An integrated MCDM approach for drought vulnerability

Assessment in semi-Arid region- Ranipet, Tamil Nadu, India

EXECUTIVE SUMMRY

Major part of the city of ranipet is used for agricultural purposed and drought can adversely affect it and hence Drought vulnerability assessment is very important for the area. For this past 35 years of rainfall data is used for six stations found for the study area using theissen polygon method. Then three drought index that is SPI (standard precipitation index), RAI (Rainfall anomaly index) and PNPI (percent normal precipitation index) is calculated. Spatial variation maps of the index is prepared in ArcGIS. The next set of data is downloaded from CRU (climatic research unit) website. Potential evapotranspiration, precipitation, wet days and temperature of past 10 years is downloaded and is extracted for our study area in ArcGIS. Now the data calculated is extracted for MCDA (multi criteria decision analysis) decision matrix for this RAI, PNPI and CRU data maps is placed in a single layer of ArcGIS and with spreading random points the data is extracted in the form of attribute table .In the decision matrix nine parameters are present and for MCDA we have to assign weight to each category this is done with entropy weight now, In MCDM two models is used WPM (weighted product method) WSM (weighted sum method).spatial variation map is prepared from both the models and then with goodness-of-fit statistics the models are validated. The results shows WSM has less percentage error and shows the final drought vulnerability map of the study area.

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List of Abbreviations

SPI	Standard precipitation index
PNPI	Percent normal precipitation index
RAI	Rainfall anomaly index
MCDM	Multi criteria decision making
MCDA	Multi criteria decision analysis
RS	Remote sensing
IMD	Indian metrological department
WSM	Weighted sum method
WPM	Weighted product method
PET	Potential evapotranspiration
TEM	Temperature
WET	Wet days
PRE	Precipitation
MSE	Mean square error
RMSE	Root mean square error
MAE	Mean absolute error

INTRODUCTION

1.1 Objective

- To determine the drought index using SPI (Standard Precipitation Index),RAI (Rainfall Anomaly Index), PNPI(Percent Normal Precipitation Index)
- To prepare spatial variation map of the metrological drought parameters
- To prepare the drought vulnerability index map using MCDM integrated with RS and GIS

1.2 Motivation

Water is one of the most important resources on the planet. There are three main sources of water which are rainwater, groundwater (wells and springs) and surface water (sea, oceans, rivers etc.). Precipitation, an important component of the global hydrological cycle, is significant in maintaining energy balance between terrestrial and atmospheric ecosystems (Mandal et al. 2020). In the recent past water scarcity has been increasing in many parts of the world due to increase in temperature as well as global warming. Moreover, Ground water reserves, domestic water supply, soil moisture, the pattern of stream flows, runoff, hydroelectric power generation, food preferences, mode of living and even the behavioural responses of the people are altered by sufficient amount of rainfall (Jain et al., 2012).Ranipet is highly dependent on agriculture for its own living according to (ranipet.nic.in) over 42,900 ha of area is used for paddy farms and over 30,00 ha of land for Pulses like Red gram, Black gram, Green gram, also Oilseeds like Groundnut, other crops Sugarcane and cotton are cultivated predominantly in Ranipet District. “Climate research and services” prepared by IMD Pune, suggests that the number of rainy days are considerably decreasing in major parts of Tamil nadu. The maximum temperature in Ranipet is over 40 degrees Celsius in the months of March, April, May, and June. Because of these high temperatures and few wet days, metrological and agricultural drought can arise that could have a negative impact on city dwellers. As a result, drought needs to be assessed and predicted so that proactive steps can be taken to speed up recovery from upcoming drought periods.

1.3 Background

Various studies have been carried out in drought assessment to find the vulnerability.

Isia et all in 2022 carried out their research in Drought Analysis Based on Standardized Precipitation Evapotranspiration Index and Standardized Precipitation Index in Sarawak, Malaysia Their objective was to identify the trends, conditions, intensity, and severity of droughts using the SPI and SPEI indicators over a specified time scale and to investigate the consistency of the SPI and SPEI as Sustainability 2023, 15, 734 3 of 18 well as their applications in monitoring drought conditions throughout different regions of Sarawak. They found that Drought occurrences differ between the southern, central, and northern regions of Sarawak. Between the years 1990 and 2020, this region was affected by a range of drought conditions, ranging from severe to extreme, as shown by the many statistical approaches used to determine drought. Significant extreme drought conditions were identified in 2017 and extended into 2018

Kamruzzamann et all in 2022 did their research on Spatiotemporal drought analysis in Bangladesh using the standardized precipitation index (SPI) and standardized precipitation evapotranspiration index (SPEI). Their objective was to compute the SPI and SPEI over a range of time scales using precipitation and evapotranspiration data and to undertake a spatiotemporal analysis of Bangladesh's drought hotspots by measuring drought intensity, drought frequency, and the precipitation trend coefficient. Their findings include that On all time scales, the SPEI drought trend in the NC and NE regions was greater than that in the SW, SE, SC, and NW regions. This indicates that the central part of Bangladesh is becoming more drought-prone, and the drought trend is moving from the southwest to the east. They discovered that the intensity of drought in Bangladesh's eastern hilly region gradually decreased over time, while the intensity of drought in the southern region gradually increased to the northern

Sahana et al in 2021 did their research on Drought vulnerability and risk assessment in India: Sensitivity analysis and comparison of aggregation techniques their objective was to conduct Multivariate drought hazard assessment using the Multivariate Standardized Drought Index and to perform drought risk assessment and mapping, combining hazard and vulnerability information. The result was Regions such as Jammu, Kashmir, Uttarakhand, Himachal Pradesh, East Rajasthan, Vidarbha, Chhattisgarh, Madhya Pradesh, Jharkhand, Karnataka, Orissa and North-eastern India are found to be severely vulnerable to droughts.

