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Quantification of Burned Severity of the Forest Fire using Sentinel-2 Remote Sensing Images: A Case Study in the Ella Sri Lanka

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ABSTRACT

Forest fire far could be considered as one of the majors concerning environmental issues mainly in tropical climate regions. In Sri Lanka, forest plantations and "sparsely used croplands" are the further most vulnerable areas of a forest fire. The case study was based on the forest fire reported in the Ella Rock region in 2019. The remote sensing techniques were utilized for the analysis in the QGIS open-source environment through Semi-automatic Classification Plugin (SCP) and Sentinel-2 images employed as the key source of data. Normalized Burn Ratio (NBR) and Normalized Difference Vegetation Index (NDVI) were initially applied on the pre and post images and then computed the difference of NBR (dNBR) and the difference of NDVI (dNDVI). Then through the change detection techniques extent of the fire and the severity levels were obtained. As revealed by the investigation 73.82 hectares of areas were burned due to the forest fire and 15.65% of the area was highlighted as a high severity of the burn. Moreover, NDVI and NBR significantly important in forest fire mapping also emphasized by the study. The unavailability of a complete database of the forest fire in Sri Lanka found as the major issue. Further, taking necessary actions to prevent forest fire a vital requirement of the current context.

Keywords:-*Forest fire, NBR, QGIS, Remote Sensing*

INTRODUCTION

Forest systems far could be considered as the heart of the ecosystem [1] and provide invaluable service to nature. Hence, conservation of the forest areas accountability of all human beings subsequently we all part of it. Deforestation, forest degradation, and forest fires might be identified as the biggest threat to the forest worldwide. In the fire ecology, burn severity is well-defined by the influence of fire on an environment [2]. Thus, frequently occurring forest fires were the foremost environmental hazard in any ecosystem [3,4] mainly due to human influences [5]. Hence taking necessary actions for the prevention is vital and could be identified as the major requirement in ecosystem conservation. Sri Lanka is a tropical island nation embrace with monsoon climate and the driving factors of the climate were wind and precipitation [6]. As per the evidence that available [7] approximately, two hundred forest fires occurring annually contingent on the current weather conditions. Further, the fire hazards were often not in native forest areas and most of them were recorded in peak vegetation and woodlands of the south and central highlands [8] and the study focused to investigate the forest fire occurred at Ella area in 2019.

Remote sensing usually defines as the remote monitoring features on the ground being without contact with them [9]. It is vital in the environmental-related analysis and hazard monitoring due to the spatial and temporal resolution characteristics and also owing to the capability of monitoring remotely. The freely available satellite data integrate with open-source software platforms provide a better framework for the experimental assessment [10]. Freely available Multispectral (MS) Sentinel-2 satellites, at the medium-high spatial resolution, allow the advance of more detailed forest fire mapping [11]. Sentinel-2 images were employed under investigation through the semi-automatic classification plugin (SCP) [12] in Quantum Geographic Information System (QGIS). QGIS is a free and Open-Source Desktop GIS platform that permits to map creation, edit, spatial analysis which established on the Geographical Information Science (GIS) [13]. Further, the SCP plays a significant role in applied remote sensing analysis such as image downloading, preprocessing, classification, post processing, raster calculation and etc.

Recognizing post-fire data is essential for post-fire administration activities and rehabilitation treatments. Hence, the main objective of the study is to map and quantifying the burned area and demarcate the levels of burn severity. Further, the specific objectives express as follows.

- To identify the burned area by the forest fire
- To demarcate the fired area by using remote sensing techniques
- To map the level of severity of the fired area
- To quantify the correlation between NDVI, NBR, and dNDVI, dNBR.

Pre and post images often use to distinguish the changes in every condition [14]. Thus, pre and post Sentinel-2 satellite images of the forest fire of the study area were implemented. Vegetation indices [15] have been exposed to enhance detection of vegetation types, level, etc., and further, ratio-based vegetation indices as well minimizing the topographic and atmospheric effects [15]. The Normalized Burn Ratio (NBR) is consumed to distinguish burned regions and deliver an amount of burn severity [16]. It is computed as a proportion among the Near Infra-Red (NIR) and Short-Wave Infra-Red (SWIR) bands in the optical remote sensing perspective. The NBR [17] employed to analyze the burned area and by subtracting a post-fire NBR image from a pre-fire NBR image, the differential NBR (dNBR) creates a rate of utter change [14]. The dNBR was employed to quantify the severity level of the forest fire [14] into seven classes as Enhanced regrowth high, Enhanced regrowth low, Unburned, Low severity, Moderate-low severity, Moderate-high severity, and High severity [16]. Normalized Difference Vegetation Index (NDVI) [18] correspondingly a well-known index widely used in ecological related analysis to extract environmental sensitive factors efficiently. Hence under the investigation, NDVI was used to extract the damage caused by the forest fire since Red and NIR bands were highly associated with vegetation cover. Further, significant diminution of NDVI values in post burned images was emphasized while, after the forest fire high reflection of Red and low absorption of NIR [17].

