International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Identifying Black Spot Accident Zones using a Geographical Information System on Kombolcha-Dessie Road in Ethiopia

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Abstract

The rate of traffic accidents is growing rapidly in Ethiopia. This paper illustrates the advantages of using a geographical information system (GIS) to identify so-called black spot locations, which would be the initial and most crucial step in the road safety analysis. This study has identified black spot accident locations in the South Wollo Zone, Ethiopia, using the Kombolcha-Dessie road segment, by using ArcGIS software as a hotspot analysis tool. Five years (2012-2016) worth of accident data history on Kombolcha-Dessie road was collected to identify locations with a higher rate of crash occurrences. This entire block of accident data was spatially distributed on the digitized map of the road (including the crash occurrence sites) and the respective weight based on their accident severity was applied. The hotspot analysis result identified five (5) accident hotspot locations. These are; Kombolcha town roundabout-1, 'Tita' curve in Dessie town, 'Kobo-Gedel' in Dessie town, entrance to 'Awscod' enterprise in Kombolcha town and a place named 'Arego' S-curve are the prioritized crash hotspot locations respectively. The study suggested that for the identification of accident-intensive prone zone, the use of geographical information system is an inevitable tool due to its advantageously accurate and quick identification of hazardous locations based on statistical significance and the ease with which a result can be presented on a single Map.

Keywords: Black spot; Crash; Ethiopia; Getis-Ord Gi*; GIS

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1. Introduction

Roadway transport has become a necessity for human beings to transport goods and themselves. It is difficult to imagine a situation where transport does not play a vital role in the life of an individual. It is logical and acceptable to say that of all modes of transportation; road transportation is easily accessible to people. That is because of its advantages of flexibility, most competitive price, and door-to-door operation while compared to other modes of transportation. Road transportation in Africa accounts for over 80% of all transportation systems and in Ethiopia, more than 90% of the overall transportation system is facilitated by road transportation [1]. Road Traffic Accident (RTA) is the primary and leading negative consequence of road transportation system. Road traffic accidents (RTAs) are a protruding means of fatalities and injuries globally, mainly affecting children and young people [2]. World Health Organization, estimates that 1,171,000 loss of lives and many more means of disability are instigated by RTAs annually [3].

It is a fact that over millions of people are killed each year due to road traffic accidents. A study conducted by Chen illustrates the negative consequences of road transportation on health, the economy, and the development of a country, especially in sub-Saharan countries [4]. In the eastern part of Africa, the rate of crashes and severity is the worst [5]. For instance, in 1999, 750-880,000 lives of people have been lost in road traffic crashes from these, about 85% of crashes occurred in developing countries [6]. Every day, thousands of people are killed and injured on road by a traffic accident. It is the leading cause of death, disabilities, and hospitalization, severe socio-economic costs, across the world. WHO in the reporting year of 2002 had shown 1.18 million death of people were caused by road accidents: with an estimated average death of 3,242 peoples per day [7]. In 2030, RTAs is forecasted to be the third leading killer of the human race by killing 2.4 million people per year [7]. Adversely affected sub-Saharan African Countries [4]. As the motorized traffic volume increased in Ethiopia, the situation of roadway safety became worse due to the increased traffic flow as well as a situation in which vehicles and pedestrians were using the same roads to move on [8]. On-street crashes continued to be the most outlined problem of the road transportation system in Ethiopia, even if the government has undertaken a major effort in road development [9]. Losses of many lives and the destruction of property are the consequences of road traffic accidents every year. In Ethiopia, the average annual road crashes have been estimated to amount to 8115 for the consecutive years of 2000/01-2010/11 [10].

According to a CSA report (2000/01-2010/11), the average annual Property Damage Only (PDO) is estimated to be greater than 15 million Ethiopian Birr [10]. The estimated rate of crash-based deaths in 2007/8 was 95 for every 10,000 motorized vehicles. This firmly places the country at one of the higher ranks of safety problems internationally [9]. In the same year, police reports stating that the number of aggregate crashes that took place in Ethiopia were 15,086 [9]. Due to this level of accidents, 2,161 lives were lost and the estimated cost of property damage came in at more than 82 million Birr [9]. Furthermore, 2.84 of every 100,000 people suffered road accident fatalities in that same year [9].

