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Spatial and Temporal Analysis of Road Traffic Accidents Using GIS

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Abstract

Road traffic accidents are becoming more common, presenting serious public safety and urban development problems. This study employs Geographic Information Systems to conduct a comprehensive spatial and temporal analysis of road traffic accidents, aiming to identify accident hotspots and underlying patterns. By integrating and analyzing accident data from police reports, the distribution and frequency of accidents across different locations and periods were studied. The accident rate has increased by 1.27% in the fiscal year 2020/2021 than 2019/2020, 2.54% in 2021/2022 than 2020/2021, and by 6.03% in 2022/2023 than 2021/2022. About 12.7% of total accidents recorded were minor, 72.4% of total accidents were major and 14.9% of total accidents recorded were observed to be fatal. The findings reveal a high concentration of accidents at the central part along the Araniko highway. Banepa municipality has a high accident rate compared to Dhulikhel and Panauti due to overspeeding, overloading, overtaking, careless driving, mechanical failures, and loss of vehicle control. Minor accidents were frequent at high-traffic intersections, whereas the major and fatal were predominantly concentrated along the Araniko highway. 41% of medium size, 38% of heavy vehicles, and 39% of light vehicles encountered accidents. The study revealed that head-on collisions on the narrow section of Araniko Highway occur often. Intersection management and signalization in Banepa need to be addressed since rear-end collisions increased during periods of high traffic congestion. Two-wheel riders and pedestrians are the more vulnerable. The study utilizes spatial statistical tools such as Kernel Density Estimation (KDE) to identify accident-prone locations. Temporal analysis further explains peak times and seasons for accidents. The findings reveal distinct spatial clusters of accidents and temporal patterns during peak and non-peak hours. This spatial and temporal analysis of accidents showed the need for specific road safety interventions. Through the identification of accident causes and the implementation of recommended measures, these municipalities can significantly lower accident rates and improve overall road safety in their locality.

Keywords: Road traffic accident, GIS, Spatio-temporal analysis, Kernel density estimate.

1. Introduction

A road traffic accident is a major cause of death and injury worldwide, resulting in significant economic and social loss. Approximately 1.19 million people died as a result of traffic accidents in 2021. The global macroeconomic cost of traffic injuries is estimated to be as high as US$ 1.8 trillion, or around 10–12% of the world's gross domestic product (WHO, 2023). Road accidents are now the leading cause of suffering globally, particularly in developing nations like Nepal. The main factors responsible for the increase in road accidents are an increase in the number of vehicles on the road, an incomplete but growing road infrastructure, a lack of lane discipline, and difficult geography (Watson & Ryan, 2024). In Nepal, there are 14 road traffic injury deaths for every 100,000 people. Road traffic injuries (RTIs) are a major problem in Nepal, where the number of fatalities on highways outside the Kathmandu Valley is higher (Karkee & Lee, 2016). In Nepal, traffic

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police keep track of all traffic accidents in each district and submit the data to the national police headquarters in Kathmandu. The date, time, place, and number of casualties, along with their name, address, gender, and the type of accident and its cause, are all included in these statistics (Watson & Ryan, 2024).

Dhulikhel, Panauti, and Banepa are rapidly urbanizing. The traffic volume is increasing at an alarming rate in these areas. There has been a rapid increase in traffic volume, leading to traffic congestion along the road section from Sanga to Dhulikhel of the Araniko highway. Besides this, poor road conditions, inadequate street lighting, a lack of efficient and effective traffic management, and adverse weather conditions added challenges to traffic safety (Bhele & Rajchal, 2023).

The use of Geographic Information System (GIS) technology to analyze hotspots and visualize accident data has grown in popularity. Numerous research papers have utilized geographic information systems (GIS) in accident investigations. GIS software also makes analysis easier by reducing time and effort. Consequently, accident record databases can be updated, maintained, and used for further analysis with the help of GIS (K & Ganeshkumar, 2010). Thus, this study on road traffic accidents using spatial and temporal analysis is significant for in-depth knowledge of traffic accident trends and patterns and identifying the causes so that concerned authorities can take immediate actions for infrastructure development along with the development of better road design and enforcing the safety measures for minimizing traffic accidents.

The objective of this research is to use GIS to conduct a geographical analysis of traffic accidents in Banepa, Panauti, and Dhulikhel, three municipalities in the Kavrepalanchowk district. The steps in the approach include identifying hotspots, analyzing spatial accident patterns, analyzing temporal maps, and doing some statistical analysis. It is anticipated that the study's findings will lead to the development of practical plans and initiatives that will reduce collisions and improve traffic safety. Besides this, the output of the study will be useful for road safety in hilly regions of Nepal, which is advancing to urbanization.

2. Literature Review

Road traffic accidents are a major concern for developing countries and substantially impact the development of their countries (Hossain & Faruque, 2019). Road traffic accidents occur when a vehicle collides with another vehicle, pedestrian, stationary objects, and stray animal resulting in minor, major and fatal accidents (Haque, et al., 2022). The locations where the frequency of occurrence of accidents is high over a long period due to traffic, road conditions, climate and environment are considered road black spots, also called hazardous or high-risk locations (Haghighi & Karimi, 2018). Areas with a high likelihood of an accident occurring are typically considered accident hotspots. But the definition can vary. The hotspots is every spot that has a higher number of accidents than other similar spots due to local risk factors (Elvik, 2007). Also, different countries have their own definition of hotspots. The definitions of hotspots in different articles are presented in Table 1.

Table 1. Definition of accident hotspots in different countries *(Rahimov & Haj, 2011)*

Country	Accident Hotspot Definition
Germany	Road sections with a length of 300 m, occurrence of more than 3 similar accidents during one year, occurrence of more than 5 accidents during three years
England	Road sections with a length of 300 m, a spot in which the total number of road accidents is more than 12 accidents over three years.
Spain	Road sections with a length of 1km, the occurrence of more than 5 injury accidents or 2 fatal accidents during one year, the occurrence of more than 10 injury accidents or 5 fatal accidents during 3 years
Czech	Road sections with a length of 250m, occurrence of at least 3 injury accidents during 1 year, occurrence of at least 3 similar injury accidents during 3 years, occurrence of minimum 5 similar accidents during 1 year
Netherlands	Occurrence of at least 10 accidents, occurrence of minimum 5 accidents with similar properties of analysis period is 3 to 5 years.

GIS (Geographic Information Systems) are crucial for enhancing urban mobility and for transportation planning in general. To generate a comprehensive image of the urban transportation system, GIS integrates data from several forms of transportation, including walking, cycling, and shared mobility services. Planners can locate the points where many transit modes converge, creating smooth linkages. In addition to assisting to identify traffic hotspots and blackspots, geospatial analysis provides a means of recognizing the spatial environmental factors that contribute to traffic accidents, including the physical environment's features such as hills and vegetation, traffic volume, and road design and construction (Watson & Ryan, 2024). Geographical information system (GIS) is a tool that has several benefits: (a) it allows to retain a large amount of data; (b) it enables to perform data analysis and visualization to explore the affinity between data; and (c) it provides graphical and non-graphical results. GIS permits hotspot maps to be electronically generated from a well-designed accident database and produce ranking based on the total accidents occurring or accident rates. GIS allows visualization of results, thus enabling sophisticated analysis and quick decision-making (K & Ganeshkumar, 2010).

Human errors are a major cause of accidents. Besides this, environmental factors, road conditions, mechanical factors, traffic volume, the expansion of the road networks, mixed traffic, pedestrians, ineffective enforcement of traffic laws, and absence of emergency services (Ansari, et al., 2000) (Bhele & Rajchal, 2023) (Wangdi, et al., 2017). Various research has been carried out on road accidents using different GIS software. A study focused on identifying accident-prone zones within Kannur district using GIS software was done. The process involved data collection, both spatial and non-spatial, georeferencing the map, digitizing the geographic features in digital form as x and y coordinates, and creating a map showing the accident location. The analysis provided the hotspot location of the Kannur district in the years 2006, 2007 (K & Ganeshkumar, 2010). ArcGIS software was used for the identification of black spots. An assessment of the width, shoulder, kind and state of the surface, obstructions, traffic signs and signals, drainage, and visibility of the road was done to analyze the accident. The locations of the dark spots were identified and offered suggestions for resolving the problems at each site (Fayaz, et al., 2023), (Stephen,, et al., 2018). Morans's I technique of spatial autocorrelation, Getis-Ord Gi* statistics, and point Kernel density functions are used to assess the spatial clustering of accidents and hotspot densities. Therefore, other analysts can more easily and visually discover statistically significant accident hotspots in the Thiruvananthapuram city corporation region (Prasannakumar, et al., 2011).

