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Forest Fire Risk Zone Mapping in Mizoram Using RS and GIS

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Abstract. In recent years, India's Northeastern territory has been plagued by wildfires. Mizoram, as per FSI, has been among the most affected regions, with approximately 20,744-recorded wildfires. Forest fire directly or indirectly affects human health, climate change, and the environment. The forest fire risk zonation is generated utilizing remote sensing data, and Geographic Information System based on specified physical and socioeconomic factors. As part of the current study, a Geographical Information System is employed to determine forest fire risk based on predetermined physical and socioeconomic parameters. This study used three distinct models of fire risk zonation index namely FRI (Fire Risk Index), HFI (Hybrid Fire Index), and SFI (Structural Fire Index) to identify the zones in the study area under the risk of forest fires. The Indian state of Mizoram is categorized into five distinct hazard zones based on the probability of wildfire incidents. Fire alerts generated using risk models, and real-time hotspot datasets (forest fire spots) received from MODIS and USGS have been validated. According to the study's findings, 18.84 km^2 of the study area is at low risk of forest fire, 11.072 km^2 is at moderate risk, and 5.38 km^2 is at high risk. The probability from each metric varies since the input and weightage of the different parameters vary from one another. SFI, therefore, therefore predicts a lower frequency of high-risk wildfire-prone zones than HFI and FRI. In this research, the coefficient of discrimination (R^2) is employed to assess the reliability of the projected fire indices being compared with real-time hot spots. Here, FRI possesses the highest accuracy (R^2=0.892), HFI has moderate accuracy (R^2=0.676), and FRI has the lowest accuracy (R^2=0.629).

Keywords: Forest Fire-Mizoram, Forest fire, Fire risk zone, HFI, DFI, SFI, MODIS.

1. Introduction

Forests constitute a valuable food source, shelter, habitat for wildlife, fuel, and essential supplies [1]. Forests occupy about one-third of the total land area on the earth [2]. India's entire forest and woodland area is 80.73 million hectares, accounting for 24.56 % of the nation's geographical area [3]. As per the status of the Forest Report (2009) by FSI, the documented forest area is grouped into three categories reserved forest (51.6%), protected forest (26.79%), and unclassified forest (17.24%) [4]. Madhya Pradesh has the maximum forest cover in India, followed by Arunachal Pradesh, Chhattisgarh, and Odisha [5]. Mizoram (85.4%), Arunachal Pradesh (79.61%), Meghalaya (76.32%), Manipur (75.46 %), and Nagaland (75.3%) are the five major states in terms of forest cover as a portion of total geographical area [3]. Because of their reliance on fuelwood, food, minor forest resources, and lumber, forests are

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intertwined with the social system [6]. Fuelwood is the primary source of energy for 70% of the Indian population, and 125 million tonnes are harvested each year [7]. Furthermore, more than half of the cattle population (270 million) is dependent on the forest for grazing resources, and the forest provides NTFP of Rs. 6.5-20 billion yearly [8].

Forest fires are the most common threat currently occurring in forests worldwide [9]

. Forest fires are complicated events driven by both natural and anthropogenic influences [10,11]. Forest fires are regarded as a catastrophe distressing land ecosystems and causing economic devastation for human beings, such as a lack of land use revenue, disruption to crops, and depletion of biodiversity [11-13]. There are three phases to forest fires: grass fires, undergrowth fires, and crown fires. Grass and non-wet undergrowth usually ignite in the absence of moisture and can be controlled easily. It becomes much more difficult to monitor if the fire reaches the top of the trees, particularly conifers, resulting in canopy or crown fire [14]. When this is transformed into a wildfire, the treetops, particularly in the specific instance of conifers, can rapidly spread flames, leading to the canopy fire. Canopy fires are much harder to control and, therefore, can quickly become a conflagration, which basically cannot be extinguished [15]. It leads to an imbalance in the environment, depletion of wildlife, biodiversity, and forest natural resources. Forest fire is primarily considered a natural hazard, although human-induced or anthropogenic influences can also be caused [16]. Initiation and propagation of fire are dependent on many crucial factors such as precipitation volume and frequency, topography, temperature, lightning, fuel availability and distribution, relative moisture concentration, and wind speed all play a role in the presence of inflammatory agents [17].

Wildfires are becoming an increasing concern as the world continues to warm exponentially, burning across international boundaries and significantly raising greenhouse gas emissions in the atmosphere. The fires are also local and national issues and global challenges [18]. The Amazon forest fire has been a recent occurrence, with the deadliest fires that struck the Amazon Basin over more than a decade in 2019. The issue of the Amazon Wildfires has become a serious concern, when environmental concerns become more political [19]. In Brazil, the Amazon rainforest initially occupied 4.1 million sq.km but decreased to 3.4 million sq. km. In the last 50 years, however, 17% of the biodiversity has been irrevocably disrupted. An additional 17% became impaired and deteriorated, primarily associated with the wildfires by human activities [15]. Australia has also experienced similar bushfire incidents recently, and the foremost issue with forest fire is human activities. Bushfires account for about 10% of the total expense of all significant natural hazards in Australia, and they are synonymous with the tremendous loss of wildlife. In Australia, bushfires are an unavoidable phenomenon. In Australia, approximately 50 million forest areas are burnt annually, with about 80 % of the fire-ravaged areas located north of Savanna areas [20]. Fire is most prevalent in the northern tropical savannas, where certain areas of land fire each year. However, the southeast, which is residence to most of the population, is particularly vulnerable to massive wildfires that threaten their lives and property [20].

According to a recent study by FSI (Forest Survey of India), close to 36% of India's forest is vulnerable to fires, with over 10% of that being extremely prone [21]. Forest fire threatens valuable environmental resources and biodiversity and is also one of the leading causes of forest destruction and air quality. According to FSI, in recent years, forest fire occurrences in India have increased in summer by 49,32% (a total of 24,817 wildfire events in 2016, which escalated to 35,888 by 2017 and 37,059 in 2018) [21]. Studies have shown that 90% of forest fires throughout India are human-induced and that around 3.73 million hectares of forest are damaged each year, which leads to losses of US$104 million [22]. Mizoram's forest coverage of 85.41 % has declined from 86.26 % in 2017, according to ISFR ("India State of Forest report"-2019) published by FSI [23]. In Mizoram, as officials stated, about 1,300 wildfires were registered in 2020. Around 1,090 accidents have been caused by Jhum cultivation (slash-and-burn agriculture) and just 210 by natural causes [24]. The forest coverage in Mizoram is 157.05 square kilometers of Very Dense Forests (VDF), 5,800 square kilometers of Moderately Dense Forests (MDF), and 12,047.71 Km^2 of Open Forests (OF). Forest cover in the state has decreased by 180.49 Km^2 since ISFR 2017.[23]. Forest officials in Mizoram claim that Jhum cultivation, the primitive farming process, explains the large number of wildfire alerts reported in northeastern states [25].