Hoque et. all in 2021 did their research on Drought Vulnerability Assessment Using Geospatial Techniques in Southern Queensland, Australia Their objective was to prepare a vulnerability map of meteorological, hydrological, and agricultural drought applying a multi-criteria FAHP-based decision-making approach .To develop a comprehensive drought vulnerability map that combines meteorological, hydrological, and agricultural drought vulnerability maps to assess the degree of drought vulnerability. The third is to evaluate the generated drought vulnerability results. . The result was the overall drought vulnerability map demonstrates severe to extreme drought vulnerability for Bulloo, Quilpie, Paroo, Murweh, Balonne and Maranoa areas of the study site

Kalura et all in 2021 did their research on Assessment of Hydrological Drought Vulnerability using Geospatial Techniques in the Tons River Basin, India Their aim to determine the Tons river basin's drought characteristics and develop a drought vulnerability (DVI) index map using multiple factors. They found that in the last 69 years, a maximum annual rainfall deficit of - 39.5% was experienced in the basin. 18.2%, 42.4%, and 37.9% of the total basin area fall under moderate, severe, and critical vulnerability zones

Saha et all in 2020 did their research on Spatial assessment of drought vulnerability using fuzzy-analytical hierarchical process: a case study at the Indian state of Odisha .their objective was To integrate geospatial methods with Fuzzy-Analytical Hierarchy Process (Fuzzy-AHP) technique and To prepare a drought vulnerability map for Odisha, India. Their findings were the physical drought vulnerability map depicts that in the western part of the study region nearly 35.08% (54,653.16 km 2) area is fallen under the high to very-high drought vulnerable category. In the drought vulnerability map (Figure 8) it is found that 15.87% (25,956.36 km2) and 18.07% (28,136.25 km2) of the study area comes under very high and high vulnerable zones, respectively

Paudel et all in 2020 did their research on Agricultural Drought Vulnerability Assessment of Tanahun District, Nepal Their aim was to analyse the pattern of rainfall and vegetation index, to prepare a Land Use Land Cover map and provide information on the environmental situation of the project area. They found with the analysis of SPI revealed that drought has occurred at different levels of severity during the period of 2007-2016. The southern and middle part of the study area has been solely affected by the meteorological drought. Correlation between mean rainfall and mean NDVI value has found to be the positive correlation of value 0.32. The seasonal pattern of rainfall and NDVI suggest that the southern part and central part of the Tanahun district is a low rainfall area, where SPI value is low and the corresponding NDVI value is also low.

Sambo et all in 2020 did their research on Drought vulnerability assessment of Minna using the standardized precipitation index (SPI) method. Their aim was to use SPI for observing and describing drought based on 70 year precipitation data of minna substation. They found that 1987 driest year and 2019 wettest. 1982 was most prone to drought with index value of -3.99. 1973 and 1976 were also have high negative index from -3 to -3.35

Mun et all in 2020 did their research in Assessment of Vulnerability to Drought Disaster in Agricultural Reservoirs in South Korea. Their aim was to present appropriate evaluation items for agricultural drought vulnerability maps. To analyze vulnerable areas in South Korea and create agricultural drought vulnerability maps through objective evaluation methods. They found that the year most vulnerable to agricultural drought was 2015. An analysis of the map of vulnerability to agricultural drought in South Korea showed that CN had the highest ratio of D, making it the most vulnerable area to agricultural drought. GN, JN, and GB are considered the safest regions owing to the high ratio of A and B

Wang et all in 2020 did their research on Urban drought vulnerability assessment – A framework to integrate socioeconomic, physical, and policy index in a vulnerability contribution analysis. Their objective was to assess and analyze the urban drought vulnerability (UDV) of the Beijing-Tianjin-Hebei (BTH) region, using the framework that integrates socio-economic, physical, and policy index. Their findings demonstrated that the BTH region is at a high level of drought vulnerability. The UDV of 13 cities in the BTH region increased from 1990 to 2016. In 2016, all cities were in a highly vulnerable state, wherein cities such as Tianjin are extremely vulnerable.

Materials and Methodology

Based on literature review and expert opinion 7 meteorological drought parameters () identified. To proceed with the project literature review is done to know the basic principles related to drought assessment. This was done referring recent journals published in the field of drought assessment.

Collecting rainfall data is the first and most crucial step in drought analysis. To download the rainfall data, Rain gauge stations were identified with Theissen polygon method. Totally 6 rain gauge stations were identified.

The IMD (Indian meteorological department) library plug in enabled in QGIS with Python code is used to download the rainfall data for the study area. 35 years of daily rainfall data from 1986 to 2020 is used for assessment. The data is in gridded form with cell size of (0.25º x 0.25º) so with the help of the pivot table, the data is converted into seasonal and annual rainfall in excel sheets. According to IMD, there are four categories of seasons summer (march- May), Monsoon (June-September), post-Monsoon (October-November), and winter (December-February). The data is then converted into monthly seasonal and annual rainfall.

Now SPI (Standard precipitation index) is calculated with the precipitation data. This was calculated using R software and we get the results in three, six, twelve months format. Twelve months data is used because it reflects long term precipitation pattern (Khan et all 2008). Then PNPI (percent normal precipitation index) and RAI (Rainfall anomaly index) is calculated in excel with the rainfall data in twelve month format.

CRU (climatic research unit) data is used to download data of potential evapotranspiration, temperature precipitation and wet days. The data is available in their website of past ten years in gridded form but the data is of the whole world, so we have to extract the data for the study area. We can do this using ArcGIS. First, we have to use multidimensional tools in that raster processing to convert them into point data. The spatial analysis tools were used to prepare the map.

For preparation of SPI index map drought severity, intensity, duration and frequency is calculated, similarly for RAI drought severity, duration and intensity is calculated and for PNPI drought magnitude and intensity is calculated then the data is added along with their coordinates and their spatial variation map is prepared. The next step is data extraction for MCDA (multi criteria decision analysis) for this all the nine parameter that is three from RAI, two from PNPI and four CRU data is used the maps of the parameter is kept in a single layer and with spreading random points the data is extracted in the form of attribute table. Then the selected parameters are divided as beneficial and non-beneficial criteria. The parameters whose value is higher will cause drought is kept as beneficial category and the parameter whose values are lower will cause drought is kept as non-beneficial category. Now we have to calculate weight of each category for MCDA this is done with the help of entropy weight, then the MCDA is done with WSM (weighted sum method) and WPM (weighted product method).

The final step is to validate our results this is done with Goodness-of-fit Statistics in this SPI is used as observed values and the values from MCDA is used as assumed value and then the percentage of error is calculated in both the methods the method with least error will be our final result.

