Integrating GIS and AHP for Forest Fire Risk Mapping in Kailali, Nepal

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KEYWORDS

Forest fire risk, AHP, GIS-MCDA, GEE, Criteria Factors

ABSTRACT

Forest are the Earth's predominant geographical phenomena distributed throughout the world and provide essential ecosystem services and products that benefit both humans and wildlife. The sustainability of the forest resources can be seriously affected by the forest fire in the dry regions covered with fire sensitive trees species. The risk of the forest fire mainly depends on the various factors such as vegetation type, topographical features, climatic parameters, socio-economic factors. Geographic Information System (GIS) and Remote Sensing (RS) technologies are frequently used for the monitoring, detection, and management of forest fires. Seven parameters: land cover, elevation, slope, aspect, land surface temperature (LST), and proximity to settlement and road were compared with each other and pair wise matrix was formed. The weight of each parameters was determined by using AHP technique. Then by using the raster calculator weighted-overlay analysis was performed to determine the final forest fire risk zone. The forest fire risk zone was categorized into five classes; very high-risk zone, high risk zone, moderate risk zone, low risk zone, and very low risk zone. The result indicated that there is a very high risk of forest fire in about 30.78%, a high risk in 34.06%, a moderate risk in 22.45%, a low risk in 9.87% and very low risk in 2.84% of total area of Kailali district.

1. INTRODUCTION

Forest is the Earth's predominant ecosystem, distributed throughout the world and produces 80% of planet's biomass (Y. Pan et al., 2013). Based on the annual report on world forest resources prepared by the Food and Agriculture Organization (FAO) in 1990, the world's total forest cover was 4.13 million hectares, but the figure diminished to 3.999 million hectares in 2015, showing a 3% reduction (FOA, 2015). Forest fires have just recently been investigated in Nepal, and the significance of these studies is not completely recognized. Consequently, there aren't many comprehensive research on forest fires. In order to tackle fire-related issues and protect forested regions, creating a fire map is a crucial first step. Planning and managing forest conservation methods can be improved by utilizing Multi-Criteria Decision Analysis (MCDA) methodologies in conjunction with Geographic Information System (GIS) technology (Feizizadeh et al., 2015). This method enables an in-depth assessment of all the variables that affect the risk of a fire, including topography, vegetation type, proximity to populated areas, and past fire trends (Mosadeghi et al., 2013). Through a methodical examination of these factors, policymakers can arrange resources and actions in a way that will reduce the adverse effects of fires and improve the resilience of forests as a whole. Various studies have been carried out around the world to model and assess forest fire risk and to identify the regions susceptible to fire. One of the methods widely used is Analytical Hierarchy Process (AHP) (Pourghasemi et al., 2016; Eugenio et al., 2016; Chhetri & Kayastha, 2015). The main objective of this research is to apply GIS-based MCDA, AHP for fire risk mapping. This method was chosen in this research because this had acceptable performance in various fields of study and classification problems. In particular, this study aims to prepare a forest fire risk map to prevent, manage and mitigate the incidence of fire in the Kailali, Nepal.

2. STUDY AREA

Kailali, one of the districts of Nepal, is located in the southwestern part of Terai in the Far Western Province. It has 3,235 Sq. Km area and among which 40 per cent is covered by plain terai land, 60 per cent is covered by hills of Chure range (DAO, Kailali). It is located at the latitude from $28^{0}22'$ North to $29^{0}05'$ North and longitude from $80^{0}30'$ East to $81^{0}18'$ East. It has elevation ranges from 109 m to 1950 m above sea level. This district constitutes of 13 local levels with one sub-metropolitan city, six municipalities and six rural municipalities. Dhangadhi is the district headquarter of Kailali district. Among total area of the district, 63.4 Percent of land is covered with forest and 27.8 percent land is fertile agricultural cultivated land. There are all together 229 community forest in this district. The Average Annual Rain Fall measured in this district is 1840 mm and Climate varies from tropical to sub-tropical (DAO, Kailali). The district is home to numerous religious, mythological, and historical sites, including Ghodaghodi Lake in Ghodaghodi Municipality, which is registered in the World Ramsar list. The study area of the project is shown Figure 1 below.

