Geospatial Application in Desertification Monitoring- Rajasthan, India

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Abstract **-Desertification is a significant environmental problem in the arid and semi-arid regions, mainly caused by climate variations, change, and anthropogenic activities. The characteristic of rainfall of Rajasthan is seasonal, erratic, and higher variability is resulting in increasing aridity and degradation of vegetation growth and desertification. This study's prime objective is to analyze vegetation trends using long-term NDVI from AVHRR for desertification monitoring. Surface vegetation is the most important indicator to assess desertification. In this study, long-term NOAA-AVHRR-GIMMS3G (1983-2011) Normalize Difference Vegetation Index (NDVI) time trends were used as a proxy for Net Primary Production (NPP). To assess the vegetation trend, annual, seasonal, and monthly NDVI, and its mean, maximum, standard deviation, and NDVI Anomaly Index, integral NDVI (iNDVI) were computed. Spatial and temporal variability rainfall and drought were studied using monthly rainfall data from 1983 to 2011 for 102 rain gauge stations. Standardized Precipitation Index (SPI) was computed for all rain gage stations then the SPI results were interpolated. The iNDVI/RF trends were estimated to assess the desertification processes. The 3-month SPI and NDVI anomaly index's spatial pattern during drought years have a higher negative anomaly during the months from July to September in the greater part of Rajasthan. For example, in 2002, higher SPI values were noticed at Bikaner (August, -3.33, July,-3.13, and September, -2.76) and Chirawa (September,-3.02, August, -2.41). The trends of iNDVI/RF ratio results suggest that about 37 % of the study area was experienced decreasing trends of vegetation growth, ongoing degradation, and desertification process. The districts of Jaisalmer, Jodhpur, Nagaur, Sikar, Bikaner, Churu, and the northwestern part of Barmer are mostly affected by land degradation. About 45% of the study area was experienced the stable condition. Only 9% showed strong positive trends in vegetation growth.**

Keywords: **Desertification, Land Degradation, NDVI Anomaly Index, iNDVI/RF trend, Vegetation growth**

I. INTRODUCTION

Desertification refers to land degradation in dry lands. Desertification is characterized by the spread of desert conditions beyond desert margins or by the intensification of desert conditions within arid regions, which is accompanied by diminished productivity. According to United Nations Convention to Combat, Desertification definition refers to the degradation of land in arid, semi land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variation and human activities (UNCCD, 1994, UNEP, 1992). Desertification is when land becomes dry, bare and unsuitable for growing trees or crops. Desertification is considered a severe environmental problem mainly caused by climate changes and human activities during the last decades (Kundu et al. 2014, Elhag et al. 2014, UNEP, 1992). The United Nations to Combat Desertification (UNCCD) programme was approved by 195 countries which mainly focus the desertification and land degradation (UNCCD, 1994). Nearly one-third of the global land surface is under the threat of desertification (Li, 2004). Vegetation is considered one of the most important aspects to monitor desertification (Badreldin et al., 2013). The Great Indian Desert of 'Thar' is located in the western part of India. About 91% of the desert (2.08 million square km) falls in Rajasthan state (Sinha et al., 2000). The Government of India undertook various programs to handle the desertification problem. For example, Desert Development Program (DDP) started in1977-78 to control desertification, restore the ecological balance of desert and semi-desert areas, and create conditions for raising production, income, and employment in these areas. In India, desertification is one of the significant sluggish hazards found in this country's northwestern part, mainly in Rajasthan (Kundu et al., 2014, 2011)

Remote sensing is the most successful approach for detecting the long-term desertification process and vegetation changes (Kundu et al., 2014, 2011, Hanan et al., 1991).The NOAA–Advanced Very High-Resolution Radiometer (AVHRR) based vegetation indices are widely accepted as good indicators for monitoring climatic variations, desertification, and droughts (Seiler et al. 2006). The NDVI is a good indicator of green biomass, leaf area index (LAI), and production pattern (Thenkable et al. 2004). The desertification process was monitored in Mongolian Plateau using MODIS tasseled cap transformation (Liu Qingsheng et al., 2018). In this study, to assess the Sanddune changes, different indices derived from the well-known tasseled cap transformation (TCT), mainly tasseled cap angle (TCA), disturbance index (DI), process indicator (PI), and topsoil grain size index (TGSI) were integrated to monitor and assess the desertification at the thirteen study sites.

