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Identification of drought prone areas in Sri Lanka using multi-temporal satellite data

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Abstract

Drought is an insidious hazard of nature with a slower onset and is often misunderstood as a minor weather hazard. Nevertheless, it has become a common and recurring natural disaster in Sri Lanka during recent times affecting the livelihood of rural agricultural sector in particular. This study has attempted to identify spatial patterns of drought prone areas to improve drought preparedness and strengthen appropriate drought management strategies. Drought prone areas for each month were produced and by aggregating them, a resultant composite map was developed showing overall drought prone possibilities across Sri Lanka.The results revealed that drought is a less frequent phenomeon in January in Sri Lanka except in some parts of Western and Southern provinces. Drought conditions at most of the North-eastern parts of the Dry zone areas of Sri Lanka could be seen during May to September with a peak drought during August and September in the Uva and Eastern provinces. Jaffna, Killinochchi and Batticaloa districts can be categorized as severe drought prone districts of the country. Accuracy of the composite map was checked using historical records of Disaster Management Centre, Sri Lanka from 2001-2017 at the DS Division level. The accuracy was 77.01%, Type I Error was 22.09% and Type II Error 0%. The Chi-Square Test showed high accuracy levels ($p<0.05$) suggesting that the vegetation condition approach is appropriate for drought assessment in Sri Lanka.

Key words: Drought prone areas, MODIS, Normalized difference vegetation index, Vegetation condition index

Introduction

Drought is more environmentally, economically and socially destructive than the other natural hazards and often misunderstood for a minor climatic disaster as its impact is not visible instantly (Tannehill, 1947). The word ‘drought’ does not have a specific definition, but is referred to as a creeping phenomenon (Wilhite and Glantz, 1985). Drought indicates a dry situation caused by lack of water, which occurs when rainfall is less than normal for several weeks, months or years (Wilhite, 2000). Drought could be categorized into four types, i.e. meteorological drought, hydrological drought, agricultural drought and socio-economic drought. The agricultural drought refers to the circumstances when soil moisture is insufficient and affects crop growth leading to production losses. It is usually defined with short-term drought situations and may overcome or deteriorated within a very short period of time depending upon the strength of drought conditions (Wilhite and Glantz, 1985).

Drought has been recognized as a global threat, which needs urgent attention at national, regional and international levels. It causes not only water and food shortages, but also impacts negatively on a wider range of sectors leading even to political crisis and civil unrest conditions (WMO, 2014). From 1970 to 2012, drought has resulted in more than 680,000 deaths in Africa due to the severe dry conditions (WMO, 2014). Scott and Lindsay (2018) reported that global drought prone area has reached a higher level in late 2015 and remained high throughout 2016. Further, Scott and Lindsay (2019) reported that extreme drought conditions have affected at least 3% of the global land area in every month of 2017, an extent that had only been observed in just a few prior years: 1984, 1985, and 2016. Rain scarcity is four times more costly than floods (Margini, 2017).

Droughts occur in all climatic zones, such as high or low rainfall areas, and are mostly related to reduction in the amount of precipitation received over an extended period of time. Temperatures, high winds, low relative humidity, timing and characteristics of rains, including distribution of rainy days during crop growing seasons, intensity and duration of rain, and onset and termination, play a significant role in the occurrence of droughts (Wilhite, 2000). Drought has become a common recurrent phenomenon in Sri Lanka in the recent years. It has produced a complex web of impacts, affecting many sectors of the economy, especially to agriculture sector that is sensitive to climate and water supply. In Sri Lanka drought has partially damaged or completely destroyed 300,000 ha of rice paddy during 2012 (OCHA, 2016). In 2014, the overall agriculture production was reduced by 40% due to a 11-month long drought and more than 1.2 million people across 19 out of 25 districts remained affected by drought during 2017 (OCHA, 2017). The failure of two paddy harvests in 2017 has raised concerns for the food security and livelihoods of affected communities in Sri Lanka.

Droughts affect many sectors in the most of the parts of the country with an increasing trend, and thus, mapping the drought prone areas was considered beneficial to improve drought preparedness and strengthen relevant drought management policies in Sri Lanka. Drought detection can be done by vegetation condition assessment using time series satellite data (Kogan, 1995). Normalized Vegetation Index (NDVI) and Vegetation Condition Index (VCI) have effectively been used to assess drought using satellite data (Bhuiyan, *et al*. 2006; Ji and Peters, 2003). The present study aimed at developing a drought prone area map of Sri Lanka by crop condition assessment using moderate resolution time series MODIS satellite data.