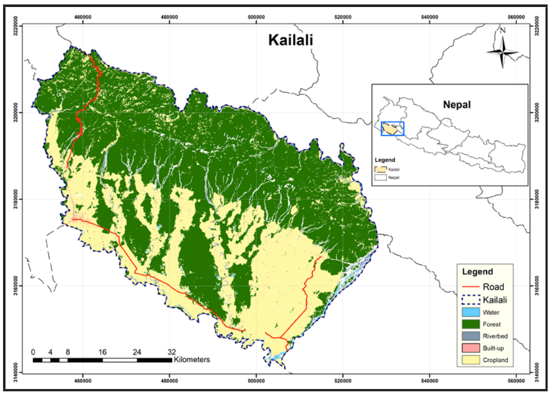

Figure 1 Study area

3. MATERIAL AND METHODS

3.1 Datasets and Software

The data used for this study are Landsat image, Digital Elevation Model (DEM), Road Network, Settlement Data, MODIS LST data, and MODIS fire hotspot data were employed for the study. GIS software was used for overall analysis and mapping purpose. Google Earth Engine (GEE) platform was used for land-cover classification.

Table 1 Datasets

S.N	Data	Data Type	Resolution	Source
1	Landsat-8 Image	Raster	30 m	USGS Earth Explorer using GEE
2	DEM	Raster	30 m	SRTM USGS Earth Explorer
3	Settlement	Point	1:25,000	OCHA Nepal
4	Road Network	Line	Vector Data	Open Street Map (OSM)
5	LST	Raster	1 km	USGS Earth Explorer using GEE (MOD11A1v 061)
6	MODIS Fire Data	Point	Derived from data of 1 km resolution	Fire Information for Resource Management System (FIRMS)

3.2 Methodology

The methods include an overview of the project's methodology, covering planning, data collection and preparation, parameter selection, and weight determination for final fire risk model. The overall methodology used for fire risk mapping is shown in the Figure 2 below.

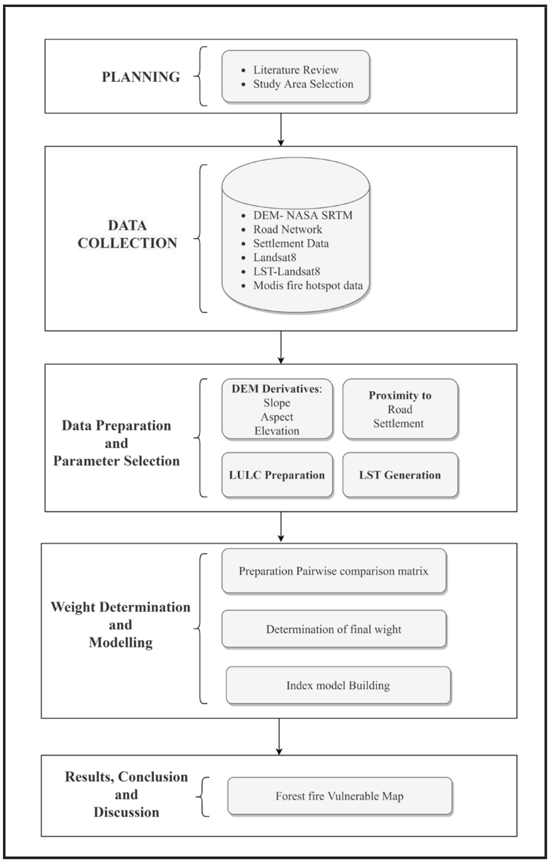

Figure 2 Work flow diagram

3.2.1 Data Collection and Data Preparation

Landsat image, DEM, Road Network, Settlement Data, LST data, and MODIS fire hotspot data were collected. Collected data were further processed with the help of GIS and GEE. DEM was used to generate slope, aspect and elevation of the study area. Land cover is considered to be the critical factor for spreading fire and has high weightage for influencing the risk. Supervised classification technique was used for image classification. Algorithm called *ee.Classifier.smileCart()* was used. Image was classified into five different classes. Forest, cultivation, built-up, water body and sand were five classes. Accuracy assessment of the classification was also done in GEE by constructing confusion matrix. Out of total sample point 70% were used for training class and 30% were used for validation. The classified landcover map is shown in Figure 3.