The desertification processes in western Rajasthan were studied (Kundu et al., 2014) using a linear spectral un-mixing method for end-number fraction estimation. This technique can monitor the desertification process in terms of fractional changes in sand and vegetation covers. Elhag et al. (2014) analyzed the desertification in the Wadi Al Kanger area, Sudan using remote sensing and GIS techniques. This study focused on the assessment and evaluation of land degradation and desertification. This study's objective was to monitor and map the land use and land cover concerning drought, sand encroachment, and land degradation processes. The study attempted to investigate the potential use of remote sensing and GIS. Satellite imageries of the years 1973, 1987, 2001, and 2011 were used to measure the extent of the sand movement and sand encroachments during the above addressed periods. Environment and the desertification of Iraq have been studied with the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Salinity Index (SI), and Eolian Mapping Index was used (Othman et al. 2014). A detailed study on the recent progress of land degradation and desertification assessment methods using vegetation index data has been evaluated (Thomas et al., 2014). This paper assessed the statistical and ecological frameworks of landdegradation and desertification and developing multi-temporal techniques. Edris et al. (2013) studied the Al-Butana Area of Sudan's desertification, Using Remote Sensing and GIS Techniques. In this study, sand encroachment and vegetation degradation was considered as desertification indicators. The desertification tendency of the Qubqi Desert in China was investigated using vegetation and soil change indices extracted from seven LANDSAT TM images. In this study, to identify the desertification tendency, firstly, the desertification extent and tendency were determined by classifying the land cover using the NDVI; secondly, the degree of desertification was classified using the Modified Soil Adjusted Vegetation Index (MSAVI). The study results demonstrated that desertification expansion was mostly evident in the eastern Qubqi and the neighboring farming land area (Guishan, Cui, et al. 2011). Changes in vegetation cover of Churu district of western Rajasthan were detected from long-term NOAA-AVHRR data. In this study, desertification was monitored through the NDVI time trend, and the study confirmed the ongoing desertification process in some parts of the Churu district (Kundu et al., 2011).

II. STUDY AREA

The Great Indian Desert or the Thar Desert is located in India's western part (Figure 1). The Great Indian Desert is an arid region that covers an area of 200,000 Sq.km. About 85% (170,000 Sq.km) of the Thar Desert belongs to India, and the remaining 15% (30,000 Sq.km) is within Pakistan. Rajasthan desert is spread across the western part of India and Southeastern Pakistan. Consequently, this vast stretch of barren land extends to the southern part of Haryana, Punjab, Northern Gujarat, and the Sind province of Pakistan. The climate of the western Rajasthan is unusually desert type and receives scanty rainfall. During the summer season, temperature increases too high up to 49°C, and the average temperature of Rajasthan varies from 40°C to 45°C.

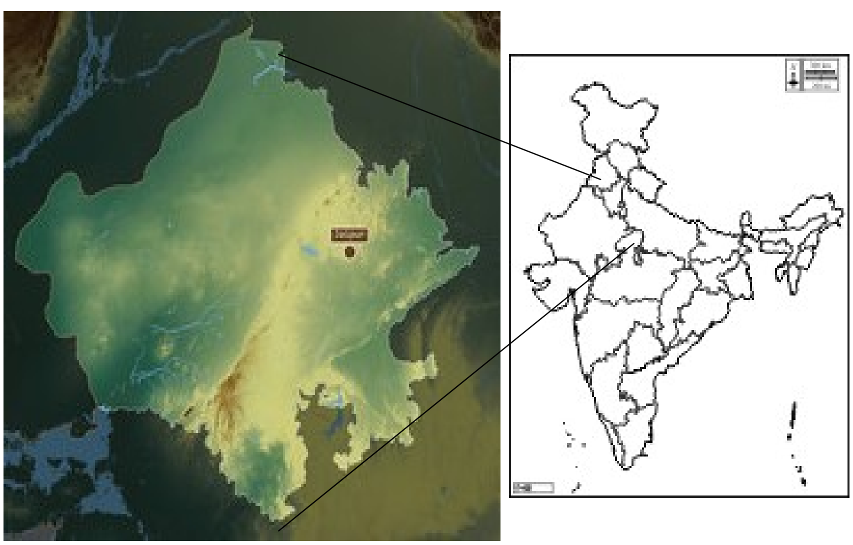


Figure1: Location of Rajasthan in India

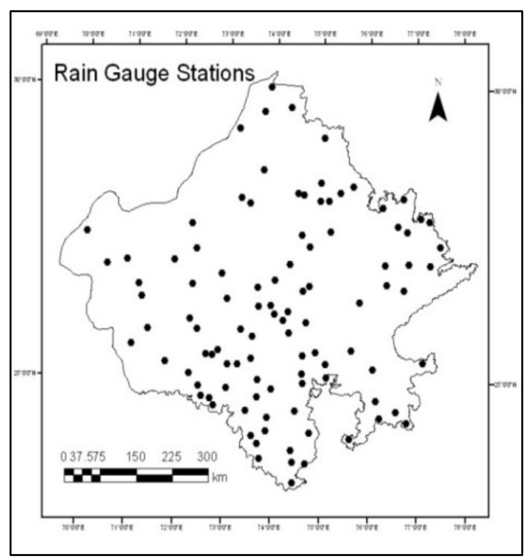


Figure 2: Location of Rain Gauge station

III. MATERIAL AND METHODS

A. NDVI Data

Data has been acquired for this study mainly from two sources. The remotely sensed data product is obtained from the NOAA Polar Orbiting Satellites-Advanced Very High-Resolution Radiometer (AVHRR), Global Inventory Modeling and Mapping Studies (GIMMS3G) data distribution Centre. The NOAA-AVHRR 15-day value composites of monthly NDVI for 29 years from January 1983 to December 2011 were used. The composite data has a spatial resolution of 8 km in Albert Equal Area Conic projection using the Clarke

1866 ellipsoid. Firstly the continental file of Eurasia (EA) was downloaded, and then the Indian region and study area were extracted. The 15a composite is the maximum value composite from the first 15 days of the month, and the second 15b is from day 16 to the end of the month (15a and15b). These tong term monthly images were re-scaled to obtain NDVI values ranging +1 to -1. The NDVI values between 0 and 0.1 indicate rock and bare soil, 0.1 designate desert, and 0.8 in dense tropical rainforest (Tucker et al. 1985).

