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A study of the Severity of Aridity in Mahaboobnagar and Nalgonda districts in Telangana, India

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Abstract: Drought is a very common climatic phenomenon in tropical and subtropical regions. In recent times it has become severe because of frequent climatic shifts, delayed onset and early withdrawal of monsoon, aberrant and unequal distribution of precipitation, vast deforestation for intensive agriculture and increasing global temperature. Aridity is an indicator of the severity of continuous drought in a region for a long period. Even though, drought is temporary, but a continuous drought results in decreasing the soil vegetation canopy which reduces the moisture holding capacity of the soil and allows maximum evaporation. And added with transpiration the region faces severe loss of soil water contents along with increased temperature that seriously affects the local weather. This phenomenon later leads to aridity and ultimately affects the hydrological cycle in long-run. Aridity not only affects the regional ecosystem rather it also affects the agricultural productivity and groundwater table as a means of its life-threatening impact. Hence it is necessary to delineate the drought prone and arid areas within vast agroecological zones to take necessary measures for the sake of the future to avoid unexpected desertification. The present study areas taken account for the research are two such districts of Telangana state situated in the table land of Deccan trap in south India. To delineate the places in the districts which have suffered severe drought condition for consecutive years between 1979 and 2018, four different empirical aridity indices proposed by De' Martonne (1925), Thornthwaite (1931), Emberger (1932) and UNEP (1992) were fitted into the climate parameters. The results revealed that, due to variation in local physical attributes, appropriate method to delineate the arid regions in the districts varied from one to other.

Keywords: Potential Evapotranspiration, Aridity, Drought Severity, Tropical Regions, Precipitation Trend, Temperature Deviation, Precision Agriculture

I. INTRODUCTION

Drought is "a period of abnormally dry weather sufficiently long enough to cause a serious hydrological imbalance" whereas aridity is defined as "the degree to which a climate lacks effective, life-promoting moisture" (Glossary of Meteorology, American Meteorological Society - 1,2). "Drought is a frequently occurring phenomenon within a defined climate region for a given period of time. It is a common occurrence in all climate regions and its characteristics significantly vary from place to place based on its causatives and influencing factors. Both the phenomena differ from their meaning as drought is a momentary occurrence while aridity is a lasting manifesting characteristic of climate of regions but both are the results of scarcity of water either in terms of scanty precipitation or soil-water deficit. With contrast to drought, which is a temporary aberration of precipitation over a region, aridity is termed as the demand and supply of water through potential evapotranspiration (PET) and precipitation over a long period of time which when the demand exceeds the supply. In contrary, drought refers to the state of moisture stress which occurs for a short period within a hydrological year. Hence, when temporarily the supply of required water for a given period does not meet the demand, it is termed as drought (National Centers for Environmental Information - 3). Farther existence from waterbodies and increasing temperature du to longer exposure to solar radiation are the major reasons which cause the rate of evapotranspiration higher in dry regions compared to the total precipitation. The rate of ET or PET is an empirically proven

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indicator in estimating the severity of aridity of regions (Tavoosi T et al -4). However, aridity indices quantitatively represent the degree of water deficit of a defined region in terms of insufficient supply of water to moist the soil for the sustainability of the vegetation to survive or grow (Stadler S.J. -5). Scaling and complying aridity is not a simple task as thorough examination of hydro-climatological and hydro-ecological variables is needed to fully understand its behavioral impact on the associated sectors. But in simple terms it can be said that a mathematically calculated impact model that is used to predict the changes in aridity is the aridity index (AI) that is closely computed from ratio between PET and precipitation which inclusively explains the concept of aridity and its degree by a unitless representative number (P Greve et al - 6). The development of AI started from the earlier work done by De' Martonne in 1925 which was then simply defined as the ratio of precipitation to the average temperature and the purpose was to classify various climate regimes and the respective vegetation canopies that grow in specific climate condition across the globe at continental level and further went on several modifications in course of time. However, the potential of AI is not limited to this, rather it is an effective indicator for analyzing the suitability of growing various crops based on the climate regime as well as risk assessment and study of groundwater has become easier to predict to take necessary precautions or measures to mitigate any future climatic hazards.

II. STUDY AREA

The regions selected for the present study are two districts of Telangana state situated on the table land of Deccan Trap in south India. Mahaboobnagar district is extended from 77.235913 °E to 78.371872 °E longitude and 16.340754 °N to 17.040240 °N latitude while to the east of it, Nalgonda district extends between 78.661913 °E to 79.699845 °E longitude and 16.356208 °N to 17.360187 °N latitude in the state (Figure 1). Both the districts geographically occupy 5085.764 km² and 7190.238 km² of lands respectively. Since both the districts are placed on the great Deccan Plateau, the terrains show undulated characteristics throughout both the districts. Most of the regions take oblique course from one end to the other. The surface elevation gradually elevates from south to north in case of Mahaboobnagar but east to west in case of Nalgonda district. As per the Planning Commission of India (PCI), the state falls within the 10^{th} Agoclimatic Zone known as the Southern Plateau and Hills. The entire state is characterized as semiarid where the temperature ranges from 13 °C to 42 °C. As annual average precipitation, the state receives 500mm to 1000mm and hence dry farming is widely practiced throughout the state. Based on the regional sub-classification, both the districts fall within the Southern Telangana Zone. The zone receives an annual normal rainfall of 809 (700—900) mm. About 77 percent of the total rainfall is received during south west monsoon only. However, the normal precipitation derived from long term average differs for both the districts that is 763.4mm for Mahaboobnagar but 816.3mm for Nalgonda district. This indicates that climate of Mahaboobnagar district is drier than that of Nalgonda district.

III. MATERIALS AND METHODS

i. Meteorological Data

Since the AI is a function of PET, precipitation and temperature, obtaining these meteorological parameters is the first priority for the computation. Precipitation and temperature are the two major meteorological parameters which was collected from multiple international climate and environmental data distributing agencies such as National Center for Atmospheric Research (NCAR)/Research Data Archive (RDA), Climatologies at High resolution for the Earth's Land Surface Areas (CHELSA), Global Weather Data for Soil and Water Assessment Tool (SWAT)/National Centers for Environmental Prediction (NCEP)/Climate Forecast System Reanalysis (CFSR)/University Corporation for Atmospheric Research (UCAR) and Climate Hazards center InfraRed Precipitation with Station data (CHIRPS) through Climate Hazards Center (CHC). A list of all the data at various spatiotemporal scale collected for the study is given below in the table (Table 1).

Table 1. List of data sources used for the study

1	2	3	4	5	6	7
Source	**Dataset**	**Name**	**Variables**	**Spatial Resolution**	**Temporal Range**	**Reference**
NCAR/RDA	ds093.0	NCEP CFSR 6-hourly Products	Precipitation & Temperature	0.312° x ~0.312°	1979-01-01 to 2011-01-01	Saha, S., et al. 2010 [7]
	ds094.1	NCEP CFSv2 Selected Hourly Time-Series Products	Precipitation & Temperature	0.205° x ~0.204°	2011-01-01 to 2019-01-01	Saha, S., et al. 2011 [8]
	ds094.2	NCEP CFSv2 Monthly Products	Precipitation & Temperature	0.205° x ~0.204°	2011-01-01 to 2019-01-01	Saha, S., et al. 2011 [9]
CHESLA	Version 1.2	Time Series	Precipitation & Temperature	30 arc second ~1km	1079-01-01 to 2013-12-31	Karger, D.N et al 2017 [10, 11, 12]
Tamu.edu	SWAT	Global Weather	Precipitation & Temperature	0.33° x 0.33°	1979-01-01 to 2014-07-31	Dile, Y. T et al 2014 [13], Fuka, D.R et al 2013 [14]

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CHC/USAID	Version 2.0	CHIRPS	Precipitation	0.05° x 0.05°	1981-01-01 to 1981-01-01	C. Funk et al. 2015 [15]

ii. Computation of PET and AI

Potential evaporation (PE), best known as Potential Evapotranspiration (PET) [Wikipedia -16] is defined as the amount of evaporation inclusive of plant transpiration that would occur if a sufficient water source were available within a given geographical extent for a given period of time. If the Actual Evapotranspiration (AET: The sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere) is considered the net result of atmospheric demand for moisture from a surface and the ability of the surface to supply moisture, then PET is a measure of the demand side. Surface and Air Temperatures, Insolation (Solar irradiance is the power per unit area received from the Sun in the form of electromagnetic radiation in the wavelength range of the measuring instrument. The solar irradiance integrated over time is called solar irradiation, insolation, or solar exposure. However, insolation is often used interchangeably with irradiance in practice), and wind all affect this. A dryland is a place where annual potential evaporation exceeds annual precipitation. For this research, The PET is estimated using the C. W. Thornthwaite's method (1948) [17]. The equation for estimation as follows:

$$\boldsymbol{PET} = 16\left(\frac{L}{12}\right)\left(\frac{N}{30}\right)\left(\frac{10T_a}{I}\right)^{\alpha} \qquad \textit{(Eq-1)}$$

Where PET is the estimated Potential Evapotranspiration (mm/month), Ta is the average daily temperature in °C (if this is -ve, use 0) of the month being calculated, N is the number of days in the month being calculated, L is the average day length (in decimal hours) of the month being calculated. The power α is calculated from the formula below:

$$\alpha = (6.75 \times 10^{-7})\, I^3 - (7.71 \times 10^{-5})\, I^2 + (1.792 \times 10^{-2})\, I + 0.49239 \qquad \textit{(Eq-2)}$$

Where, *'I'* is calculated from the given formula below which is a Heat Index that depends on the 12 monthly mean temperature T_{ai}.:

$$\sum_{i=1}^{12}\left(\frac{Tai}{5}\right)^{1.514} \qquad \textit{(Eq-3)}$$

Potential evapotranspiration is mainly driven by the density of vegetation canopy, quantity of surface water as well as precipitation, temperature, wind and vapor demand of the atmosphere. After a complex calculation, Monthly to Annual, Decadal and then the Normal of PET were calculated for both the districts.

Based on De' Martonne's Aridity Index, as it is the first index based on aridity developed by De' Martonne in 1925 [18], the calculation procedure was made very simple. This is an aridity–humidity index and is only applicable locally. This measure of aridity of a region is given by the following relationship:

$$A_m = \frac{P}{T+10} \qquad \textit{(Eq-4)}$$

Where, P is the annual total precipitation in mm and T is the annual average temperature in °C. Since the method is based on the inverse relationship between Precipitation and Temperature, it is evident that at a given constant temperature, higher values of the index are indications of higher rate of precipitation or less prone to aridity, which is a very simplest method of assessing the risk of aridity at a local scale where usually the temperature varies very less because of smaller spatial extent. The classification of the values is given in the table (Table 2).

Table 2. Aridity Index based on De' Martonne (1925)

Aridity Index	Classification
00 – 05	Hyper-Arid
05 – 10	Arid
10 – 20	Semiarid
20 – 24	Mediterranean
24 – 28	Semi-Humid
28 – 35	Humid
35 – 55	Very Humid
Above 55	Extremely Humid

Thornthwaite's Precipitation Effectiveness Index (alias: Precipitation Efficiency) [19,20] is another effective technique used in this study to delineate the regions with certain degree of dryness where the vegetation being determined by precipitation effectiveness. Precipitation effectiveness or precipitation efficiency, he defined it as only the amount of total precipitation which is available for the growth of vegetation. He used precipitation efficiency ratio for the calculation of this amount of water available to vegetation. It (P/E ratio) is calculated by dividing the monthly precipitation by monthly evaporation and precipitation

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efficiency index (P/E index) is derived by summing the precipitation efficiency ratios for 12 months of a year which is used to define five humidity provinces, with associated vegetation. Since it was often difficult to obtain the data of evaporation for all the places, hence Thornthwaite suggested the following formulae for the calculation of precipitation efficiency ratio and index:

$$PE_{index}{}_1^n = \sum_{n=1}^{12} 115 \times \left(\frac{P}{T-10}\right)^{\frac{10}{9}} \quad \text{(Eq-5)}$$

Where, P is the monthly precipitation in inches, T is the temperature in ˚F and n is Months 1 – 12. His climate classification scheme is given in the table (Table 3).

Table 3. Aridity Index based on Thornthwaite (1931)

Aridity Index	Classification
Less than 16	Arid
16 – 31	Semiarid
32 – 63	Sub-Humid
64 – 127	Humid
128 above	Wet

The computation of Emberger's Aridity Index (IE 1932) [21] involves the mean annual precipitation and mean temperature of both the coldest and hottest months and is determined using the following formula:

$$AI = \frac{100 \times P}{M^2 - m^2} \quad \text{(Eq-6)}$$

Where M is the average maximum temperature of the hottest month in °C, m is the average minimum temperature of the coldest month in °C and P is the annual average precipitation in 'mm'. The classified climate zones based on the Index are given in the table (Table 4).

Table 4. Aridity Index based on Louis Emberger (1932)

Q (IE)	Climate Type
00 – 17	Hyper Arid
17 – 30	Arid
30 – 57	Semiarid
57 – 98	Sub Humid
98 – 150	Humid
>150	Hyper Humid

As suggested by Thornthwaite C. W. in 1931, to classify the climate zones the involvement of evaporation is required, UNEP in 1992 [22] finally redeveloped the index and instead of only evaporation, it accounts to the Potential Evapotranspiration for any given hydrological year in a region. The ratio between the precipitation and the potential evapotranspiration gives a better accuracy of measurement in classifying the climate zones from micro to global scale. So, the formula is developed as:

$$AI = \frac{P}{PET} \quad \text{(Eq-7)}$$

Where P is the average annual precipitation in mm/cm and PET is annual potential evapotranspiration in mm/cm. (Thornthwaite – 1948). The boundaries that define various degrees of aridity and the approximate areas involved are given in the table (Table 5).

Table 5. Aridity Index as per UNEP (1992-1997)

Aridity Index	Classification
Less than 0.05	Hyper Arid
0.05 – 0.20	Arid
0.20 – 0.50	Semiarid
0.50 – 0.65	Dry Sub-Humid
Above 0.65	Humid

IV. DISCUSSION

i. Temperature trend in both the districts

Deviation in rainfall has always been the area of interest for every climate analyst and agricultural researcher. Especially the annual average temperature which is derived from the minimum and maximum temperature throughout the year and the average precipitation during the monsoon season as well as the individual months which the monsoon seasons consist of are the key

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factors that reveal the actual climatic scenario of any study region. This helps in understanding the reason of changes in agricultural production-productivity and patterns-practices of agriculture for any specific agroclimatic region. Here we are analyzing various degrees of the climate variability and it is suitability for agricultural practices for both the Study Areas with the help of Temperature and Precipitation distribution over a period of 40 years from 1979 to 2018 and the Normal are also derived from the assumed study duration instead of the existing ones.