Consideration of suitable bandwidth and cell size are very essential to the kernel function itself, and this selection is also subjective in defining the right density estimate (Yalchin & Duzgun, 2015) (O'sullivan & Wang, 2007). The cell size and bandwidth in Planar Kernel Density Estimation are shown in table 2.

Table 2. Cell size and Bandwidth in Planar Kernel Density Estimation.

S.N	Author	Year	Cell Size (m)	Bandwidth (m)	Country and area type
1	Anderson TK (Anderson, 2009)	2009	100	200	United Kingdom
2	Erdogan et al. (Erdogan, et al., 2008)	2008	500	500	Turkey
3	Erdogen et al. (Erdogan,, et al., 2015)	2015	50	700	Turkey
4	Thakali et al. (Thakali, et al., 2015)	2015	400	400, 800	United states
5	Yoshiki et. al. (Yoshiki, et al., 2016)	2016	250	250	Japan

GIS was used to identify geographical and temporal patterns. The Getis-OrdGi* statistic and Moran's approach of spatial autocorrelation have been used to analyze the hot spots and determine the temporal patterns and distribution of accidents. The research revealed that the northeastern province, which has a mountainous climate and experiences more than 500mm of rainfall annually, has a higher-than-average accident rate. These places also exhibit a lower weight cluster concentration, and in the northwest roads,

despite less traffic, the number of fatalities was higher. The study also advised to plan for a thorough investigation to find the reasons and causes of such problems (Aghajani, et al., 1017). The spatial distribution of local traffic accidents was done using statistical techniques and spatial analysis. The study concentrated on looking at traffic accidents in Peshawar's Moyatabad neighborhood. The primary goal of the project was to use ArcGIS 10.2 to detect accident hotspots in the Nistal area using advanced statistical approaches. A method was created to use ArcGIS to find hotspot clusters by analyzing the geographical pattern of traffic incidents. The results highlight the significance of implementing traffic regulations by suggesting that illegal parking infractions and traffic rule violations are factors in accidents that occur in these hotspots (Fayaz, et al., 2023), (Rabbani,, 2019). A study was conducted demonstrating how to use GIS in transportation planning by combining it with the GIS-based program "Gram++" to streamline the road safety audit procedure. For their investigation, they selected a 3-kilometer segment of road between Panvel and Iidapur. They also digitalized the road's features and built a database to make it easier to analyze the layered road segments in an organized way. Road auditors may find their study useful in analyzing all layer segments at once (Sayed & Mhaske, 2013).

Spatial data and analysis are the most essential information for traffic accident analysis. GIS provides information to analyze the accident-prone area, hotspots, and ward spots. The analyst can combine accident data and calculate the frequency and rate of accidents and select the variable for stratification so as to compute the mean and standard deviation of accident rates (Liang, et al., 2005). Numerous studies have examined GIS technology and its uses in accidents and the study's spatial pattern since 1990. These include segment and intersection analysis, pattern analysis, proximity analysis, spatial query, and models for spatial accident analysis. Traffic safety studies look at how different elements affect safety performance. These include the impact of geographical location, environmental variables (such as weather), and geometric elements of road design on the frequency of accidents (Shankar, et al., 1995). Kernel density estimation was used to identify hotspots, and GIS was used to map, visualize, and examine accident data (Sandhu, et al., 2016).

The weighted severity index and accident severity index were used to identify black spots on the road stretch of the Araniko Highway in Nepal from Sanga to Dhulikhel. The research focused on the temporal and spatial distribution of accidents. The majority of victims were men; most accidents happened in the late afternoon, and the highest percentage involved a vehicle and a pedestrian. In order to lower traffic accidents, the study recommends evidence-based infrastructure development, public awareness campaigns, and law enforcement tactics (Bhele & Rajchal, 2023). The post-mortem reports from nine hospitals in the Kathmandu Valley were used to conduct the study so as to determine the characteristics of RTA in the central region of Nepal. It was observed from the study that there were 2.3 male victims for every female victim. Similarly, soft tissue injuries were the most frequent type of damage, followed by open wounds, fractures, and traumatic brain injuries, and road safety education should be made mandatory for those in the 15-49 age range, as well as helmet use for both wheeled and backseat riders (Huang, et al., 2016). A correlation between weather, drunk driving, and bad road conditions was observed and found that the main causes of traffic accidents are road conditions and bad weather conditions (Manandhar, 2022). The present situation of accidents in relation to several different variables was studied using secondary data from the metropolitan traffic police division in Kathmandu for the years 2068 to 2076. The study found that the majority of traffic accidents involved drivers between the ages of 21 and 40. Motorbikes, scooters, tractors, and tempos were the vehicle types involved in these accidents, and the hours of the accidents were between 6 p.m. and 12 a.m. Similarly, it was observed that a greater death rate is among male motorcyclists as well as pedestrians, and accidents occurred 17.8% more frequently between the hours of 12 p.m. and 6 p.m. and 68.15 percent more frequently between the hours of 6 p.m. and 12 a.m (Tharu & Shrestha, 2021).

3. Methodology

3.1. Study area

Banepa, one of the rapidly urbanizing municipalities of Karvepalanchowk district, lies along the Araniko highway, nearly 26 kilometers east of the Kathmandu valley. The geographic coordinates of Banepa is 27°37′47″N 85°31′13″E. Banepa is a major commercial and transportation hub connecting Kathmandu to

eastern Nepal through the Araniko highway. The road network of this urban area experiences high traffic volumes, contributing to a notable number of road traffic accidents. Besides this, the growth of both urban and rural roads along with the increase of vehicular movement have made Banepa, a crucial area of traffic accident studies. Similarly, Panauti is a historically important town located in the Kavrepalanchowk district, nearly 32 kilometers southeast of Kathmandu Valley. The roads in Panauti are narrow, and both increasing population and vehicles have been challenges in traffic safety. The geographic coordinates of Panauti are 27°35′N 85°31′E. Dhulikhel is nearly 30 kilometers east of the Kathmandu valley. It is one of the most popular tourist destinations for its scenic and hiking trails. It serves as a starting point for several roads, including Arniko Highway and B.P. Highway. This strategic location results in substantial traffic, which, along with local vehicular traffic and pedestrian movement, creates a challenging environment for road traffic safety. The geographic coordinates of Dhulikhel are 27°37′06″N 85°33′07″E. These urban areas have distinct traffic patterns influenced by geographical features, commercial and cultural characteristics. The study area for the accident study is shown in the figure 1.

