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Calculation of Normalized Burn Ratio and Derivation of Fire Radiative Power by Comparing Reflectance of Satellite Images Before and After Forest Fires

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1. Introduction

Most nuclear power plants (NPPs) in Republic of Korea are surrounded by forests. In particular, such terrain can affect transmission lines in the event of a forest fire, causing loss of off-site power (LOOP).

A forest fire that occurred in Uljin-Samcheok in March 2022, was the historically longest forest fire in Korea since the started to the record 1950s [1]. It was very close to approach the NPPs site border and effecting to transmission line integrity. The insulation of the transmission line was failed due to heat, smoke, and other combustion materials then affecting 4 roots(8 lines) connected to the Hanul Nuclear Power Plant, causing a failure in the off-site power supply system.

However, compared to general fires, forest fires have a wider damage range and have the characteristic of continuously spreading through the surrounding environment, making it difficult to quantify the risk of a specific area.

Therefore, in this study, quantitative risk will be derived by comparing the reflectance of the affected area before and after a forest fire using satellite images, and introducing to risk analysis method for transmission lines by forest fire.

2. Basic Methodology for Wildfire Risk Analysis

2.1 Normalized Burn Ratio

The normalized burn ratio (NBR) is an index designed to highlight damaged area in large fire zones. The formula is similar to normalized difference vegetation index (NDVI), except that the formula combines the use of both near infrared (NIR) and shortwave infrared (SWIR) wavelengths.

Healthy vegetation shows a very high reflectance in the NIR, and low reflectance in the SWIR portion of the spectrum the opposite of what is seen in area devastated by fire. Recently damaged area demonstrate low reflectance in the NIR and high reflectance in the SWIR, i.e. the difference between the spectral responses of healthy vegetation and damaged area reach their peak in the NIR and the SWIR regions of the spectrum.

$$NBR = \frac{NIR - SWIR}{NIR + SWIR}$$

2.1.1 Identifying Burn Severity

The difference between the prefire and postfire NBR obtained from the images is used to calculate the delta NBR (dNBR or ΔNBR), which then can be used to estimate the burn severity. A higher value of dNBR incidents more severe damage, while area with negative dNBR values may indicate regrowth following a fire

$$dNBR \ or \ \Delta\text{NBR} = \text{PrefireNBR} - \text{PostfireNBR}$$

dNBR values can vary from case to case, and so, if possible, interpretation in specific instances should also be carried out through field assessment; in order to obtain the best results. However, the United States Geological Survey (USGS) proposed a classification table to interpret the burn severity, which can be seen below.

Severity Level	dNBR Range (scaled by 10^3)	dNBR Range (not scaled)
Enhanced Regrowth, high (post-fire)	-500 to -251	-0.500 to -0.251
Enhanced Regrowth, low (post-fire)	-250 to -101	-0.250 to -0.101
Unburned	-100 to +99	-0.100 to +0.99
Low Severity	+100 to +269	+0.100 to +0.269
Moderate-low Severity	+270 to +439	+0.270 to +0.439
Miderate-high Severity	+440 to +659	+0.440 to +0.659
High Severity	+660 to +1300	+0.660 to +1.300

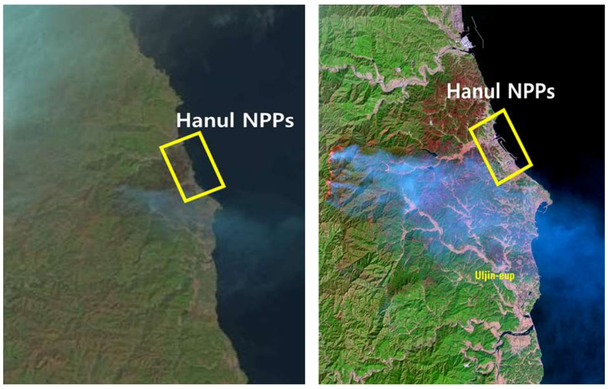
Fig. 1. Burn severity levels obtained calculating dNBR(USGS Proposed)

Burn severity data and maps can aid in developing emergency rehabilitation and restoration plans postfire. They can be used to estimate not only the soil burn severity, but the likelihood of future downstream impacts due to flooding, landslides, and soil erosion.

In this study, a methodology for analyzing the risk of transmission lines according to the severity of forest fire damage was presented using the 2022 Uljin-Samcheok forest fire as a model.

2.1.2 Obtaining and Correcting Satellite images

In order to quantify the severity of forest fire damage through the difference in reflectance before and after a forest fire, dNBR according to reflectance must be calculated using satellite images [2] of the 2022 Uljin-Samcheok forest fires. The reflectance of satellite images needs to be corrected using the Geographic Information System (GIS) mapping program.



(a) (b)

Fig. 2. (a) Satellite image before correction, (b) Satellite image after correction

2.2 Transmission Lines Risk Analysis Procedure

The procedure for quantitative method the severity of forest fire damage and the risk of transmission lines using reflectivity before and after a forest fire is as follows.

