Analysis of the agriculture drought severity and spatial extent using Vegetation Health Index (VHI) in Manganga watershed of Maharashtra, India

Article *in* Disaster Advances · February 2021

Abhijit S. Patil
Shivaji University, Kolhapur

Akshay Patil
Kingston University

Sachin Shantaram Panhalkar
Shivaji University, Kolhapur

Analysis of the agriculture drought severity and spatial extent using Vegetation Health Index (VHI) in Manganga watershed of Maharashtra, India

Patil Abhijit S.*, Patil Akshay A., Patil Somnath P., Saundade Sushant D., Chugule Kusum A., Katavare Shital B. and Panhalkar Sachin S.
Department of Geography, Shivaji University, Kolhapur, Maharashtra, INDIA
*abhijit.patil8893@gmail.com

Abstract
Drought is a major environmental problem that causes severe losses in agricultural production, water supplies, livestock and ultimately, the environment as a whole. The monitoring of drought is essential to prevent and mitigate the effects of drought. Drought assessment using remote sensing-based indices of drought has been widely conducted for monitoring droughts. The main objective of this study is to analyze the intensity of agricultural drought and its spatial extent using the VHI that includes NDVI, VCI, LST and TCI in the Manganga watershed.

According to the results, mild and moderate drought types are observed throughout the study area's agricultural fields except for the adjacent area along the river. The analysis also indicates that the relationship between NDVI-LST and LST-VHI is negative while the relationship between NDVI-VHI is positive.

Keywords: NDVI, LST, TCI, VCI, VHI, Manganga Watershed.

Introduction
Drought is a prolonged occurrence of an abnormally dry period and inadequate rainfall to satisfy usual requirements resulting in massive damage to human beings, agriculture, livestock and decreased yields.[1,9,29] Drought is one of the hydro-meteorological disasters most frequent in many parts of India, which leads to an enormous threat to the national economy and agricultural development. It is a major environmental threat that causes significant losses in crop production, water supply and livestock.[23] The most vulnerable shock is realized in dry areas, where the rainfall pattern is highly variable.[18] In India, the geographical area of 28 percent is vulnerable to mild to extreme drought.[25]

Managing drought is also a big problem and dealing with this natural phenomenon requires extensive water resource and agricultural management. Therefore, the monitoring of drought is essential to prevent and mitigate the effects of drought events. The drought can be easily monitored by the use of remote sensing equipment over large areas. The remote sensing data acquired by satellite provides a synoptic view of the earth's surface and can be used to assess drought spatially.[7] The monitoring of drought can be assessed using remote sensing drought indices which include duration, intensity, severity and spatial extent.[19] Several vegetative drought indices have been implemented based on remote sensing data. Vegetation Health Index (VHI)[13,16] revealed the higher potential and showed better suitability for detecting drought.[3,6]

VHI considers the vegetation condition index (VCI) and the temperature condition index (TCI) within one observation period. Thus, VHI evaluates the drought in the vegetation affected by temperature.[3,12] The VHI has also been widely used for agricultural purposes such as predicting crop yields.[4,14,24] The prime objective of this study is to analyze the intensity of agricultural drought and its spatial extent using the VHI that includes NDVI, VCI, LST and TCI in the Manganga watershed of Maharashtra, India. The temporal analysis of drought is conducted as per the availability of relatively clear Landsat satellite data of the study area.

Study Area
Maharashtra is one of the most well-developed and industrialized Indian States. It is the third-largest State with a total area of 307713 sq. km, with a population of 112.3 million.[22] The region in which drought frequently occurs is the Manganga watershed in Maharashtra. In the present investigation, the Manganga river tributary of Bhima River is considered for the drought analysis which originates from the hills lying in the eastern part of the Satara district at Kulakjai village and flows through Sangali and Solapur districts and finally meets Bhima river in Sarkoli. The latitudinal and longitudinal extent of Manganga river watershed are between 17^0 27'N to 17^0 44'N and 74^0 95'E to 75^0 14'E.

The watershed catchment area is 4757 square km and the river's main channel length is 151.35 km (Fig. 1). Agriculture is a significant occupation that supports more than 80 percent of the population living in the basin. The climatic condition of the study area is tropical. The annual average rainfall in the study area is about 1094 mm and the average annual temperature is around 24^0C.

Database and Methodology
In this study, the Vegetation Health Index is analyzed using long-term sequence data for 2001, 2010, 2015, 2017 and 2019 dry season using Landsat data. The satellite data is being used in the analysis to precisely measure how

normalized difference vegetation index (NDVI), land surface temperature (LST) and the VHI are affected by changes in the drought analysis.

Multi-temporal smoothed quarter-month Landsat satellite images from 2001 to 2019 at a spatial resolution of 30 m are taken from USGS. For this study, three Landsat satellite images (January, May and September) are acquired yearly (Table 1). In order to derive VHI, it is necessary to process various indices that are carried in the following manner. Figure 2 gives a brief and standardized flow of complete analysis.

Normalized Difference Vegetation Index (NDVI): Drought analysis of applied vegetation indices method using the spectral representation of the vegetation leaves defined NDVI.[20] This is commonly used to determine both global and local vegetation conditions and climate impacts on vegetation. The NDVI is produced by Landsat images using the ratio of bands 4 (red) and 5 (near-infrared) eq. 1:

$$NDVI = (NIR - RED)/(NIR + RED) \quad (1)$$

where NIR=near-infrared reflectance and RED= visible red reflectance.

NDVI is computed for three months (January, May and September) for the years 2001, 2010, 2015, 2017 and 2019.

