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Analyzing road traffic accidents through identification and prioritization of accident-prone areas on the dembecha to injibara highway segment in amhara region, ethiopia

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Every year, millions die in road accidents globally, imposing significant economic and humanitarian costs. While road traffic accidents are a major health concern, many developing countries, including Ethiopia, struggle to address this issue effectively. Ethiopia ranks second in East Africa for severe road traffic accidents, highlighting the need for improved injury reduction strategies. This study introduces a novel approach by chronologically identifying and prioritizing accident black spots in the studied area, Ethiopia. This method provides a valuable tool for transportation authorities and traffic police to target high-risk areas for immediate intervention. Focusing on the Dembecha-Injibara highway segment, the study employs both descriptive and inferential analyses, using the Zegeer method to calculate accident rates. It also uses factors of weight contributing to road traffic accidents and their severity to rank accident-prone areas. The findings reveal that areas near Finote Selam, Banja, and Burie are highly prone to severe accidents, with specific accident frequencies and priority values identified. Recommendations are offered to address these high-risk areas and mitigate severe traffic accidents in the study region.

Keywords Road Traffic accidents, Severity, Prioritization and identification of Black Spot

The global population has successfully stabilized the number of fatalities in recent years, with road traffic accidents emerging as a major cause of these fatalities worldwide. According to the World Health Organization's Global Status Report on Road Safety (2018)³⁰, more than 1.35 million people die annually, and up to 50 million suffer injuries on the world's roadways. It is crucial to note that these deaths and injuries are preventable, as effective interventions have been identified.

In low- and middle-income countries, there has been a significant increase in road accident fatalities from 1965 to 1985, as detailed analyses of global accident statistics by the United Kingdom Transport Research Laboratory (TRL 2000)²⁴ reveal. As WHO (2011)³¹ report, developing countries face a higher fatality rate per licensed vehicle compared to industrialized countries, and road accidents cost approximately 1% of the annual gross national product (GNP) resources of developing countries, making them unaffordable for many.

WHO (2009) Global Status Report on Road Safety²⁹, road traffic crashes rank as the leading cause of death and disability, second only to HIV/AIDS for individuals under 44 years old.

Developed countries have lower rates of road traffic accidents compared to developing countries. For example, most member countries of the International Transport Forum²⁰ experienced a decrease in fatalities due to road traffic accidents in the first decades of the 21st century. Overall, the number of road traffic fatalities in 2013 decreased by 5% in the 34 countries studied, with only one country reporting an overall increase in fatalities from 1995 to 2013. In contrast, developing countries like those in sub-Saharan Africa, such as the Kilimanjaro Region in Tanzania, have seen an increase in accidents. For instance, in 2008, there were 906 reported accidents, which rose to 1125 in 2009, a 24% increase.

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The World Health Organization's Global Status Report on Road Safety (2018)³⁰ reports that Governments, international agencies, civil society organizations, and private companies from more than 100 countries have launched the Decade of Action for Road Safety 2011–2020. This initiative aims to save 5 million lives over the course of 10 years. India has also pledged its commitment to this campaign, and on May 11, the initiative was inaugurated with renewed determination to reduce road accidents. Despite efforts, countries such as Ethiopia have experienced an increase in road traffic accidents, attributed to the growing traffic volume and conflicts between vehicles and pedestrians, as highlighted in another study by Guyu¹⁴.

In another study documented by the National Road Safety Coordination Office (2006)¹⁸, it is pointed out that Ethiopia's population is increasing by approximately 3% annually. Additionally, the estimated annual growth rate of the motor vehicle fleet, ranging from 10 to 15%, is exacerbating the strain on road safety. Another investigation conducted by the Ethiopian police commission (2013–2017)⁹, the Ethiopian Road Authority (2013)⁸, and the Amhara Regional State Police Commission (2017–2018)³ reveals that as a consequence, the country has witnessed over 83,960 road traffic accidents in the past four years. The Amhara region has recorded elevated accident rates, followed by the Oromia region.

The case study findings from the United Nations Economic Commission for Africa (2009)²⁵ indicate that despite government endeavors to enhance road infrastructure, road crashes persist as a significant challenge in Ethiopia's road transport sector. These accidents involve different types of road traffic accidents, with a particular concentration in the Amhara region, notably along the Dembecha-Injibara road segment.

The global impact of road traffic accidents is evident, with varying degrees of severity observed across different regions. The frequency and severity of these accidents are influenced by factors such as people's standards of living and the effectiveness of transportation policies aimed at reducing accidents. Identifying hazardous locations and prioritizing black spots, where accidents are most prevalent, is crucial for improving road safety.

Based on my field observations at the study location, several issues were identified, including problems related to road geometry, on-street parking in cities, drainage conditions, road edge obstructions, and road failures. For example, in and around Burie city, the highway intersection lacks a roundabout, making it difficult for drivers to navigate safely. Additionally, the geometric layout of the road around Burie poses problems due to the topography feature and edge obstruction which leads to sight distance issues and overturning risks. In the Banja section, there is significant road failure, resulting in sudden speed changes and abrupt braking, which can cause traffic accidents. Furthermore, around Finote Selam, there is a slight curve near a river and edge obstructions causing sight distance problems and leading to frequent traffic accidents.

One of the primary challenges in identifying accident black spots is determining the locations with the highest incidence of accidents and understanding the underlying causes. There is currently no standardized definition of black spots, leading to variations in how investigating bodies define them based on their data collection methods and the specific areas under examination. True black spots are areas where deficiencies, incorrect road layouts, or other factors contribute to a higher frequency of accidents. In contrast, false black spots are locations incorrectly identified due to sporadically high accident rates during the data collection period.

Efforts to reduce road accidents include systematically identifying and addressing hazardous locations, focusing on factors related to roads, vehicles, and drivers. Developing a model to prioritize these hazardous accident locations, or black spots, is essential for implementing effective measures to improve road safety. Additionally, comparing real-time data with police records can provide valuable insights for understanding and mitigating road traffic accidents.

The primary aim of this research is to analyze road traffic accidents with a specific focus on the Dembecha to Injibara highway segment in the Amhara region of Ethiopia. The study seeks to identify and prioritize accident-prone areas (black spots) along this highway segment to develop targeted strategies for improving road safety and reducing the frequency and severity of traffic accidents.

Objectives of the study

- **Identification of Accident Black Spots:** Utilize historical accident data to pinpoint specific locations along the Dembecha to Injibara highway segment where road traffic accidents are most frequent and severe.
- **Prioritization of Black Spots:** Employ quantitative methods to prioritize the identified black spots based on the severity and frequency of accidents, and weightage of factors, ensuring that resources are allocated effectively to the most critical areas.
- **Assessment of Road Traffic Accidents:** Conduct a comprehensive analysis of road traffic accidents in the study area, considering factors such as time of the day, road users (drivers, passengers, pedestrians), road conditions (road failure and pavement type), approximate number of vehicles/day, types of vehicles involved, drainage condition, and road geometry.
- **Analysis of Road Traffic Severities and Countermeasures:** Examine the severity of accidents at each black spot and propose countermeasures tailored to the specific conditions and causes of accidents in these locations.

By achieving these objectives, this research aims to contribute to the development of effective road safety interventions that can significantly reduce traffic accidents and their associated impacts in the study area and beyond.

Literature review

Road traffic accidents (RTAs) are a significant contributor to global mortality rates, ranking among the top causes of death worldwide and claiming millions of lives annually. Understanding the characteristics of road users is crucial in analyzing traffic accidents, as their judgment, education, awareness, emotional makeup, age, sex, marital status, alcohol and drug use, and seatbelt use play pivotal roles in accidents.

Peden et al¹⁹, mention that road traffic accidents have significant social, economic, and political repercussions worldwide, ranking them as the third leading cause of death following HIV/AIDS and tuberculosis.