Road safety is one of the great problems worldwide since it touches the socio-economy of the country in advance. One of the most cost-effective road safety interventions is to eliminate so-called crash hotspots, that is, to remedy accident-prone locations along the roads. This comprises the following steps; identify the hotspots, learning the problems (diagnosis) at each spot, design appropriate safety mitigations, estimate their effects, set priorities, implement, and finally, follow up and evaluate the results [11].

With all this in mind, an efficient and practical road safety management tool and model is required for managing accidents and mitigating against its drawback. Road safety analysis has been done with deferent methodologies. A study by Ghosh et al illustrates for efficient road safety analysis the use of GIS has become a preferable tool [12]. The reports prepared by the Federal Highway Administration of the US Department of Transportation also supports this idea [13]. The document briefly discusses the methodologies and implementation of road safety analysis tools developed by them. For managing accident database system for analysis and entries of RTAs application systems can be developed like GIS and Road Accident View System. For instance, a system designed in University Putra Malaysia is used in a study done by Lim [14]. Reshma and Sheikh used ArcGIS software for the analysis of accidents and prioritized the major accident hotspot areas by assigning possible weights for RTAs [15]. A study by Nagarajan and Cefil is done by using remote sensing and GIS for the identification of accident hotspot zones particularly starting from Tambaram to Chengalpet [16]. In their study, they were prioritized eleven accident intensive prone zones using high-resolution satellite Map. This paper presents the advantages of using GIS software for road safety management and in identifying accident hotspot locations. Around the globe, accident hotspots can be identified by using a variety of techniques such as Accident Frequency, Accident Rate, Accident Density, and Accident Severity Indexes. Currently, GIS has become a superior tool for road safety management, especially in identifying hotspot locations. GIS combines spatial attributes with statistical analysis to present hotspot results in a simple, visualized manner. GIS creates valuable and meaningful results by using statistical and geographical data as an input variable during spatial analysis, mapping and identifying any factors that contribute to accidents.

2. Crash Analysis Using ArcGIS

The traditional approach to detecting higher crash zones, which is currently working in Ethiopia, is something known as the sliding scale analysis. But nowadays, other GIS techniques for the identification of accident hotspots are gaining in popularity. These include Cluster and Anselin Local Morans I, Kernel Density Estimation (KDE) and hotspot (Getis-Ord Gi*) analysis. For example, Steenberghen, et al determines the spatial clustering of accidents using kernel density [17]. [18] identified hotspot crashes based on the statistical significance of events by applying Kernel Density and Poisson Regression while Budiharto & Saido identified hotspot crashes using three different approaches, which were kernel density, cluster, and an outlier analysis [19].

Tortum and Atalay used Moran’s I for hotspot analysis [20] while Yalcin and Duzgun applied three different approaches. These were kernel density, nearest neighbor distance, and the K Function (which measures spatial clustering/dispersion for a group of geographical features in the surplus of a range of distances) [21].

2.1. Spatial Analysis tool of ArcGIS

The ArcGIS spatial analysis tool is applied to geographically locate crashes and detect the statistical significance of hotspot zones on a map.

2.1.1. Moran’s I Statistics

Moran's I statistics tool, part of ArcGIS, determines spatial auto-correlation from crash incident locations depending on the frequency of crashes and zone locations. It measures feature proximity and the similarity of the location from this measurement. It also estimates an index value. The difference among the overall mean value and frequency of individual locations represents the attribute similarity of crash frequency between two locations. According to Truong and Somenahalli, the Moran Index is determined by using equations (1) and (2) [22].

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\left(\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}\right) \left(\sum (x - \bar{x})^2\right)} \dots\dots\dots\dots\dots\dots\dots \quad (1)$$

$$z = \frac{I - E(I)}{\sqrt{VAR(I)}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (2)$$

Parameter definition, I-Moran index

wij-is the spatial weight between location i and location j;

n-is the overall number of crash locations;

xi-denotes the total number of crashes at location i;

$\bar{x}$ -is the global mean value.

