Proceedings of 14th IOE Graduate Conference
Peer Reviewed
Year: 2023 Month: December Volume: 14
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Multi-Hazard Mapping of Chandragiri Municipality, Kathmandu, Nepal

Ujjwal Giri [a], Basanta Raj Adhikari [b], Sangeeta Singh [c]

[a, b] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[c] *Department of Architecture, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] ujjwalgiri.ug@gmail.com

Abstract

The purpose of this research is to conduct a Multi-Hazard Mapping of Chandragiri Municipality, Kathmandu, Nepal using the Analytic Hierarchy Process (AHP) method. The study focuses on identifying the potential hazards that the municipality may face and the relative importance of each hazard. The hazards considered in this study include earthquakes, landslides, floods, and fire. To achieve the objectives of the study, data were collected from various sources, including government agencies, academic literature, and expert opinions. The AHP method was used to analyze the data and to identify the relative importance of each hazard. The results of the analysis provide a comprehensive understanding of the potential hazards that the municipality may face and the relative importance of each hazard. The findings of the study suggest that earthquake is the most critical hazard that the municipality may face, followed by landslide, flood, and fire. The study also identifies several factors that contribute to the vulnerability of the municipality to these hazards, including population density, infrastructure, and land use patterns. Overall, this study provides valuable insights into the potential hazards that Chandragiri Municipality may face and the relative importance of each hazard. The findings of this study can be used to develop effective disaster management plans and strategies to mitigate the impact of these hazards on the municipality and its residents.

Keywords

Multi-Hazard, AHP, Earthquake, Fire, Flood, Landslide, Hazard

1. Introduction

Hazards are dangerous phenomena that can cause loss of life, injury, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. Examples of hazards include floods, landslides, earthquakes, fires, epidemics, and storms. Vulnerable elements such as people, infrastructure, or the environment are affected by these hazards, leading to disasters. Disasters involve widespread human, material, economic, or environmental losses and impacts that exceed the ability of the affected community or society to cope using its resources [1].

Hazards can be natural (e.g., earthquakes, storms, floods) or man-made (e.g., fires, accidents). They can occur independently, at the same time, or one after another. In most cases, one form of hazard is accompanied by another, such as a landslide causing LDOF or floods causing epidemics, dysentery, and diarrhea [2]. Nepal has a history of numerous disasters, including epidemics, earthquakes, landslides, floods, and fires. Between 1971 and 2016, Nepal recorded 26,665 occurrences and 43,865 individual fatalities due to these hazards [3] The major disasters in urban areas include earthquakes, landslides, floods, and fires. Chandragiri municipality, for example, is prone to multiple hazards, with earthquakes, landslides, floods, and fires being the major ones [4].

Historically, studies have focused on one type of hazard, but multi-hazard risk research is rare in Nepal. Hazard maps are used to depict the spatial-temporal distribution of a natural hazard's principal repercussions, but they often differ in terms of hazard definition, procedure, and handling of uncertainty. Incorporating such maps into legislation, preparation measures, and resource allocation strategies is challenging [5]. Natural disasters are complex processes with escalating, provoking, knock-on, and chain reactions. To reduce and plan for such complex processes, a holistic treatment with multiple hazards and their interconnections is necessary, known as multi-hazard risk assessment. This approach helps decision-makers take initiative and planning from a multi-hazard perspective, ensuring the safety and well-being of all citizens. A multi-hazard assessment is essential for providing a comprehensive picture of an area regarding hazard scenarios. A composite probabilistic map depicting what, where, and what magnitude hazard may occur can be a major tool for local level planers in the fight to save life, property, and the environment from hazards [2].

1.1 Study Area

Chandrigiri municipality, located in the southwestern region of Kathmandu Valley, has a population of 85,198 as of the Central Bureau of Survey Census-2068. The municipality has a total of 433.04 km road networks, the electricity grid is connected to the national grid with sufficient connection and supply and has 39.7% cement-bonded brick stone masonry houses, 31.60% mud-bonded brick/stone masonry houses, and only 25.75% RCC houses [4] The municipality has predominantly hilly terrain, a mild climate subtropical climate zone, and lies in the Midland Region, a tectonic basin of the sub-Himalayas. Developing countries and growing urban areas, particularly Chandragiri, are at a higher risk of disaster due to poorly planned, overpopulated, and newly growing municipalities. Due to the growing migration of about 600 households per year, the municipality has experienced significant land purchases and construction, leading to haphazard land plotting and building construction. Proper land use planning with a multi-hazard perspective is crucial for a safe and prosperous municipality [6].