METHODOLOGY

Study Area [Figure 1]

The topography on the terrain and pattern of the wind produces dual fire periods such as from February to March in the wet zone as shorter fire season and a from June to September in the dry zone as longer fire season. And the forest fires are common in forest plantations, particularly in eucalypt and pine plantations in Sri Lanka. Ella (6.8667° N, 81.0466° E) is a small town in the Badulla District, which is disseminated among tourists due to the sites such as the Nine Arch Bridge and Little Adam’s Peak and correspondingly for hikes and feel the countryside environment. The Ella rock fire started on August 22nd and continued up to August 25th of 2019 as per the evidence from the news reported on the web since there is no proper forest fire database to access in Sri Lanka. Hence, identifying the correct location of the forest fire is one of the major concerns of the study.

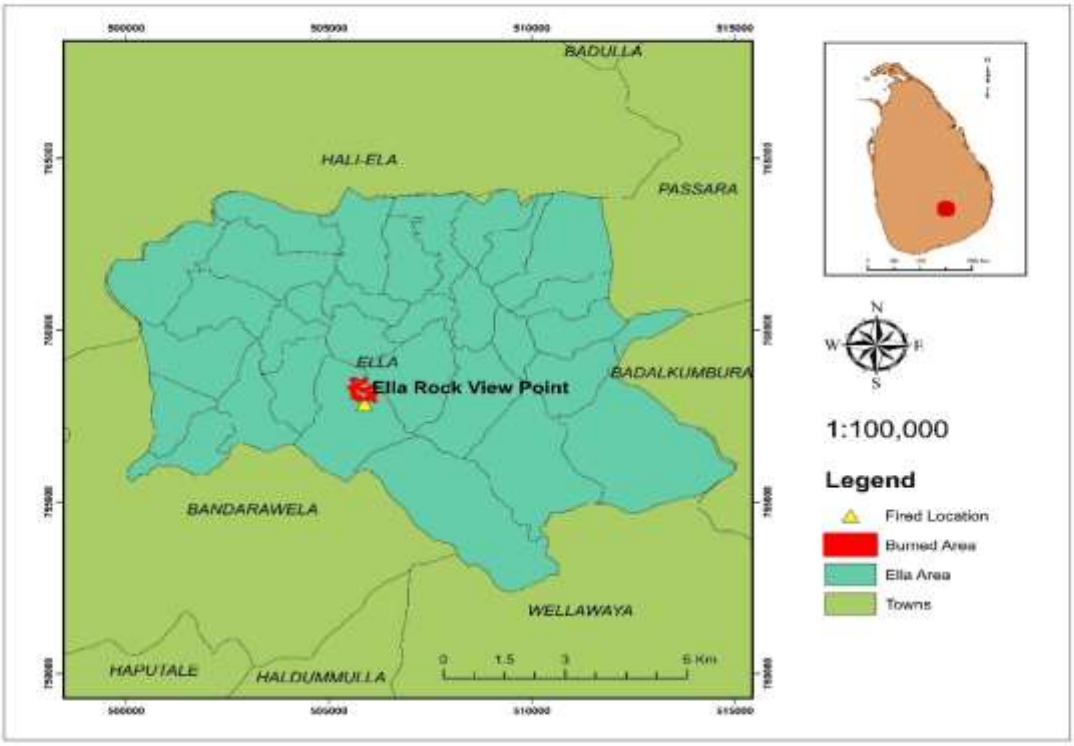

Fig. 1: *Study Area - Ella, Sri Lanka*

Consequently, by utilizing google earth images visually identified the fired location as the preliminary phase of the study. The forest fire was an annual occurrence mainly due to the lack of awareness and the dry weather condition in the area. Intending to grow fresh grass for the farmlands people of the area practiced to fire the area and this fire was also a result of such human influence on nature.

DATA USED

Freely available optical remote sensing satellites provide continuous measures of the ground with reasonable spatial resolution and owing to that the image data affords the greatest platform for scientific investigation. The Copernicus Sentinel-2 mission was started on 23rd June 2015 and compromised with two polar-orbiting satellites placed in the same sun-synchronous orbit, phased at 180° to each other as Level-1C and Level-2A [19]. Further, the Multi-Spectral Instrument (MSI) acquires 13 spectral bands extending from Visible and NIR to SWIR wavelengths along a 290-km orbital swath. Consequently, Sentinel-2 level 1C products downloaded from the Sentinel Scientific Data Hub are used as the main source of data.