Downing et al⁷, found that urban areas account for 35–70% of all road crashes, making a substantial contribution to national road traffic accident rates. Developing countries, particularly those in sub-Saharan Africa, confront significant health, economic, and developmental hurdles as a result of road traffic accidents.

Atubi (2009b)² highlighted in his research that road traffic accidents represent significant yet avoidable public health challenges globally. Many individuals lose their lives in road traffic accidents worldwide. Road traffic accidents occur regularly at flash points such as where sharp bends, potholes and bad sections of highways occur. At such points, speeding drivers usually find it difficult to control their vehicles, which can then result in fatal traffic accidents, especially at night.

According to the findings of Downing et al (2000)⁷, and Aeron-Thomas et al (2000)¹, it was estimated that in 1999, 750,000 to 880,000 individuals died in road traffic accidents, with about 85% of these deaths occurring in developing nations.

In another study by Nantulya VM and Reich MR (2002)¹⁷, it was found that the total number of deaths rose from 147 in 2008 to 202 in 2009, representing a 37% increase. Additionally, the total number of injuries increased from 622 in 2008 to 933 in 2009, indicating a 50% increase. These findings highlight the urgent need for solutions to reduce the fatality, injury, and property damage resulting from road traffic accidents in developing countries.

Various techniques and statistical models have been employed by researchers to address the concerning number of global road traffic accidents. For instance, Geurts et al¹³, conducted a sensitivity analysis to assess the impact of changes in traffic safety policy on accident locations and types. Similarly, Singh, R. K., & Suman, S. K²¹ developed an accident prediction model based on factors like average annual daily traffic (AADT) and road conditions to forecast future accidents. The model suggested that accident rates per km-year increase with AADT but decrease with improved road and shoulder conditions.

I.A. Sayer¹⁶ proposed two approaches for accident investigation: accident reduction, which aims to reduce the number and severity of accidents, and accident prevention, which focuses on implementing measures to prevent accidents in the future. The Design Mobility Plan Flanders (2011) emphasizes the importance of an integrated approach to road safety, vehicle safety, and user behavior in achieving long-term traffic safety.

In his study, Stijn Daniels²² discusses the Design Mobility Plan Flanders (2011), where the Flemish government underscores that sustainable enhancements in traffic safety necessitate a holistic approach encompassing vehicle safety, road infrastructure (including its environs), and road user behavior. The interaction among these three factors is often a contributing factor to accidents, highlighting the need for traffic safety measures to address this interaction.

Caliendo C et al⁵, suggest that road traffic accidents result from a combination of factors, including behavioral and non-behavioral elements like road design, traffic conditions, vehicle features, and environmental influences. These factors collectively contribute to 54% of all road traffic fatalities. Getu Segeni¹² notes in another study that sharp curves tend to have higher accident rates than gentler curves, particularly showing an increase in accident rates below a 20-meter radius. Past research consistently demonstrates that accidents are more common on horizontal curves, intersections, and bridges.

BERHANU G⁴ asserts that driver behavior remains a key contributing factor in the majority of traffic accidents, with studies suggesting that about 80–90% of road traffic accidents are caused by driver errors, with male drivers being the predominant group.

Aeron-Thomas et al¹, found that although there were expectations of a significant reduction in road deaths in 2020 due to COVID-19 mobility restrictions, the actual decrease was not as significant as anticipated. However, in Ethiopia, COVID-19 did not affect the severity of road traffic accidents, and the incidence of road traffic accidents continues to increase annually. Chen⁶ mentions that the impact of injuries and fatalities falls disproportionately on impoverished individuals, who are frequently pedestrians, cyclists, or passengers of buses and mini busses.

In the 2018 study by Geremew G¹⁰, the findings indicated that the frequency of accidents was higher on this road segment, with pedestrians being particularly vulnerable to road traffic accidents (RTAs). The study also revealed that male drivers, male passengers, and male pedestrians were more significantly affected compared to females. According to Wanit Treeranurat and Suthathip Suanmali (2021)²⁸, the study identified black spots where most accidents occurred due to frontal and rear-end collisions caused by exceeding speed limits. Additionally, a study by Z. Guo et al. (2003)³⁴ found that investigations into highway safety and accident causation reveal speeding as the primary cause of accidents on both expressways and other types of highways. The study's results also indicated significant variations in running speeds among different vehicles, including commercial trucks. Zia ur Rehman et al. (2023)³³ stated that human error was a major contributing factor in road traffic accidents. Consequently, public awareness campaigns on road safety are essential, and the use of alarm systems to prevent drowsiness while driving is recommended.

Zhuang-Zhuang Wang et al. (2022)³² state that while some research indicates that drivers may become accustomed to black spots and begin to disregard road signs, optimization measures in accident black spot areas extend beyond merely installing road signs. These measures also include road reconstruction, the deployment of police, and the installation of automatic law enforcement equipment.

In their 2023 study titled “Identifying Traffic Accident Trends and Black Spot Locations on National Road,” Wahyu Satyaning Budhi et al. (2023)²⁷ state that the study will map traffic accident trends and black spot locations to help reduce the high incidence of traffic accidents on the National Road.

In determining the most hazardous accident sites, the Flemish government analyzed accident data obtained from the Belgian “Analysis Form for Traffic Accidents.” Criteria for identifying dangerous sites include the occurrence of three or more accidents within the last three years and a priority value (P) of 15 or more, calculated

using a specific formula of $P = X + 3*Y + 5*Z$ (1): where X represents light injuries, Y represents serious injuries, and Z represents deadly injuries.

Vindhya Shree M P et al. (2020)²⁵ highlight a major advantage of using this approach to prioritize accident black spots on roads: it requires minimal additional data, mainly relying on the road network map. This makes the model's results easily applicable for planning road safety measures and can complement results from other methods. Moreover, these findings can serve as a quick reference for road network planners and authorities concerned with accident prevention strategies.

When assessing accident trends, the Design Mobility Plan (2011) concludes that its policy aimed at reducing accidents at black spots has been successful. However, the data also suggest that accidents are becoming less concentrated spatially, which may limit the effectiveness of similar safety measures in the future. Accurately identifying crash locations and consistently recording them in the road crash database are crucial for analyzing black spots.

The road safety report by the Australian Transport Safety Bureau (2001)²³ highlights the effectiveness of roundabouts and new traffic lights without turn arrows in enhancing safety in urban and regional areas. The likelihood of such significant improvements happening by chance is less than one in ten thousand. Roundabouts have shown strong evidence of safety improvement regardless of their cost or size. Similarly, new traffic lights featuring turn arrows, medians, and nonskid surfaces have been successful in urban areas. In regional areas, signs and new traffic lights with turn arrows have enhanced safety, while medians, shoulder sealing, edge lines, and improved lighting have shown moderate evidence of increasing safety. Traffic islands on approaches and indented right- and left-hand turns have also proven highly effective in improving safety in urban areas. Overall, the Black Spot Program has been highly effective in reducing casualty crashes, preventing approximately 32 fatal crashes and 1539 serious crashes between 1996 and 97 and 1998–99. The program is estimated to have saved at least 32 lives and prevented numerous injuries over these three years, with further benefits expected from the ongoing impact of the black spot treatments.

Research methodology

Study area

As shown in Fig. 1 below, the study area is located in Ethiopia's Amhara region, along the Dembecha to Injibara road segment.