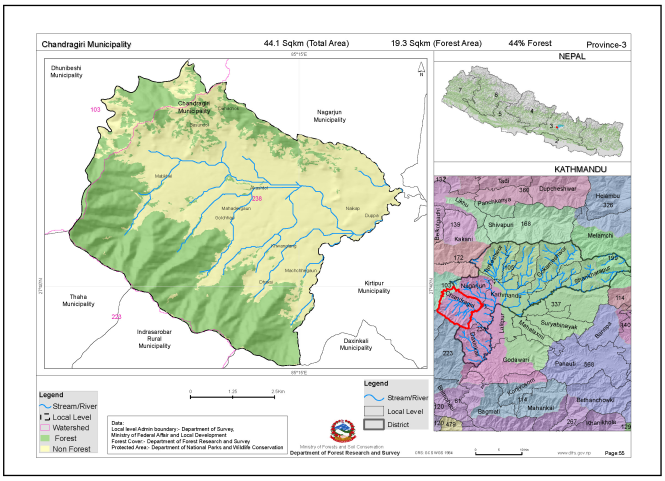

Figure 1: Chandragiri Municipality Map. (Department of Forest Research and Survey, 2015, Pg 55)

1.2 Research Purpose

The identification of the hazards is the first step in Disaster Risk management. With proper knowledge of What, where, and of what degree of hazard, a multi-hazard and multi-sectoral, people-centric DRM practice can be formed. A multi-hazard assessment is necessary at the local level to prepare land use plans and conduct prevention, mitigation, transfer, and preparedness activities for efficient, effective, and participatory Disaster Risk management. For this research following research questions need to be studied to research the area properly [7].

- Where do the major hazards namely; earthquake, landslide, Flood, & fire affect the most?
- Which areas are most sensitive regarding the multi-hazard perspective?

2. Materials and Methods

A thorough study was conducted which showed that there is a clear relation between the topography, geography, geology, land use (i.e. Distance from fault, Slope, Aspect, Profile curvature, Distance from the stream, LULC (land use land cover), Lithology, Distance from the road, Annual precipitation, NDVI (Normalized Difference Vegetation Index), Elevation, Population, Distance from fire brigades, Distance from the gas station, Distance from the transmission line, Distance from the electric substation, Distance from the main settlement, Distance from the old settlement, Seismic intensity, Soil liquefaction, Dominant building type, etc.) of a location and its susceptibility to hazards.

This research intends to understand the multi-hazard susceptibility of different areas of Chandragiri municipality using the AHP method. The weightage given to each factor and hazard is dependent on experience and expert judgment. Furthermore, the DEM resolution has a vast impact on the output of data. However, the method we use here is scientific, and with the same technique and data, the outputs are bound to be the same.

2.1 Data Collection

The data collection process for the Multi-Hazard Mapping of Chandragiri Municipality, Kathmandu, Nepal using AHP involved several steps. The first step was to conduct a thorough literature review to gather existing information on hazards, vulnerabilities, and risks in the study area. This involved reviewing published research papers, reports, and other relevant documents.

The second step was to conduct an ariel and field survey to collect primary data on the physical, social, and economic characteristics of the study area. This included collecting data on land use, population, infrastructure, and other relevant variables. The field survey was conducted using a combination of observation, and collection of aerial imagery.

The third step was to identify hazard events of interest and collect data on their occurrence, magnitude, and frequency. This involved reviewing historical records of hazard events in the study area, such as earthquakes, landslides, floods, and fires. Data on hazard events were also collected through expert consultations with local authorities and stakeholders.

Table 1: Datasets Considered for Hazard Assessment

Dataset	Landslide	Flood	Fire	EQ
Fault	✓			✓
Slope	✓	✓		✓
Aspect	✓			
Prof Curvature	✓			
Stream	✓	✓		
LULC	✓	✓	✓	✓
Soil Map	✓	✓		✓
Road	✓		✓	
Precipitation	✓	✓		
NDVI	✓			
Elevation	✓	✓		
Pop-density			✓	✓
Fire Brigades			✓	
Gas Stations			✓	
Lines			✓	
Transformers			✓	
Main Settlement			✓	✓
Old Settlements			✓	✓
Soil Liquefaction				✓
Seismic Intensity				✓
Building Type				✓

*Here Fault, Slope, Stream, Road, Fire Brigades, Gas Stations, Lines, Transformer, Main Settlements, and Seismic Intensity means "Distance from each of those" Simultaneously in *Table 1*.

Overall, the data collection process was a comprehensive and iterative process that involved a combination of primary and secondary data collection methods, expert consultations, and the use of analytical tools such as GIS and the AHP method. The spatial data has been obtained directly from Chandragiri

Municipality, government-published journals, published journal articles, and open sources such as geofabrik.de, data.humdata.org, and opendatanepal.com i.e., the study is done based on secondary data. The data collected were in 12.5MX12.5M Spatial resolution. Every factor doesn't have a significant influence on every hazard, the factors (i.e., data layers) considered for assessment of each hazard are as shown in *Table 1*.