Temperature Deviation in Mahaboobnagar: Fluctuation in Temperature is evident as time passes. Over 40 years of study elucidates a great detail about the fluctuation of Temperature in the District from Monthly to Annual or Decadal and are measured on a scale of Deviation from the Normal. The limit is of the positive and negative deviations of Maximum, Minimum and Mean Temperature for each month for 40 years is given in the table (Table 6). The table describes that, during the colder months (colored as green), the Maximum Temperature positively deviated by 0.06°C to 2.17°C for 24 to 26 years and the Minimum Temperature increased by 0.01°C to 1.82°C in 20 to 22 winters out of 40 years. As it is seen in the Maximum Temperature declined by 0.01°C to 4.98°C for 13 to 16 years, also the similar is observed in case of the Minimum Temperature. In 18 to 20 winters, the Minimum Temperature is recorded to be decreasing by 0.07°C to 1.98°C from the Normal. Similarly, in 21 to 23 winter months the Mean Temperature showed 0.01°C to 1.82°C positive deviation whereas 17 to 17 winter months showed 0.07°C to 1.98°C negative Deviation. This indicates that most of the winters were not much colder as expected but certain winters remained colder than the Normal.

During the summer months (colored as red), the Maximum Temperature is recorded to be deviating positively by 0.11°C to 2.39°C for 21 to 22 months and the Minimum Temperature increased by 0.01°C to 4.30°C for 18 to 19 months. In contrary the Maximum Temperature decreased by 0.01°C to 6.70°C for 18 to 19 months and the Minimum Temperature also declined by 0.01°C to 3.51°C for 21 to 22 months. This implies that nearly half of the total study period, the summer months were either too hot or cooler than the normal summer. But looking at the Mean Temperature, it is clear that, 22 to 24 summer months showed a positive deviation of Mean Temperature from 0.03°C to 2.05°C indicating the summers were hotter than the usual and 16 to 18 summers were apparently cooler as the Mean Temperature decreased by 0.09°C to 4.94°C.

It is observed during the two Monsoons (colored as red) the Maximum Temperature deviated positively by 0.01°C to 3.23°C for nearly 19 to 23 years but the Minimum Temperature showed 0.01°C to 3.42°C increase for 17 to 20 years. This indicates that most of the Monsoon months remained hotter than the usual. In reverse the Maximum Temperature decreased by 0.01°C to 3.96°C for 17 to 21 years and so the Minimum Temperature also declined by 0.02°C to 3.21°C for nearly 21 to 23years. The Mean Temperature also recorded to be increasing by 0.01°C to 2.26°C and decreased by 0.02°C to 2.28°C for 17 to 21 and 19 to 23 years respectively.

Table 6 No. of occurrences & Deg. of +ve & -ve dev. of Temp. in Mahaboobnagar (1979-18)

MAXIMUM TEMPERATURE													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual
No. of Negative Dev.	14	13	16	19	18	18	19	21	19	19	17	19	10
No. of Positive Dev.	26	27	24	21	22	22	21	19	21	21	23	21	30
Lowest Negative Dev.	-4.06	-4.98	-4.98	-3.50	-6.70	-3.89	-3.82	-3.55	-3.82	-3.48	-3.40	-3.96	-2.84
Highest Negative Dev.	-0.08	-0.42	-0.01	-0.05	-0.01	-0.04	-0.04	-0.06	-0.08	-0.24	-0.01	0.00	-0.02
Lowest Positive Dev.	0.07	0.06	0.14	0.11	0.13	0.10	0.13	0.09	0.01	0.06	0.12	0.02	0.03
Highest Positive Dev.	1.84	2.17	1.94	2.10	2.39	3.23	3.15	2.53	2.29	3.47	2.35	2.40	1.16
MINIMUM TEMPERATURE													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual
No. of Negative Dev.	20	18	20	21	22	23	23	23	20	22	21	23	26
No. of Positive Dev.	20	22	20	19	18	17	17	17	20	18	19	17	14
Lowest Negative Dev.	-2.57	-3.77	-3.71	-3.51	-3.01	-1.62	-1.08	-0.95	-1.12	-1.72	-3.21	-2.30	-0.86
Highest Negative Dev.	-0.11	-0.01	-0.01	-0.01	-0.01	-0.20	-0.09	-0.09	-0.07	-0.06	-0.18	-0.02	-0.02
Lowest Positive Dev.	0.03	0.08	0.12	0.02	0.01	0.19	0.01	0.00	0.01	0.03	0.05	0.02	0.05
Highest Positive Dev.	5.63	3.67	4.00	4.30	3.98	3.42	2.62	2.12	1.23	2.23	3.45	2.96	1.85
MEAN TEMPERATURE													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual
No. of Negative Dev.	17	18	19	18	16	21	18	20	19	21	17	21	21
No. of Positive Dev.	23	22	21	22	24	19	22	20	21	19	23	19	19
Lowest Negative Dev.	-1.55	-1.98	-1.90	-2.16	-4.94	-2.28	-2.18	-2.14	-2.06	-1.95	-1.84	-1.51	-0.83
Highest Negative Dev.	-0.07	-0.09	-0.07	-0.15	-0.09	-0.09	-0.04	-0.04	-0.06	-0.02	-0.03	-0.09	-0.02
Lowest Positive Dev.	0.05	0.05	0.01	0.03	0.08	0.12	0.03	0.04	0.06	0.06	0.02	0.01	0.01
Highest Positive Dev.	1.82	1.22	1.30	2.05	1.76	2.26	1.88	1.82	1.32	2.17	1.57	2.06	0.71

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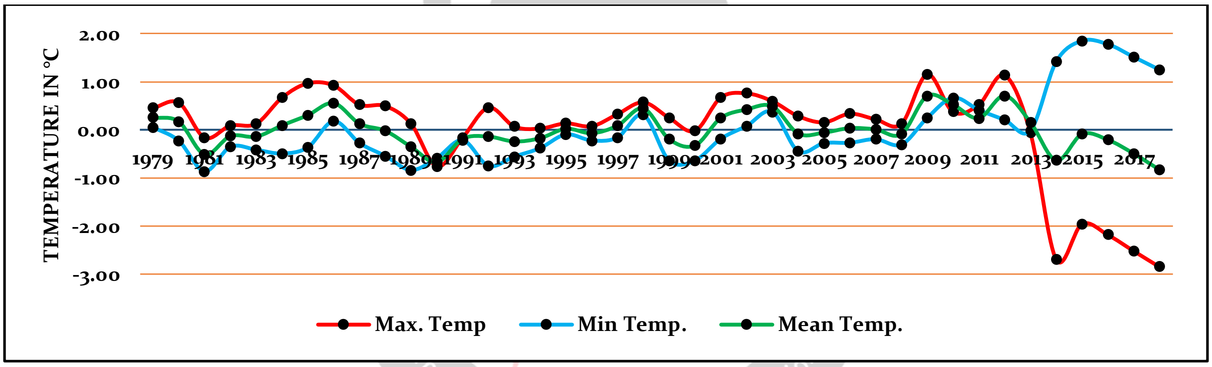
Overall looking at the deviation of Annual average Maximum and Minimum Temperature (colored as yellow), it can be exactly said that nearly one-third of the total study period (14 years), the district suffered hotter, one-fourth of the period (10years), cooler and rest of the 16 years the climate was dynamic since the Maximum and Minimum Temperature are reported to be positively deviating for 30 and 14 years (common 14 hotter years) respectively. Whereas, the negative deviation for both is recorded for 10 and 26 years (common 10 cooler years) respectively.

Finally, from the limit is of the deviation of the Mean Temperature in the table above and the deviation of Annual average Maximum, Minimum and Mean Temperature from the Normal for 40 years which is illustrated in the graph (Graph 1) below, shows 19 years positive deviations, while the years 1981-83, 1989-96, 1999-2000, 2005-08 and 2014-18 have shown apparently negative deviation from the Normal. Very unlike the precipitation variation, the temperature also showed a continuity of positive or negative variation for 3-4 times. 1979-80, 1984-87, 1997-98, 2001-03 and 2009-13 are the continuous hotter years consisting of a set of 2-4 years in a row as the deviation was positive from the Normal. And hence, a continuation of apparently colder years was also observed. Hotter weather in a sequence, result more surface evaporation leaving the agricultural lands dry and unpredicted sudden heavy down pour causing more runoff, erosion and flood. On the other hand, continuity of cooler weather years resulted in less surface evaporation causing less precipitation resulted in continuous drought for the successive year or years.

Table 7 Month-wise & Annual avg. dev. & var. of Mean Temp. from the Normal in Mahaboobnagar

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual
Normal	23.81	26.50	29.72	32.13	32.96	29.06	27.01	26.44	26.63	25.99	24.37	23.08	27.31
Avg ∂m	0.66	0.68	0.64	0.70	0.94	0.99	0.64	0.50	0.65	0.61	0.68	0.75	0.28
Avg σ²	0.66	0.65	0.65	0.71	1.66	1.36	0.73	0.44	0.65	0.64	0.70	0.80	0.13
Avg σ	0.81	0.81	0.81	0.84	1.29	1.17	0.85	0.66	0.81	0.80	0.84	0.89	0.36

Graph 1 Year-wise Mean dev. of avg. Annual Max., Min. and Mean Temp. in Mahaboobnagar



The above table (Table 7) describes that for each monsoon month i.e., June to December, the variance shows positive. Which means overall these Monsoon months (orange shaded columns) always were hotter than the Normal. As discussed before, hotter weather years face unpredicted precipitation. Here, it is to be understood that, hotter weather is expected in summer months instead of the months of monsoon season. As the graph shows the average deviations for these monsoon season months are positive, this means on an average all the 40 years were apparently hotter than before and the precipitation received was also comparatively less. This of course is a big challenge for the agricultural producers in the district.

Temperature Deviation in Nalgonda: As discussed in the previous session, it is already seen that even though the pattern of Annual Mean Temperature fluctuation in both the districts are similar, in all the cases the lowest limit of Minimum, Maximum or Mean temperature is at least 1°C to 1.5°C higher than Mahaboobnagar. This indicates that Nalgonda went through hotter climate throughout the last 40 years. The limit is of the Positive or Negative Deviations for Minimum, Maximum and Mean Temperature for each month as well as on a seasonal basis is given in the table (Table 8). The table describes that for the Maximum Temperature, 24 to 29 months showed to be positively deviated ranging from 0.02ºC to 2.9ºC during the winter months (colored as green) when at the same time in 19 to 21 winter months the Minimum Temperature positively deviated ranging from 0.01°C to 7.0°C. This indicates how for more than half of the study period, the usual cold weather of the winters turned into hotter months. On the other hand, the Maximum Temperature showed negative deviation ranging from 0.12ºC to 5.0°C with the Minimum Temperature deviating from 0.01°C to 3.53°C for 11 to 16 and 19 to 21 years' winter months respectively. This indicates that at least 11 to 16 winters were recorded to be colder and 19 to 21 years the winters were unusually hotter than the average ones. This can be seen in case of the Mean Temperature deviated positively for 22 to 25 years by 0.05°C to 1.66°C when negatively deviated for the 15 to 18 years by 0.02°C to 2.47°C.

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Most of the summer months (colored as red) were also observed to be hotter than the usual as in 21 to 24 summers the Maximum Temperature of the constituting months positively deviated from 0.01°C to 2.56°C with the Minimum Temperature positively deviating during the summer months in 19 to 21 years ranging from 0.03°C to 3.92°C. In reverse, for 16 to 19 years the Maximum Temperature in the summer months negatively deviated from 0.05°C to 7.48°C where the negative deviation of Minimum Temperature ranged from 0.02°C to 3.78°C for 19 to 21 years. Also, the Mean temperature showed a positive deviation for 19 to 27 years by 0.02°C to 2.09°C whereas negatively only during the summers in 13 to 21 years by 0.03°C to 2.59°C. So, at least in16 to 19 years, the summer months were unexpectedly cooler and 19 to 21 years the summers were piercingly hotter than the usual.

Similar case is observed in case of both the Monsoon seasons (colored as blue) for the district. Nearly for two-third (19 to 25 years) of the total time period, the Maximum temperature positively deviated from 0.01°C to 2.99°C with the Minimum Temperature to be increasing in parallel by 0.02°C to 3.68°C for 16 to 21 years. Hotter weather during the Monsoon Seasons is an indication of erratic precipitation too. It is recorded as, during the Monsoon months for 15 to 21 years, the Maximum Temperature deviated negatively by 0.01°C to 4.04°C when the Minimum Temperature negatively deviated by 0.02°C 2.6ºC for 19 to24 years. The Mean Temperature also increased by 0.01°C to 2.47°C during the Monsoons in 17 to 24 years while in 16 to 23 years the Mean Temperature decreased by 0.01°C to 2.72°C. This implies that only for 15 to 19 years the Monsoons were fairly active, whereas for 16 to 19 years because of hotter climate the Monsoons were not as healthy as expected.

