Using Remote Sensing and GIS Techniques for Drought Monitoring of Purulia District, West Bengal-India

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Abstract:

The study of advance remote sensing & GIS was conducted to monitor and assess drought conditions in Purulia district, West Bengal. The study based on satellite image data analysis and GIS technology for drought monitoring from LANDSAT-8 OLI satellite image. The final result based on calculation of SPI value and weighted overlay analysis using the four parameters, namely (LST, NDVI, Rainfall and LU/LC), the final results depict in four classes namely: Mild Drought, Low Drought, Low to Moderate Drought and Moderate Drought. The Mild Drought area indicates 1086.23 Sq km about 17%, found in south and south-western part, covered with the forest land, the Low Drought area shows 2363.99 Sq km about 38% found in south-western, south-eastern and eastern part, covered with agriculture, vegetation and barren land, the Low to Moderate Drought area indicates 2453.06 Sq km about 39% on the middle part and north-eastern part, covered with agriculture, scattered vegetation, settlement and agriculture fallow land, the Moderate Drought area indicates 355.72 Sq km about 6% on the north-eastern part covered with barren land, settlement, agricultural land and agricultural fallow land of the study area. On the other hand SPI value range varies between -0.80 to -1.02 it shows that the Purulia district comes under the Mild & Moderate Drought region.

Keywords: Remote Sensing, GIS, LST, NDVI, SPI, Weighted Overlay Analysis.

1. Introduction:

A drought is a term relative to normal conditions while water shortage is an absolute term for water demand (Obi Reddy et al., 2001; Alshaikh., 2015). Drought is defined as a deficiency of precipitation over an extended period of time, resulting in water shortage that causes extensive damage to crops, living as well as non-living things (Mishra and Singh., 2010). In simple terms, it is the absence of water for a long period of time, at a place where it is considered 'not normal' comparable to its usual conditions (Mishra and Singh., 2011). Several drought indices utilize ground-based measurements. Some indices are based on energy-balance models, where as other indices use space-borne data, either solely or in combination with energy-balance models (Heim., 2002) to determine the meteorological, agricultural, hydrological, and socioeconomic aspects of drought (Nagarajan., 2010). Drought is one of the major natural hazards affecting the environment and the economy and worldwide sustainable development (Albert et al., 2002). In contrast, remote sensing from space represents a fast and economic method for drought monitoring (Alshaikh., 2015). The droughts are generally classified into four categories (Wilhite and Micheal., 1985; AMS., 2004; Hennessy et al., 2008), which include: Meteorological Drought, Agricultural Drought, Hydrological Drought and Socioeconomic Drought.

2. Study Area:

Purulia district is a part of West Bengal state in Eastern India, geographically lies between 22.60 degrees and 23.50 degrees north of the latitude. On the Eastern side it is located between 85.75 and 86.65 East longitude

(Figure 1). Purulia experiences subtropical climate and owing to this it is one of the most drought prone districts of West Bengal. The region sees extremely high temperatures during the summer months and lowest nippy temperatures in winter. The typical temperatures during these months are: 52 degrees during the summer months and an extreme frosty temperature of 3.8 degrees in winter. During summer, the weather is extremely dry, but the amount of precipitation is low.