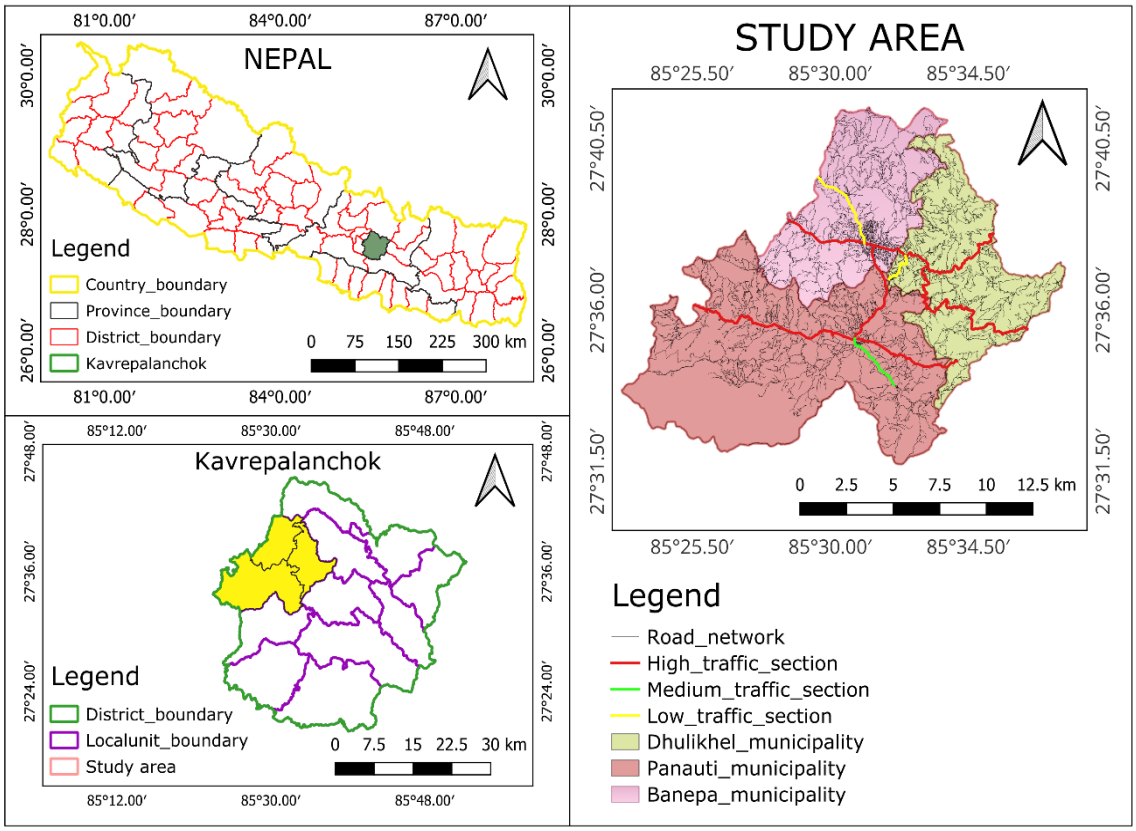


Figure 1. Study area.

3.2. Data collection

The secondary source of data includes traffic volume data from Department of Road, Nepal and road accident reports from district traffic police, Kavrepalanchowk covering the years 2019 to 2023. From the report, the data related to accident types, location of the accident, date, time, vehicles involved during accidents, causes, etc. were recorded. The Google Earth interface of the study area was imported into GIS.

3.3. Data Processing

The road accident data were standardized, ensuring consistency in the format of the data. After that, the accident locations identified from the record were converted into geographical coordinates. Finally, all the data sets were integrated into a single dataset, ensuring there were no duplicate records. Similarly, all accident dates and times were used in a convenient format for temporal analysis, and all those data were aggregated into convenient time intervals. Finally, these data were stored in a GIS data system for easy retrieval and

analysis. Thus, data processing was done through the steps: data cleaning, geocoding, data integration, and data transformation.

3.4. Accident analysis

3.4.1. Statistical Analysis

The frequency distribution table was generated to quantify the accident numbers based on accident nature, causality number, causes of accident, and accident collision nature using Statistical Package for Social Science (SPSS).

3.4.2. Spatio-temporal Analyses

Spatio-temporal analyses were conducted to explore the annual and seasonal occurrences. Initially, the time of occurrence and coordinates of the location of the accident were obtained. For the study, the accident data were classified as: dry season and monsoon season. This concept allowed for a graphical representation of accident distribution based on seasonal fluctuations in accident frequency.

3.4.3. Accident severity analysis

Accident analysis was done based on the severity level. The classification of accidents for quantifying the impact of each accident was as follows:

1. Minor accident: Minor damages to property and road users
2. Major Accident: Severe accident leading to significant injuries and need to refer hospital for further treatment.
3. Fatal Accident: Catastrophic incidents that may result in the death of road users.

Based upon the above severity level, a detailed spatiotemporal analysis was performed to develop a map showing accident distribution over the study area.

3.4.4. The Kernel Density Estimation

The Kernel Density Estimation was adopted to generate a subjective heat surface of the variation of traffic accidents from high to low. This technique helps to estimate the proportion of the total accidents that can be expected to occur at any given location. These techniques calculate the proportion of accidents that are likely to occur at any particular location (Afolayan, et al., 2022). A 1000 m bandwidth and 100 m cell size were adopted to develop a hotspot map and the kernel density estimation was performed using the following equation (Haghighi & Karimi, 2018)

$$f(\mathrm{x},\mathrm{y}) = \frac{1}{nh^2}\mathrm{K}(\frac{d_i}{h}) \quad (1)$$

Where,
f (x, y) = The density estimate of the location (x, y)
n = The number of observations
h = Bandwidth
K = The kernel function
di = Distance between the location (x, y)

4. Result and discussion

4.1. Traffic Volume.

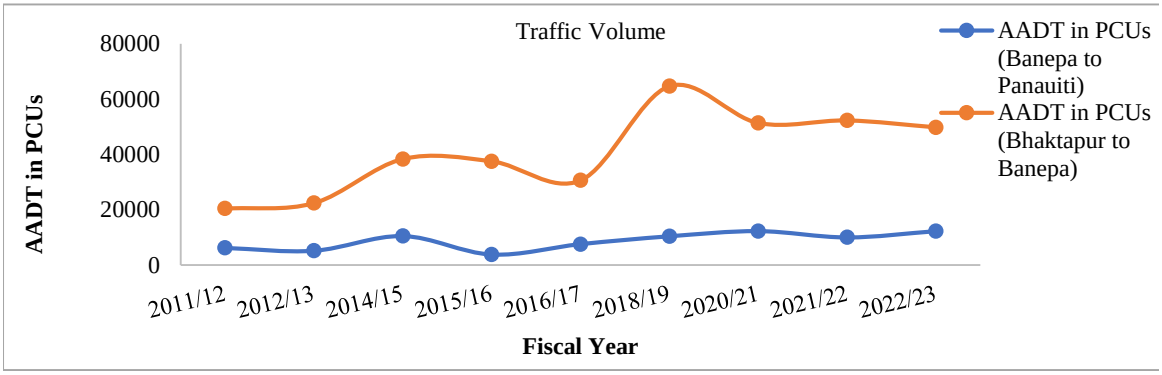


Figure2. Traffic volume (DOR, 2024)

The traffic volume on the major roads is shown in figure 2. Bhaktapur to Banepa road consistently carries more traffic than Banepa to Panauiti, indicating its importance as a national highway connecting to the Kathmandu Valley. There is need for maintenance, expansion of road and traffic management intervention due to its heavy usages. The Banepa to Panauiti route is experiencing moderate growth indicating an increase in local traffic demand but still needs attention, particularly in the long term.

4.2. Road accident analysis

The accident data obtained from traffic police covering the years 2019 to 2023 were studied. The distribution of accident frequency by fiscal year is shown in the figure 3. It was observed that the accident rate has increased by 1.27% in the fiscal year 020/021 than 019/020, 2.54% in 2021/022 than 020/021, and by 6.03% in 022/023 than 021/022.

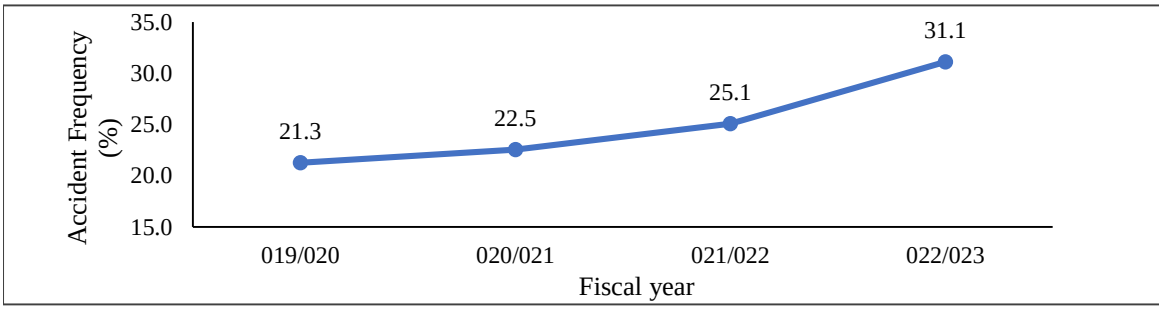
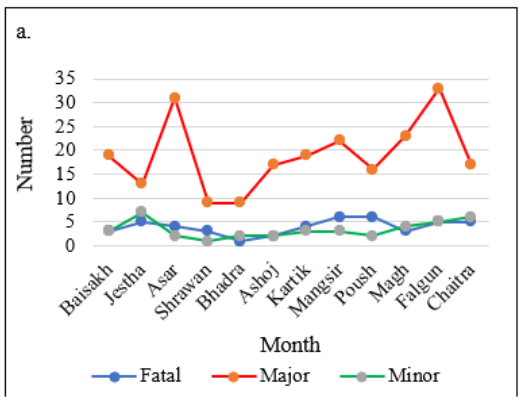
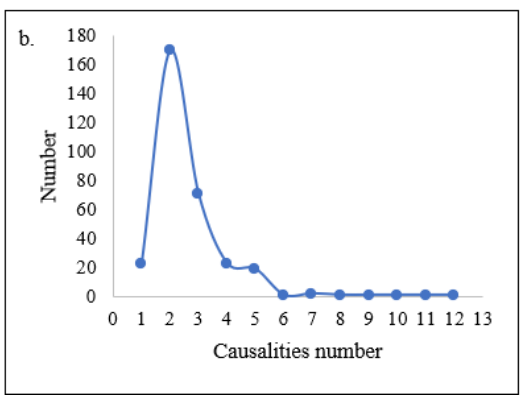