Table 8 No. of occurrences & Deg. of +ve & -ve dev. of Temp. in Nalgonda (1979-18)

Maximum Temperature													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean Annual**
No. of Negative Dev.	11	15	16	19	16	17	21	21	21	19	15	16	11
No. of Positive Dev.	29	25	24	21	24	23	19	19	19	21	25	24	29
Lowest Negative Dev.	-4.22	-5.00	-4.39	-2.67	-7.48	-4.00	-3.52	-3.71	-3.39	-3.44	-3.65	-4.04	-2.63
Highest Negative Dev.	-0.12	-0.07	-0.16	-0.07	-0.05	-0.33	-0.08	-0.01	-0.01	-0.02	-0.03	-0.12	-0.08
Lowest Positive Dev.	0.09	0.02	0.11	0.12	0.01	0.08	0.01	0.16	0.11	0.01	0.06	0.02	0.04
Highest Positive Dev.	1.91	2.90	2.37	2.03	2.56	2.56	2.94	2.72	2.60	2.99	1.82	2.08	1.04
Minimum Temperature													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean Annual**
No. of Negative Dev.	21	19	20	21	19	22	24	19	23	21	21	20	24
No. of Positive Dev.	19	21	20	19	21	18	16	21	17	19	19	20	16
Lowest Negative Dev.	-2.52	-3.53	-3.52	-3.78	-3.56	-1.80	-1.06	-0.94	-1.36	-1.52	-2.60	-2.27	-0.90
Highest Negative Dev.	-0.01	-0.01	-0.10	-0.02	-0.04	-0.04	-0.02	-0.11	-0.02	-0.06	-0.08	-0.06	-0.02
Lowest Positive Dev.	0.02	0.01	0.15	0.04	0.03	0.07	0.04	0.02	0.02	0.00	0.10	0.02	0.04
Highest Positive Dev.	7.00	2.86	3.27	3.92	3.89	3.51	2.58	1.41	1.00	2.85	3.68	3.33	1.32
Mean Temperature													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean Annual**
No. of Negative Dev.	17	18	15	21	13	20	23	18	22	17	16	21	17
No. of Positive Dev.	23	22	25	19	27	20	17	22	18	23	24	19	23
Lowest Negative Dev.	-1.83	-2.47	-1.75	-2.59	-5.28	-2.66	-2.10	-2.38	-1.94	-2.20	-2.72	-2.24	-1.06
Highest Negative Dev.	-0.02	0.00	-0.13	-0.03	-0.24	0.00	-0.05	-0.02	-0.01	-0.01	-0.02	-0.11	-0.05
Lowest Positive Dev.	0.11	0.00	0.05	0.20	0.02	0.01	0.14	0.01	0.11	0.01	0.05	0.01	0.02
Highest Positive Dev.	1.66	1.37	1.29	2.09	1.99	2.47	2.09	1.57	1.54	1.42	1.48	1.65	0.59

On an average, for 29 years the average Annual Maximum and 16 years the Minimum Temperature increased up to 1.04°C and 1.32°C while decreased up to 2.63°C and 0.9°C for rest of the years. So, it is presumed that 16 to 29 years the overall climate was apparently hotter. It is known from the previous table that for 23 years the average Annual Mean Temperature deviated positively up to 0.59°C and negatively for 17 years up to 1.06°C. The irregularity or the inconsistency of the Maximum, Minimum and Mean Temperature deviation from the Normal between successive years is shown in the graph (Graph 2). Years such as 1979-87 (9 years), 1993-95 (3 years), 1997-98 (2 years) 2001-03 (3 years), 2009-13 (5 years) were sets of years when the deviation was consecutively higher than the Normal. In contrary to the positive deviations, rest of the years also showed consecutively negative deviation. Such continuation in either positive or negative deviations of temperature, sets the region in a state of unpredictable weather and calamities like drought and flood. However, the deviation of temperature in both the districts seems very similar. The fluctuation of maximum temperature also zig-zagged like the minimum temperature but in a reverse manner which implies that when the minimum temperature decreased the maximum temperature increased.

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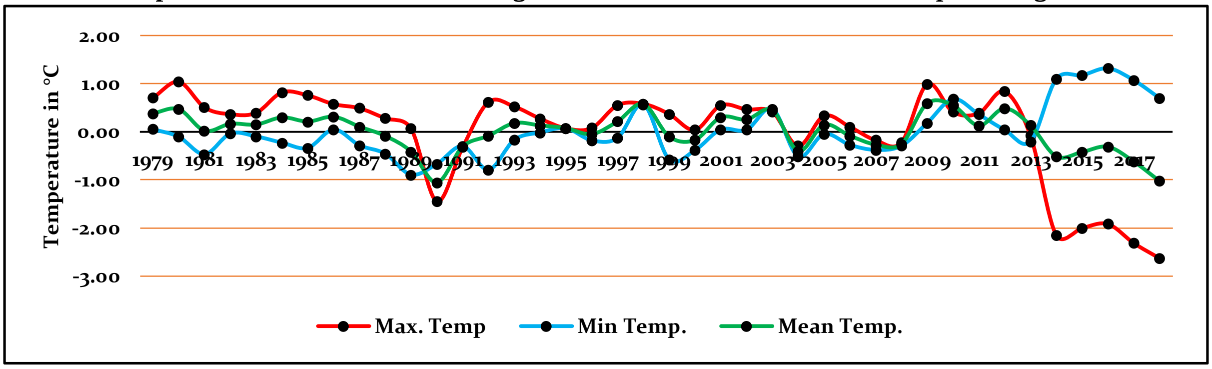
Table 9 Month-wise & Annual avg. dev. & var. of Mean Temp. from the Normal in Nalgonda

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual
Normal	23.60	26.14	29.28	31.81	33.71	31.09	28.88	28.15	27.88	26.71	24.59	23.05	14.56
Avg ∂m	0.70	0.66	0.62	0.76	1.00	0.99	0.71	0.54	0.52	0.51	0.71	0.70	0.31
Avg σ^2	0.74	0.70	0.60	0.91	1.84	1.49	0.79	0.53	0.46	0.56	0.82	0.77	0.15
Avg σ	0.86	0.83	0.78	0.96	1.36	1.22	0.89	0.73	0.68	0.75	0.90	0.88	0.39

Graph 2 Year-wise Mean dev. of avg. Annual Max., Min. and Mean Temp. in Nalgonda



Similar to Mahaboobnagar district, overall, this District also showed a positive variation of temperature for each monsoon month, which is given in the table (Table 9) above. The variation ranges from +0.77°C to +1.49°C where the mean deviation of temperature ranges from +0.7°C to 0.99°C (shaded in orange color) for June to December respectively. Approximately the temperature of the region has risen to 1°C over a period of 40 years. This is a clear indication of severe drought for most of the hydrological years in the district. Temperature is the prime factor responsible for all climatic phenomena. Precipitation and agriculture both get highly affected by the variation of the temperature in any geographical location. Therefore, it is necessary to understand the distribution and variation of temperature at various scales (time and place) in any region to correlate the precipitation and agriculture.

ii. Precipitation trend in both the districts

Rainfall Deviation in Mahaboobnagar: Since Temperature is the cause and Precipitation is the effect, it is obvious that the rainfall will be unpredicted when the temperature has a dynamic variation in every alternative year. In this district, the rainfall distribution during the two monsoon months and the deficit months which were having below Normal precipitation over a period of 40 years can be clearly identified from the table below (Table 10). The study reveals that the Normal rainfall received by the district during South-west Monsoon is nearly 5 times higher than the North-east Monsoon. Apart from that, the district received below Normal rainfall for 22 years during southwest monsoon season and 27 years during northeast monsoon season. Northeast monsoon seems to be more erratic than the southwest in case of this district. Nearly three fourth of study period the total 40 years of period received less precipitation than the Normal. As discussed earlier, the Normal rainfall of Mahaboobnagar is even less than the Normal rainfall of Nalgonda district, it is obvious that the district is more arid than Nalgonda. The graph (Graph 3) describes that, out of 40 years only seven years i.e., 1979, 1981, 1983, 1995, 2005, 2008 and 2017, the district received higher rate of Precipitation. The remaining 22 years were apparently dry which received either near Normal or below Normal rainfall as a whole. The graphs (Figure 2a, 2b, 2c, 2d, 2e & 2f) showing the year wise Mean Deviation of Precipitation for each month describe that the South-west Monsoon months received erratic rate of precipitation. July, which is the second month of South-west Monsoon, except for the years 1982, 1983, 1989, 2005, 2010, 2016, and all the other years showed negative mean deviation. Coming to August, the third, and September, the last month of South-west Monsoon, it is observed that there is a positive deviation for the month of August, it immediately became negative for the month of September. It means most of the rainfall occurred only in one month out of the three month of actual Southwest monsoon season. The concentration of Monsoon Precipitation in only one month causing the other months to get pulled by drought and the rainy months clout the farmlands by flood, heavy runoff and soil erosion.

Table 10 Monsoon months with Average Precipitation below it is Normal (mm) in Mahaboobnagar District for the period between 1979 & 2018

Monsoon Months	No. of years below Normal RF (out of 40 years)	Range of MD from Normal RF of deficit years	Normal RF
Jun	21	-95.97 to -00.40	96.81
Jul	22	-108.48 to -00.55	139.51
Aug	22	-128.75 to -00.34	172.50
Sep	23	-125.09 to -04.09	145.21

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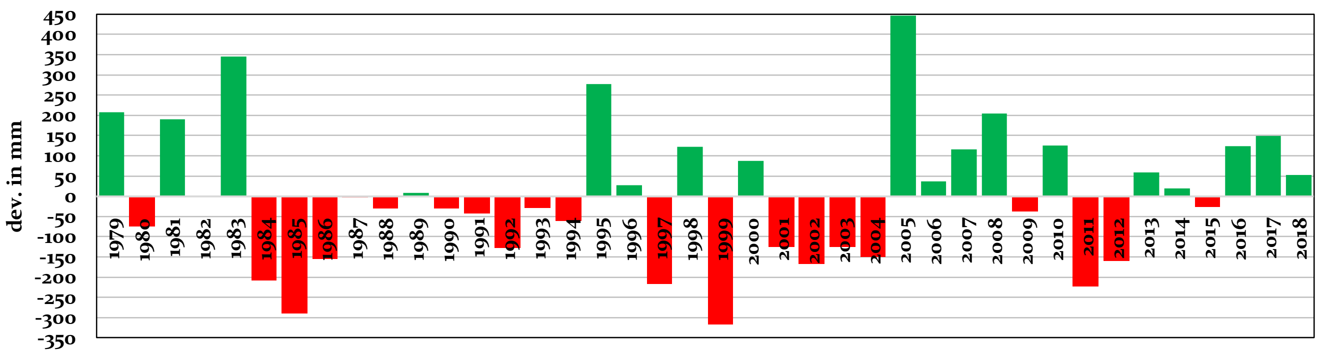
Avg. SWM	**22**	**Monsoon Average**	**554.02**
Oct	23	-82.16 to -14.37	93.67
Nov	27	-21.92 to -02.08	21.92
Dec	30	-05.42 to -01.77	05.42
Avg. NEM	**26.7**	**Monsoon Average**	**121.02**

Graph 3 Year wise Mean Deviation of Annual average Precipitation in Mahabubnagar



In case of Northeast monsoon, it is observed that from 1993 to2005 most of the years, the district received apparently plenty of rainfall for the month of October which became completely dry in the month of November. It's also observed that from 1984-88 (5 years), 1990-94 (5 years), 2001-04 (4 years) and 2011-12 (2 years) there was a continuity in negative deviation. Which means, within a span of 40 years, nearly 3-4 times there was a continuous erratic precipitation in the district for 4 to 5 years in a row without interruption. A statement of 22 deficit years consisting 4 to 5 years of continuous erratic rainfall for more than 3 times is enough to throw back the district into drought prone. As southwest monsoon is the only assured source of water sufficiency in the district, an erratic rainfall is just like a curse for the farmers who produce most of the food crops.

Rainfall Deviation in Nalgonda: Distribution of Rainfall is obviously not same for all places even if they are adjacent to each other. Several causes are there for which the distribution varies from one place to another. This is observed in case of Nalgonda and Mahaboobnagar district. Both the districts received erratic rainfall. But the table below (Table 11) shows Nalgonda received more erratic rainfall than Mahaboobnagar. For a period of 40 years of study, the district received 542.87mm of an average rainfall during the South-west Monsoon which is quite less than Mahaboobnagar. Also, there are 23 deficit months observed during South-west Monsoon and 27 deficit months observed during North-east Monsoon. The district received slightly better precipitation during the North-east Monsoon as compared to Mahaboobnagar. But, still erratic. Same as Mahaboobnagar district, one third of the total period of study, the district received unexpectedly less rainfall during the North-east monsoon. On a whole, this District also was lacking of water sufficiency for which the farmers depend on the annual monsoons every year. As the state of Telangana receives most of the rainfall during south-west monsoon which extends from mid-June to mid-September, hence apart from the pre-monsoon in the month of June the quantity and pattern of distribution of rainfall for the months of July, August and September play a key role in cultivating food crops. A study of the month of July reveals that only in the years 1988, 1989, 2003, 2005 and 2010 showed remarkably above Normal rainfall other than these years almost all the other years showed either negative or negligibly positive deviation from the Normal (Figure 3a, 3b, 3c, 3d, 3e & 3f). On the other hand, for the month of August in the years 1983, 1996, 2008 and 2009 the district received comparatively better rainfall whereas in the rest of the years the monsoon was almost erratic. The most disastrous and retarding factor is that during the initial months (July and August) the monsoon was erratic. The last month i.e., September showed more than ten such years when the district received quite higher i.e., above Normal precipitation and the rest of the years it showed negative deviation from the Normal. This explains that there was remarkable deficit of water during the seeding and growing season of the crop and the availability of water was plenty during the crop harvesting which is of no use. Coming to North-east monsoon, the years 1981, 1994, 1995, 1998, 2001, 2005, 2013 received above Normal rainfall the deviation was very high but rest of the years were completely erratic for the month of October and subsequently the last month of north-east monsoon (November). This implies neither southwest nor northeast monsoon can promisingly help in agricultural activity.

Table 11 Monsoon months with Avg. Precipitation below its Normal (mm) in Nalgonda District for the period between 1979 & 2018

Monsoon Months	No. of years below Normal RF (out of 40 years)	Range of MD from Normal RF of deficit years	Normal RF
Jun	24	-72.16 to -06.46	86.58
Jul	21	-110.68 to -00.25	139.76
Aug	23	-145.02 to -00.79	179.81
Sep	22	-105.37 to -02.69	136.71

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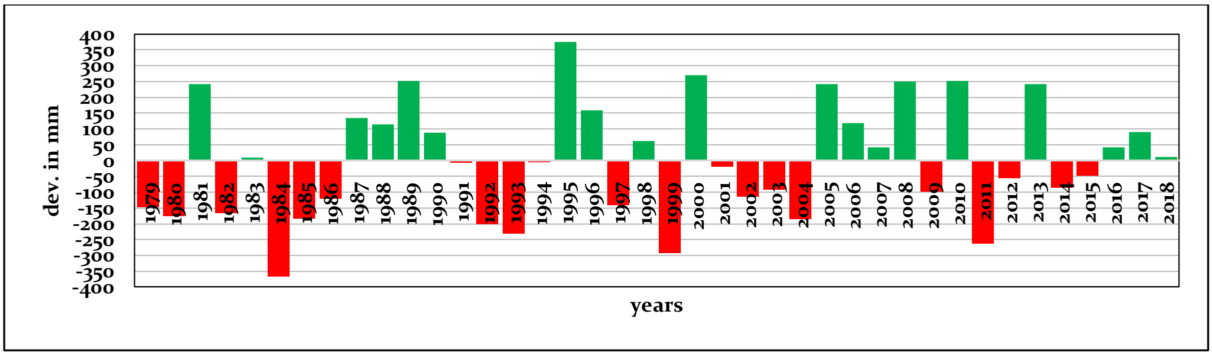
Avg. SWM	**23**	**Monsoon Average**	**542.87**
Oct	25	-107.95 to -04.05	128.64
Nov	26	-34.38 to -3.49	34.38
Dec	30	-08.59 to -01.81	08.59
Avg. NEM	**27**	**Monsoon Average**	**171.61**

GRAPH 4 Year wise Mean Deviations of Annual Average Precipitation in Nalgonda



The given graph (Graph 4) justifies the previous table. It depicts, 22 years out of 40 years were erratic in the district where the Mean Annual Deviation showed negative. Similar to Mahaboobnagar district, in this district also a continuous dry year were reported. 1979-80 (2 years), 1984-86 (3 years), 1991-94 (4 years), 2001-04 (3 years), 2011-12 (2 years) and 2014-15 (2 years) were the years when the district received less than Normal rainfall for more than one year in a row. But the difference is that, the continuation of below Normal rainfall years in a row was not that long like Mahaboobnagar district. Even though the continuity of less than Normal rainfall years were observed consecutively 2 or 3 years, but the occurrence of interval of such situation was very frequent after every continuous good rainfall year. This type of climatic fluctuation or frequent variation in rainfall is not at all assured for practicing food crops unless there is a 100 percent accurate weather forecast is relayed to the farmers. It is therefore pertinent that the strategy of rainfall in the district is quite unpredictable and uneven for every two to three years.