The calculated Moran's index and variances can be used to determine the standardized Z-score. In the case, ArcGIS calculates the index value of Z-score and P-value with this analysis tool while the significance of that index is determined. Where Z-score is a standard deviation and P-value is probability.

2.1.2. Getis-Ord

The ArcGIS hotspot analysis tool Getis-Ord Gi* determines the significance of spatial statistics for all the crash locations. Getis-Ord Gi* works by matching the proportion of the local sum for every zone. If the local aggregate does not match or fit with the expected local aggregate, then the result will possibly be a statistically significant crash hotspot or cold spot. However, it does not automatically mean that a location with higher statistical values is a crash hotspot. To be a crash hotspot zone, the crash location must feature a high statistical value and must be bounded by high values from the surrounding area. Equation (3) is used to determine Getis-Ord Gi* [23]:

$$\text{Gi} * = \frac{\left(\sum_{j=1}^{n} w_{ij} x_j - \bar{x} \sum_{j=1}^{n} w_{ij}\right)}{s \sqrt{\left(\frac{\sum_{j=1}^{n} w_{ij-}^2 \left(\sum_{j=1}^{n} w_{ij}\right)^2}{n-1}\right)}} \dots\dots\dots\dots\dots\dots\dots \quad (3)$$

Where Gi*-is statistical z-score

xj-is the value of location j;

wij-is the spatial weight between location i and j;

n-is the total number of locations.

2.1.3. Kernel Density

The Kernel density is among the necessary spatial analysis tools currently available in ArcGIS software. K is applied to determine the aggregation of accidents within a bandwidth of 300m. First, K separates the whole area into several zones based on the bandwidth determination. It then applies a quadratic kernel formula to adopt a slickly diminished surface to all crash zones [24]. The Kernel function is defined in this equation (4):

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x - x_i}{h}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (4)$$

Parameter definition: *h*-is the bandwidth, radius or smoothing factor;

K-is kernel estimator;

f(x)-is the probability density function;

n- is the overall number of crash points;

xi-is the value of location i

The Kernel function depends on the selection of the appropriate bandwidth (h); hence, the choice of appropriate bandwidth is highly influenced by the purpose of the study.

3. Methodology

In this study, a Getis-Ord Gi* has been used to identify hotspot crash segments along the road. Getis-Ord Gi* is found to be a better analysis method than others seeing as how it considers the weights resulted from the combination of the number of accidents, fatalities, and injuries in association with statistical significance during analysis [25].

3.1. Data Collection

To identify accident-intensive prone zones, we required information on accidents and maps of road networks for the Kombolcha-Dessie road, including information on spatially distributing road traffic accidents on the digitized map of the road. The significant data collected came in the form of traffic accidents and the geographical map of the road network as well as the contribution of information from traffic police officers and field observation. The main data collected during this research is presented as follows.

3.1.1. Road Network Map

Hotspot crash analysis was carried out with the ArcGIS 10.2 software. Thus, crash history was spatially distributed on the digitized map of Kombolcha-Dessie road network. The road network map was provided upon request by the Ethiopian Mapping Agency (EMA) which is currently changed to Ethiopian Geospatial Information Agency. The road network map obtained was not digitized and thus, all the road links and nodes were digitized using ArcGIS software.

3.1.2. Road Accident Data

Emphasis is placed on the fact that the accident events used in this study are reported data, not observed data. In Ethiopia, the police force records crash data at or after a crash site has been visited. This data can provide useful information on the collision type, the number of people involved, the characteristics of the road (and environmental factors such as weather), and surface conditions. A disadvantage to this data is that it is estimated based on second-hand information obtained either by the people involved in the collision or by the traffic police officer. Post-crash reports may result:

- In bias opinions from the driver, thus influencing speed and time of the collision to avoid penalties/prosecution.
- In the location of the accident being may also be estimated by the police officer due to cars being projected further from the point of collision.

