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Space time dynamics of road crashes occurrence in Punjab, Pakistan: A GIS Perspective

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Abstract. This study proposes a comprehensive Geographic Information System (GIS) based time series analysis of varying trends of Road Traffic Crashes (RTCs) in different regions of province Punjab, Pakistan. GIS provides geographical framework to analyze spatial characteristics of a particular event for accurate road safety risk assessment. In order to evaluate potentially emerging accident ratios, monthly data based on RTCs from 2015 to 2018 collected from all the units of study area is initially geographically displayed using GIS. The results and analysis has been based on 3125094 emergency events occurred in Punjab, providing a strong base to the conclusive spatio-temporal patterns. The peak RTCs regions of Lahore, Faisalabad, Gujranwala and Multan have been studied for 227111, 102276, 64036 and 70194 events occurred in the four year span, whereas the rate of annual increase in RTCs in these cities has been measured to be 11153, 3229, 1730 and 4000 respectively. A comparative analysis of time rate of change of RTCs not only highlights varying trends along mutually bounded regions but also reveals prominence of seasonal and local factors behind increasing and decreasing ratios of road accidents. However, despite limited local information regarding road crash events, conclusions suggest that GIS based temporal analytical practices for precise risk assessment provide a cost effective decision support system to local administration and policy makers.

Keywords: road traffic crashes, spatio-temporal analysis, emergency management, geospatial technologies, geographic information system (GIS)

Introduction

Road Traffic Crashes (RTCs) are increasing day by day despite prevalent road safety measures with high population growth rate and inadequate risk mitigation facilities. About 1.2 million people lose their lives annually due to RTCs and it is predicted to increase by 65% in next 20 years (Osayomi and Areola, 2015). Like developed world, in developing countries, transportation by land is the most popular mode for movement of goods and people since last five decades. But as a consequence of poor road network infrastructure, lack of resources, dilapidated vehicle conditions and lack of law enforcement, fatality rate due to traffic accidents has increased significantly (Deshpande, 2011). In addition to human loss, extensive use of private cars and heavy vehicles cause negative environmental impacts and ultimately exert pressure on economy and energy resources of a country (Iamtrakul and Hokao, 2012). Generally, a high correlation has been observed between economic growth and RTCs by many economic researchers in developing countries. As economy grows rapidly, purchasing demand of motor vehicles rises which results in high rates of road crashes (Cheng *et al*., 2019). Economic and social needs are highly dependent on road traffic. Therefore, eliminating associated risks of crashes to an absolute level is not possible but plan can be devised to lower the possibility of such incidents (Peden, 2004).

Pakistan is an eminent developing country in southern Asia and ranks as sixth most populous country in the world. It is classified as a low to middle-income country, where RTCs disabilities and death rate range between 85 to 90% (Peden, 2004). In Pakistan, the ratio of traffic accident fatalities is 39% by motor riders (2 to 3 wheelers) and 41% by pedestrians. Poor safety measures like over loading, over speeding, use of cell phone, negligence by drivers, lack of awareness about traffic rules and poor law enforcement by the road traffic authorities are main issues behind growing incidents of RTCs in the country (Imran and Nasir, 2015). Safe traveling is inevitably important for safe transportation system of a country and fulfilling this fundamental need

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is essential (Hammad *et al*., 2019). Further, RTCs are mainly associated with suffers, their families and with economic development of a nation. Therefore, most of the policy makers, economists and researchers at both international and national level are keenly observing influencing factors behind rising RTCs locally and globally.

A precise road safety analysis requires accurate time series data for investigating temporal or spatial trends of RTCs in a region. Conventionally, for analyzing road crash patterns, a bulk of collected data were stored in form of liner record files in a database which only help to generate tables and do not provide spatial distribution to analyze the varying trends of RTCs across regions (Olajuyigbe *et al*., 2014).

Geographic Information Systems (GIS) has revolutionized analytical practices by relating attribute data to spatial data helping elaborate the spatial characteristics of a certain event with respect to location. In GIS, geographical data can be stored, organized or retrieved to generate maps, presenting spatio-temporal dynamics to show how a particular phenomenon changes (Budzyński *et al*., 2018). Particularly, spatial maps highlight critical spots for efficient risk assessment to analyze the developmental stages of a natural or anthropogenic hazard. Moreover, spatial distribution not only provides the geographical pattern of peculiar behaviour of a particular variable but also facilitates decision makers to evaluate relationship between the location and available services to mitigate risk in the concerned region. Worldwide, many emergency management services use geospatial technologies like GIS for adequate collection, integration and interpretation of bulks of data to establish a comprehensive risk assessment and management program regarding any emergency (Kekic, 2016). In road safety risk assessment, GIS also contributes effectively in data handling and spatial analytics related to accidents ratios, road density, number of vehicles etc. In accordance with space and time dynamics reported by (Budzyński *et al*., 2018). Recently, many investigations and researches nullified the old Notions about the randomness of acute RTCs. Apart from growing population rates and varying weather conditions, human caused disasters associated with road traffic crash hazards are also based on definite space time variables. Geospatial technologies like GIS, Remote Sensing, and GPS provide a complete framework to design cost effective road safety risk assessment strategies by analyzing trends of spatio-temporal distribution of RTCs in any region. Ong *et al*. (2008) provided demand analysis of ambulance deployment in Singapore to describe geographic epidemiology using geographic time distribution of emergency response time in a day. Conclusions suggested that optimal use of GIS based system for deployment of emergency services helps to control death ratios due to cardiac arrest by reducing response time. Mohaymany *et al*. (2013) used GIS based spatial auto correlation methods to evaluate road segments of Arak-Khomein road with potential road traffic crash risk using temporal data. Shah *et al*. (2017) introduced two analytical models to identify the high risk segments and predict risk of RTCs on two main motorways of Belgium in a GIS environment. Results of the presented research work provide assistance to transportation authorities and safety specialists in framing precautionary strategies towards identified road traffic risk segments.