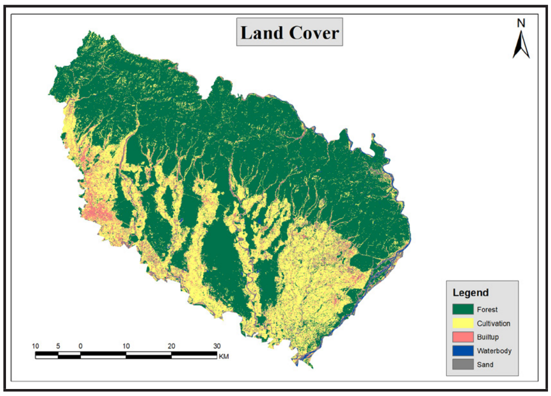

Figure 3 Landcover in Kailali

Land surface temperature can be generated form the NASA/MODIS images (Parajuli et al., 2020). In this study, monthly mean land surface temperature from 2016 to 2022 was extracted from NASA/MODIS image in GEE.

Distance to a road and settlement are used to identify the risk areas where maximum human activities occur. The fires are more common near roads and rivers because of increased movement there (Parajuli et al., 2020). So, based on the different research studies (Parajuli et al., 2020, Pourghasemi et al., 2016; Eugenio et al., 2016; Chhetri & Kayastha, 2015) road network and settlement data were used and grouped into following five categories: 0-1000m, 1000- 2000m, 2000-3000m, and above 4000m. Then multi ring buffer with 1000m interval were carried out using GIS.

3.2.2 Weight Determination and Model Preparation

The forest fire risk map was planned by using the GIS based AHP method by considering risk factors including land cover, elevation, slope, aspect, land surface temperature, and proximity to settlement and road. AHP was first described by Myers and Alpert (1968) and then modelled by (Saaty, 1994). A set of evaluation criteria is evaluated and optimum solution among a set of alternative option is searched in the AHP method. In the process of AHP, the study area was classified into five forest fire risk classes: very low, low, moderate, high and very high. The main criteria used were land cover, elevation, slope, aspect, land surface temperature, and proximity to settlement and road. A weight of each criteria was generated by using decision maker's pairwise comparison. In order to determine the pairwise comparison matrix between the selected seven parameters different literatures were studied. References were taken from Akay & Şahi (2019), Parajuli et al., (2020), Lamat et al., (2021), and Parajuli et al., (2023) for constructing the pairwise comparison matrix. Pairwise comparison matrix is as shown in Table 2 below. After the construction of the pairwise comparison matrix, eigenvector and weighting coefficient were calculated and then consistency ratio was calculated using online based AHP weight calculator tool.

Table 2 Pairwise Comparison Matrix

Parameters	Land cover	Temperature	Proximity to Settlement	Proximity to Road	Slope	Aspect	Elevation
Land cover	1	3	5	5	5	7	7
Temperature	1/3	1	3	3	3	5	5
Proximity to Settlement	1/5	1/3	1	1	1	2	2
Proximity to Road	1/5	1/3	1	1	1	2	2
Slope	1/5	1/3	1	1	1	2	2
Aspect	1/7	1/5	½	1/2	12	1	1
Elevation	1/7	1/5	½	1/2	1/2	1	1

The eigenvector and weighting coefficient calculation and consistency ratio calculation was done using following equation (Saaty, 1994).

The eigenvector (Vp) is calculated using equation as follows:

$$Vp = \sqrt[k]{W1 * \ldots \ldots Wk} \quad \ldots\ldots\ldots\ldots(1)$$

Where k is the number of factors, and W is the ratings of the factor.

The weighting coefficient (Cp) is calculated using equation as follows:

$$Cp = \frac{Vp}{Vp1 + \ldots Vpk} \ldots\ldots\ldots\ldots (2)$$

The sum of Cp of all parameters of a matrix must be equal to 1. The matrix is normalized by dividing each element by the sum of the column. Then, Consistency Ratio (CR) is calculated by using equation as follows:

$$CR = \frac{CI}{RI} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$CI = \lambda \max - k)/(k-1) \ldots\ldots\ldots\ldots (4)$$

Where CI is consistency Index and λmax is the maximum eigenvalue obtained as 7.06576.