2.2 Methodology

This research intends to understand the multi-hazard susceptibility of different areas of Chandragiri municipality using the AHP method. The weightage given to each factor and hazard is dependent on experience and expert judgment. Furthermore, the DEM resolution has a vast impact on the output of data. However, the method we use here is scientific, and with the same technique and data, the outputs are bound to be the same. Hence, the researcher believes that everything can't be known in this research and the research falls under the post-positivist paradigm.

The researcher believes that there is a clear relation between the topography, geography, geology, land use (i.e. Distance from fault, Slope, Aspect, Profile curvature, Distance from the stream, LULC (land use land cover), Lithology, Distance from the road, Annual precipitation, NDVI (Normalized Difference Vegetation Index), Elevation, Population, Distance from fire brigades, Distance from the gas station, Distance from the transmission line, Distance from the electric substation and transformers, Distance from the main settlement, Distance from the old settlement, Seismic intensity, Soil liquefaction, Dominant building type, etc.) of a location and its susceptibility to hazards.

The necessary data for the study can be found from aerial photo interpretation, Google Earth engine, survey, historical data, and literature review and can be cross-referenced with pilot field observations. As the research will be done with theanantitative data observed from the field, aerial photographs, AHP, etc., the research will be quantitative. For the research first, the weightage of the layers is determined using AHP, the individual hazard is assessed and inventory map is constructed based on influencing factors, and the generated hazard maps for four hazards are superimposed based on their weightages to produce the final map.

2.3 Methods and Technique

The method and techniques used for the Multi-Hazard Risk Assessment of Chandragiri Municipality, Kathmandu, Nepal using AHP involved several steps.

2.3.1 Hazard Event of Interest Identification

In this research, the identification of hazard events of interest was done through a combination of literature review, expert opinion, and historical data analysis. The study identified four main hazards of interest: landslides, floods, fires, and earthquakes. The literature review provided an overview of the hazards that are prevalent in the study area and their impacts. The expert opinion was gathered through interviews and discussions with local government officials, disaster management personnel, and community members. They were asked to identify the most significant hazards that have occurred in the past and are likely to occur in the future. Historical data analysis was done to determine the frequency and severity of each hazard event over the past decade. Based on the combination of these three sources of information, the study identified the four main hazards of interest and developed hazard maps for each of them using the Analytic Hierarchy Process (AHP) method. These maps provided a spatial representation of the hazards and their potential impact on the study area.

2.3.2 Establishment of criteria and sub-criteria

The establishment of criteria and sub-criteria for each hazard is a crucial step in the multi-hazard assessment process. This step involves the identification and selection of criteria and sub-criteria that are relevant to each hazard under study. In this research, the criteria and sub-criteria for each hazard were established based on a review of relevant literature, expert opinions, and consultations with stakeholders.

The identified criteria and sub-criteria were then used to develop a questionnaire, which was administered to experts in the relevant fields, such as geologists, engineers, and disaster management professionals. The experts were asked to assign weights to each criterion and sub-criterion based on their relative importance in determining the hazard under study. The weights assigned by the experts were then used in the AHP model to calculate the overall hazard risk score for each location in the study area.

2.3.3 Prioritization and Weight Generation

Table 2: Weightage taken for different factors for different hazard

Factor	Landslide	Flood	Fire	Earthquake
F1	0.254	0.337	-	0.075
F2	0.114	0.249	-	-
F3	0.142	0.169	-	-
F4	0.099	-	-	0.096
F5	0.084	-	-	-
F6	0.046	0.077	-	0.043
F7	0.045	0.000	-	-
F8	0.038	0.105	-	-
F9	0.042	-	-	-
F10	0.079	0.063	0.083	0.064
F11	0.057	-	0.113	-
F12	-	-	0.054	0.044
F13	-	-	0.164	-
F14	-	-	0.213	-
F15	-	-	0.192	0.178
F16	-	-	0.047	-
F17	-	-	0.030	-
F18	-	-	0.104	-
F19	-	-	-	0.178
F20	-	-	-	0.161
F21	-	-	-	0.161

Here,

F1 = slope,

F2 = distance from streams,
F3 = annual precipitation,
F4 = distance from fault,
F5 = normalized difference vegetation index (NDVI),
F6 = lithology,
F7 = aspect,
F8 = elevation,
F9 = profile curvature,
F10 = land use land cover (LULC),
F11 = distance from road,
F12 = population density,
F13 = distance fire brigades,
F14 = distance from gas station,
F15 = distance from old settlement,
F16 = distance from transmission line,
F17 = distance from electric substation,
F18 = distance from main settlement,
F19 = seismic intensity,
F20 = soil liquefaction,
F21 = dominant building type in Table 2.