However, because slash-and-burn activities often coincide with dry and windy seasons of the year, wildfires that spread beyond the boundaries of designated zones into surrounding woods are not uncommon. Such flames can entirely destroy entire villages or small communities [26]. Forest fires (i.e., lightning strikes) have unusual natural causes. Forest fires typically refer to actions of human beings, like jhum, where highly flammable flakes of bamboo and charcoal are blown into adjacent regions, leaf litter, and dry grasses are burnt to flames. No firebreaks around the jhum field before combustion occurs. In February and March, annual removal and burning are typically carried out at the driest time of the year. Cattle grazers scorch dry grasslands and forest floors during the dry season to eliminate weeds and promote the growth of fresh grazing shoots. Forest floors are burned to increase visibility for poaching wild animals. Inadequate approved burning, as well as fire line planning and design. Building structures, agriculture, road construction, shifting cultivation, and so on are examples of some other human activities inducing forest fires [26].

To develop a thorough study on forest fire probability, environmental and socioeconomic factors must be considered, and the correlation between various factors and fire risk is established. The term "fire risk," when used in an analysis, refers to the probability of the initiation of a fire or of a region getting burnt, as influenced by the magnitude and occurrence of causative factors [27-29]. Performing fire risk minimization by rebuilding the fire regime and maintaining the fire regime is essential to effectively controlling wildfires. [30]. Since the 1920s, the concepts of hazard and risk have been regularly employed in fire-control matters throughout the United States [28]. According to the MiSRaR project of the European Union, the risk is a combination of hazard and harmful consequences. [31]. Forest fire control, in general, includes of four steps of assessment and evaluation of successful fire response: mapping possible fire risk and danger, detecting hot spots, tracking current fires, and analyzing post-fire depletion [32]. The most critical step is assessing fire risk and deciding where the hazard is greatest; it is necessary to limit harm to people, property, and natural resources. In this work, we focused on determining the spatial range of fire risk across Mizoram. The "Joint Research Center" of the EU ("European Union") has proposed three classes of indices to assess fire risk based on their temporal scale, namely structural indices, dynamic indices, and combined indices [33]. Structural indices are the long-term indices that primarily portray static data at a worldwide scale [34]. They do not alter in short periods. Elevation, vegetation, land use, land cover, aspect, slope, proximity to roads and settlement [35], climate factors, soils [36], and population density are instances of such indices [37]. Dynamic indices are short-term indices that shift somewhat over time due to vegetation or climatic conditions. The indicators are designed to monitor forest fuel's flammability during wildfire incidents. Therefore, the dynamic indexes use variables that change over a brief period and rely on the probability of the ignition and proliferation of forest fires [38]. The combined indices comprise both dynamic and structural variables mentioned above. In this method, the most crucial aspect is how the relevant variables can be easily combined to generate a logical concept [39].However, gathering all accurate details from such a North-eastern state as Mizoram is challenging. As a result, the current study has been dependent on readily available indicator variables. Geographic information systems and Remote sensing are by far the most effective and necessary methods for developing a wildfire susceptibility model to determine and distinguish high-risk and fire risk zones in today's world. The knowledge available on the Internet was also highly beneficial in the development of our project. The purpose of this study is to illustrate the risk of the forest fire scenario in Mizoram. This study aims to establish the correlation between fire risk and various biophysical and socioeconomic variables (elevation, slope, radiation appearance, soil moisture, distance to roads, proximity to settlements, etc.) The aim has been divided into objectives to create a fire risk index and characterize the zones based on fire risk.

2. Study Area

Mizoram is among the seven states that make up the region of India's northeast renowned as the "Land of 7 Sisters." [40]. Compared to other states of India, Mizoram is a small state (fifth smallest state) covering 21,081km^2 [41]. The forests cover 91 % (15, 94,000 hectares) of Mizoram's total area, putting it third among Indian states in total forest cover [42]. According to the 2011 census, Mizoram's total population was 1091,014, India's second inhabited state [43].The latitudinal extension of the state is 21^o 58'N to 24^o 35' N, and the longitudinal extension is 92^o 15' E to 93^o 29' E [44] (figure 1). The neighbouring states of Mizoram are Assam, Tripura, and Manipur and share a 722-kilometre border with the neighbouring countries of Bangladesh and Myanmar in the southeast [45]. Mizoram does have the most varied hilly terrain in India's eastern region. The steeply sloped hills are segregated by rivers that flow either north or south, forming deep gorges across the mountain ranges. The hills have an average elevation of around 1000 meters. Phawngpui (Blue Mountain) is Mizoram's highest elevation, standing at 2210 meters [46]. Mizoram does have a moderate climate, of summer temperatures ranging between 20°C - 29°C, while temperatures are steadily rising due to climate change. The region is dominated by monsoons, with heavy rain during the dry (cold) season between May and September. With total rainfall of 254 cm/year, the climatic condition is tropical humid subtropical. The rainfall is approximately 215cm in Aizawl and around 350 cm in Lunglei [47].

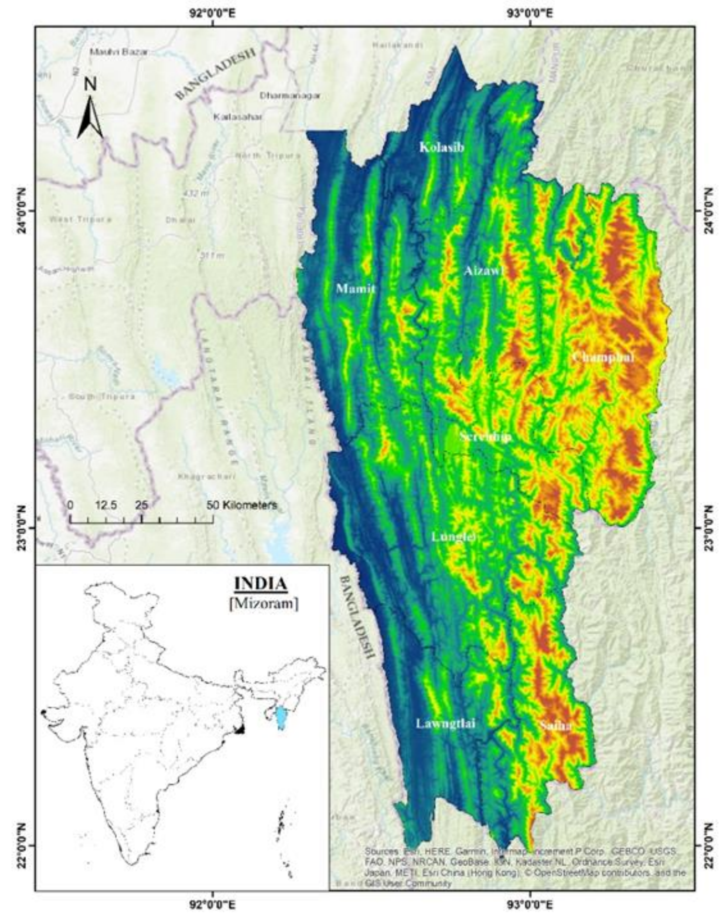

Figure 1. Study area (Mizoram) map selected for the current study.

