clear that generally the western part of the Maharashtra state received comparatively high annual total rainfall up to 800 mm, to certain extend far eastern side of the Maharashtra state also received more rainfall as compared to central Maharashtra, particularly, eastern part of Sangli district, Osmanabad district, Latur, Bid, Jalna, Nanded, and Parbhani district continuously received average annual temperature above 26^{O}C and total annual rainfall below 100 mm. Hence, high average annual temperature and low total annual rainfall created the water deficiency, which ultimately responsible for drought situation in above-mentioned districts. Very specifically the severe drought situation in the year 2012 in the Osmanabad district is associated with above mentioned meteorological causes. So, the ten years figures of rainfall and temperature reveal that the study area is major drought affected and water deficit district in Maharashtra (Fig. 2,3,4,5,6).

ANALYSIS OF TEMPERATURE CONDITIONS USING THE CLIMATOGRAPH (1971-2000)

The temperature conditions of thestudy area were analyzed by climatograph, which is prepared for 30 years of average temperature data made it clear that Osmanabad district falls in thehot climatic zone. The month wise analysis of average temperature denotes that in the month of January temperature is near about 60^{O}F, while after this month, the temperature is continuously increasing up to the May, which is the hottest month in the case of Osmanabad. Later on, thetemperature gradually decreases but it did not fall below 60^{O}F. Hence, the average temperature conditions in the study area denote the hot climatic zone (Fig. 7).

WATER BUDGET ANALYSIS (1901-2002)

The water deficiency and water surplus months in the case of Osmanabad district found out with the help ofwater budget analysis. For the present investigation, 101 years of annual mean rainfall and potential evapotranspiration data were analyzed by using water budget graph. The water budget analysis reveals that rainy season from month of April to October received rainfall ranges between 20 mm to 180 mm. while the maximum rainfall, which ranges from100 mm to 180 mm is observed between months of June to October, while, all the months having more than 180 mm of potential evapotranspiration, except August month. So, all the months in the study area are falls in water deficit months. No single month represents water recharge or water surplus. The graph clearly denotes that not for single month rainfall exceeds potential evapotranspiration, which means study area faces the acute meteorological drought condition. In addition to that improper irrigation practices and mismanagement convert this situation into water scarcity conditions called as droughts (Fig. 8).

Thornwaite's TMI Analysis

Table 1 Osmanabad: PET, Rainfall, and TMI Index (1901-2002)

Sr. No.	State	PET (mm)	Rainfall (mm)	TMI	Climatic Type
1	January	193.75	3.24	-98.32	High Arid
2	February	199.08	3.28	-98.35	High Arid
3	March	244.59	3.64	-98.51	High Arid
4	April	256.2	15.68	-93.87	High Arid
5	May	272.18	29.80	-89.05	High Arid
6	June	215.1	108.40	-49.60	Arid
7	July	182.28	136.24	-25.25	Semi-arid
8	August	176.39	109.12	-38.13	Semi-arid
9	September	180.3	178.26	-1.13	Dry Sub Humid
10	October	198.03	81.73	-58.72	Arid
11	November	184.5	25.83	-86	High Arid
12	December	184.45	5.16	-97.20	High Arid