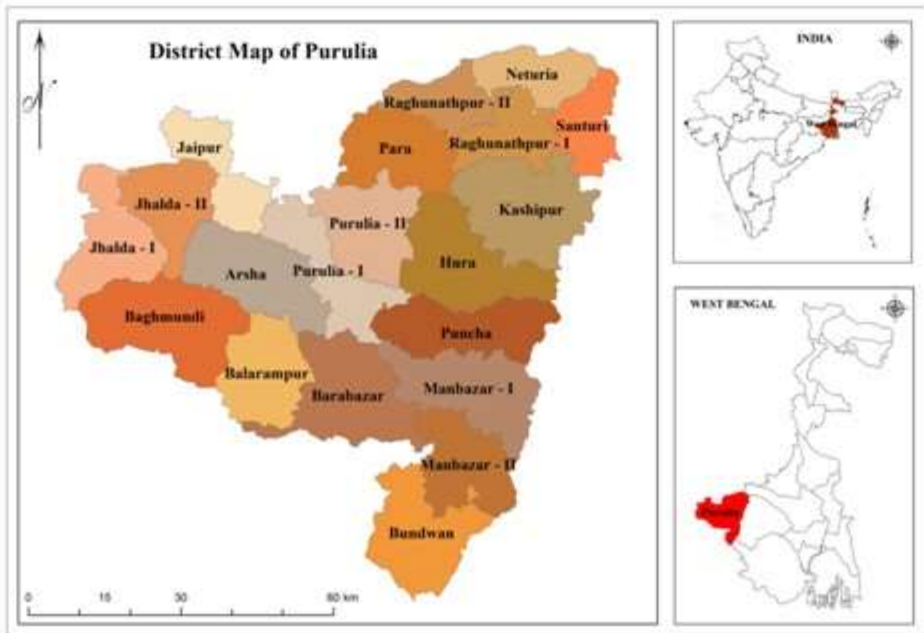

Figure 1: Location Map of the Study Area

3. Data Sets:

Satellite image of the study area Landsat-8 OLI download from USGS (<https://glovis.usgs.gov/>). The toposheets map collected from SOI (Survey of India), scale 1:50000 and Annual average rainfall download from the Indian Meteorological Department (http://www.imd.gov.in/Welcome%20To%20IMD/Welcome.php).

4. Methodology:

The methodology adopted for this study was prepared LU/LC, LST and NDVI map using Landsat 8 OLI satellite image, Rainfall distribution map was prepared from average annual rainfall data using an IDW statistical analysis tool in ArcGIS software. All thematic maps reclassify and weighted overlay analysis using suitable weighted value according to their importance. On the other hand SPI value calculates using rainfall data for finding the actual drought scenario of the study area. The methodological flow chart is shown in **(Figure 2).**

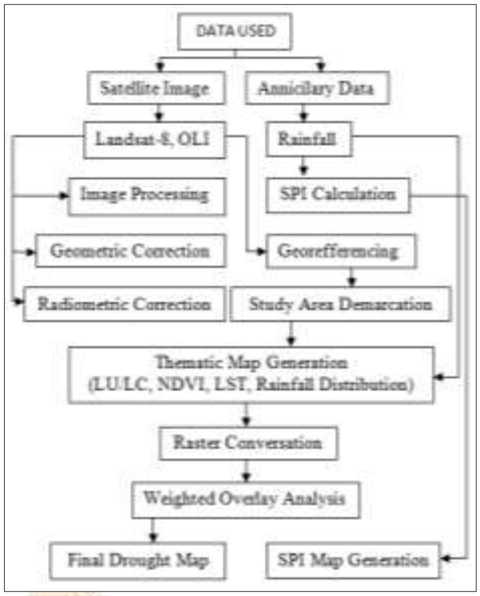

Figure 2: Methodological Flow Chart

4.1 Procedure and Formula for Computation of SPI:

4.1.1 The transformation of the precipitation value in the standardized precipitation index (SPI) has the purpose of:

a. Transforming the mean of the precipitation value adjusted to 0;
b. The Standard deviation of the precipitation adjusted to 1.0
c. Skewness of the existing data has to be readjusted to zero.

When these goals have been achieved the standardized precipitation index can be interpreted as mean 0 and standard deviation of 1.0.

4.1.2 The Mean of the precipitation can be computed as:

$$\text{Mean} = \bar{x} = \frac{\sum x}{N}$$

Where N is the number of precipitation observations. In Excel the mean is computed as Mean = Average.