The present study provides a cost effective GIS based approach to identify and evaluate contributing factors behind increasing or decreasing trends of RTCs in the different regions of Punjab, Pakistan. This geographic-time based analysis of RTCs also puts emphasis on utilization of geospatial technology in finding swift, productive safety measures by concerned emergency response authorities for effective hazard risk assessment in the study area.

Materials and Methods

Study area. Punjab is the second largest province in terms of area and most densely populated region of Pakistan. Geographically, it is located at 31.1704° north and 72.7097° east, where it is bordered by India. Punjab is the land of five rivers i.e. Sutlej, Beas, Ravi, Chenab and Jhelum which meet at the point of Panjnad near Bahawalpur district. Due to fertile agricultural land and rich cultural diversity, Punjab occupies a profound position in the region (Khan, 2009). It consists of about 36 districts including famous regions like Lahore, Faisalabad, Gujranwala, Rawalpindi, Multan, Sheikhupura, Sargodha, Bahawalpur, Gujrat, Jhelum etc., as mentioned in the Fig. 1. Lahore is the provincial capital of Punjab and it is the second largest metropolitan of Pakistan. According to census report of Pakistan-2017, Punjab is home to 53% of the whole population of the country with an annual growth rate equal to 2.13pc. Growing population along with inadequate resources and high migration rate to urban areas are common factors which are greatly increasing

inaccessibility of public services and modern infrastructure in Punjab (Paras *et al*., 2018). According to the census report-2017, about 40% road traffic accidents have been reported in Punjab (Pakistan Bureau of Statistics, 2017). Therefore, road safety has become a primary concern of government authorities in different regions of the study area catering to high urban demand for public transport.

Keeping in view the vital role of emergency medical services during a disaster response, an emergency ambulance service pilot project was introduced by Punjab local government in 2004 at Lahore. It was launched as first professional pre-hospital emergency ambulance service for emergency preparedness, response and prevention in comparison to other private organizations. After the success of pilot project, it was transformed to Punjab Emergency Services (Rescue 1122) with passing of Punjab Emergency Act in 2006 to provide quick emergency response, rescue and pre-medical treatment with an average response time of about 7 min in comparison to world leading emergency services.

Punjab Emergency Services can be easily accessed by emergency toll free number 1122 in all functioning regions of emergency services and its network has been expanded not only to 36 districts of Punjab but also in other provinces of Pakistan. Due to efficient emergency service record in fire rescue, disaster management, animal rescue, water rescue and community safety emergency services, Rescue 1122 has been declared as Pakistan's leading Disaster Response Force by Government of Punjab and Provincial Disaster Management Authority (PDMA) reported by (Naseer, 2009).

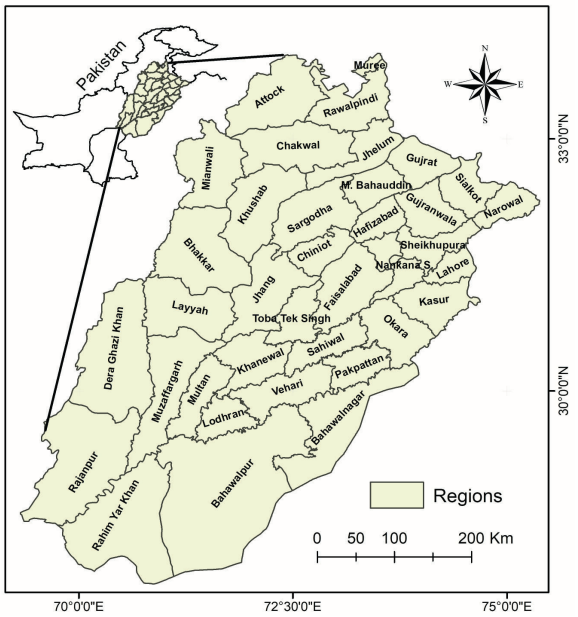

Fig. 1. Study area.