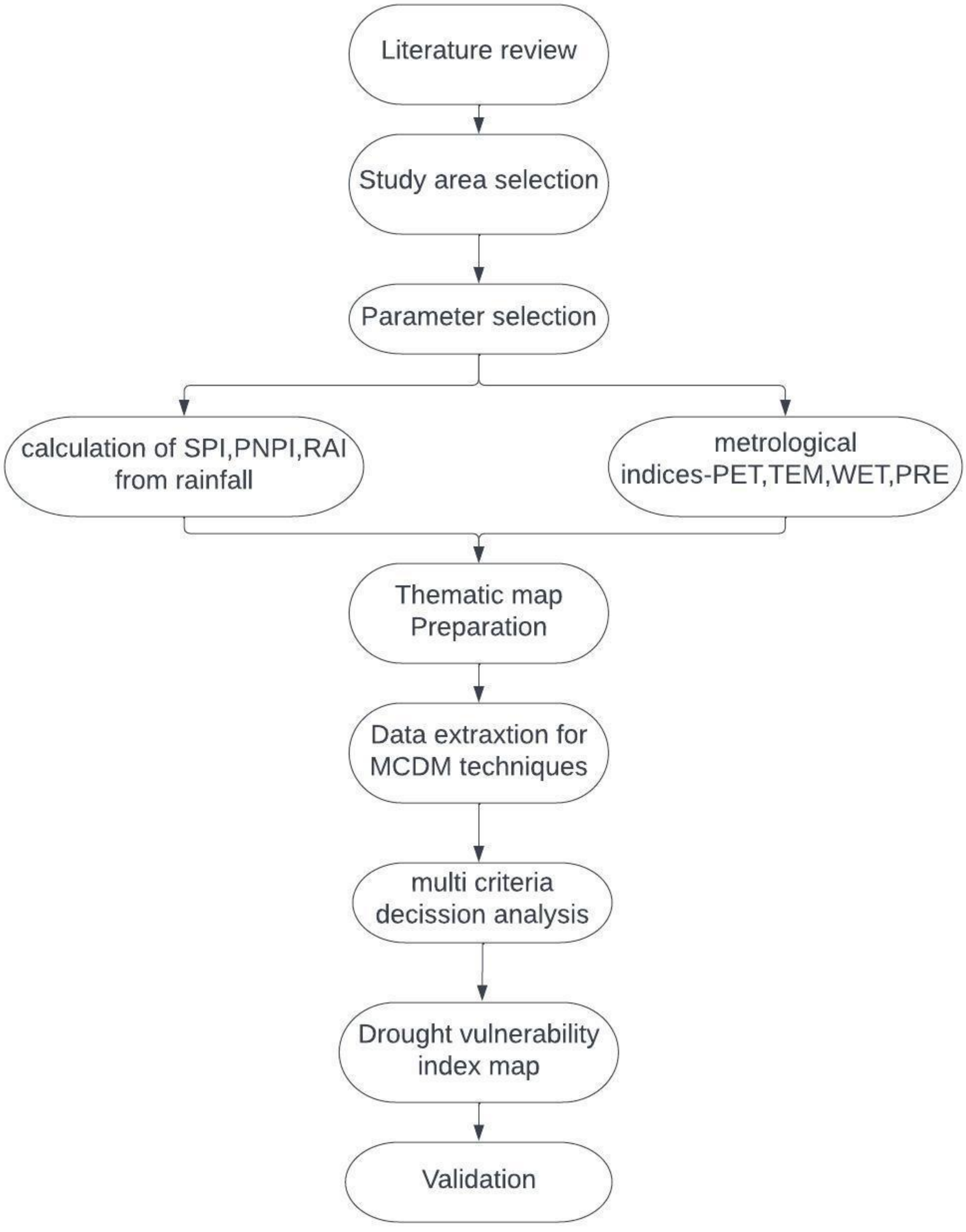


Figure 3.1:- Methodology Flow Chart showing Drought Vulnerability Index map preparation

3.1 Standard Precipitation Index

The standard precipitation index is used to characterize meteorological drought. It is computed by dividing the difference between the normalized seasonal precipitation and its long-term seasonal mean by the standard deviation. (Bhuiyan et al. 2006)

The formula of SPI is given by:

$$SPI = (X_{ij} - X_{im})/\sigma$$

X_{ij} is the seasonal precipitation at I^{Th} rain gauge station, j^{Th} observation, X_{im} is the long-term seasonal mean, and σ is its standard deviation. Table 1 shows the standard precipitation index categories based on range values.

Table 3.1: SPI index Classification	
SPI Values	**Drought Class**
+2 to more	Extremely wet
1.5 to 1.99	Very wet
1 to 1.49	Moderately wet
-0.99 to 0.99	Near Normal
-1 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 to less	Extremely dry

3.2 Rainfall Anomaly Index

RAI is also used to classify positive and negative severities of the drought. The average of the top ten highest and the top ten lowest rainfall data is calculated for RAI. The positive RAI and negative RAI are computed by using the mean of ten extremes. (Rooy et al. 1965)

Positive RAI is given by:-

$$RAI = +3\,\frac{P - \bar{P}}{\bar{\bar{M}} - \bar{\bar{P}}}$$

M Bar is the mean of the ten highest precipitation records for the period under study, P bar the mean precipitation of all the records for the period, and the P precipitation for the specific year.

The formula for negative RAI is given by:-

$$RAI = -3 \frac{P - \bar{P}}{\bar{m} - \bar{P}}$$

m Bar be the mean of the ten lowest precipitation records for the period under study

Classification of the RAI index is given in table 2

Table 3.2: classification of RAI index	
RAI	**CLASS DESCRIPTION**
>3.00	Extremely wet
2 to 2.99	Very wet
1.00 to 1.99	Moderately wet
0.50 to 0.99	Slightly wet
0.49 to -0.49	Near Normal
-0.50 to -0.99	Slightly dry
-1.00 to -1.99	Moderately dry
-2.00 to -2.99	Very dry
<-3.00	Extremely dry

3.3 Percent Normal Precipitation Index

The percent Normal Precipitation Index is a widely used drought index that reasonably estimates droughts' intensity, magnitude, and spatial extent. (Asrari et al.2011)

We can calculate PNPI using the following formula

$$PNPI = (Pi/P) \times 100$$

Where

Pi = total of precipitation in each year

P = average rainfall in the period.

Classification of the PNPI index is given in table 3

Table 3.3: Classification of PNPI index	
INDEX PERCENT	**CLASSIFICATION**
>80	normal
70-80	Weak drought
50-70	Moderate drought
40-50	Severe drought
<40	Extreme drought

3.4 MCDM

Multi-criteria decision-making (MCDM) is one of the main decision-making problems which aims to determine the best alternative by considering more than one criterion in the selection process. For multi criteria decision analysis decision matrix is prepared which will contain locations in x axis and parameter details in y axis. Then the decision matrix is normalised the formula of normalised decision matrix is given by

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}$$

Then to calculate the entropy weight of each parameter, the weight of entropy of i^{th} indicator could be defined as (Hong et all 2006)

$$w_i = \frac{1 - H_i}{m - \sum_{i=1}^{m} H_i}$$

In which, $0 \leq w_i \leq 1, \sum_{i=1}^{m} w_i = 1$

WSM

The weighted sum model (WSM) is probably the most commonly used approach, especially in single dimensional problems. If there are m alternatives and n criteria then, the best alternative is the one that satisfies (in the maximization case) the following expression (MacCrimon, 1968; Triantaphyllou and Mann, 1989)

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} \; w_j$$

Where w_j is weight (relative importance) of j^{th} criterion.

WPM

The weighted product model (WPM) is very similar to the WSM. The main difference is that instead of addition in the model there is multiplication. Each alternative is compared with the others by multiplying a number of ratios, one for each criterion. (Miller and Starr, 1969; Triantaphyllou and Mann, 1989), the total relative importance of i^th^ alternative is evaluated using the following equation:

$$Q_i^{(2)} = \prod_{j=1}^{n} \left(\bar{x}_{ij}\right)^{w_j}$$

Where, n is the number of criteria, a_{ij} is the actual value of the *i-th* alternative in terms of the *j-th* criterion, and W_j is the weight of importance of the *j-th* criterion.

