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Identification of High-Risk Road Traffic Crash Zones for Spatial Allocation and Distribution of Proximate Health-Care Facilities: An Application of GIS Tools

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ABSTRACT: The time interval between the road traffic crash (RTC) and the first aid provided to RTC victim has an important role in reducing the fatality rates. Therefore, the allocation and spatial distribution of small-scale emergency health-care units along the high-speed road network system plays a critical role. The primary objective of this study is to propose a methodological framework that is capable of identifying high-risk priority road stretches and aids in allocating the emergency health-care units along the high-speed road network system in an optimum way. Addressing such issues using traditional techniques is not only cumbersome but inefficient as well. Thus, the proposed methodological framework in this study utilize the Geographic Information System (GIS) tools. Using the available RTC data, this framework was applied to the Union Territory of Jammu & Kashmir, India. This resulted in the extraction of a map delineating the high-risk priority zones. The proposed methodological framework provides useful insights that would be helpful to policy-makers towards allocation and spatial distribution of emergency health-care units which, in turn, will reduce the fatality rates in RTCs.

Keywords: Road Traffic Crashes, Emergency Health-care, GIS, Case study.

Abbreviations: RTC, Road Traffic Crash; GIS, Geographic Information System; GPS, Global Positioning System; NH, National Highway; SH, State Highway, MDR, Major District Road; ODR, Other District Road; VR, Village Road; AR, Arterial Road; IRC, Indian Roads Congress.

I. INTRODUCTION

Transiting the transportation systems towards sustainability is a pre-requisite for achieving sustainable development [1]. The development of high-speed road network systems like highways and expressways have no doubt improved the overall mobility and connectivity; however, at the same time, it has posed a huge risk to human lives, particularly in the low and middle-income countries. Addressing safety within the transportation system has a prodigious impact on sustainable development [2, 3]. As per the WHO report [4], 90 percent of the global road traffic crashes (RTCs) occur in low and middle-income countries. In India, for example, on an average, every hour 57 RTCs are reported resulting in 17 deaths [5]. It is important to note that, as far as the ground reality is concerned, these numbers are always more, owing to the under-reporting issues [6, 7]. The worst affected are the vulnerable road users (VRUs) that include pedestrians, cyclists and two-wheeler motorists [8]. The economic losses due to RTCs are also alarmingly large [9]. The annual average global economic losses due to RTCs alone are estimated to be around 518 billion dollars which means a loss of approximately 2% Gross Net Product (GNP) in high-income countries while 1.5% GNP in low to middle-income countries [10].

The spatio-temporal analysis provides insights on the trends and patterns of RTCs that are useful in formulating strategies towards minimizing the overall losses [11–13]. Most of the research studies have focused on the identification and modeling of hotspots [10,14–21]. For example, Aghajani *et al.* [10] identified hotspots in Ilam Province, Iran while Benedek *et al*. [18] analyzed RTCs to determine hotspots in Cluj-Napoca, Romania. Researchers working towards road safety have used a number of spatial analysis tools; however, GIS-based tools stand out owing to the following advantages: (1) it allows careful and accurate data selection, screening and reduction, and (2) it allows the development of geo-referenced spatial statistics [22].

As evident from the literature, the accessibility to health-care facilities and the time interval between the RTC and the first aid provided to RTC victim plays a crucial role in reducing the fatality rates [23]. This time interval depends on various factors [24]. One of these major factors is the distance between the point where RTC occurs and the availability of proximate emergency health-care facilities such as an ambulance. Moreover, it is important to understand that major health-care facilities cannot be provided at shorter intervals along the highway, however, it is feasible to establish small scale emergency units at relatively shorter intervals along the length of the high-speed road network system. The location and spatial distribution of these resources and facilities along the high-speed road network system are, therefore, vital [25]. In order to address this issue, the main aim of this study is to propose a methodological framework that is capable of identifying high-risk priority road stretches and aids in allocating the emergency health-care units along with the high-speed road network system in an optimum way.

II. METHODOLOGY

In order to achieve the objectives of this study, a methodological framework is developed (see Fig. 1). This framework is broadly divided into two stages. The first stage sheds light on the spatial and temporal variation of RTCs across various districts in Union Territory (UT) of Jammu & Kashmir (J&K), India. This stage utilizes the following GIS-tools: (1) extraction tool, (2) joining tool and (3) mapping tool. The extraction tool is used to demarcate the boundaries of the study area. The joining tool is used to integrate the spatial data (i.e. the study area boundaries) with the non-spatial data (i.e. RTC data sets). The mapping tool is utilized to prepare the heat maps to represent the spatio-temporal variation of RTCs across the study area.