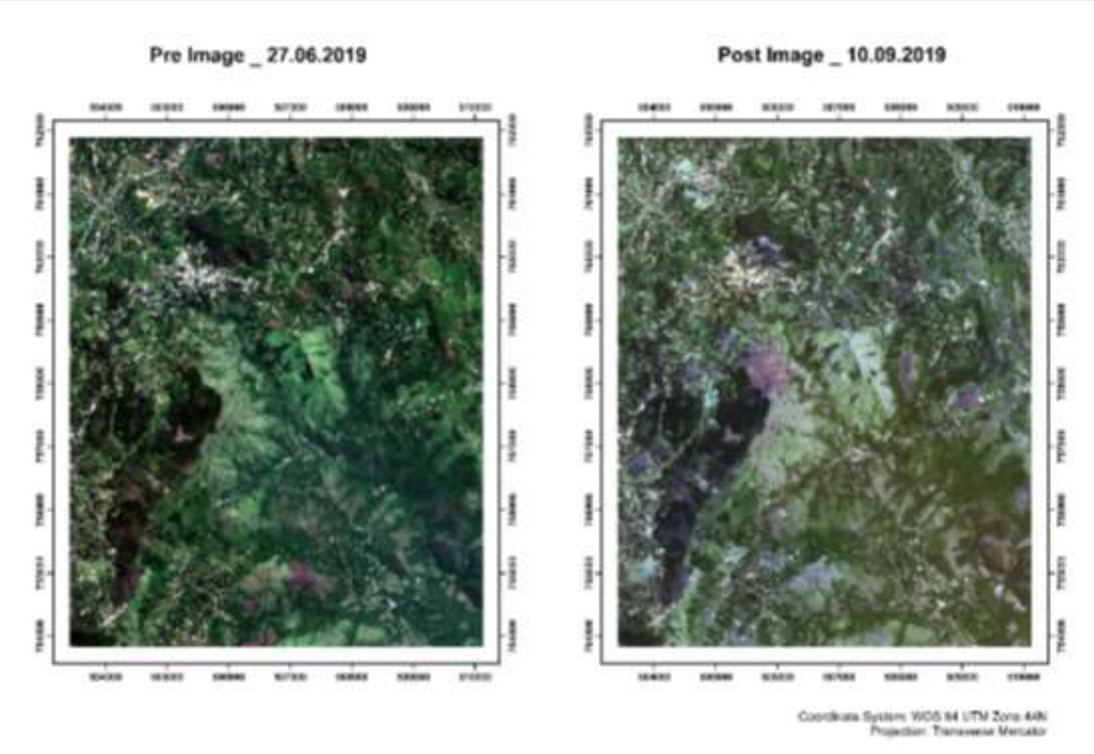

Fig. 2:*Pre and Post Sentinel-2 images*

To detect changes occurred by an incidence, it requires clear cloud-free satellite images of the same area before and after the incidence. Hence, pre and post Sentinel-2 images were employed that captured on 27th June 2019 and 10th September 2019 respectively since the incident occurred on 22nd August 2019 as shown in Figure 2. Even though, it necessitates an immediate satellite image just after the incidence for better analysis, it was unable to collect due to the cloud cover presence. Therefore, the closely acquired image that available was used and ultimately obtained reasonable results.

METHODOLOGY APPLIED

Google Earth images were used to identify the actual ground area by the forest fire subsequently it is difficult to find a database of the fire. Hence news articles and reports regarding the forest fire were used as evidence. Then, the exact date and the location of the fire were identified by using Google Earth temporal images. Sentinel 2 images were downloaded from Copernicus Sentinel Scientific data hub and applied preprocessing to both images through the SCP in QGIS. The overall methodology implemented over the investigation state in Figure 3.

Normalized Burn Ratio (NBR) [Figure 4]

The raw Satellite image is compromised with a spectral band in spatial resolution and each spectral band has its way of interact with the features on the ground [16] and the vegetation indices are defined based on the absorption and reflectance characteristic with the ground features and respective wavelength regions. The NBR has been developed to measure the burned areas efficiently by Key and Benson in 1996 [16] and further, it's much similar to NDVI. NBR is a ratio-based vegetation index and can be stated as follows