3.5 Goodness-of-fit Statistics

A goodness-of-fit is a statistical test that tries to determine whether a set of observed values match those expected under the applicable model.in this we will use MSE (mean square error) RMSE (root mean square error) and MAE (mean absolute error)

MSE

Mean squared error (MSE) measures the amount of error in statistical models. It assesses the average squared difference between the observed and predicted values. When a model has no error, the MSE equals zero. As model error increases, its value increases. The mean squared error is also known as the mean squared deviation (MSD).

The formula for the mean squared error is MSE =

$$\Sigma(y_i - p_i)^2/n$$

Where y_i is the i th observed value, p_i is the corresponding predicted value for y_i, and n is the number of observations. The Σ indicates that a summation is performed over all values of i. (Stewart, Ken 2023)

RMSE

Root mean squared error (RMSE) is the square root of the mean of the square of all of the error. The use of RMSE is very common, and it is considered an excellent general purpose error metric for numerical predictions.

$$\text{RMSE}= \sqrt{\frac{1}{n}\sum_{i=1}^{n} y_i - p_i^2}$$

Where y_i are the observations, p_i predicted values of a variable, and n the number of observations available for analysis (Christie and neill 2022)

MAE

The MAE score is measured as the average of the absolute error values. The Absolute is a mathematical function that makes a number positive. Therefore, the difference between an expected value and a predicted value can be positive or negative and will necessarily be positive when calculating the MAE. (Schneider and Xhafa 2022)

The MAE value can be calculated as follows:

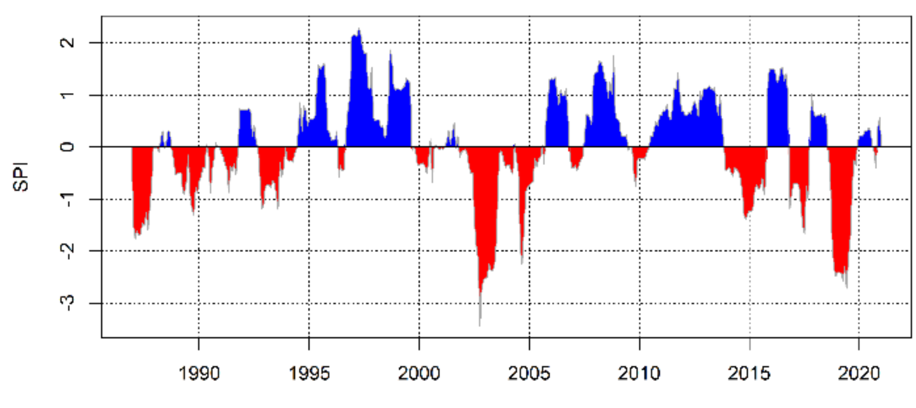
$$\frac{1}{n}\sum_{i=1}^{n}|y_i - p_i|^2$$

Results and Discussion

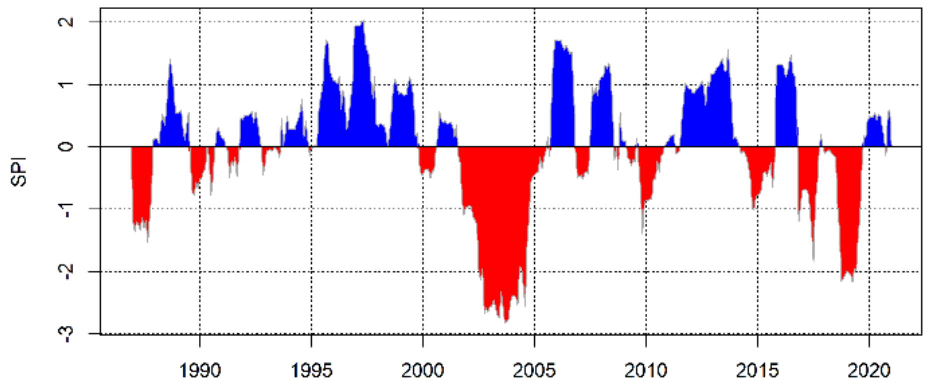
The 35 years of precipitation data are downloaded from IMD (Indian meteorological department) Pune website. Then the rainfall data of the particular station were collected and converted into monthly seasonal and annual rainfall data using pivot tables. SPI, RAI, and PNPI were calculated for six stations in ranipet, and the results obtained are given below

4.1 Standard precipitation index

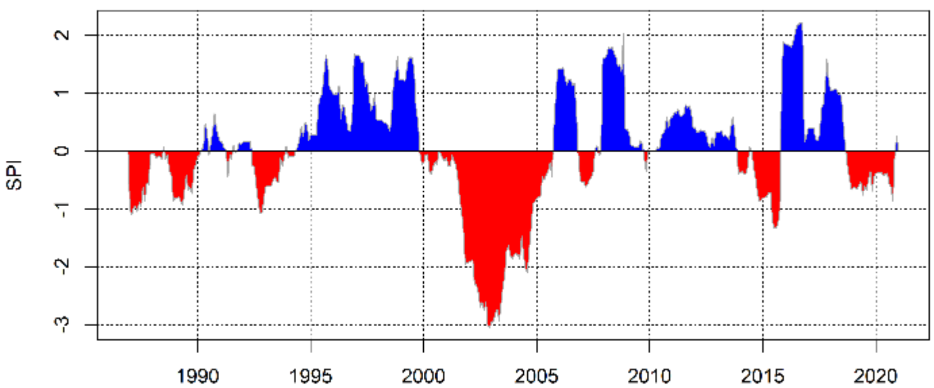
SPI is calculated using R software. Monthly rainfall data and a python code were used to find the index. The results were in three, six, twelve, and twenty-four months formats. Since thirty five years of data is used for analysis twelve-month format will be used for further calculations. Figure 2 to figure 7 shows the graph obtained from six stations given below.