Materials and methods

The study covered entire Sri Lanka (latitudes 5° and 10° N, longitudes 79° and 81° E; a total area of 65,610 km²). The time series MODIS/Terra (MOD13Q1 250m) satellite data pertaining to past 16 years (2001–2016) were mainly used for this study. Two scenes (h25v08 and h26v08) for each 16-day (46 scenes per year) of MODIS satellite data for 16 years (GeoTiff raster grid format) were acquired from the United States Geological Survey (USGS) free web portal (https://earthexplorer.usgs.gov/). The MOD13Q1 provides 16-day composited average NDVI values at a 250×250 m^2 spatial resolution (Didan, 2015). As auxiliary data, past drought records from 2001 to 2017 available at Divisional Secretariat Division (DSD) level at the Disaster Management Centre (DMC) of Sri Lanka were used for accuracy assessment. All types of image processing, including image mosaicking, geo-correction, image stacking, layer wise data integration for time series analysis, were performed by using the ENVI 4.5 software. The ArcGIS 10.3 software was used for raster-based analysis and final map production.

NDVI and VCI

The Normalized Difference Vegetation Index (NDVI) is the ratio between difference and summation of reflectance pertaining to Infrared and Red spectral region. The NDVI for each pixel can be expressed by Equation 1;

$$NDVI = (\rho NIR - \rho RED) / (\rho NIR + \rho RED)$$

where, 'ρ' is the reflectance in respective spectral bands and RED and NIR stand for the spectral reflectance measurements acquired in the red (visible) and near-infrared regions, respectively. The NDVI is an indicator of the level of photosynthetic activity and reflects whether the vegetation is stressed or not (Tucker, 1979). The MODIS 16-day composite provide maximum value of NDVI pertaining to each 16-day period (Huete *et al*., 1999). The Vegetation Condition Index (VCI) developed by Kogan (1990) normalizes NDVI on a pixel-by-pixel basis, scaling between minimum and maximum values of NDVI. The VCI values range from 0% to 100%. The VCI for each pixel for a considered period can be derived using the Equation 2 (Kogan, 1990);

$$VCI = (NDVI_i - NDVI_{min})/ (NDVI_{max} - NDVI_{min})$$

Where, $NDVI_i$ is the NDVI pertaining to considered year and the period, $NDVI_{min}$ is the minimum $NDVI_i$ and $NDVI_{max}$ is the maximum NDVI of considered period for all years. The VCI compares the NDVI pertaining to a particular period to the range of values observed in the same period in previous years. The VCI can estimate the status of vegetation according to the best and worst vegetation vigour over a particular period in different years and gives a more accurate result as compared to NDVI while monitoring drought at a regional scale (Bajgiran *et al*., 2008). The NDVI shows seasonal vegetation dynamics and VCI rescales vegetation dynamics in between 0 and 100 to reflect relative changes in the vegetation condition from extremely bad to optimal (Kogan, 1995; Kogan 2000; Ji and Peters, 2003; Meng and Wu, 2008).

Drought assessment

As suggested by Kogan (1995), when VCI is greater than 50% the pixel was assigned as normal condition of vegetation, if the values range from 50% to 35% those pixels were assigned as moderate drought condition, and at values below 35% the pixels were assigned as severe drought condition. All raster calculations were performed using the raster calculator of ArcGIS software. The drought maps (192; 16 for each month) for 16 years (2001 to 2016) were developed.

Development of drought prone area map

Drought prone area maps developed based on the VCI pertaining to each month were stacked to produce monthly drought maps. Later, all the monthly drought maps merged to produce the drought prone area maps of Sri Lanka. Considering the number values of moderate and severe drought events during the period of 2001-2016, classification using natural break classification method of ArcGIS software was adopted for development of drought prone area map of Sri Lanka (Jenks, 1977).

Accuracy assessment

Accuracy of prediction of the drought prone area was evaluated with past drought records. The data were inserted to a spatial database and map was created illustrating the drought affected areas in Sri Lanka. This was compared with the VCI-based drought severity map. A contingency table was created to calculate the accuracy, Type I error and Type II error of the map ($p=0.05$). Mapped drought prone areas were tested with past records at DS division level. Drought prone area map was overlaid with the drought incident map and drought areas were compared by a visual interpretation to calculate the accuracy. A Chi-Square Test ($p=0.05$) was performed to test the significance between reported drought incidents and the VCI-based drought map.