CI was found to be 0.0109599. Both values of λmax and CI were obtained from AHP tool. RI is the random index. RI is the average CI depending on the order k of the matrix (Kil et al., 2016) and utilizes the value given by Saaty (1994) as in Table 3. In this study total seven criteria are used namely; land cover, elevation, slope, aspect, land surface temperature, and proximity to settlement and proximity of roads, so the value of RI is 1.32.

Table 3 Random index

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

As described by Satty (1994) the value of CR should be less than 0.1 so that the judgements are reliable else the process should be repeated. In this analysis, CR is 0.0083 (less than 0.1), so the judgments are reliable. The final weight obtained using AHP method is shown in Table 4 below.

Table 4 Weight, value and rating assigned to different variable

Variable	Wt.	Class	Rank	Rating
Land cover	0.43	Forest Sand Water Body AGR Built up	1 3 4 5 5	Very High Moderate Low Very Low Very Low
LST	0.23	>36 34-36 34-32 30-32 29-30	1 2 3 4 5	Very High High Moderate Low Very Low
Proximity to settlement(m)	0.08	<1000 1000-2000 2000-3000 3000-4000 >4000	1 2 3 4 5	Very High High Moderate Low Very Low
Proximity to Road (m)	0.08	<1000 1000-2000 2000-3000 3000-4000 >4000	1 2 3 4 5	Very High High Moderate Low Very Low
Slope (Degree)	0.08	<5 5-15 15-25 25-35 >35	5 4 3 2 1	Very Low Low Moderate High Very High
Aspect	0.05	South South West South East West East North West North East North	1 1 2 3 3 4 4 5	Very High Very High High Moderate Moderate Low Low Very Low
Elevation (m)	0.05	<200 200-400 400-600 600-800 >800	1 2 3 4 5	Very High High Moderate Low Very Low
Total	1			

4. RESULTS

4.1 Fire Risk Model

Seven parameters were used to model fire risk in Kailali district. According to weight given to each parameter and their impact on forest fire, the total area was divided into five zone. The five risk zones Very High, Moderate, Low, Very Low and Very Low risk zones are divided using GIS methodologies. By using the raster calculator final fire risk model was prepared. Total seven parameters; elevation, slope, aspect LST, land cover, proximity to road, and proximity to settlements were used. Figure 3 below shows the forest fire risk map and the area is shown in the Table 6. According to the findings, there is a very high risk of forest fire for 99788.76 hectares, a high risk for 110423.07 hectares, a moderate risk for 72771.39 hectares, a low risk for 32016.24 hectares and very low risk for 9174.78 hectares.

The expression used in raster calculator to calculate the final forest fire risk zone based on the weight used is given below.

FRI = 0.43* landcover + 0.23 * LST + 0.08 * Proximity to settlement+0.08*Proximity to road+0.08*Slope+0.05*Aspect+0.05*Elevation……………..(7)

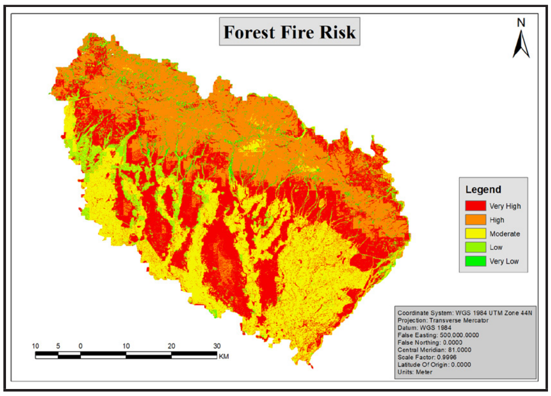

Figure 4 Forest fire risk map of Kailali

So, according to the finding there is a very high risk of forest fire in about 30.78%, a high risk in 34.06%, a moderate risk in 22.45%, a low risk in 9.87% and very low risk in 2.84% of total area.