Figure 3. Accident Frequency





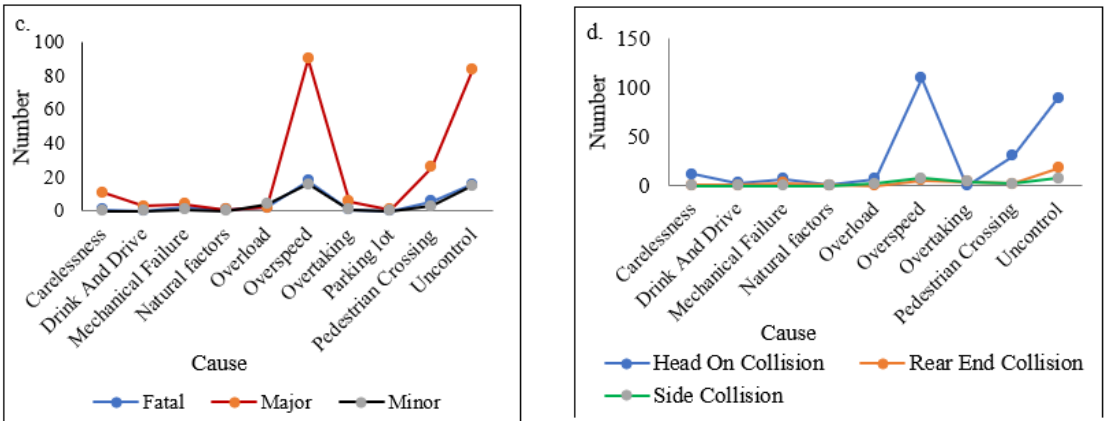
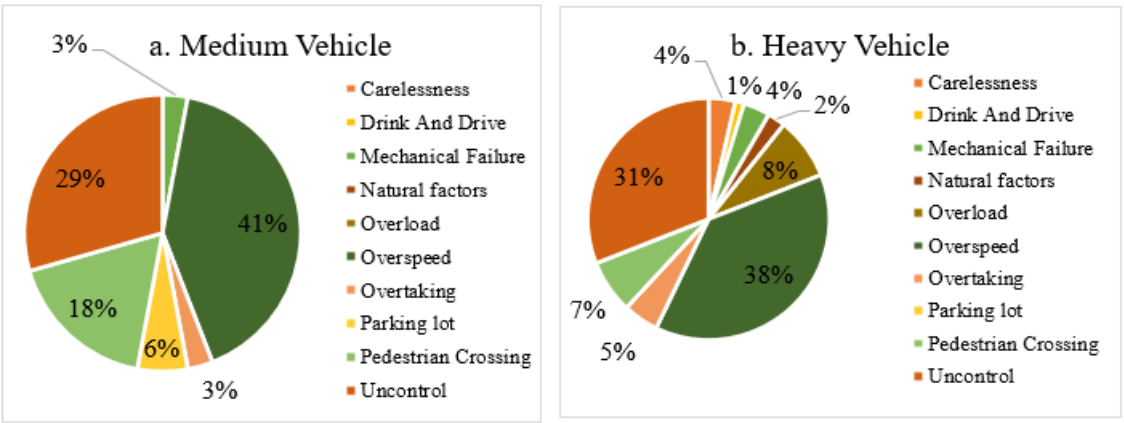


Figure 4. Accident Trend, (a) Accident number by month, (b) Accident number by casualties' number, (c) Accident number by causes and (d) Accident number by Collision type.

The accident trend over the study area is shown in figure 4. The frequency of accidents with a greater number of casualties per accident is observed to be lower. This trend indicates that the higher the casualties number, the lower the frequency of accidents. According to the study, two-wheel riders and pedestrians are the more vulnerable. Similarly, major accidents occurred more frequently in the months Asar and Falgun, the fatal accident on Jestha. Mansir and Poush, and minor accidents occurred more frequently on Jestha. The causes of accidents are shown in figure 4 (c) where overspeed and uncontrollability are the major causes of major accidents. Due to haphazard driving, the driver losses the controlled over the vehicle, which results into accident. Besides this, poor road condition is also responsible for loss in the control over the vehicle while driving. During overspeeding and uncontrolled over the vehicle, head-on collisions are more frequent in comparison to the other two types of collision.

The distribution of accidents by vehicle type based on the cause of the accident is shown in the figure 5. The major causes of accidents are carelessness, drink and drive, mechanical failure of the vehicle, natural factors, overload, overspeed, overtaking operation, parking issues, pedestrian crossing haphazardly, and loss of control. It was observed that 41% of medium size, 38% of heavy vehicles and 39% of light vehicles encountered accidents because of overspeeding while driving. Thus, provisions should be made to control the overspeeding practice so that the accident rate can be reduced.



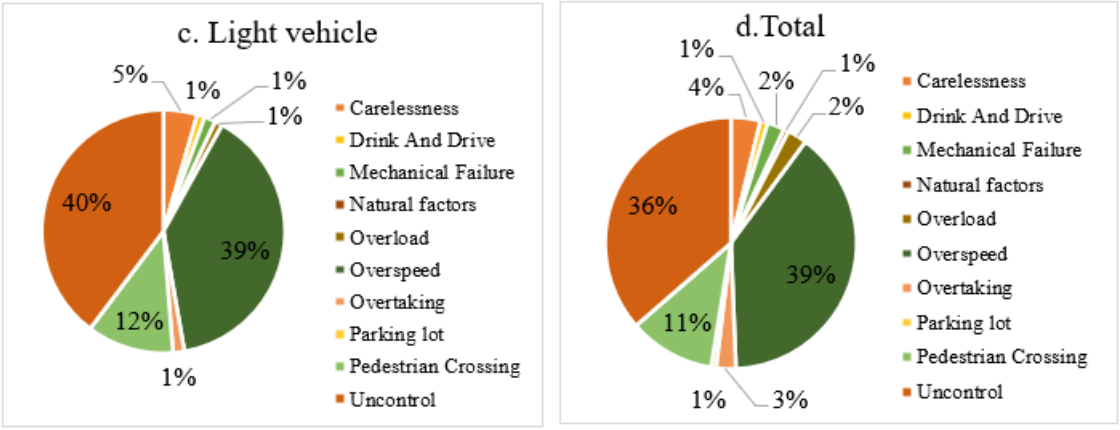


Figure 5. Accident distribution by vehicle (a) Medium Vehicle, (b) Heavy Vehicle, (c) Light Vehicle, (d) Total vehicle.

4.3. Accident frequency

Over the past four fiscal years, accidents that have been recorded at various locations within these municipalities as per police records are shown in figure 6. These accidents have been documented at more than 50 different locations. Red star symbols indicate the location of accidents. These stars are scattered throughout the municipalities. The accident map developed showed that the accident in the studied area is concentrated more in the central part of the study area through which the national highway Araniko Highway passes. Based upon the site visit, it was observed that highlighted areas have more traffic and have intersections contributing to a significant number of accidents. Similarly, Banepa Municipality has the most concentrated area of accidents in comparison to Panauti and Dhulikhel. The road network and its interaction with accident locations can be analyzed to explore how road design and traffic contribute to accidents.