The road accident data over five (5) years, from 2012 to 2016, was collected from the "Kombolcha and Dessie Police Commission Booklet". The available and collected data from this booklet includes the following:

- Rough drawings to show the location of crashes with reference to the nearest college, factory, religious building, recreation site, office, hospital, residential park, open areas, petrol stations, pedestrian crossings, narrow bridge culverts, etc.
- Category of accident severity (i.e. fatal, serious injury, light injury, property damage only, etc.)
- Date, month, and year;
- Light conditions (daylight, the dark hour with good street light, the dark hour with poor street light, the dark hour with no street light, etc.);
- Involvement (pedestrian, animal and other objects);
- Name, sex, age, education, the address of the driver, type, and license number.

The RTA data recording in Ethiopia is done manually and in a traditional manner. This leads to a lack of compatibility with a GIS interface. The spatial distribution of accidents was done on the digitized map of Kombolcha-Dessie road by using ArcGIS software based on the indicated rough drawings obtained.

3.2. Data Processing and Analysis

After the collection of accident data of Kombolcha-Dessie road for the consecutive five (5) years and map of the road network, data processing and analysis was carried out to achieve the objective of the study. In the beginning, a map of the road network was digitized by using ArcGIS tool of editing toolbox then, accident data was spatially distributed to their crash occurrence with their respective severity weight. Since, distance is one of the variables for crash hotspot analysis, the map used for this analysis was projected coordinate system rather than a geographical coordinate system. Finally, the analysis output was obtained by running hotspot analysis tool of ArcGIS. Data processing and analysis of the study is summarized in Figure 1.

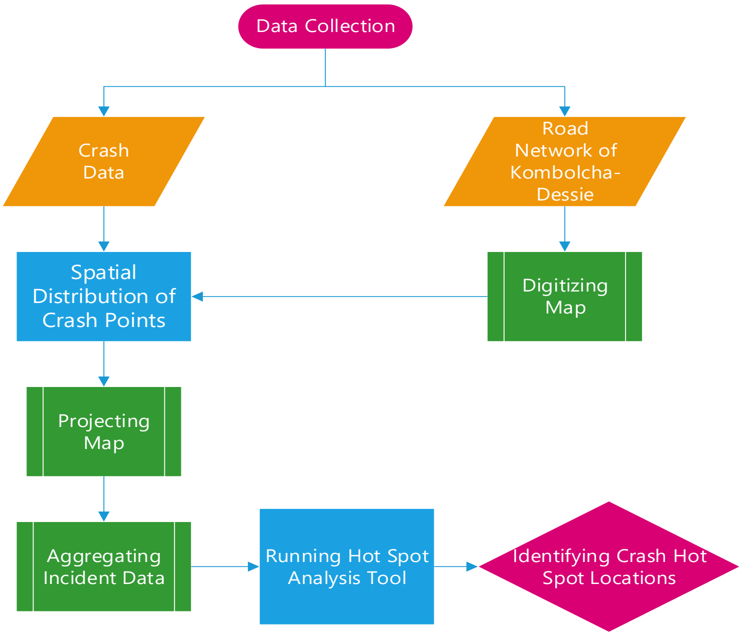

Figure 1: Flowchart of data processing and analysis

3.2.1. Data Processing and Analysis

The latitude and longitude of each accident point were marked as a point object according to the locations indicated on the rough drawing during crash occurrences. ArcGIS 10.2 was used for accident mapping on Kombolcha-Dessie road. Figure 2 shows marked and spatially distributed accident points.