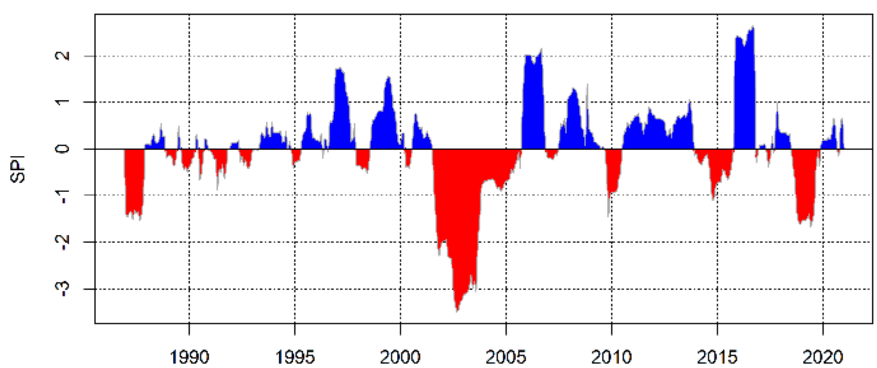
(a) Station 1



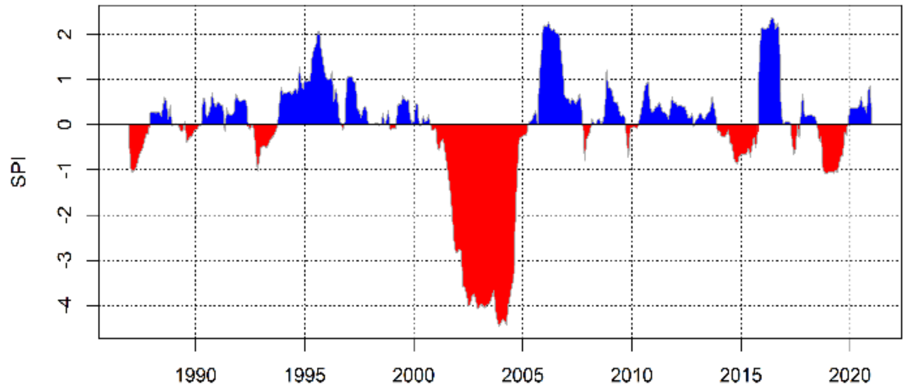
(b) Station 2



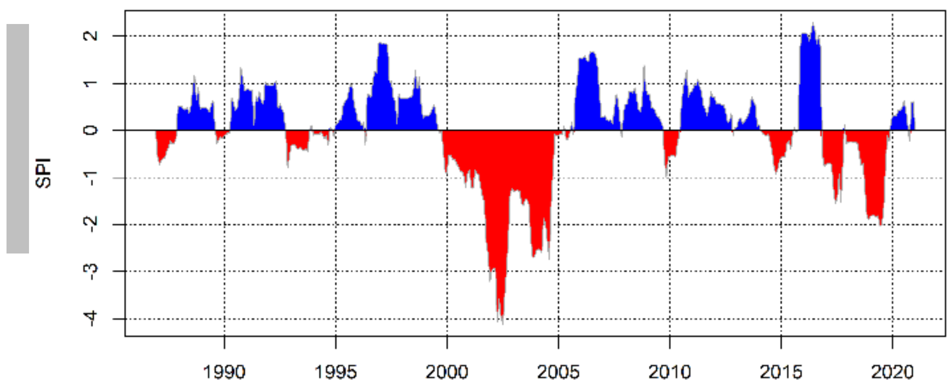
(c) Station 3



(d) Station 4



(e) Station 5



(f) Station 6

Fig4.1: SPI index Variation of all six stations

A drought event for time scale is defined here as a period in which the SPI is continuously negative and the SPI reaches a value of -1.0 or less. The drought begins when the SPI first falls below zero and ends with the positive value of SPI following a value of -1.0 or less (McKee et all 1993) from 2000 to 2005 the index values is going -1 and below continuously showing drought period.

Now, with the help of the SPI index drought frequency, duration, severity and intensity is calculated. The results are shown in table 4

Table 4.1: SPI parameters table						
Description	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
frequency	8	6	4	5	4	4

duration	151	126	112	95	96	112
severity	143.83	146.28	124.99	136.86	167.73	148.66
intensity	0.95	1.16	1.11	1.44	1.74	1.32

Now, the data calculated above is added to an excel sheet alongside the coordinates of the station and used as input for map preparation in ArcGIS. The results shown in figure 3. Major part of the study area (32.47%) has low drought duration whereas drought intensity is very high for 33 % of the total study area. 38% of the study area has medium drought frequency ranging from 5 to 6 drought period, severity is also medium for 39 % of ranipet.