After the establishment of criteria and sub-criteria for each hazard, the next step is prioritization and weight generation. The prioritization and weight generation process involves assigning weights to each criterion and sub-criterion based on their relative importance in contributing to the hazard event of interest. In this study, the weights for the criteria and sub-criteria were generated through a pairwise comparison matrix using the AHP method. The pairwise comparison matrix allows experts to compare the relative importance of each criterion and sub-criterion in relation to each other. The matrix is then analyzed using mathematical algorithms to generate the weightage for each criterion and sub-criterion. The weights generated from the pairwise comparison matrix were then normalized to ensure that they sum up to one. This normalization process allows for the comparison of the relative importance of each criterion and sub-criterion, regardless of the scale used for comparison. The weights generated from the pairwise comparison matrix were used to calculate the overall score for each hazard event of interest. The overall score provides a quantitative measure of the relative importance of each hazard event, taking into account the contribution of each criterion and sub-criterion. The weights of factors taken into consideration for each hazard are shown in *Table 2* and subsequently Multi-Hazard is shown in *Table 3*.

Table 3: Weightage for Multi-Hazard

Hazard	Weightage (Wi)
Earthquake	0.498
Landslide	0.214
Flood	0.166
Fire	0.122

2.3.4 Use of GIS Software to Create Hazard Maps

GIS software plays a crucial role in creating hazard maps for multi-hazard assessment. It allows for the integration and analysis of different types of spatial data such as topography, land use, geology, and infrastructure, which are essential for identifying and assessing potential hazards. One of the key features of GIS software is the ability to overlay multiple layers of data to create a comprehensive hazard map[8]. For example, a map of potential landslide hazards may include layers showing slope gradients, soil types, and vegetation cover. These layers can be combined and analyzed to identify areas with a higher risk of landslides.

GIS software also provides tools for spatial analysis and modeling, which allow for the creation of sophisticated hazard maps. For instance, modeling tools can be used to simulate the impact of an earthquake on buildings and infrastructure or to predict the path of a flood based on topography and hydrological data. Another important aspect of GIS software is its ability to display hazard maps in a user-friendly and interactive way [8]. These maps can be shared online or printed for use by emergency responders, city planners, and other stakeholders. They can also be updated and revised as new data becomes available, making them a valuable tool for ongoing hazard assessment and risk management. In this study, GIS software was used after the weight generation process to create hazard maps for the Chandragiri Municipality in Nepal. The hazard maps were developed based on the weights assigned to each criterion and sub-criterion using the Analytic Hierarchy Process (AHP) method. The hazard maps showed the spatial distribution of the different hazards, including earthquakes, landslides, floods, and fires, and their corresponding levels of susceptibility and vulnerability. The GIS software was used to integrate and analyze different types of spatial data, including topographic maps, geology and soil maps, land use and land cover maps, and population and infrastructure data. The hazard maps were created using different GIS tools and techniques, such as overlay analysis, proximity analysis, and spatial interpolation. The resulting hazard maps were then validated using different methods, including field surveys, historical data analysis, and expert opinions.

In summary, the method and techniques used for the Multi-Hazard Risk Assessment of Chandragiri Municipality, Kathmandu, Nepal using AHP involved identifying hazard events of interest, establishing criteria and sub-criteria, prioritizing them using the AHP method, creating hazard maps using GIS software, and validating the maps using historical data and expert opinions.

3. Result and Discussion

3.1 Individual Hazard Mapping

3.1.1 Earthquake Hazard Mapping

The Earthquake Hazard map of Chandragiri Municipality reveals that 78.29 hectares fall in a Low susceptible zone, 352.17 hectares in a Medium susceptible zone, and 36.38 hectares in a High susceptible zone. Ward 6 has the highest percentage of land in the High susceptible zone (2.63%). Wards 3,5,6,10,11,12,13,14&15 are most susceptible to earthquake hazards, with most land area in the Medium susceptible zone. Ward 1,2&4 are least susceptible, with more land in the Low susceptible zone and less in the High susceptible zone. The earthquake hazard map is presented in *Figure 2*.

The areas near Matatirtha Kunda, Macchenarayan Temple, Thankot Hospital, and Balambu are in a highly susceptible zone due to old Newari settlements and restricted building code applications. An Exposure Analysis showed that 314.75 km (88.67%) of roads are in the Medium susceptible zone, 38.53 km (10.85%) in the Medium, and 5.34 km (1.5%) in the High susceptible zone.

Further analysis revealed that 86.67% of roads were in the medium susceptible zone, with 29,793 houses in this zone. The medium susceptible zone had a higher vulnerability to collapse, with 126 brick-in-mud mortar houses and 103 stone masonry houses in high susceptible zones. This poses a risk to 870 people in the municipality, with 870 people at risk of fatal injury. The number of people exposed was calculated by multiplying building data with the average occupancy of the municipality.