4.1.3 The standard deviation for the precipitation is computed as:

$$s = \sqrt{\frac{\sum(X - \bar{X})^2}{N}}$$

4.1.4 The skewness of the given precipitation is computed as:

$$\text{Skew} = \frac{N}{(N-1)(N-2)} \sum \left(\frac{\mathrm{X} - \bar{\mathrm{X}}}{\mathrm{s}}\right)^3$$

4.1.5 The precipitation is converted to lognormal values and the statistics U, shape and scale parameters of gamma distribution are computed:

$$\log mean = X\ln = \ln(\bar{X})$$
$$= \mathrm{U} = \overline{Xln} - \frac{\sum \ln(x)}{N}$$

Shape parameter = $\beta = \frac{1+\sqrt{1+\frac{4U}{3}}}{4U}$

Scale parameter = $\alpha = \frac{\bar{X}}{\beta}$

The resulting parameters are then used to find the cumulative probability of an observed precipitation event. The cumulative probability is given by:

$$G(x) = \frac{\int_0^x x^{a-1} e \frac{-x}{\beta} dx}{\beta^{\alpha} T(\alpha)}$$

Since the gamma function is undefined for x = 0 and a precipitation distribution may contain zeros, the cumulative probability become:

$$H(x) = q + (1-q)G(x)$$

Where, q is the probability of zero.

The cumulative probability H (x) is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI following Edwards and McKee., (1997); we employ the approximate conversion provided by Abramowitz and Stegun., (1965); as an alternative:

$$Z = SPI = -\left(t - \frac{c_{0+} c_{1t+} c_{2t^2}}{1 + d_{1t} + d_{2\,t^{2+} d_3 t^3}}\right) 0 < H(x) \leq 0.5$$

$$Z = SPI = +\left(t - \frac{c_{0+} c_{1t+} c_{2t^2}}{1 + d_{1t} + d_{2\,t^{2+} d_3 t^3}}\right) 0.5 < H(x) \leq 1$$

Where,

$$t = \sqrt{\ln\left(\frac{1}{H(x)^2}\right) 0 < H(x) \leq 0.5}$$

$$t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right) 0.5 < H(x) \leq 1.0}$$

c0 = 2.515517, c1 = 0.802583, c2 = 0.010328, d1 = 1.432788, d2 = 0.189269, d3 = 0.001308. The values of c0, c1, c2, d1, d2, d3 are constants widely employed for SPI computation (Abramowitz and Stegun., 1965).

4.2 Normalized Difference Vegetation Index (NDVI):

The Normalized Density of Vegetation Index (NDVI) is one of the most successful indices for simple and quick identification of vegetated areas and their condition (Vikram Agone and Bhamare., 2012). The NDVI from LANDSAT 8 LOI data has been extensively used for vegetation monitoring, crop yield assessment, and drought detection (Benedetti and Rossini., 1993). The NDVI is calculated as: NDVI= (NIR-RED) / (NIR+RED) where NIR is the reflectance radiated in the near-infrared waveband and RED is the reflectance radiated in the visible red waveband of the satellite radiometer (Justice et al., 1985; Rouse et al., 1974). Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1). Zero indicates no vegetation and +1 (0.8–0.9) indicates the highest possible density of green leaves (John and Herring., 2000).

4.3 Land Surface Temperature (LST):

Land-Surface Temperature (LST) can be defined as the thermal emission from a land ‘‘surface”, including the top of a canopy for vegetated surfaces as well as other surfaces such as bare soils (Ahmad et al., 2006). For estimating LST from satellite thermal data, the digital number (DN) of image pixels needs to be converted into spectral radiance using sensor calibration data (Markham and Barker., 1986).

The formula for converting DN to radians using LMIN and LMAX values is

L = LMIN + (LMAX-LMIN)* DN/255

Where: L =spectral radiance

LMIN= minimum spectral radiance of DN value

LMAX = minimum spectral radiance of DN value

DN = digital Number

Once the DN's for the thermal bands have been converted to radiance values, the inverse of the Planck function can be applied to derive the temperature values. The formula to convert radiance to temperature is
Where:

$$T = \frac{K2}{In(\frac{K1}{L_\lambda} + 1)}$$

Where: T =effective at-satellite temperature in Kelvin.
K2 =calibration constant (1321.08).
K1 =calibration constant (774.89).
L_λ= the cell value as radiance.
The temperature values are estimated in degree Kelvin and then converted to degree Celsius.
T (Celsius) = T (Kelvin) – 273.