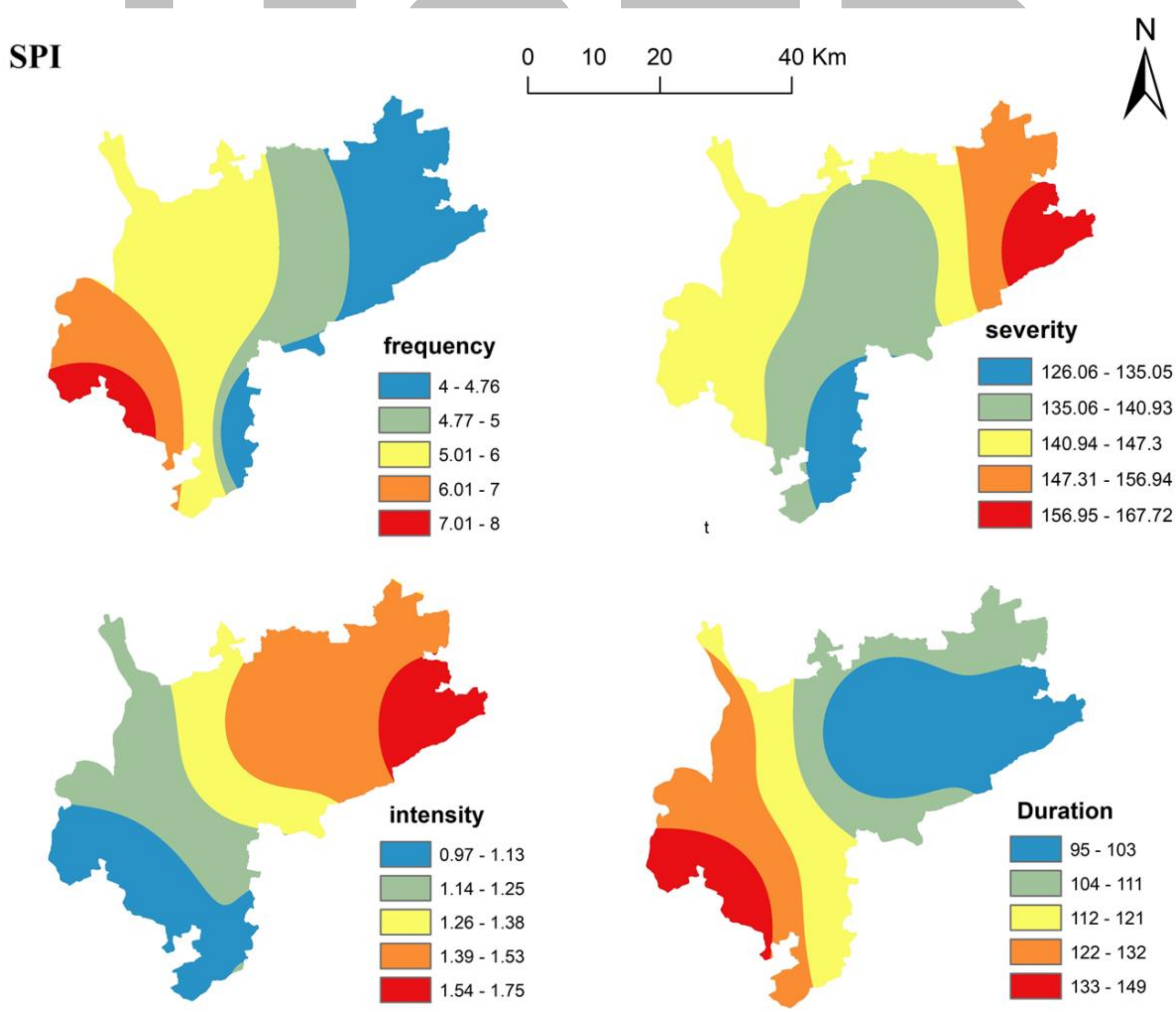


Figure 4.2: SPI frequency, severity, intensity, and duration maps

4.2 Rainfall anomaly index

The rainfall anomaly index is used to classify positive and negative severities of the drought. It Addresses droughts that affect agriculture, water resources and other sectors, as RAI is flexible in that it can be analysed at various timescales. The results obtained in one year time scale is shown in table 5

Table 4.2 : RAI results

RAI	CLASS DESCRIPTION	Station 1 Years	Station 2 Years	Station 3 Years	Station 4 Years	Station 5 Years	Station 6 Years
>3.00	Extremely wet	1996,2005, 2007, 2015	1996, 2005, 2015, 2012	2015,1996, 2007, 2005,1998 ,2017	2015,2005, 1996	2005, 2015,1995	2015,1996, 2005
2 to 2.99	Very wet	1998,2012	1995,2007, 2011,1998	1995	2007	1996, 2020,1993	1991,2008, 1990
1.00 to 1.99	Moderately wet	1991,1997, 2008,2010, 2011,2017, 2020	2020,1988	1997,2010	1998,2011, 2020,2010, 1993,2012	2008,1994, 2006,1991	2010,2011, 1997,2020, 1987
0.50 to 0.99	Slightly wet	1994	1991,2019, 2000,1997	2011,2008	2017,2008, 2000	2011,1990	1988,1995, 2007
0.49 to - 0.49	Near normal	1987,1990. 1995,2000, 2019	1990,2013, 2008,1987, 2010,2017	2012,1990, 2020,2016, 1994,1991, 1993,2009, 1997	1995,2019, 1999,1987, 1991,1990, 2016	2010,1987, 2017,2019, 2012,1999, 1997,2016, 1998	2006,1998, 2019,1993 2013,2012
-0.50 to - 0.99	Slightly dry	2001,2009	1994	2000,1999, 1989	2013,2006, 1988,1992	2009, 2000,1998, 1989,2013	1986,2004, 1994,1989
-1.00 to - 1.99	Moderately dry	1988,1999, 2003, 2006,2013	1992,1999, 2004,2006, 1989	2013,2019, 2006	1997,1994, 1989,2004, 2014	2004, 2007,1986	2017,1992, 2009,2014

-2.00 to -2.99	Very dry	1989,2004,2016,1986,1992	2014,1989, 2009,2016, 2001	2018,1986, 2014,1988, 2004,1992	2009,1986	2014,1992, 2018	2016,1999, 2000
<-3.00	Extremely dry	**2002**,2014, 2018	2018,**2003**, **2002**	**2003**,**2001**, **2002**	2018,**2001**, **2003**,**2002**	**2001, 2002, 2003**	**2002**,2018, **2003**, **2001**

The RAI results of ranipet shows that in station 1 there are 13 wet years, 6 normal years and 15 dry years. In station 2 there are 14 wet years, 6 normal years and 14 dry years. In station 3 there are 11 wet years, 9 normal years and 15 dry years. In station 4 there are 13 wet years, 7 normal years and 15 dry years. Station 5 has 12 wet years, 9 normal years and 14 dry years. Station 6 has 14 wet years 6 normal years and 15 dry years. According to (Elango et al., 2021) three highlighted years fall in the category of all India Drought years between 1981 and 2015.

Now RAI severity, intensity and duration is calculated from the index calculated above. The results are shown in table

Table 4.3: RAI parameter table

Station	intensity	severity	duration
Station 1	1.34	156	209.38
Station 2	1.59	114	181.46
Station 3	1.46	116	169.73
Station 4	1.5	86	129.83
Station 5	1.58	81	128.23
Station 6	1.53	72	111.42

The data calculated in table 6 is added along with station latitude and longitude to prepare spatial variation map shown in figure 4. Both severity and duration have similar variation maps with around 40% of the area under low severity and duration. But on the other hand intensity is high for more than 45% of Ranipet.

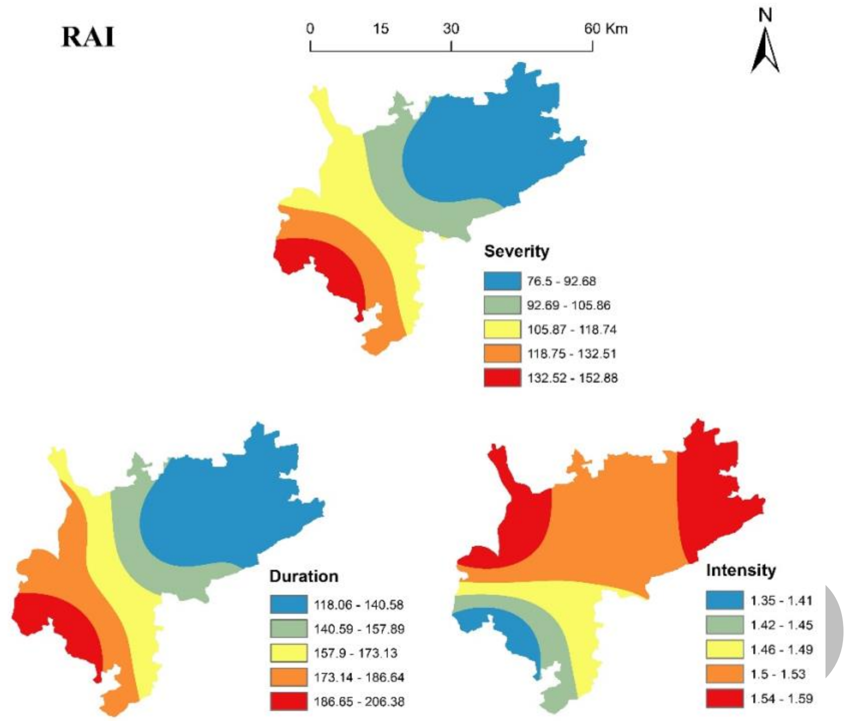


Fig 4.3: RAI severity, duration and intensity map

4.3 Percent normal precipitation index

PNPI is a quick and easy to calculate index and is computed by dividing actual precipitation by normal precipitation for the time being considered and multiplying by 100. For all the positive values of RAI value of PNPI is more than 100 and for values which is less than zero PNPI index value is less than 100.

