SPATIO-TEMPORAL MAPPING OF THARPARKAR DROUGHT USING HIGH RESOLUTION SATELLITE REMOTE SENSING DATA

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ABSTRACT: *Increasing temperature and altered precipitation patterns are indications to the utmost weather events like Drought which severely affects the agricultural production. As the Pakistan's agriculture is largely dependent on the Monsoon, a slight change in it affects the production as well as the crop yield drastically. The agricultural drought monitoring, assessment as well as management can be done more accurately with the help of geospatial techniques like Remote Sensing. The purpose of the study is to analyze the vegetation stress in the Tharparkar district with the calculation of NDVI values. The MODIS data is used for the calculation of NDVI for the period of 2009-2013 with the temporal resolution of sixteen days. From 2009-2013, the general trend of NDVI is negative in the pre monsoon and post monsoon over the whole region of Tharparkar. The decay in the areal coverage of vegetation was observed form 2012 and abrupt change was observed in 2013 that leads to the drought condition. The NDVI normalized difference vegetation index provides very useful information for agricultural drought monitoring and early warning system for the farmers.*

INTRODUCTION

Drought is the result of climate variations that occur in massive geographic extent irrespective of any specific boundary. Drought causes food security threat more than any other natural disaster. Drought prediction concerning about the happening, extent, duration and its magnitude is great challenge as related to other disasters like flood, landslides and cyclonic storms [1]. On the basis of environmental aspects it disrupts, droughts are classified into meteorological, agricultural, hydrological and socioeconomic [2-4].

Meteorological drought concern about the decrease in rainfall, whereas the agricultural drought is the consequence of water scarcity, shortage of required water for plant development. Hydrological drought is associated with the deficiency of surface and subsurface water supply. Lastly, socioeconomic drought refers to insufficient supply to fulfil the necessities of various economic good with the above three types of drought like food scarcity. Meteorological drought is more frequently occurred than other droughts and it usually causes other kind of droughts to happen i.e. agricultural, hydrological, and socioeconomic drought [5].

Drought indices proved to be very useful for the efficient monitoring of drought estimated from station-based meteorological data. The Palmer Drought Severity Index (PDSI), Palmer Moisture Anomaly Index (z-index) [6], deciles [7], and the Standardized Precipitation Index (SPI) [8] drought indices that incorporate the percent of average precipitation to assess the drought.

Station-based drought indices can efficiently observe the drought conditions just around area under influence of meteorological station, but lacks in the continuous spatial analysis as well as limits the ability to capture the local scale variation and detail spatial pattern of drought variability, especially in area where less of number of meteorological stations are present and high spatial variability exists.

To overcome this problem modern remote sensing technology can be used which provides very powerful and effective monitoring of natural phenomenon [9-10]. Remote sensing community states drought as a period of remarkably low rainfall that changes the vegetation situations [11-12]. As related to in situ indices, drought indices extracted from remote sensing data are more suitable for spatial drought situations monitoring. Among many remote sensing techniques based drought indices, the normalized difference vegetation index (NDVI) based vegetation condition index [13-14] and land surface temperature (LST) based temperature condition index [14] are two effective tools for observing the extent, length and effect of drought on local or large scale [15]. Previously researchers have found that NDVI is suitable for monitoring large scale drought effect on vegetation, along with agricultural drought and food scarcity, and NDVI has a strong correlation with the crop yield [16-18].

Pakistan, with maximum of its land area categorized into arid and semi-arid is enormously vulnerable to the permanent threat of drought. The total land mass of Pakistan is 79.6 mha, out of which 70 mha is arid to semi-arid which is about 88% of its total geographical area [19]. The 41mha land mass of Pakistan is categorized as arid area, out of which 11 mha comes under main deserts where climate is hyper arid [20]. The major deserts (Thar, Thal, Cholistan, and Chagi-Kharan) of Pakistan being categorized as hyper arid are permanently vulnerable to drought. Only 9% of Pakistan collects more than 50 cm of rain per year, 22 % receives between 20 to 50 cm and the remaining 69% receives less than 25 cm. Rainfalls mainly happen in the monsoon months of July, August and September which is 70 to 80% of the total rainfall of Pakistan [21]. In all season particular regions of the country are very dry and constantly suffer from drought. If following seasons do not get adequate rainfall, therefore lack of rainfall causes drought conditions emerge in these areas and gaining severity. So that drought has become a recurrent phenomenon in Pakistan particularly, in Sindh due to a growth in pollution and climatic changes. According to the report issued by the Economic Survey of Pakistan, the drought is one of the factors accountable for poor growth performance in the country. People have sufficient knowledge of historic drought patterns but now they are unaware of the recent dynamics and are unable to understand the reason for latest drought that affected more by the fluctuations in the pattern of climate. As stated by a Tharri person, ‘’such rainfall is of no use to us. If there is less rain there is a drought, and more rain also means more drought, because unusual rainfall affects the grass, and the livestock, the crops become sick and that leads to drought.”