Data collection. For this time-based study, emergency response data related to RTCs has been obtained from main head quarter of Punjab emergency services (Rescue 1122). In 2004, ambulances in Punjab were only manned by trained paramedics for triage and basic life support emergency services. After successful establishment of Emergency services academy, proper training to emergency medical technicians is given for immediate preparedness of necessary documentation. On the other hand, movement of vehicles is simply monitored by a comprehensive tracking system. Moreover, call monitoring system preset at control center also tracks emergency response time and emergency location both for rural or urban regions. For any case of road traffic crash, Rescue 1122 ambulance service provides immediate response and fills an emergency response form in the first place, which includes cause and type of crash, demographics of injured and involved vehicles (Tahir *et al*., 2013).

For present study, only RTC values are considered to carry out time series geographic trend analysis of RTCs in 37 different regions of Punjab. The collected data is mainly composed of month wise spread sheets of individual year from January 2015 to December 2018. In Table 1, month wise detail of RTCs is provided to give a brief account of total recorded road accidents in four years (2015-2018).

Pre-data analysis. Primarily, RTC data sheets collected from Rescue 1122 were transformed to single data sheet to get an overall trend in existing dataset including each month from 2015 to 2018. After compilation of tabular data, a descriptive frequency distribution graph of road traffic accidents between time interval (2015-2018) is plotted to identify a general trend in dataset as given in Fig. 2. Afterwards, RTCs data has been rearranged to generate 12 excel sheets such that each excel sheet includes RTCs data of four years (2015-2018) for a single month.

Statistical and temporal analysis. Assessment of RTCs ratio in any region can possibly be done using multiple analytical techniques. Initially, all twelve sheets were used to provide a basic framework for descriptive statistical analysis of varying trends of data values with

respect to time. Figure 2 illustrates a general frequency distribution plot of total RTCs reported from 2015 to 2018 (month wise) in the area. For geographic time-based analysis of growing trends of RTCs, all transformed excel data sheets have been exported to GIS environment to overlay with district boundaries of Punjab. Subsequently, district boundary layers were generated to assign the geographic coordinates to each included region of the study area using different methods of digitization. Subsequently, using all the layers of RTCs, maps have been created for the assessment of temporal variations of RTC trends in different regions of Punjab. Each data set has been re-ordered by using equal interval classification to identify the common regions to justify the existing trend in the RTCs in different areas of Punjab. There exists a list of other classifiers i.e. natural break, equal frequency etc. but use of equal interval technique has been made in order to quantized the interval for each class, making comparison among classes possible over a same quantified level.

Results and Discussions

Generally, frequency distribution plot in Fig. 2. shows a continuous increase in number of RTCs with some anomalies. It only provides an overall distribution of data and its spread which illustrates a general trend present in the data. The results compiled from multiple data layers created in GIS based environment are classified in two different ways to explicitly describe the variability in the provided data set more efficiently. At first phase, all the data layers of individual years for each month were compared on the basis of number of RTCs in each region. In second stage, all the yearly data for each individual month were combined in such a way to give a slope value of RTCs occurrence. Each unique slope value actually depicts the rate of change of road crashes in a region. Here slope values represent the rate of change of RTCs occurrence with time that has been used to study changings over time in relation with seasons.

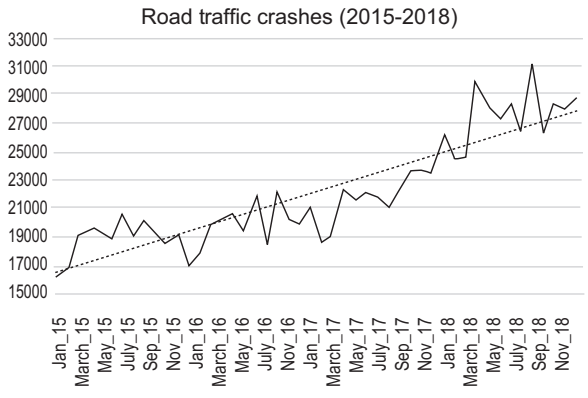

Fig. 2. Frequency distribution plot of RTCs reported from 2015-2018 (month wise).

Spatio-temporal distribution of RTCs. In this stage, obtained data is represented in geographic frame to highlight the potential regions with varying trends of road crashes. The comparison of year wise data layers for individual month have been given in Fig. 3 and 4, in which every region shows a particular range of estimated RTC values from 2015 to 2018.

Maps suggest that Lahore is the most prominent region with significantly high number of RTCs in comparison to all other divisions. Although, range of RTC values varies across different months but still it is the epicenter of high accident ratios. However, many north western and western regions represent a similar trend of existing cold spots with a slight increase in crashes particularly in Dera Ghazi Khan and Muzaffargarh region from 2017 to 2018. Interestingly, Dera Ghazi Khan and Muzaffargarh show co-exiting behaviour of varying number of RTCs almost in all months. Space time distribution of different regions especially central and north eastern regions also portray common variability with small increment. But associated data of Sargodha, Jhang and Khanewal provides a distinct increase upto average varying trends of road accidents predominantly in the months of March, July and September. Other adjacent regions (Pakpattan, Vehari and Lodhran) situated in lower south eastern Punjab show almost similar varying trends in RTC values. Regardless of Pakpattan and Lodhran divisions, Vehari shows a comparatively average increase in RTCs mainly in mid-summer and somewhat in the months of March and December. On southern edge of study area, two regions, Bahawalpur and Rahim Yar Khan, with shared boundary also give equally varying trends with average increase in RTCs throughout the years. Certainly, a visible trend of below average values in Rahim Yar Khan division as compared to Bahawalpur division has been observed in April, June, September and November of 2019. Both Sheikhupura and Sahiwal has been categorized as the average rate of change in RTCs occurrence and exhibit similar behaviour in almost all months though not being geographically contiguous, leading towards the