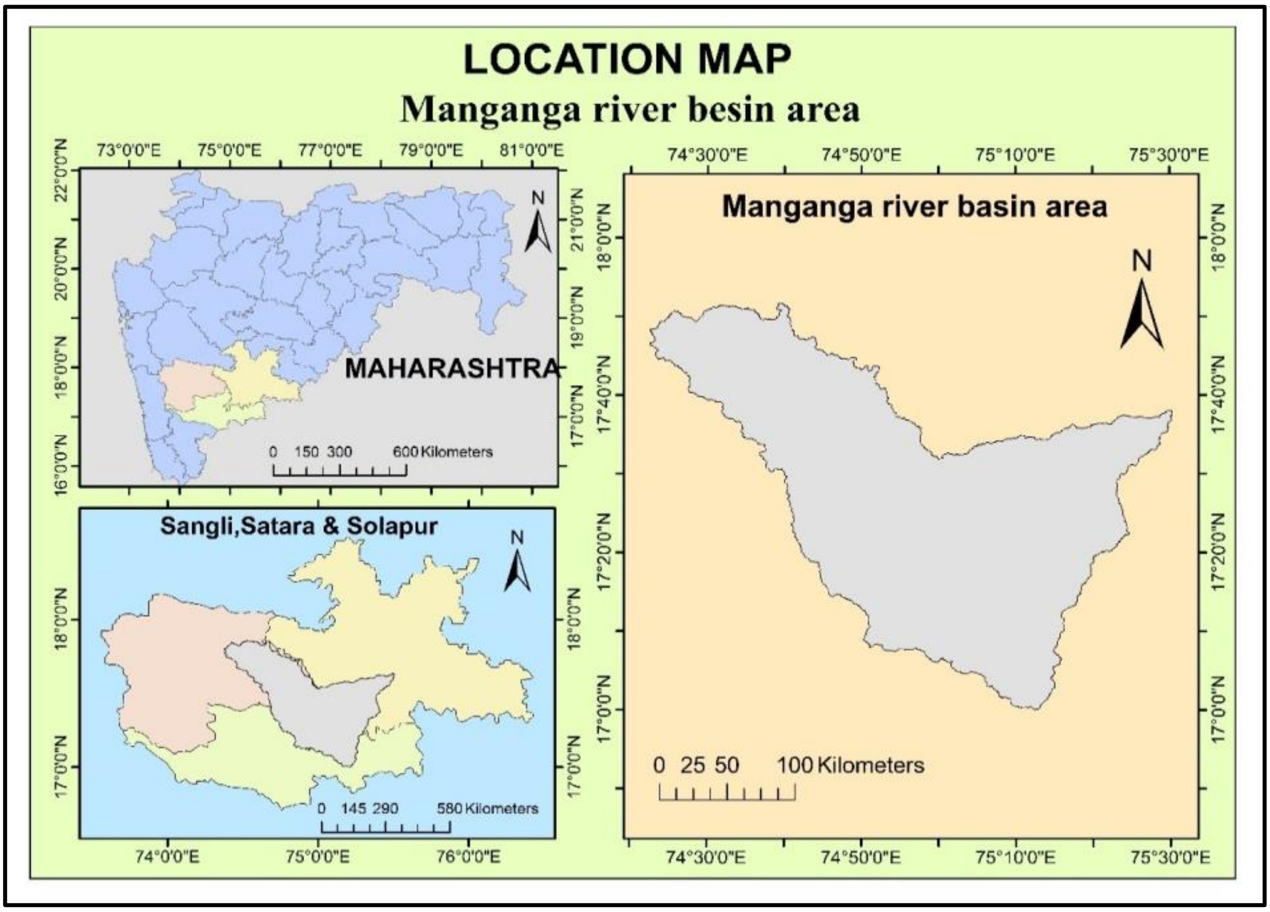

Fig. 1: Geographical Location of the Study Area

Table 1
Satellite database for drought assessment

S.N.	Satellite & Sensor Name	Resolution	Year	Month
1	Landsat (TM)	30m	2001	January, May and September
2	Landsat (ETM+)		2010	
3			2015	
4	Landsat (OLI)		2017	
5			2019	