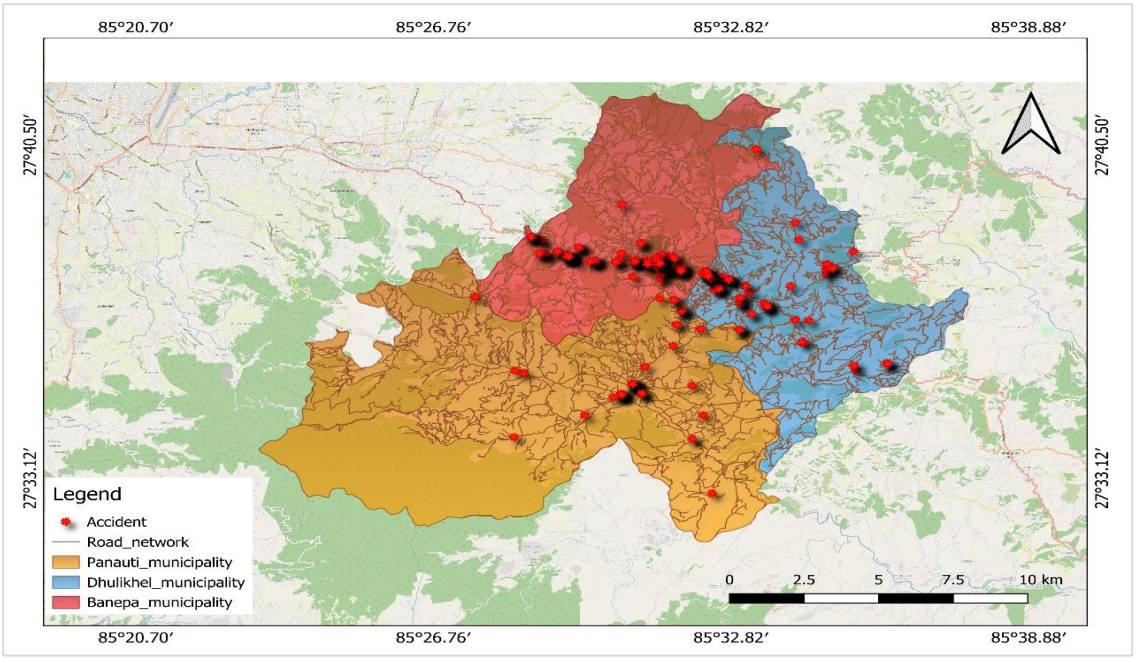


Figure 6. Accident Distribution over the study area.

4.4. Accident Heat Map

The accident heat map showed a cluster of dark red areas mainly along the Araniko highway as shown in figure 7. The red marks indicate that these areas are high-risk areas where accidents are more frequent. The

light pink color indicates an area with a lower concentration of accidents. Based upon the heat map, it was observed that the road network mainly in Panauti has fewer records of accidents than the roads of Banepa Municipality. It is observed that accidents are more concentrated primarily along the Araniko highway, which passes through the central part of the study area. The area along the Araniko highway where the accidents are concentrated has no traffic signs and signals and road markings. Besides this, there is a lack of pedestrian crossing, which has also contributed to the accident rate. This heat map has highlighted the need for road safety measures, enforcing traffic rules and regulations, for controlling the rate of traffic accidents.

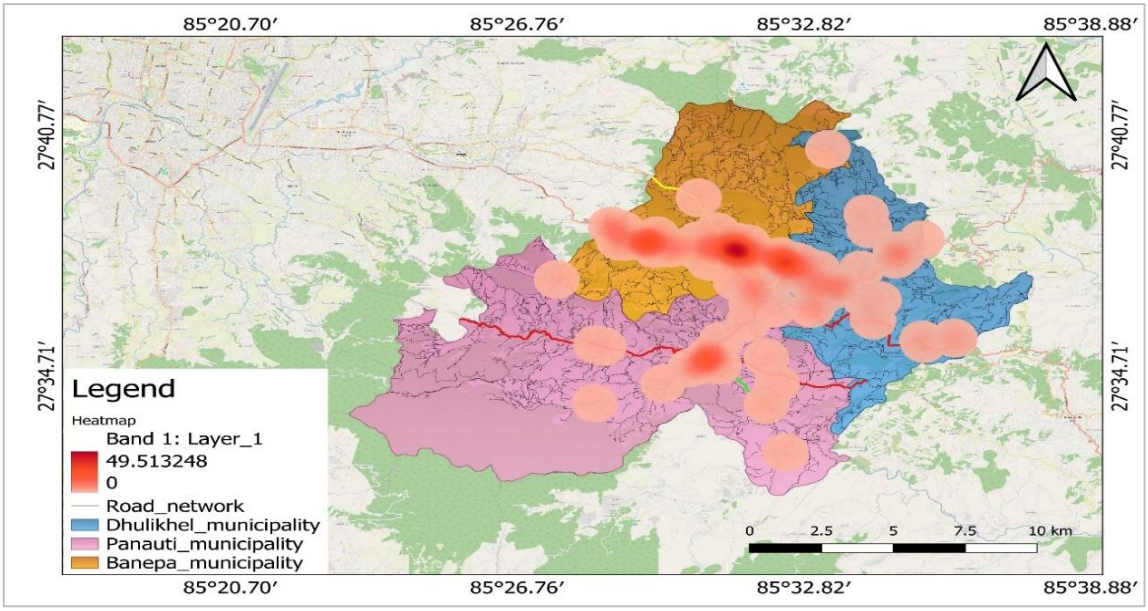


Figure 7. Accident Heat Map

4.5. Accident frequency and severity analysis

All accidents were grouped into minor, major, and fatal. Minor damages which account for 12.7% of total accidents recorded were classified as damage only; major accidents which account for 72.4% of total accidents recorded encompass property damages along with injuries, while fatal accidents which account for 14.9% of total accident recorded include both loss of life and property. The total accidents based on severity nature and based on severity over four fiscal years is shown in figure 8 and figure 9 respectively.