Results and discussion

Monthly drought severity over Sri Lanka

A comparison of monthly drought severity is illustrated in Figure 1. The results revealed that although the drought affected areas are lesser in the month of January, some parts of the Western and Southern provinces could be affected by severe drought. The drought affected areas tend to increase in February and the drought condition seems to cease in the rest of the months. However, in most parts of the Northern and North Central provinces, drought conditions tend to increase during March. Further, the drought conditions gradually spread to North Central, Uva and Eastern provinces during May to September with Uva and Eastern provinces experiencing peak drought conditions during August and September.

Drought prone areas of Sri Lanka

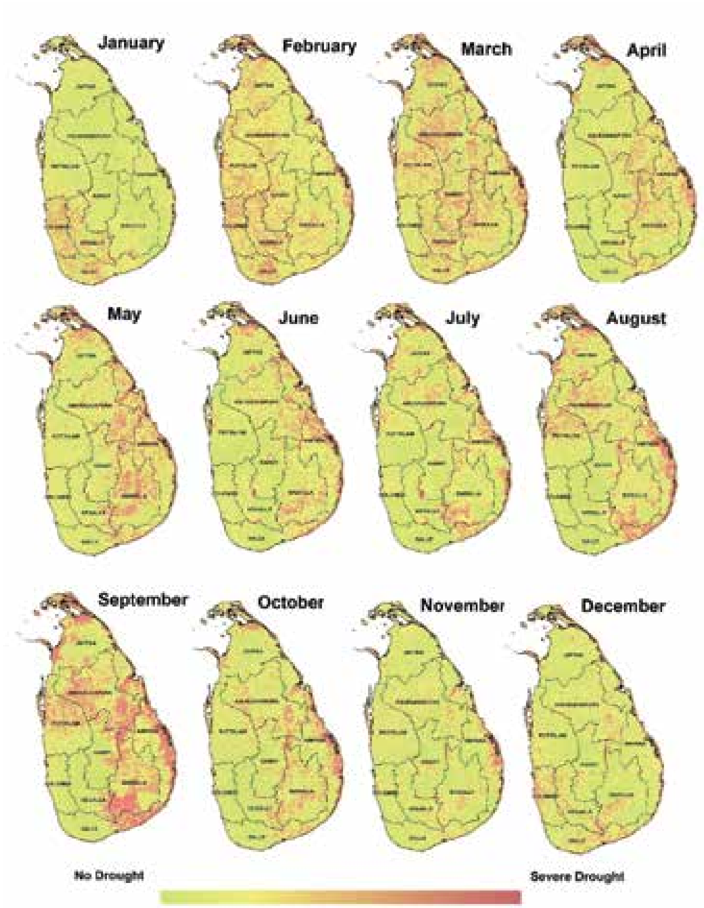

Figure 1. Monthly drought severity maps based on Vegetation Condition Index (VCI)

Drought prone area map of Sri Lanka showing spatial variability of drought occurrence under three drought classes i.e. no drought, moderate drought and severe drought is depicted in Figure 2. The summary statistics of district-wise area affected by different drought conditions is given in Table 1. Jaffna, Killinochchi and Batticaloa districts can be categorized as severe drought prone districts as most of the areas in the districts are affected with severe droughts. Southern part of Trincomalee, Eastern part of Ampara, central part of Hambantota and the western part of Mannar districts also can be categorized as drought prone areas. Most of the areas in Anuradhapura, Polonnaruwa, Puttlam and Badulla districts moderately drought affected. The western part of Kalutara, eastern part of Ratnapura, southern part of Vavuniya and northern part of Kurunegala have also been classified as moderately drought prone areas. The map of drought incident areas is shown in Figure 3. According to the official database with disaster records obtained for the study as auxiliary data from the DMC, Colombo, between 2001 and 2017, 255 DS Divisions have experienced drought while in some DS Divisions drought has occurred several times.