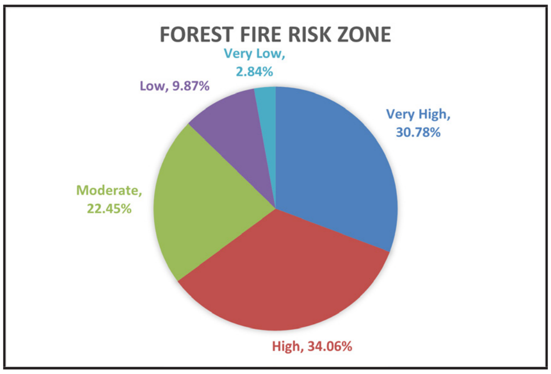

Figure 5 Pie chart showing forest fire risk zone

4.2 Validation

Fire Information for Resource Management System (FIRMS) uses satellite observations form the MODIS and Visible Infrared Imaging Radiometer Suite (VIIRS) instruments to detect active fires and thermal anomalies. Historical fire data from 2014 to 2023 were downloaded from the NASA FIRMS. From the downloaded data only point data that have confidence higher than 50 percentages were extracted for validation purpose. Out of total extracted points random 1000 points were used for overlay over risk zone. When those points were overlay over the fire risk map, 475 points were on very high risk zone, 413 on high risk zone, 84 were on moderate risk zone, 17 on low risk and 11 on the very low risk zone. This demonstrated that the risk region in Kailali district was accurately reflected on the forest fire risk map. The spatial distribution of sample points on study area is shown in figure 5 below.

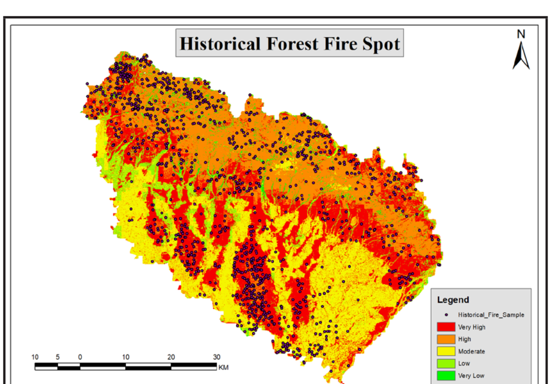

Figure 6 Spatial distribution of historical fire spots

5. CONCLUSION

GIS-based MCDA can be done for mapping forest fire risk. According to this study, there is a very high risk of forest fire for 99788.76 hectares, a high risk for 110425 hectares, a moderate risk for 72770 hectares, a low risk for 32015 hectares and very low risk for 9175 hectares approximately of Kailali district. Elevation, slope, aspects, landcover, land surface temperature, distance from road, distance form settlement area all have an impact on forest fire risk in Kailali district.

6. RECOMMENDATION

Kailali district has a lot of religious, mythological and historical places and have maximum land cover covered with forest that helps to maintain ecosystem and sustain a lot of wildlife. However, there is risk of forest fire in this district. This study recommends the following fot the study area:

i) About 62% of Kailali district is covered with forest and 30% of which is at very high risk of forest fire. A proper fire control approach such as clearing the forest floor before summer and constructing fire line should be done for reducing fire and associated damages.

ii) District administration and related sectors should remain alert and prepared for combating wildfires, especially during the summer season.

iii) Fire towers and alarm system should be installed where risk is high

iv) More research related to forest fire should be encouraged and promoted that help in prevention and control of hazardous fire.

REFERENCES

Akay, A. E., & Erdoğan, A. (2017). GIS-Based Multi-Criteria Decision Analysis for Forest Fire Risk Mapping. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *IV-4/W4*, 25–30. https://doi.org/10.5194/isprs-annals-IV-4-W4-25-2017

Akay, A. E., & Erdoğan, A. (2021). Developing Validation of Forest Fire Risk Maps Based on Historical Fire Incidences. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLVI-4/W5-2021*, 33–38. https://doi.org/10.5194/isprs-archives-XLVI-4-W5-2021-33-2021

Akay, A. E., & ŞahiN, H. (2019). Forest Fire Risk Mapping by using GIS Techniques and AHP Method: A Case Study in Bodrum (Turkey). *European Journal of Forest Engineering*, *5*(1), 25–35. https://doi.org/10.33904/ejfe.579075

Beckley, T. M. (1998). The Nestedness of Forest Dependence: A Conceptual Framework and Empirical Exploration. *Society & Natural Resources*, *11*(2), 101–120. https://doi.org/10.1080/08941929809381066