5. Result:

5.1. Land Use / Land Cover:

The LU/LC map of the study area (purulia district) classifies using LANDSAT-8, OLI (Operational Land Imager) satellite image, the classified map divided into nine classes, namely river, forest, water bodies, river sand, barren land, vegetation, settlement, agriculture and agriculture fallow land **(Figure 3)**. The agricultural area covered 2759 sq km about 44.09% found in all parts of the study area. The barren land covered 1584.60 Sq km about 25.32% north-west, northeast and some southeastern part of the study area. The vegetation area covered 755.905 Sq km about 12.08%, east, south and southwest part. The forest area covered 649.134 sq km about 10.37%, south-west, south and some portion of the middle part of the study area. The water bodies covered 193.22sq km about 3.09%, north and southeast part. The agriculture fallow land covered 156.481 Sq km about 2.50%, south-west and some part of northeast part. The settlement area covered 148.201 Sq km about 2.37%, northeast and middle part of the study. The river sand covered 11.78 Sq km about 0.19 %, northeast, and southeast of the study area. The classification area of the study is shown in **(Table 1).**

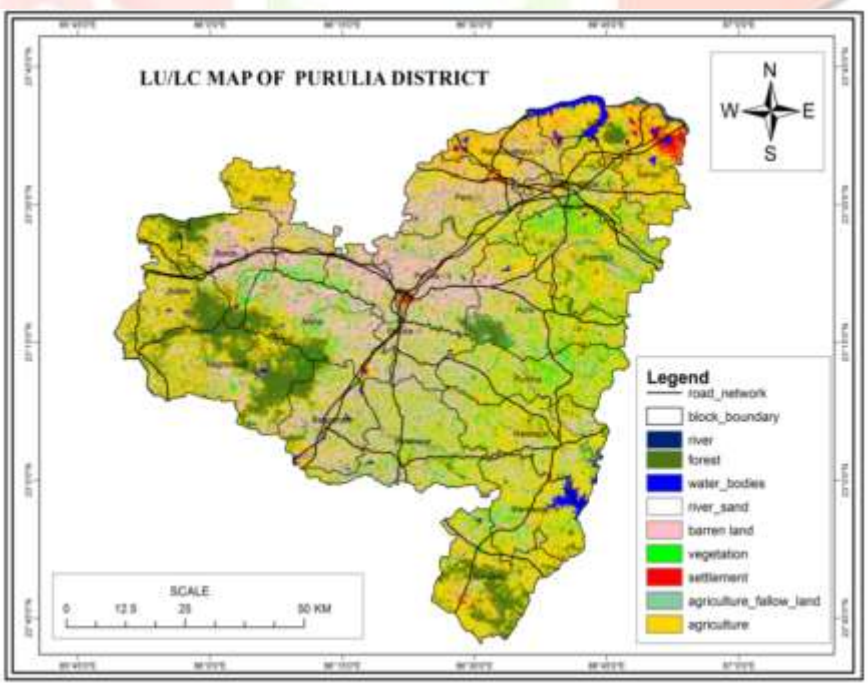

Figure: 3: LU/LC Map of Purulia District (2016)

Table 1: LU/ LC Area of the Purulia District (2016)

Class Name	Area in (Sq km)	Area (%)
Agricultural Land	2759.67	44.09
Barren Land	1584.61	25.32
Vegetation	755.91	12.08
Forest	649.14	10.37
Water Bodies	193.21	3.09
Agricultural Fallow Land	156.48	2.50
Settlement	148.20	2.37
River Sand	11.78	0.19
Total	**6259.00**	**100.00**

5.2: Land Surface Temperature (LST):

The LST range varies between 1º C to 34º C **(Figure 4).** The red color shows high LST (34º C) in the middle part of the study area and it's covered with barren land, settlement and agricultural land. The green color shows low LST (1º C) in the southwestern part of the study area and it's covered with forest land, on the other hand yellow color shows the average temperature of the study area found in all portions of the purulia district (Land surface temperature is the emitted temperature from the earth surface).