The objective of this study was (1) to map spatio-temporal variation in vegetation of Tharparkar using remote sensing data and (2) to perform statistical analysis for drought variations.

MATERIALS AND METHODS

Study Area

The study area for this research was Tharparkar District, which spread over 22,000 square kilometers with a population of about 1.5 million residing in 2,300 villages and urban settlements. Divided into six talukas that are Mithi, Islamkot, Chachro, Dihly, Diplo and Nagarparkar, the area often receives unpredictable levels of rainfall or none at all.

The area is categorized as arid climate, scant vegetation and unmanageable poverty. Precipitation is inadequate, water table is too low to pull buckets through human effort and require camels to pull water. Rain-fed agriculture is the main cause of livelihood which is often affected by drought, and on livestock rearing for their livelihood.

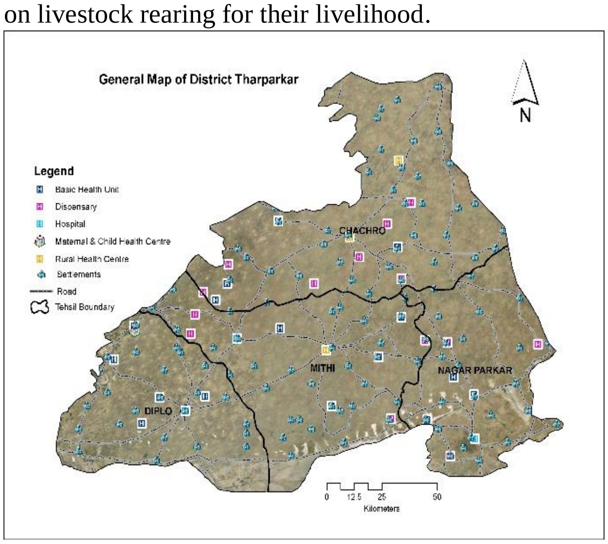

Figure 1: Location map of study area: the Lahore.

Population Estimation Using LandScan

The government has not conducted a proper census after 1998 even though the population can be predicted form the readily available and correct data on spatial population distribution by LandScan [22] as shown in figure 2.

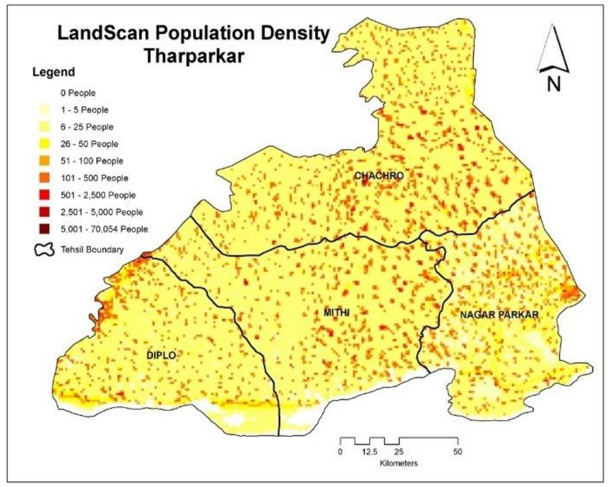

Figure 2. Map of spatial population distribution estimated by LandScan satellite.

Satellite Data

The detail methodology of the research work is illustrated in figure 3. In this research total 115 MODIS (Moderate Resolution Imaging Spectro-radiometer) satellite images were acquired. MOD09A1v5 and MOD13Q1v5 from 2009 to 2013 were used with sixteen days temporal resolution. These MODIS satellite images constructed from the red and near infrared channels with spectral windows of 645-nanometers and 858-nanometers respectively with 250m spatial resolution.