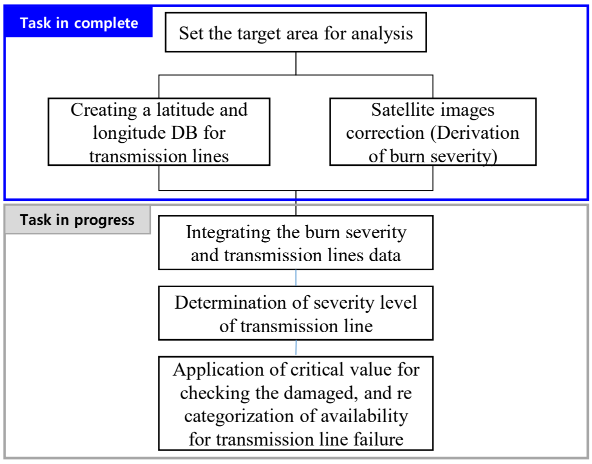


Fig. 3. Transmission Lines Risk Analysis Procedure

2.2.1 Determination to the target area for analysis

According to the Korea Forest Service, the damaged area by the Uljin-Samcheok forest fire in 2022 is 14,140ha in Uljin and 2,162ha in Samcheok. Therefore, 20,000ha of the boundary of the analysis area was selected, including the damaged area in the two regions.

Fig. 4. Determination to the target area for analysis

2.2.2 Satellite Images Correction for Derivation of Burn Severity Level

Differences in reflectance are corrected by comparing the NBR of satellite images before (a) and after (b) a forest fire then confirm the dNBR (c). After that the level of severity map is generated by applying the burn severity level which is presented by the USGS (d).

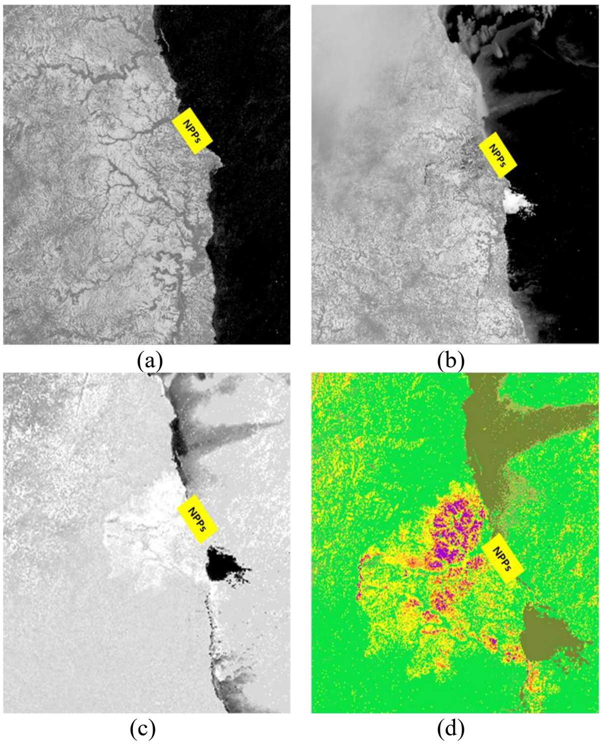


Fig. 5. (a) NBR(Pre-fire), (b) NBR(Post-fire), (c) dNBR(Pre-Post), (d) Apply to burn severity level

2.2.3 Creation of Transmission Lines Coordinate DB

When the wildfire damaged area for analysis is confirmed, a database must be constructed that indicates the location of power transmission lines located in the area by latitude and longitude. This database will later be combined with burn severity maps.