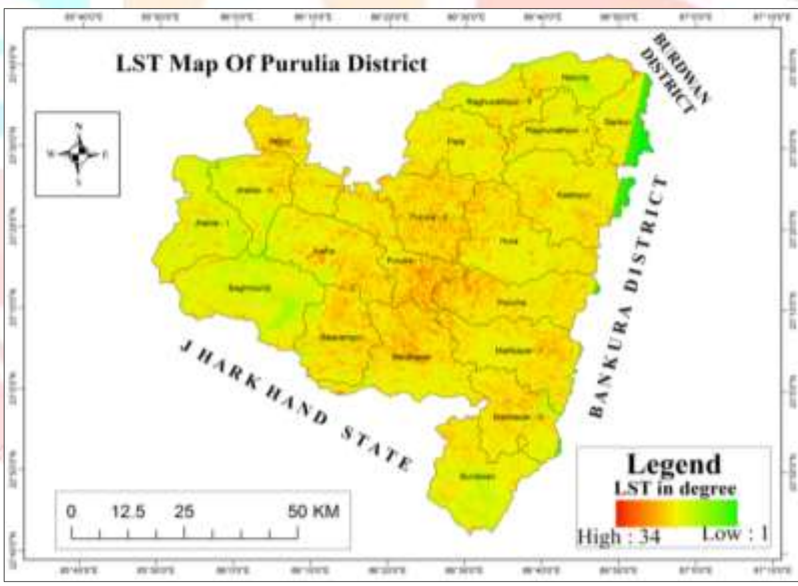

Figure 4: LST Map of the Purulia District

5.3: NDVI of the Study Area:

The NDVI map of purulia district is prepared by using LANDSAT-8 OLI satellite image data. The NDVI value varies between high to low +1 to -1 **(Figure 5).** The high NDVI value (+1) indicates the presents of vegetation covers in the study area and its covers the southwestern, south, and some part of southeastern of the study area in green color. The low NDVI value (-1) covers the middle and the northeastern part of the study area in violet color and it indicates others features of the study area.

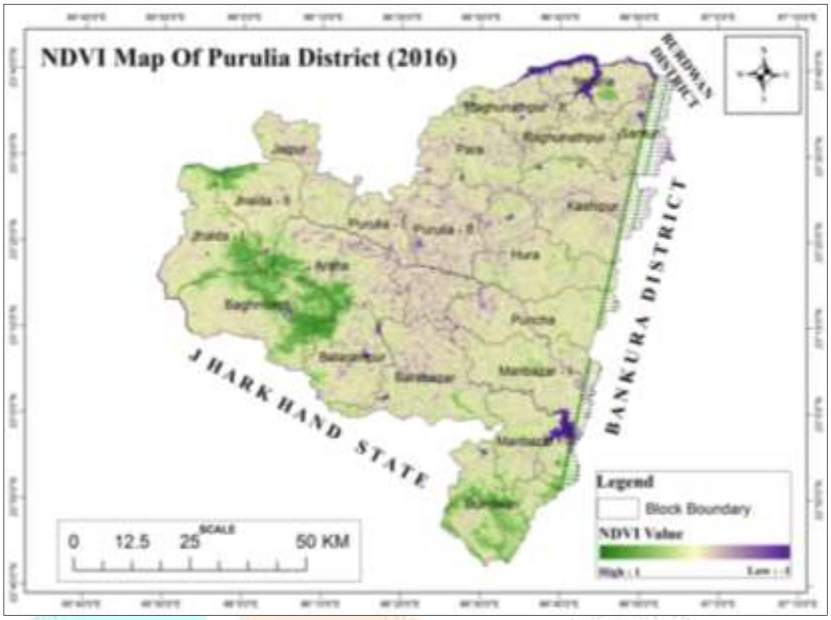

Figure 5: NDVI Map of the Purulia District

5.5: Rainfall Distribution:

The Rainguage Station wise average annual rainfall **(Table 2)** of the study area varies between 823.5 to 1143.7 mm in the year 2016 **(Figure 5).** The lowest average annual rainfall (823.5 mm) presents in the northern part of the study area, shows in red color, high average annual rainfall (1143.7 mm) covered south-west part of the study area show in green color and the moderate average annual rainfall covered upper middle to southeastern part of the study area indicates in yellow color.