2.1. Land use and Land Cover

Mizoram has the most extensive forest cover in the state based on the total land area[23]. The land use/land cover types (figure 2) found in this region are primarily vegetation agricultural lands, current shifting cultivation lands, mining sites, wetlands settlement and wastelands etc. The vegetation in the region is divided into four types evergreen or semi-evergreen, deciduous, forest plantations and scrublands. Deciduous trees are the most prominent and widespread however they are highly flammable

[21]. The evergreen forest has been presently concentrated in the study area's eastern section, whereas the forest plantation is primarily found in the southwest region. Scrubland covers the majority of the north and northwestern portion. The general settlement pattern is scattered, and linear forms of settlement can be found alongside roads and cultivated lands. Figure 3 shows that most agricultural fields are found accross the north-eastern portion of the state. Within the study area, fields used for shifting cultivation are mostly found in the northeastern and eastern sections. These regions are very vulnerable to fire caused by human activity. Various physical and socioeconomic causes linked to the fire have been chosen. This section creates a fire risk map with various variables to determine how each factor affects the fire itself.

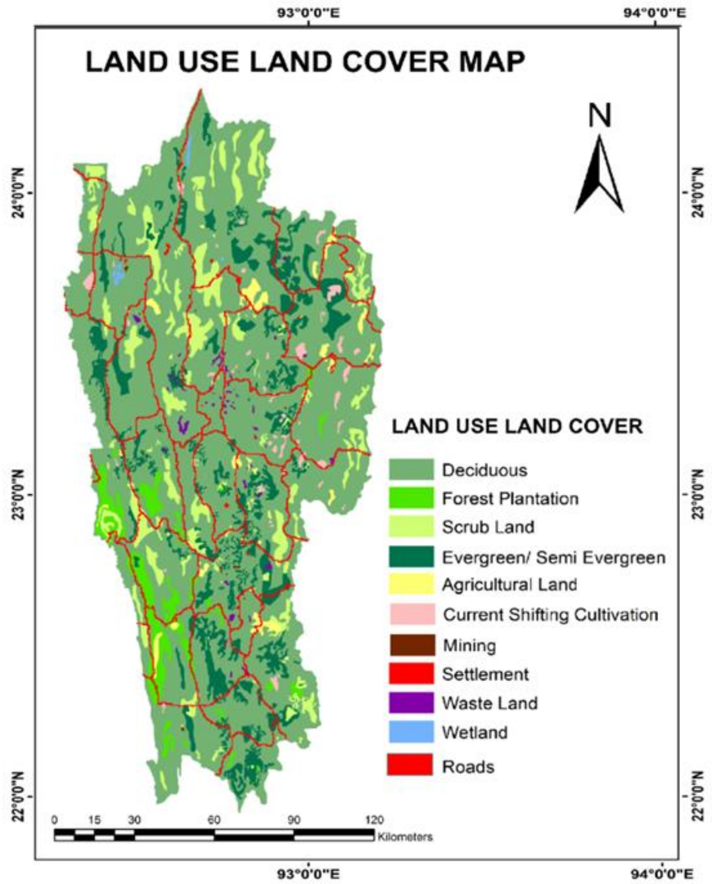

Figure 2. Land Use and Land Cover Map of the study area

3. Materials and Methods

3.1. Data

The current study is based on remotely sensed data that is currently available. The datasets described in table 1 provide insight into the inputs (figure 2 and figure 3) used to accomplish the objectives mentioned earlier regarding the current study to delineate the study area's forest fire risk zones. The remotely sensed LANDSAT 8 OLI/TIRS [48] datasets have been utilized to acquire the scenarios of the land cover, settlement pattern, and soil moisture across Mizoram. Line vector data sets have been acquired from OpenStreetMap and are used for road layer analysis [49], shown in figure 3. The region's height, slope, and aspect have been then estimated using the SRTM DEM dataset of 30 meter spatial resolution [50] as inputs for the current investigation, as shown in figure 3. The datasets of real-time fireplaces in Mizoram were then obtained from MODIS [51] for validation purposes. ArcGIS 10.3.1 has been employed to evaluate geospatial and remotely sensed datasets in a GIS framework. Excel is being used for specific quantitative data processing and assessment regarding the current study.

Table 1. Datasets used for the current study.

Data Type	Description	Location/Extension	Time	Resolution	Source
Land-cover	Multispectral Satellite Imagery (Landsat)	Mizoram (21º 58' N-24º 35' N 92º 15' E -93º 29' E)	2019	30 metres	https://earthexplorer.usgs.gov/
Settlement (BUI)	Multispectral Satellite Imagery (Landsat)	Mizoram (21º 58' N-24º 35' N 92º 15' E -93º 29' E)	2019	30 metres	https://earthexplorer.usgs.gov/
Roads	Line Shapefile	Mizoram (21º 58' N-24º 35' N 92º 15' E -93º 29' E			https://openstreetmap.in/#4.37/22.82/82
Soil Moisture (NDMI)	Multispectral Satellite Imagery (Landsat)\	Mizoram (21º 58' N-24º 35' N 92º 15' E -93º 29' E)	2019	30 metres	https://earthexplorer.usgs.gov/
Real-time Fire points	MODIS	Mizoram (21º 58' N-24º 35' N 92º 15' E -93º 29' E)	2019	1km	https://earthdata.nasa.gov/active-fire-data
Elevation	Digital Elevation Model (DEM)	Mizoram (21º 58' N-24º 35' N 92º 15' E -93º 29' E)	2019	30 metres	https://srtm.csi.cgiar.org/
Slope	Digital Elevation Model (DEM)	Mizoram (21º 58' N-24º 35' N 92º 15' E -93º 29' E)	2019	30 metres	https://srtm.csi.cgiar.org/
Aspect	Digital Elevation Model (DEM)	Mizoram (21º 58' N-24º 35' N 92º 15' E -93º 29' E)	2019	30 metres	https://srtm.csi.cgiar.org/