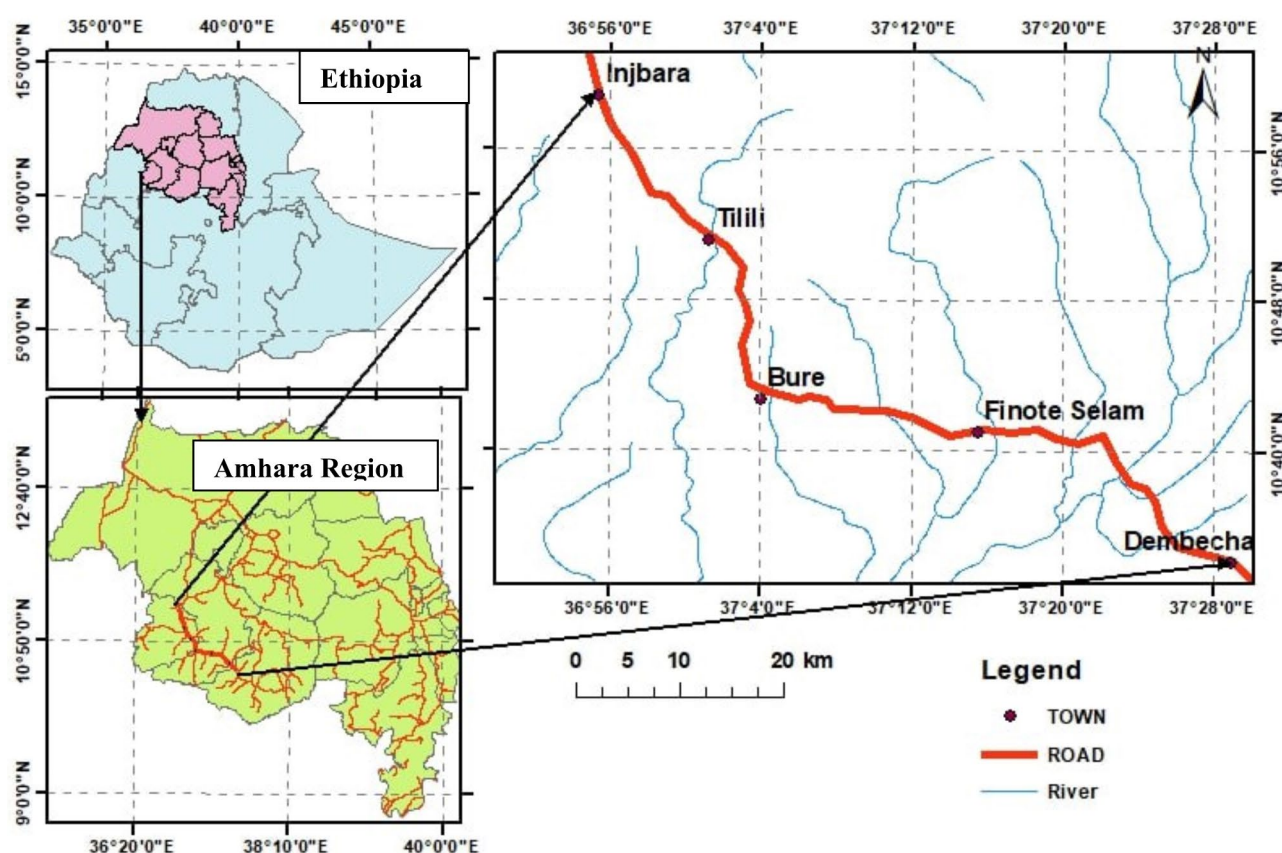


Fig. 1. Study Area of the Research (Generated from ARCGIS: Version 10.5).

Additionally, the Dembecha-Injibara road (shown in Fig. 1) is a significant segment, stretching 94 km along a key highway that connects Addis Ababa, Ethiopia's capital, to Bahir Dar, a major town in the northwestern part of the country. This road is vital not only for regional connectivity but also for national economic activities, as it serves as a crucial transportation corridor. Its proximity to Lake Tana, Ethiopia's largest lake and the source of the Blue Nile, further underscores the strategic importance of this route. The road's role in facilitating trade, tourism, and access to resources makes it a critical focus for transportation and road safety studies.

Study design (research frame)

This research aimed to comprehensively analyze accidents on a specific road segment by collecting diverse data, such as crash severity, the categories of road users affected, the types of vehicles involved, and the causes of crashes.

The evaluation provided strong evidence that the implemented program significantly improved safety at locations with a history of crashes resulting in fatalities or serious injuries. However, the analysis also revealed that not all road engineering interventions were equally effective in reducing casualty crashes, underscoring the need for targeted treatments.

Accident-prone areas were identified through a reactive method that relied on statistical data, particularly accident records obtained from traffic police stations. This approach allowed for the precise identification of black spots based on historical accident data. Additionally, black spots were prioritized not only by the number and severity of accidents but also by considering factors such as vehicle types, road conditions (e.g., pavement types and failures), traffic volume, road user demographics, drainage conditions, and road geometry.

To guide the analysis and conclusions, the methodological flowchart was developed to illustrate the step-by-step process of the study. The flowchart visually outlines the research design, from data collection to accident analysis, and informs the subsequent conclusions and recommendations. The flowchart is depicted in Fig. 2, and it is positioned at this point in the manuscript to provide a clear understanding of the research framework.

In conclusion, this methodological flowchart plays a crucial role in demonstrating the research steps and ensuring clarity in the analysis process. By using this visual aid, the study effectively communicates the complexity of accident analysis and the rationale behind the recommendations for improving road safety.

In addition, during the study period, the researcher considered both the weights of road traffic accident severities and the factors contributing to those severities.

a. Factors and Their Weights Leading to Accident Severities:

- Road width.
- Number of lanes in each direction.
- Approximate number of vehicles per day.
- Drainage facilities.
- Surface conditions of the pavement.
- Frequent vehicle types.
- Presence of shoulders, edge obstructions, and median barriers.

Based on the factors listed above, prioritization involves assigning appropriate weights to each factor to achieve the desired outcome. In this model, factors influencing accidents on roads are assigned weights on a scale of 0–10, with factors that increase the probability of accidents receiving lower weights.

b. Accident Severity and Its Weights:

By analyzing crash severity data from traffic police stations in Finote Selam and Injibara, the prioritization of black spots was examined using the TRL 2000 method. Ratios of accident costs by degree of severity were also determined using the same method. The weights assigned are as follows: 5 for fatal accidents, 3 for serious injuries, and 2 and 1 for light injuries and property damage, respectively. The formula used to estimate the ranking of sites is as follows:

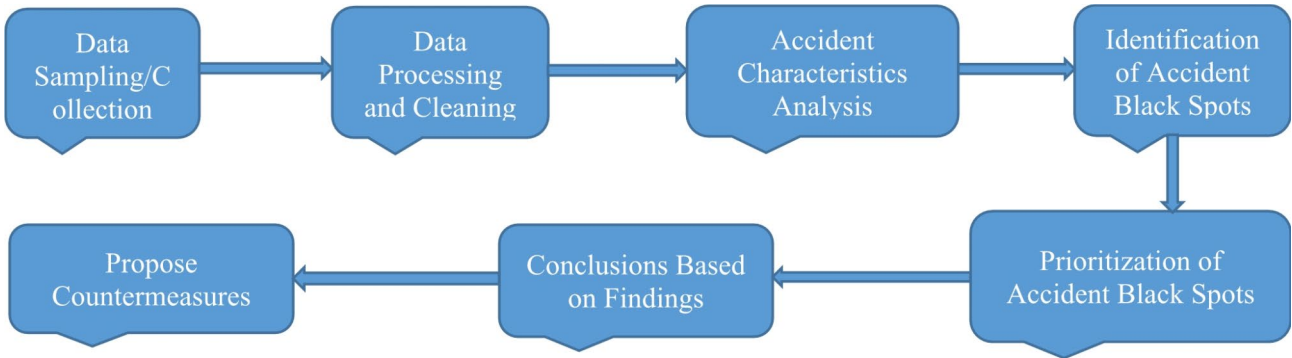


Fig. 2. Methodological Flowchart of the Study.

$$P = \left[\frac{1*W + 2*X + 3*Y + 5*Z}{D} \right]$$

where
P = Priority value;
W = Total number of property damages;
X = Total number of light injuries;
Y = Total number of serious injuries;
Z = Total number of deadly injuries;
D = Total number of distances traveled by the black spot section in kilometers.