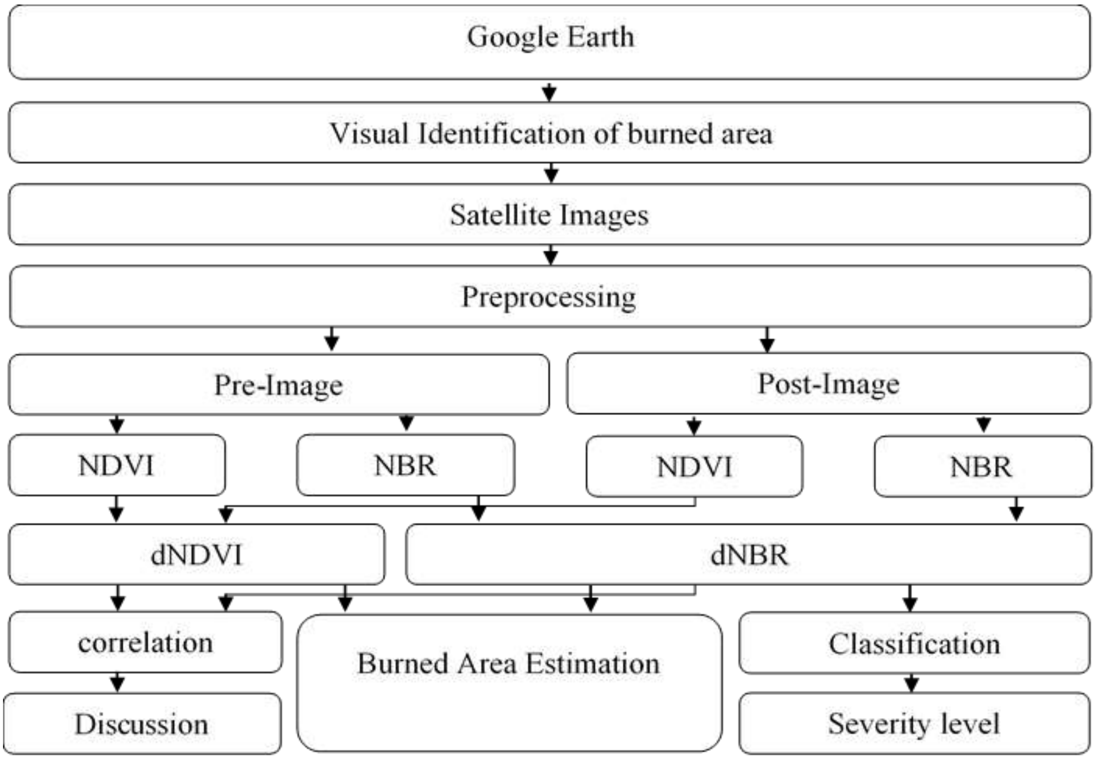

Fig. 3: *Methodological Framework applied over the investigation*

For detecting fire scars, NBR was outperformed than the other remotely sensed indices as per the recently published research papers [16], [17], [20] and, moreover NBR is subtle to the quantity of moisture content, ash in the soil, and Chlorophyll content in plants.

This separates the actual reflective variances among the bands, which allows spatial and multitemporal assessment of the resulting NBR values efficiently.

Change detection [15] analysis significant in measuring the changes that occurred due to particular incidence [16], [17], [20].

$$\boldsymbol{Normalized\ Burn\ Ratio\ (NBR)} = \frac{Near\ Infrared - Short\ Wave\ Infrared}{Near\ Infrared + Short\ Wave\ Infrared}$$

Mostly, Mid Infrared upsurges from pre-fire to post-fire while the variation is utmost in extent related to other bands, and the discrepancy in between burns is greatest [16].

The ration-based indices benefit to remove within-scene topographic effects and between-scene solar illumination effects.

Hence, pre and post-images are required to quantify the alteration.

Consequently, to demarcate burned from unburned regions and to quantify the change that arises, the pre and post-NBR images were subtracted. The delta NBR (ΔNBR) or dNBR [16] can be stated as follows.

ΔNBR or dNBR*= (NBR_Prefire) – (NBR_Postfire)*

The pre-fire image contains high NIR values and low SWIR Digital Number (DN) values and further, the post-fire image contains low NIR values and high SWIR DN values comparatively.

The levels of the burn severity obtained by classifying the dNBR as per the United States Geological Survey (USGS) to decode the burn severity as shown in Table 1.

Table 1:*The Levels of severity and dNBR range (scaled by 10^3)*

Severity Level	dNBR Range
Enhanced regrowth high	–500 to –251
Enhanced regrowth low	–250 to –101
Unburned	–100 to +99
Low severity	+100 to +269
Moderate-low severity	+270 to +439
Moderate-high severity	+440 to +659
High severity	+660 to +1300

The higher dNBR signifies more severe damage and regions with negative dNBR values imply improved efficiency after the fire [16]. The following Figure 5 illustrates the burn harshness level map of the study area.

Due to the cloud cover and the unavailability of data, the post-fired image collected after two weeks from the fire happened nonetheless capable to obtain a sensible production.