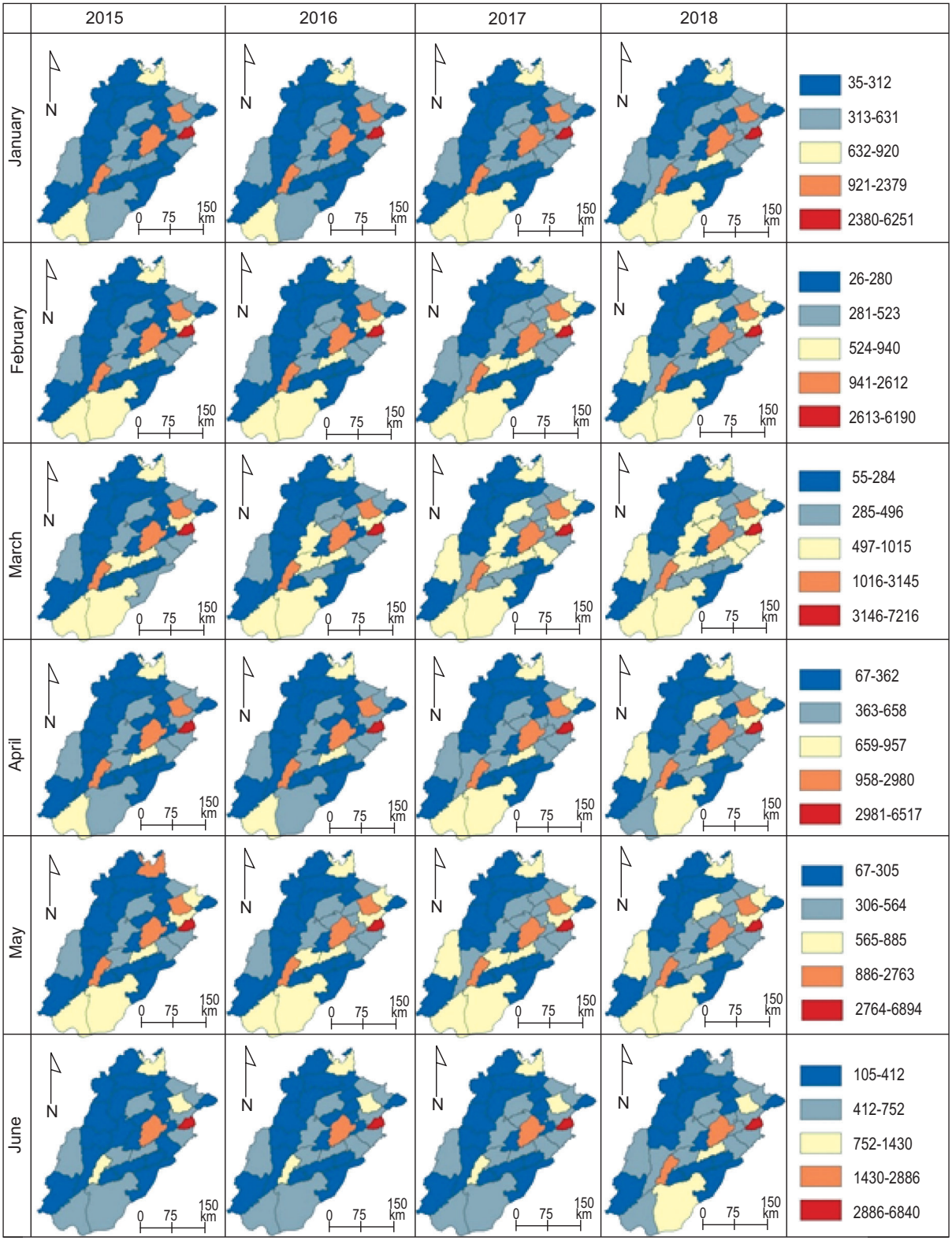

Fig. 3. Road traffic crash (RTC) in different regions of Punjab from January to June (2015-2018).