Thus, as guided by the instruction mentioned above, this study combines the weights of primary accident factors and the weights of severity levels of accidents concurrently. By integrating the severity weights of road traffic accident severities with relevant factors to prioritize high-risk areas, this methodology stands out from existing literature and leads to more substantial insights.

Sample size and sampling procedure

This study utilized purposive sampling, selecting all recorded road traffic accidents (RTAs) from 2018 to 2021 between Dembecha and Injibara towns. Traffic police commission officers provided crucial information on RTA severity. Independent variables included road user characteristics, vehicle details, and road-related factors, days of the week, drainage condition, while dependent variables covered various RTA severities such as fatal crashes, minor injuries, serious injuries, and property damage.

Data collection procedures

The research employed both primary and secondary data sources. It involved a literature review and analysis of road project reports, documents, and manuals. The First Information Report (FIR) from police stations was the source for accident-related information. Data were identified, extracted, and collected systematically, with field measurements of traffic volume, pavement condition (pavement type and failure), drainage condition, vehicle types, and geometric features of the highway.

Data processing and analysis

Descriptive and inferential statistics were used for data analysis. The data were processed using tabulations, charts, and quality control methods. The quality control method (Zegeer method) and analysis of accident factors weightage and weightage of severity types were applied to identify and prioritize black spots based on the comparison of accident rates and critical values.

Additionally, the significance of the results was assessed, and comparisons of crash rates with critical crash rates were used to identify hazardous locations. Prioritization was then employed to rank sites known for being accident-prone or “black spots” on the roads. The data for identifying black spot sections on the Dembecha-Injibara roads were collected from 2018 to 2021. Among the methods used for identifying black spots were the quality control method for accident rate calculation and determining the critical accident rate through relative calculations, along with prioritization of accident prone areas by analyzing weightage of accident factors and weightage of severities.

Analysis, results, discussion and interpretation
RTA severity and factors on the study road

Further discussion about road traffic accident scenarios, along with tabulation and a graph based on the collected data, is presented below.

As indicated in Table 1, there were 228, 91, 39, and 79 instances of fatal, serious, slight, and property damage, respectively, recorded during the study period. It was observed that fatality was the most prevalent among the various types of road traffic accident (RTA) severities.

Figure 3 illustrates an annual increase in the total number of road traffic accidents. Specifically, in 2018, 2019, 2020, and 2021, the severities of road traffic accidents were 92, 96, 113, and 136, respectively.

Table 2 shows that 85.13% of road accidents were caused by male drivers. Among these, approximately 43.02% (188) were fatal accidents, 16.9% (74) were serious injuries, 8.9% (39) were slight injuries, and 16.25% (71) were property damages. In contrast, the casualties from road traffic accidents involving female drivers were minimal, ranging from 0 to 3.66% in terms of RTA severity.

Table 3 provides a breakdown of the age distribution of drivers and their impact on the levels of road traffic accidents (RTAs). It indicates that approximately 3.66%, 54.23%, 21.74%, and 2.29% of reported driver casualties were aged under 18, 18–30, 31–50, and over 50 years, respectively. Among driver accident victims, those under 18 were the least affected age group, likely due to the minimum age requirement of 18 for acquiring a

Types of RTAs severity	Fatal	Serious	Light	Property damage
Total severity for each	228	91	39	79
% from total	52.2	20.8	8.91	18.1
Total RTAs severity	437			

Table 1. Road traffic accident (RTA) severity on the study road.

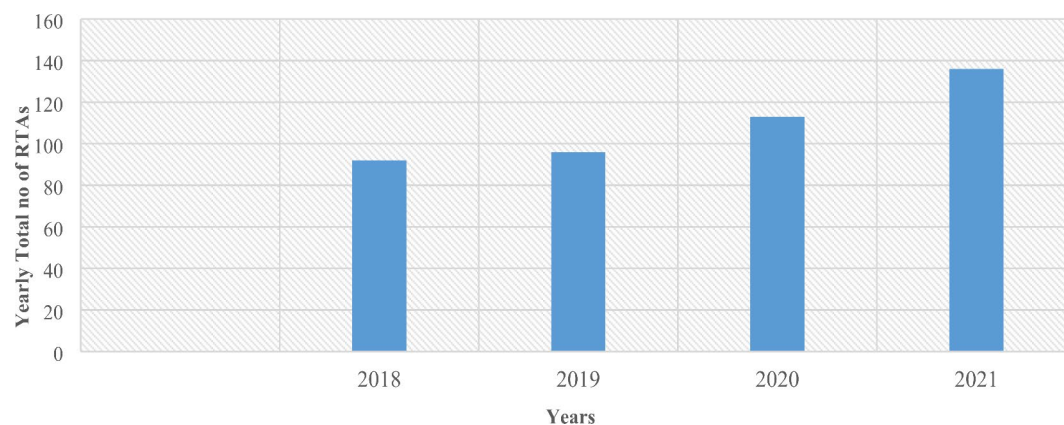


Fig. 3. Yearly RTA severities.

Sex	Fatal	Serious	Slight	Property damage	Total	%
M	188	74	39	71	372	85.1
F	6	8	0	2	16	3.7
Unknown	34	9	0	6	39	11.2
Total	228	39	39	79	437	100

Table 2. Sex and type of road traffic accident severity.

Age of drivers	Fatal	Serious	Slight	Property	Total	%
Below 18 years	8	4	2	2	16	3.66
18–30 years	120	52	23	42	237	54.23
31–50 years	44	17	5	29	95	21.74
Above 51 years	0	4	3	3	10	2.29
Not known	56	14	6	3	79	18.08
Total	228	91	39	79	437	100.00

Table 3. Age distribution of drivers for RTA severity in this road section.

driver's license. The study concluded that the number of drivers who died or sustained serious or light injuries decreased as the drivers' age increased beyond 50 years, and the highest proportions of drivers involved in accidents fell between the ages of 18 and 50 as illustrated in Table 5. This pattern suggests that older drivers are more conscientious about traffic safety compared to those under 50. It is conceivable that older drivers, having more experience, are inclined to take greater responsibility than their younger counterparts. The causes of death among road users (drivers, pedestrians, and passengers) by age and sex on the study road are discussed below.

As can be seen in Table 4 and the results depicted in Fig. 4 above display the distribution of road traffic accident (RTA) victims by age group and sex. The data indicate that pedestrians are more susceptible to traffic accidents than passengers and drivers. Pedestrians aged 18–30 and 31–50 years accounted for the highest percentage of accident victims among age groups under 7, 7–13, 14–17, and over 51 years. Drivers, Pedestrians, and Passenger Casualties by Age and Sex.

Overall, road accident victims (drivers, pedestrians, and passengers) in the 18–30 age group were the most affected during the period studied, followed by those in the 31–50 age group. Conversely, road users under 7 years old were the least common victims of RTAs on this road section. Additionally, as depicted in Table 4, the analysis of road user RTA severity indicates that male passengers outnumber female passengers at all severity levels. Alarming, the most affected road users were in the younger productive age groups during this period, specifically those aged 18 to 30 years, followed by those aged 31 to 50 years, as shown in Fig. 3. The trends of RTAs in all three categories deaths, serious injuries, and slight injuries for both sexes in the 18–30 and 31–50 age categories increased, as indicated in Table 4; Fig. 4 above.

Figure 5 and the corresponding statements below illustrate the effect of the days of the week on traffic accident occurrence.