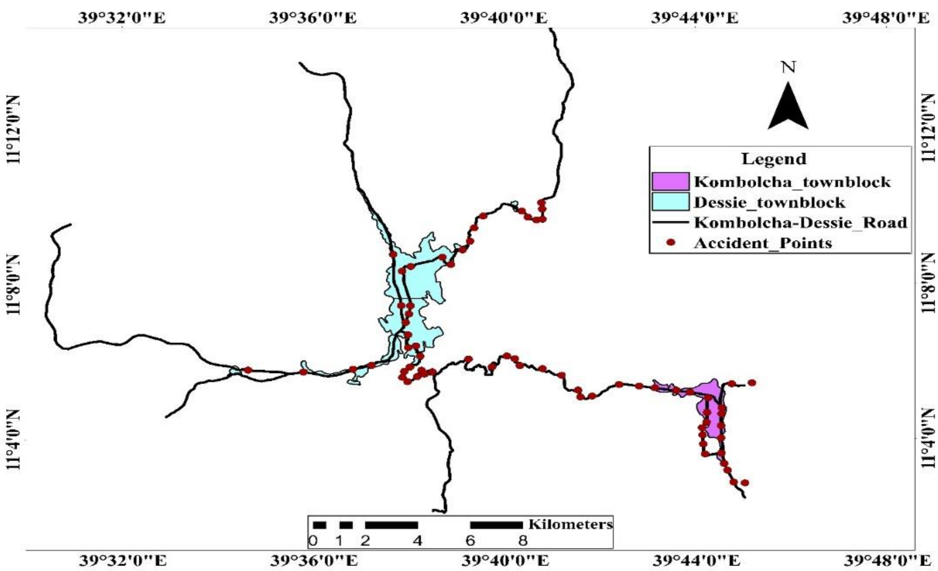

Figure 2: Spatially distributed accident points

3.2.2. Projecting the Incident Points

Whenever distance is a parameter of hotspot analysis tool, which is usually true with spatial statistics, the map is projected using a projected coordinate system on behalf of the geographical coordinate system. An RTA map of the study area was projected according to the following number and parameters:

Projection:	Transverse_Mercator
Geographic coordinate system:	GSC_Adindan
Datum:	D_Adindan
Prime meridian:	Greenwich
Angular unit:	Degree

3.2.3. Consideration of the severity of accidents

Studies were performed using accident incident points to determine high and low clustering. However, deprived of weighted data, it is very difficult to determine whether the observed clustering is correct or not. To identify unsafe locations, crashes should be weighted according to severity. In order to take the severity of an accident in consideration, this study employs the Belgian severity weighting system along with incidental accident data in analyzing high- and low-level clustering. This system was successfully adopted to identify black spots in the three national highways of Kerala in India (Karuppanagounder, 2011). The severity index (SI) for each location can be calculated via an equation (5).

$$SI = 5 * X_1 - 3 * X_2 + X_3 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5)$$

Where: X1= is the total number of fatal crashes

X2= is the total number of grievous crashes

X3= is the total number of minor and property damage only crashes

3.2.4. Aggregating the Incident Data

The projected RTAs were aggregated using the "Integrate and Collect Event Tool" provided by ArcGIS before running the hotspot analysis tool. When this tool is applied, a stack of coincident features is created by snapping crash points within some specified default distance (in case of this study 50 meter is used), then having the same X and Y coordinates counted to the I-count field of the attribute table. Figure 3 illustrates the results of aggregated RTA.