The above analysis explains that, in both Mahaboobnagar and Nalgonda, number of hotter summer years were more, winter months were also unexpectedly hotter. For more than half of the study period the Monsoon months were hotter. For remaining years, the winter, summer or Monsoon months were cooler than the usual. A hotter monsoon is a sign of erratic rainfall and a cooler monsoon is a sign of unpredicted heavy down pouring. In both the cases the monsoon is not dependably trustworthy for the cultivators of the districts. Month-wise comparative view of the Annual Average Min. /Max. And Mean Temperature Deviation clarifies the unstable climatic condition of both the districts which are illustrated in a series of graphs (Figure 4 & 5 a, b, c, d, e, f, g, h, i, j, k, l).

Summer has the most important role for any Hydrological year. Monsoon or any instantaneous convectional precipitation depends on the local temperature and the duration of the summer in any region. In general, longer the summer, delayed the monsoon. Hotter the summer, heavier the rainfall and/or earlier the monsoon. The two Monsoons play significant roles in this study. Deviation in Min./Max./Mean Temperature in other months affect the net Evapotranspiration and decide the arrival of Monsoon. But, the deviation of temperature during Monsoon periods, decide the net precipitable amount of water. It is pertinent that, since the Southern Peninsula receives most of it is precipitation from South-west Monsoon. Hence, a micro level climate analysis is required to clarify the potential, dependability and trustworthiness of the seasons in both the districts to test it is impact on Agriculture.

iii. Potential Evapotranspiration in both the districts

PET in Mahaboobnagar: The decadal averages of the PET from 1979 to 2018 for the district is given in the map (Figure 6a). It is seen that the PET kept on increasing diagonally from North-east to South-west in every decade. The spatial pattern of Mean Annual PET for each year and is given in a series of maps (Figure 7) which describe that for the years 1979-80, 1982-89, 1991-2012 and 2015-17 the rate of PET was very high from the Southern half of the district. Especially during the years 1986, 1998, 2002-03, 2009-10and 2012, in the Southern and South-western regions, maximum PET occurred. The reason was very obvious as the South and South-west regions covering Deverkadra and Chinna Chinta Kunta mandals always received below Normal rainfall, hotter weather with no or less vegetal cover and unprotected openly available surface water. A comparative study of the Annual Mean Temperature Deviation, Annual Mean Precipitation and Annual average PET (Graph 5) reveals that the trend of PET was always parallel with the deviation of mean temperature but the Precipitation showed opposite trend for most of the years and that is in a consecutive manner. This means, when there was a positive deviation of the Temperature, PET was more but for most of such years the Precipitation was erratic. Also, it can be seen on the graph 4.7 that the PET was always much higher than the Precipitation in the district. The order of Precipitation was also most often opposite to the Temperature and PET.

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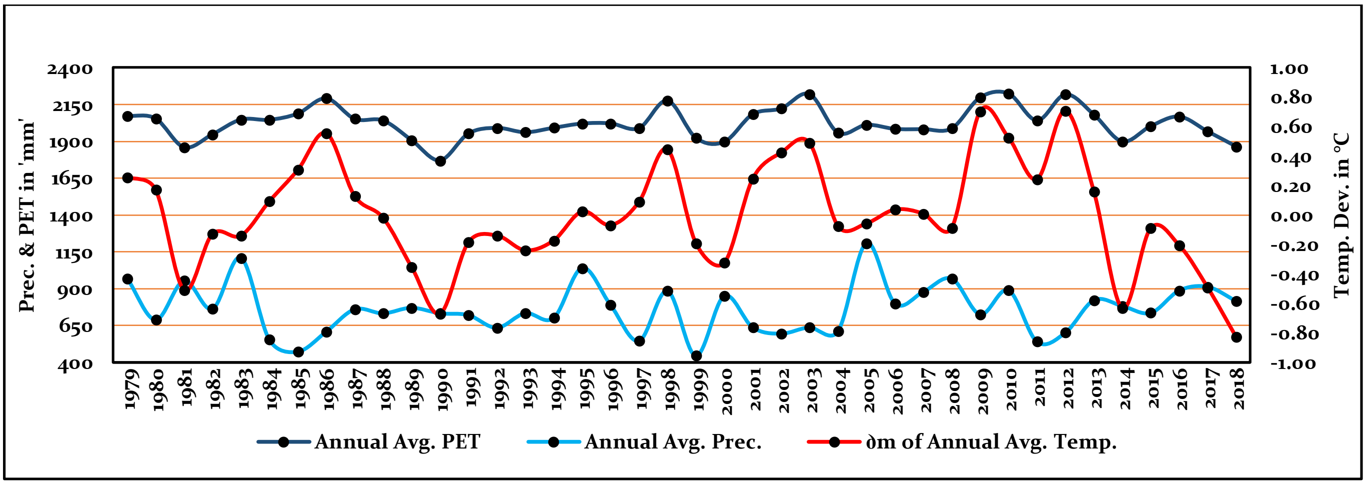
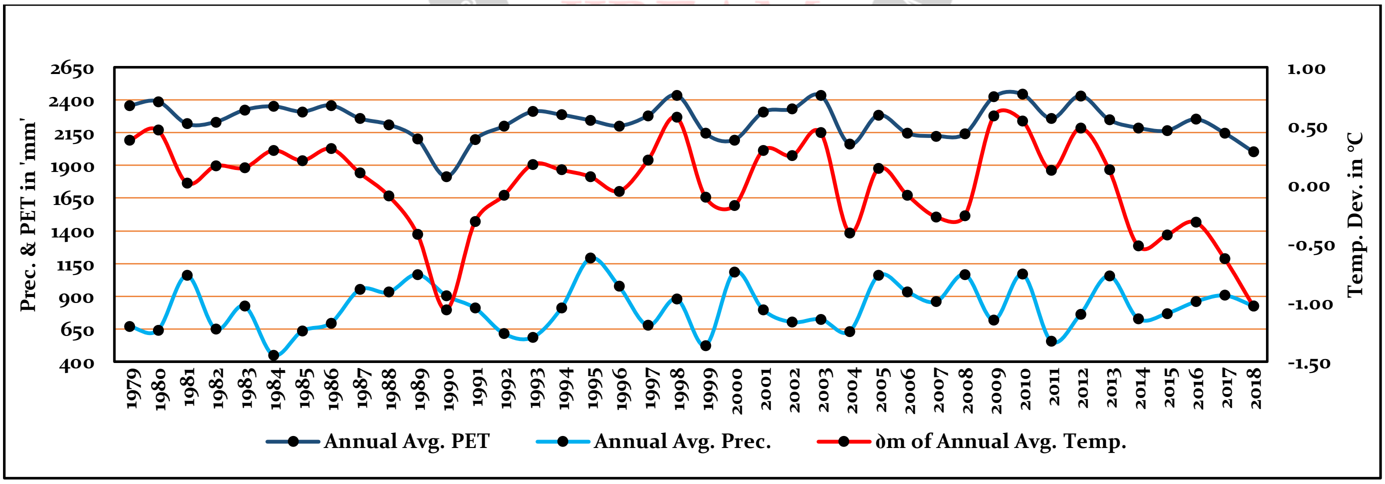
If the PET is more the Precipitation is less. This is the most addressable problem that caused the southern and south-western regions Drier and hotter resulting in drought.

Graph 5 Comparative view between Temperature Deviation, Precipitation & PET in Mahaboobnagar



PET in Nalgonda: It is discussed earlier that the average temperature of Nalgonda is normally 1ºC to 1.5ºC higher than of Mahaboobnagar. Also, one of the major rivers i.e. The river Krishna flows alongside the eastern to southern boundary of the district forming a major water reservoir i.e., Nagarjuna Sagar, in the South. So, it is palpable that PET would be much higher than Mahaboobnagar in Nalgonda. This is shown in the decadal map (Figure 6b) which explains that the trend of PET goes on increasing from west to east reaching to the maximum degree on the Krishna River in the eastern border and is much higher comparative to Mahaboobnagar. It is obvious as the temperature was observed to be increasing from South West to South East all the time and the south and South East regions covering Adavi Devuplapalle, Damacherla, Vemmulapalle and Miriyalguda mandals which received good rainfall and also this region is within the Krishna River basin watershed. The annual average PET maps (Figure 8) showed that except for the years 1988-92, 1999-2000, 2004, 2006-08, and 2014-18 all other years went through maximum rate of PET. But the central regions maintained the same trend in degree of PET throughout whole 40 years. Unlike Mahaboobnagar, for this District also, the comparative study of Temperature Deviation, Mean Annual Precipitation and Mean Annual PET (Graph 6) shows that the rate of PET varies in parallel with the variation of temperature but for most of the years consecutively the amount of precipitation was just opposite. Even though the PET was measured to be higher at rate in

Graph 6 Comparative view between Temperature Deviation, Precipitation & PET in Nalgonda



V. RESULTS

Case I – Mahaboobnagar district: As per De' Martonne's Aridity Index, the places showing the values below 20 are to be categorized as semiarid to hyper-arid regions based on the degree of the dryness. Otherwise, the climate of the region for the given period is either Mediterranean or a degree of Humid. As shown on the maps (Figure 9a & 9b), the places alongside the main three drainage networks remained arid throughout the 40 years except for the years 1981, 1983, 1995, 2008 and 2016-17. During these 6 years no regions within the district are classified under arid zones as the index shows, the consecutiveness of aridity over these river sheds was not continuously for 40 years. The map shown that each river shed became arid for a specific period of years while the other/others were not arid at the same time. It was observed that other than the delineated regions

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(commonly remained arid regions) which are shown on the maps, even though the other regions were arid but for shorter period without any consecutive repetition and hence can be characterized only as prone to drought for shorter periods. However, the southern and the southeastern regions remained arid for the mentioned 36 years immaterial of the spatially shifting trend of the aridity in the district.

Case I – Nalgonda district: As per De' Martonne's Aridity classification, 13 such years were marked when the entire district was non-arid. Also, its measured that the duration of aridity over the delineated regions was for short term but the repetition was very frequent as displayed in the maps (Figure 10a & 10b). The spread of arid regions in Nalgonda was not similar to that of Mahaboobnagar. It's shown on the map that even though the pattern of aridity of different regions in the district was similar to Mahaboobnagar (means if one place is arid for a given set of years the other regions were not), but all the regions of the district at least for one set of periods remained arid within a span of 40 years. It is seen that, during the first 20 years mostly the southern river shed regions repeatedly remained arid for longer period while in the second 20 years all the places alongside the water channels became arid. However, none of the regions of the district were left to be arid at least for a year out of 40. Mostly it is observed in both the districts, for De' Martonne's Aridity Index that the places beside the drainage networks become arid when the temperature increases or the precipitation decreases.

Case II – Mahaboobnagar district: As per the index above, for the places if the annual index shows below 31 are declared as arid zones. Same as previous, here also the semiarid (Index ranging between 16-31) and the arid (index ranging below 16) are clubbed and represented in the maps (Figure 9c & 9d). Applying Thornthwaite's PE Index it is seen that, for the first 15 years, the places neighboring to the drainage networks in the central and northeastern regions remain arid same as De' Martonne's Index. But coming to the next 25 years, the entire district shown to be suffered by aridity. Especially the southern and the southwestern regions remained arid in common for most of the years out of 40 years as shown in the maps. For this District only for the years 1995 and 2005, none of the regions were demarked as commonly falling within arid zones. The continuation of aridity for individual zones in the district also was longer as observed and compared to the classification made by De' Martonne's index. For some individual years like 1995 to 1999, most of the geographical area of the district were classified as arid but due to the shorter time period it was not taken into account but would like to mention those places to be suffering from severe to extreme drought for the mentioned years in individual.

Case II – Nalgonda district: Analyzing the maps (Figure 10c & 10d) of Nalgonda, it is found that same as Mahaboobnagar the continuation of the Aridity is common for the zones in the district are way too longer than as compared to the case of De' Martonne's classification. No such years were marked when there would be no place in the district with aridity within past 40 years of study. At least some places were traced to be remaining arid continuously for few years in the district. The remarkable dynamism in the district which was observed is that, for the initial 15 years (1979 to 1994), diagonally most parts of the left half, (southern and southwestern regions) surrounding the waterlines and catchments, of the district, remained semiarid to arid for successive years. Whereas, the rest of the 25 years (1995 to 2018), the other half (north-central and southeastern regions) including the southern waterbodies surrounding areas remained arid.

Case III – Mahaboobnagar district: Spatially plotting the derived index on map (Figure 9e & 9f) it is observed that, for 28 years except 1979, 1981, 1995, 2005-08 and 2014 to 18, aridity was prevailing hither and thither in the district. The dynamism in spread of arid zones were observed to be repeated after initial 15 years. During the beginning (from 1980 to 1994) 14 years, in 1980, most of the geographical area (except north central region) of the district was mapped as arid. But the regions around the river banks in the north east and longitudinally spreading in the middle of the district were marked to be arid repeatedly for rest of the years till 1994. During the next 25 years the continuation of this aridity appeared to be shifting towards south and the same vertically spreading central river bank regions along with the Southern and southwestern regions continued to be arid till the end of 2013. Unlike De' Martonne's classification, in this classification also the aridity often seemed to be discontinued for one to five years for any defined arid zone but for all these 28 years, the vertical central and the southern region remained arid consecutively for longer time.

Case III – Nalgonda district: Ironically as per the climate classification based on Emberger's Index, after 1999 none of the arid zones were marked (Figure 10e & 10f). But, till 1999, almost the entire district was mapped as arid in distinct patches during different years. For most of the years, Nalgonda was mapped as non-arid.

Case IV – Mahaboobnagar district: As shown in the map (Figure 9g) diagonally divided into two halves of the District, South-western half is marked as arid zone in distinct patches for different set of consecutive years (i.e., 1979-2004, 2005-2010 and 2010-2018). This is evident as the regions were marked as hotter regions with scanty precipitation.

Case IV – Nalgonda district: Applying the index on Nalgonda, it was observed that the case is not similar to Mahaboobnagar. For the initial 12 years the western highlands shown to be arid but later for last 28 years the places surrounding to the major river channels became arid. These places were observed to be spread-out centrally from north-central to southeast and the bank of

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Krishna River in the extreme east (Figure 10g). Also, the foot hill regions of the western highlands became arid for last 28 years in a row.