Analysis of RTA severity on the study road by day of the week revealed accidents occurring on all days. Notably, there were a significant number of accidents, 23.34% and 15.56%, on Saturday and Thursday, respectively; however, Sunday had a relatively low number of RTAs.

Road users injury severity	Age	RTAs by severity type and by sex					
		Fatal		Serious		Slight	
		Male	Female	Male	Female	Male	Female
Drivers	Below 18 years	0	0	1	0	0	0
	18–30 years	20	0	2	0	2	0
	31–50 years	6	0	2	0	3	0
	Above 51 years	2	0	0	0	3	4
Pedestrians	Below 7 years	5	3	6	0	4	4
	7–13 years	16	9	2	0	6	8
	14–17 years	2	6	0	0	2	2
	18–30years	40	24	36	18	21	6
	31–50 years	34	22	32	12	13	2
Passengers	Above 51 years	8	4	2	4	0	2
	Below 7 years	2	0	0	0	2	0
	7–13 years	0	2	4	0	0	0
	14–17 years	4	0	2	0	0	0
	18–30years	34	22	30	11	37	41
	31–50 years	28	18	34	15	38	8
	Above 51 years	6	2	12	0	23	0

Table 4. Drivers, Pedestrians, and Passenger Casualties by Age and Sex.

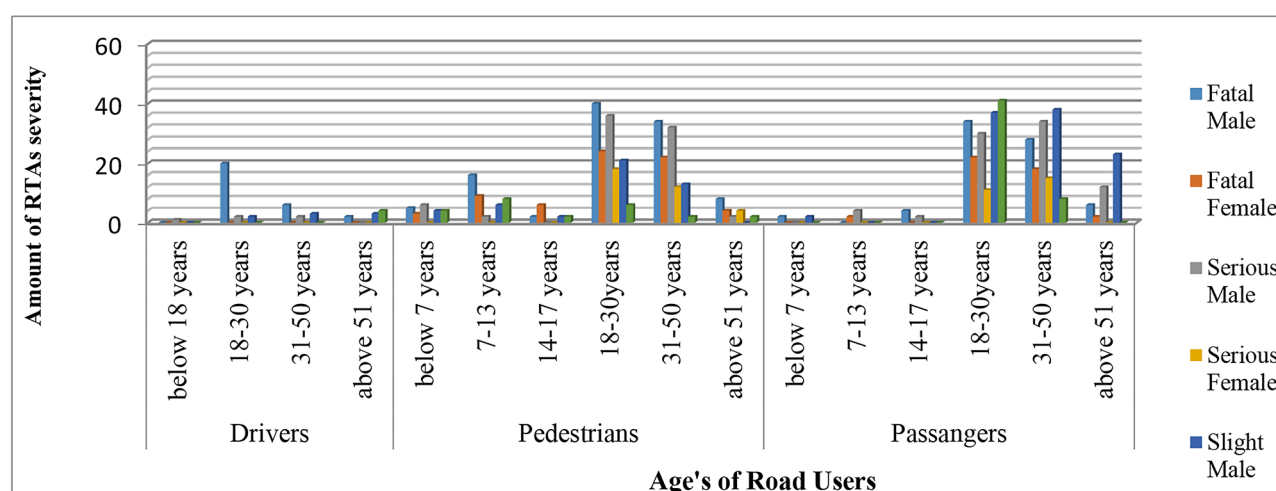


Fig. 4. Drivers, Pedestrians and Passengers' Casualties in this Road section by Age.

In general, the analysis confirmed that more accidents occurred on Thursday and Saturday. These days are market days, resulting in increased vehicular, passenger, and pedestrian movements (refer to Fig. 5 above).

Driver experience is a significant factor influencing road traffic accident (RTA) severity. Therefore, based on the accumulated experiences of drivers, the factors and effects on RTAs are discussed below. Table 5 below presents RTA severity based on driver experience.

According to Table 5, high levels of road traffic accidents (RTAs) occurred across all severity levels when drivers had 2–5 years of experience (29.52%). This suggests that young drivers with moderate experience may drive irresponsibly and carelessly due to a lack of concern and overconfidence that doesn't take into account the consequences of RTAs. As a result, young drivers are frequently involved in collisions. In contrast, older drivers with extensive experience, who have family responsibilities and drive their own vehicles, tend to drive more cautiously, reducing their risk of collision.

The causes of RTA severity can lead to increased severity for a particular road segment. Table 6 below presents the causes of RTAs and their severity.

Based on the results presented in Table 6, the main contributors to road traffic accident (RTA) severity include speeding, failure to yield to pedestrians, overtaking, overloading, failure to yield to other drivers, pedestrians being unaware of vehicle movements, and vehicles driving on the wrong side of the road. These factors resulted in 239, 92, 19, 19, 18, 9, and 9 accidents, respectively, totaling 437 crashes.

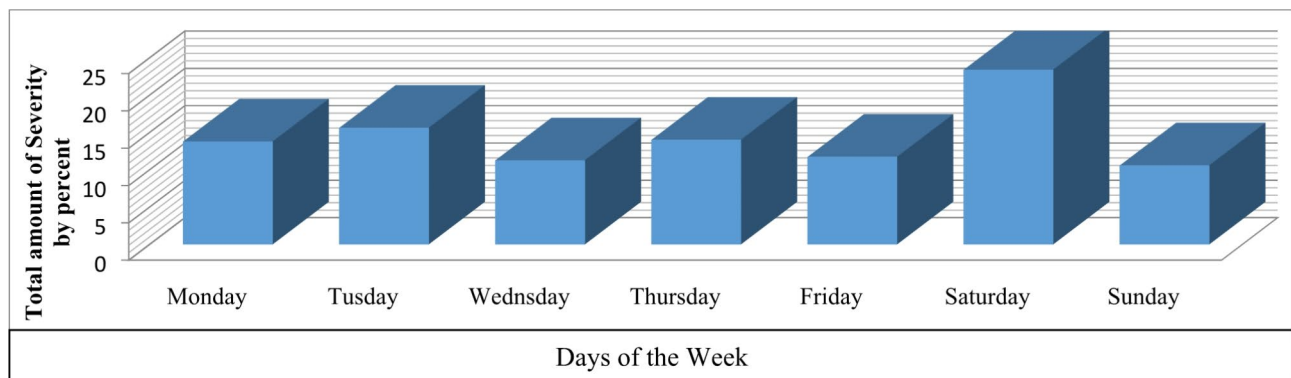


Fig. 5. RTAs (%) vs. Day of the Week.

Driver's experience	Fatal	Serious	Slight	Property damage	Total	%
Have not license	5	4	1	1	11	2.52
≤ 1 year	25	15	3	8	51	11.67
1–2 year	31	10	9	18	68	15.56
2–5 year	56	28	12	33	129	29.52
5–10 year	31	13	8	15	67	15.33
> 10 year	10	5	4	1	20	4.58
Not known	70	16	2	3	91	20.82
Total	228	91	39	79	437	100

Table 5. RTAs by experience of drivers on the study road.

Causes of RTAs severity	Fatal	Serious	Slight	Property damage	Total	%
Alcohol	1	1	0	3	5	1.1
Addiction	0	0	0	0	0	—
By driving left side	3	2	1	3	9	2.1
Fault of drivers on priority	7	2	0	9	18	4.1
Overtaking problems	6	1	4	8	19	4.3
Fault of driver on pedestrians	56	27	8	1	92	21.1
Passing in up and down grade	1	0	0	0	1	0.2
Passing in curves	1	0	0	0	1	0.2
Over speeding	126	49	23	41	239	54.7
Turing without rule	2	2	0	1	5	1.1
Ignoring traffic light	1	0	0	0	1	0.2
Ignoring stop sign	0	0	0	0	0	—
Stopping without rule	0	0	0	0	0	—
Sleeping/Fatigue	2	0	0	0	2	0.5
Thinking	0	0	0	0	0	—
More lighting	0	0	0	0	0	—
Excess loading	8	1	1	9	19	4.3
Road failure	1	0	2	1	4	0.9
Pedestrian failure	6	3	0	0	9	2.1
Other	3	2	0	0	5	1.1
Not known	4	1	0	3	8	1.8
Total	228	91	39	79	437	100

Table 6. Causes of RTA severity.