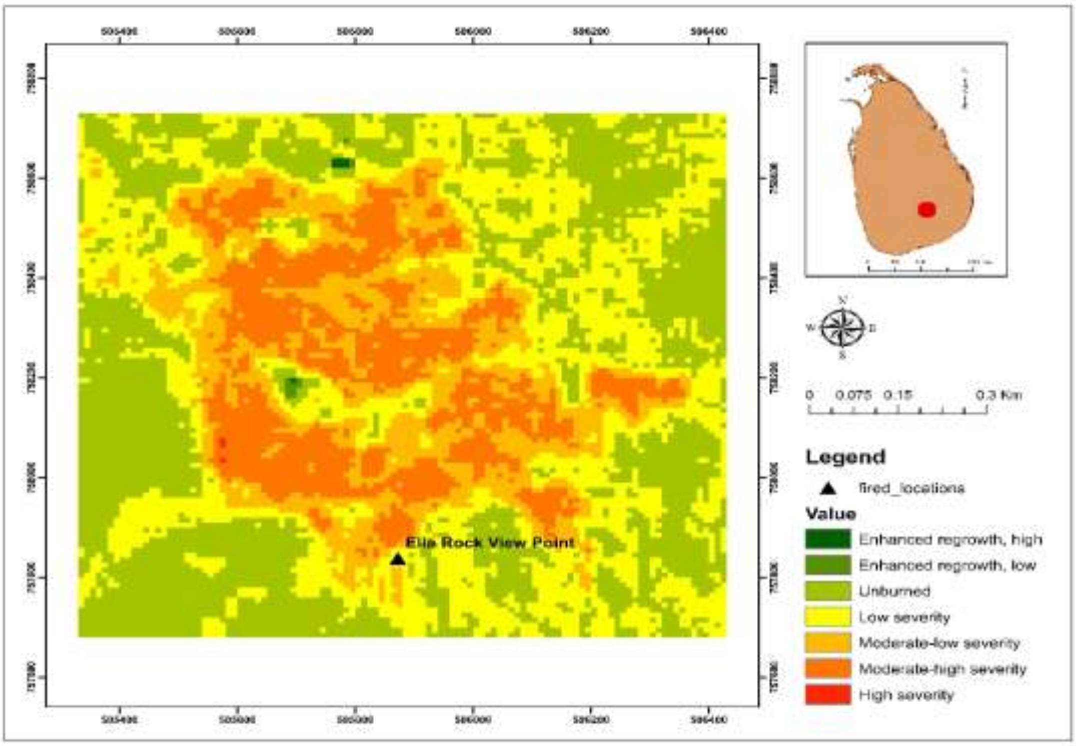

Fig. 4:*The Burn severity classification*

Normalized Difference Vegetation Index (NDVI)

The normalized difference vegetation index (NDVI) is commonly used to evaluate the fluctuations in vegetation cover [21]. The ratio-based vegetation index, NDVI calculate using Red and NIR bands.

$$\boldsymbol{NDVI} = \frac{Near\ Infrared - RED}{Near\ Infrared + RED}$$

Tucker first suggested NDVI in 1979 as an index of vegetation health and density and also it is a virtuous indicator of green biomass, leaf area index, and patterns of production. The NDVI values vary from +1 to-1, the positive NDVI values are linked with vegetated areas in different conditions, although zero and negative values match bare soil and water bodies. Moreover, the NDVI is used to measure the biophysical characteristics on the ground and also for long-term vegetation-related analysis and change detection.