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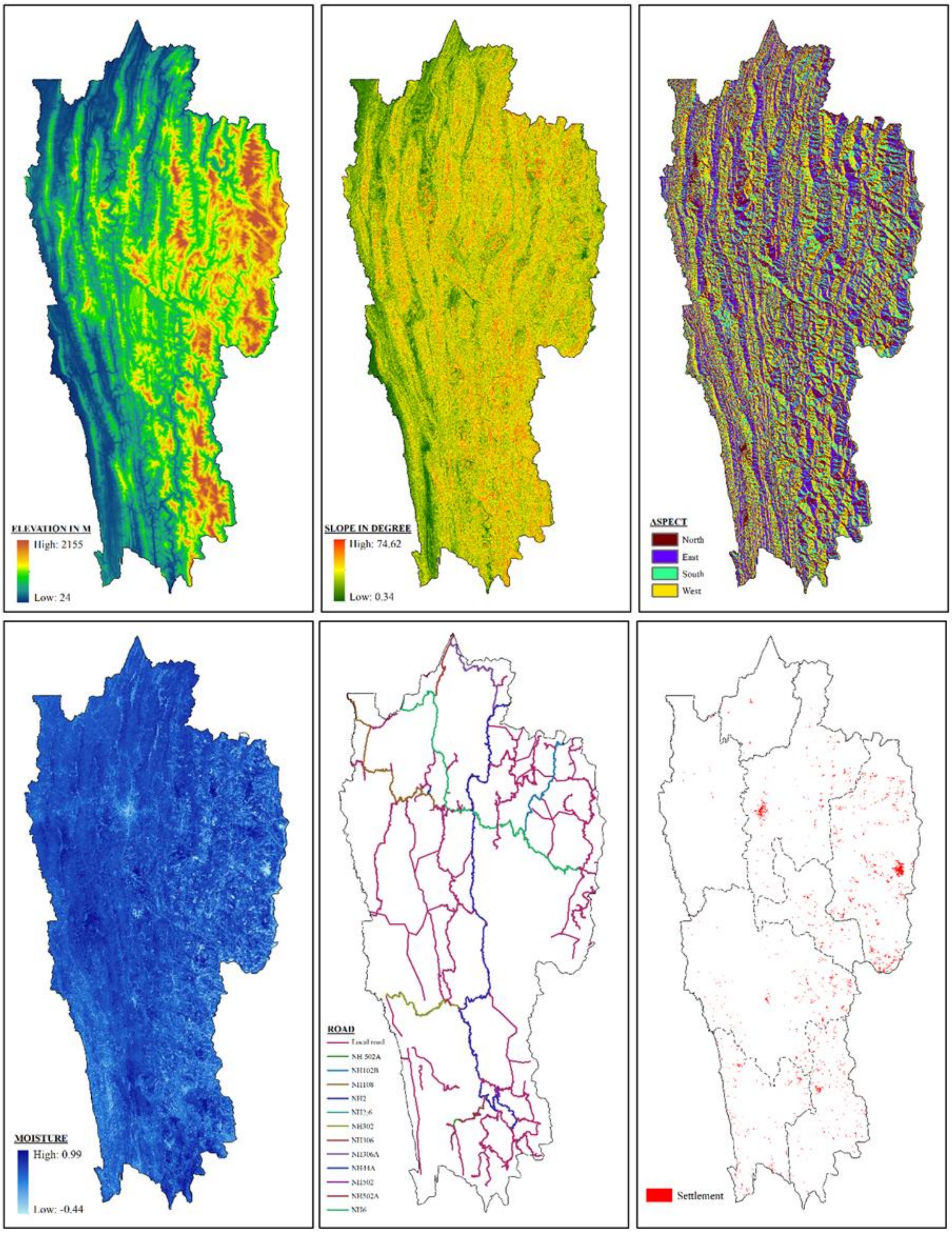

Figure 3. The current study requires the above-illustrated datasets: Elevation, Slope, Aspect, Moisture, Road, and Settlement

3.2. Methods

Figure 4 displays a flow chart that outlines all the measures used with the datasets incorporated to generate the current study results. The steps have been executed in the application of ArcGIS 10.3.1 has been employed to evaluate geospatial and remotely sensed datasets in a GIS framework. Excel is being used for specific quantitative data processing and assessment regarding the current study.

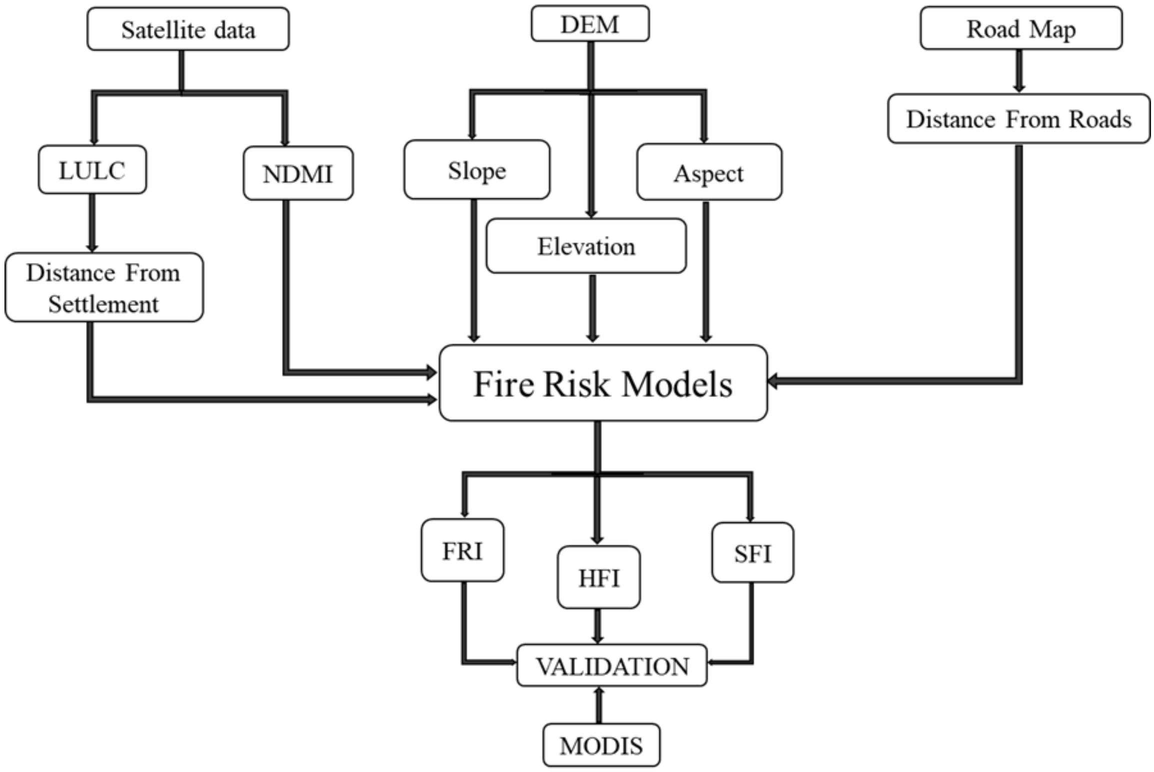

Figure 4. Flow chart showing the Methodology of the current study.