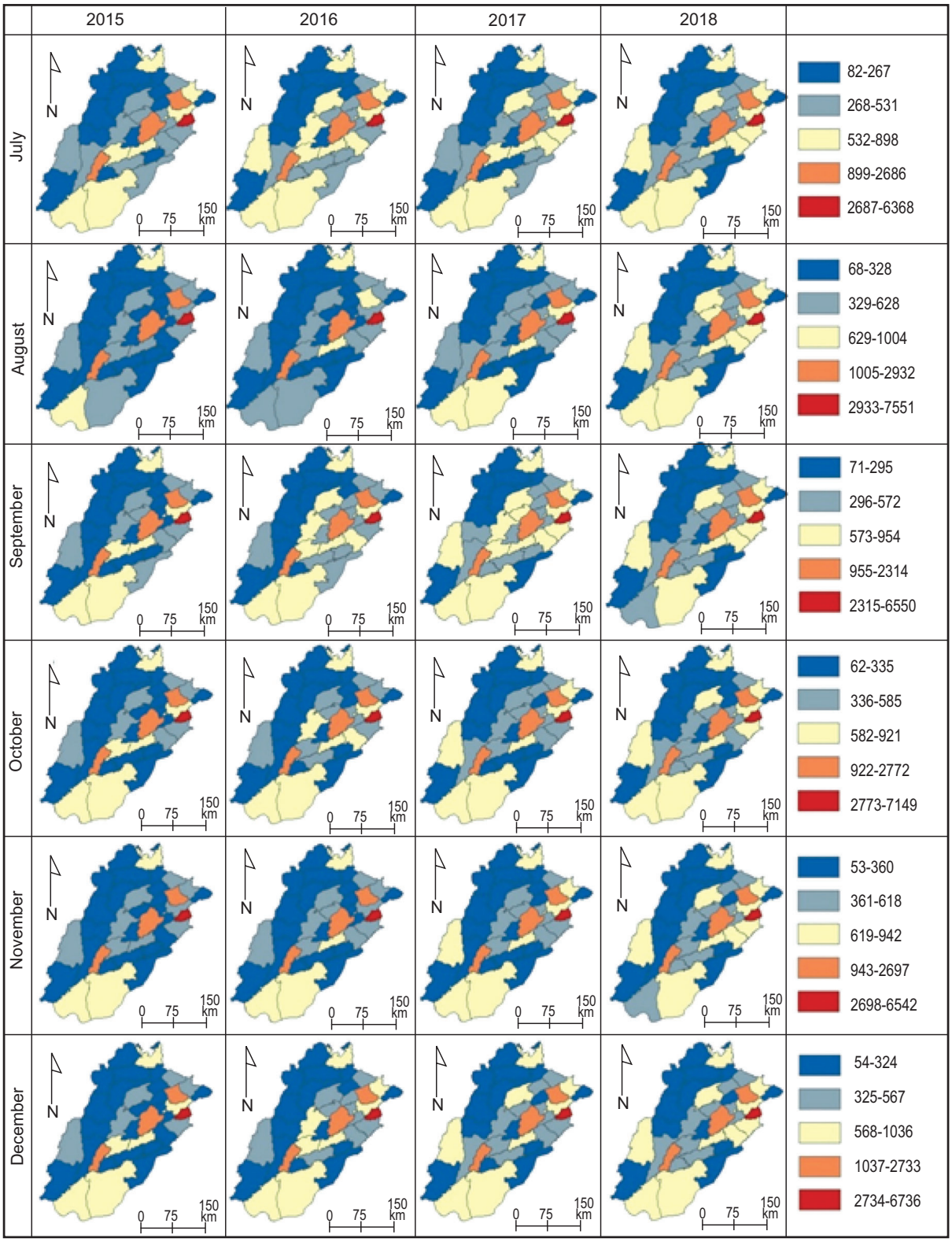

Fig. 4. Road traffic crash (RTC) in different regions of Punjab from July to December (2015-2018).

possibility of a similar development plan and human behaviour. The most distinguished and continuous average RTCs values can be seen over Rawalpindi region across all months in every year from 2015 to 2018. On the other hand, Gujranwala, Faisalabad and Multan divisions are prominent with relatively high ratios of traffic accidents in contrast to other regions. Although not adjacent to each other, all these three divisions show a co-existing trend of comparatively above average values of total crash incidents in the study area. All these observations based on geographic-time based maps of RTCs provide a basic framework to evaluate the potential causes behind increasing or decreasing values not only of spatially contiguous divisions but also dispersed regions with similar varying trends of RTCs.

Rate of change of RTCs (2015-2018). Time rate of change of RTCs in different regions of Punjab summarizes the varying or steady trends in single view where each value provides a comprehensive geographic overview of ongoing trends in RTCs.