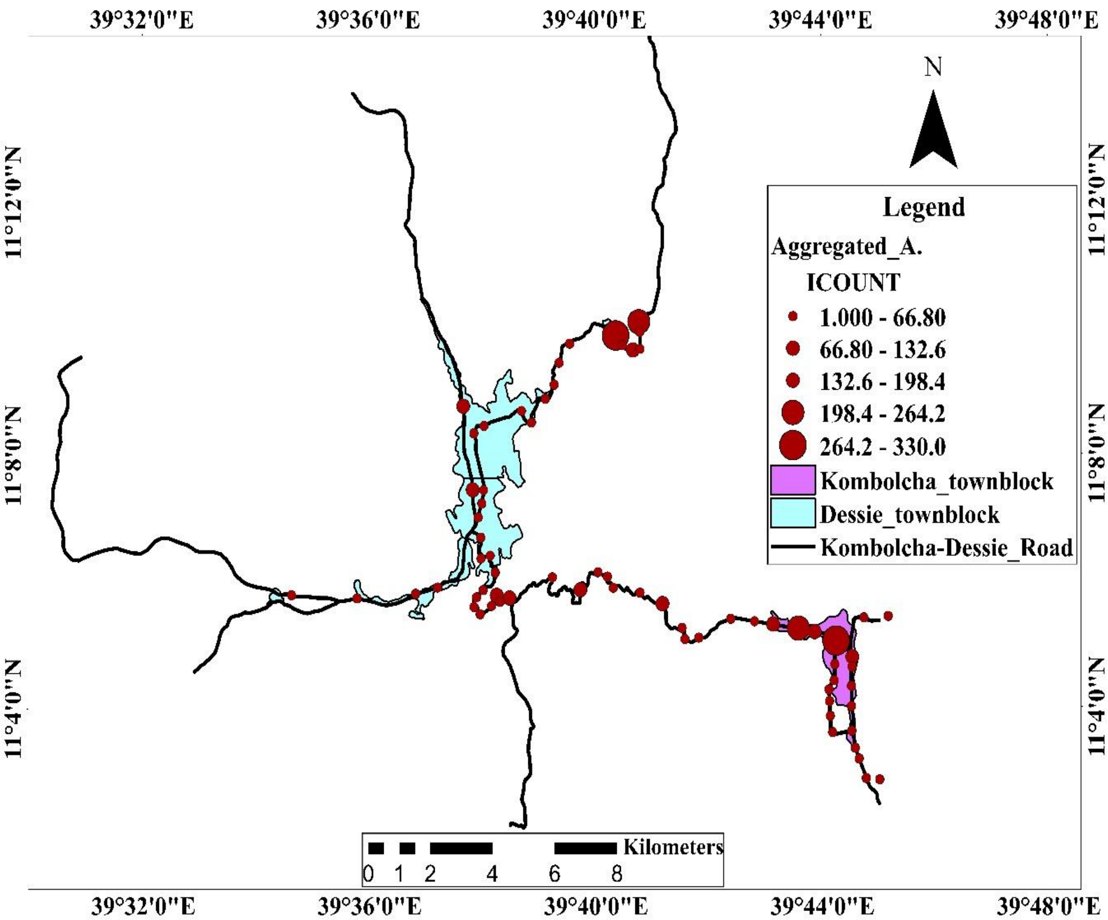

Figure 3: Aggregated incident data

3.2.5. Running the Hotspot Analysis Tool (Getis-Ord Gi)*

ArcGIS' important hotspot tool "Getis-Ord Gi*" is used to identify crash hotspot segments of the road with 'I Count' as an input field for statistical determination.

4. Results and Discussion

Creating a visualization surface is critical for understanding the results of hotspot analysis and thus, a visualization surface has been created. There are many ways to create an interpolated surface that will effectively visualize the results of a hotspot analysis. In this study, the IDW tool (spatial analyst) was adopted. It interpolates a raster surface from points by means of an inverse distance-weighted technique. Figure 4, (a) and (b), shows the results of hotspot analysis.

The results obtained from hotspot analysis by ArcGIS identify five (5) hotspot crash locations on Kombolcha-Dessie road. Table 1 shows the prioritized hotspot crash locations with their statistical significance of Z-score and P-values obtained from the hotspot analysis result.