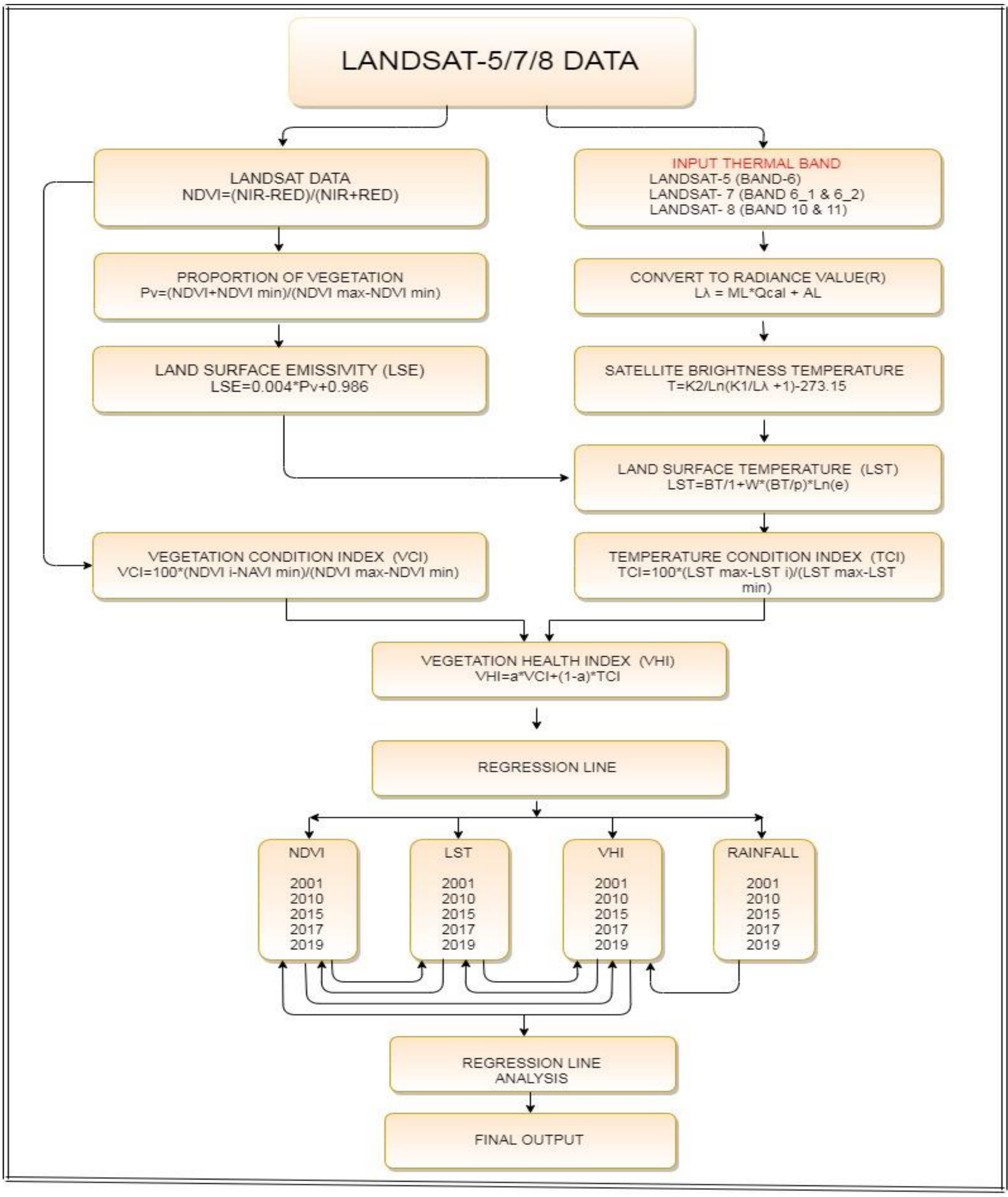

Fig. 2: Research Methodology

Land Surface Temperature (LST): LST is defined as the surface radiometric temperature corresponding to the instantaneous field of view of the sensor. Information about land surface temperature is obtained using Landsat data from the following formula (Eq. 2). These data are being used as input for the TCI and VHI computation, an advanced and optimized model of agricultural drought monitoring.

$$LST=BT/1+w*(BT/p)*In(e) \quad (2)$$

where BT = At satellite temperature, W = wavelength if emitted radiance, P = h*c/s (1.438*10^-23 m k), h = Plank's constant (1.38*10^-23 j/k), s = Boltzmann constant and c = velocity of type (2.998*10^8 m/s).

Vegetation Condition Index (VCI): The index is widely applicable for the assessment of vegetation stress and for the analysis of vegetation response.[10] In this study, the s NDVI data are used as input to compute the VCI model. Vegetation Condition Index values indicate how much vegetation has improved or degraded about environmental conditions. According to Kogan[12], the VCI value is expressed in the percentile ranged from 0 to 100. A high VCI value indicates a healthy and unstressed condition of vegetation. The VCI value of 50–100% indicates above normal or wet conditions. In this study, the VCI model is used to examine the agricultural drought condition of the study area as follows eq. 3:

$$VCI = 100 \times \; NDVI_i - NDVI_{min} - / \; NDVI_{max} - NDVI_{min} \quad (3)$$

where $NDVI_i$= the current smoothed NDVI value of i^{th} month, $NDVI_{min}$ and $NDVI_{max}$, are multi-year (2001– 2019) absolute minimum and maximum NDVI values for every pixel at a particular period.

Temperature Condition Index (TCI): The LST data is used as an indicator of the energy balance at the earth's surface called the greenhouse effect in climate change studies.[7] The TCI has proposed that higher temperatures appear to cause deterioration or drought during the vegetative growth cycle whereas low temperatures are generally beneficial to vegetation during its production. The model has improved considerably in order to determine the vegetation response to temperature. In this study, the LST data are rescaled and converted into °C (degree Celsius) unit. The TCI is estimated using the following mathematical expression eq. 4:

$$TCI = 100 \times (LST_{max} - LST_i)/(LST_{max} - LST_{min}) \quad (4)$$

where LST_i=LST value of i^{th}-month, LST_{max} and LST_{min} are the smoothed multi-year maximum and minimum LST.

Vegetation Health Index (VHI): The VHI show the availability of moisture and temperature or thermal condition in vegetation.[13] The VHI has been used for various applications such as prediction of drought, extent and duration of drought, early warning of drought.[27] The VHI model has been described as a comprehensive agricultural drought-monitoring index and has strong effectiveness in exploring the spatial scale of extreme agricultural drought. VHI depends on the weather and environmental factors of the area.[28]

Seiler[27] has shown that the VHI combination of TCI and VCI is significant in classifying the spatial area, frequency and intensity of agricultural droughts in a manner consistent with precipitation patterns. This drought index has improved performance for monitoring agricultural drought.[21] Marufah et al[17] stated that VHI had been used to consider the duration, spatial distribution and intensity, or type of agricultural drought. The VHI is mathematically computed as follows eq. 5:

$$VHI = a \times VCI + (1 - a) \times TCI \quad (5)$$

where VHI=Vegetation Health Index, a=0.5 (contribution of VCI and TCI), VCI=Vegetation Condition Index, TCI=Temperature Condition Index.

Results and Discussion

NDVI: Theoretically, NDVI values are represented as a ratio ranging in value from -1 to 1, but in practice, extreme negative values represent water, values around zero represent bare soil and values close to one represent dense green vegetation. The spatial distribution of NDVI over part of the Manganga river basin area for 2001, 2010, 2015, 2017 and 2019 is shown in figure 3.

After January's observation month (2001 and 2010), most of the area has been covered by non-vegetation, but for January 2015 and 2017 months, vegetation cover has decreased and the 2019 non-vegetation area has decreased. May is a very hot month this month. The temperature is also high in Maharashtra. High temperature affects vegetation as well. The vegetation is scarce in May 2001 and 2010, although some increase in greenery in 2015 and 2017.

However, there is less vegetation in May 2019. September 2001 is a very critical condition for vegetation because this year, the bulk of the vegetation cover is almost lost as per the observation. However, in September 2010, 2015, 2017 and 2019, vegetation condition changed and vegetation cover increased. Overall, if we consider all the years, the year 2001 is not ideal for vegetation in the non-vegetation areas in general. Afterward, vegetation increased (2010, 2015 and 2017), yet another negative vegetation change was in 2019.

LST: The LST of the Manganga river watershed highlights the spatial distributions of the hot areas based on 2001, 2010, 2015, 2017 and 2019 images (Fig. 4). The land surface temperature has been classified into four classes, the first less than 20, 20 to 30, 30 to 40 and the last greater than 40°C. In January 2001 and 2010, the temperature is decreased below the first two categories, while in 2015 the temperature increases. Some regions indicated more than 40° C in 2019. The LST marginally decreased in 2017 while the LST increased significantly in 2019. May is a very hot month. Temperature is pretty high everywhere. With findings in May 2001, 2010, 2015, 2017 and 2019, only May 2001 is generally below 40 + C. In September 2001, variability in temperature is everywhere. It implies all four categories in temperature in the study area.

VHI: The classification scheme for drought monitoring based on VHI is divided into five groups as extreme drought (VHI < 10), severe drought (10 < VHI < 20), moderate drought (20 < VHI < 30), mild drought (30 < VHI < 40) and no drought (VHI > 40).[15] As per the observation, many areas fell under the medium drought and mild drought in January 2001. No Drought condition around the river is due to the availability of a sufficient amount of water of the river. As the distance from the stream increases, the various conditions of drought can be observed. Year 2010 is better for vegetation health condition as much of the region is contained within the area without drought. However, the VHI decreases in 2015 and 2017 (Fig. 5).