B. Rainfall Data

Long-term monthly rainfall data for 102 rain gauge stations in Rajasthan were collected from the India Meteorological Department (IMD) and the Department of Revenue for 29 years from1983-2011. The location of rain gauge stations is shown in Figure 2.

C. Analysis

For monitoring the trend of vegetation annual, seasonal and monthly NDVI and its mean maximum, standard deviation, and NDVI Anomaly Index, integral NDVI (iNDVI), and rainfall ratio were computed in pixel level. The trends were estimated by linear regression considering the rate of iNDVI/RF as a dependent

variable and time (years) as the independent variable. The correlation between the long-term iNDVI and rainfall was tested. The entire processing of data has been analyzed using ENVI 5.3 and ERDAS IMAGINE 10.2. The computation method is expressed below.

NDVI max = max (NDVt, NDVIt2, NDVIt3 ……………. NDVItn)

NDVIm = mean (NDVt1, NDVtI2, NDVIt3……….……….NDVI tn)

iNDVI = 30/2 (NDVIt1,+2*NDVIt2,+2*NDVIt3… …… NDVItn

NDVI anomaly index = NDVI-NDVI m /NDVIs

Anomaly NDVI i = (NDVI maxi- mean NDVI max)/(mean NDVI max)*100

iNDVI/RF= iNDVI * 100/RF

The US National Drought Mitigation Center introduced the Standardized Precipitation Index (SPI) to monitor rainfall anomaly and drought conditions. SPIs were suggested (Guttman, 1998) Pearson type III distribution. Gamma distribution with three parameters: a, s, r respectively mean, standard deviation, andskewness. SPI was computed for 1, 2, and 3 -3-month time scale for 102 rain gauge stations to study the rainfall anomaly and meteorological droughts.

$$\delta F = \left[\left(\frac{1}{\sigma\Gamma(p)} \right) \left(\frac{x-\alpha}{\sigma} \right)^{p-1} \left(e^{-\left(\frac{x-\alpha}{\sigma} \right)} \right) \right] \delta x$$

Where, $\alpha \leq x < \infty$, p>2 and $\Gamma(p)$ is incomplete gamma function of p

Rainfall and SPI results were interpolated to study the spatial variability of climate. Drought is then examined from the normalized rainfall series following the SPI criteria (Table 1).

Table1: Drought Severity Classification (modified)

SPI Values	Categorization
-0.5 and above	No drought
-0.5 to -0.7	Abnormally Dry
-.0.8 to -1.2	Moderate drought
-1.3 to -1.5	Severe drought
-1.6 to -1.9	Extreme drought
-2 and less	Exceptional drought

Source: US Drought Monitoring Mitigation Centre

IV RESULTS AND DISCUSSION

A. Rainfall Pattern

The causes of desertification and vegetation destructions are due to natural and human-induced. The desertification process is enhancing due to long-term climate changes, fluctuations, periodic droughts, and the destructive consequences of human activities. A good vegetation cover depends on the availability of water. Rainfall is the predominant climatic variable that determines vegetation growth and density. Consequently, the variability of precipitation creates the worst drought hazards, degradation of vegetation, especially in arid and semi-arid climates, where slight departure from the mean may be the critical factor in vegetation and crop failure.

A consequence of high rainfall variability is perhaps the high degradation of vegetation and ecological deterioration facing desert regions, mainly in the western Rajasthan. Rainfall occurs mostly (90%) during the southwest monsoon season (from June to September). The average seasonal rainfall of Rajasthan is 494mm. However, the western Rajasthan average rainfall is less than (313mm) than the eastern Rajasthan (675mm). The variability of rainfall is more significant in the northwestern hyper-arid western arid and eastern semi-arid plains than in the Southeastern humid and sub-humid plains. The seasonal rainfall pattern is given in Figure 3.