Boyi Jiang. (2011). *GIS-based Multi-criteriaAnalysis Used in Forest Fire Estimation: A Case Study of Northernmost Gävleborg County in Sweden.*

Carmel, Y., Paz, S., Jahshan, F., & Shoshany, M. (2009). Assessing fire risk using Monte Carlo simulations of fire spread. *Forest Ecology and Management*, *257*. https://doi.org/10.1016/j.foreco.2008.09.039

Chhetri, S., & Kayastha, P. (2015). Manifestation of an Analytic Hierarchy Process (AHP) Model on Fire Potential Zonation Mapping in Kathmandu Metropolitan City, Nepal. *ISPRS International Journal of Geo-Information*, *4*(1), 400–417. https://doi.org/10.3390/ijgi4010400

District Administration Office, Kailali. (n.d.). Retrieved April 29, 2025, from https://daokailali.moha.gov.np

Eugenio, F. C., Dos Santos, A. R., Fiedler, N. C., Ribeiro, G. A., Da Silva, A. G., Dos Santos, Á. B., Paneto, G. G., & Schettino, V. R. (2016). Applying GIS to develop a model for forest fire risk: A case study in Espírito Santo, Brazil. *Journal of Environmental Management*, *173*, 65–71. https://doi.org/10.1016/j.jenvman.2016.02.021

FAO, F. (2016). State of the world's forests 2016. Forests and agriculture: Land-use challenges and opportunities. *FAO Report*.

Feizizadeh, B., Omrani, K., & Aghdam, F. B. (2015). Fuzzy Analytical Hierarchical Process and Spatially Explicit Uncertainty Analysis Approach for Multiple Forest Fire Risk Mapping. *GI_Forum*, *1*, 72–80. https://doi.org/10.1553/giscience2015s72

FOA. (2015). *Global Forest Resources Assessment 2015*.

Gigović Ljubomir, Gordana Jakovljević, & Dragoljub Sekulović i Miodrag Regodić. (2018). GIS Multi-Criteria Analysis for Identifying and Mapping Forest Fire Hazard: Nevesinje, Bosnia and Herzegovina. *Tehnicki Vjesnik - Technical Gazette*, *25*(3). https://doi.org/10.17559/TV-20151230211722

Gülci, N., Akay, A. E., & Erdaş, O. (2020). Optimal planning of timber extraction methods using analytic hierarchy process. *European Journal of Forest Research*, *139*(4), 647–654. https://doi.org/10.1007/s10342-020-01275-7

Hong, H., Naghibi, S. A., Moradi Dashtpagerdi, M., Pourghasemi, H. R., & Chen, W. (2017). A comparative assessment between linear and quadratic discriminant analyses (LDA-QDA) with frequency ratio and weights-of-evidence models for forest fire susceptibility mapping in China. *Arabian Journal of Geosciences*, *10*(7), 167. https://doi.org/10.1007/s12517-017-2905-4

Jafari Goldarag, Y., Mohammadzadeh, A., & Ardakani, A. S. (2016). Fire Risk Assessment Using Neural Network and Logistic Regression. *Journal of the Indian Society of Remote Sensing*, *44*(6), 885–894. https://doi.org/10.1007/s12524-016-0557-6

Kant Sharma, L., Kanga, S., Singh Nathawat, M., Sinha, S., & Chandra Pandey, P. (2012). Fuzzy AHP for forest fire risk modeling. *Disaster Prevention and Management: An International Journal*, *21*(2), 160–171. https://doi.org/10.1108/09653561211219964

Khatakho, R., Gautam, D., Aryal, K. R., Pandey, V. P., Rupakhety, R., Lamichhane, S., Liu, Y.-C., Abdouli, K., Talchabhadel, R., Thapa, B. R., & Adhikari, R. (2021). Multi-Hazard Risk Assessment of Kathmandu Valley, Nepal. *Sustainability*, *13*(10), 5369. https://doi.org/10.3390/su13105369

Kil, S.-H., Lee, D., Kim, J.-H., Li, M.-H., & Newman, G. (2016). Utilizing the Analytic Hierarchy Process to Establish Weighted Values for Evaluating the Stability of Slope Revegetation based on Hydroseeding Applications in South Korea. *Sustainability*, *8*(1), 58. https://doi.org/10.3390/su8010058