Thus the drought levels begin to increase. May is a very hot month and high temperatures do have a big effect on Vegetation Health; therefore, vegetation health condition is not likely to be good during this period. May 2001, 2010, 2015, 2017 and 2019 are main regions of the mild drought, medium drought and some portion are in severe drought. As per the investigation, the only adjacent area along the river basin is observed as without drought condition. The month of September contains rainy days and this time is well balanced for vegetation health. The healthy condition of vegetation is found in September 2001, 2010, 2015 and 2017, although it was poor in 2019. According to the result, the mild and moderate type of drought are observed in the study area.

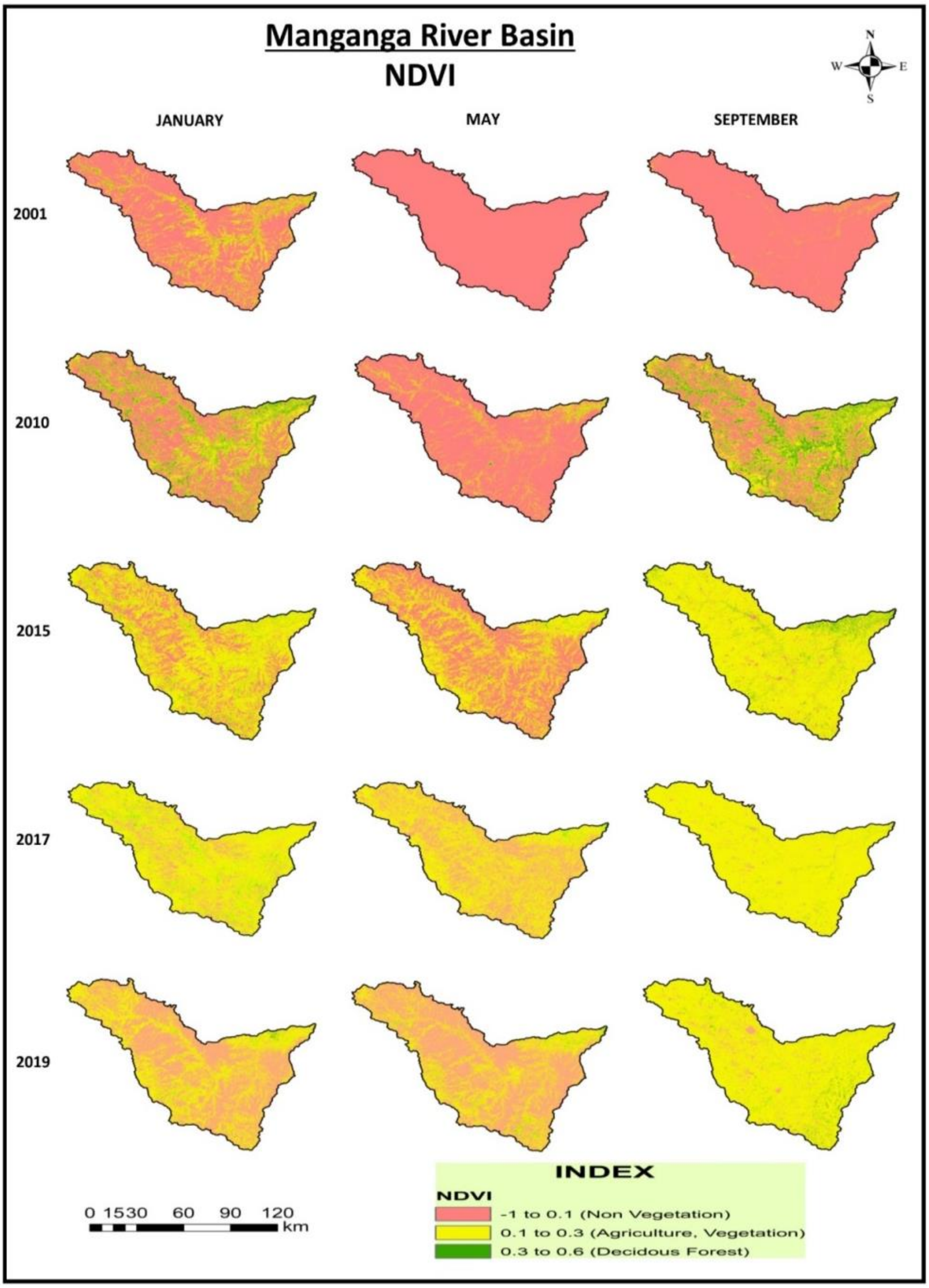