Comparison of all thematic layers of slope values depicts that Lahore is considered to be the most vulnerable region with a peculiar behaviour of increasing rate of change of RTCs. Although in Lahore division maximum number of crashes was reported in August but highest rate of change in RTCs has been estimated from October to December. The positive rate of change is slightly low in the month of August but it is higher than the values estimated in the months of January, March and June. However, a significant decrease in rate of change in the month of July at Lahore region is indicating the presence of a strong influencing factor behind the variations. The above results show that most of the north western, western and certain eastern regions of Punjab lie in the category where positive rate of change of RTCs is relatively low even closer to zero in all the months, mean independent of the seasons and advancement. Apparently, in these regions, number of accidents increase with a constant ratio from one year to another. As Multan, Faisalabad and Gujranwala districts are cultural and agricultural zones of the study area, therefore, almost a persistent increase in accident ratios have been estimated in all the months with certain exceptions. An unusual trend of rate of change is observed for Faisalabad division in September apparently without any significant variation. In Gujranwala district, a consistent positive trend is present from October to December and January to April but it is somewhat reduced in May and lasts till July. Although both Faisalabad and Gujranwala regions are prominent industrial zones of northern Punjab, high rate of change of RTCs has been observed in Multan region particularly in June, August and December. So, overall traffic crash rate is relatively lower in Gujranwala region as compared to the Faisalabad and Multan divisions. The comparison of different thematic layers given in Fig. 5, shows an interesting scenario of slightly growing accidents in Okara, Sahiwal and Chiniot regions, present only in the month of August. Particularly an unusual trend of high rate of change of RTCs in Chiniot in the month of January is slightly higher than the estimated values in Faisalabad and Gujranwala. In northern Punjab Narowal, Rawalpindi and Murree are the prominent regions, where negative values have been observed in the time series analysis (2015-2018). An unusual trend of negative values traffic accidents at Narowal district from 2015 to 2018 in all the months excluding March provides an evidence of possible factors behind decrease in road accidents. A comparison of temporal analysis of varying trends of rate of change in Rajanpur and Rahim Yar Khan collectively show a similar and substantial decrease in accident ratios along the shared boundary only in the months of January and February. On the other hand, negative values show a notable decrease in accident ratios at Rahim Yar Khan region excluding March and August. A common pattern of accumulated negative values of rate of change in upper northern regions including Murree, Rawalpindi, Jhelum and Gujrat regions in particular months shows seasonal impact on rate of change of RTCs. Although, Khanewal is closer to Multan district but negative trend in crash rate in given time frame from April to May and September to December shows an unexpectedly varying trend of RTCs in the region. Moreover, a co-existing negative trend of rate of change of RTCs in October at shared boundary locations of Jhang, Khanewal and Toba Tek Singh is highlighted as prominent zone.

This study intends to provide a framework based on spatio-temporal series analysis (2015-2018) of varying number of RTCs in all thirty-seven regions of province Punjab. Results of this study demonstrate the utilization of GIS for accurate risk assessment and optimization of pre-determined emergency services in any region. Because of limited sources of quality data available for RTCs and incident locations, it is hard to perform spatial analysis of traffic accidents in Pakistan. Growing rate of RTCs has extremely increased the number of fatalities