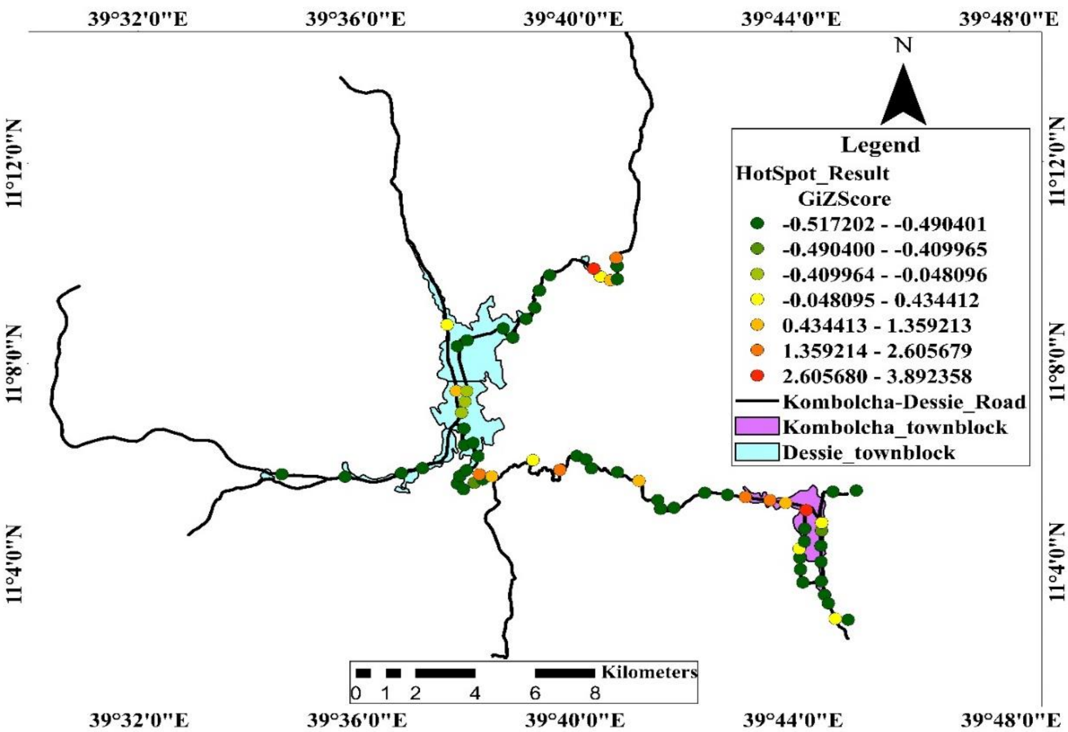

Figure 4: Hotspot analysis result

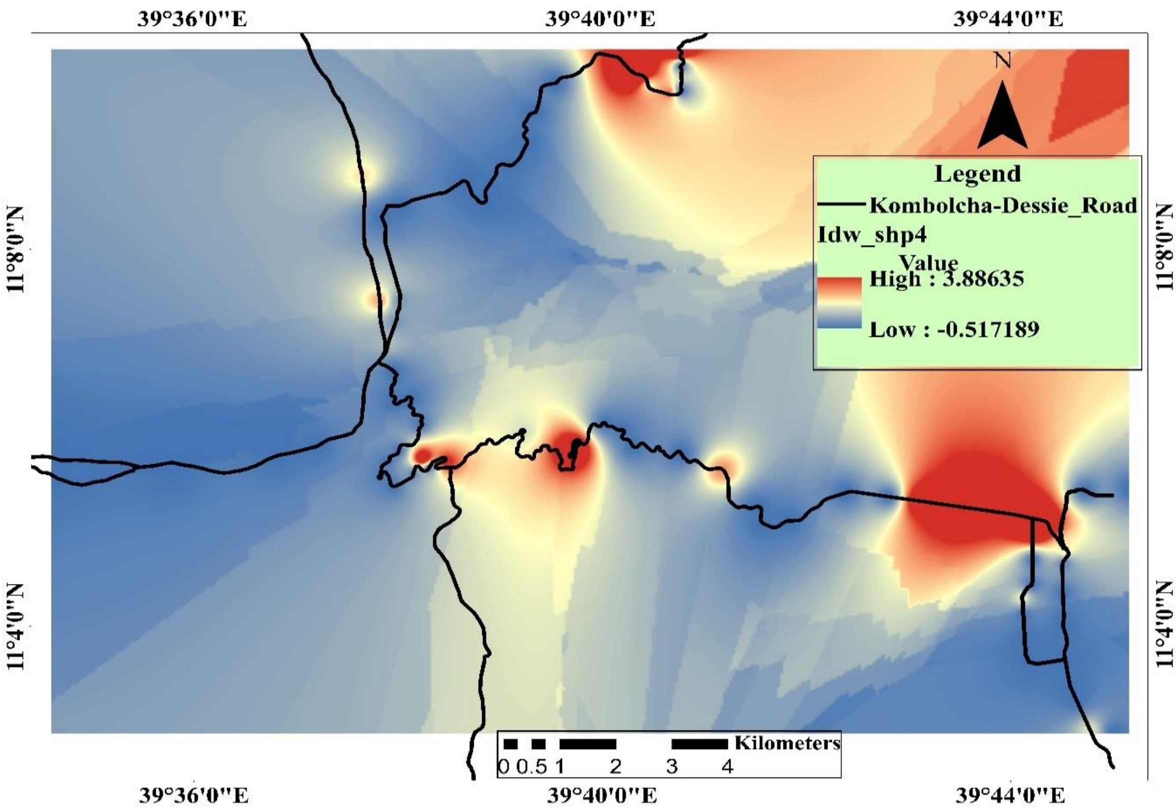

Figure 5: Created the visualization surface of Inverse Weighted Distance (IDW)

Z-score, which represents standard deviation, and P-values, which represent probability, are the statistical parameters used in the ArcGIS hotspot analysis tool to prioritize hotspot crash locations. The statistical values returned from this analysis help a person to decide whether the crash location is a hot or cold spot. For hotspot crashes, the Z-score is positive and larger, which means that the penetration of high cluster values is larger, and the inverse will be the case for cold spot crashes. According to the results obtained from the hotspot analysis tool, which is based on the Z-score and P-value, a prioritization of hotspot crash locations on the Kombolcha-Dessie road is presented in Table 1. Accordingly, a roundabout located in Kombolcha town encounter a higher crashes with a Z-Score value of 3.892358 and P-Value of 0.000099. Also, the rest four crash hotspot locations on Kombolcha-Dessie road are ranked and listed in Table 1 according to their larger Z-Score to lower Z-Score and lower P-Value to larger P-Value.

Table 1: Hotspot locations on Kombolcha-Dessie road

№	Location	Z-Score	P-Value
1	Kombolcha town roundabout	3.892358	0.000099
2	Dessie town ‘Tita’ curve	3.356247	0.00079
3	Dessie town ‘Kobo-Gedel’ zig-zag curve	2.605679	0.009169
4	Kombolcha town entrance to ‘Awscod’	2.284018	0.02237
5	‘Arego’ S-curve	2.069561	0.038493

5. Conclusion

Generally, this study has identified accident blackspot zones on the Kombolcha-Dessie road with the aid of ArcGIS software. Results from this study show that the hotspot analysis tool from ArcGIS is a preferable tool for road safety analysis because of its accurate identification of hazardous locations with statistical significance, advantage of minimizing the tedious part of traditional analysis (which is still working in Ethiopia), provision of the simplest output presentation within a single map, and classifying crash hot and cold spots with colors legendary.