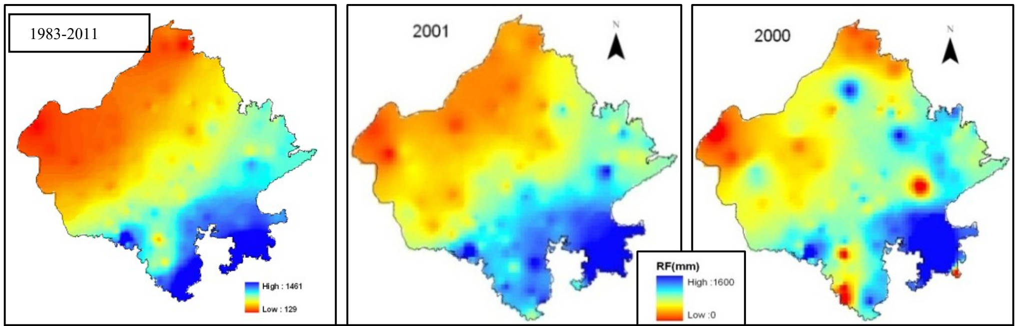
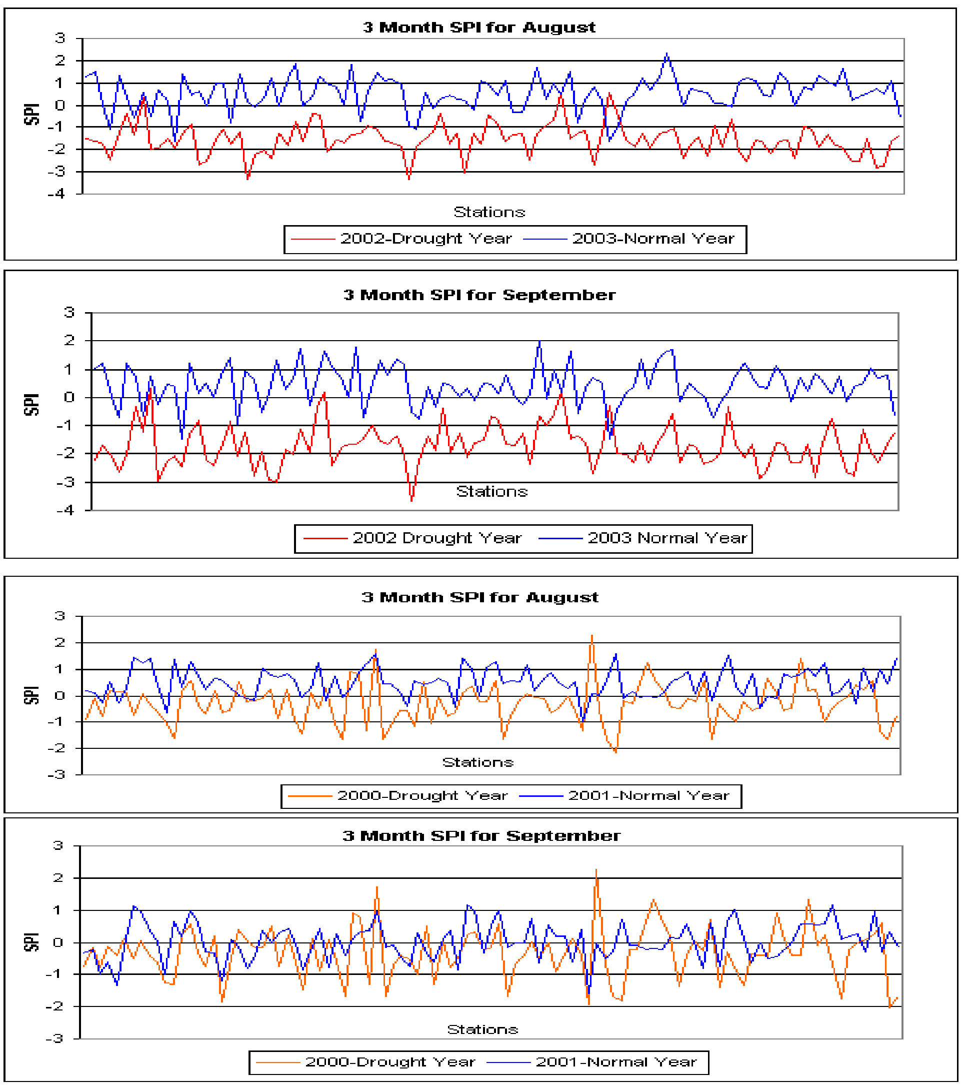


Figure 3Mean Rainfall Pattern and rainfall in 2001 & 2000

4.2 Rainfall Anomaly (SPI) and NDVI Anomaly Index during Drought and Normal Years

Drought can lead to desertification, or it often triggers clear signs of desertification. The SPI and NDVI anomaly index for the selected drought year of 2002 and the normal year of 2003 were presented to illustrate the pattern of rainfall anomaly and droughts. Figure 4 shows the temporal variability of 3-month SPI for August for the drought year of 2002 and the normal year of 2003

Figure 4: 3Month SPI for Drought and Normal Year



A higher negative SPI was noticed during the drought year of 2002 than the normal year of 2003. The SPI for the selected station is given in table-1. SPI results revealed that exceptional and extreme drought was noticed in the greater part of Rajasthan during the month of August and September in 2002. The exceptionally higher SPI values were reported at Bikaner (July, -3.13, August,-3.33) and Chirawa (September,-3.02).

Table 1: SPI for the month of July, August, and September in the 2002 drought year

Station	July	August	September	Station	July	August	September
Aklera	-2.77	-2.47	-2.65	Bhilwara	-2.16	-1.73	-2.08
Bakani	-1.38	-1.99	-2.97	Bikaner	-3.13	-3.33	-2.76
Bali	-1.5	-1.94	-2.27	Bilara	-2.64	-2.24	-2.04
Banswara	-0.9	-1.53	-2.06	Bundi	-1.38	-2.07	-2.92
Barisadar	-1.72	-1.95	-2.47	Chirawa	-1.55	-2.41	-3.02
Beawar	-2.27	-2.7	-2.22	Chohtan	-1.84	-1.79	-2.04
Begun	-2.15	-2.53	-2.41	Degana	-1.92	-2.11	-2.4

Drought has frequently been affecting the desert state of Rajasthan; however, drought-affected districts, villages, and people vary over the years. For example, according to the government report, in 2015, 19 districts, 14487 villages, and 194.87 lakh people were affected. In the history of Rajasthan, 2002 drought was worst affected, all 32 districts, 40990 villages, 447.80 lakh of people were also affected this drought was

widespread not only in Rajasthan but also Punjab, Haryana, Rajasthan, Uttar Pradesh, Madhya Pradesh, Chattisgarh, Uttaranchal, Karnataka, Andhra Pradesh and Tamil Nadu due to failure of southwest monsoon. Table 1 shows the SPI value for selected stations in Rajasthan, and Figure 5a&b depicts the spatial pattern of SPI for the drought (2002) and normal year (2003).