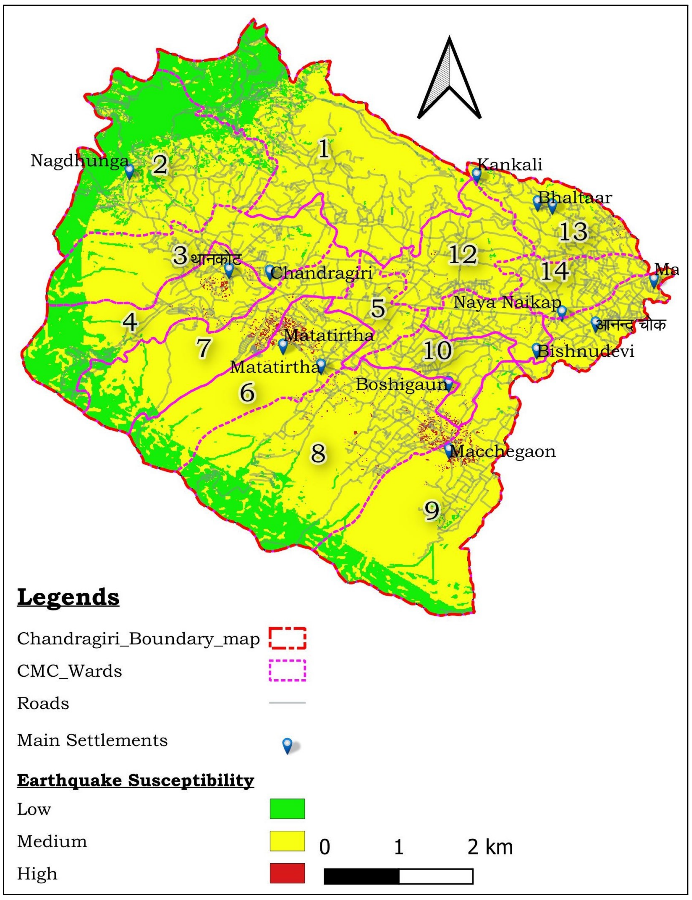

Figure 2: Earthquake Susceptibility Map

3.1.2 Landslide Hazard mapping

The Landslide Hazard map revealed that 82.70 hectares of Chandragiri municipality are in a Low susceptible zone, 341.00 hectares in a Medium susceptible zone, and 7.53 hectares in a High susceptible zone. Ward 7 had the highest percentage of land in the High susceptible zone (5.98%). Wards 4, 6, 7, 8, and 9 were most susceptible to landslide hazards, with most land in a moderately susceptible zone and some in a Highly susceptible zone. Ward 11, 14, and 15 were the least susceptible, with most land in a low zone and remaining in a moderately susceptible zone. The north-facing slopes of Matatirtha, Chandragiri hills, Puspalal Park, Macchegaun, and near Indradaha were found to be in a highly susceptible zone, which is also historically prone to landslides. Further analysis revealed that a significant portion of the municipality's roads and agricultural land are in the medium susceptible zone, with 72.24% of roads and 77.07% of agricultural land in this zone. The majority of houses, including stone houses, are in this zone, with 75.46%. This alarming situation highlights the need for effective risk management strategies. The landslide hazard map is presented in *Figure 3*.