VI. CONCLUSION

The spatial pattern of changing drought prone areas in both the districts are observed not to be similar and also the four indices which were used to delineate the arid regions within both the districts did not show same results. Based on the pilot tour and interactive mass interview with the people of the identified regions in both the districts based on all four indices, it was revealed that the Aridity index based on De'Martonne-1925 best fits for the delineation of the severity of aridity in Mahaboobnagar district while the index proposed by Emberger-1932 gave the maximum accuracy to map the arid regions in Nalgonda district. Even though both the districts fall within the same agroclimatic zone as per the regional agroclimatic subclassification, both the districts do not show similar climatic characteristics. Since the accuracy of arid area delineation is a vital course for planners and policy makers while risk management to mitigate the challenge and attain the goals of sustainability by taking necessary measures in terms of preparedness and combating strategies, it is therefore important to cross verify the empirical or modern indices ever proposed by several climatologists by ground truth. An accurate aridity assessment is a potential tool at micro-level studies for appropriate land management in terms of landuse and land cover patterns and also to improve agricultural patterns and practices assisted by the knowledge-based approach gained from science and technology to design an effective precision agricultural model.

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Figure 1 Location of Mahaboobnagar and Nalgonda District in Telangana India

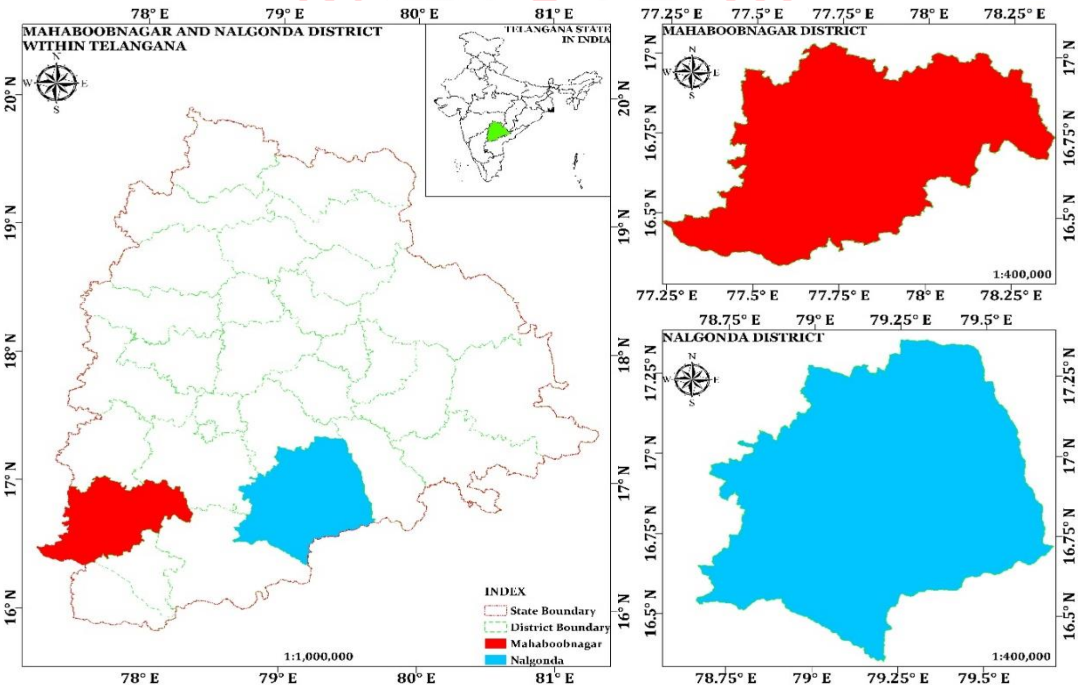

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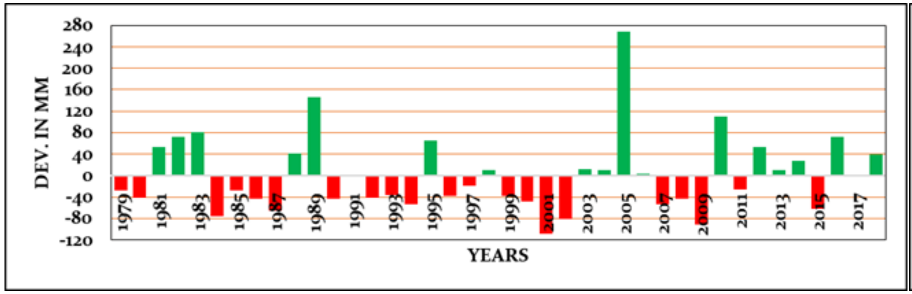
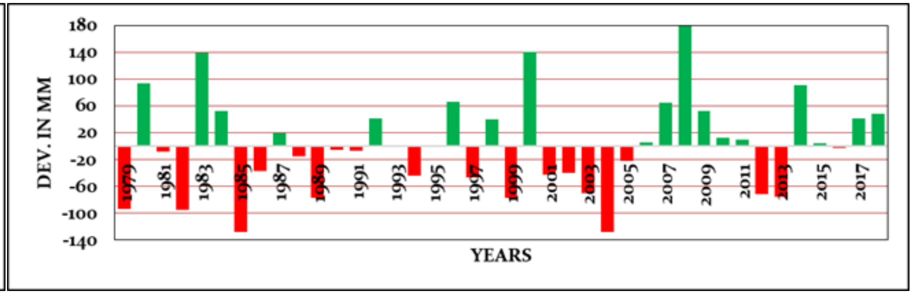
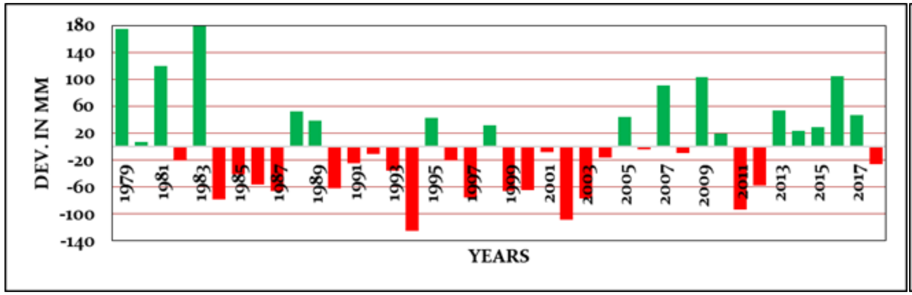
Figure 2 Year wise Mean Deviations of Average Precipitation in Mahaboobnagar district



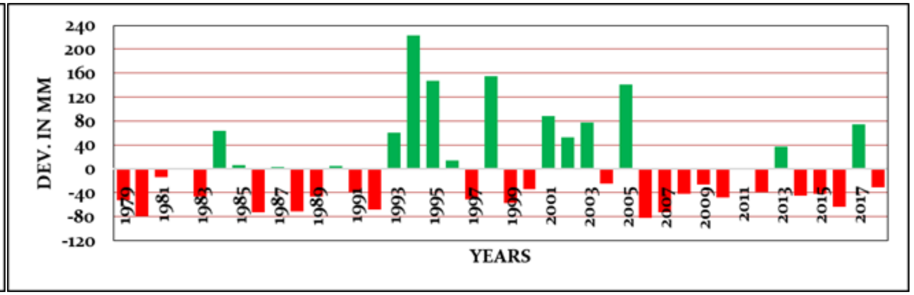
(2a)



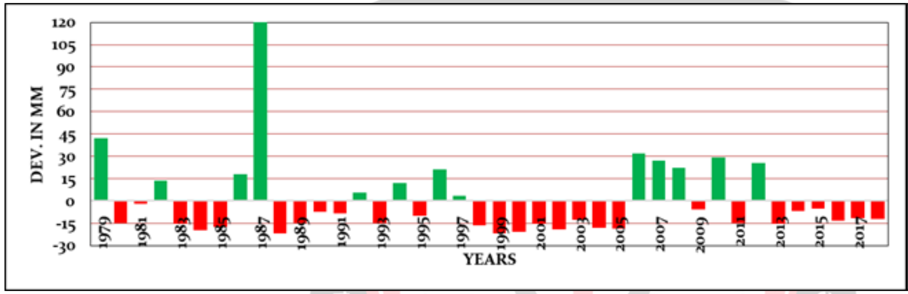
(2b)



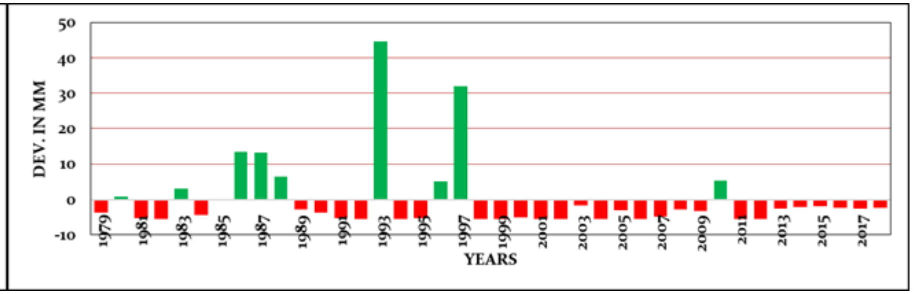
(2c)



(2d)



(2e)



(2f)

(a) – July, (b) – August, (c) – September, (d) – October, (e) – November, (f) – December

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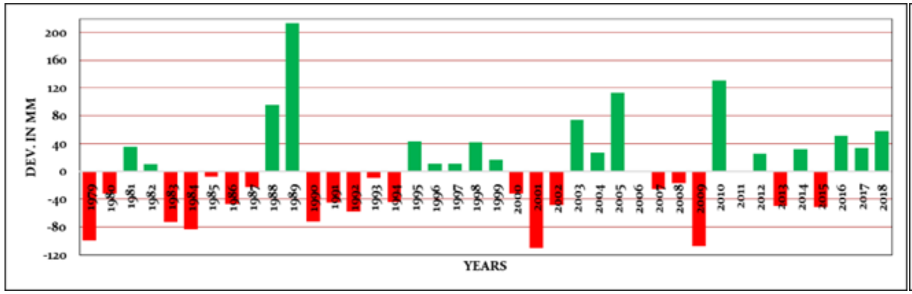
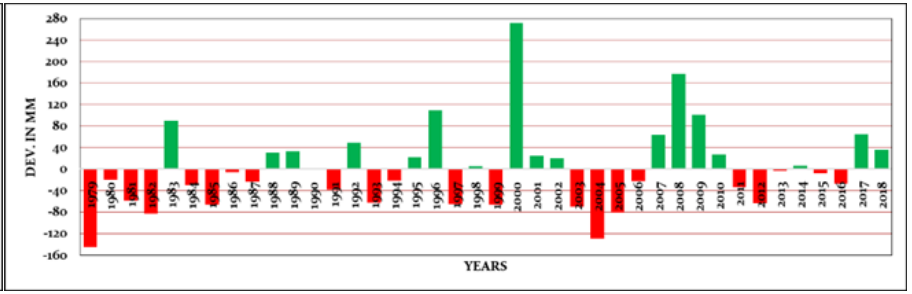
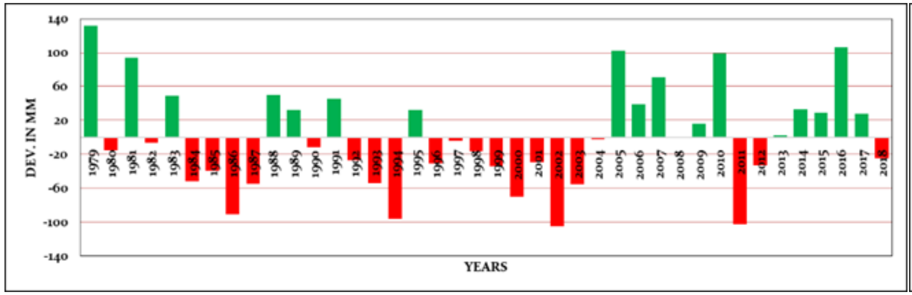
Figure 3 Year wise Mean Deviations of Average Precipitation in Nalgonda district



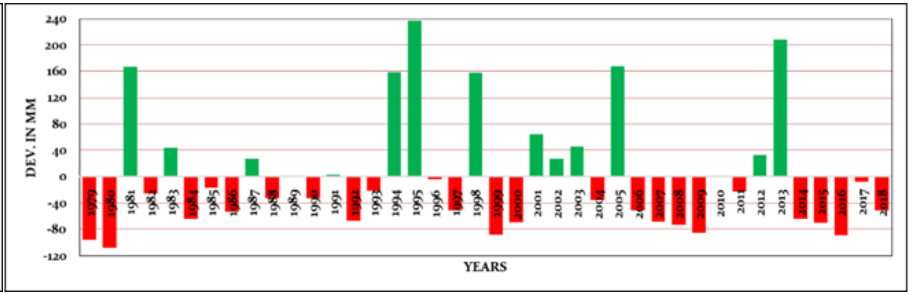
(3a)



(3b)



(3c)



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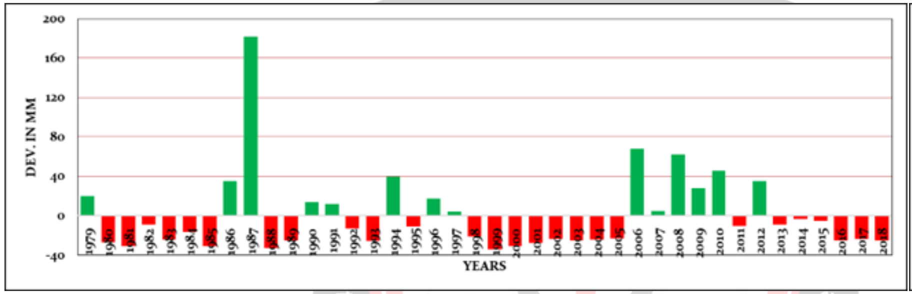

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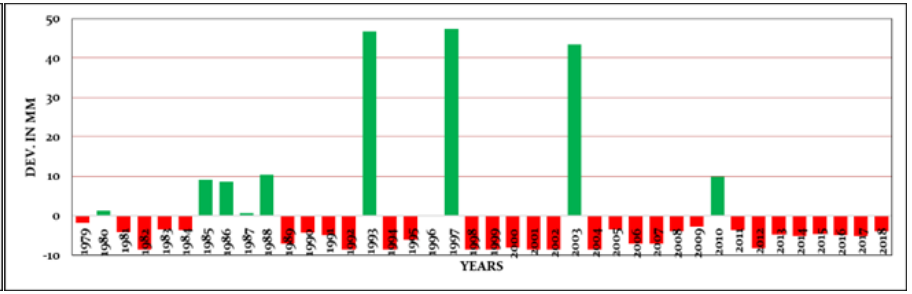

(3f)