Figure 5a: 3 Month SPI for 2002-Drought Year

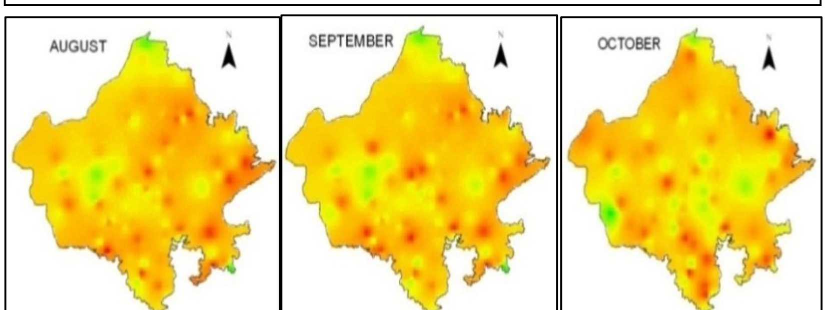
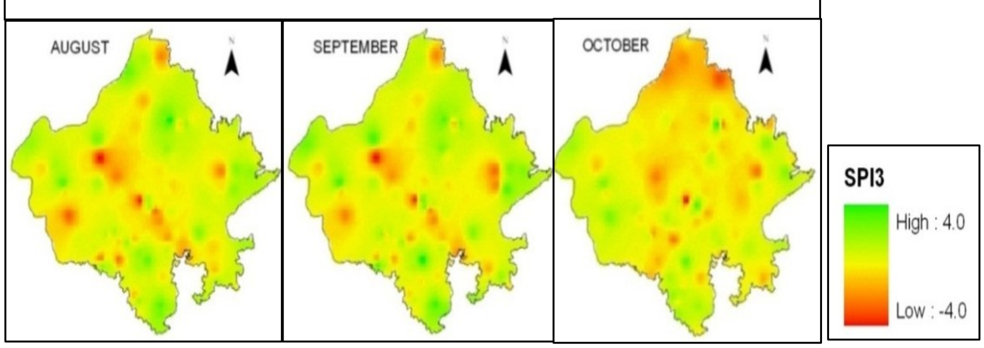


Figure 5b: 3 Month SPI for 2003-Normal Year



The spatial pattern of NDVI anomaly for the month of August, September, and October for the drought year 2002 and the normal year 2003 is given in Figure 6a&b. The spatial variability of rainfall or SPI is highly corresponding with NDVI and NDVI anomaly index variability. The negative NDVI anomaly is widespread in most of these areas during July, August, September, and October, significantly intensified in the western Rajasthan during thedrought year of

2002 than the average year 2003(Figure 6a&b). Spatial variability of NDVI revealed the declining trend of vegetation greenness and degradation of vegetation growth during drought year than normal monsoon year.

Figure 6a: NDVI Anomaly Index for 2002: Drought Year

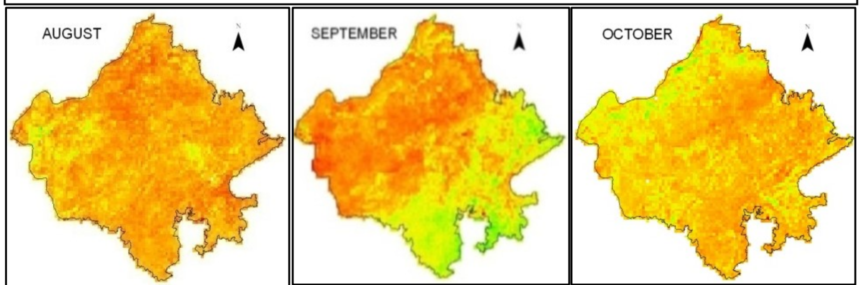


Figure 6b: NDVI anomaly index for -2003:Normal Year

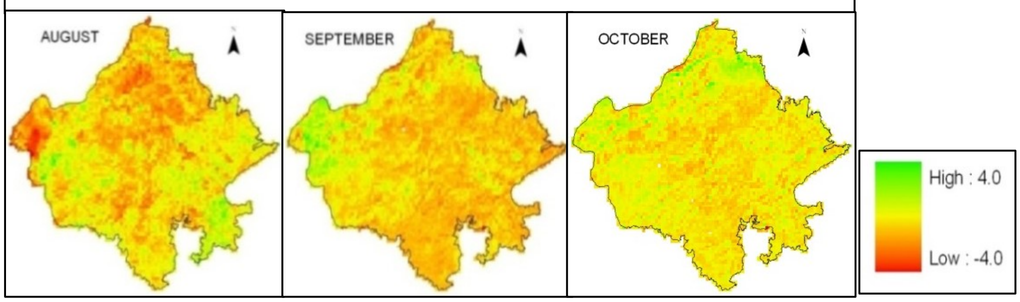


Figure 6a & b: NDVI Anomaly Index for 2002-Drought year 2003- Normal Year

B. NDVI Phenology

The average monthly NDVI phenology demonstrates the temporal pattern of monthly greenness variability over the years. It reveals during the pre-monsoon period, vegetation growth is less than monsoon, and vegetation degradation is in progress during drought years and vice-versa in normal monsoon years. Long-term monthly NDVI Phenology is given in Figure.7

