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Integrated GIS Tool for Investigating the Relationship of Road Characteristics with Road Traffic Accidents

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ABSTRACT

Road accidents pose a serious economic and social problems given that the number of fatal accidents continue to rise at the national and international levels. This study investigates the relationship between three road parameters, namely number of lanes, level of service (LOS), and slope, with road accidents. The data for road accidents were obtained from the Police Department - Contingent Headquarters (IPK) Alor Setar, Kedah, the data for roads, namely number of lanes and traffic volume, were obtained from Public Works Department (JKR), while the TanDEM-X Image was provided by the licensed holder. The ArcGIS software 10.5 was used to process the data; this is followed by performing the regression and kernel density estimation to determine the relationship between the parameters with accident cases. The majority of road accidents in Kedah occurred on two-lane roads. LOS is negatively correlated with road accidents, which indicates that less accidents occurred with higher level of flow. Slope is negatively correlated with road accidents, indicating that a smaller number of accidents occurred on roads with higher slope values. Alor Setar and Sungai Petani have been identified as road traffic accident hotspots for the period from 2013 to 2015. In summary, the findings of this study provide the relevant authority such as the Traffic Police with the critical information required to make a better decision when formulating strategies to reduce road traffic accidents.

Keywords: Road accidents; number of lanes; Level of Service (LOS); slope; GIS application

INTRODUCTION

According to the World Health Organization, WHO (2017), the lack of road safety, which has resulted in between 20 and 50 million injuries annually, has a negative effect on the mortality rate of low and middle income economies. A large percentage of the fatalities involved those in the age group of 15-29 years old. In addition, half of the road traffic deaths involve pedestrians, cyclists, and motorcyclists. Globally, road accidents have been ranked as the ninth cause of death in 2009 and it is projected to be the seventh cause of death by the year 2030 (WHO 2018). In 2016 the Ministry of Transport (MOT), Malaysia recorded a total of 521,446 road traffic accidents, which is an increase of 7% from the 489,606 recorded in 2015. The total number of fatal road accidents also increased 7% from 6,706 in 2015 to 7,152 in 2016. Of the total 400,788 road accidents recorded in the first nine months of 2017, 6,083 were fatal accidents. The Traffic Enforcement Investigation Department (JSPT), Bukit Aman (2016) reported that, since 2010, over 6,000 fatal road accidents are recorded in Malaysia annually. Hence, there is a critical urgency to evaluate and improve road safety in Malaysia (Yahia et al. 2017).

The Ministry of Works proposed four (4) approaches to improve road traffic safety: (i) prevent accidents; (ii) reduce the rate of accidents; (iii) good road maintenance; and (iv) construct new roads (Sultan et al. 2016). Road is an important aspect in the effort to improve road safety because it is the second most common cause of road accidents after human behaviour (Umar & Gokcekus, 2019; & Yaacob et al. 2018). Among the road characteristics that contribute to road accidents are road geometry (Borhan et al. 2018 & Dadashova et al. 2016); road pavement (Tsubota et al. 2018); type of road (Claire et al. 2019); number of lanes (Claire et al. 2019); level of service (Matthias 2020); and topography (Joshi et al. 2014).

Kurdin et al. (2017) analyzed the effect of road geometry and environment on road accidents and found that inappropriate road geometry at certain locations is one of the factors contributing to road accidents. Raut et al. (2016)

pointed out that inadequate sight distance and improper curve design can cause road accidents. Furthermore, the type of road influences the spatial pattern of road accidents, where urban areas have a higher occurrence of road accidents although the degree of injury is less severe; in contrast, even though the rate of accident on rural roads is lower the rate of fatality is much higher (Shamsuddin et al. 2015). Sultan et al. (2016) stated that the location of road accidents in both urban and rural areas is influenced by weather, where the authority in rural areas have recorded the highest number of accidents during bad weather. Yaacob (2019) analyzed the findings of 28 previous studies and found that 79% of the research reported that even though the highest number of accidents was recorded in urban areas the accidents caused only light injuries or minor damage; the remaining 21% of the research reported that the smaller number of accidents in rural areas were more severe and caused serious injuries and death. This is because the small volume of traffic in rural areas encourage high speed driving, thereby increasing the likelihood of road accidents occurring when the driver lost control of their vehicles. The road accidents in urban areas are less severe due to the high volume of traffic (Potoglou et al. 2018).