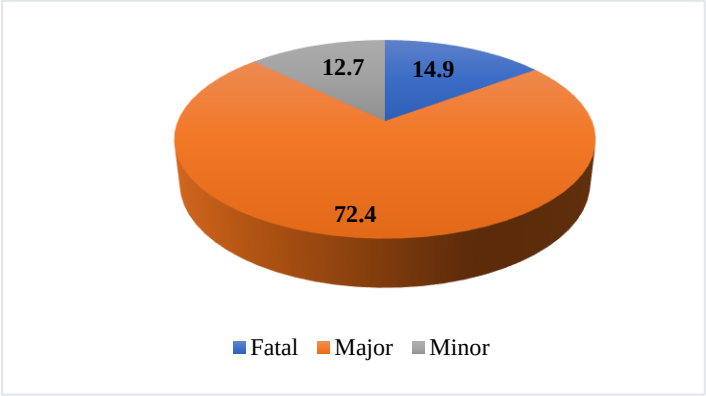


Figure 8. Distribution of accident on the basis of Severity level

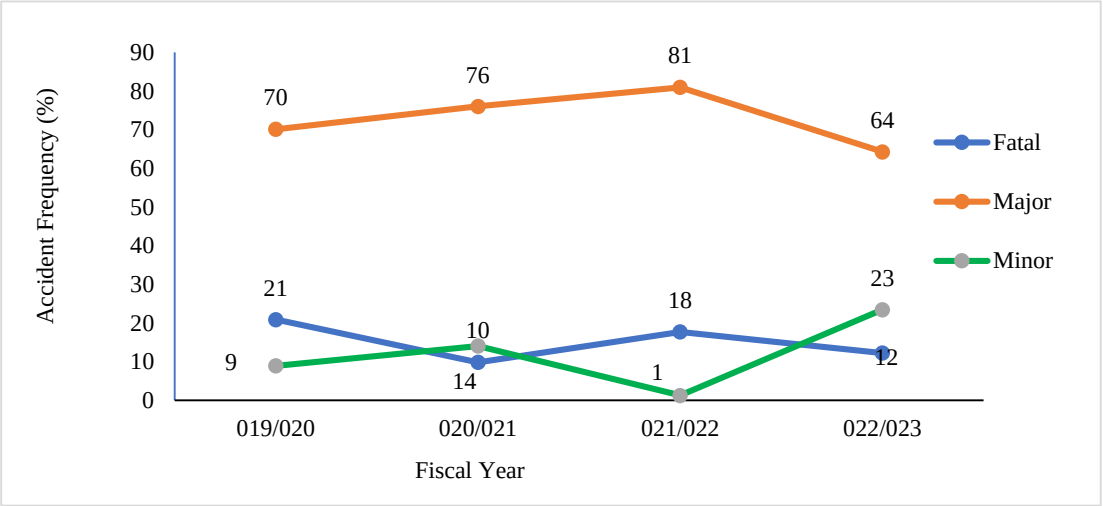
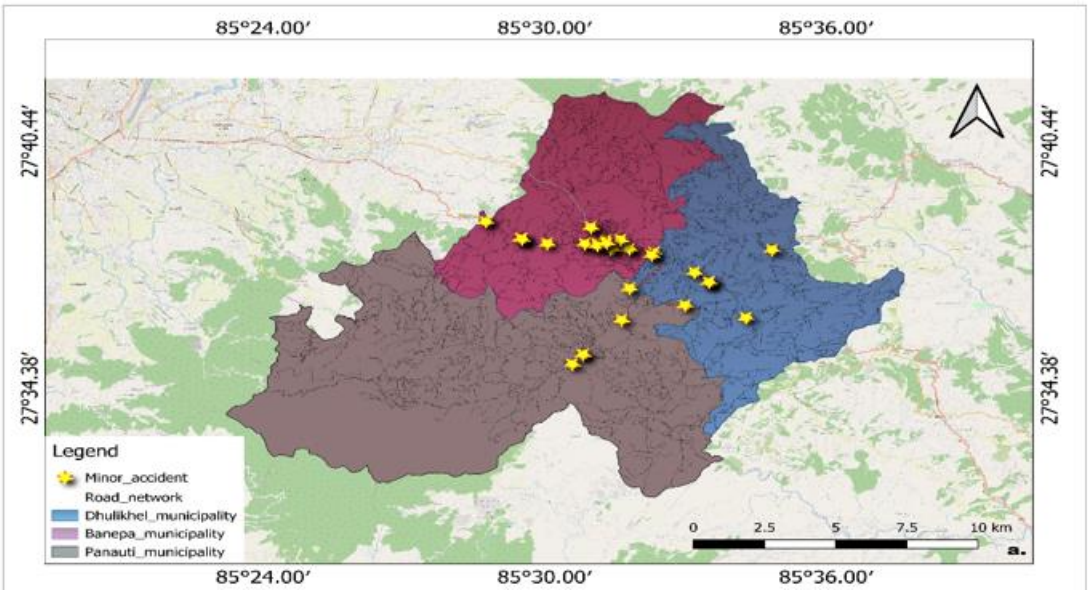


Figure 9. Distribution of accident by severity level over study period.

Accident area map based on the nature of accident is shown in the figure 10. A minor accident area map was developed with a yellow star indicating the area of a minor accident. The areas of minor accidents are scattered across the municipalities, with more concentration in the junction of three municipalities. The frequency of minor accidents is higher along the road network where traffic volume is high. Major accidents were distributed over all three municipalities, with more concentration in Banepa and Dhulikhel along the Araniko Highway and fewer accidents were noticed in Panauti municipality. It is observed that most major accidents have occurred along the Araniko Highway, particularly in the Banepa Bazar and Dhulikhel areas. Therefore, to minimize the frequency of major accidents, the causes behind such accidents needs to be studied, and concerned authorities need to take action to minimize accidents. It is clear that the majority of these fatal accidents have occurred along the Araniko Highway, particularly in the Banepa Bazar area, similar to a major accident distribution pattern. The concentration of fatal accidents along the Araniko highway suggests that this road is hazardous. Besides this, the terrain and road conditions are also major causes of fatal accidents at these locations. In conclusion, all three types of accidents occurred near the central area and along the Araniko highway. This suggests that traffic congestion, road conditions, traffic volume, weather conditions, and a lack of proper drainage systems are contributing factors for high accident rate. Similarly, minor accidents are scattered, whereas major and fatal accidents show clear patterns of concentration near main roads and intersections.



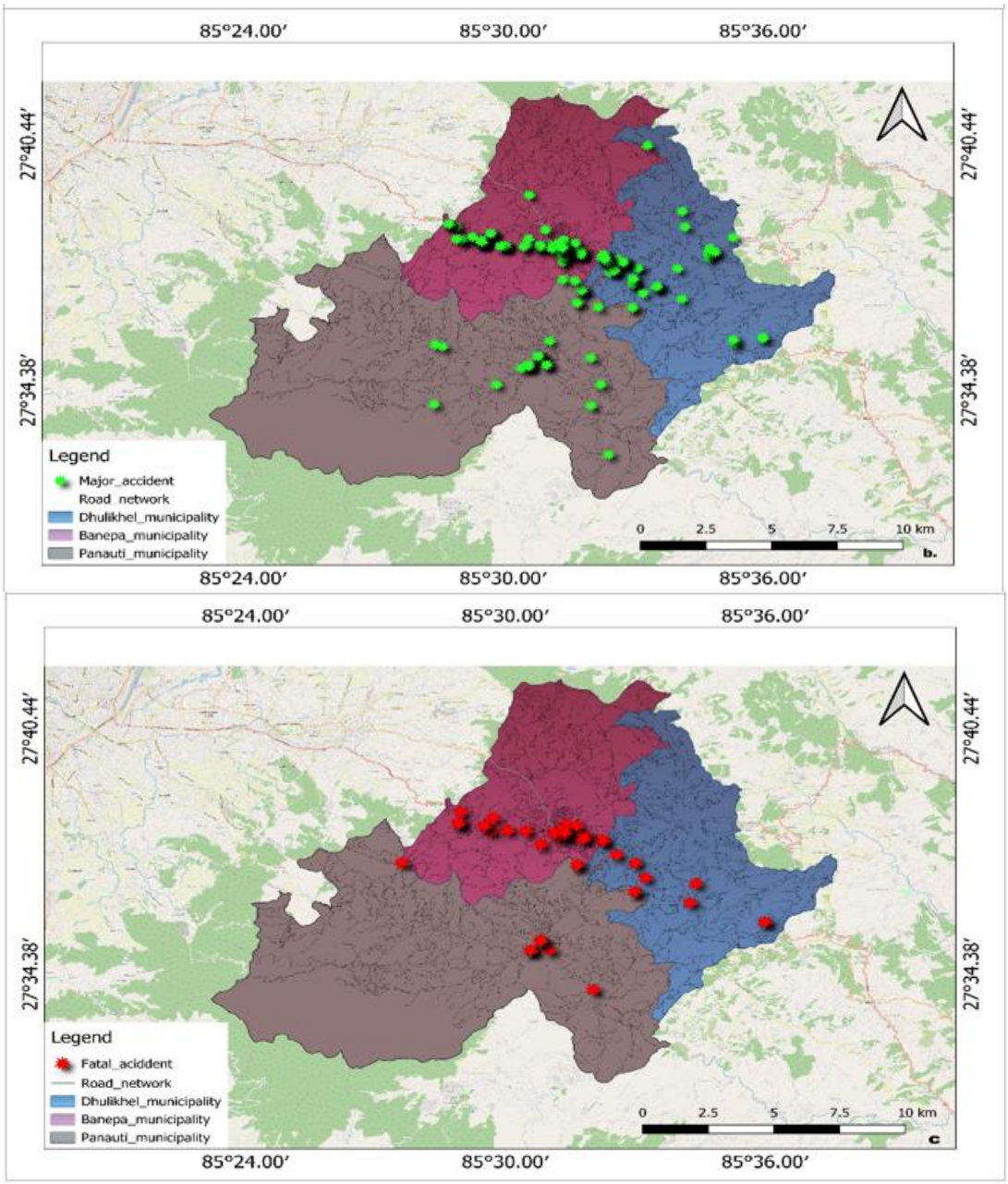


Figure 10. Accident Map by Severity nature; (a) Minor Accident, (b) Major Accident, and (c) Fatal Accident

4.6. Spatial Distribution of Accident by Collision Type

The accident data were studied based on collision nature as head-on collision, rear-end collision, and side-on collision. The detailed GIS map showing the collision natures is shown in figure 11.