Table 2: Rainguage Station wise Annual Average Rainfall

Year	Rainfall Station			
	Station-1	**Station-2**	**Station-3**	**Station-4**
2016	1076.9	823.5	876.8	1143.7

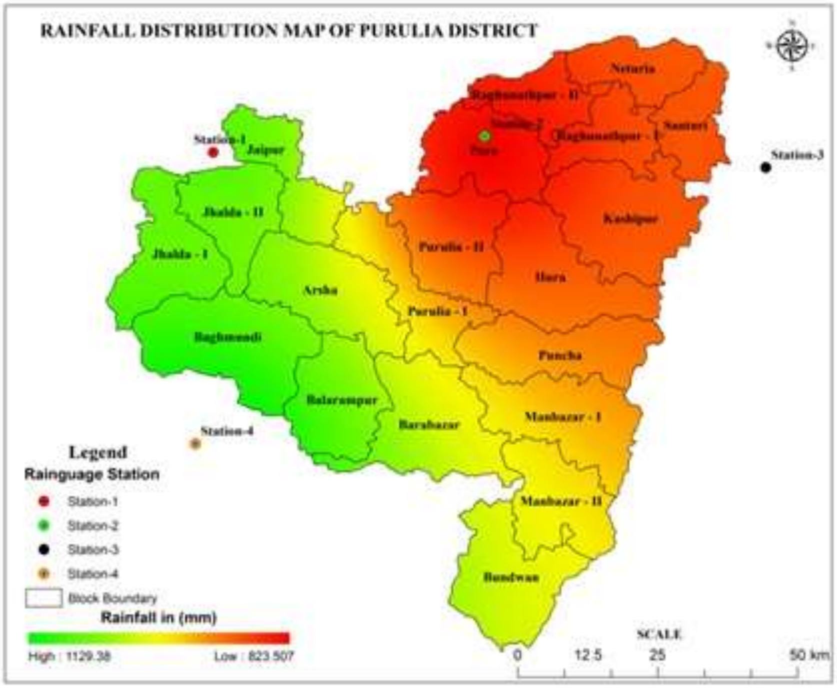

Figure 5: Rainguage Station Wise Annual Rainfall Distribution Map of Purulia District

5.6 Standardized Precipitation Index (SPI):

The categories of drought, according to SPI value is shown in **(Table 3).** According to SPI value the study area under of Mild & Moderate Drought area. The SPI values vary between -0.80 to -1.20 **(Table 4).** The lowest SPI value shown in north-eastern part of the purulia district its mean high drought risk area, highest SPI value shows northwestern part of the study area its fall in a low drought risk area of the study and moderate SPI values shows upper middle to the southeastern part of the study area **(Figure 6).**

Table 3: Drought categories from SPI (McKee *et al*., 1993).

SPI Value	Drought Category
0 to −0.99	Mild drought
−1.00 to −1.49	Moderate drought
−1.5 to −1.99	Severe drought
−2.00 or less	Extreme drought

Table 4: SPI Value of the Study Area

	Rainguage Station				SPI Values			
Year	Station-1	Station-2	Station-3	Station-4	Station-1	Station-2	Station-3	Station-4
2016	1076.9	823.5	876.8	1143.7	-0.97	-0.80	-0.82	-1.02

Figure 6: SPI Map of Purulia District

5.6 Drought Map of Purulia District:

The final drought map is prepared by using different parameter (LU/LC, rainfall distribution, LST and NDVI) with the help of weighted overlay analysis method, assigning a weighted value of each class according to their importance **(Table 5)** in ArcGIS software. The final drought map classified into four classes, namely Mild Drought, Low Drought, Low to Moderate Drought and Moderate Drought. The Mild Drought (green color) area covered 1086.23 sq km about 17%, in the southwestern part, Low Drought (yellow in color) area covered 2363.99 sq km about 38%, in the upper part of southwestern and lower part of north-eastern, Low to Moderate Drought (orange in color) contains 2453.06 sq km about 39%, in the north-eastern part and Moderate Drought (red in color) contain 355.72 sq km about 6%, and it is scatter distributed north-eastern part of the study area **(Figure 7).** The area of drought is shown in **(Table 6).**