(a) – July, (b) – August, (c) – September, (d) – October, (e) – November, (f) – December

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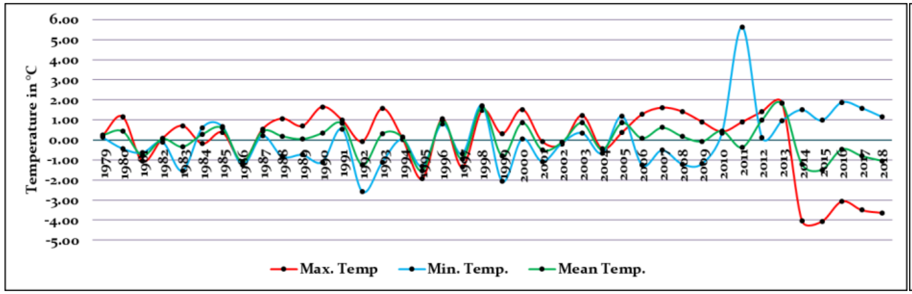
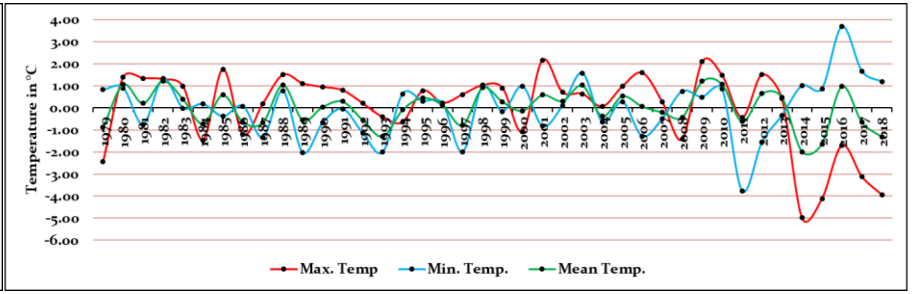
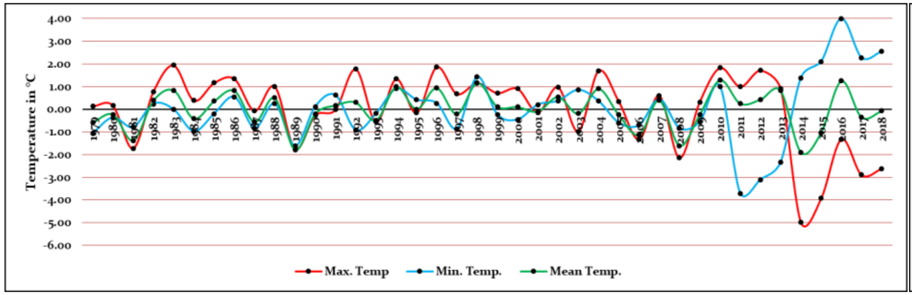
Figure 4 Year-wise Mean Deviation of Avg. Max., Min and Mean Temperature in Mahaboobnagar



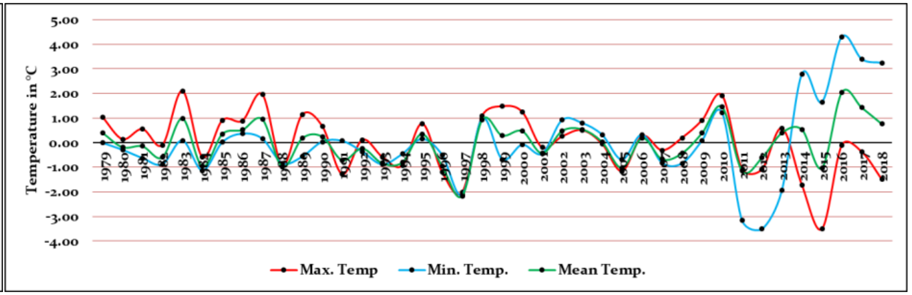
(4a)



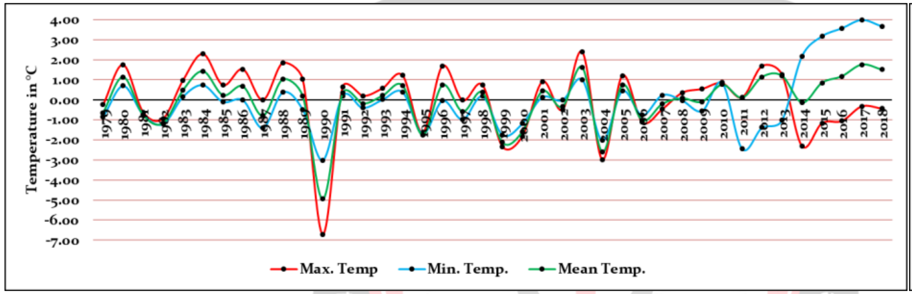
(4b)



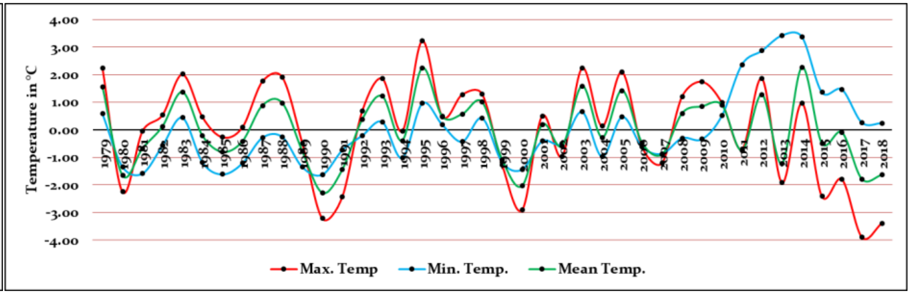
(4c)



(4d)



(4e)



(4f)

(a) – January, (b) – February, (c) – March, (d) – April, (e) – May, (f) – June

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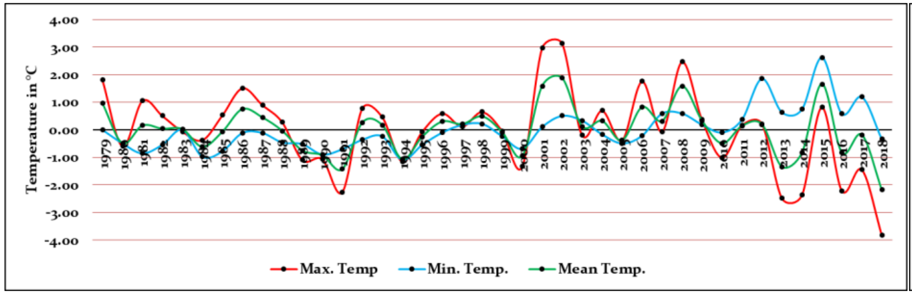
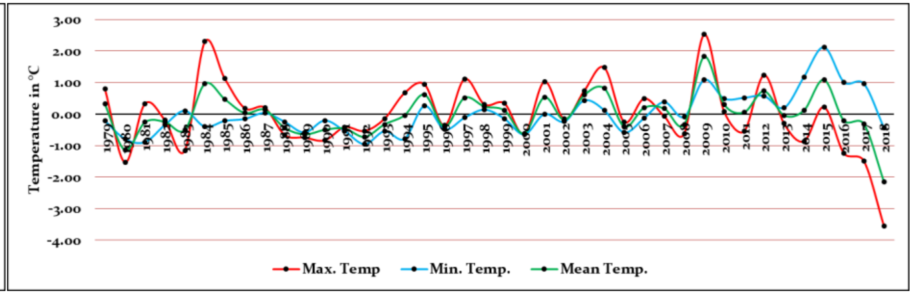
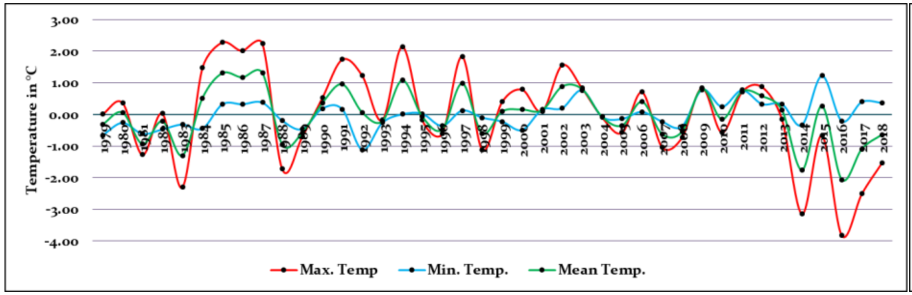
Figure 4 Year-wise Mean Deviation of Avg. Max., Min and Mean Temperature in Mahaboobnagar (cont.)



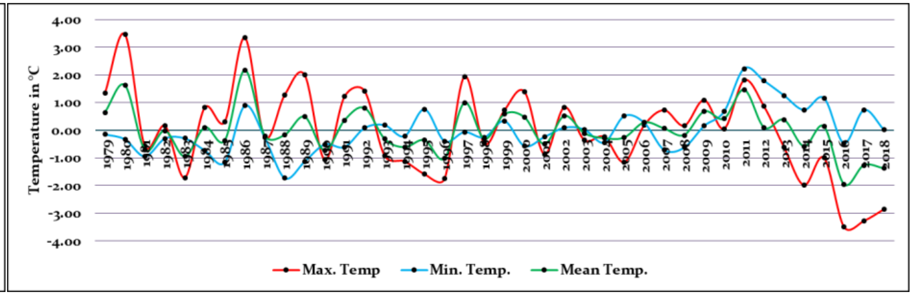
(4g)



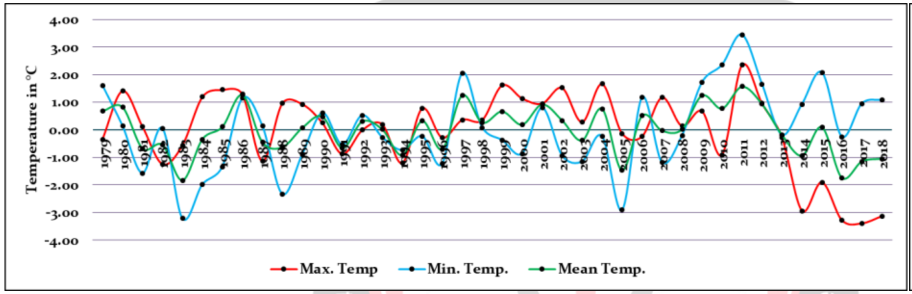
(4h)



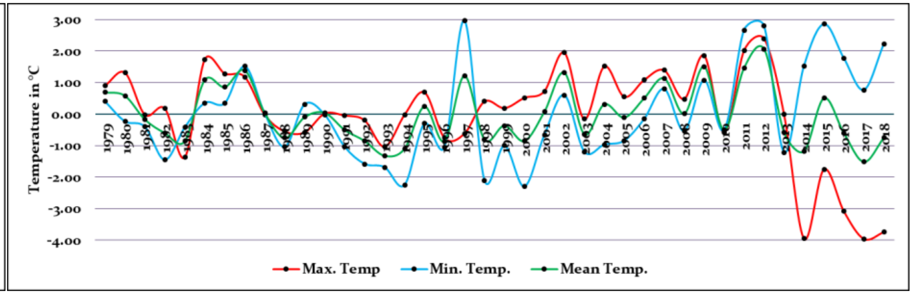
(4i)



(4j)



(4k)



(4l)

(g) – July, (h) – August, (i) – September, (j) – October, (k) – November, (l) – December

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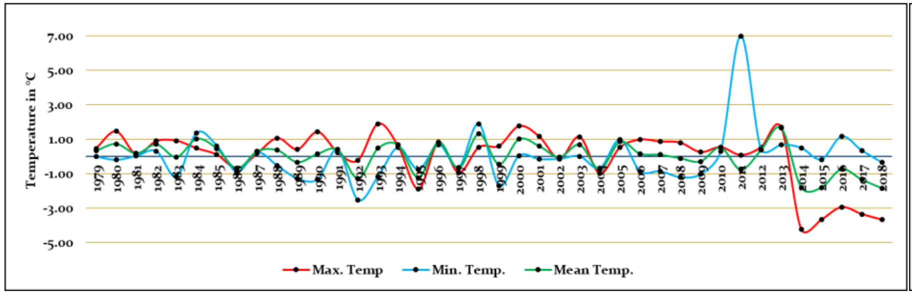
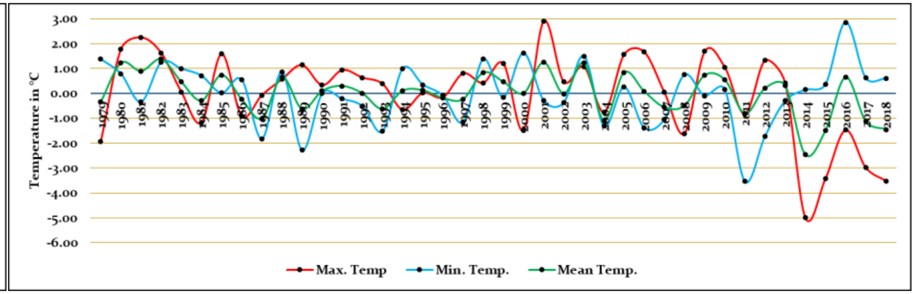
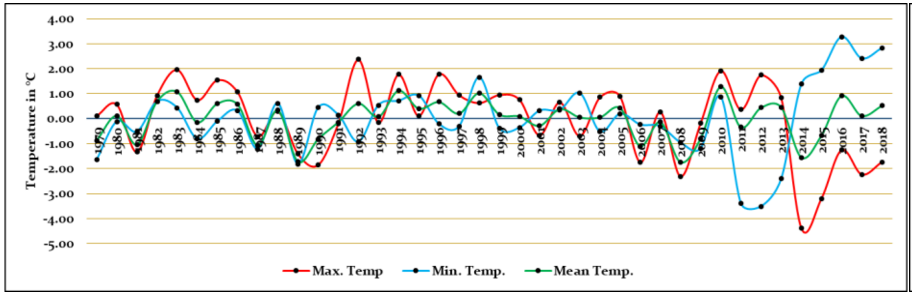
Figure 5 Year-wise Mean Deviation of Avg. Max., Min and Mean Temperature in Nalgonda



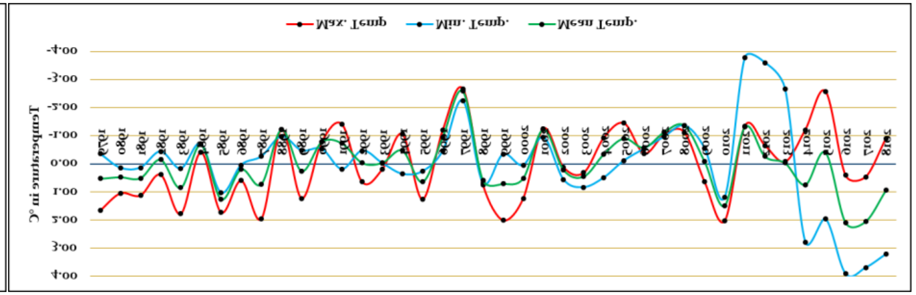
(5a)