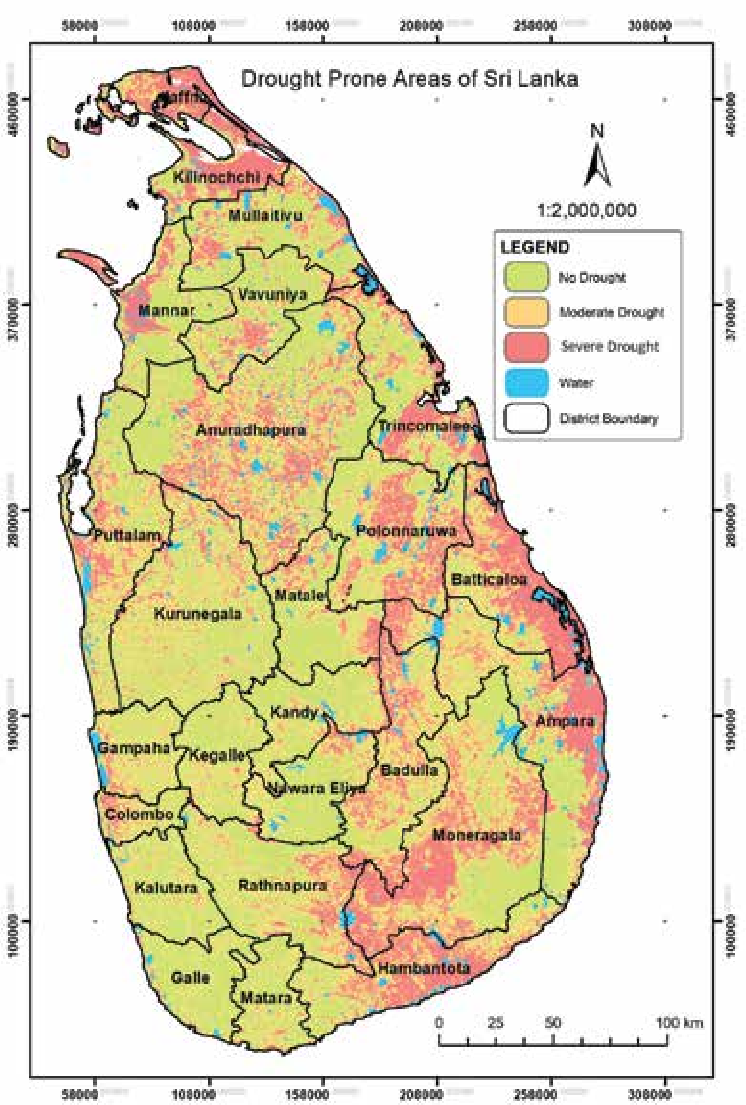

Figure 2. Drought prone area map of Sri Lanka based on Vegetation Condition Index

Table 1. Summary of area affected by different drought conditions in all districts of Sri Lanka

No	District	Area percentage			Total Area of district (ha)
		Low drought	Moderate drought	Severe drought	
1	Ampara	39.3	28.8	31.9	4439
2	Anuradhapura	42.7	32.5	24.8	7213
3	Badulla	31.9	39.0	29.1	2872
4	Batticaloa	17.2	27.9	54.9	2482
5	Colombo	45.9	33.3	20.9	668
6	Galle	76.8	18.6	4.6	1592
7	Gampaha	55.9	33.1	11.0	1367
8	Hambantota	29.9	31.4	38.7	2594
9	Jaffna	14.7	16.2	69.1	916
10	Kalutara	71.0	24.0	5.0	1632
11	Kandy	67.9	24.2	8.0	1937
12	Kegalle	70.5	25.8	3.7	1664
13	Kilinochchi	24.9	13.7	61.4	1131
14	Kurunegala	56.4	32.1	11.5	4908
15	Mannar	57.1	16.1	26.8	1948
16	Matale	63.4	22.8	13.8	2072
17	Matara	68.3	25.4	6.3	1296
18	Monaragala	35.0	31.8	33.2	5764
19	Mullaitivu	54.6	21.7	23.7	2603
20	Nuwaraeliya	69.3	22.4	8.4	1739
21	Polonnaruwa	35.9	32.7	31.4	3441
22	Puttalam	47.9	29.8	22.2	3023
23	Ratnapura	53.6	30.1	16.3	3295
24	Trincomalee	41.5	25.3	33.2	2628
25	Vavuniya	62.5	22.8	14.7	2014

Accuracy assessment

The map developed with past drought data records from DS divisions are illustrated in Figure 3. Drought conditions were reported at 166 DS divisions in the considered years. The accuracy of the VCI-based drought map, which was done by overlaying the drought prone area map (Figure 2) with the drought incident map (Figure 3) and by a visual interpretation of drought areas is shown in Table 2.