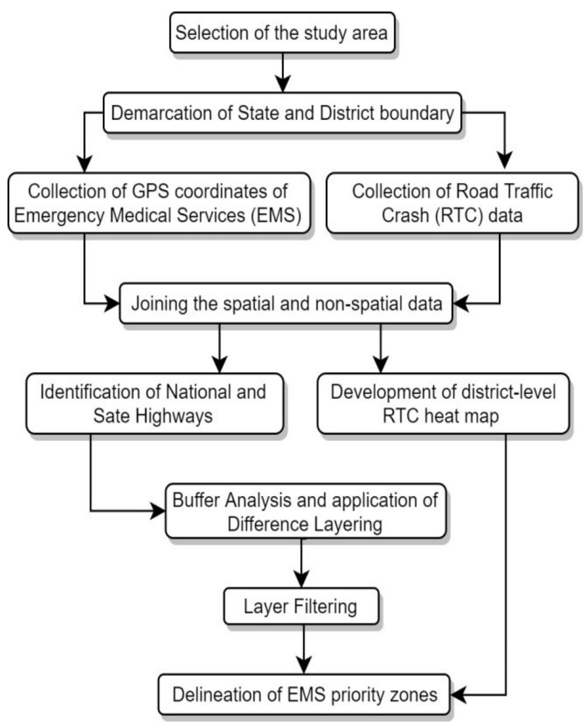


Fig. 1. Flow chart of the proposed methodological framework for delineation of priority zones.

The main aim of the second stage is to delineate the high priority risk zones for the allocation of proximate emergency health-care facilities. In addition to the tools used in the first stage, this stage utilized the following tools: (1) buffer tool, (2) difference layering tool, and (3) layer filtering tool. The buffer tool is used to create buffers around the health-care facilities and the road network system comprising of National Highways (NHs) and State Highways (SHs). It is worth mentioning that the buffer radius should be based on the calculations and expert opinion. It is primarily focused on the time taken by the emergency facility from receiving the information about RTC to the arrival of the RTC victim at the facility. After these buffers have been created, difference layering tools and layer filtering tools are used to obtain a map with the difference of these buffers, highlighting and delineating the problematic and high-risk RTC zones.

III. CASE STUDY

In this research, UT of J&K was taken as the case study. J&K is the second largest (area= 42,241 km^2) and second most populous (approximately 12.6 million) UT of India. The motivation for considering this as the case study derived from a report by the National Crime Records Bureau [23]. As per the report, J&K topped the list of high accidental death prone areas. Also, it was reported that the probability of fatality in J&K due to RTCs is 0.64. The causes of high risk, as reported, were found to be those of poor accessibility to emergency health-care facilities and delayed first-aid to the RTC victims.

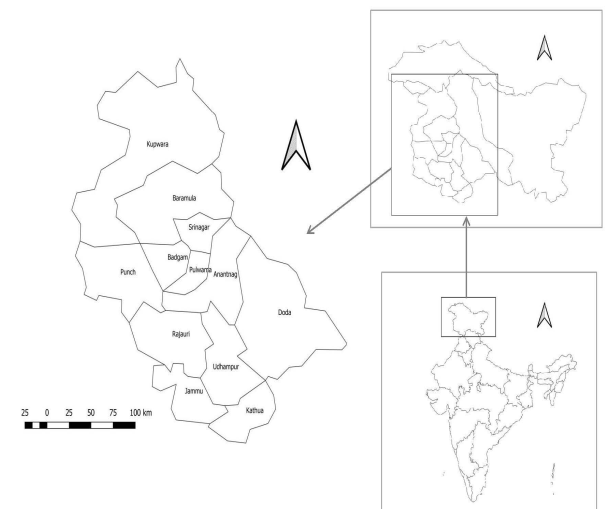


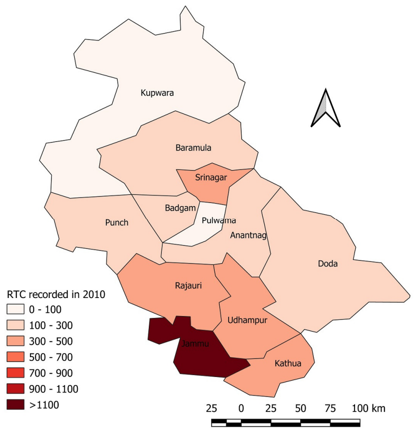
Fig. 2. District level map of UT of J&K (case study).