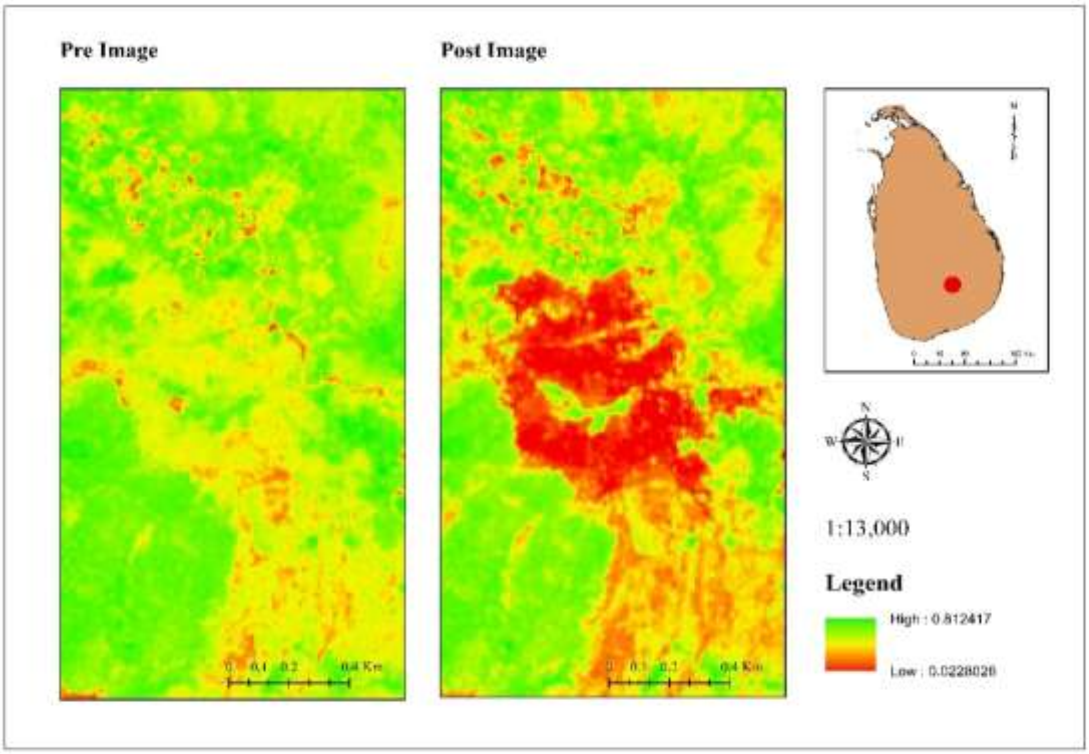

Fig.5:-*Pre and Post NDVI Images of the Study Area*

Under the investigation to generate the risk map and to determine the pattern of vegetation NDVI have been intended in Figure 6. Thresholds-based segmentation was applied over the two NDVI images to contrast vegetation and non-vegetation zones in a fired condition in Figure 7 below [22].

- NDVI < 0.128 non-Vegetation
- NDVI > 0.128 Vegetation

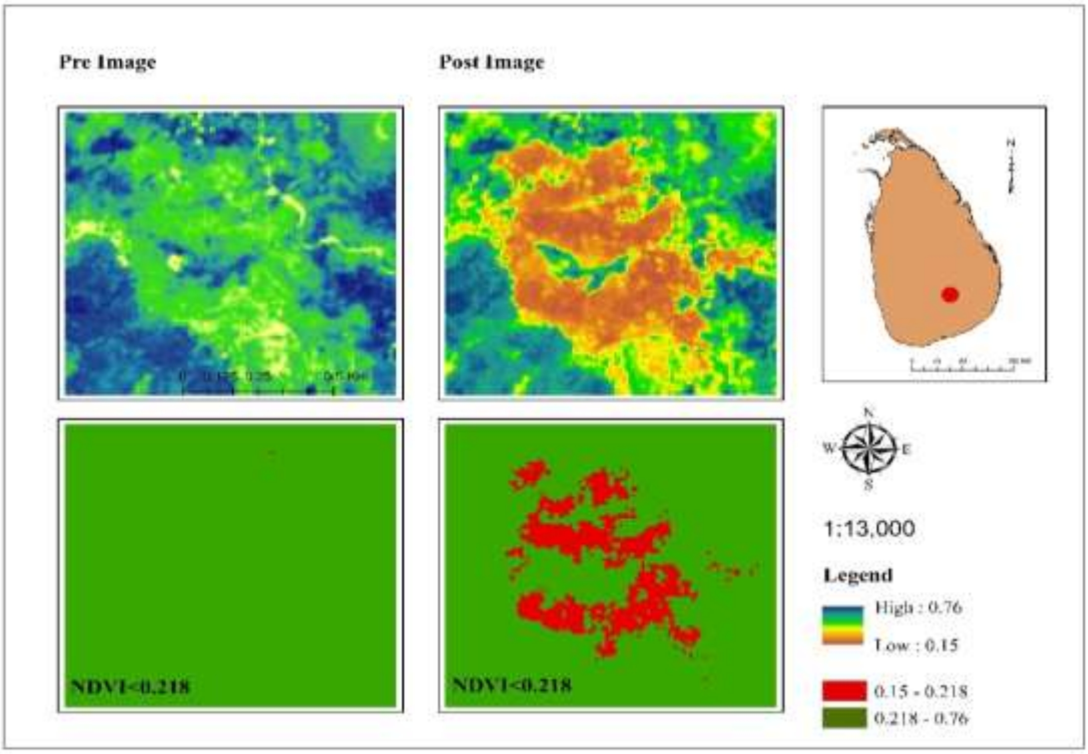

***Fig.6:**-Threshold applied Pre and Post NDVI Images of the Study Area*

RESULT AND DISCUSSION

Burned Area Extraction and Harshness Level mapping from the Forest Fire

In the study area, nearly 73.82 hectares of area burned by the forest fire, and 63.92 % of the area highlighted as burned severity while 15.65% of the area highlighted as high severity as per the following Table 2.

***Table 2:**-Severity Level, Area coverage, and Percentage of coverage of the study area*

Severity Level	Area in hectares	Percentage of Coverage
Enhanced regrowth high	00.07	00.06%
Enhanced regrowth low	00.12	00.10%
Unburned	41.49	35.92%
Low severity	36.12	31.27%
Moderate-low severity	19.63	17.00%
Moderate-high severity	18.04	15.62%
High severity	00.03	00.03%

The Profile graphs of the pre- and post-NBR and NDVI indicate the fluctuation o the values with the forest fire in Figure 8. All the values were comparatively low in the post images while indicating the damage caused to nature due to the burning of the ground.