In contrast, less significant factors in this study area include alcohol consumption, improper turning, drowsiness or fatigue, road defects, and passing on inclines or curves. However, issues such as addiction, ignoring traffic lights, improper thinking, ignoring stop signs, and poor lighting were not found to contribute to RTAs in this segment. Despite alcohol addiction, drowsiness, and fatigue being frequently cited as major causes of RTA severity in other research, this study did not identify alcohol addiction as a primary cause of RTAs.

Overall, drivers who exceed speed limits and disregard traffic regulations are primarily responsible for serious accidents along the studied road. It is crucial for traffic authorities to strictly enforce speed limits and traffic rules, and to penalize violators, in order to mitigate the severity of RTAs on this road.

The geometric features of roads play a significant role in determining the severity and frequency of accidents in a given area. Figure 6 below illustrates the number of accidents based on road geometry.

In the discussion of accident severity by road geometry, as illustrated in Fig. 6, reports that the highest levels of accident severity were observed on straight road segments. These segments were associated with fatalities, serious injuries, slight injuries, and property damage. The finding supports that over speeding was a predominant factor contributing to the high severity of accidents on these straight segments.

Additionally, the findings on Fig. 6 indicate that slight upgrades, slight reverse curves, and Juntel downhill roads have a medium impact on road traffic accidents. These road features were associated with a moderate level of severity in accidents. Conversely, other road characteristics, including highly steep upgrades, straight uphill and downhill segments, strictly reverse curves, and Juntel uphill roads, did not show a significant effect on accident severity in the study area.

Prioritization and identification of black spot locations on the study road

Identification of black spot locations

General The following locations were selected for investigation based on their history of accidents in the Amhara region along the major highway segment from Dembecha to Injibara: Dembecha and its surroundings, Finote Selam city and its surroundings, Burie, Banja, Guagusa Shikudad, and Injibara city.

Data on various factors contributing to accidents were collected from these sites, and accident records were obtained from the police stations of Finote Selam city and Injibara city to validate the study.

To compare results and validate the effectiveness of the quality control/critical crash rate factor method Hamburger¹⁵, the study considered the number of different types of road traffic accidents (RTAs) (fatal injuries, serious injuries, minor injuries, property damage) and the length of the black spot section. A location was identified as an accident black spot if it showed an abnormal crash frequency rate compared to other locations. This method also used exposure data such as traffic volume and road section length to determine if the critical accident rate at a particular location was significantly higher than the average for each factor. Accident rate calculations and black spot identification were carried out using the quality control/critical crash rate factor method Hamburger et al¹⁵. The following two steps were taken:

I. Determination of accident location:

The accident location was determined based on exposure data such as traffic volume, with the length of the road section considered at a rate per million vehicle kilometers (Uf), calculated as follows:

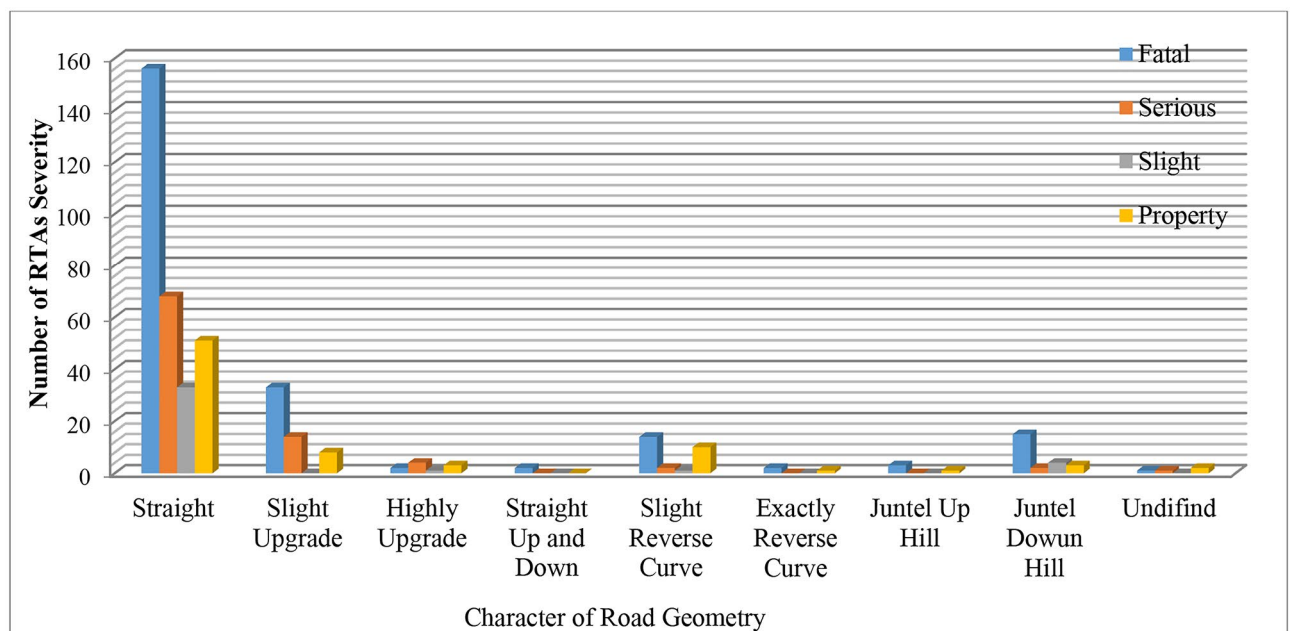


Fig. 6. RTAs vs. Characters of Road Geometry.

For Junctions:

$$U_f = U \times 106 / (AADT \times 365 \times n)$$

For Road Sections:

$$U_f = U \times 106 / (AADT \times 365 \times n \times L)$$

where

U_f = Injury accidents per million vehicle-km;

U = Number of reported injury accidents during period n ;

n = Number of years;

L = Section length (km).

II. Calculating the Critical Crash Rate:

The critical crash rate is determined using the following formula, which provides the data for calculating the critical accident rate (R_c). This method assumes that crashes follow a Poisson distribution.

$$R_c = R_a + \text{Confidence level} \times \sqrt{\frac{R_a}{MEV} + \frac{1}{2 \times MEV}}$$

where

R_c = Critical Accident Rate (accidents per million vehicles or accidents per million vehicle-km);

R_a = Average crash rate;

MEV = Millions of vehicle (km) during the analysis period;

$$MEV = \frac{AADT \times 365 \times Y}{1000000}$$

$$R_j = \frac{f_j \times 10^6}{365.25 \times Y \times L_j \times AADT}$$

$$R_a = \frac{\sum f_j \times 10^6}{365.25 \times Y \times \sum L_j \times AADT}$$

where

R_j = Accident rate at site j (acc/Mveh-km);

R_a = average accident rate (acc/Mveh-km);

f_j = Accident frequency at site j ;

Y = Period of analysis (year);

L = Section length at site j (km).

For Road Sections

$$R_c = \text{Average Crash Rate} + \left[(k) \sqrt{\frac{\text{Average Crash Rate}}{365 \times Y \times (AADT) \times \frac{L_j}{1000000}}} \right] \left[\frac{1}{2(365 \times Y \times (AADT) \times L_j / 1000000)} \right]$$

For Junctions

$$R_c = \text{Average Crash Rate} + \left[(k) \sqrt{\frac{\text{Average Crash Rate}}{365 \times Y \times (AADT) / 1000000}} \right] \left[\frac{1}{2(365 \times Y \times (AADT) / 1000000)} \right]$$

where

$AADT$ = average annual daily traffic for the spot (for an intersection, the sum of the volumes on all approaches);

Y = Number of years analyzed;

L = Length of the segment in kilometers (for intersection L is 1);

K = Confidence level (95% confidence interval, $k = 1.645$).