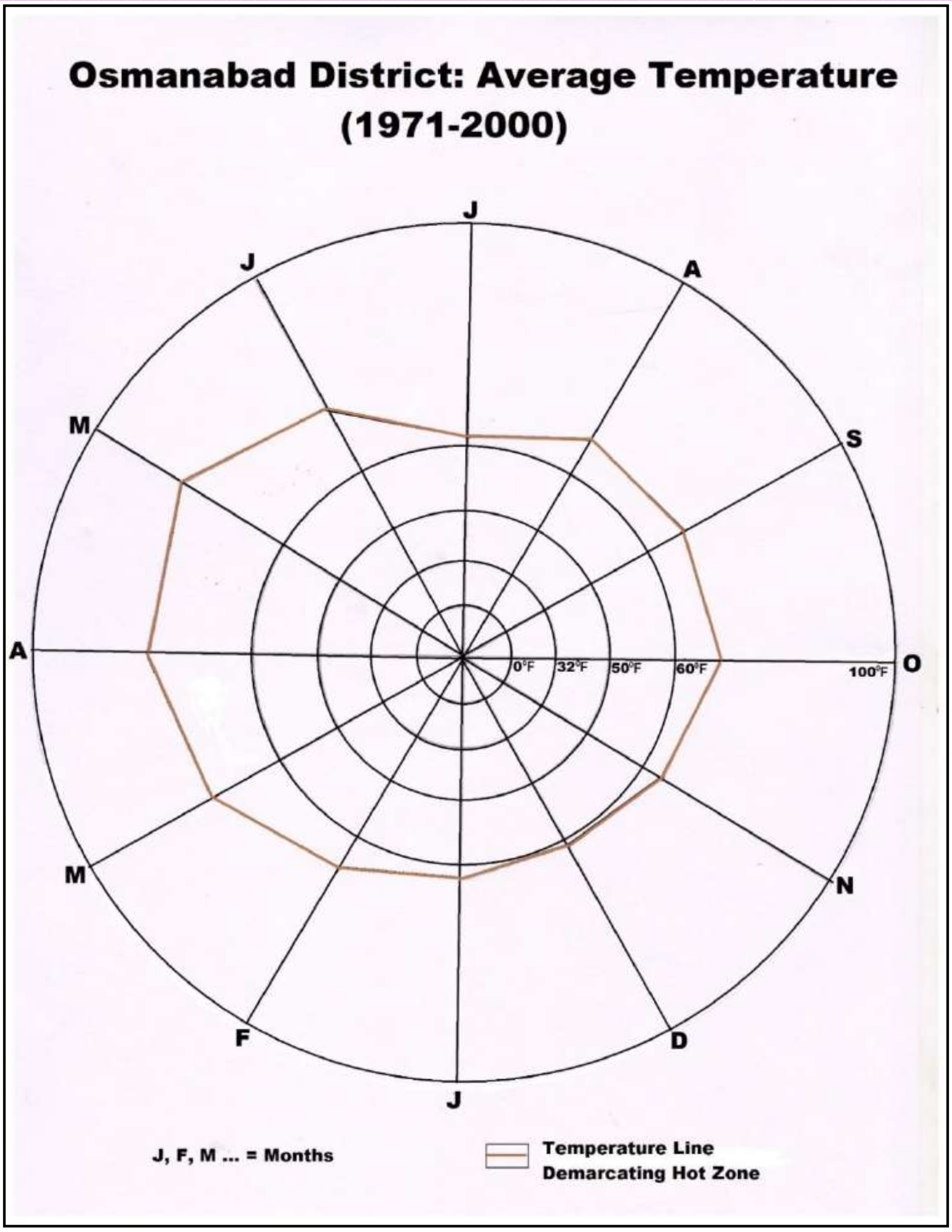
Source: www.waterportal.org.

High Arid Months

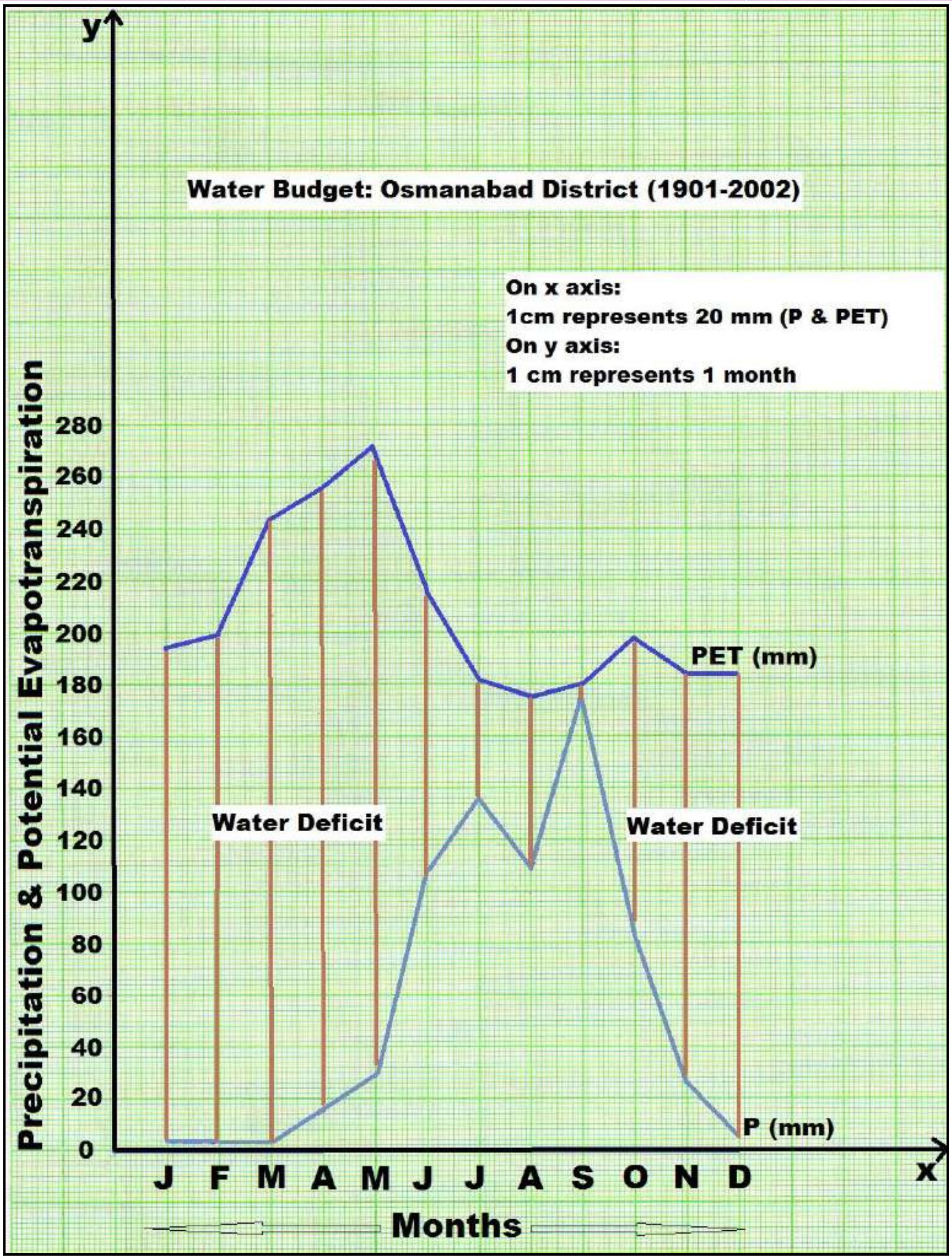
The high arid climatic conditions were found in the case ofJanuary, February, March, April, May, November and December Months. Particularly the March month having very high arid index value (TMI= -98.51) followed by the month February with -98.35 TMI value. Incase of an average figures above mentioned months in Osmanabaddistrict are having very high arid conditions (Fig. 8).