Fig. 3: NDVI

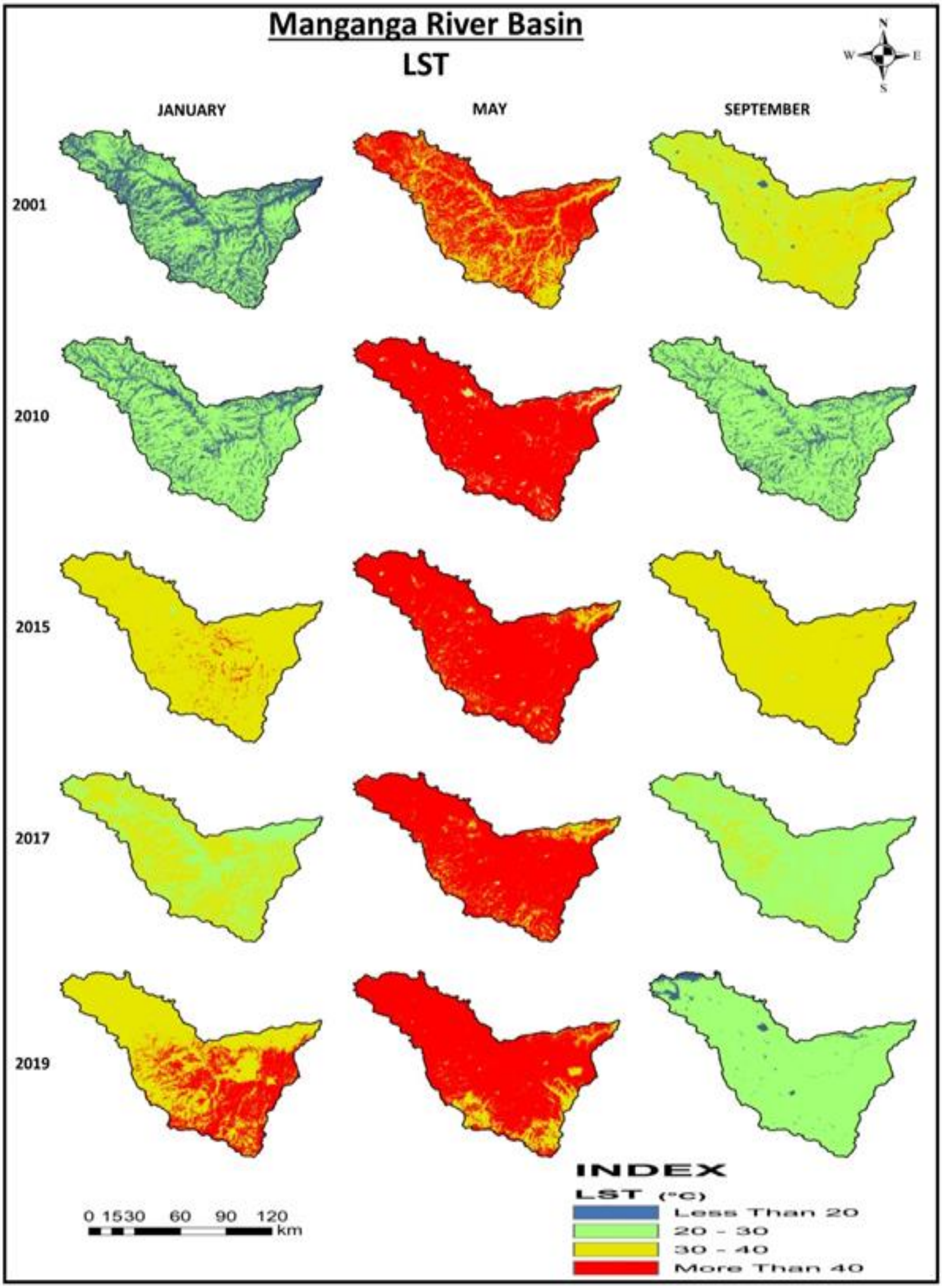
Manganga River Basin
LST
JANUARY
MAY
SEPTEMBER
2001
2010
2015
2017
2019
N
S
W
E
0 15 30 60 90 120
km
INDEX
LST (°C)
Less Than 20
20 - 30
30 - 40
More Than 40

Fig. 4: LST

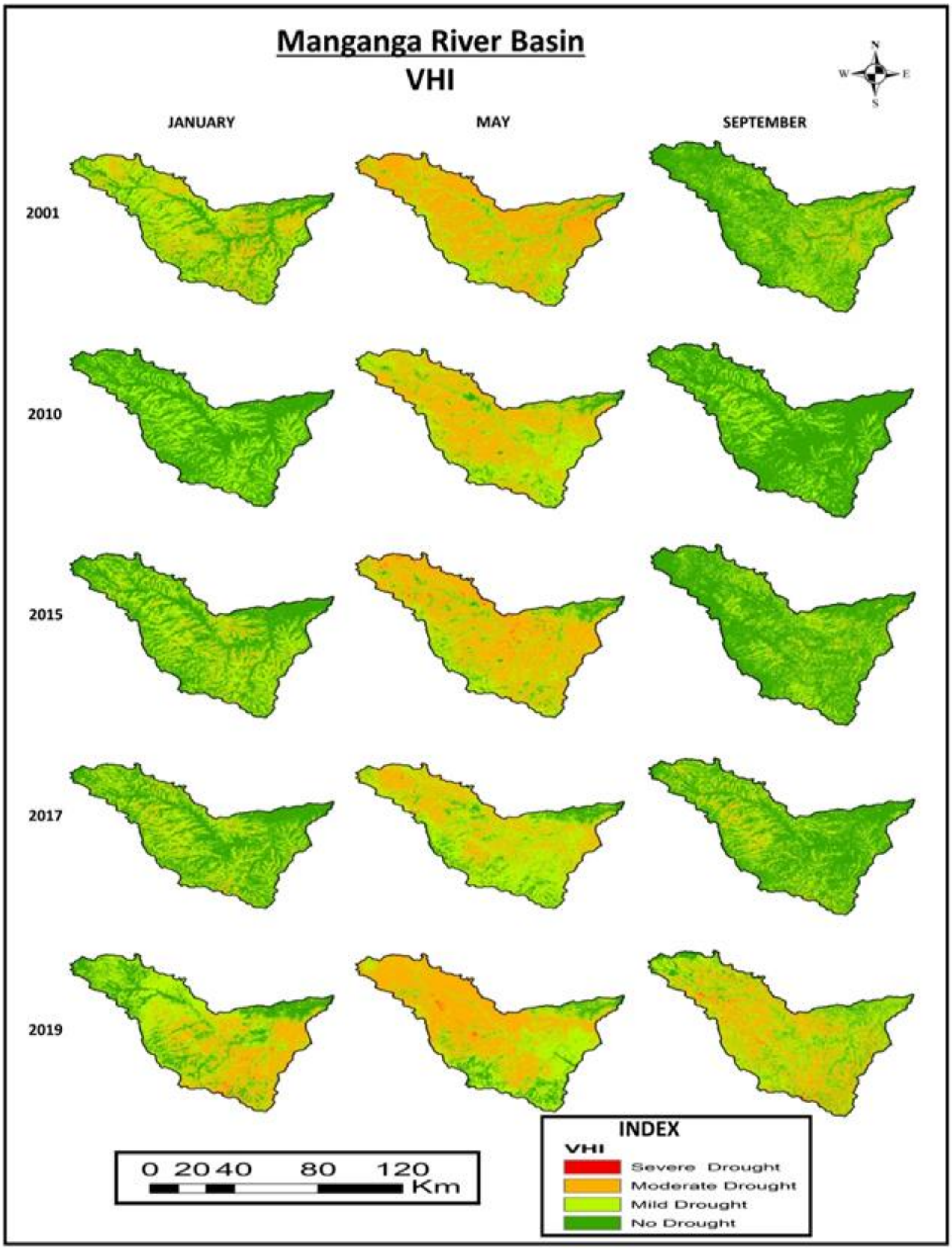

Fig. 5: VHI

Correlations between indices

The goal of regression analysis is to construct a statistical model that can be used to measure dependent variable's values based on an independent variable's value. The analysis reveals that the land surface temperature (LST) and NDVI change over time depending on the changes in the vegetation health and, ultimately, drought categories of the study area. Therefore, a comparison of concern indices has been carried out by using 100 sampling points in the study area (Fig. 6, 7, 8).