III. Comparing the location's crash rate with the critical crash rate:

If the crash rate exceeds the critical crash rate, the location is classified as an accident black spot. The quality control method is used to identify black spot segments on roads by calculating the accident frequencies of all spot segments over a specific period. According to this method, a location is classified as a black spot if its safety parameter (i.e., crash rate) exceeds a critical value. The accident spots are then ranked based on the severity calculated using the TRL method.

In this study, the researcher utilized the accident frequency data from Table 7 and applied quality control methods to identify black spot segments on the road. The accident frequencies for each spot segment were calculated for the individual accident rate, average accident rate, and critical crash rate over the specified period (See Table 7 below). Based on the analysis values in Table 7, locations where the individual crash rate exceeded the critical crash rate, such as Burie, Banja, and near Finote-Selam, were considered black spot locations.

Accident segment Areas	Length KM	AADT	Accident Frequency	Individual Accident Rate(Acci/MVCH-km)	Average Accident Rate(Acci/MVch-km)	Critical Crash Rate(Rc)	Conditions
Banja	14	2,114	78	4.81	3.81	4.81	Black spot
Burie	9	2,114	69	6.62	3.81	4.81	Black spot
Dembecha	7	2,037	22	2.82	3.96	4.95	Under
F/selam City	11	2,037	58	4.72	3.96	4.95	Under
Guagusa Shikudad	15	2,114	54	3.11	3.81	4.81	Under
Injibara City	9	2,114	36	3.45	3.81	4.81	Under
Around Dembecha	20	2,037	26	1.16	3.96	4.95	Under
Around F/selam	14	1,705	94	7.19	4.73	5.72	Black spot
Total	99	16,272	437				

Table 7. RTA severity spot segment areas on the study road.

Accident record location	Road width	Number of lane	Approximate number of vehicles/day	Drainage conditions	Frequent vehicle type	Presence of shoulders	Edge obstructions	Median barriers	Surface type
Banja	6 m	2 m	2,114 PCU	Poor	Bus/Truck	No	No	No	Otherbituminous
Burie	6 m	2 m	2,114 PCU	None	Bus/Truck	No	Yes	No	Other bituminous
Dembecha	6 m	2 m	2037 PCU	Poor	3wheelers	Yes	No	No	WBM
F/selam	6.1–7.5 m	2 m	2038 PCU	Satisfactory	3wheelers	Yes	No	No	WBM
Guagusa Shikudad	6 m	2 m	2114PCU	Poor	Bus/Truck	No	No	No	Other bituminous
Injibara City	6.1–7.5 m	2 m	2114PCU	Satisfactory	3wheelers	Yes	No	No	WBM
Around Dembecha	6 m	2 m	1705PCU	Poor	Bus/Truck	No	No	No	Other bituminous
Around F/selam	6 m	2 m	1705PCU	Poor	Bus/Truck	No	Yes	No	Other bituminous

Table 8. Contributing factors to accidents based on data collected from the site.

Black spot locations were identified based on the table above. The findings indicated that Finote Selam, Burie, and Banja were affected by accident black spots.

Prioritization of black spot locations

To prioritize accident-prone areas, the researcher considers both the weights of accident factors and the types of accident severity.

In the study area, various factors contributing to road traffic accidents were identified. Table 8 below provides an overview of these factors along with the corresponding accident record locations.

Based on Table 8, the factors contributing to road traffic accidents were considered, and weightages were assigned to each factor. To determine the overall impact of these factors on each road section, the final weightage for each factor was assigned and is detailed in Table 9 below.

The ultimate weight assigned to each road link is determined by summing all individual weights and then normalizing this sum using the maximum possible weight, which is 90 in this scenario. The calculation is performed as follows:

$$\text{Total weight} = (\sum \text{Individual Weights}) \times 100/90$$

Using the factors and their associated locations detailed in Table 8, along with the specific weights assigned to these factors as shown in Table 9, the total weight for each road segment was calculated using the formula above. The results of these calculations are summarized in Table 10 below.

Consequently, road links with higher final weights are deemed less prone to accidents, whereas those with lower final weights are considered more accident-prone. The classification of roads based on accident occurrence, according to these final weights, adheres to the scheme detailed in Table 11 below.

Therefore, based on the factor weights utilized in the analysis of road traffic accidents, as shown in Table 10, and the prioritization scheme for accident-prone level weightages outlined in Table 11, the locations of Burie, Around Finote Selam, and Banja were identified with the lowest weights of 31, 34, and 37, respectively. These results suggest that these areas are highly susceptible to accidents, as they fall within the high accident-prone level range of 0 to 40. In comparison, the remaining locations are categorized as moderately prone to accidents, with a medium accident-prone level ranging from 40 to 60.

Another method for prioritizing black spot sites involves determining the ratio of accident costs to the degree of accident severity using the TRL (2000) method²⁴. For fatal accidents, a weight of 5 is assigned, for serious injuries a weight of 3, and for light injuries and property damage weights of 2 and 1, respectively. The formula for estimating the ranking of sites is as follows:

Factors affecting occurrence of accidents	Possible variations	Weights assigned	Factors affecting occurrence of accidents	Possible variations	Weights assigned
Number of lanes in each direction	1	4	Surface condition of the pavement	Concrete	10
	2	6		WBM	8
	3	8		Other bituminous	6
	4	10		Surface painted	4
Number of vehicles per day	0–40,000	2		Earth roads	2
	40,001–60,000	4	Frequent vehicle type on the road	Bus/Truck	2
	60,001–80,000	6		Car/3 wheeler	4
	80,001–1,00,000	8		Two wheeler	6
	1,00,000 above	10		Bicycles	8
Width of the road	Less than 6 m	2	Presence of shoulders	Cart	10
	6.1–7.5 m	4		Yes	10
	7.6–10.5 m	6	Presence of edge obstructions	No	4
	10.6–15 m	8		Yes	4
	15 m above	10	Provision of median barriers to channelize the traffic	No	10
Drainage facilities provided	Good	10		Yes	10
	Satisfactory	7		No	4
	Poor	4			
	No drainage	1			

Table 9. Factors used in prioritization with possible weights (Vindhya Shree, M. P. et al. 2020)²⁶.

Location	Total weight	Location	Total weight
Banja	37	Guagusa Shikudad	40
Burie	31	Injibara City	55
Dembecha	50	Around Dembecha	40
F/selam City	55	Around F/selam	34

Table 10. Results of calculated total weights for individual locations.

Final weight	Accident prone level
80–100	Very low
60–80	Low
40–60	Medium
0–40	High

Table 11. Prioritization scheme (Vindhya Shree, M. P. et al. 2020)²⁶.

$$P = \frac{1 \cdot W + 2 \cdot X + 3 \cdot Y + 5 \cdot Z}{D}$$

where

P = Priority value;

W = Total number of property damages;

X = Total number of light injuries;

Y = Total number of serious injuries;

Z = Total number of deadly injuries;

D = the total distance traveled by the black spot section in kilometers.

To rank these locations based on the severity of road traffic accidents (RTAs), the researcher utilized the ratios of accident costs by degree of severity established by the TRL. As a result, as shown in Table 12, each segment was assigned a rank ranging from 1 to 8. The locations of Burie, around Finote Selam, Banja (around Injibara), Finote Selam, Injibara, Machakel, and Guagusa Shikudad, as well as near Dembecha and Dembecha towns, were ranked from 1 to 8, respectively (refer to Table 12 below).