Table 5: Weighted value of each feature

Feature	Class Name	Class Weighted	Theme Weighted
Rainfall	901.30-973.14	9	30
	973.14-1,051.82	7	
	1,051.82-1,132.21	6	
	1,132.21-1,217.73	4	
	1,217.73-1,335.75	4	
NDVI	-1-0.083	9	30
	0.083-0.29	7	
	0.29-0.41	6	
	0.41-0.73	5	
	0.73-1	3	
LU/LC	Forest, Vegetation, water body	1	17
	River Sand, Barrenland, Agricultural Fallow land	4	
	Settlement	5	
	Agriculture	7	
LST	1.00-6.50	1	23
	6.50-12.00	2	
	12.00-17.5	3	
	17.5-23.00	4	
	23.00-28.5	5	

	28.5-34.00	7	

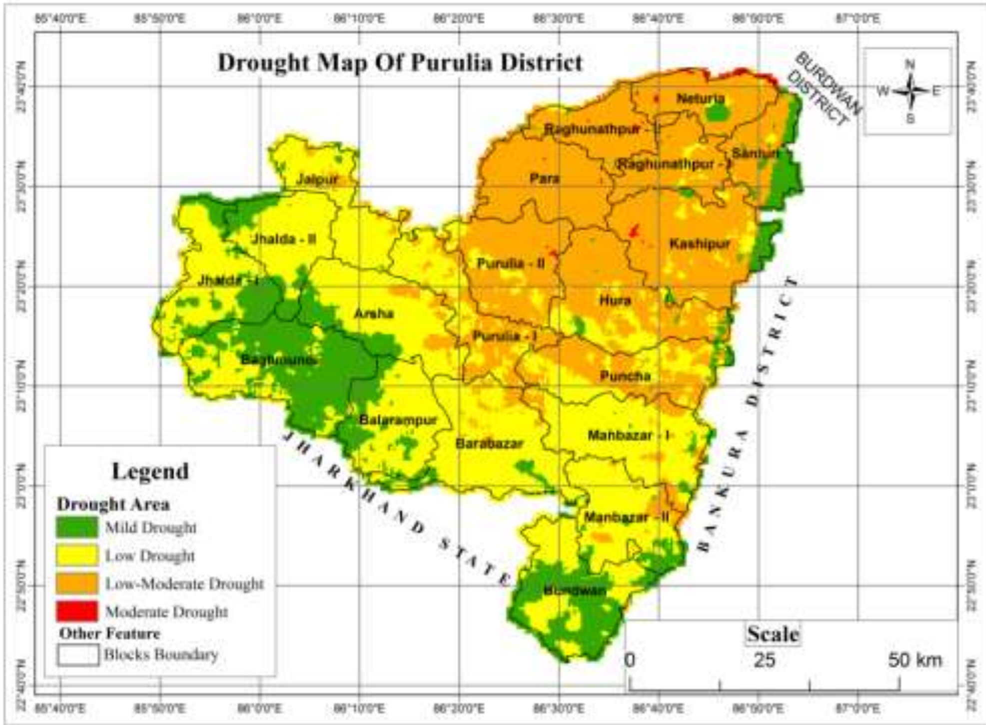

Figure 7: Drought Map of Purulia District

Class Name	Area in (sq km)	Area (%)
Mild Drought	1086.23	17
Low Drought	2363.99	38
Low to Moderate Drought	2453.06	39
Moderate Drought	355.72	6
Total	**6259**	**100**

Table 6: Area and Percentage of Drought

6. Conclusions:

Remote Sensing & GIS based study for drought monitoring find a reliable, cost effective and time saving technology, using satellite imagery and rainfall data, different parameter analysis using the weighted overlay analysis method and calculate an SPI value for demarcation the drought affected area of purulia district. According to SPI value (-0.08 to -1.02) the purulia under the Mild to Moderate drought affected area, however final drought map indicates four classes (Mild Drought, Low Drought, Low to Moderate Drought and Moderate Drought) of the study area. The two different maps (SPI & Drought) are clearly shows that the mild drought affected area presents of vegetation cover, but moderate drought area represents agriculture land, barren land, agriculture fallow land and settlement. Drought conditions and Land use pattern both are linearly related. The study must be recommended to develop the greenbelt area, surface water conserved and use of water (ground water & surface water) in a sustainable manner to reduce the drought influence and make a living environment for human and wildlife.

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