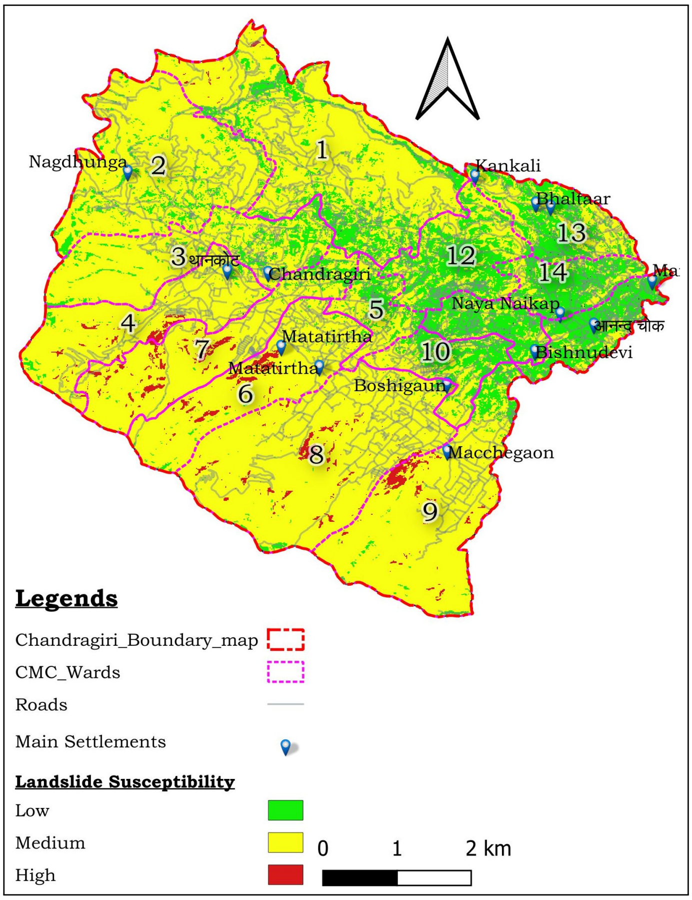

Figure 3: Landslide Susceptibility Map

3.1.3 Flood Hazard Mapping

The Flood Hazard map of Chandragiri Municipality reveals that 186.49 hectares of land fall in a Low susceptible zone, 127.13 hectares in a Medium susceptible zone, and 120.46 hectares in a High susceptible zone. Ward 5 has the highest percentage of land in the High susceptible zone (81.97%). Wards 5,11&12 are most susceptible to flood hazards, with most land in the Highly susceptible zone and remaining in the Moderately susceptible zone. Wards 1,2,4,7,8,9&10 are the least susceptible, with most land in the Low susceptible zone and remaining in the Moderate susceptible zone. The low-lying plains of Panighatta, Balambu, Gurjudhara, Macchegaun, Satungal, Jhulpokhari, and areas near Balkhu River and its tributaries are in a highly susceptible zone, historically prone to urban flooding and induation during the monsoon season. An Exposure Analysis showed that 145.60 kilometers (41.02%) of roads are in the Medium susceptible zone, 65.12 kilometers (18.35%) in the Medium, and 147.91 kilometers (41.67%) in the High susceptible zone. 2580 houses

(8.37%) are in the Medium susceptible zone, 12941 (41.98%) in the Low, and 15307 (49.65%) in the High susceptible zone. The flood hazard map is presented in *Figure 4*.

Further analysis revealed that 145.60 km (41.02%) of roads were in the medium susceptible zone, 65.12 km (18.35%) in the medium, and 147.91 km (41.67%) in the high susceptible zone. Agricultural land was also in the medium susceptible zone, with 188.00 hectares (13.15%) in the low susceptible zone and 654.9 hectares (45.79%) in the high susceptible zone. The majority of houses (8.37%) were in the medium susceptible zone, with 64.12% of brick in mud mortar houses in the high susceptible zone.

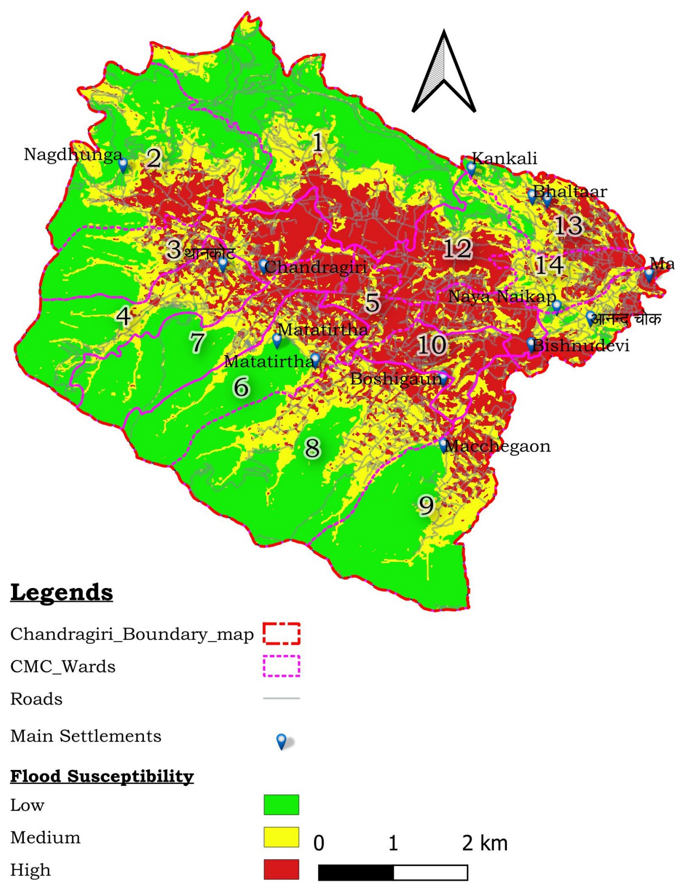

Figure 4: Flood Susceptibility Map

3.1.4 Fire Hazard Mapping

The fire hazards map in Chandragiri Municipality reveals that 136.60 hectares fall in a low susceptible zone, 301.52 hectares in a medium susceptible zone, and 0.3 hectares in a high susceptible zone. Ward 14 had the highest percentage of land in the high susceptible zone (94.93%). Wards 3, 6, 13, 14, and 15 were most susceptible to fire hazards, with most land in the medium susceptible zone and remaining in the low susceptible zone. Ward 1, 2, and 11 were the least susceptible, with most land in the low and moderately susceptible zone.

Densely populated and old settlements like Balambu, Thankot, Macchegaun, Kisipidi, Tinthana, and areas near Kalanki with few fuel stations, transmission lines, and transformers were found to be in a highly susceptible zone, historically prone to urban fire. An exposure analysis showed 84.93% of agricultural land in the medium susceptible zone, with 24547 houses in the medium susceptible zone, 6450 in the low susceptible zone, and 3 in the high susceptible zone. Over 70% of the houses were in a medium susceptible zone, indicating alarming levels of exposure. The fire hazard map is presented in *Figure 5*.