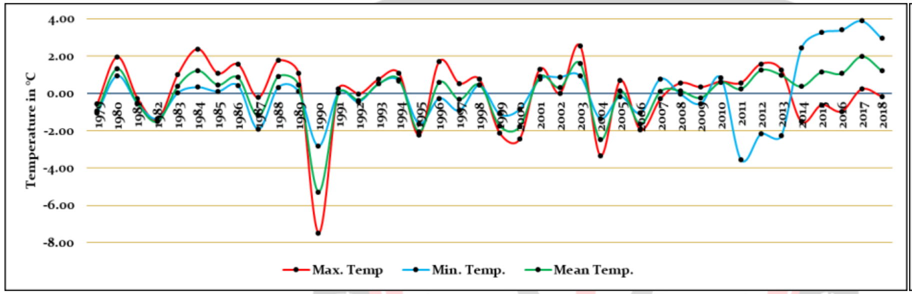
(5b)



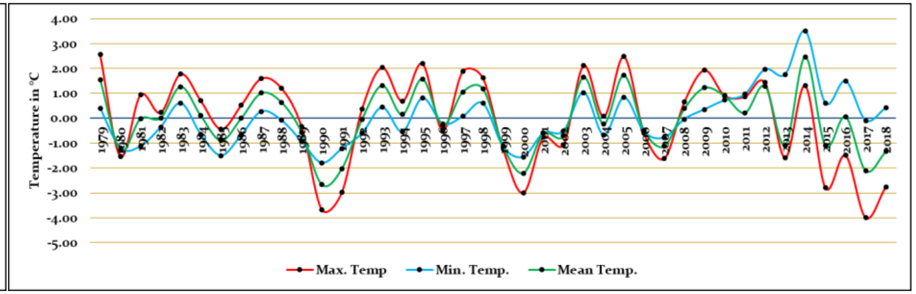
(5c)



(5d)



(5e)



(5f)

(a) – January, (b) – February, (c) – March, (d) – April, (e) – May, (f) – June

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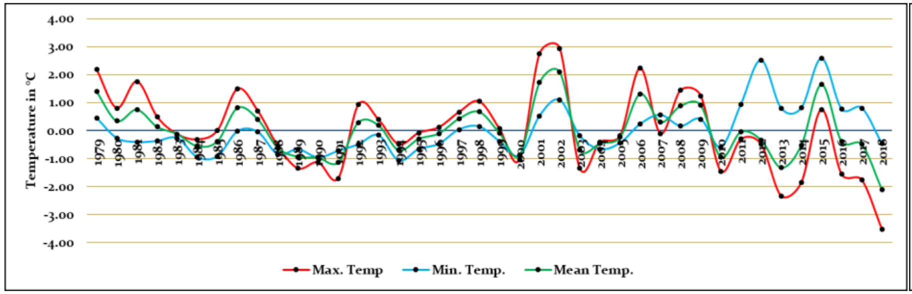
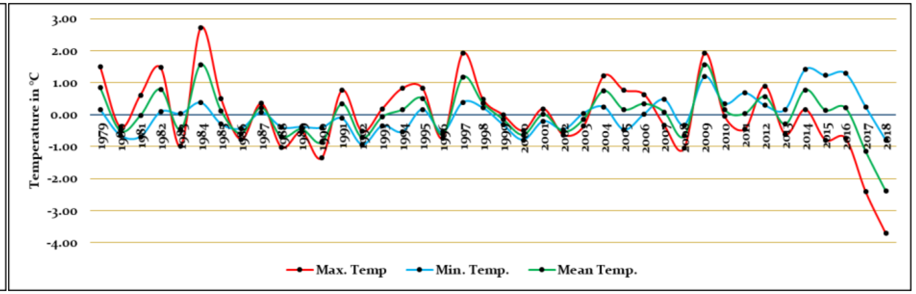
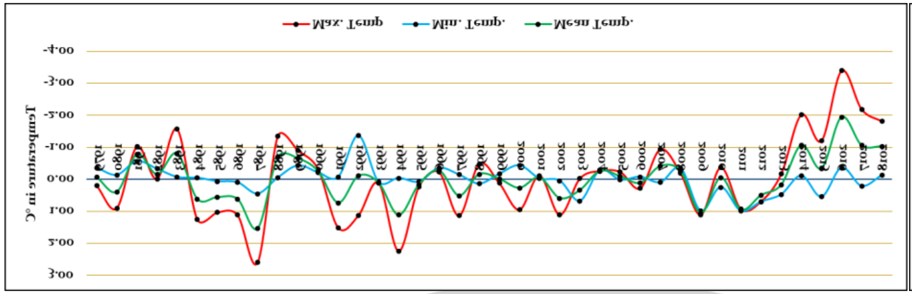
Figure 5 Year-wise Mean Deviation of Avg. Max., Min and Mean Temperature in Nalgonda (cont.)



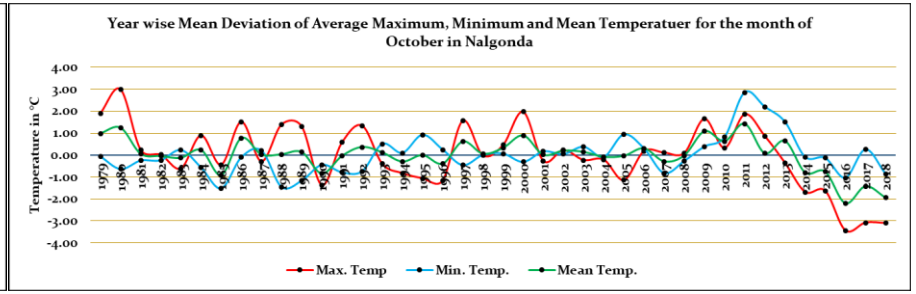
(5g)



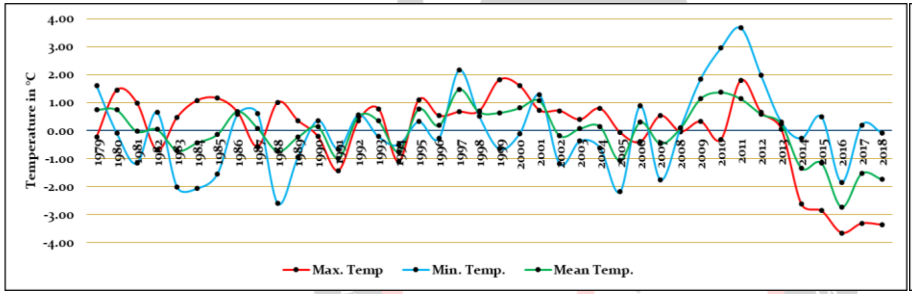
(5h)



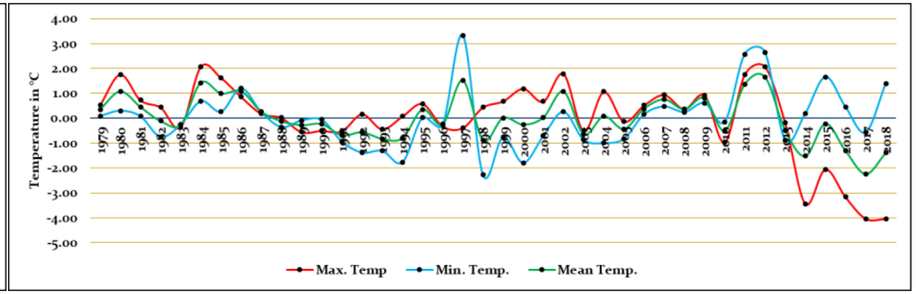
(5i)



(5j)



(5k)



(5l)

(g) – July, (h) – August, (i) – September, (j) – October, (k) – November, (l) – December

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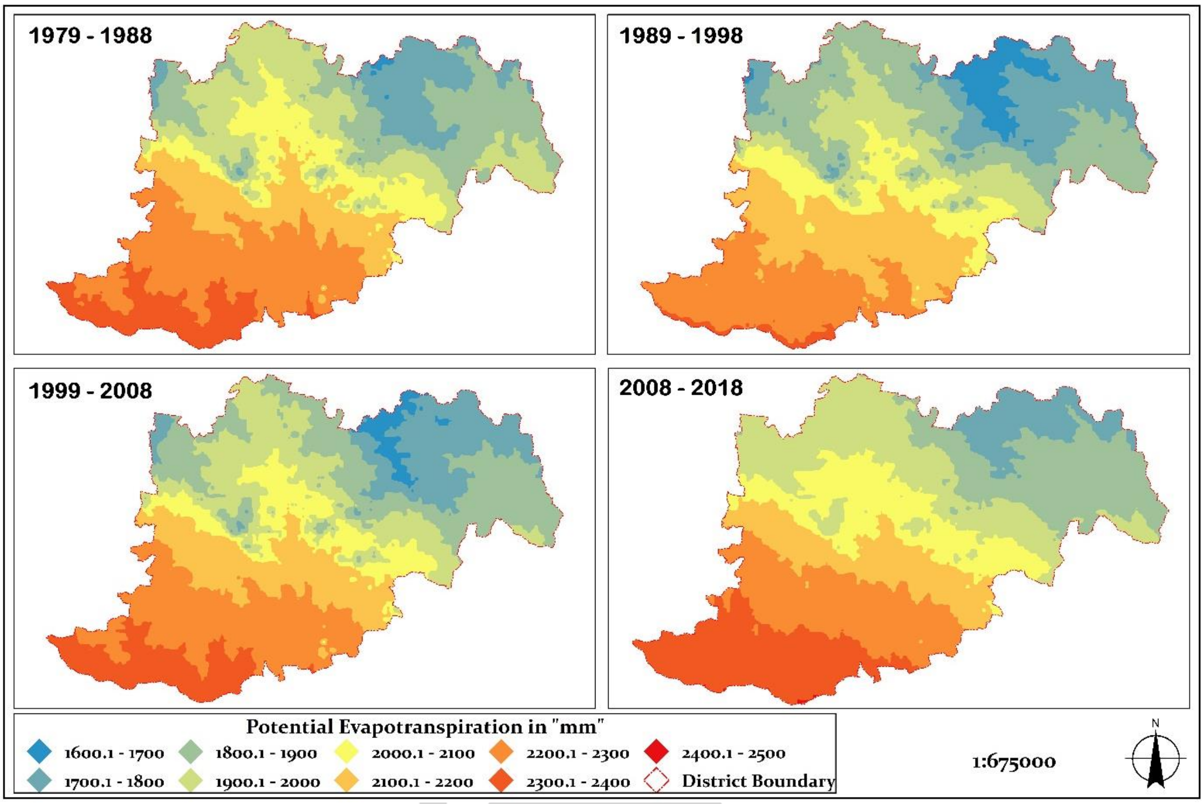
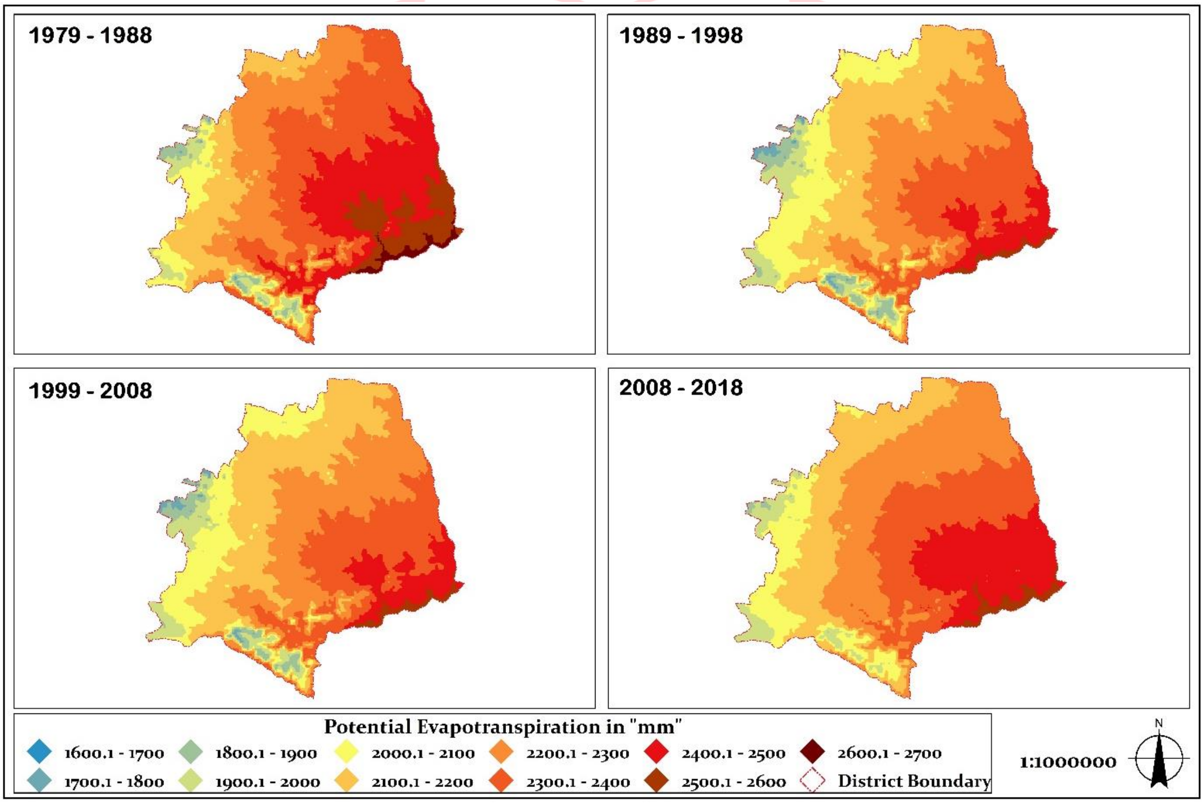
Figure 6 Tetra-decadal Average PET in both the districts



(6a – Mahaboobnagar)



(6b – Nalgonda)

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Figure 7 Annual PET in Mahaboobnagar district from 1979 to 2018