LST is related to NDVI. Empirically, the temperature decreases as NDVI increases over a landscape.[2,5,11,26] It is observed that the nature of the relationship between LST and NDVI is linear and negative (Fig. 6). The same conditions which are observed in the case of LST and VHI are negative relationships (Fig. 7). However, high NDVI means strong vegetation health in the case of NDVI and the VHI relationship between both of these is positive (Fig. 8).

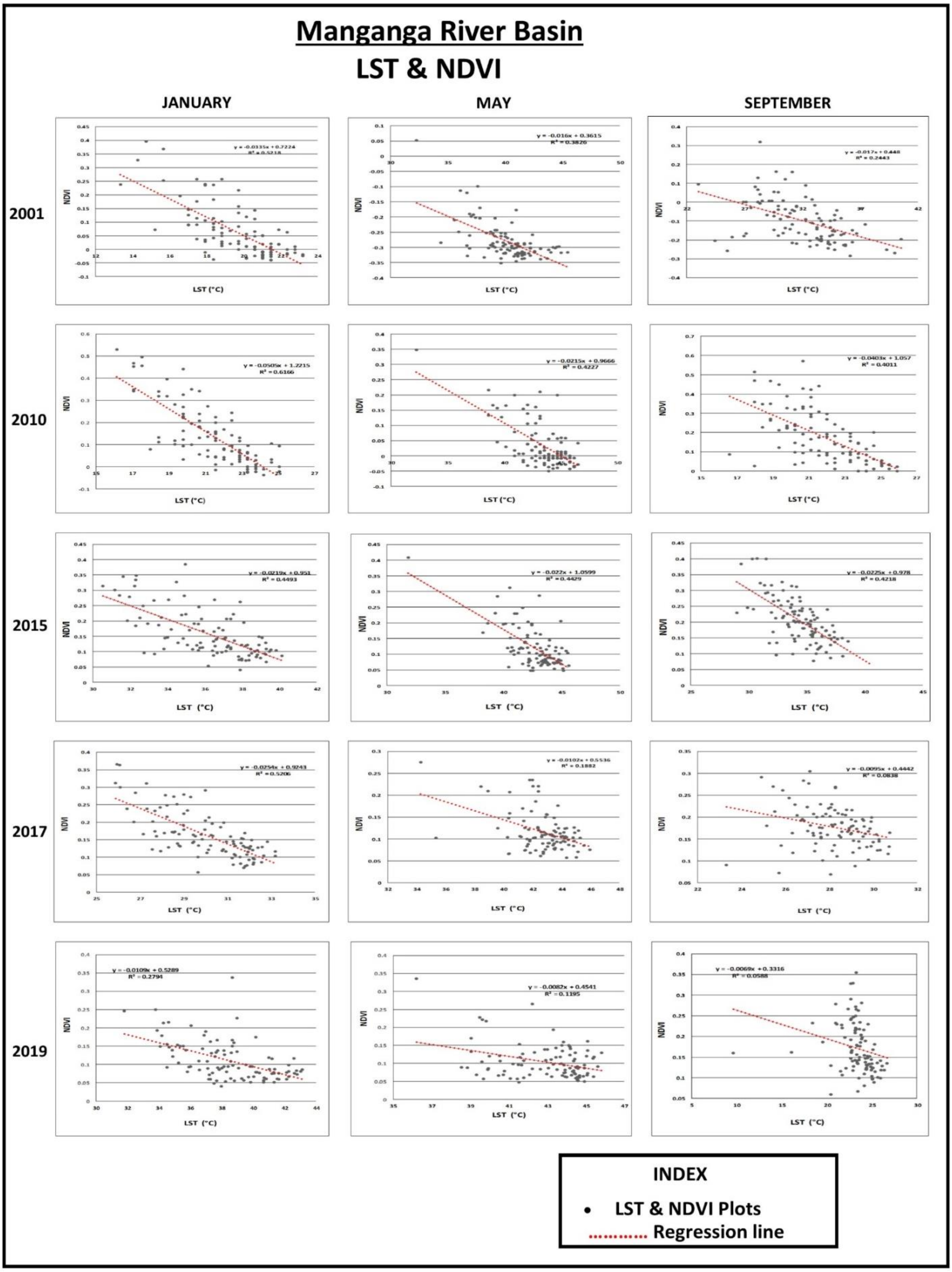

Fig. 6: Correlation between LST and NDVI

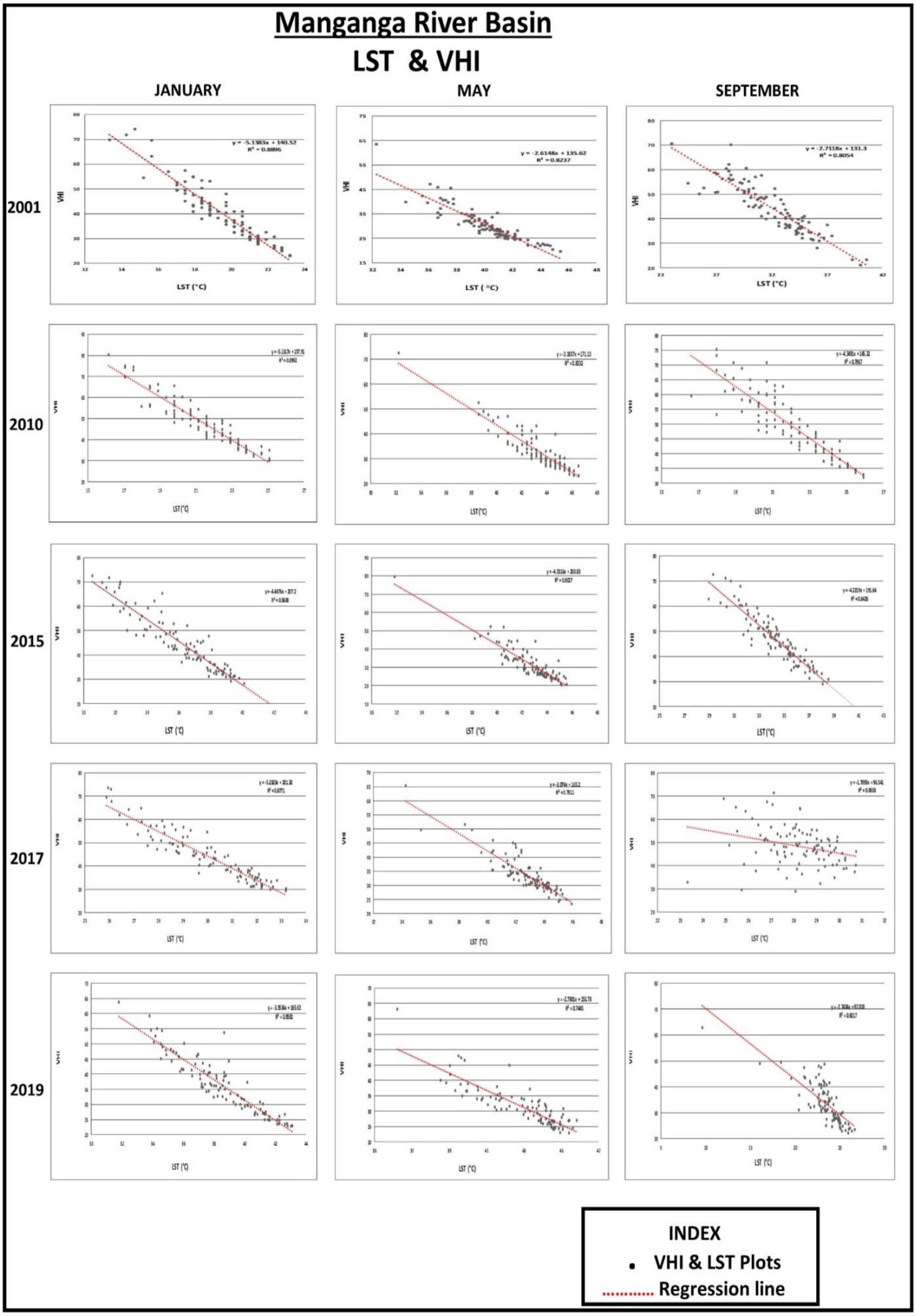

Fig. 7: Correlation between LST and VHI

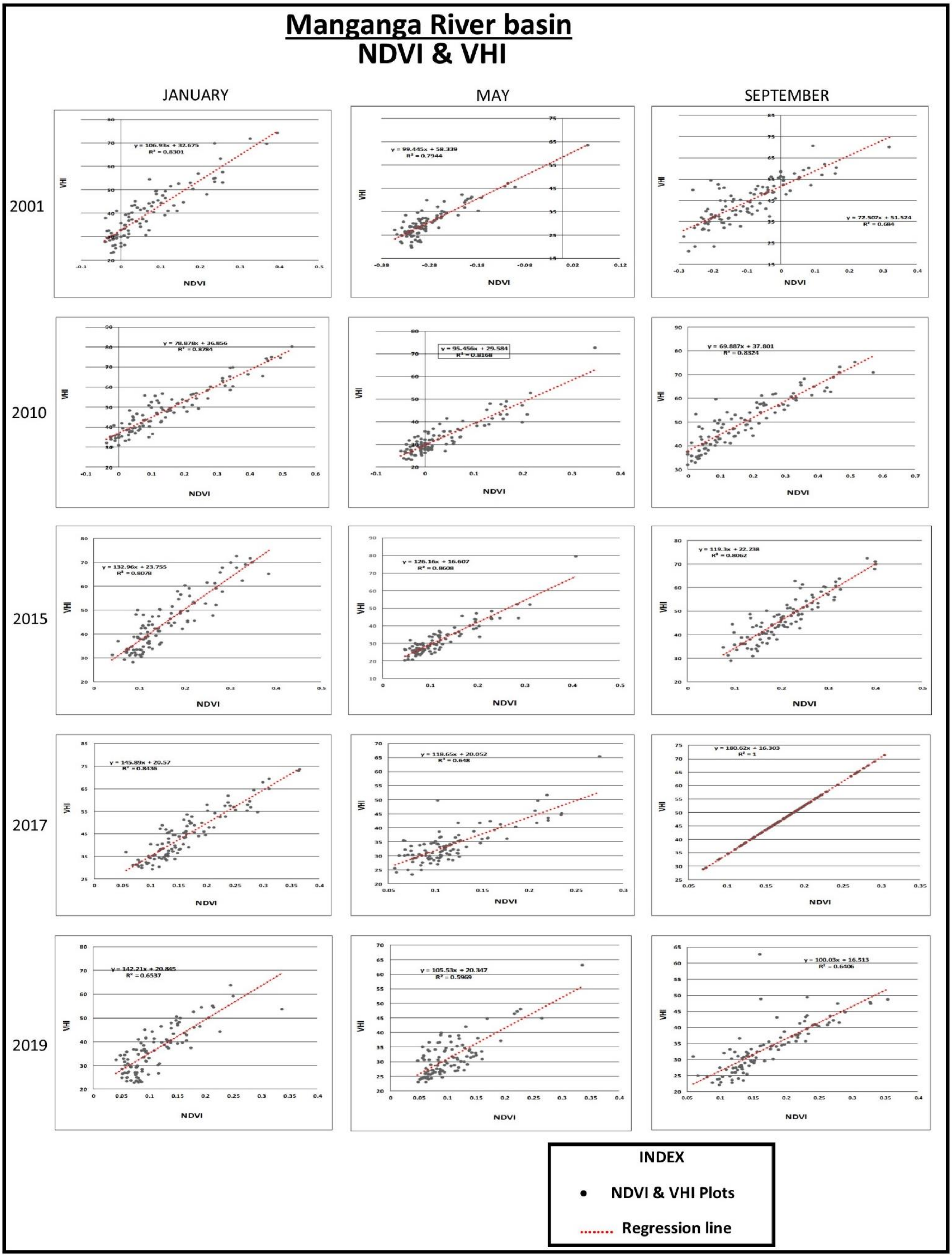

Fig. 8: Correlation between NDVI and VHI

Conclusion

This study attempts to analyze the intensity of agricultural drought and its spatial extent using the VHI that includes NDVI, VCI, LST and TCI in the Manganga watershed of Maharashtra, India. The VHI is successfully used to determine the spatiotemporal extent of agricultural drought.

As per the outcomes, mild and moderate type of drought is observed throughout agriculture fields of the study area excepting only the adjacent area along the river. The study also shows that the relationship between NDVI-LST and LST-VHI is negative whereas NDVI-VHI has a positive relationship. The outcomes of this study could be helpful for future decision-making processes on drought management.