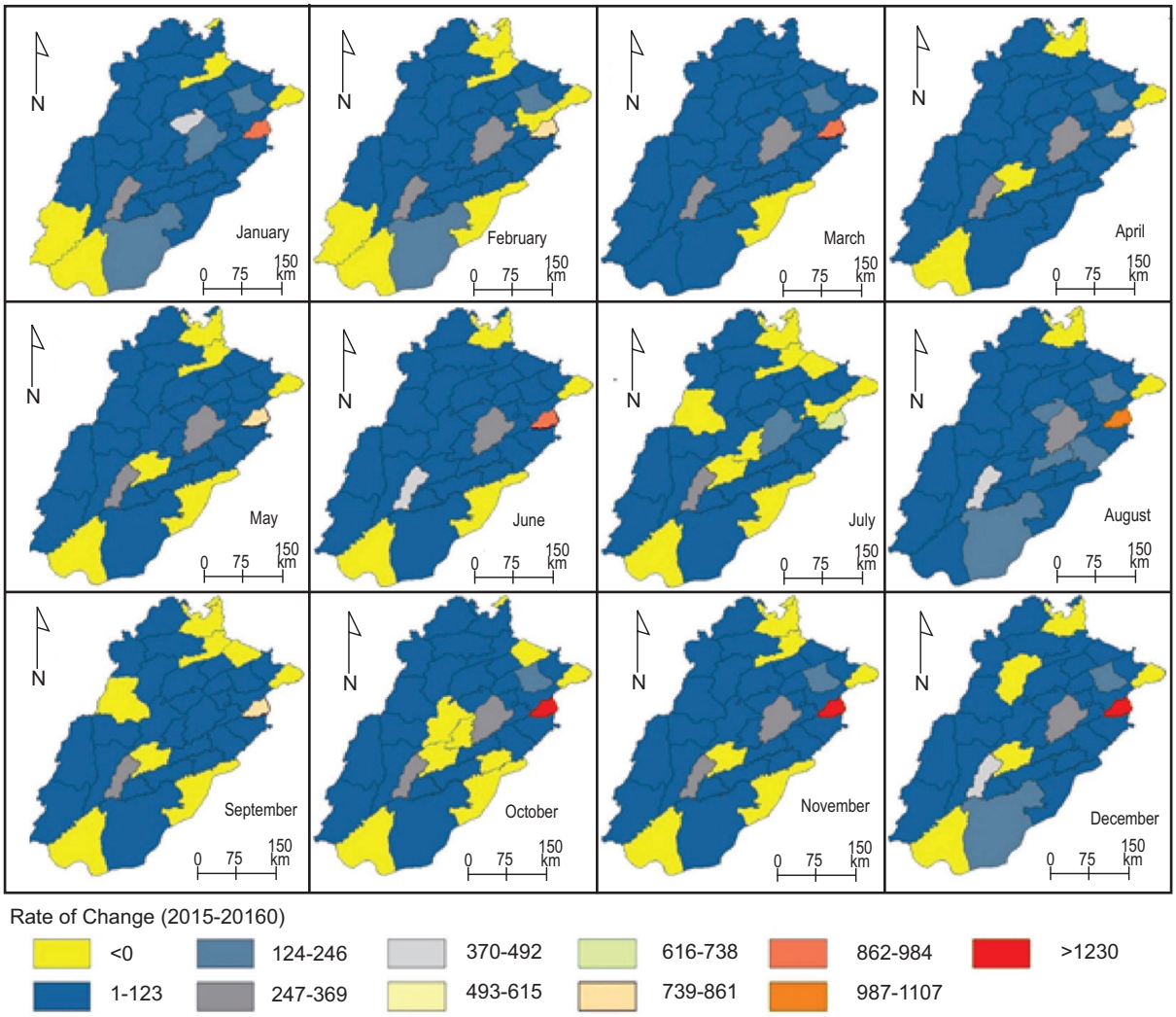

Fig. 5. Rate of change of RTCs (2015-2018) from January to December.

particularly in the densely populated province of Pakistan. In last few years many authorities and emergency services in Punjab have started to pay serious attention towards this emerging issue. Many recent research studies related to emergency management services suggest that emergency events are not caused by random chance but actually occur in certain patterns to give variability trends that can be visualized using multiple analytical techniques. Simple descriptive statistical analytical techniques are not much effective as geospatial techniques are to describe any phenomenon related to a geographic location within a certain time frame. In the present study, a more comprehensive way to analyze the varying patterns of RTCs in different regions of Punjab has been introduced by using geospatial technologies like GIS. Geographic-time based distribution of RTCs shows diverse range of varying patterns of road crashes in all the months corresponding to time series 2015-2018.

Analysis of existing trends of RTCs in space-time distribution maps provides aid in future decision making. For example, a persistent trend of limited number of crashes in most of the north western regions reflects that high accident ratios predominantly exist in industrial and agricultural zones of the study area. Demographically, Punjab is the densely populated province of Pakistan and Lahore is the historic center of cultural, commercial and economical activities of the Punjab since olden times. Many studies pronounced that highest ratios of RTCs are present in the culturally rich urban areas, industrial and agricultural zones as compared to rural areas of Punjab. In current study an interesting

trend of decrease, after former increase, in RTCs rate of change from January to September reflects the influence of local factors along with the seasonal variations in Lahore. Particularly, high rates of RTCs from October to December signify a strong impact of climate change and poor air quality indices due to rising smog. A report published by Environmental Protection Department, (EPD) Punjab verifies that since last seven years Punjab is experiencing multiple environmental and health issues because of low visibility in the duration of October to February commonly caused by the winter smog mainly in north eastern regions like Rawalpindi, Lahore, Sheikhupura, Gujranwala and Faisalabad. But it could not be the only reason behind growing rates of traffic accidents in all the regions of Punjab. Seasonal trend for the major cities has been shown in Fig. 6. Being highly populated and hub of the province Lahore has highest RTCs with peak falling in low visibility months of October to December.

The recently developed phenomenon of smog emergence in these areas has clearly shown its visibility effects on RTCs occurrence. Population density is also increasing steadily and about 40% of population consists of young people in Punjab (Khan, 2011). Further, population growth directly affects the expansion of road networks with rising demand of vehicles in urban regions that ultimately increases the risk of RTCs. According to smog commission report, a considerable increase in number of vehicles in Punjab is due to high migration rate from rural areas to urban region. According to census report 2017, in Faisalabad and Gujranwala population growth is higher as compared to Multan, but the results suggests that rate of changes of RTCs is relatively higher in the latter region. A comprehensive research work on RTCs in Multan region suggests that the potential causes of growing RTCs are poor road conditions, over speeding, utmost use of cell phones during driving and bad weather conditions (Nadeem *et al*., 2015). All the above mentioned studies elaborate the statistics and reasons behind growing road RTCs in the study area. However, the ultimate influencing factors behind increase or decrease in RTCs in individual regions are still to be verified from explicit ground surveys.

The use of location based RTCs trend analysis over the region is highlighting importance of GIS in context of spatial statistics, above to its usual popularity of providing a geographic display. The term rate of change provides a single discrete value to identify by which