Another road factor is the number of lanes. Darma et al. (2017) have shown that the number of lanes affect the occurrence of road accidents. Potoglou et al. (2018) have demonstrated that the number of road accidents is higher on two-lane roads while Wedajo et al. (2017) believed that narrow lanes also contribute to road accidents. Manan et al (2017) used the Multinomial Logistics Regression and Pseudo Elasticity methods to investigate the association of number of lanes with road accidents and found that adding the number of lanes help to reduce the occurrence of road accidents.

In terms of the level of service (LOS), Arkatkar (2018) stated that there is a close relationship between LOS and road capacity. LOS is the qualitative measure of traffic while road capacity is the quantitative measure of a facility. In other word, LOS is a term to classify the varying conditions of traffic flow, where consists of six (6) type of LOS description such as free flow, stable flow, stable flow approaching unstable flow, unstable flow, and forced flow. Table 1 shows the description of each level flow with its load factor. The worst road condition leads to traffic congestion. According to the Raheem et al. (2015), traffic congestion occurs when the number of vehicles on the road at a particular time is greater than the capacity of the road. Traffic congestion can be caused by several factors, including haphazard parking of vehicles on the road, behaviour of road users, rush hour traffic, bad weather and accidents (Olusina and Samson, 2014).

Concerning the effect of topography on the occurrence of road accidents, Lin et al. (2013) stated that the critical areas for road accidents are mountain roads because of the complex topographical conditions and geometric design of roads. Rusli et al. (2015) pointed out drivers must have an effective driving skill to drive on constrained topography and complex road geometry, in particular when driving in bad weather conditions. Joshi et al. (2014) analyzed accident cases in hilly areas and found that road accidents are caused by improper design and construction, for example, poor curved design, the absence of guide rails, narrow shoulder drop-offs, poor visibility at intersections on curves or hills; and unsuitable positioning of lights. The researchers believed that the number of road accidents can be reduced by taking these factors to take into account. An in-depth study of how road characteristics influence road accidents would be able to help relevant agencies such as the Department of Public Works (JKR) and PLUS to improve road construction and formulate effective policies for road maintenance work

Each road accident has a spatial dimension and spatial attributes. The spatial dimension is a coordinate value (x,y) while the spatial attributes are a description of the accident, such as time and date of occurrence, type of accident, severity and others. Geographical Information System (GIS) is a system designed to capture, store, check, integrate, manipulate, analyze and display the data for a specific location, and thus its use is able to facilitate analysis (Fifi Susanti Sjafri et al. 2018). At present, GIS is widely used to analyze road traffic accidents since it is able to provide decision-makers with quick outputs that facilitate sound decision making and resolution of problems.

This study investigates the relationship of three (3) road characteristics, namely the number of lanes, level of service (LOS) and slope derivation, with road accidents. This study uses GIS applications to analyze the spatial and pattern of road accidents for better understanding through mapping techniques.

METHODOLOGY

STUDY AREA

The state of Kedah was selected as the study area because the accident statistics provided by the Bukit Aman Traffic Branch showed that Kedah recorded a total of 120,003 accident cases for the period from 2010 to 2015, which is the highest number of road accidents compared to other states in Malaysia. This study involved all districts in Kedah with the exception of Langkawi district. Figure 1 shows the map of Kedah.

DATA COLLECTION

This study used three (3) primary data, namely road accident data, TanDEM-X image to extract road slope, and road data. The ArcGIS software was used to create a database and to synchronize the format of available data, as well as to carry out the analysis.

The data for road traffic accidents for the period from 2013 to 2015 was obtained from the IPK Kedah. The data

TABLE 1. Investigation on car-driver interaction

LOS	Reference	Description	Load Factor
A	Free Flow	Low volume, low density and high vehicle speed.	<0.24
B	Stable Flow	Vehicle speed starting depends on the volume of a vehicle on the road.	0.25 – 0.39
C	Stable Flow	Vehicle speed is influenced by volume of vehicle.	0.40 – 0.69
D	Approaching unstable flow	Lower vehicle speed. Tolerable delay.	0.70 – 0.89
E	Unstable Flow	Lower vehicle speed may cause a brief traffic stoppage. Lead to traffic congestion.	0.90 – 1.00
F	Forced Flow	Speed of vehicle can drop to zero and cause the worst traffic congestion.	>1.00