Table 2. Accuracy percentages of the VCI based drought map

Accuracy	Percentage (%)
Accuracy	77.1
Type I Error	22.9
Type II Error	0

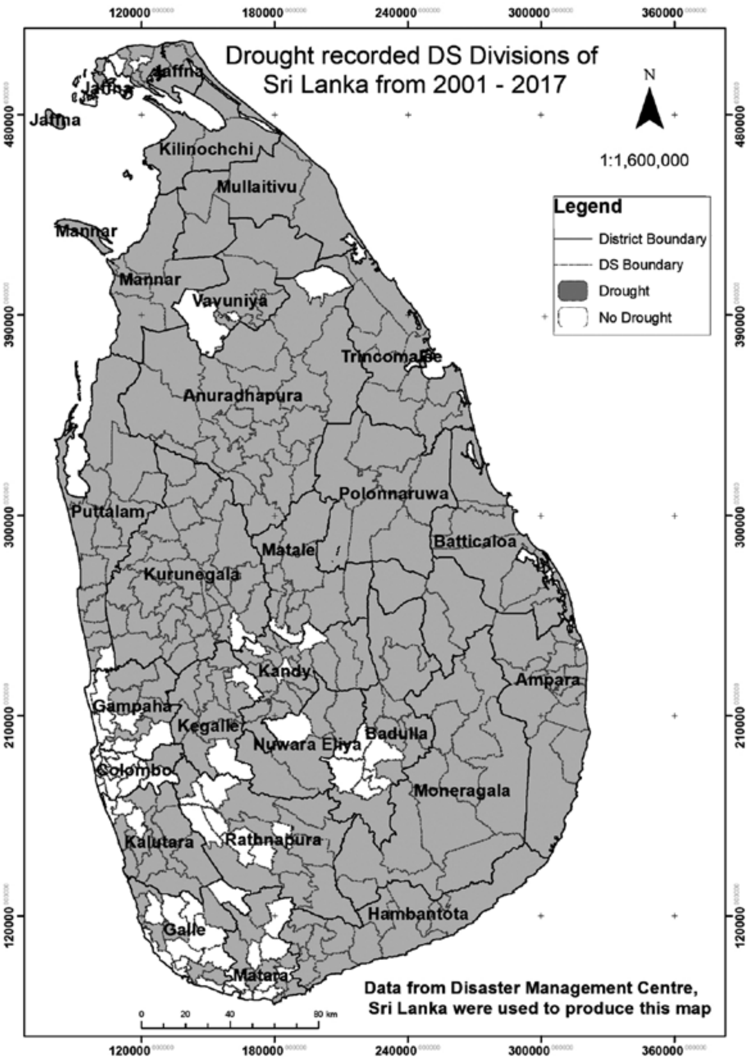

Figure 3. Drought reported DS divisions during 2001 - 2017

As shown in Table 2, an overall accuracy of 77.1% could be achieved for drought mapping with time series MODIS 16-day NDVI composite data. The lower Type I and Type II errors indicate that the VCI could be adopted for mapping and assessing drought prone areas with high accuracy, confirming the recommendation of VCI for drought mapping made by many researches (Kogan,1995; Dutta *et al*., 2015; Kogan, 2000; Kogan and Sullivan, 1993).

The results of the Chi square test performed further confirmed the accuracy of the drought incidents mapped based on VCI ($p<0.05$) as shown in Table 3. The results suggests that the VCI-based drought mapping with MODIS 16-day composite is a better approach for mapping of drought prone areas in Sri Lanka.

Table3. Chi-Square (p=0.05) test performed for VCI-based drought map

	Observed Values	**Expected Values**
TRUE	256	166
NO	66	166

Conclusion

Drought assessment using MODIS 16-day time series NDVI satellite data pertaining to year 2001 to 2016 for mapping of drought prone areas was successful with VCI assessment at an overall accuracy of 77.2%. Drought prone areas for each month and a composite map showing overall drought prone possibilities across Sri Lanka were developed. Spatial pattern of areas with drought prone possibilities for each month shows that drought was lesser in January, except in some parts of western and southern provinces. Drought conditions at most of the north eastern parts of Dry zone of Sri Lanka could be seen during May to September with peak drought conditions during August and September at Uva and Eastern provinces. The spatio-temporal information could be useful to increase drought preparedness and management planning at regional level.

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