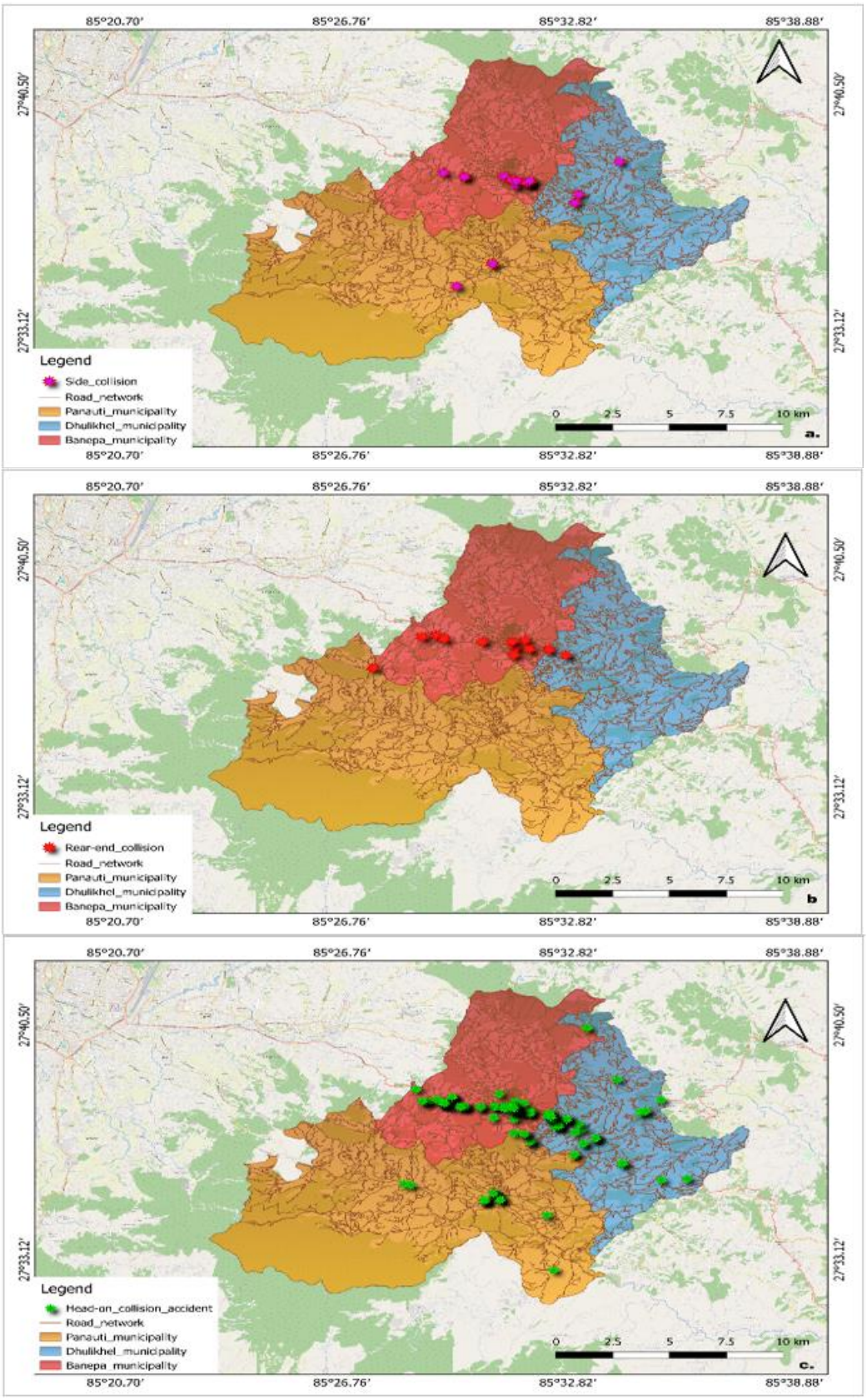


Figure 11. Spatial Distribution of Accident by collision type; (a) Side collision, (b) Rear end collision, (c) head-on collision.

Notably, the highest number of head-on collisions occurred along the Araniko Highway. Other locations are include Roshi, Bhumlu, Dhulikhel, Banepa, Packhhal, and Namobuddha. The locations associated with side

collisions are Roshi, Bhumlu, Dhulikhel, Banepa, Packhhal, and Namobuddha. The locations associated with these rear-end collisions are Roshi, Bhumlu, Dhulikhel, Banepa, Packhhal, and Namobuddha. Head-on collisions and rear-end collisions were observed to encounter more at the road section from Sanga to Dhulikhel, where traffic volume was observed to be higher. The road section where head-on collisions and rear-end collisions have occurred frequently is narrow; the intersection does not have any traffic signals. Lacks of street lights result in poor visibility in the night time because of which the accidents had occurred. Similarly, rear-end collisions are more prominent during peak time. Side impact collisions are observed at an intersection in Banepa. From the traffic police report and site observation, it was observed that the major causes behind the collision were rainfall and foggy weather, overspeeding, overloading, careless driving and road crossing, poor road conditions, and lack of traffic signals. Thus, evidence-based interventions need to be implemented and enforced to calm traffic to minimize traffic accidents.

4.7. Spatio-temporal Analyses

The spatial and temporal dimension of road traffic accidents was studied using GIS so as to determine hotspot based on time as shown in figure 12. In this study, peak hours range between 8:00 A.M to 11:00 A.M and 3:00 P.M to 7:00 P.M. In both peak and non-peak hours, the accidents were more concentrated at Banepa and Dhulikhel along the Araniko Highway.