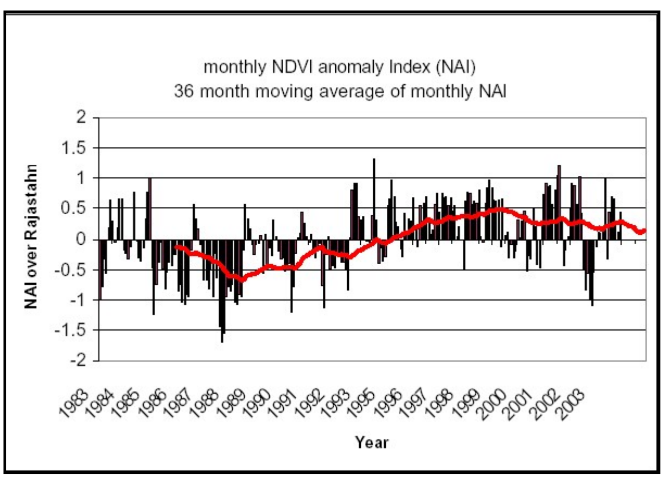
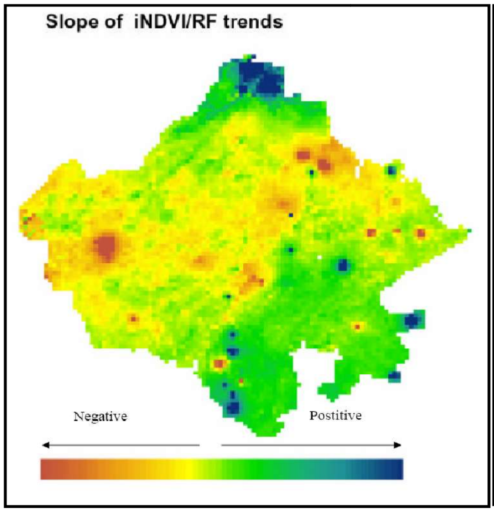


Figure7: NDVI Phenology

C.iNDVI/RF Ratio and Trends

The NDVI is considered as a 'greenness' index in studies of dryland vegetation cover. The NDVI has a close association with leaf area index, Greenleaf, and biomass (Nicholson et al., 1998). Time series of NDVI permit the monitoring of the dynamic nature of vegetation phonology. The trends were estimated by linear regression considering the ratio of iNDVI/RF as a dependent variable and time (years) as the independent variable. The regression slopes were recorded for each pixel level (Figure 8a). Each slope was mapped into five classes indicating strong or weak positive or negative and stable trends (Figure 8b). The regression procedure supplies a student t-te. This p-level was used as a criterion to define the class boundaries. The trends for the iNDVI/RF ratio may be labeled as 'strong' (if p-level more than 0.1 in one-tailed t-test), 'weak' (if the p-level is between 0.1 & 0.3), 'stable' up to 0.3. The long-term linear trends for each pixel in the iNDVI/RF ratio could be evaluated as the measure of possible degradation or improvement of the vegetation growth.



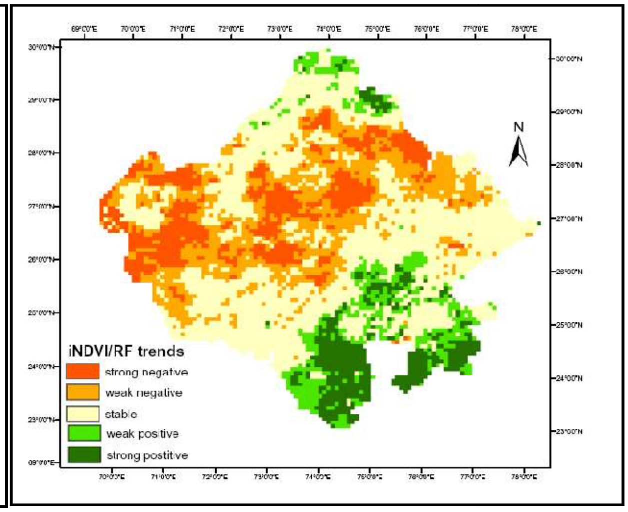


Figure 8a: Slope of iNDVI/RF trendsFigure 8b: iNDVI/RF trends

The NDVI integrals covering the entire growing season from June to October were computed in order to assess the seasonal vegetation growth. The net increase of biomass or net primary production is a measure of the production of the ecosystem, which has a direct relationship with photosynthesis, and NDVI is strongly correlated with both, particularly in arid lands. Houerou (1984) suggest the ratio of primary production to rainfalliNDVI /RF is a better parameter to characterize arid and semi-arid region like Rajasthan. The correlation between iNDVI (biomass) and rainfall was computed and reveal that the rainfall-iNDVI relationship is relatively strong (r =>0.5) in the hyper-arid and arid districts of Jaisalmer Bikaner, Churu, Barmer, and Jodhpur.