Table 4.4: PNPI results							
INDEX PER-CENT	**CLASS**	**Station 1 year**	**Station 2 Years**	**Station 3 Years**	**Station 4 Years**	**Station 5 Years**	**Station 6 Years**
>80	normal	1996,2015, 2007, 2005,2012, 1998, 1991,2011, 2017, 2010,2008, 1997,2020, 1994,1995, 2019,1990, 1999, 1987,2000, 2001,2009, 1999,2003, 2006, 2013,1988	1996,2005, 2015,2012, 1995,2007, 2011,1998, 2020,1988, 1993,1991, 2019,2000, 1997,1990, 2013,2008, 1987,2010, 2017,1994, 1992	2015,1996, 2007,2005, 1998,2017, 1995,2010, 1997,2011 ,2008,2012, 1990,2020, 2016,1994, 1991,1993, 2009,1987, 2000,1999, 1989,2013, 2019	2015,2005, 1996,2007, 1998,2011, 2020,2010, 1993,2012, 2017,2008, 2000,2995, 2019,1999, 1987,1991, 1990,2016, 2013,2006, 1988,1992, 1997,1994, 1989	2005,2015, 1995,1996, 2020,1993, 2008,1994, 2006,1991, 2011,1990, 2010,1987, 2017,2019, 2012,1999, 1997,2016, 1988,2009,2 000,1998, 1989,2013, 2004,2007	2015,1996, 2005,1991, 2008,1990, 2010,2011, 1997,2020, 1987,1988, 1995,2007, 2006,1998, 2019,1993, 2013,2012, 1986,2004, 1994,1989, 2017
70-80	Weak drought	1998,2004, 2016	1999,2004, 2006,1989	2006,2018, 1986	2004,2014	1986,2014	1992,2009, 2014,2016
50-70	Moderate drought	1986,1992, 2014	2014,1989,200 9,2016,2001	2014,1988, 2004,1992	2009,1986, 2018	1992,2018	1999,2000, 2002
40-50	Severe drought	2018,2002	-	2003,2001	2001	-	2018
<40	Extreme drought	-	2018,**2003**, **2002**	**2002**	**2003**,**2002**	**2001**,**2002**, **2003**	**2003**,**2001**

PNPI is calculated in excel and the index values shows that station 1 has 28 normal years and 8 dry years. Station 2 has 23 normal years and 12 dry years. Station 3 has 25 normal years and 10 dry years. Station 4 has 27 normal years and 8 dry years. Station 5 has 28 normal years and 7 dry years. Station 6 has 25 normal years and 10 dry years. According to (Elango et al., 2021) three highlighted years fall in the category of all India Drought years between 1981 and 2015. Now for preparing map drought intensity and magnitude is calculated table 7 shows the data

Table 4.5 : PNPI intensity and magnitude		
Station	**Intensity**	**Magnitude**
Station 1	45.71	124.71
Station 2	48.57	128.81
Station 3	45.71	130.36
Station 4	48.57	126.16
Station 5	45.71	130.81
Station 6	48.57	127

Now, the data calculated above is added in an excel sheet alongside with the coordinates of the station and used as an input for preparing map in ArcGIS. The results are as shown in figure 5. According to PNPI index drought magnitude is low for 48% of ranipet on the other hand intensity is varied low for only less than 20% of the total area.

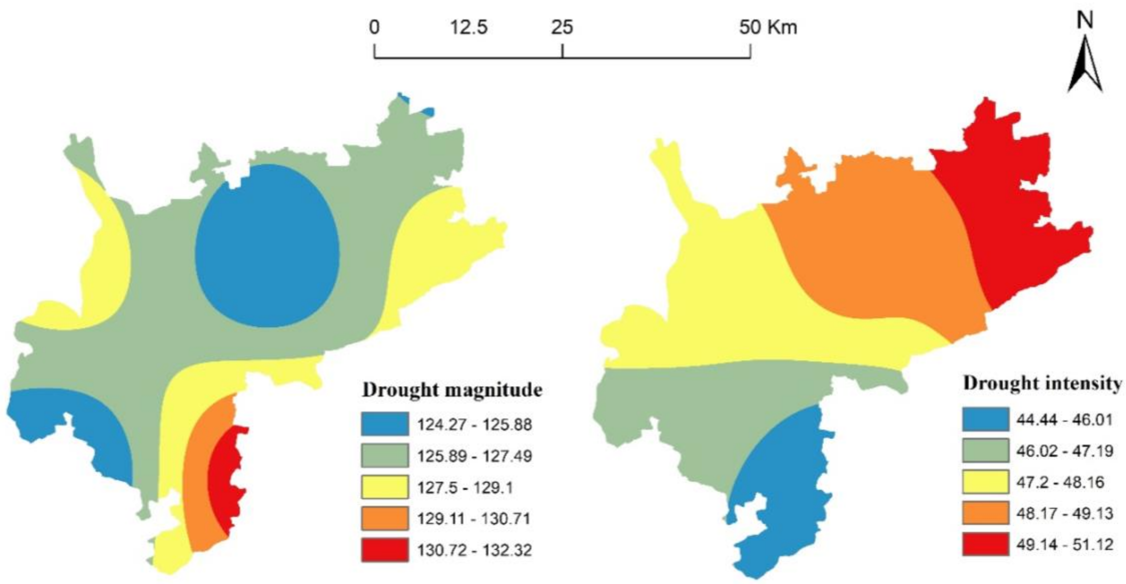


Fig 4.4: Drought magnitude and intensity map according to PNPI

4.4 CRU (Climatic Research Unit) data

This is usually simply defined as a period of time where there has been less rain recorded. Four metrological drought parameters are selected for analysis potential evapotranspiration is the potential evaporation from soils plus transpiration by plants, Temperature, Precipitation which is defined as any liquid or frozen water that forms in the atmosphere and falls to the Earth and Wet days which is days are totals of at least 0.01, 0.10, 0.20 and 0.50 inches of rain in 24 hours.