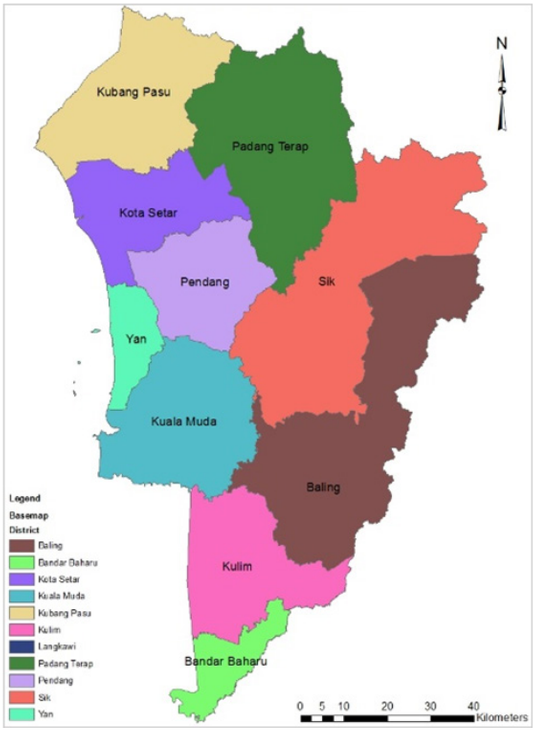

FIGURE 1. Map of Kedah

contains information on the location and coordinate, date, time, and types of accidents. In this study the severity of accidents was determined based on vehicle damage, degree of injury, and death. A total of 44,767 accident cases from the three-year study period were analyzed after removing incomplete data (Figure 2).

Road data was provided by JKR. The data includes the name of the roads, length of road, number of lanes, and LOS. The LOS data is classified from A to F, where it was calculated from traffic volume data that observed twice in a year which were in March and September.

The slope data was extracted from the TanDEM-X image. The image provides the location attribute (x, y) values, heighting (z) and 12m accuracy of spatial resolution (Satellite Mission of eoPortal Directory, 2018). According to Zink et al. (2014), the accuracy is intolerance where it is enough to relate slope derivation with a road accident. Table 1 shows the TanDEM-X specification parameters and Figure 3 shows the TanDEM-X image for Kedah.

METHODOLOGY WORKFLOW

A number of processes were used to investigate the relationship between number of lanes, LOS and slope with road accidents, for instance creating a database for accidents, calculating traffic volume, deriving the slope, and analyzing the data by using regression methods, as shown in Figure 4.

The ArcGIS software 10.5 was used to create a road accident database which contains all the data used in this study. The database was processed in five (5) steps: (i) data cleaning and filtering to remove incomplete data, (ii) coordinate conversion, (iii) adding the XY data to plot the actual accident location on a map, and (iv) entering the attribute information (Figure 5). Following this, the join and relate method was used to relate the road data with the road accident data.

The service level of traffic flow on roads, also known as LOS, was determined based on traffic volume. LOS has a qualitative term to describe the condition of road flow which range from A to F, where A represents free flow

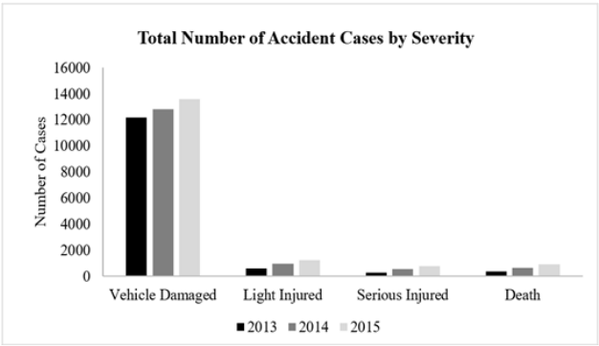

FIGURE 2. Total Number of Road Accidents for the Period of 2013-2015

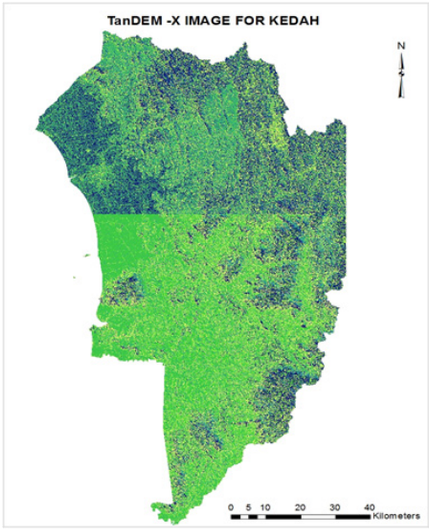

FIGURE 3. TanDEM-X Image

TABLE 2. Investigation on car-driver interaction

Requirement	Description	Main components
Relative vertical accuracy	90% linear point-to-point error over a 1° x 1° cell	2 m (slope <20%)
Absolute vertical accuracy	90% linear error	10m
Absolute horizontal accuracy	90% circular error	10m
Spatial resolution	Independent Pixels	12m (0.4 arc sec @ equator)
Coverage	Percentage of Land Masses	97%

and F represents the worst flow (Table 2). The formula for establishing the LOS of a road is given by Equation (1). The capacity of a road is a constant value which differs depending the number of lanes, where the values for one- and two-lane roads are 1200 and 3000, respectively (JKR, 2017).