3.2.1. Elevation. The elevation is a critical topographical factor that plays a significant role in the rapid flame spread. It is a significant physiographic parameter related to temperature, humidity, and wind [52]. It also affects vegetation structure, moisture content fuel, and air humidity [53]. Thus, higher elevations are more susceptible to fire because the winds are more effective. The study area has been categorized into five categories based on its elevation (in meters): High (960-2155 m), Moderate (479 - 960 m), and Low (<479 m), depicted in figure 5(a) and table 2. The classified elevation pattern of the study area is illustrated in figure 5(a), with the north-eastern and south-eastern regions being more vulnerable to wildfire due to their higher elevation. On the other hand, the western portion has lower elevation zones and therefore bears a lower fire risk.

3.2.2. Slope. Among the factors that influence the spread of fire is slope [54]. Consequently, calculating the region's steepness and inclination is essential. The slope of the study area, depicted in figure 5(b), has been calculated using the SRTM DEM. The potential of fire's spread rises when the fire moves closer to the land surface, which is further boosted by winds [55]. The fire spread is quicker in the uphill direction than in the downhill direction [56]. The slope in the study area was measured in degrees and classified into five separate groups based on steepness, as shown in figure5(b). They are classified as Low (< 15%), Moderate (15 – 28%), and High (>35 %). From east to west, the terrain slopes downward. The south-eastern portion of the region has a steeper slope and is more prone to forest fires.

3.2.3. Aspect. The amount of solar energy received by a region is proportional to its aspect (figure 5 c). As per figure 5(c), the classified part of the area indicates that the east-facing slopes get more sunshine, have higher temperatures, and are steeper. As a result, vegetation on east-facing slopes is usually drier, deciduous, and less dense. There is much-shifting cultivation and wasteland; thus, the east-facing slope is high fire-risk zones. The north-facing slopes are moderately prone to forest fires. Then, the west and south-facing slopes of the research area are the least vulnerable to forest fires.

Soil Moisture. Soil moisture content has a direct influence on the occurrence and spread of forest fires [11,57,58]. As a result, developing a soil moisture map (figure 5d) of the study area is critical to determining the correlation between soil moisture and fire risk. Soil moisture and fire risk are inversely related, with wet soil indicating a lower risk of wildfire and dry soil indicating a higher risk of wildfire. SWIR (short-wave infrared) bands absorb more moisture than NIR (near-infrared) bands because of the increased reflection of NIR (near-infrared) bands in thin canopy layers. In the current investigation, the NDMI (Normalized Difference Moisture Index) has been computed utilizing the bands of NIR and SWIR to assess the level of moisture in the vegetation [59]. This index is responsive to fluid water composition variations in vegetative canopies.

$$\text{NDMI} = (\text{NIR} - \text{SWIR}) / (\text{NIR} + \text{SWIR}) \tag{1}$$

Lower NDMI values imply that excessively dry vegetation ignites more readily than lush and wet vegetation having a higher value of NDMI [60]. As per figure 5(d), the region has been categorized into three categories based on NDMI values representing soil moisture content, namely high (<0), moderate (0 – 0.02), and low (>0.2), as mentioned in table 2.

Table 2. Categories of input variables as per the level of fire risk

Feature	High	Moderate	Low
Elevation(m)	960–2155	479 - 960	24-479
Slope(°)	>28	15 - 28	<15
Aspect(°)	East	North	West, South
Moisture (NDMI)	<0	0 - 0.2	>0.2
Distance from Road (m)	<1000	1000 - 2000	>2000
Distance from Settlement (m)	<1000	1000 - 2000	>2000

3.2.4. Distance from Roads. Road density and proximity are potentially significant criteria because roads enable people to infiltrate forested regions and trigger ignitions. Furthermore, forested or grassland regions surrounding communities are more vulnerable to firebreaks since residents within the forest could accidentally trigger fires [61,11]. Roads are essential because there is a direct correlation between the distances across roads to the forest and the accessibility generated by the road, which impacts the capability of firefighters to manage major fires [62]. Furthermore, road structures raise the danger of human-induced fire, so it is crucial to keep a safe distance from the road diagram, as seen in figure 5 (e). As per figure 5(e), the region was divided into three distinct categories (in meters): high (<1000 meters), moderate (1000-2000 meters), and low (>2000 meters), depicted in table 2. Figure 5 (e) shows the longitudinal segments of pink adjacent to the forest and are most vulnerable to forest fires. Although zones highlighted in blue are farther away from the trees, they are less vulnerable to forest fires. Forest regions that are less than 1000 meters from a road face a greater risk of human-induced fire.

3.2.5. Vicinity to settlements. Anthropogenic variables, such as the vicinity to settlements and roads, are significant variables that affect fire incidents [63]. Human settlements surrounding forests are another critical aspect that could pose a problem to the environment. The tribal communities within the forests can also be a significant cause of forest fires [16]. Sometimes, tribal communities set fire to the forest for "*Jhum*" cultivation, clear pathways, gather cooking fuel, and so on, but it can also happen unintentionally due to carelessly tossing cigarette butts, a campfire, or the gathering of non-timber forest items. Figure 5(f) depicts the proximity of the forest fire danger zone from the settlements. To further assess the zones at high risk from human populations, the study area has been categorized into 3 distinct classes of vulnerability based on distance (in meters), namely highly vulnerable (1000 metres), moderately vulnerable (1000 – 2000 metres), and least vulnerable (>2000 metres) to forest fire risk, as shown in figure 5 (f) and table 2.