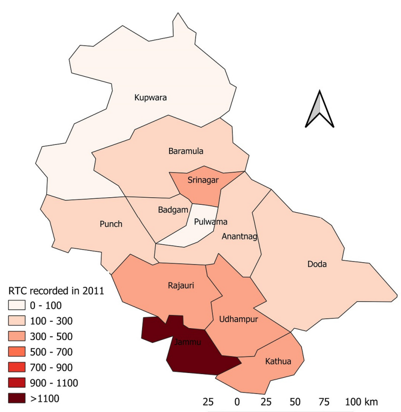
A. Data Sets

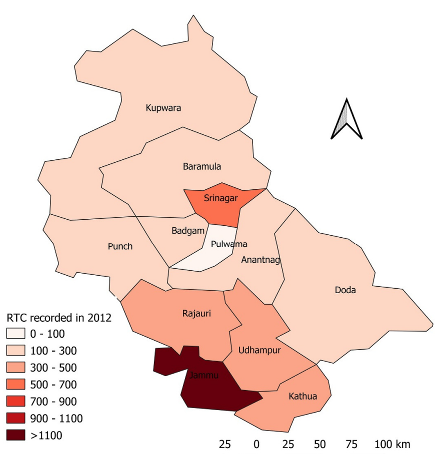
Two types of data were required for this study- spatial and non-spatial data. Spatial data comprised of the state and the district level shape files, GPS coordinates of health-care facilities, and shapefile of the NHs and the SHs. The shapefiles were obtained from *Info GIS* Map [26] while the GPS coordinates were obtained using *DGPS GNSS-R8 (Trimble)*. As far as non-spatial data is concerned, it comprised of the number of reported RTCs including both fatal as well as non-fatal cases and the list of primary health-care facilities across the districts of J&K. The former data sets were obtained from the Department of Traffic Police, J&K [27] while the latter data set was obtained from the Department of Health and Medical Education, J&K [28]. It is noteworthy that the data sets related to RTCs were collected between 2010-2018.

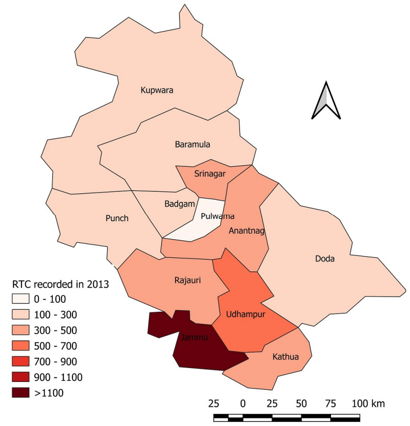
IV. RESULTS AND DISCUSSION

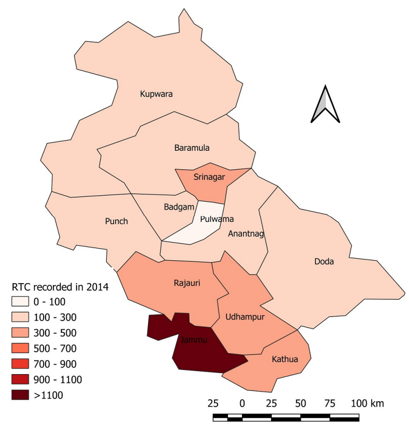
The proposed methodological framework was broadly divided into two primary stages: (1) spatio-temporal analysis stage and (2) delineation stage. For the information of the readers, it is worth mentioning that both the stages were analyzed and mapped using *QGIS* *software (ver. 3.4.7)*. The spatio-temporal analysis of RTCs across the districts of J&K involved primarily following three GIS tools: (1) extraction tool, (2) joining tool, and (3) mapping tool. First, the study area was extracted from the available shapefile. It was then joined with the (non-spatial) RTC data. The results were mapped to observe the spatio-temporal variation of RTCs across the districts of J&K. Seven-level heat color scale was used to show the spatio-temporal variation of RTCs as shown in Fig. 3. Results showed that Jammu, Udhampur and Srinagar were the worst affected districts with a relatively high number of reported RTCs.