$$\text{Formula: LOS} = \text{Traffic Volume/Road Capacity} \quad (1)$$

For slope data, the Global Mapper software was used to extract the coordinate and heighting value of the earth surface based on the location of road accidents. The heighting value was used to perform the Triangulated Irregular Network (TIN) which was then converted into a raster image. Finally, the slope surface process was calculated in percent rise output.

The Excel software was used to carry out statistical and regression analysis to establish the association between the number of lanes, LOS, and slope with road accidents. Regression analysis was used to determine the relationship of two or more variables; among the types of regression analysis are linear regression, Poisson regression, ordinal regression, polynomial regression and others. According to Kumar and Toshniwal (2015), researchers often use this technique to determine the relationship between road accidents and their causes. In this study the linear regression method was used to analyse a one-to-one variable, namely one (1) dependent variable and one (1) independent variable. Additionally, the kernel density estimation method was used to determine the road traffic accident hotspots in Kedah. It is a non-parametric method

for estimating the probability density function of a random variable by calculating the magnitude-per-unit area from a point or polyline (Bil et al. 2013). The kernel density is given by Equation (2), where *SD* is standard distance; *Dm* is median distance; and *n* is total number of points (Bil et al. 2013).

$$\text{Search Radius} = 0.9 \times \min n\text{-}0.2 \left(SD, \sqrt{\frac{1}{\ln(2)}} * Dm \right) * \quad (1)$$

RESULTS AND DISCUSSION

NUMBER OF LANES

The number of lanes parameter was evaluated as a factor contributing to road accidents (see Figure 6). The number of accidents on two-lane roads decreased between 2013 and 2014, but increased in 2015. However, there was an increase in the occurrence of road accidents on four-lane roads between 2013 and 2014, the number of accidents decreased in 2015. In brief, there was a higher occurrence of road accidents on two-lane roads compared to on four-lane roads during the three-year period. This is because drivers have a smaller space to manoeuvre their vehicles in the case of an accident (Selvasofia & Arulraj 2016). For example, if the vehicle in front brakes suddenly, drivers may be able to turn left or right. Each lane of a road has a purpose, where drivers travelling at lower speed should use the left lane while those travelling at higher speed should use the right lane. The outcome of this investigation is similar to those obtained by Schwab (2015) and Milenkovic et al. (2016) in that even though the number of road accidents are higher on two-lane roads, they are generally less severe accidents. In contrast the smaller number of road accidents on four-lane roads are often more serious. In conclusion, there is a relationship between numbers of lanes with road accidents in Kedah. Hence, in order to deal with this problem future research should focus on the association of number of lanes with the severity of road accidents.

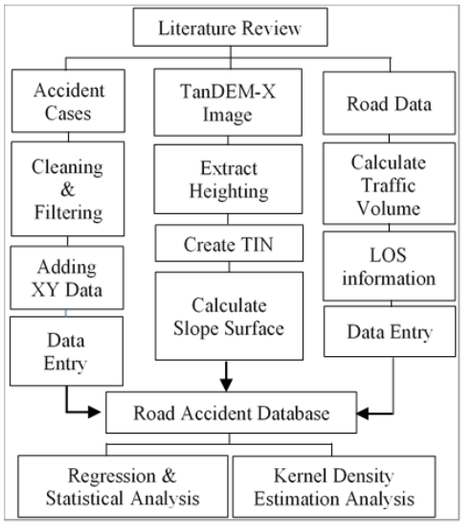

FIGURE 4. Methodology workflow

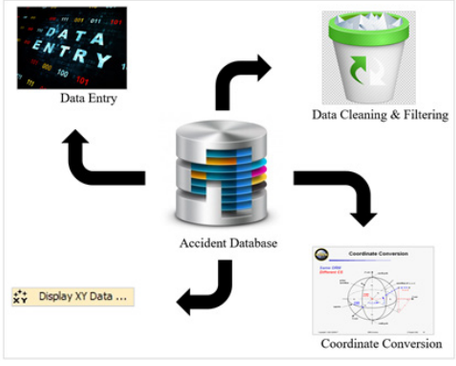

FIGURE 5. Steps in Accident Database Processing

LEVEL OF SERVICES (LOS)