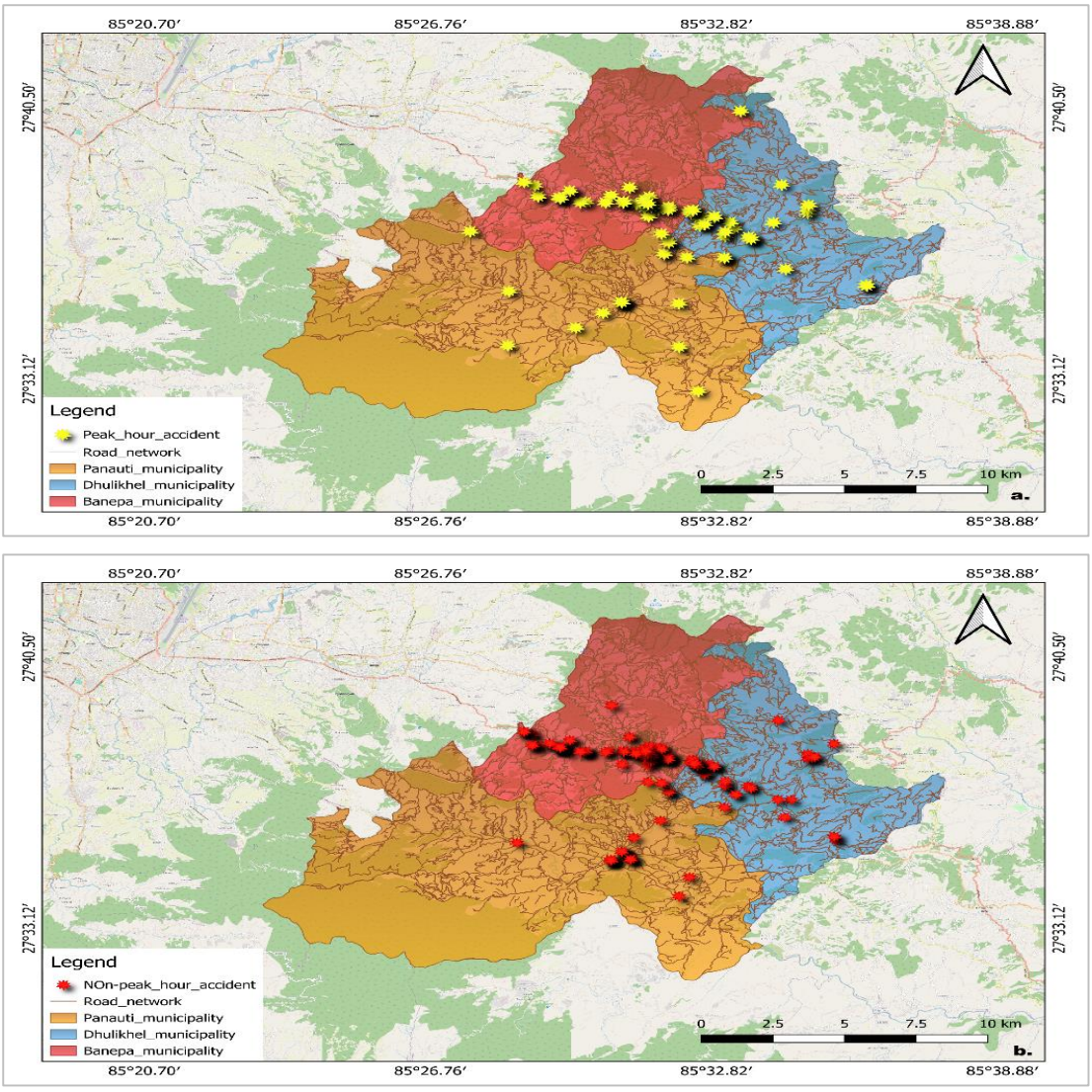


Figure 12. Spatio-temporal accident map; (a) Peak hour and (b) Non-peak hour

The dry season typically spans several months, offering better road visibility and traction compared to the rainy months. Despite these favorable conditions, factors such as increased vehicle speeds, road maintenance issues, and human error contribute to the occurrence of accidents during this time. GIS is used to map the spatial distribution of accidents during monsoon and dry seasons. In the comparison to monsoon, the accidents had occurred in the dry season. Similarly, spatial clustering techniques in GIS were used to identify accident hotspots area within the study area and it was observed that the accidents had occurred more in Banepa on the road section from Sanga to Banepa Chardobato. In comparison to Panauti, Dhulikhel has more hotspot areas where accidents had occurred during the dry season. During the monsoon season, there is an observable increase in accidents across the study area. The potential causes of accidents during this period include slippery road conditions due to rainfall, reduced visibility, and increased traffic congestion as people navigate through challenging weather conditions. During the dry season, characterized by minimal rainfall and generally clearer weather conditions, accidents still occur across the study area as depicted in the figure. The detail regarding the distribution of accidents over study area over monsoon and dry seasons are shown in figure 13.

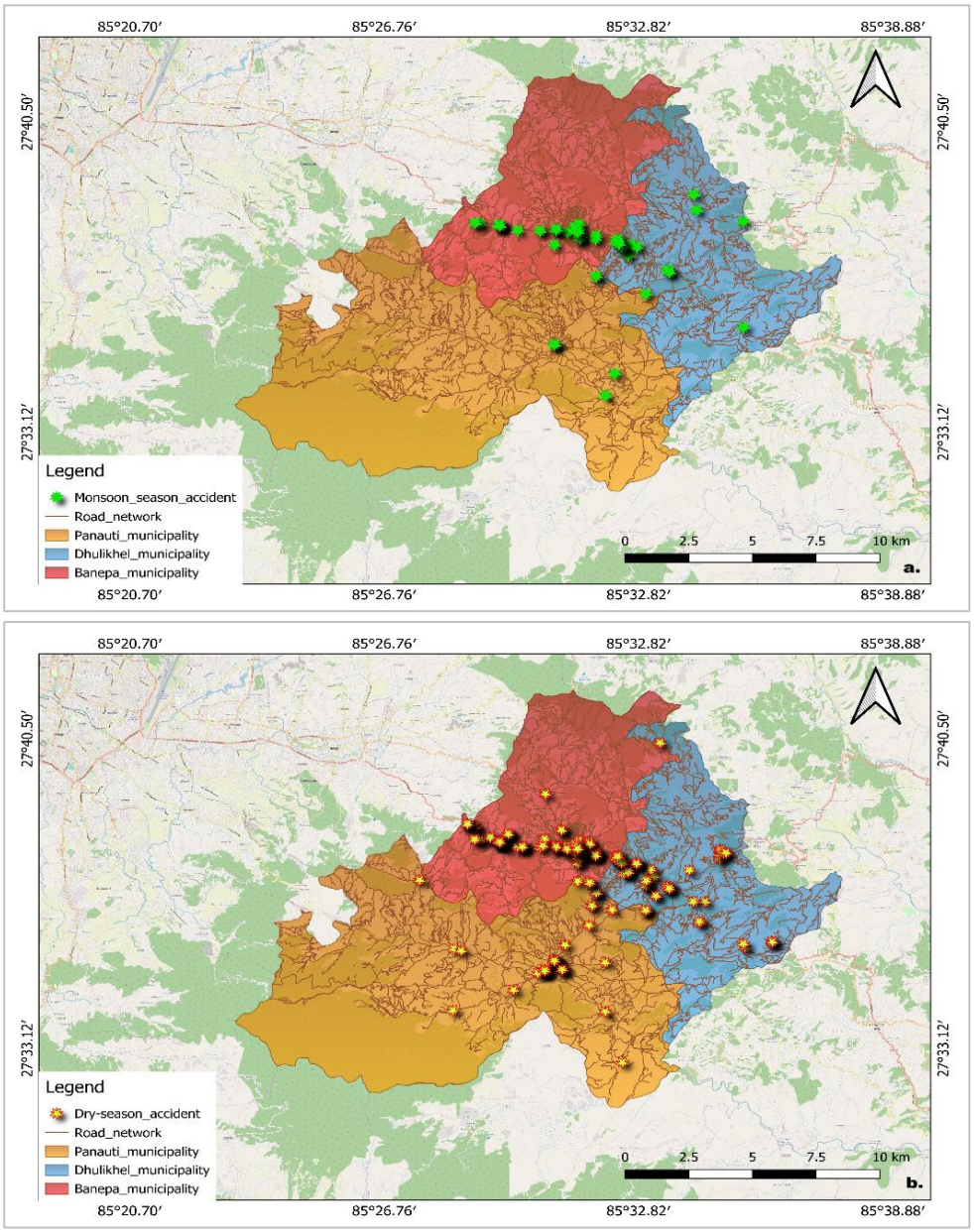


Figure 13. Spatio-temporal accident map; (a) Monsoon season and (b) Dry season

From the analysis of traffic police data, it was observed that the major reasons behind the accidents in these areas are careless driving, road crossing, overloading of vehicles, speed, overtaking and loss of control of the vehicle in the driving. Besides this, from the field inspection in the hotspot identified area, there is a lack of road marking, pedestrian crossing, street lights, proper drainage system and the pavement condition is poor. These factors have contributed for the increasing accident rate in the study area.

5. Conclusion and recommendation

The spatial and temporal distribution of road traffic accidents over the past four fiscal years reveals the actual accident hotspots and contributing factors. The accidents are predominantly concentrated in the central part of the study area, mainly along the Araniko highway. This highway is a main traffic artery showing a high rate of accident rate due to its heavy traffic flow and intersections without safety measures. Similarly, Banepa municipality had the highest concentration of accidents in comparison to the other two municipalities. The reasons behind this pattern of accidents are speeding, drinking and driving, careless driving, overloading the vehicle, mechanical failure, and uncontrolled driving.

Minor accidents which account for 12.7% of total recorded accidents are distributed over the study area with higher frequency at intersections. Similarly, major accidents which account for 72.4% of total recorded accidents are concentrated along the Araniko highway. This indicates that this specific section of road is hazardous and needs to implement safety measures to reduce the accident rate. Similar to major accidents, fatal accidents which account for 14.9 % of total recorded accidents occurred more on the Araniko Highway indicating severe road safety issues. The higher frequency of head-on collisions along the Araniko highway indicates that this particular road section is narrow, there is a lack of traffic signals and road markings. Rear-end collisions are frequent during peak times during which there is high traffic volume and side collisions are noticed mainly in Banepa suggesting for providing better intersection management and signalized intersections. The accidents increased during monsoon season due to slippery roads, reduced visibility, and high traffic volume whereas although there are better road conditions, accidents increased in the dry season due to overspeeding, road maintenance issues, and human error. The persistently high rate of accidents in the dry season highlights the need for continuous road safety measures. Thus, the spatial and temporal analysis of accidents in Banepa, Dhulikhel, and Panauti highlight the need for specific road safety interventions, identification of causes behind the accidents and implementing the recommended measures so as to reduce accidents in order to ensure the road safety.

The primary focused of this study is spatiotemporal analysis of accident in identifying hotspots with a potential to yield valuable insight on accident nature, collision natures, causes, periods of accident. Further research work enhance study by considering factors such age of vehicle driver, age of casualties, environmental factors. The analysis is based on the study of accident report provided by traffic police. Better result can be presented if the hospital report, insurance records from insurance company have been considered during the study.

The accidents had been increasing in the study area day by day. Thus to reduce the rate of accidents road safety measures such as the installation of traffic signs and signals at the intersection, providing proper road marking, pedestrian crossing and street lighting for better visibility at night time along Araniko highway and intersection should be implemented. The traffic rules and regulations to control speeding, overloading, and careless driving should be enforced. Regular maintenance of road, side drain, and patch repairing should be encouraged. Awareness campaigns to educate road users about road safety especially during peak times and adverse weather conditions should be conducted. Proper traffic signals at intersections should be provided to ensure better traffic mobility.

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