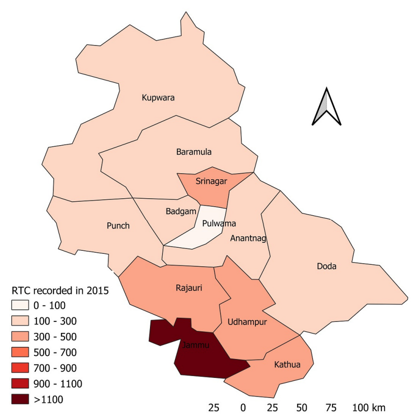


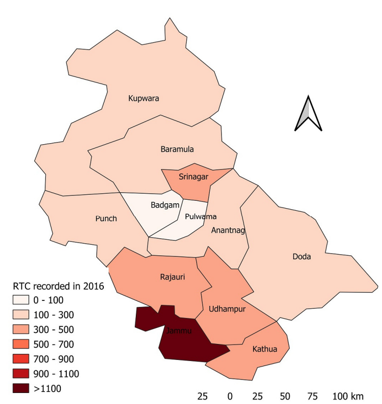












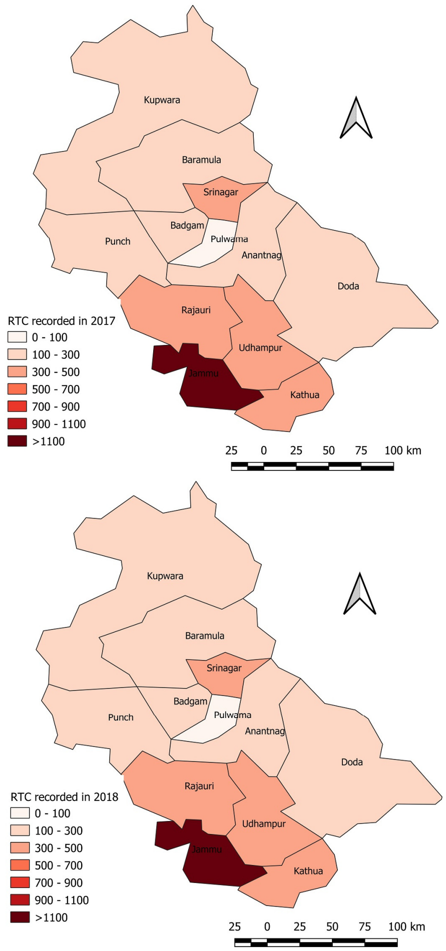


Fig. 3. Mapping of RTCs at the district level from 2010 to 2018.

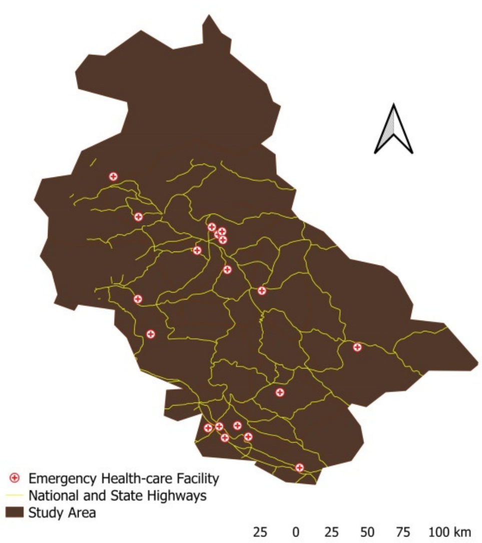


Fig. 4. Map showing the spatial distribution of the health-care facilities and high-speed road network system.