The net annual increase of biomass, or primary production, is a measure of the production of the desert ecosystem. The spatial pattern of the slope of iNDVI/RF trends is shown in Figure 8a. The map illustrates two categories of iNDVI/RF trends; a positive trend represents the progress of vegetation growth, and a negative trend indicates the degradation of vegetation. On the whole, about 37% of the area recorded a negative slope of NDVI trends which revealed the declining trend in vegetation. The districts of Jaisalmer, Jodhpur, Nagaur, Sikar, Bikaner, Churu, Jhunjhunun, and the northwestern part of Barmer seem to have been the most affected by land degradation. About 18% of the area was reported a positive NDVI trend which signifies the development in vegetation trend, while the remaining 45% of the area is characterized by a stable vegetation condition (Figure 8a&b). Out of 37% of the negative slope of NDVI time trend, about 15% of the area has a strong negative slope of NDVI, which indicates the highest possible degradation of the vegetation growth and ongoing desertification over two decades. About 22% of the area presented a weak negative change which illustrates the moderate vegetation degradation trend (Figs. 8&9). About 45% of the study area demonstrated relative stability. Only 9% showed a weak positive, and the remaining 9% illustrated strong positive trends which undergone an increasing trend of vegetation.

Figure 9a: iNDVI/RF Trends

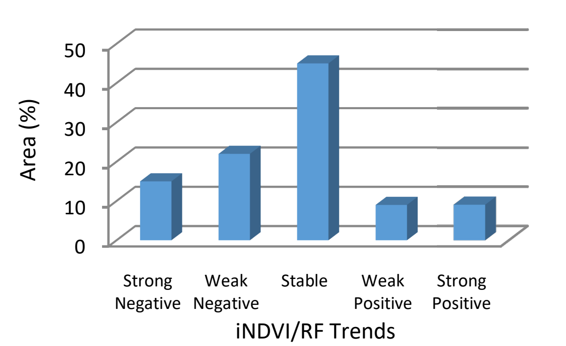
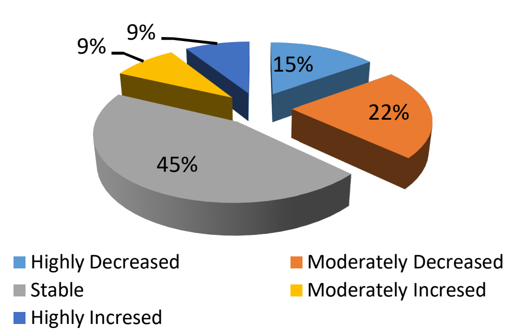


Figure 9b: Area wise distribution of NDVI time trend



V. CONCLUSION

In this study, the prime objectives are to analyze vegetation trends using long-term NDVI from AVHRR as a descriptor for desertification monitoring. The results revealed NOAA-

AVHRR NDVI products have great potential resources for monitoring vegetation, desertification, and drought. The study showed that the spatial and temporal patterns of NDVI are closely linked with precipitation, and there is a strong association between SPI and NDVI anomaly. The higher negative SPI and NDVI anomaly is widespread in most of these areas during drought years, particularly which intensified in the western Rajasthan. The exceptional drought was noticed in the greater part of Rajasthan during the month of July, August, and September in 2002. Consequently, SPI's exceptionally higher negative values were reported (i,e. Bikaner: July, -3.13, August,-3.33, and Chirawa: September-3.02). Spatial variability of NDVI revealed that the declining trend in vegetation greenness, degradation, and destruction of vegetation growth during drought Year than normal monsoon year. The correlation between iNDVI and rainfall revealed that the iNDVI and rainfall relationship is relatively strong in the hyper-arid and arid districts. The trends of integral NDVI/RF ratio results suggest that about 37 % of the study area has experienced decreasing vegetation growth trends, ongoing degradation, and desertification process. About 45% of the study area presented relative stability. Only 9% showed a weak, and the remaining 9% illustrated strong positive trends.

REFERENCES

[1] Edris, O.H.A., Dafalla, M.S., Ibrahim, M.M.M., Elhag, A.M.H, (2013). 'Desertification monitoring and assessment in Al-Butana area, Sudan, using Remote Sensing and GIS Techniques,' International Journal of Science & Technology, Research Volume 2,(3), pp181-184.

[2] Elhag, A.M.H, Abubaker, H., Mohamed, A. and Almaleeh. R, Elsheikh, (2014), 'Desertification assessment using Remote Sensing, GIS, and other techniques. Case study: Wadi Al Kanger', Sudan, Journal of Nat. Resour. &Environ.Stu., 2.3,(10) pp1-6.

[3] Fuller, D.O., (1998), 'Trends in NDVI time series and their relation to rangeland and crop production in Senegal: 1987-1993', International Journal of Remote Sensing, 19, (10), pp2013-2018.

[4] Guishan, C., Woo-Kyun L., et al. (2011). 'Desertification monitoring by LANDSAT TM satellite imagery,' Forest Science and Technology,7,(3), pp110-116.

[5] Guttman, N.B., (1998), 'Comparing the Palmer Drought Severity Index and Standardized Precipitation Index,' Journal of the American Water Resources Association, 34, pp113-121.

[6] Hanan, N.P., Prince, S.D., and Hiernaux, P.H.Y., (1991). 'Spectral modeling of multicomponent landscapes in the Sahel', International Journal of Remote Sensing, 12, pp1243-1258.