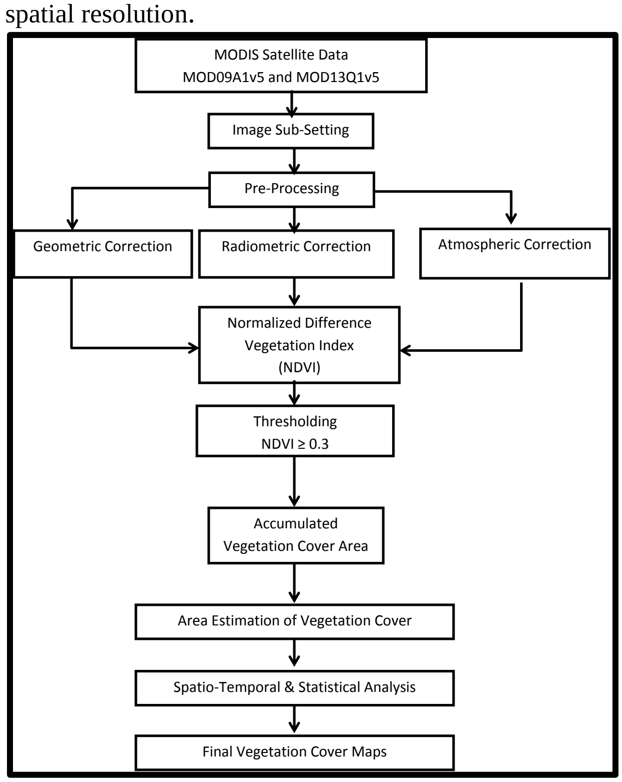

Figure 3. Flow chart of research methodology.

Pre-Processing

Image pre-processing techniques were applied like Geometric correction (to remove the distortions due to errors in the satellite’s positioning on its orbit), Atmospheric correction (to removing the effects of the atmosphere on the reflectance values of images taken by satellite) and radiometric corrections (to avoid radiometric errors or distortions, making it possible to discriminate between objects and to detect real changes in Earth processes). These Imageries were first analyzed then pre-processing techniques were was applied on the required imageries. Cloud removal algorithm was not applied as there was no cloud problem present in MODIS products MOD09A1v5 and MOD13Q1v5.

Normalized Difference Vegetation Index (NDVI)

This index was developed [23] for the estimation of physiological variables of vegetation. Liang used NDVI to monitor the spatial dynamics of greenness i.e. vegetation [24]. In this study NDVI was used to efficiently extract the vegetation cover of Tharparkar district. Radiance measured in Near Infrared Band R_NIR (0.78–0.90 µm TM/ETM+ and 0.72–1.1 µm AVHRR) and Red band R_R (0.63–0.69 µm TM/ETM+ and 0.58–0.68 µm AVHRR) wavelengths were used to calculate the Normalized Difference Vegetation Index (NDVI).

$$\text{NDVI} = \frac{R_{\text{NIR}} - R_{\text{R}}}{R_{\text{NIR}} + R_{\text{R}}}$$

NDVI gives the range of values from -1 to 1. Gutman and Ignatov suggested NDVI values of greater than equal to 0.2 [25], while Hatfield et al. suggested the NDVI values of greater than equal to 0.3 will be used to increase the confidence level about the vegetation mapping [26]. In this research, the NDVI value greater than equal to 0.3 was used as a threshold level to increase the confidence level up to 95%.

Area Estimation of Vegetation Cover

After NDVI generation the area of vegetation cover was estimated by multiplying the number of pixels with the area of one pixel. The area of each year with eight days interval was estimated using S-Plus statistical software and that areal coverage values were plotted using SigmaPlot 12.3 software.

RESULTS AND DISCUSSION

Drought has become a recurrent phenomenon in Pakistan due to high pollution and climatic changes and its variability. Tharparkar, with a population of just 1.5 million people, has been hit hard by droughts every two or three years. Since 1968, the area has been officially stated for a natural disaster affected area by drought about 15 times started from 1968, then in 1978, 1985, 1986, 1987, 1995, 1996, 1999, 2001, 2004, 2005, 2007 and as latest in 2014.

The drought of 1998-2002 was considered worst in history of Pakistan. In Sindh, 127 people died, mostly in the Tharparkar region, as a consequence of extreme water scarcity and dehydration. The precipitation during these durations over Pakistan was much less than the average and extremely below average in Tharparkar district even some of the areas didn’t get rain at all.

The most recent official announcement of uttermost drought came forth in 2013 and 2014. To examine the drought trend normalized difference vegetation index NDVI was calculated using the MODIS products MODIS MOD09A1v5 and MOD13Q1v5 with the sixteen days interval for the years ranges from 2009 to 2013. The sixteen day composite maps of NDVI were generated for the years 2009, 2010, 2011, 2012 and 2013 with the temporal resolution of sixteen days shown in Annex A, B, C, D and E respectively.

Maps showing the decrease in vegetation cover in whole Tharparkar district from year 2009 to 2013, significant change was observed in November 2013. The main reason of Thar influenced by devastating drought was precipitation. During monsoon 2013, Tharparkar district received 30% less than average rainfall. Local variations ranged from only 6% deficit in Chhor to 54% less in Mitthi. From March 2013 to February 2014, a significant 31% less rainfall was received in Mithi, which recorded 189 mm of rainfall against normal of 277.2 mm. The worst affected towns of Diplo, Chachro and Mithi were hardly received a drop of water for months and vegetation for their survival and livelihood.