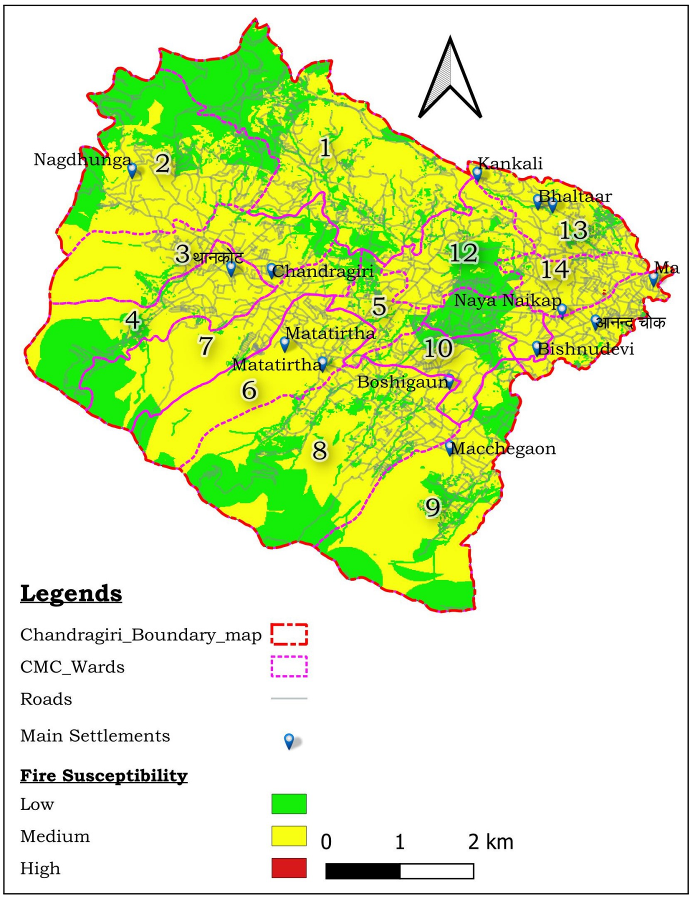

Figure 5: Fire Susceptibility Map

3.2 Multi Hazard Mapping

From the preparation of the Multi-Hazard susceptibility map, it was seen that 65.22 Hectares of Chandragiri Municipality fall in a Low susceptible zone, 365.97 Hectares in a medium susceptible zone, and 0.31 Hectares in a High susceptible zone. The Hazard-wise susceptibility map is shown in *Figure 6*. After a ward-wise comparison, it was seen that Ward 14 had the highest percentage of land in the medium susceptible zone (98.74%). It was observed that wards 5, 7, 10, 11, 12, 13, 14 &15 were most susceptible to Multi-hazard with most of their land area (more than 90%) in the Medium susceptible zone. Ward 1,2&4 were least susceptible to Multi-Hazard hazard with more of their land area in low (20%-30%) and remaining in the moderately susceptible zone and a low percentage of their land area in the high susceptible zone. It was observed that the areas near Matatirtha Kunda, and Macchenarayan Temple were observed to be in a highly susceptible zone.

An Exposure Analysis showed 320.37 KM (90.26%) of roads were observed to be in the medium susceptible zone, 34.52 KM (9.73%) in the Medium, and 39 M (0.01%) in the High susceptible zone. Similarly, 1380.60 Hectares (97.33%) of Agricultural Land was observed to be in the medium susceptible zone, 37.5 Hectares (2.64%) in the Low and 0.3 Hectares (0.02%) in the High susceptible zone. In total 29,904

(98.10%) houses were observed to be in the medium susceptible zone, 572 (1.88%) in the Low, and 7 (0.023%). These seven houses in a Highly susceptible zone are at very high risk. The result was similar to people as the number of people exposed was estimated by multiplying building data with the average occupancy (3.80) of the municipality.