This study has sought to identify accident hotspot zones as an important leading step in road safety analysis because it helps engineers focus on the black spot segments of the road so as to assess the inconsistency in their geometric design and finally come up with a solution. The study was conducted using ArcGIS software and found this software to be an absolutely crucial tool in identifying black spot zones for accidents.

By running hotspot analysis of ArcGIS in spatial statistics toolbox, on Kombolcha-Dessie road five accident intensive prone zones or hotspots have been identified based on the results of Z-score and P-value. These are; Kombolcha town roundabout-1, ‘Tita’ curve in Dessie town, ‘Kobo-Gedel’ in Dessie town, entrance to ‘Awscod’ enterprise in Kombolcha town and a place named ‘Arego’ S-curve.

6. Limitation

Traffic police commission of Ethiopia, doesn't have a computer-based or web-based traffic crash database and, location of crash is recorded on a rough drawing so, the exact coordinate of the crashes doesn't recorded well. This makes crash data collection difficult and tedious and, the work of spatial distribution of crashes rest on the researchers.

7. Recommendations

The application of GIS and GPS must have to be adopted in traffic police commission to have the exact spatial location of crashes and crash database records. Thus, decreasing data errors acquisition and making road safety analysis better and real.

Road Traffic Accidents (RTAs) charge the country a lot of resources in terms of deaths, injuries and destruction of property. We recommend further research on the detailed information about the total costs of traffic crashes in Ethiopia.

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