There is no stream of fresh water in the region. However, in Nagarparkar there are two perennial springs, namely Anchlesar and Sardhro. as well as temporary streams called Bhatuyani River and Gordhro River which flow during the rainy season. In 2013, Nagarparkar taluka received plentiful rain. Due to presence of streams and plentiful rainfall, Nagarparkar affected less as shown maps. The Crops have been cultivated in over 336,000 acres and are adequate to adequate to sustain an average tehsil population of about 212,000.

For the period 2009-2013, the overall trend of NDVI was negative in the pre monsoon and post monsoon over the whole region of Tharparkar. The difference in areal coverage of vegetation in square Kilometers from years 2009 to 2013 is shown in figure 4. The setback in areal coverage of vegetation was observed for all months except in start of August and for the whole month of September gain was noticed. The cumulative difference in vegetation from 2009 to 2013 is not very meaningful in this highly dynamic environment where considerable seasonal fluctuations around the normal. Pakistan Meteorological Department specified that the current disaster in early 2014 may be called as “socio-economic disaster” rather than simply drought because seasonal and annual rainfall was moderately below to climatic averages. As far as food uncertainty is concerned, the whole Thar region is agro-based and nearly entirely rain-fed that means agriculture will be affected if there is no or untimely rainfall.

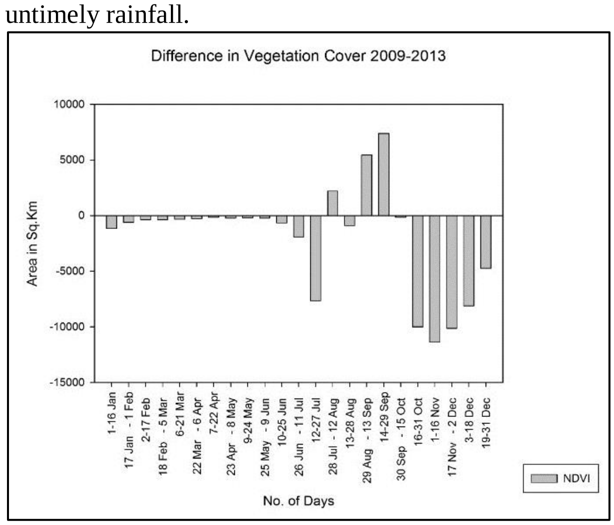

Figure 4. Difference in areal coverage of vegetation from 2009 to 2013.

The results of NDVI reflected the onset, duration, extent and severity of drought shown in figure 5. For the years 2009 to 2012, on the onset dated 26th June to 11th July the NDVI trend was same but the change observed in NDVI value with the rise in value with the passage of time. Prominent shift was observed in the start of August during the years 2011 and 2012 but following the same trend as in 2009 and 2010. The maximum area under vegetation observed was nearly about 20,000 Sq. Km. for years 2009 to 2012 in start of September to end of August but the year 2013 depicted condition changed from normal, anomaly was perceived with the decline in vegetation when the area coverage was high for other years under consideration during the time span of 14th to 29th of September shown in figure 5. The decay in vegetation was observed form 2012 and abrupt change was detected in 2013 that leads to the drought condition. This was mainly because of shifting of monsoon season from historic patterns i.e. from July-August to August-October. The frequency and intensity of the rainfall has also been altered. According to Pakistan Metrological Department, monsoon rainfall between the months of June and September is the main source of water for Tharparkar district in which 87% of annual precipitation was observed. A rainfall deficit of roughly 30 percent between March 2013 and February 2014 in Tharparkar, alarmingly no significant precipitation, has been recorded in Tharparkar district since November 2013.

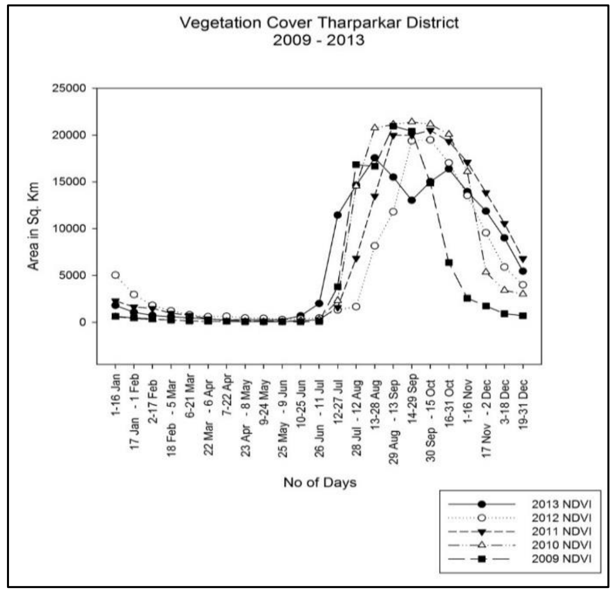

Figure 5. Areal estimation of vegetation for the period 2009 to 2013 in Tharparkar district.