The analysis results from the table indicate that the Burie section was ranked first among accident black spot locations, followed by areas around Finote Selam, Banja, Finote Selam, Injibara, Dembecha, Guagusa Shikudad, and around Dembecha.

	Types of severity				Prioritization						
Location of RTAs severity	Fatal	Serious	Slight	Property	Z	Y	X	W	D	P	Rank
Burie	41	4	4	20	205	12	8	20	9	27.22	1
Around Finote Selam	34	26	20	14	170	78	40	14	14	21.57	2
Banja	45	11	8	14	225	33	16	14	14	20.57	3
Finote Selam	28	22	2	6	140	66	4	6	11	19.64	4
Injibara	22	6	2	6	110	18	4	6	9	15.33	5
Dembecha	12	8	1	1	60	24	2	1	7	12.43	6
Guagusa Shikudad	26	10	2	16	130	30	4	16	15	12.00	7
Around Dembecha	20	4	0	2	100	12	0	2	20	5.70	8
Total	228	91	39	79					99		

Table 12. Prioritized and ranked RTA segments on the study road.

Therefore, by focusing on high-risk accident areas using the importance of key factors that leads to traffic accidents and the severity of traffic incidents, significant understandings about road accidents can be gained. This is particularly advantageous when the assigned weights for varying levels of accident severity types and associated weights of factors incident seriousness are uniform. As a result, the findings from the analysis become more trustworthy and insightful.

Conclusions

In general, the primary advantage of using this approach to prioritize accident black spots on roads is its minimal data requirements, as it mainly relies on road network maps. This makes the analysis results easily usable for planning road safety measures, which can be complemented with results from other approaches. Consequently, these findings can serve as a quick reference for road network planners and relevant authorities involved in accident mitigation efforts.

Specifically, the study’s conclusions are as follows:

- The major causes of RTA severity were identified as over speeding, failure to yield to pedestrians, unlawful overtaking, excess loading, failure to yield to other drivers, pedestrian non-compliance with traffic rules, and driving on the wrong side of the road.
- The locations of Burie, around Finote Selam, and Banja (near Injibara) are identified as the most dangerous areas, classified as black spots. The prioritization of these black spots for treatment is as follows: Burie, around Finote Selam, Banja (near Injibara), Finote Selam, Injibara, Machakel, Guagusa Shikudad, and the areas near Dembecha and Dembecha towns. These locations were ranked from 1 to 8, respectively.
- Among the severity groups of road traffic accidents (RTAs), 52.2% had high fatality rates, with 20.8% for serious injuries, 8.9% for slight injuries, and 18.1% for property damage.
- The research revealed significant disparities in road traffic victims among different road users (drivers, passengers, and pedestrians). Pedestrians were found to be more vulnerable to road traffic accidents (RTAs) than other road users, and male road users (drivers, passengers, and pedestrians) were more affected than their female counterparts.
- The analysis indicated that the highest percentages of drivers involved in accidents were aged between 18 and 50, suggesting that older drivers may be more cautious due to their experience and responsibilities.
- Young drivers with moderate experience were identified as more vulnerable to severe RTAs due to their irresponsible and overconfident driving behavior. In contrast, older drivers with more experience tended to drive more carefully.
- Road geometry was found to significantly impact the severity and frequency of accidents, with straight and slightly upgraded geometries recording the highest accident severities likely due to high-speed driving.
- Saturdays and Thursdays were identified as days with higher accident frequencies, likely due to increased vehicular and pedestrian movements associated with market days along the study road.

In summary, the study’s unique approach to prioritizing accident black spot locations, considering the weights of associated factors and severity types of road traffic accidents simultaneously, produced consistent and reliable results. These findings provide valuable insights for policymakers looking to prioritize road infrastructure investments.

Recommendations

Based on the study findings and conclusions, the following recommendations and suggestions are proposed:

1. In Burie:
 - Issues Identified: High accident rates due to poor geometric alignment and lack of superelevation.
 - Recommendations: Redesign the geometric alignment and provide superelevation or install a roundabout, along with edge protection at the intersection, followed by reconstruction. Additionally, 1 km from the center of Burie toward Guagusa Shikudad, redesign the geometric alignment, provide super elevation, and recon-

struct. Remove edge obstructions, provide edge protections, improve road width, install a median barrier, and add a shoulder at the identified accident black spot location.

2. In the Banja Section:

- Issues Identified: Sight distance problems caused by the topography's geometric features, road failures, and drainage issues.
- Recommendations: Perform maintenance and remove sight distance obstructions to address sight distance problems.

3. Around the Finote Selam Section:

- Issues Identified: Sight distance obstructions and inadequate edge protections at slight reverse curves.
- Recommendations: Remove sight distance obstructions, provide edge protections, and widen the pavement at slight reverse curves.

4. General Enforcement:

- Issues Identified: Non-compliance with safe driving speeds and traffic rules contributes significantly to the severity of RTAs.
- Recommendations: Enforce safe driving speeds and traffic rules, with strict penalties for violators, to reduce RTA severity.

5. Installation of Black Spot Signs:

- Issues Identified: Lack of awareness about black spot locations among road users.
- Recommendations: Install black spot signs and raise awareness among road users about black spot locations and appropriate traffic signs at all road sections, especially at previously identified black spot locations.

6. Safety Education:

- Issues Identified: Communities lack adequate safety education regarding RTAs.
- Recommendations: Provide safety education to communities, including pedestrians, drivers, and traffic police, through schools, workplaces, and mass media in the affected areas as a short-term solution. In the long term, include RTA safety education in school curricula and address it at the national level through mass media, including private media.

7. Driver Training and Testing:

- Issues Identified: Inadequate driver training and testing procedures contribute to RTAs.
- Recommendations: Revise drivers' training and testing procedures to include a minimum amount of driving experience as a requirement before issuing a license. Additional prerequisites should include educational background, good behavior, maturity, ample driving experience, freedom from addiction (e.g., chewing chat and alcoholic drinks), freedom from criminal acts, and compliance with traffic regulations).

8. Traffic Signals:

- Issues Identified: Scarcity and frequent technical failures of traffic signals at squares and junctions contribute to accidents.
- Recommendations: Address the scarcity of traffic signals, such as traffic lights, and their frequent technical failures at squares and junctions to reduce traffic accidents. This includes maintaining existing lights and expanding their installation to other accident-prone squares and junctions.

9. Policy and Infrastructure Attention:

- Issues Identified: The study identified high- and medium-level accident-prone conditions on the highway segment.
- Recommendations: Infrastructural officers and policymakers in the region are strongly urged to pay more attention to this highway segment to address this urgent problem.

Data availability

All data generated or analyzed during this study are included in this published article (or its Supplementary Information files).

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Author contributions

In this study, titled ‘Analyzing Road Traffic Accidents through Identification and Prioritization of Accident-Prone Areas in the Amhara Region: A Focus on the Dembecha to Injibara Highway Segment, Ethiopia’, all aspects of the research were conducted solely by the author. This included the conceptualization of the study, the design of the research methodology, the collection and analysis of data related to road traffic accidents in the Amhara Region, and the identification and prioritization of accident-prone areas along the Dembecha to Injibara Highway Segment. The author also drafted the manuscript, including all sections such as the introduction, methodology, results, discussion, and conclusion.

Competing interests

I hereby declare that there are no competing interests associated with this manuscript. The research findings, analysis, and conclusions presented in this study are not influenced by any financial, personal, or professional affiliations that could be perceived as having a potential impact on the objectivity and integrity of the

research. Including such a statement in the manuscript demonstrates transparency and assures readers that the research is conducted without any conflicts of interest, contributing to the credibility and trustworthiness of the work.

Consent for publication

I give consent for the manuscript to be published and take responsibility for the correctness of the statements provided in the manuscript.

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