Line 1 Root 1-1	latitude	longitude	Line 1 Root 1-2	latitude	longitude	Line 2 Root 2-1	latitude	longitude	Line 2 Root 2-2	latitude	longitude
1	37 05 25 N	129 22 47 E	1	37 05 26 N	129 22 48 E	1	37 05 26 N	129 22 49 E	1	37 05 27 N	129 22 49 E
2	37 05 26 N	129 22 47 E	2	37 05 26 N	129 22 47 E	2	37 05 26 N	129 22 48 E	2	37 05 27 N	129 22 48 E
3	37 05 26 N	129 22 46 E	3	37 05 27 N	129 22 47 E	3	37 05 27 N	129 22 48 E	3	37 05 28 N	129 22 48 E
4	37 05 27 N	129 22 46 E	4	37 05 27 N	129 22 46 E	4	37 05 27 N	129 22 47 E	4	37 05 28 N	129 22 47 E
5	37 05 26 N	129 22 45 E	5	37 05 27 N	129 22 45 E	5	37 05 28 N	129 22 47 E	5	37 05 28 N	129 22 46 E
6	37 05 26 N	129 22 44 E	6	37 05 27 N	129 22 44 E	6	37 05 28 N	129 22 46 E	6	37 05 28 N	129 22 45 E
7	37 05 26 N	129 22 43 E	7	37 05 26 N	129 22 44 E	7	37 05 28 N	129 22 45 E	7	37 05 28 N	129 22 44 E
8	37 05 26 N	129 22 42 E	8	37 05 26 N	129 22 43 E	8	37 05 27 N	129 22 44 E	8	37 05 28 N	129 22 43 E
9	37 05 25 N	129 22 42 E	9	37 05 26 N	129 22 42 E	9	37 05 27 N	129 22 43 E	9	37 05 27 N	129 22 42 E
10	37 05 25 N	129 22 41 E	10	37 05 26 N	129 22 41 E	10	37 05 27 N	129 22 42 E	10	37 05 27 N	129 22 41 E
11	37 05 25 N	129 22 40 E	11	37 05 26 N	129 22 40 E	11	37 05 27 N	129 22 41 E	11	37 05 27 N	129 22 40 E
12	37 05 25 N	129 22 39 E	12	37 05 25 N	129 22 40 E	12	37 05 27 N	129 22 40 E	12	37 05 27 N	129 22 39 E
13	37 05 24 N	129 22 39 E	13	37 05 25 N	129 22 39 E	13	37 05 26 N	129 22 40 E	13	37 05 27 N	129 22 38 E
14	37 05 24 N	129 22 38 E	14	37 05 25 N	129 22 38 E	14	37 05 26 N	129 22 39 E	14	37 05 26 N	129 22 38 E
15	37 05 23 N	129 22 38 E	15	37 05 24 N	129 22 38 E	15	37 05 26 N	129 22 38 E	15	37 05 26 N	129 22 37 E
16	37 05 22 N	129 22 38 E	16	37 05 23 N	129 22 38 E	16	37 05 26 N	129 22 37 E	16	37 05 26 N	129 22 36 E
17	37 05 21 N	129 22 39 E	17	37 05 22 N	129 22 38 E	17	37 05 26 N	129 22 36 E	17	37 05 26 N	129 22 35 E
18	37 05 20 N	129 22 39 E	18	37 05 21 N	129 22 38 E	18	37 05 25 N	129 22 35 E	18	37 05 26 N	129 22 34 E
19	37 05 19 N	129 22 39 E	19	37 05 20 N	129 22 38 E	19	37 05 25 N	129 22 34 E	19	37 05 26 N	129 22 33 E
20	37 05 18 N	129 22 39 E	20	37 05 19 N	129 22 38 E	20	37 05 25 N	129 22 33 E	20	37 05 26 N	129 22 32 E
21	39 05 17 N	129 22 39 E	21	37 05 19 N	129 22 39 E	21	37 05 25 N	129 22 32 E	21	37 05 25 N	129 22 32 E
22	37 05 16 N	129 22 39 E	22	37 05 18 N	129 22 39 E	22	37 05 25 N	129 22 31 E	22	37 05 25 N	129 22 31 E
23	37 05 16 N	129 22 40 E	23	37 05 17 N	129 22 39 E	23	37 05 25 N	129 22 30 E	23	37 05 25 N	129 22 30 E
24	37 05 15 N	129 22 40 E	24	37 05 16 N	129 22 39 E	24	37 05 25 N	129 22 29 E	24	37 05 25 N	129 22 29 E
25	37 05 14 N	129 22 40 E	25	37 05 15 N	129 22 39 E	25	37 05 25 N	129 22 28 E	25	37 05 25 N	129 22 28 E
26	37 05 13 N	129 22 40 E	26	37 05 14 N	129 22 39 E	26	37 05 24 N	129 22 27 E	26	37 05 25 N	129 22 27 E
27	37 05 12 N	129 22 40 E	27	37 05 13 N	129 22 39 E	27	37 05 24 N	129 22 26 E	27	37 05 25 N	129 22 26 E

Fig. 6. Transmission lines coordination DB

2.2.4 Determination of Transmission Lines Risk Level

By integrating the burn severity map and transmission line data ordered by latitude and longitude coordination, the burn severity according to coordinates is determined.

The fire intensity will be calculated [3] from the each cell where the transmission lines are located. The critical value at which the transmission line is damaged is calculated, and then it is determined whether the coordinates where the transmission line is located are damaged.

The critical value can be calculated by deriving standards for temperature, heat flux, and radiant heat at which transmission lines are damaged through manual calculation, or converting fire burn severity into fire intensity [4].

3. Conclusions

This report presented a methodology for determining the risk and damage of transmission lines located in the area based on a method of deriving the severity of forest fire damage by comparing the reflectance of satellite images before and after a forest fire.

An ongoing study will figure out the transmission line coordinate data is input into a forest fire damage severity map to check the burn severity level of the area where the transmission line is located.

Transmission lines located in areas classified according to burn severity can be judged on the actual possibility of damage by applying critical value such as damageable heat, heat flux, or radiant heat, and can be excluded from damage if its necessary.

However, in order to apply to the transmission lines risk analysis that can be generally applied to other domestic nuclear power plants not only for Hanul NPPs, it is necessary to analyze the distribution trend of forest fire burn severity for multiple forest fire cases.

These results can be used as basic data for safety evaluation of external events for nuclear power plants.

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