CONCLUSION

By acquiring drought information in time, through the use of advanced and latest tools, it is possible to lessen damages and increase the crop production. Although period, intensity and spatial extent determine the severity of drought, it will also depend upon water demand of specific region vegetation. In short due to its complex nature, it is very difficult to quantify the impact of drought in social, economic or environmental context. This is a great challenge to scientists involved in climate assessment and the proper monitoring of the vegetation trend. Remote sensing techniques proved to be very effective to forecast the drought condition by the analyzing the crop production with high spatial and temporal variations. So that it would be more helpful for Pakistan Government in making National Drought Policies that move towards a strategy to alleviate the effects of drought, increase public awareness and coordination for better response to drought.

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REFERENCES

[1.] Kogan, F. N. Global drought watch from space. *Bulletin of the American Meteorological Society*, **78**: 621–636 (1997).

[2.] American Meteorological Society. AMS statement on meteorological drought. *Bulletin of the American Meteorological Society*, **85**: 771–773 (2004).

[3.] Peters E, Torfs P, van Lanen H, Bier G. Propagation of drought through groundwater—a new approach using linear reservoir theory. Hydrol Process.;**17**(15):3023-3040 (2003).

[4.] Wilhite D. *Drought And Water Crises*. Boca Raton: Taylor & Francis; (2005).

[5.] WMO. Drought monitoring and early warning: Concepts, progress and future challenges. *World Meteorological Organization, Report WMO-No. 100692-63-11006-9*, **24**(2006).

[6.] Palmer, W. C. Meteorological drought. Research Paper No. 45. Washington, D.C.: U.S. Department of Commerce Weather Bureau; (1965).

[7.] Gibbs, W. J., & Maher, J. V. Rainfall deciles as drought indicators. Australian Bureau of Meteorology Bulletin, **48**: 37 (1967).

[8.] McKee, T. B., Doesken, N. J., & Kliest, J. The relationship of drought frequency and duration to time scales. *Proceedings of the 8th Conference on Applied Climatology Anaheim, CA: American Meteorological Society Boston*, 179–184 (1993).

[9.] Mahboob M, Iqbal J, Atif I. Modeling and Simulation of Glacier Avalanche: A Case Study of Gayari Sector Glaciers Hazards Assessment. *IEEE Trans Geosci Remote Sensing*, **53**(11):5824-5834 (2015).

[10.] Mahboob M, Atif I, Iqbal J. Remote Sensing and GIS Applications for Assessment of Urban Sprawl in Karachi, Pakistan. *Science, Technology and Development*, **34**(3):179-188 (2015).

[11.] Heim, R. R., Jr. A review of twentieth century drought indices used in the United States. *Bulletin of the American Meteorological Society*, **83**, 1149–1165 (2002).

[12.] Maselli F. Monitoring forest conditions in a protected Mediterranean coastal area by the analysis of multiyear NDVI data. *Remote Sensing of Environment*, **89**(4):423-433 (2004).

[13.] Kogan, F. N. Drought of the late 1980s in the United States as derived from NOAA polar-orbiting satellite data. *Bulletin of the American Meteorological Society*, **76**, 655–668 (1995)

[14.] Kogan, F. N. Application of vegetation index and brightness temperature for drought detection. *Advanced Space Research*, **15**, 91–100 (1995)

[15.] Singh R, Roy S, Kogan F. Vegetation and temperature condition indices from NOAA AVHRR data for drought monitoring over India. *International Journal of Remote Sensing*, **24**(22):4393-4402 (2003).

[16.] Liu, W. T., & Kogan, F. N. Monitoring regional drought using the vegetation condition index. *International Journal of Remote Sensing*, **17**(14), 2761-2782 (1996).

[17.] Unganai, L. S., & Kogan, F. N. Drought monitoring and corn yield estimation in Southern Africa from AVHRR data. *Remote Sensing of Environment*, **63**(3), 219-232 (1998).

[18.] Salazar, L., Kogan, F., & Roytman, L. Use of remote sensing data for estimation of winter wheat yield in the United States. *International journal of remote sensing*, **28**(17), 3795-3811 (2007).

[19.] Anjum, S. A., et al. An assessment to vulnerability, extent, characteristics and severity of drought hazard in Pakistan. *Pakistan Journal of Science***64**.2 (2012).