References

1. Al-Riffai Perrihan et al, Droughts in Syria: an assessment of impacts and options for improving the resilience of the poor, *Quarterly Journal of International Agriculture*, **51(1),** 21 **(2012)**

2. Badeck F.W., Bondeau A., Bottcher K., Doktor D., Lucht W., Schaber J. and Sitch S., Responses of spring phenology to climate change, *New Phytol*., **162**, 295–309 **(2004)**

3. Bhuiyan C., Singh R.P. and Kogan F.N., Monitoring drought dynamics in the Aravalli region (India) using different indices based on ground and remote sensing data, *International Journal of Applied Earth Observation and Geoinformation,* **8**, 289-302 **(2006)**

4. Bokusheva R., Kogan F., Vitkovskaya I., Conradt S. and Batyrbayeva M., Satellite-based vegetation health indices as a criteria for insuring against drought-related yield losses, *Agric. For. Meteorol*., **220**, 200–206 **(2016)**

5. Carlson T.N., Gillies R.R. and Perry E.M., A method to make use of thermal infrared temperature and NDVI measurements to infer soil water content and fractional vegetation cover, *Remote Sens. Rev.*, **52**, 45–59 **(1994)**

6. Choi M., Jacobs J.M., Anderson M.C. and Bosch D.D., Evaluation of drought indices via remote sensed data with hydrological variables, *Journal of Hydrology*, **476**, 265-73 **(2013)**

7. Frey C.M., Kuenzer C. and Dech S., Quantitative comparison of the operational NOAA-AVHRR LST product of DLR and the MODIS LST product V005, *Int J Remote Sens,* **33(22),** 7165–7183 **(2012)**

8. Gu Y., Brown J.F., Verdin J.P. and Wardlow B., A five-years analysis of MODIS NDVI and NDWI for grassland drought assessment over the central Great Plains of the United States, *Geophysical Research Letters,* doi:10.1029/2006GL02912, **34,** L06407 **(2007)**

9. Gupta Anil Kumar et al, Bundelkhand Drought: Retrospective Analysis and Way Ahead, National Institute of Disaster Management, New Delhi 148 **(2014)**

10. Karnieli A., Agam N., Pinker R.T., Anderson M., Imhof M.L., Gutman G.G. and Goldberg A., Use of NDVI and land surface temperature for drought assessment: merits and limitations, *J Clim* **23(3),** 618–633 **(2010)**

11. Karnieli A., Bayasgalan M., Bayarjargal Y., Agam N., Khudulmur S. and Tucker C.J., Comments on the use of the vegetation health index over Mongolia, *Int. J. Remote Sens.*, **27**, 2017– 2024 **(2006)**

12. Kogan F.N., Application of vegetation index and brightness temperature for drought detection, *Adv Space Res*, **15(11),** 91–100 **(1995)**

13. Kogan F.N., Operational space technology for global vegetation assessment, *Bull Am Meteor Soc*, **82(9),** 1949 **(2001)**

14. Kogan F., Salazar L. and Roytman L., Forecasting crop production using satellite-based vegetation health indices in Kansas, USA, *Int. J. Remote Sens.*, **33**, 2798–2814 **(2012)**

15. Kogan F.N., World droughts in the new millenium from AVHRR-based Vegetation Health Indices, *Eos Trans. Am. Geophys. Union*, **83**, 562–563 **(2002)**

16. Kogan F.N., Global drought watch from space, *Bull. Am. Meteorol. Soc.*, **78**, 621–636 **(1997)**

17. Marufah U., Hidayat R. and Prasasti I., Analysis of relationship between meteorological and agricultural drought using standardized precipitation index and vegetation health index, In IOP Conference Series: Earth and Environmental Science, IOP Publishing, Bristol, 012008 **(2017)**

18. Maybank J., Bonsai B., Jones K., Lawford R., O'brien E.G., Ripley E.A. and Wheaton E., Drought as a natural disaster, *Atmos Ocean,* **33(2),** 195–222 **(1995)**

19. Mishra A.K., Ines A.V.M., Das N.N., Khedun C.P., Singh V.P., Sivakumar B. and Hansen J.W., Anatomy of a local-scale drought: Application of assimilated remote sensing products, crop model and statistical methods to an agricultural drought study, *Journal of Hydrology*, **526**, 15-29 **(2015)**

20. Myneni R.B., Hall F.G., Sellers P.J. and Marshak A.L., The interpretation of spectral vegetation indexes, *IEEE Trans. Geosci. Remote Sens.*, http://dx.doi.org/10.1109/36.377948, **33**, 481–486 **(2015)**

21. Parviz L., Determination of effective indices in the drought monitoring through analysis of satellite images, *Agric Forest Poljoprivreda I Sumarstvo,* **62(1),** 305–324 **(2016)**

22. Registrar General, India, Census of India 2011: provisional population totals-India data sheet, Office of the Registrar General Census Commissioner, India, Indian Census Bureau **(2011)**

23. Rojas O., Vrieling A. and Rembold F., Assessing drought probability for agricultural areas in Africa with coarse resolution remote sensing imagery, *Remote sensing of Environment,* **115**, 343-52 **(2011)**

24. Salazar L., Kogan F. and Roytman L., Using vegetation health indices and partial least squares method for estimation of corn yield, *Int. J. Remote Sens.*, **29**, 175–189 **(2008)**

25. Samra J.S., Review and analysis of drought monitoring, declaration and impact management in India, IWMI Working Paper 84, Drought Series Paper 2, International Water Management Institute, Colombo, Sri Lanka **(2004)**

26. Sandholt I., Rasmussen K. and Andersen J., A simple interpretation of the surface temperature/vegetation index space for assessment of surface moisture status, *Remote Sens. Environ.,* **79,** 213–224 **(2002)**

27. Seiler R.A., Kogan F. and Sullivan J., AVHRR-based vegetation and temperature condition indices for drought detection in Argentina, *Adv Space Res,* **21(3),** 481–484 **(1998)**

28. Singh R.P., Roy S. and Kogan F., Vegetation and temperature condition indices from NOAA AVHRR data for drought monitoring over India, *Int J Remote Sens*, **24(22),** 4393–4402 **(2003)**

29. Wilhite Donald A., eds., Drought and water crises: science, technology and management issues, CRC Press **(2005)**.

(Received 12th August 2020, accepted 02nd November 2020)