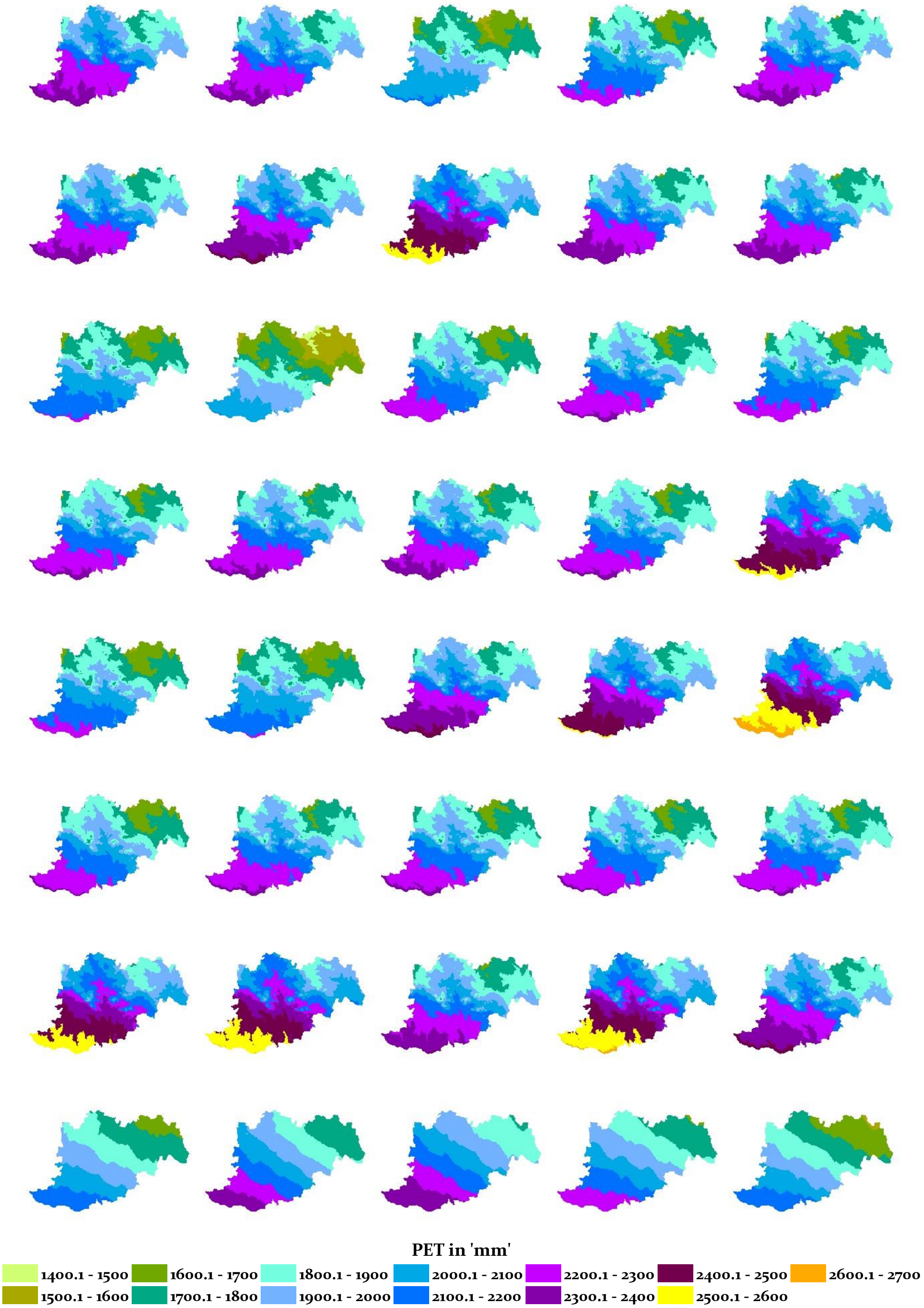

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Figure 8 Annual PET in Nalgonda district from 1979 to 2018

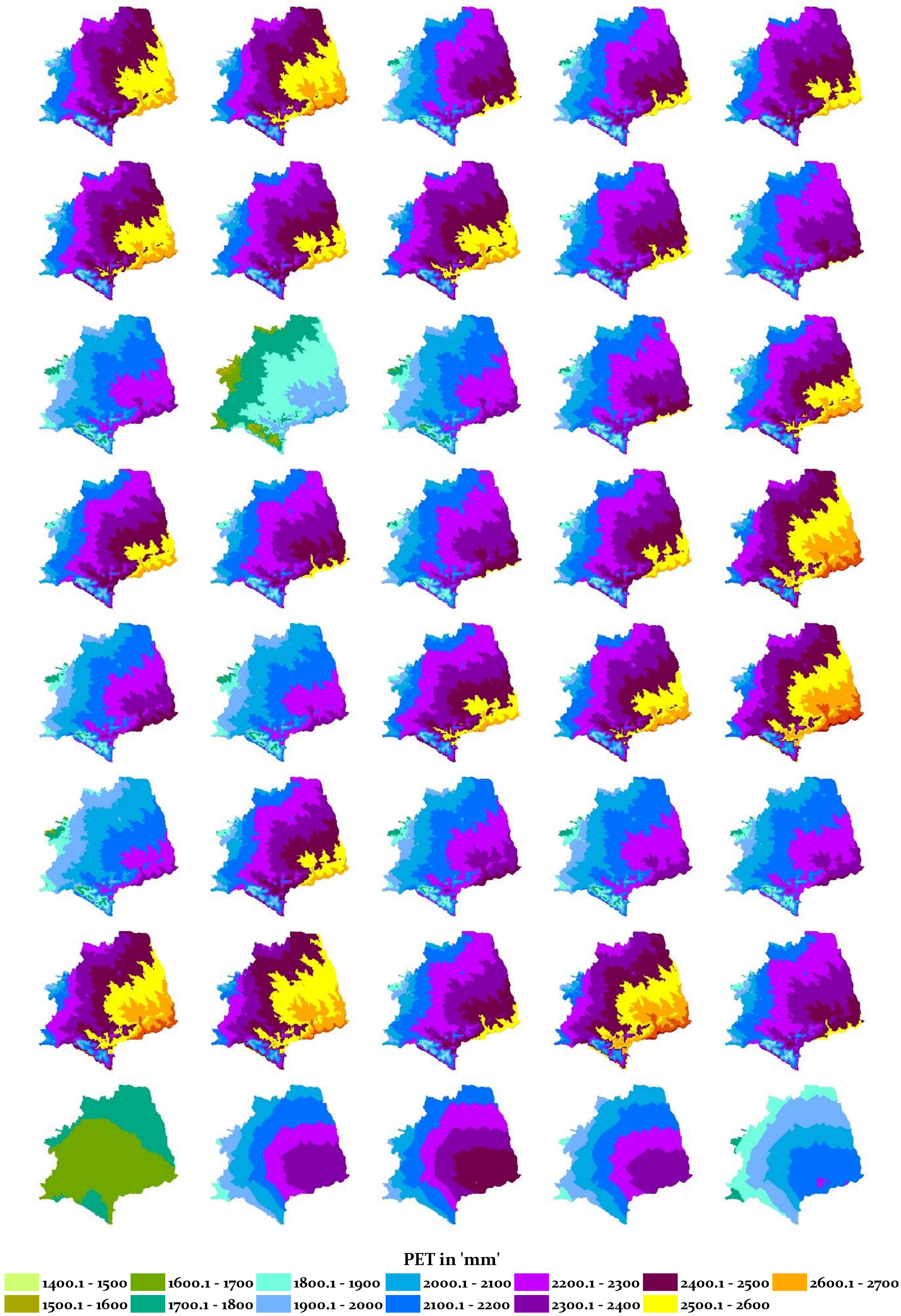

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Figure 9 Regions remained Semiarid for consecutive years in Mahabuoobnagar district

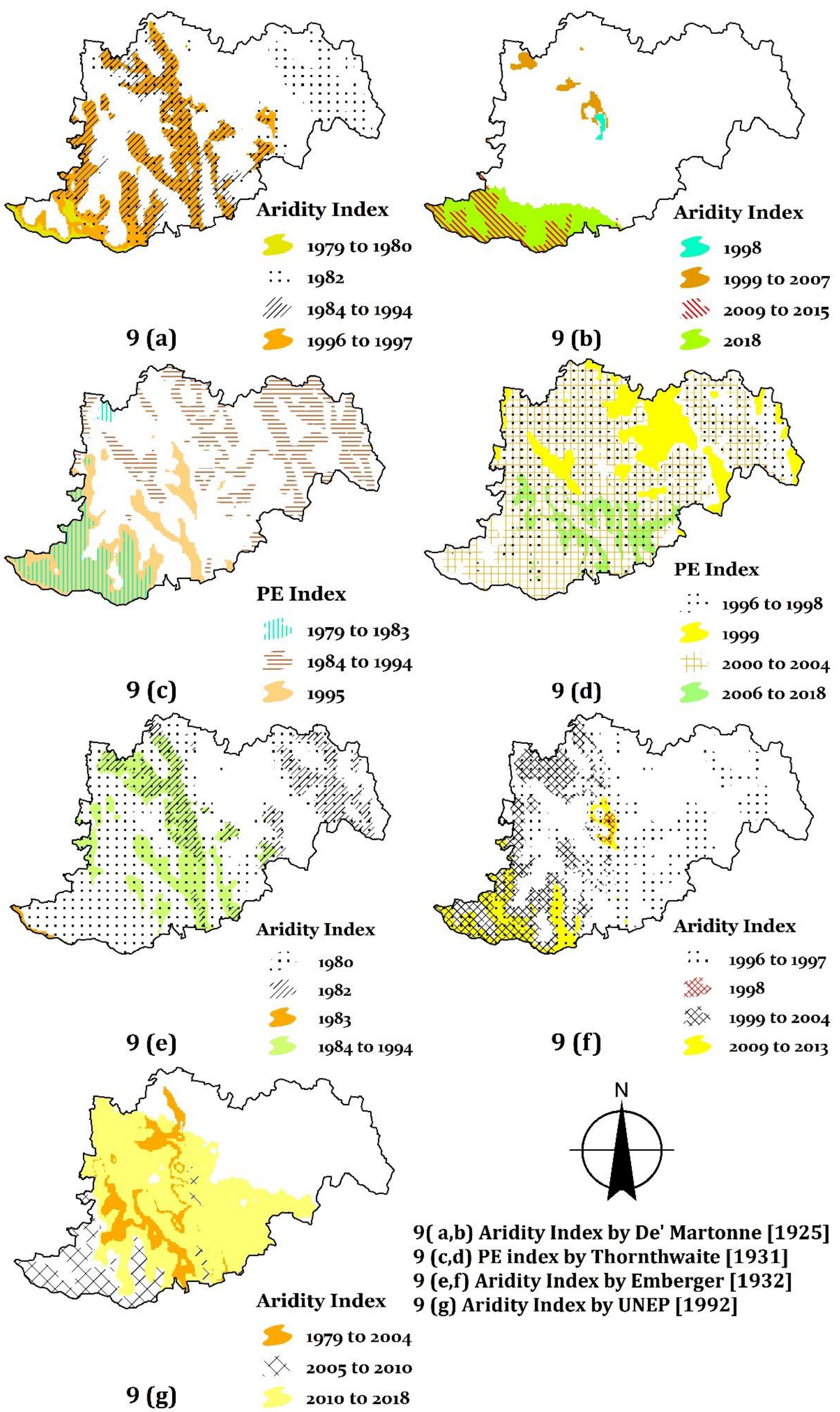

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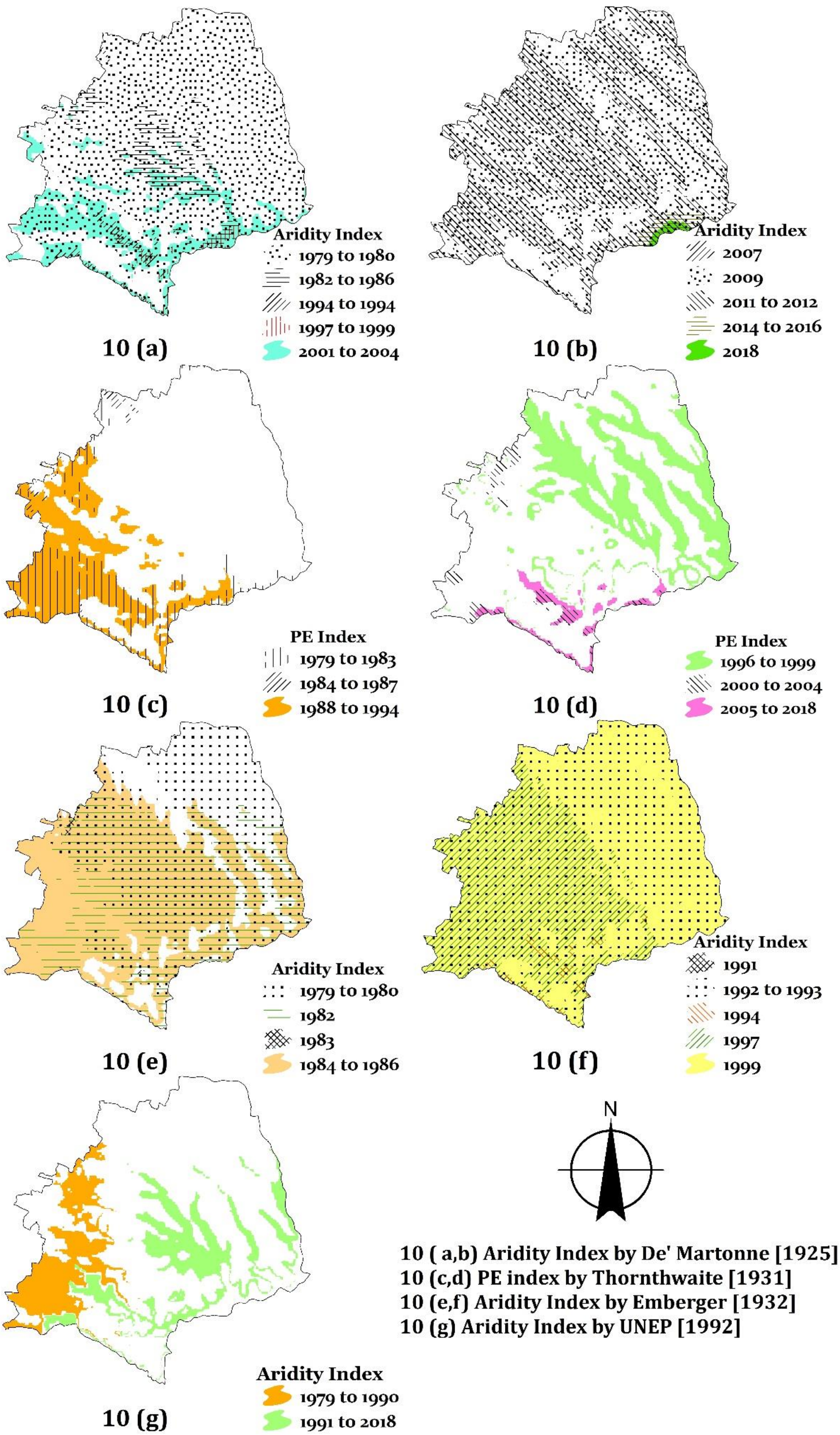
Figure 10 Regions remained Semiarid for consecutive years in Nalgonda district



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