In the second stage, three layers were utilized. These consisted of the study area (extracted) boundary layer, high-speed road network system layer, and health-care facility location layer. Alternatively, these layers are also known as area layer, line layer and point layer, respectively. These three layers were stacked over each other. However, in doing so, it is important to note that the point layer should always be placed at the top, followed by the line layer and then the area layer at the lowest position. Therefore, in this analysis, the extracted boundary layer was placed at the lowest level. The high-speed road network system layer was placed in the middle. The location of health-care facilities was placed at the top of the stacked-layer system. The three-layer system is demonstrated in Fig. 4. It is noteworthy that among various other categories of roads, only the NHs and SHs, in which the speed limit ranges between 80 to 120 kmph were considered in this study. This consideration was based on the recommendations by Indian Roads Congress (IRC). As per the provisions of IRC, the remaining category of roads such as Major District Roads (MDRs), Other District Roads (ODRs), Village Roads (VRs), Arterial Roads (ARs) other urban streets have relatively lower speed limits; hence, these were excluded from the analysis performed in this study. After the three layers (i.e. point, line, and area layers) were successfully stacked, buffer analysis was performed. The foremost requisite of buffer analysis is that the selection of buffer radii should be done considering various factors that affect the risk of fatality in RTCs. In this study, following three aspects were considered: (1) the distance between the point where RTCs can occur and the proximate health-care facility available, (2) time taken by the emergency response team to take the RTC victim to the health-care facility from the location of RTC, and (3) expert opinion regarding the critical time in which the first aid should be given to the RTC victim. All these three aspects play an important and crucial role in reducing the risk of fatalities in RTCs. It is noteworthy that this study assumed the NHs and SHs to be composed of an infinite number of points. The road buffers were, therefore, set about the centers of all these points. In addition to the road buffers, buffers were set about the centers of health-care facilities as well. This process was followed by the "difference layering" and "layer filtering" operations in the GIS platform. The output map is shown in Fig. 5. In these operations, the intersection of the road buffers and health-care buffers was removed. This can be understood from the fact that if the buffer radii of roads and health-care facilities are intersecting, it means that the accessibility to the nearest emergency health-care facility is adequate. On contrary to this, those zones in which the buffer radii of the roads and health-care facilities are not intersecting, it means that the accessibility to the nearest emergency health-care facility is not adequate and should be addressed by the concerned policy-makers.

It is important that the output(s) of the sustainability models are parsimonious among various stakeholders for better understanding and interpretability [29, 30]. Thus, the output generated in this study could be useful for safety planners and policy-makers. They can utilize the output map to better understand the spatial position and distribution requirement of emergency health-care facilities along the high-speed road corridors. Therefore, the allocation of small-scale emergency health-care facilities supplemented with emergency vehicles could be optimized.

Nevertheless, the developed framework could be tailor-made by adjusting the critical parameters such as the time taken between the RTC and first-aid provided to RTC victim, the buffer radii of both the hospitals and the emergency health-care units, etc. The output generated from the application of the framework could also be analyzed for sensitivity of various parameters towards the overall impact on the safety of vulnerable road users.

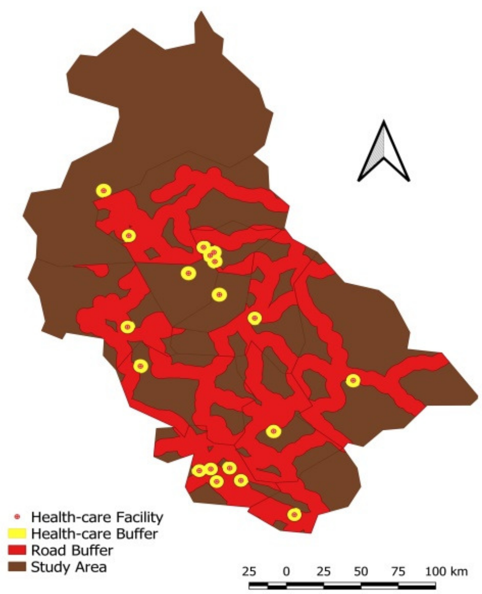


Fig. 5. Delineated priority zones where emergency health-care facilities are required to be allocated.

V. CONCLUSIONS & FUTURE RECOMMENDATIONS

Owing to the importance of location and distribution of emergency health-care facilities along a high-speed road network system, the primary objective of this study was to design and test a framework that is capable of identifying high-risk priority zones. In this line, a methodological framework was proposed and tested in J&K, India. The proposed framework utilized various GIS tools to perform a spatio-temporal analysis of RTCs in various districts of J&K and then delineate the high-risk priority zones along with the NHs and SHs. The former provided insights on the spatial and temporal variations of RTCs in the study area while the latter highlighted those zones in which emergency health-care facilities should be located and distributed. The delineated map would be useful to road safety policy-makers and planners by aiding in identifying the priority zones for the establishment of the emergency health-care facilities along with the high-speed road network system. The framework is flexible, for example, the buffer radii could be adjusted to suit other case studies as well. Thus, the proposed framework possesses transferability. It is, therefore, recommended to apply the framework to other study areas. Finally, it is also recommended to identify other factors that could be incorporated in the selection of buffer radii to both the health-care facilities as well as the high-speed roads.

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Conflict of Interest. The authors do not have any conflicts of interest.

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