[20.] Qureshi A, Akhtar M. *Analysis Of Drought-Coping Strategies In Baluchistan And Sindh Provinces Of Pakistan*. Colombo, Sri Lanka: International Water Management Institute; (2004).

[21.] Bendix J, et al. e. A case study on rainfall dynamics during El Niño/La Niña 1997/99 in Ecuador and surrounding areas as inferred from GOES-8 and TRMM-PR observations. *Erdkunde*, **57**(2):81-93 (2003).

[22.] Dobson, J. E., Bright, E. A., Coleman, P. R., Durfee, R. C., & Worley, B. A. LandScan: a global population database for estimating populations at risk. *Photogrammetric engineering and remote sensing*, **66**(7), 849-857 (2000).

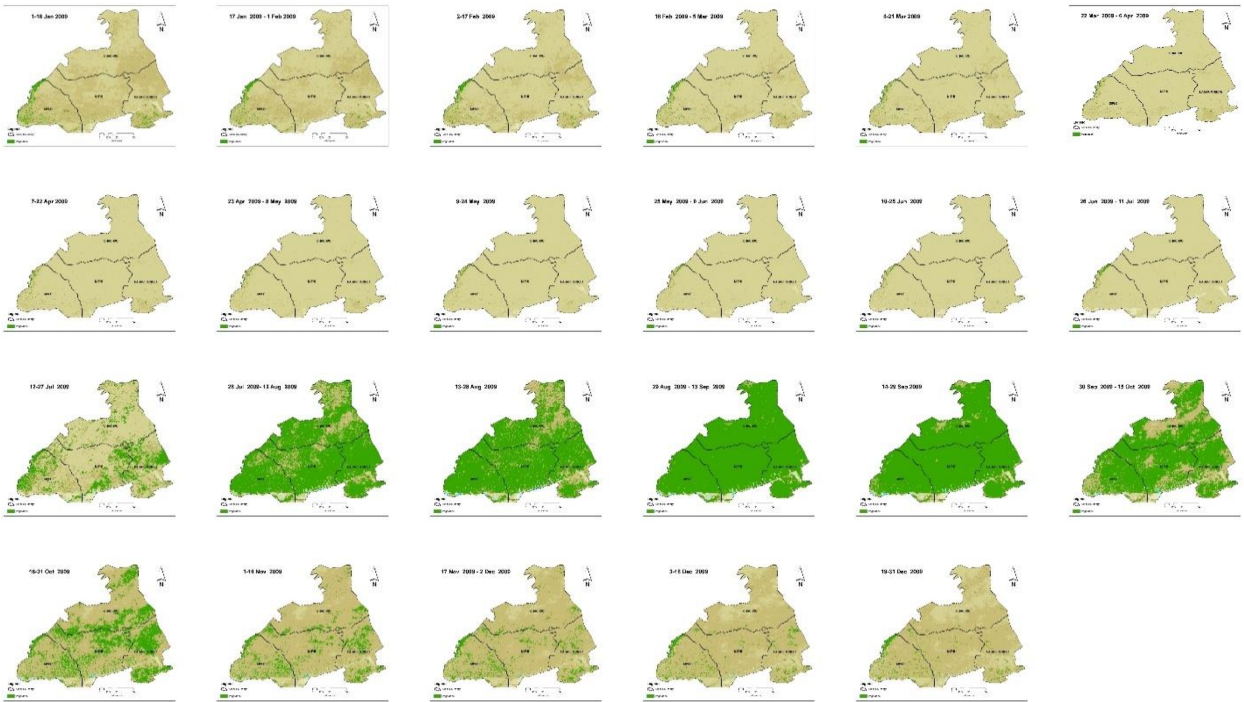
[23.] Rouse, J.W., Haas, R.H., Schell, J.A., & Deering, D.W. Monitoring vegetation systems in the Great Plains with *ERTS Third ERTS Symposium, NASA* SP-351 NASA, Washington, DC, **1**, 309–317 (1973).

[24.] Liang, S.L. Quantitative remote sensing of land surfaces John Wiley & Sons, Inc., Hoboken, New Jersey. (2004).