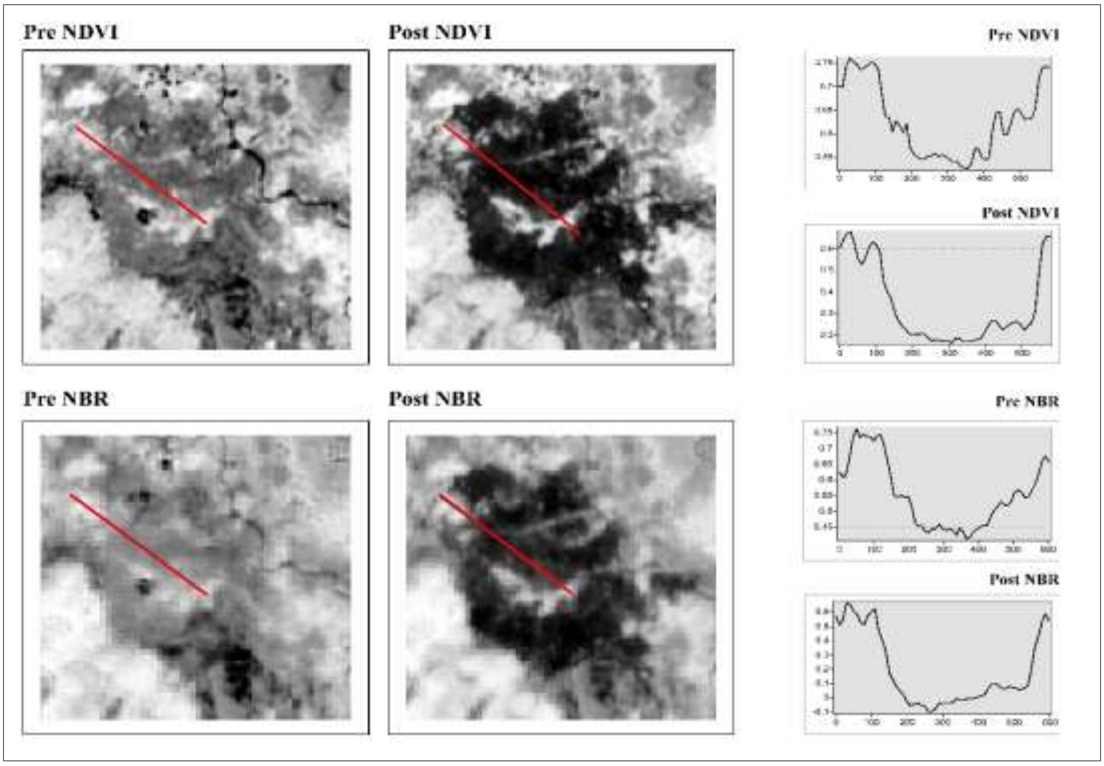

***Fig.7:-**Profile graphs of the pre and post NBR and NDVI*

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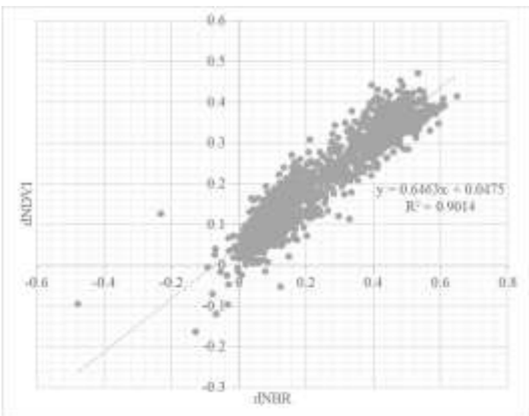
Correlation Mapping of the pre and post vegetation conditions

The Correlation coefficient is statistical index of a single number that represents the degree to which two variables are associated, or related. When two variables are strongly associated, the result in a positive correlation, and when the two variables were inversely proportioning then negative correlation values resulted, and when two variables are not associated with each other it indicates by the value zero. Hence, the correlation values could be able to utilize the degree of the association between the variables in the present study as follows.



(a)