Potential evapotranspiration and precipitation has similar variation maps with 41% of the total area in high PET and low precipitation whereas temperature is more than 29º for less than 40 % of the study area wet. Low wet days are also responsible for causing drought which is evident in the map shown in fig 6

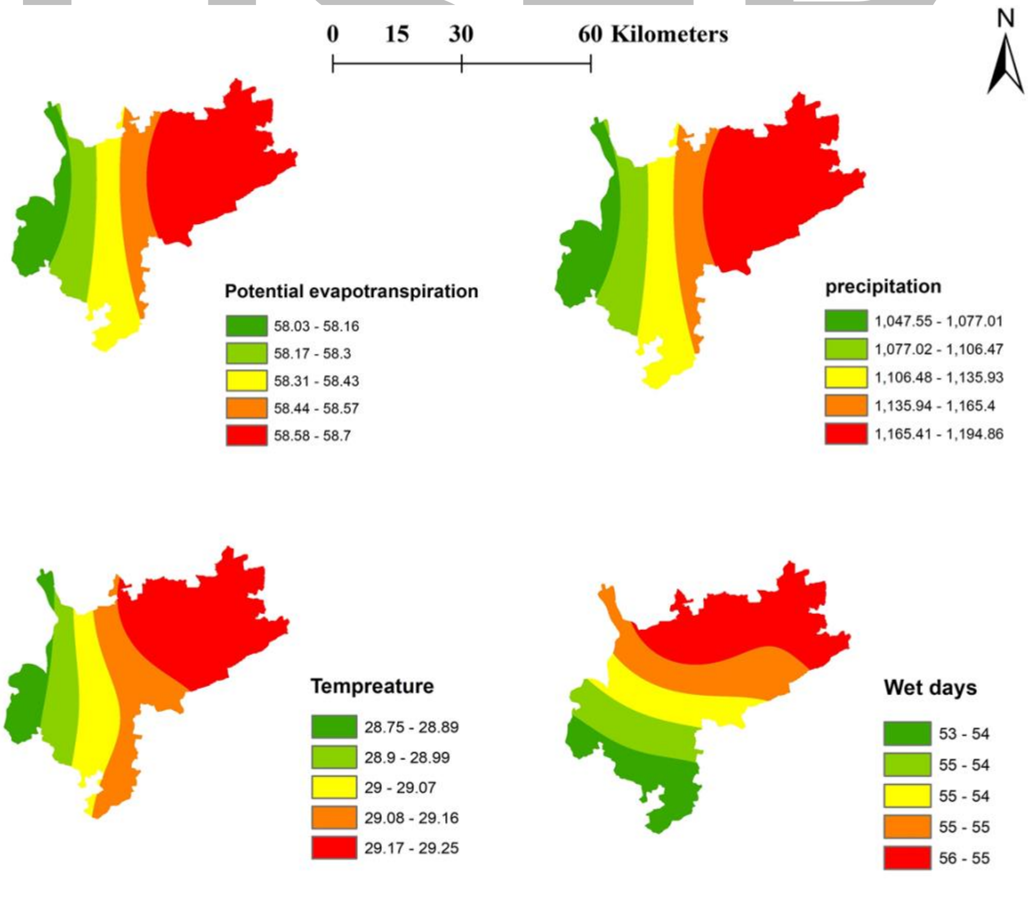


Fig 4.5: potential evapotranspiration, precipitation, temperature and wet days variation map

4.5 MCDA

Two methods were used in the analysis WSM and WPM then the values obtained from the analysis is used to plot the spatial variation maps of MCDA. Figure 7 shows map obtained from weighted sum method.

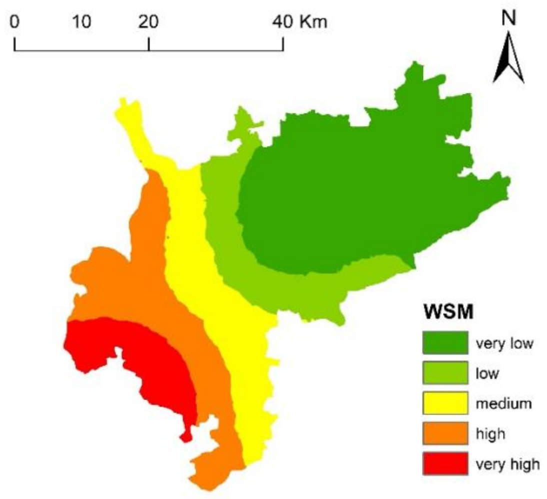


Fig 4.6: map of weighted sum method

According to weighted sum method 41.6% area of ranipet falls under very low vulnerability and only 8.4% of the area falls under very high vulnerability. 17.7% and 18.49% is under medium and high vulnerability. Map of weighted sum method is shown in figure 7

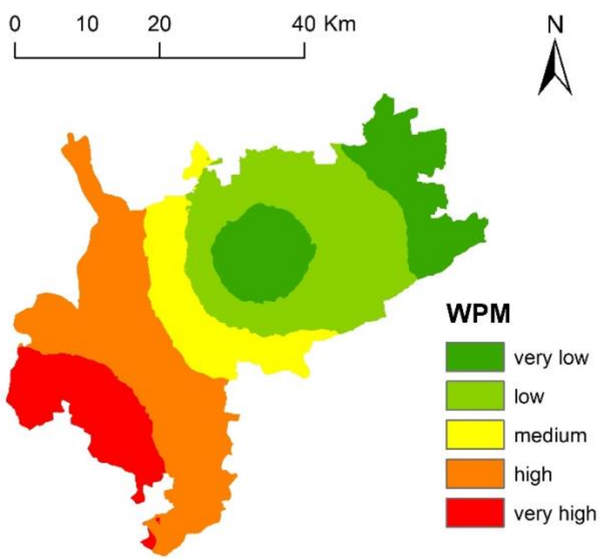


Fig 4.7: Map of weighted product method

According to Weighted product method 29.71% of the total area falls under high risk category. 27.38% of the area is under low vulnerability. Only 11.85 percent of the area is under very high vulnerability.

4.6 Validation

Validation is carried out with goodness-of-fit statistics in this values obtained from MCDA is used as assumed value and SPI is used as observed value. The results obtained are shown in the table 9

Table 4.6: goodness-of-fit statistics

	MSE	RMSE	MAE
WPM	0.686	0.582	0.695
WSM	0.578	0.368	0.548

From table 9 WSM has lesser error percentage and hence the result from WPM model is more accurate

Conclusions

Rainfall of past 35 years is downloaded and is used to download SPI, PNPI and RAI drought index. The values obtained shows that year 2002, 2003, 2004, and 2005 were in extreme drought period as SPI, RAI values were continuously negative and PNPI values were below 100 for the corresponding year. Now the index data combined with CRU data is used for MCDA. Weighted sum model shows that 41.6 % area is under very low vulnerability,17.7 % under medium vulnerability and 18.49% area under high vulnerability. Weighted product model had different variation , it shows that only 27.38 % of the total area is under low vulnerability and 29.71% of the area is under high vulnerability to drought. Both the model of MCDA is validated with Good-fit-statistics which shows that WSM has lower error percentage and hence is mpre accurate.

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