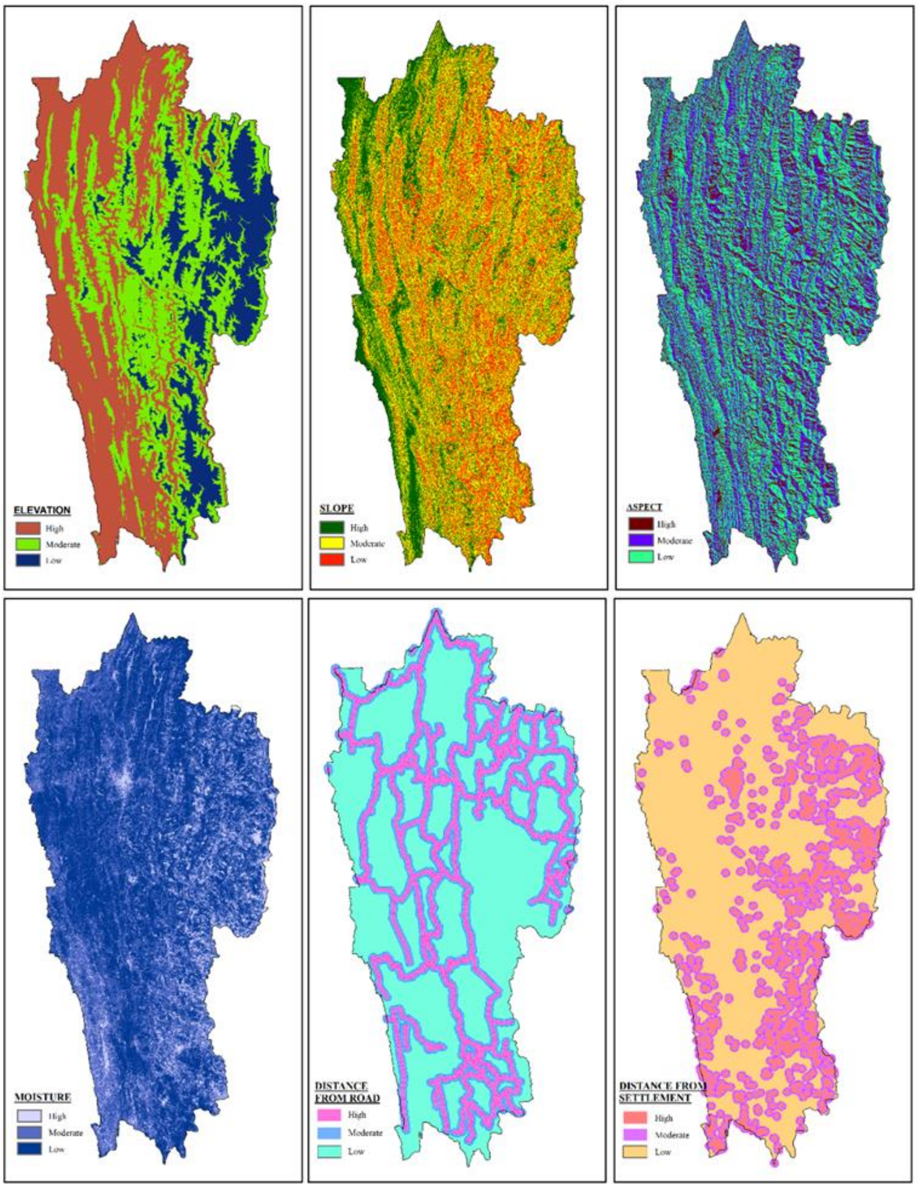

Figure 5. Classified input datasets for the above-illustrated datasets: Elevation, Slope, Aspect, Moisture, Road, and Settlement

3.2.6. Fire risk indices. In different regions, structural, dynamic, as well as combined indices have been widely used. Since they are designed for a specific region, they have varying levels of potential to monitor forest fire risk [11]. However, no distinctions have been made among the indices to determine their effectiveness in the study area.Different fire risk indices for the current study have beenestimatedto create an accurate fire risk index. The following indices are the methods for determining potentially vulnerable fire risk zones of the state:

- Fire Risk Index**:** FRI is an experimental index implemented by Erten *et al.*[64] in Turkey and by Siachalou *et al.*[64,65] in Greece.FRI stands for fire risk index, generated using the parameters. The following equation (2) [11] has been used to estimate SFI to determine fire risk :

$$\text{FRI} = 7\ x\ vt + 5\ (s + a) + 3\ (Dr + Ds) \quad (2)$$

Where the parameters like moisture (vt), slope (s), aspect (a), distance from road (Dr), distance from the settlement (Ds, have been used to estimate the index of FRI.

- Structural Fire Index**:** The Structural Fire Index (SFI) is a quantitative index focused on a compilation of five significant parameters on fire risk: elevation, slope, vegetation moisture, and vicinity to roads [66]. The soil's moisture has been given more weightage than the other variables in this fire index [11].In this study, the following equation (3) has been used to estimate SFI in order to determine fire risk :

$$\text{SFI} = 1 + 100v + 30s + 10a + 5r + 2e \quad (3)$$

where it have the factors such as moisture (v), aspect (a), elevation (e), slope (s), distance from road (r) has been used to estimate this particular index.

- Hybrid Fire Index**:** The indices FRI and SFI do not apply the factors of proximity to settlements and altitude. Since each variable does affect fire risk, the omitted parameters could impede the indices' capability to identify fire risk [11]. Consequently, it is believed that integrating all variables from the FRI and SFI indices will improve the study's outcomes**.** HFI, has been estimated by using the following equation (4).

$$\text{HFI} = \{100v + 50s + 25a + 10(r + c) + 10e\} / 10 \quad (4)$$

Where the index has been calculated by using the parameters of moisture in vegetation (*v*), aspect (*a*), slope (*s*), distance from roads (*r*), proximity to settlements (*c*), elevation (*e*). Each of the variables has a different weightage

4. Results and Discussion

In the current study, Mizoram's forest fire risk zonation has been carried out based on physical parameters including elevation, slope, aspect, soil moisture, and human-induced factors like proximity from road and settlement. The risk zone analysis is applied to all variables dependent on their susceptibility to flames. The three indices of SFI, FRI, and HFI have been estimated (figure 6) to determine the research area's forest fire risk zones. As a consequence, the study region has been classified into three forest fire risk categories, namely high, low, and moderate, relying on their influence on forest fire occurrence.

According to the HFI index for the study area (figure 6 c), 18.14 km^{2}of the region are within the low-risk zone, 14.53 km^{2}are in moderate risk, and 7.15 km^{2}are under the high-risk zone of the forest fire. The area with a high fire risk is highlighted in red in figure 6(c), mainly across the northeastern and southern regions of the research area. As per figure 6(a), FRI index shows that the region of 21.14 km^2 is in a low-risk area. The 16.64 km^2 is then encompassed within a zone of moderate fire risk. Them an area of 8.43 km^{2}comes under the high forest fire risk zone. According to the FRI index, figure 6(a) shows that the northeastern, southeastern portion of the state bears a high forest fire risk. The SFI index, depicted in figure 6(b), indicates that 18.84 km^2 of the study area is at low risk. Then, 11.076 km^2 of the study area is at moderate risk, and 5.38 km^2 is highly susceptible to forest fires. SFI implies a lesser concentration of high-risk areas than other indices such as HFI and FRI.