Arid Months

June and October months are representing the arid climatic conditions. Among all arid months October is thehighestaridity with -58.72 TMI value. Whereas, June month denotes the low Aridity (Fig. 8).



Data Source: IMD, Pune **Fig. 7**



Data Source: www.waterportal.org.**Fig. 8**

Semi-Arid Months

About two months in thecase ofthe Osmanabad districtrepresents semi-arid climatic conditions as per the TMI index. Especially the study area faces water scarcity problem in months of July and August (Fig. 8).

Dry Sub-Humid Months

As per the Thornthwaite's TMI, just one month (September) falls under dry sub-humid climatic zone (-1.13) in thestudy area (Fig. 8).

CONCLUSION

Generally, the western part and the far eastern side of the Maharashtra state received high annual total rainfall, which is up to 800 mm, as compared to central Maharashtra. While the eastern part of Sangli district, Osmanabad district, Latur, Bid, Jalna, Nanded, and Parbhani district were continuously received average annual temperature above 26^{O}C and total annual rainfall below 100 mm. Hence, high average annual temperature and low total annual rainfall created the water deficiency, which ultimately responsible for drought situation in above-mentioned districts. Very specifically the severe drought situation in the year 2012 in the Osmanabad district is associated with above mentioned meteorological causes. So, the ten years figures of rainfall and temperature reveal that the study area is major drought affected and water deficit district in Maharashtra, which needed proper irrigation and water resource management practices.

In the month of January temperature is near about 60^{O}F and after this month, the temperature is continuously increasing up to the May, which is the hottest month in the case of Osmanabad district. Later on, thetemperature gradually decreases but it did not fall below 60^{O}F. Hence, the study area isincluded ina hot climatic zonedue the above mentioned average temperature conditions.

In therainy season from the month of April to October, study area received rainfall between 20 mm to 180 mm. while the maximum rainfall is observed between months of June to October,which ranges from100 mm to 180 mm.But, all the months are having more than 180 mm of potential evapotranspiration, except August month. So, all the months in the study area are falls in water deficit months. The graph clearly denotes that not for single month rainfall exceeds potential evapotranspiration, which means that the study area faces the acute meteorological drought condition. In addition to that improper irrigation practices and mismanagement of water resources convert this situation into water scarcity conditions called as droughts.

The climatic conditions of Osmanabadare varied from high arid to the dry sub-humid. According to the values obtained, about seven months in Osmanabad are having severe arid climatic conditions. Very specifically the month of March is having very high arid index value (TMI= -98.51). Besides that, six other months represented the high arid and dry climatic conditions, made it clear that the Osmanabad district is vulnerable to the drought. Due to the lack of irrigation facilities and mismanagement of water supply in Maharashtra state, most of the districts in south-eastern and central Maharashtra are vulnerable to drought. Therefore, at the current situation a case study of Osmanabad district represented that about 99 % area of Osmanabad district is drought affected.

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