[7] Herrmann, S.M. Anyamba, A., and Tucker, C.J., (2005), 'Recent trends in vegetation dynamics in the African Sahel and their relationship to climate.' Glob. Environ. Change, 15, pp394–404.

[8] Heumann, B.W., Seaquist, J., Eklundh, L. and Jönsson, P., (2007), 'AVHRR derived phenological change in the Sahel and Soudan, Africa, 1982–2005'. Remote Sens. Environ, 108, pp385–392.

[9] Hielkema et al.,(1986), 'Rainfall and Vegetation monitoring in the Savana zone of the democratic –the republic of Sudan using the NOAA advance very high-resolution radiometer,' International Journal of Remote Sensing, 7, pp1499-1513.

[10] Karrar, G. and Stiles D., (1984), 'The global status and trends in desertification.' Journal of Arid Environment 7, pp309–312.

[11] Kundu, A. & Patel, N. R., Saha, S. K. and Dutta, D.,(2014), 'Monitoring the extent of desertification processes in western Rajasthan (India) using geo-information science,' Arab J Geosci, DOI 10.1007/s12517-014-1645-y.

[12] Kundu, A., and Dutta, D., (2011), 'Monitoring desertification risk through climate change and human interference using Remote sensing and GIS techniques,' International Journal of Geometrics and Geosciences, 2(1), pp21-33.

[13] Li B., Tao, S. and Dawson R. W., (2002). 'Relation between AVHRR NDVI and eco-climatic parameters in China,' International Journal of Remote Sensing, 23, pp989-999.

[14] Li CUI., (2008), 'Research on Monitoring the Changes of Desertification based on Remote Sensing,' The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVII. Part B7. Beijing.

[15] Li HQ., (2004), 'The desertification research process,' World Forest Res. (17) pp11–14

[16] Li J., Lewis J., Rowland J., Tappan G. and Tieszen, L., (2004). 'Evaluation of land performance in Senegal using multi-temporal NDVI and rainfall series,' Journal of Arid Environments, 59, pp463-480.

[17] Liu Qingsheng, Liu Gaohuan, Huang Chong,(2018), 'Monitoring desertification processes in Mongolian Plateau using MODIS tasseled cap transformation and TGSI time series,' Journal of Arid Land, (1), pp12-26.

[18] Martiny, N., Chamberlin, P., Richard, Y. and Philipp on, N., (2006), 'Compared regimes of NDVI and rainfall in semi-arid regions of Africa.' Int. J. Remote Sens., (27), pp5201–5223.

[19] Nicholson, S. E., Tucker, C. J., and Bai, M. B., (1998). 'Desertification, drought, and surface vegetation: an example from the West African Sahel,' Bulletin of the American Meteorological Society, (79), pp1-15.

[20] Othman, A.A., AI-Saady, YI, AI-Khafaji, AK, Gloauen, R., (2014), 'Environmental change detection in the central part of Iraq using remote sensing data and GIS,' Arab J. Geosci. 7, pp1017-1028.

[21] Piao, S. Fang, J. Liu, H. Zhu, B., (2005), 'NDVI-indicated decline in desertification in China in the past two decades. Geophys. Res. Lett., (32), doi:10.1029/2004GL021764.

[22] Seiler Kogan et al., (2006), 'Seasonal and inter-annual responses of the vegetation and production of crops in Cordoba-Argentina assessed by AVHRR derived vegetation indices,' Advances in Space Research, (39), pp89-94.

[23] Sinha, R. K., Bhatia, S., and Vishnoi, R., (2000). 'Desertification control and rangeland management in the Thar desert of India,' Indira Gandhi Centre for Human Ecology, Environment, and Population Studies,' Rajasthan University, Jaipur, 302004 (INDIA).

[24] Symeonakis, E., Drake, N., (2004), 'Monitoring desertification and land degradation over sub-Saharan Africa', Int. J. Remote Sens. (25), pp573–592.

[25] Thinkable, P. S. and M. S. D. N. Gamage., (2004), 'The Use of Remote Sensing Data for Drought Assessment and Monitoring in Southwest Asia,' Colombo, Sri Lanka, International Water Management Institute: pp 123.

[26] Thomas, P. Higginbottom, and Elias Symeonakis, (2014). 'Assessing Land Degradation and Desertification Using Vegetation Index Data: Current Frameworks and Future Directions,' Remote Sens., (6), pp9552-9575.

[27] Tucker, C. J., Townshend, J. R. G. and Goff, T. E., (1985), 'African land cover classification using satellite data,' Science, 227, pp369–375.

[28] UNCCD, (1994) 'Status of ratification and entry into force,' United Nations Convention to Combat Desertification, Paris.

[29] UNCED, (1992), 'Earth Summit Agenda 21: Programme of Action for Sustainable Development', United Nations Department of Public Information.

[30] UNEP, (1992), 'Status of Desertification and Implementation of the United Nations Plan of Action to Combat Desertification.' Report of the Executive Director, Nairobi: United Nations Environment Programme.

[31] Wessels, K.J., van den Bergh, F. and Scholes, R.J., (2012), 'Limits to detectability of land degradation by trend analysis of vegetation index data. Remote Sens. Environ. 125, pp10-22.