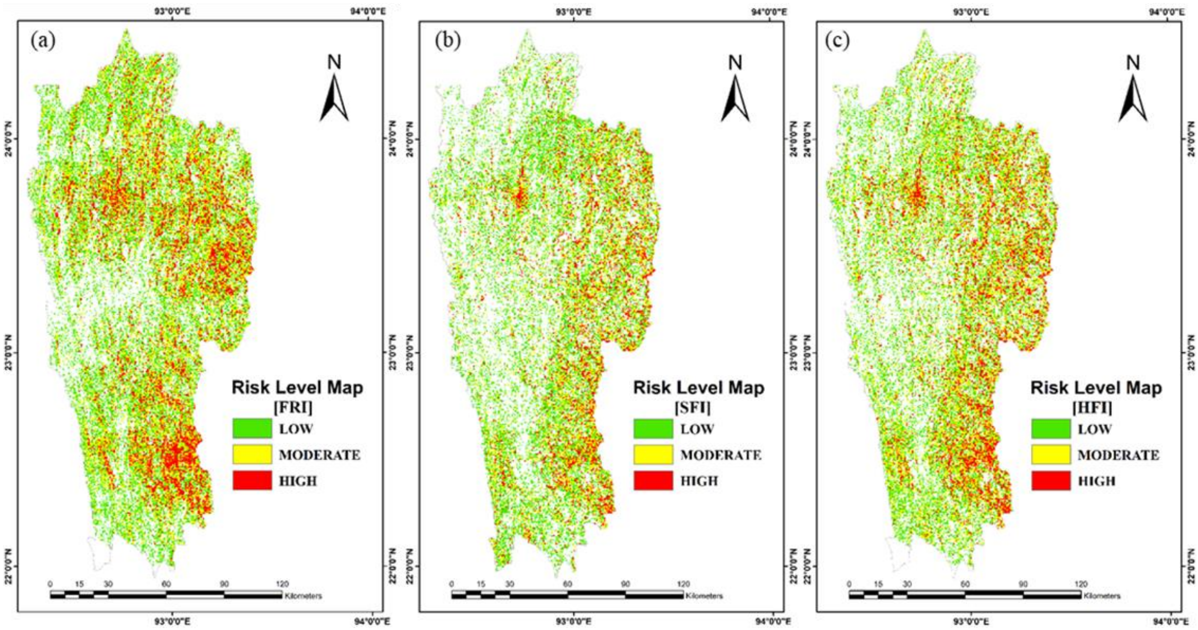

Figure 6. Fire risk indices: a) FRI (Fire Risk Index) b) SFI (Structural Fire Index) c) HFI (Hybrid Fire Index)

4.1. Probability Distribution:

The level of fire risk in the study area has been illustrated by using probability distributions (figure 7) by quantifying the risks of forest fires in a specific region, based on the afore-mentioned estimations of FRI, SFI, and HFI. Thus, the level of fire risk has been shown in line graphs, which are estimated for three respective fire index models (SFI, FRI, and HFI) used in this study. In the current study, forest fire risk has been categorised by utilizing probability distributions, determined by each index into three fire risk categories: low, moderate, and high (figure 7). Hence, probability distributions of forest fire risk have been estimated, based on the SFI, FRI, and HFI to assess the frequency of fire risk over the study area. Then the probability from each index differs since the weightage and input of the various parameters vary. Forest fire risk levels in the line graphs indicate low, moderate, and high levels according to the risk levels indicated by the indices. Values between 1 - 10 indicate low risk, 11 - 30 indicate moderate risk, 60 - 100 indicate high risk. According to the current study's estimates, FRI project a higher probability of forest fire risk in the study area than SFI and HFI (figure 7) in all three categories of forest fire risk (low, moderate, and high).

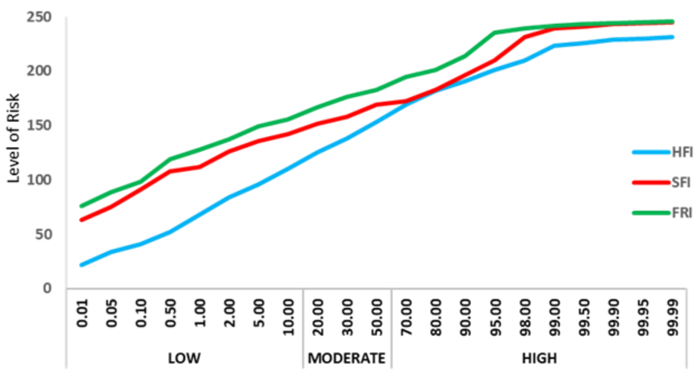

Figure 7. Three indices (HFI, SFI, and FRI) derived from the probability distribution, encompassing levels of the minimal, medium, and severe fire risk.

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4.2. *Estimation of Accuracy of Fire Indices*

Due to the varying weightage assigned to the different factors used to measure the fire indices. It is now necessary to determine the consistency of the models. Real-time hot spots (fire points) data have been used to determine the precision of three distinct models. . The statistical meaure, Coefficient of Determination (r-squared or R^2) represents the degree of accuracy to real-time results. In this study, R^2 has been used to assess how accurate the results of our study's estimated fire risk indices (FRI, SFI, HFI) are the dependent variable, with real-time fire hotspots functioning as independent variable. R^2 quantifies the amount of variation within the dependent parameter (fire risk indices FRI, SFI, HFI) that can be characterized by the considered independent variable (actual fire hotspots). As a result, by correlating the estimated fire indices to real-time hot locations, R^2 has been used to validate the results. Figure 8 shows that FRI has the highest accuracy (R^2=0.892), HFI has moderate accuracy (R^2=0.676), and FRI has the least accuracy (R^2=0.629), shown in the graphs(figure 8) below.