Lamat, R., Kumar, M., Kundu, A., & Lal, D. (2021). Forest fire risk mapping using analytical hierarchy process (AHP) and earth observation datasets: A case study in the mountainous terrain of Northeast India. *SN Applied Sciences*, *3*(4), 425. https://doi.org/10.1007/s42452-021-04391-0

Leal, B. E. Z., Hirakawa, A. R., & Pereira, T. D. (2016). Onboard fuzzy logic approach to active fire detection in Brazilian amazon forest. *IEEE Transactions on Aerospace and Electronic Systems*, *52*(2), 883–890. https://doi.org/10.1109/TAES.2015.140766

Matin, M. A., Chitale, V. S., Murthy, M. S. R., Uddin, K., Bajracharya, B., & Pradhan, S. (2017). Understanding forest fire patterns and risk in Nepal using remote sensing, geographic information system and historical fire data. *International Journal of Wildland Fire*, *26*(4), 276. https://doi.org/10.1071/WF16056

Mosadeghi, R., Warnken, J., Tomlinson, R., & Mirfenderesk, H. (2013). Uncertainty analysis in the application of multi-criteria decision-making methods in Australian strategic environmental decisions. *Journal of Environmental Planning and Management*, *56*(8), 1097–1124. https://doi.org/10.1080/09640568.2012.717886

Pan, J., Wang, W., & Li, J. (2016). Building probabilistic models of fire occurrence and fire risk zoning using logistic regression in Shanxi Province, China. *Natural Hazards*, *81*(3), 1879–1899. https://doi.org/10.1007/s11069-016-2160-0

Pan, Y., Birdsey, R. A., Phillips, O. L., & Jackson, R. B. (2013). The Structure, Distribution, and Biomass of the World's Forests. *Annual Review of Ecology,* *Evolution, and Systematics*, *44*(1), 593–622. https://doi.org/10.1146/annurev-ecolsys-110512-135914

Parajuli, A., Gautam, A. P., Sharma, S. P., Bhujel, K. B., Sharma, G., Thapa, P. B., Bist, B. S., & Poudel, S. (2020). Forest fire risk mapping using GIS and remote sensing in two major landscapes of Nepal. *Geomatics, Natural Hazards and Risk*, *11*(1), 2569–2586. https://doi.org/10.1080/19475705.2020.1853251

Parajuli, A., Manzoor, S. A., & Lukac, M. (2023). Areas of the Terai Arc landscape in Nepal at risk of forest fire identified by fuzzy analytic hierarchy process. *Environmental Development*, *45*, 100810. https://doi.org/10.1016/j.envdev.2023.100810

Pourghasemi, H. R., Beheshtirad, M., & Pradhan, B. (2016). A comparative assessment of prediction capabilities of modified analytical hierarchy process (M-AHP) and Mamdani fuzzy logic models using Netcad-GIS for forest fire susceptibility mapping. *Geomatics, Natural Hazards and Risk*, *7*(2), 861–885. https://doi.org/10.1080/19475705.2014.984247

Rahimi, I., Azeez, S. N., & Ahmed, I. H. (2020). Mapping Forest-Fire Potentiality Using Remote Sensing and GIS, Case Study: Kurdistan Region-Iraq. In A. M. F. Al-Quraishi & A. M. Negm (Eds.), *Environmental Remote Sensing and GIS in Iraq* (pp. 499–513). Springer International Publishing. https://doi.org/10.1007/978-3-030-21344-2_20

Saaty, T. L. (1994). How to Make a Decision: The Analytic Hierarchy Process. *Interfaces*, *24*(6), 19–43. https://doi.org/10.1287/inte.24.6.19

Scott, A. C. (2000). The Pre-Quaternary history of fire. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *164*(1–4), 281–329. https://doi.org/10.1016/S0031-0182(00)00192-9

Vadrevu, K. P., Eaturu, A., & Badarinath, K. V. S. (2010). Fire risk evaluation using multicriteria analysis—A case study. *Environmental Monitoring and Assessment*, *166*(1), 223–239. https://doi.org/10.1007/s10661-009-0997-3

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