The number of accidents was classified based on the LOS of roads, as shown in Figure 7. The road accidents in Kedah is influenced by only four (4) of the six (6) levels of LOS, namely free flow, stable flow, approaching unstable flow, and congested flow. The highest number of accidents during the three-year period occurred during stable flow, followed by free flow, approaching unstable flow, and congested flow. This finding is similar with that of a previous study, where the highest number of road traffic accidents happened during free and stable flow and less accidents occurred during congested flow (Coruh et al. 2015).

Table 3 shows the results of regression analysis for the association of LOS and road accidents. The R2 values for 2013, 2014 and 2015 are - 0.10, - 0.51 and - 0.54, respectively, which indicate a 10, 51 and 54 percent negative relationship between LOS and road accidents. The higher the value of level flow, the lower the number of road accidents. This finding is congruent with that made by Admassie (2015) that road accidents usually occur during free flow and stable flow. In conclusion, there is a correlation between LOS and road accidents during the three-year period.

SLOPE

The Guide on Geometric Design of Roads published by JKR (1989) states that there are two types of slope grades for standard roads: (i) 10% tolerance, which is known as the desirable maximum slope grade; and (ii) 25% tolerance, which is known as maximum grade slope (Table 4). All standard roads in Malaysia are to be constructed within the tolerance stated in this guideline.

Table 5 presents the result for regression analysis of the slope factor affecting road accidents. The table shows that the R2 value of -0.32 for the desirable slope grade category is constant for the period from 2013 to 2015. This indicates a 32% negative relationship between slope factor and road traffic accidents. The R2 for maximum slope grades for 2013, 2014 and 2015 are -0.81, -0.76 and -0.80, respectively. This shows that there is a 81%, 76% and 80% negative relationship between slope and road accidents. Thus, it can be concluded that, for both slope grade categories, the higher the percentage of slope grade the lower the number of road accidents.

Figure 8 shows the map for slope derivation for Kedah that has been overlaid with the road traffic accidents hotspots for the period from 2013 to 2015. The map clearly shows that the road accident hotspots consist of moderate level, dangerous level and very dangerous level occurring at low slope grades. This shows that the majority of road accidents during the three-year period occurred in flat areas. Another perspective of the map shows that roads were constructed in compliance with the regulations set by JKR. In summary, the result of this regression analysis shows that there is a correlation between slopes and road accidents in Kedah at lower slope grades.

A hotspot area is a location where there is a frequent occurrence of road accidents. It is of utmost importance that road safety authority implements effective road safety counter measures (Rankavat & Tiwari, 2013 and Perrels et al. 2015). In this study, the kernel density and Getis-Ord Gi methods were used to identify the road traffic accident hotspots. Researchers often used this method to identify hotspot areas because its ability to recognize the risk spread of an accident and to allow for some events to weigh more heavily than others (Soltani & Askari, 2014). Two locations have been identified as road traffic accident hotspots during the three-year period. The two hotspots are Alor Setar and Sungai Petani, both of which are categorized as urban area. According to Marquez et al. (2016), most road accidents occurred in urban areas. This is because (i) urban areas have a large volume of vehicle on the roads and this leads to tailgating and reckless driving; (ii) potholes may cause drivers to lose control of their vehicles and this in turn may cause road accidents; and (iii) running red lights. Although the number of road accidents in urban areas are high, they are less severe than the smaller number of road traffic accidents in rural areas. These findings are congruent with those made by Shahid et al. (2015); Aghajani et al. (2017); and Oyesiku et al. (2019).