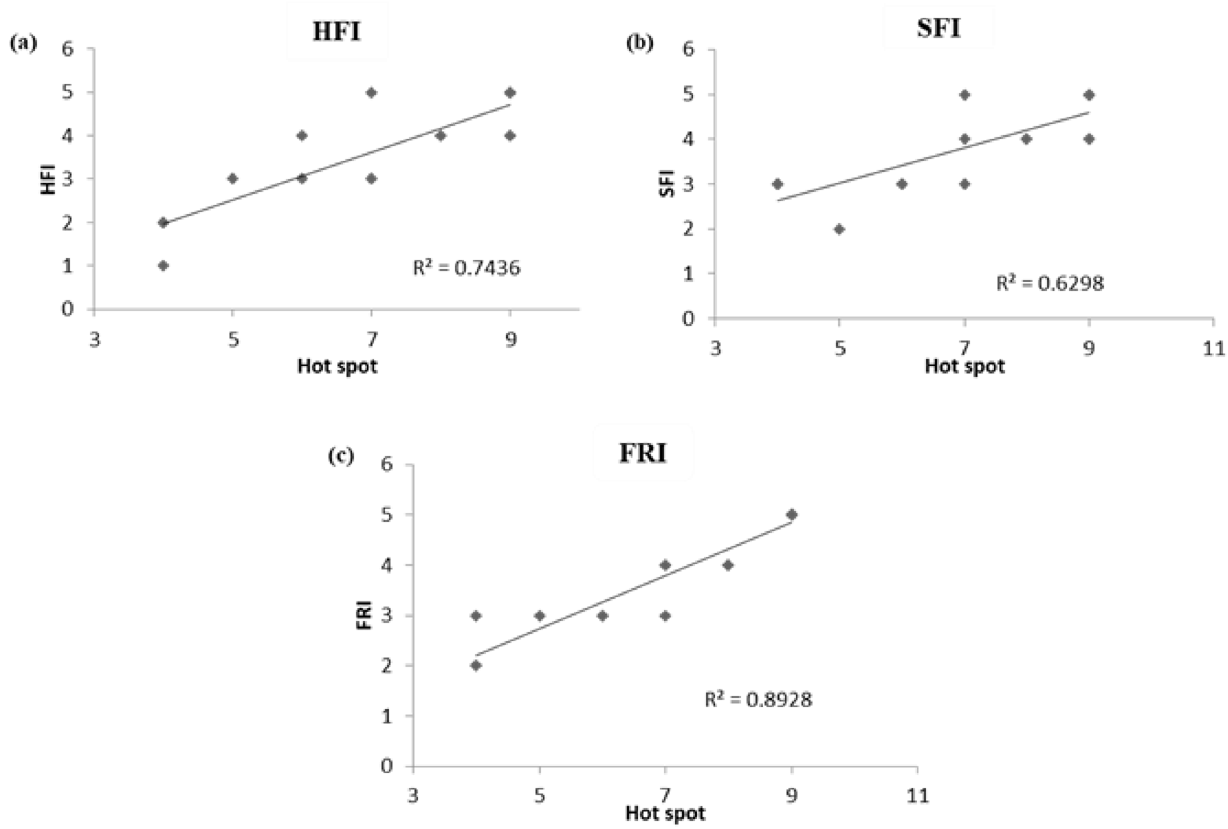

Figure 8. Accuracy estimation of the forest fire risk indices: (a) HFI, (b) SFI and (c) FRI

4.3. *Model Validation*

Model validation is a critical aspect of risk zone mapping. It evaluates the projected model's precision or predictive potential by comparing it to a real-time dataset [67]. In this study, the fire risk was deemed to be the most credible finding (figure 9)—all of the real-time hotspot data derived from MODIS. Figure 8 depicts the highest number of hot spots in the high-risk region and a few hot spots clustered in the moderate risk zone, with very few hot spots found in the low-risk zone. It indicates that the data obtained from this fire risk index map is correct in locating specific regions vulnerable to fire risk.

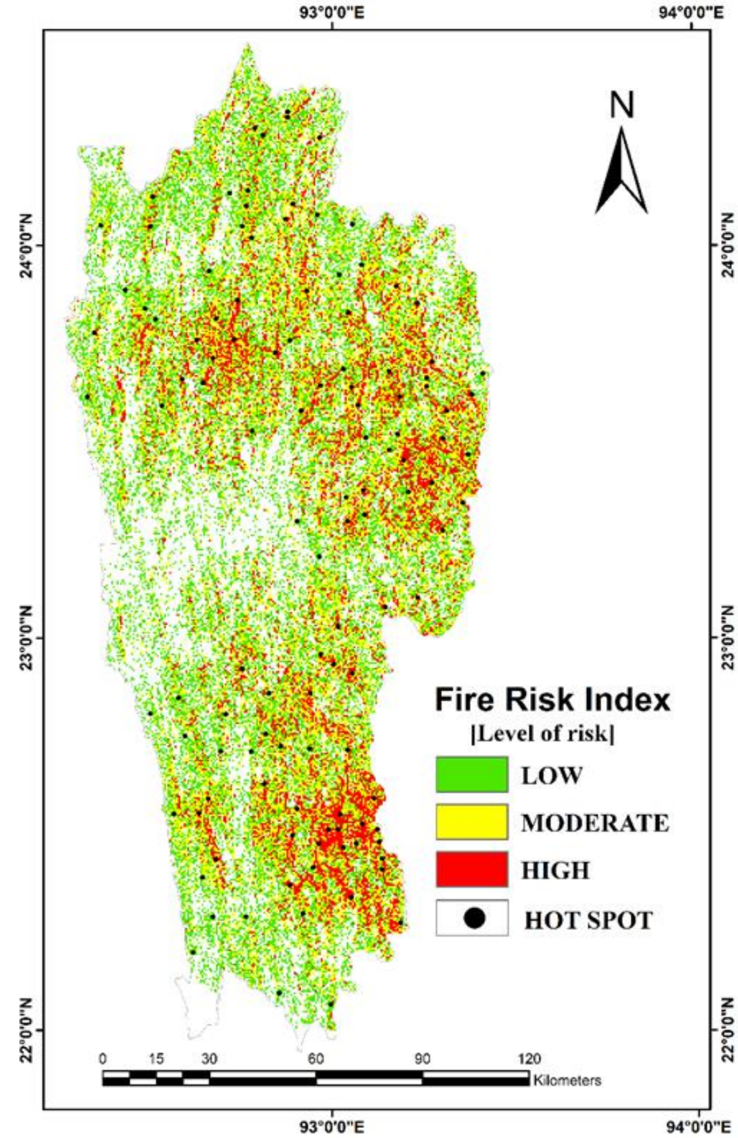

Figure 9. Model validation map

5. Conclusions:

As part of this study GIS has been used to integrate multiple layers of datasets for use in the modeling of forest fire risk, and the use of remote sensing enabled fire risk information to be obtained. Our main aim is to find out the risk zone area of forest fire, and in the result, we get the accurate risk zone area by using FRI, SFI, HFI, model, but according to model validation and accuracy, FRI model gives us more accurate result to finding risk zone map. In FRI, the result shows that many fire points fall around the shifting cultivated land, roads, and settlement. These are the origin of fires that indicates the increasing number of fire incidents are mostly affected by human activities. Its affects environmental balance, climatic condition, and loss of biodiversity. Sometimes human activities become most vulnerable. As a result, the recent Amazon forest fires have had an impact on the ecology, climatic conditions, and biodiversity loss. As satellite sensors capture images of wildfires over a large area, RS and GIS applications were used to map forest fire risk zones in the research area, and the results have the potential to improve disaster management in mitigating forest fires.

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