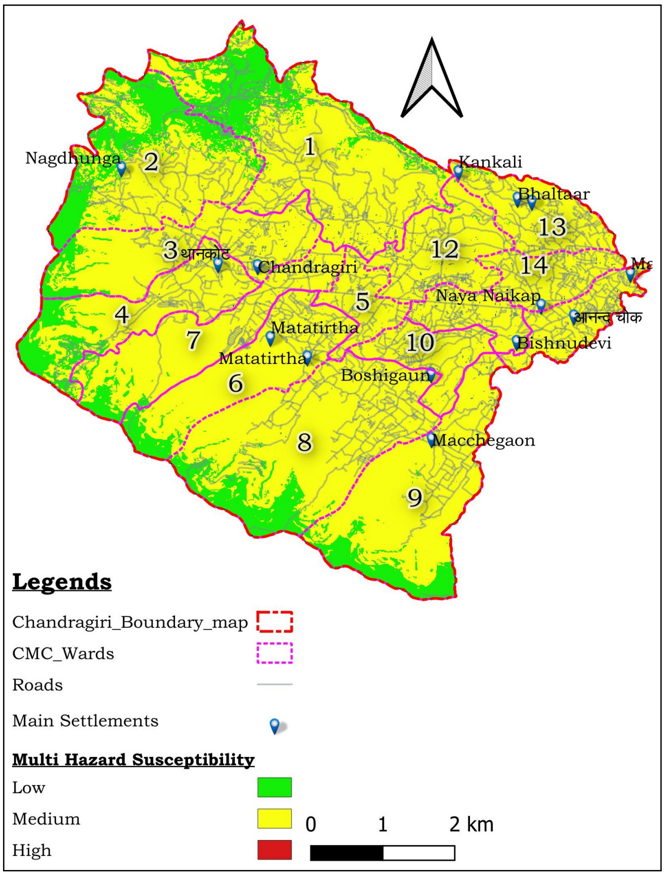

Figure 6: Fire Susceptibility Map

4. Conclusion

In conclusion, this thesis has presented a comprehensive multi-hazard assessment of Chandragiri Municipality, Kathmandu, Nepal, employing an integrated approach involving GIS, AHP, and exposure analysis. The study focused on four major hazards: landslides, floods, fires, and earthquakes. Through a meticulous analysis of various factors and their weightages, hazard susceptibility maps were generated, providing valuable insights into the vulnerability of the municipality to these hazards.

The Landslide Hazard assessment identified specific areas prone to landslides, with north-facing slopes and historical landslide-prone regions showing higher susceptibility. The ward-wise analysis further revealed varying susceptibility levels across different wards, highlighting areas demanding immediate attention for mitigation strategies. The exposure analysis revealed that roads, agricultural lands, and buildings are significantly at risk, which necessitates targeted measures to enhance resilience. In the case of Flood Hazard, the study pinpointed flood-prone regions, with low-lying plains and areas near rivers exhibiting higher susceptibility. The exposure analysis underscored the vulnerability of roads, agricultural lands, and buildings, reiterating the importance of focused strategies for risk reduction.

The Fire Hazard assessment revealed areas with high susceptibility, notably densely populated settlements, and regions with prominent infrastructure like fuel stations and transmission lines. The exposure analysis indicated substantial risks for agricultural lands, buildings, and population, underscoring the urgency of fire prevention and preparedness measures. In terms of Earthquake Hazard, the study identified areas vulnerable to seismic events, emphasizing regions with historical vulnerability. The exposure analysis highlighted the potential impact on roads, buildings, and population, necessitating enhanced seismic resilience strategies.

The culmination of hazard assessments led to the generation of a comprehensive Multi-Hazard susceptibility map. This integrated map provides a holistic perspective on the overlap of susceptibilities, guiding policymakers and stakeholders in prioritizing multi-hazard mitigation initiatives. The findings of this study offer a valuable foundation for informed decision-making and urban planning, enabling the municipality to develop targeted strategies for disaster risk reduction and resilient development. However, this study acknowledges its preliminary nature and the ongoing data collection process for building typology data, which will further refine the accuracy and depth of the hazard susceptibility assessments. In the quest for a safer and more resilient municipality, this research presents a significant step forward, equipping local authorities and stakeholders with the knowledge needed to safeguard lives, properties, and the environment against the multifaceted challenges posed by various hazards.

References

[1] UNSIDR. *The Pocket GAR*. The United Nations, 1st edition, 2015.

[2] UNDRR. *Global Assessment Report on Disaster Risk Reduction 2017*. The United nations, 1st edition, 2017.

[3] Government of Nepal. Nepal disaster risk reduction portal, 2018.

[4] DUDBC. *Municipal Profile of Chandragiri Municipality*. Department of Urban Development and Building Construction Babar Mahal, 2020.

[5] Rajesh Khatakho, Dipendra Gautam, Komal Raj Aryal, Vishnu Prasad Pandey, Rajesh Rupakhety, Suraj Lamichhane, Yi-Chung Liu, Khameis Abdouli, Rocky Talchabhadel, Bhesh Raj Thapa, and Rabindra Adhikari. Multi-hazard risk assessment of kathmandu valley, nepal. 2021.

[6] Chandragiri Municipality. *Integrated Disaster Risk Reduction Plan of Chandragiri Municipality*. Chandragiri Municipality, 2021.

[7] S. Singh, R. Shrestha, and K. Rijal. Multi-hazard assessment of kathmandu valley, nepal using analytical hierarchy process. 2020.

[8] Patrick McHaffie, Sungsoon Hwang, and Cassie Follett. *GIS An Introduction to Mapping Technologies*. CRC Press, 1st edition, 2019.