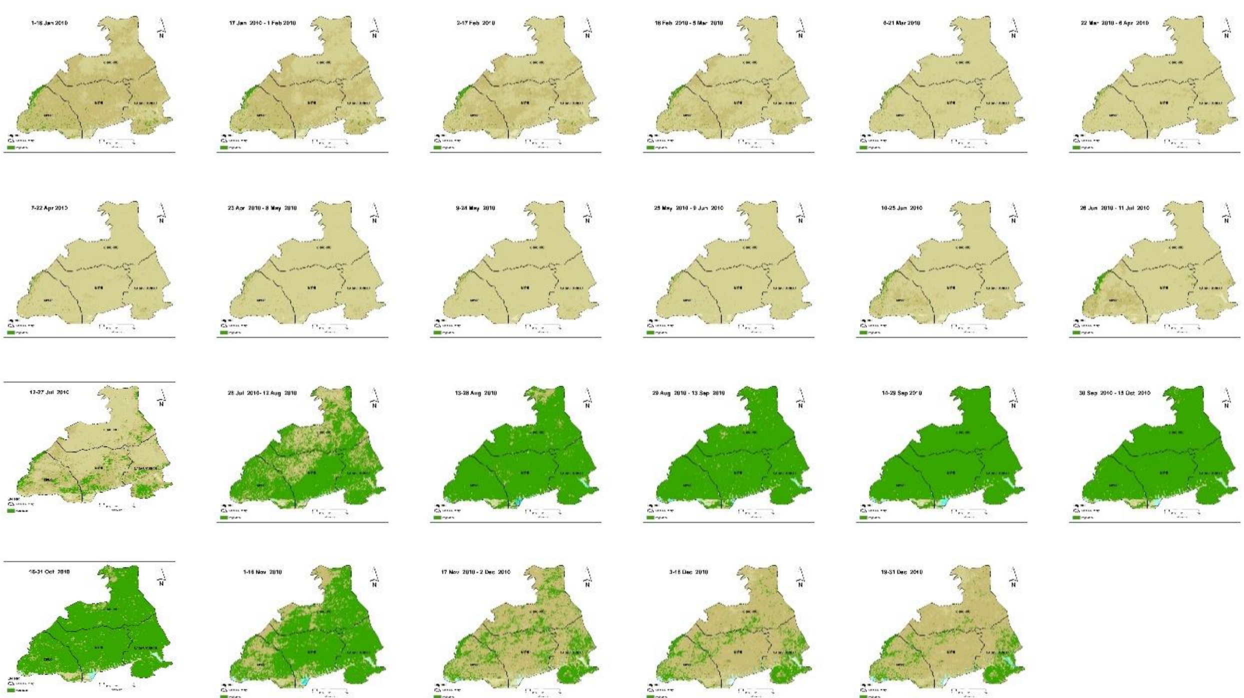
[25.] Gutman, G., & Ignatov, A. The derivation of the green vegetation fraction from NOAA/AVHRR data for use in numerical weather prediction models. *International Journal of remote sensing*, **19**(8), 1533-1543 (1998).

[26.] Hatfield, J. L., Gitelson, A. A., Schepers, J. S., & Walthall, C. L. Application of spectral remote sensing for agronomic decisions. *Agronomy Journal*, **100** S-117 (2008).

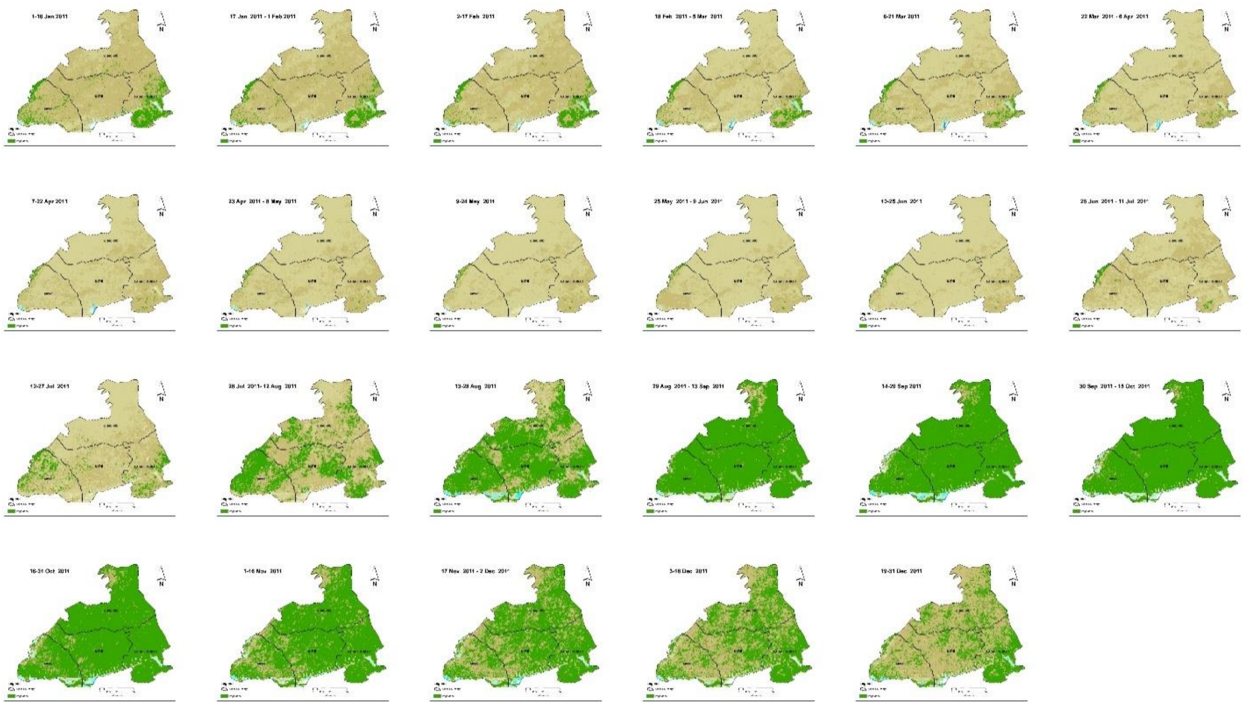
ANNEX-A: SPATIO-TEMPORAL MAPPING OF NDVI IN THARPARKAR FOR THE YEAR 2009.