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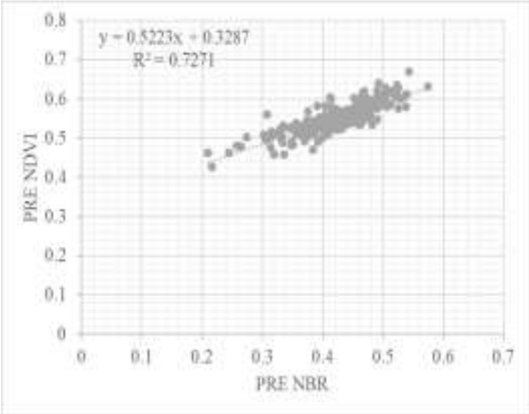
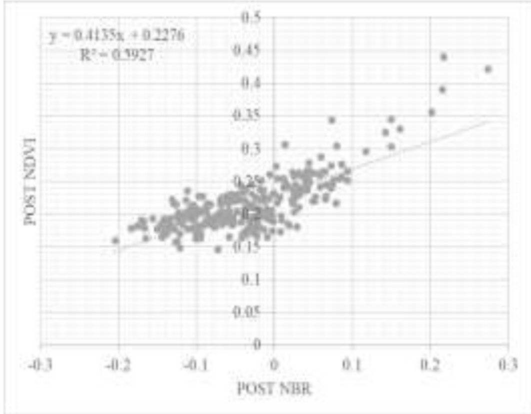
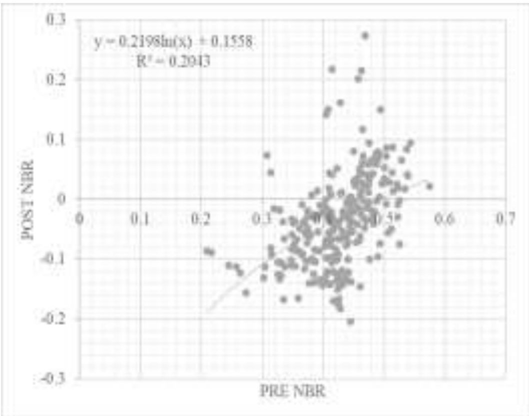


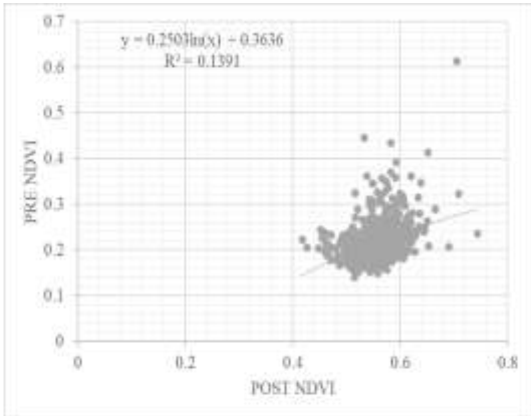
(b)



(c)



(d)



(e)

Fig.8: *Scatter-graph of correlation analysis between the variables the implemented over the study, (a) dNBR and dNDVI, (b) Pre NBR and Pre NDVI, (c) Post NBR and Post NDVI, (d) Pre NBR and Post NBR, (e) Pre NDVI and Post NDVI*

The graph [Figure 9] in-between dNBR and dNDVI shows a high positive correlation as the sign of interrelationship between the two indices. Hence, both indices were vital in forest fire mapping. Further, as per graph (b) and (c) indicate moderate positive correlation can be observed between Pre NDVI to Pre NBR and Post NDVI to Post NBR. Hence it shows the importance of having differential values for better representation of both indices than using indices alone. Hence, subtracting pre- and post-images could be able to obtain a better result than the single indices representation. Moreover, Post NBR and NDVI values show more negative points which were not presented at the Pre NBR and NDVI scatter plots. Thus, it indicates most of the values turn negative due to the forest fire incident.

The considerable differences should be present between pre- and post-images (before and after the forest fire) due to the fire. There should not remain a correlation

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between the Pre and Post images. The hypothesis proved to from the correlation analysis. Graphs (d) and (e) (the scatter plots of Pre and Post NBR and NDVI) expressed a relatively weaker correlation by emphasizing the effect of the burn.

CONCLUSION AND RECOMMENDATION

Remote sensing analysis plays a significant role in forest fire mapping and for better representation of the result required to integrate with the field measurements vital. Further, the freely available satellite images and the open-source platforms provide an excellent framework for scientific investigations. The NBR and NDVI indices were vital in forest fire mapping and recommend using in-field measurement when the physical approach gets disturbed or difficult. Even though the optical satellite images were providing better analysis, the cloud cover could be identified as a major drawback. Hence, integrated optical data with microwave data would be effective than a single type. As per the investigation, 73.82 ha were burned, and it is not a small value compared to our country.

Continuous measuring of the forest fires and maintain a proper web-based fire management database timely requirement of the country and it is better to change the manual bookkeeping to the database management system for storing and retrieving the forest-related data. That will help future forest management, policy development, awareness, and also for scientific instigations like predicting the future pattern of the forest fire.

Further, relevant authorities should take necessary actions to prevent forest fires since it is difficult to measure the damage that affects nature due to the forest fires. The majority of the forest fires in Sri Lanka occurred due to human influences directly or indirectly. Throwing cigarette butts to forest areas, burning dead grass debris, burning due to shifting cultivations, animal hunting can be identified as the major causes of the forest fire under the influence of the human being. Hence, proper awareness between the general public, policy development, and implementation of proper new laws could be some solutions for the issue. Further, for prevention of the fire effects implementing fire and fuel breaks, introducing Fire belts, Vegetation implementation, Firefighting reservoirs, and establishing adequate fire brigades would be some solutions.

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