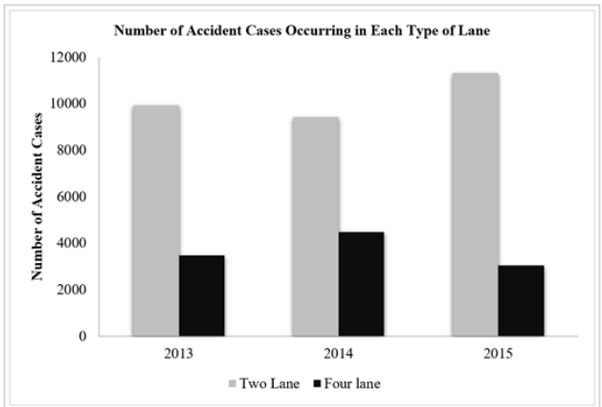

FIGURE 6. Number of accident cases occurring in each type of lane

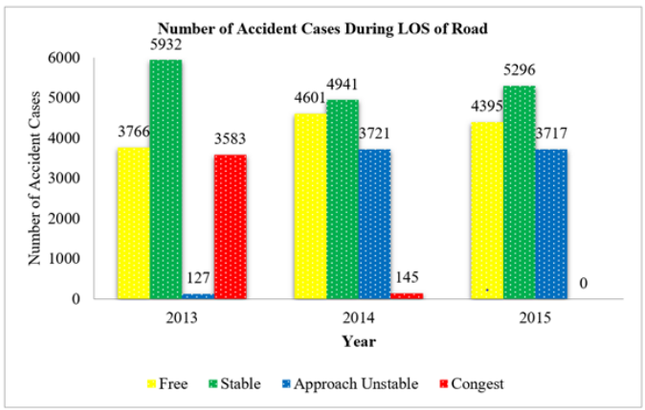

FIGURE 7. Number of accident cases vs LOS of road

TABLE 3. Regression Result for LOS Factor

No	Year	Specification
1	2013	- 0.1019
2	2014	- 0.5147
3	2015	- 0.5381

TABLE 4. Slope grade for standard roads

Type	Desirable Maximum Grade (%)	Maximum Grade (%)
Standard Road	10	25

Source: Public Works Department of Malaysia (1989)

TABLE 5. Regression Result for Slope Derivation Factor

Year/Grade	R^2 Value	
	Desirable Slope	Maximum Slope
2013	- 0.3151	- 0.8143
2014	- 0.3150	- 0.7644
2015	- 0.3163	- 0.8033

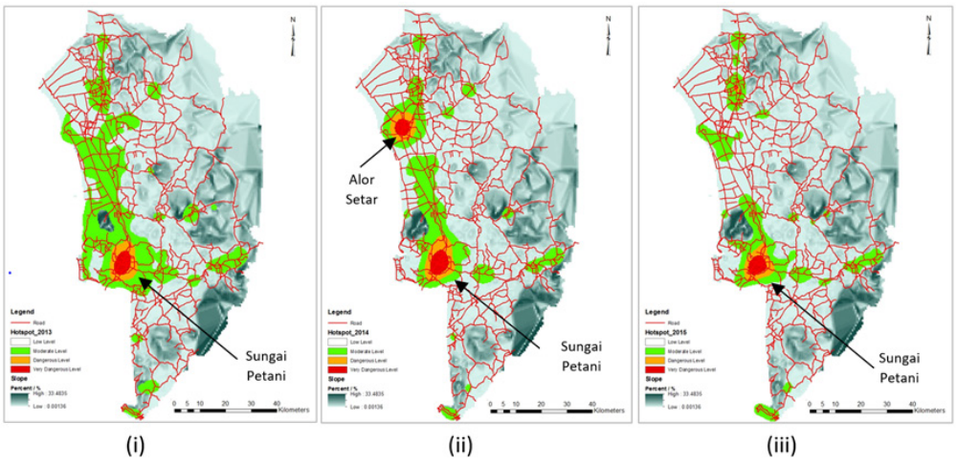

FIGURE 8. Accident Hotspots Area Overlaid with Slope Derivation for Year (i) 2013; (ii) 2014 and (iii) 2015

CONCLUSION

The present study used the data for road accidents in Kedah for the period from 2013 to 2015 to investigate the relationship between road characteristics and the occurrences of accidents. An integrated GIS application was used to gain a more in-depth understanding by presenting all relevant information graphically. Regression, statistical and KDE analysis were carried out to determine the relationship between type of lane, LOS and slope with road accidents. Results showed that most road accidents occurred on two-lane roads and during stable flow; almost all road accidents occurred at lower slope grade, which means that more road traffic accidents occurred in flat areas. The road traffic accident hotspots in Kedah for the three-year period are Alor Setar and Sungai Petani. In conclusion, the three investigated parameters were found to influence the occurrence of road traffic accidents. Besides that, the lack study of road geometric and road pavement parameter will be instituted meaningfully, where the future research can evaluate its relation toward occurrence of road accident, where community safety can be improved.

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DECLARATION OF COMPETING INTEREST

None.

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