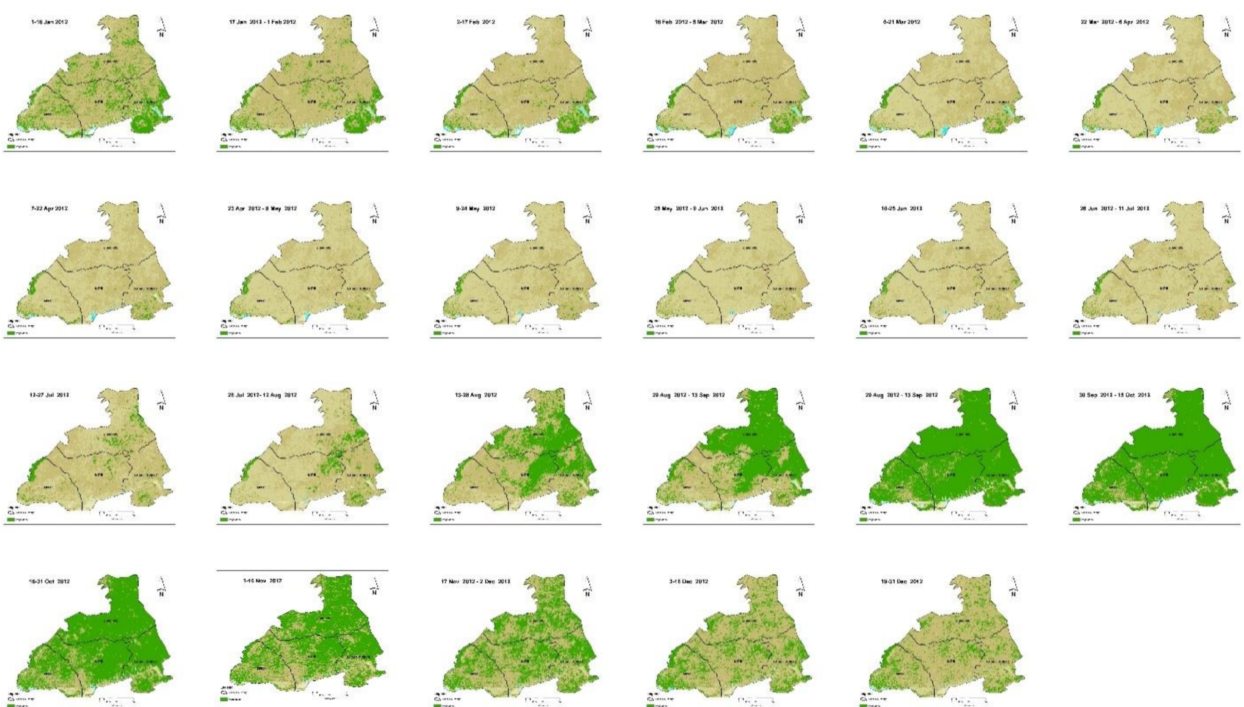
ANNEX-B: SPATIO-TEMPORAL MAPPING OF NDVI IN THARPARKAR FOR THE YEAR 2010.



ANNEX-C: SPATIO-TEMPORAL MAPPING OF NDVI IN THARPARKAR FOR THE YEAR 2011.



ANNEX-D: SPATIO-TEMPORAL MAPPING OF NDVI IN THARPARKAR FOR THE YEAR 2012.



ANNEX-E: SPATIO-TEMPORAL MAPPING OF NDVI IN THARPARKAR FOR THE YEAR 2013.