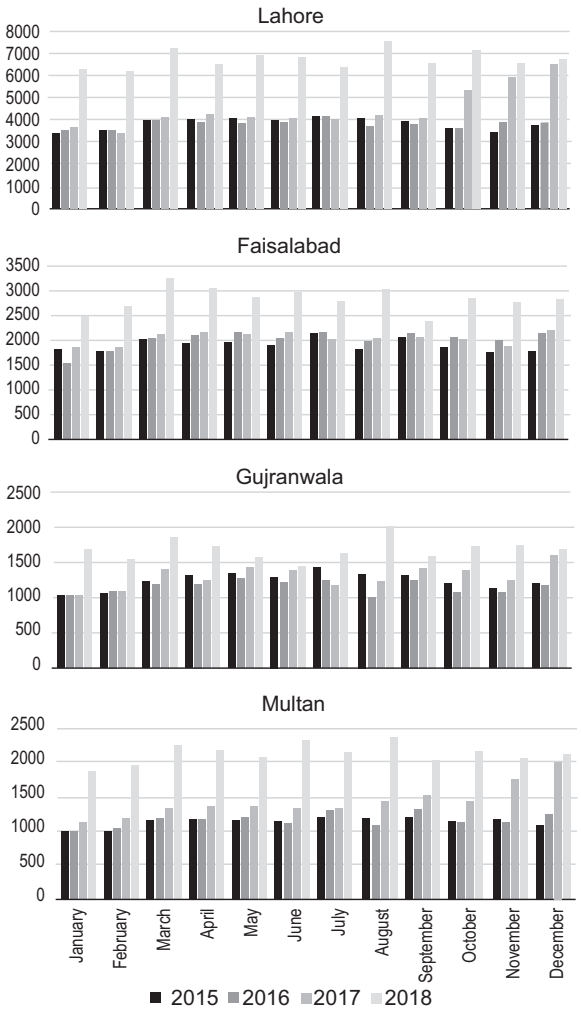

Fig. 6. Seasonal trends of major cities monthly averaged for all the years.

factor number of RTCs vary over time. Figure 5 illustrates the geographic distribution of rate of change of the incidents in all the regions of Punjab to identify the positive and negative trends in accidents ratios. Almost all the studies related to RTCs only focus on the potential causes behind growing accident ratios in any region but somehow miss out the regions with decreasing trend of crashes, which can prove to be the practices that can significantly control RTCs. This study provides a pictorial view of increasing and decreasing rates of number of RTCs in individual regions from 2015 to 2018 for all the months. The results verify the presence of such regions in both northern and southern Punjab, where number of crashes were reduced with the passage of time. In Narowal, Rawalpindi and Rahim Yar Khan divisions a predominant increase in negative

values of rate of change has been estimated from 2015 to 2018. According to local community, Muridke-Narowal main road was considered to be a deadly road since long ago due to heavy traffic load for two ways traffic on single road. But a couple of years ago, improvements made in infrastructure of road networks have minimized the number of casualties in this region. Ultimately, the results of this research work will provide a basic analytical framework to all the administrative authorities and policy makers related to road safety, health assurance, emergency services, safe transportation, and road networking working throughout Punjab.

Conclusion

This study illustrates the spatio-temporal investigation of RTCs status in the densely populated province of Pakistan, called Punjab. This land of five rivers has a significant contribution in elevation of economic, social and cultural status of the whole country. In comparison to many old statistical approaches, spatial representation of varying trends of road crashes in this region are presented as a base for future studies and planning. Current GIS based mapping of RTC data has not only provided a pictorial view of number of crashes all over the Punjab but also helped illustrate rising and decreasing rate of change of road crashes from 2015 to 2018. The study has set its base on a large number of recorded emergency calls measuring to 623371, 671686, 794015 and 1036022 for the year 2015, 2016, 2017 and 2018 respectively. So, the study has analyzed 3125094 of the recorded events to analyze spatial as well as statistical patterns of their occurrence. In northern Punjab, Lahore, Faisalabad and Gujranwala regions have comparatively high ratios of RTCs with annual averages of 56777, 25570 and 16010 that ranges in the studied time period as 406060-80804, 22246-32899 and 13710-19975 respectively, whereas in southern Punjab Multan is the only region with a relative positive trend of rate of change of traffic accidents with annual RTCs range of 13575-25572, averaging to 17548. Results concluded from the current study indicate geographical patterns of varying rate of change of RTCs not only in geographically contiguous locations but also in dispersed regions with similar trends. Most of the previous studies suggest rapid urbanization, growing population and high migration ratio from rural to urban areas as key factors behind bad road infrastructure, limited resources, illiteracy rate, massive increase in vehicles and poor law enforcement in urban areas of Punjab, due to which number of RTCs are increasing in main cities of Punjab every year particularly in Lahore. But these all are general reasons as suggested by a preview analysis of many studies. Another interesting finding of the current study is the identification of regions with negative varying trends of RTCs. These regions include many areas of south western and north eastern Punjab. Predominantly, an unexpected declining trend of RTCs in the fourth largest city of Pakistan, namely Rawalpindi, in all the months excluding January, March and October presents evidence of the presence of some unusual causal factor. Availability of local information behind each road crash including number of RTCs, affected victims, colliding vehicles, injury patterns and geographical location is substantial for in-depth analysis of temporal variation of RTCs in different regions of Punjab. This study will prove to be useful in finding possible relationship between growing crash rate with different varying socio-economic parameters in different regions of Punjab. It also emphasises the use of GIS as an optimum analytical approach in relating attribute data to spatial data to provide spatial importance of a certain event in a given region.

Conflict of Interest. The authors declare no conflict of interest.

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