# IMPACT OF SPATIAL–TEMPORAL VARIATIONS ON FIRE VULNERABILITY: A CASE STUDY OF THE SOUTH-WEST DIVISION OF DELHI, INDIA

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ABSTRACT

Delhi, the capital of India, is experiencing a perennial influx of migrating population in highly congested, unplanned colonies having lack of basic civic and infrastructure amenities. The concentration of humans in numbers and activities in these areas has fostered new dimensions to fire hazards with enhanced risk to life and property. A greater proportion of poor quality housing, inadequate planning, monitoring and control in metropolitan cities lead to a greater number of fires and other urban disasters. Statistical tools coupled with geo-spatial techniques can be used to locate areas of high fire and life risk. Application of these techniques has the potential to help decision makers with proactive preventative measures and better resource allocations. This paper uses geo-spatial techniques to analyze the patterns of fire incidents in the South-West Division of Delhi from 2013–2016. Thematic maps depicting high, moderate and low level fire and life risk have been produced under a Geographical Information System (GIS) Environment for the area under study. The highest number of fire incidents was found to have occurred in low rise residential apartments and private dwellings. The occupants of residential colonies having low economic status were found to be more prone to injury and death during a fire incidence. In a domestic fire, Liquefied Petroleum Gas (LPG) was found to cause maximum injuries. The number of injuries due to fires was also observed to be higher during cold winter months, and fire incidents more frequent during 18:00 hrs–24:00 hrs. The number of fire deaths was found to be much higher between midnight and 06:00 hrs.

*Keywords: fire, fire hazard, risk analysis, migration, geospatial, mitigation, unplanned.*

## 1 INTRODUCTION

Large cities are experiencing higher load on energy facilities, more traffic on roads, congested buildings and increase in population density [1]. This expansion of cities necessitates proper planning and its implementation for good quality of city life [2]. Occurrence of urban fires is a worldwide problem and each year large numbers of deaths happens globally due to unintentional fires and most of these occur in home [3]. A demand in urban infrastructure is being faced by the cities due to increased urbanization which is a universal trend. In many developing countries such as India the growth of the cities has taken place in an unplanned way. Migration and increase in population, over the decades, has led the cities to become over-populated and over-crowded [4]. Decision makers, planners and service providers face new challenges due to this unplanned growth in the city. Delhi, the capital of India, is a metropolitan city having an area of 1,483 square kilometres, with a population of 16,368,899 [12]. Delhi consists for the 1.39% of national population whereas it occupies only the 0.05% India’s geographical area [13]. The infrastructure and population increase in Delhi has been significant which had resulted in the setting up of many unauthorized colonies in unplanned manner. Existing buildings grow vertically and residential colonies expand in rural areas without any planning for civic amenities. Delhi’s population has increased by 21.20% since 2001 census. There has been an increase of 52% in fire and other emergency incident calls and an increase of 68% and 53% in the number of

WIT Transactions on Engineering Sciences, Vol 121, © 2018 WIT Press
www.witpress.com, ISSN 1743-3533 (on-line)
doi:10.2495/RISK180241

fatalities and injuries respectively from the year 2001 in Delhi [14]. Spatial and temporal analysis can help authorities to set priorities for risk reduction interventions to be more effective in high fire vulnerable areas of the city. Urban fires can be tackled more efficiently, if we try to find three location-based questions, viz., where, the hazards are, where, the areas at highest risk are and where, the most valuable resources are located. The population characteristics of census areas can be used to identify risk factors associated with residential fires and fire related deaths and injuries [5]. Corcoran et al. [6] studied trends in five types of fire incidents in Australia and found that risk associated with all types significantly increased during holidays and weekends. They also found that fire incidences in socially disadvantaged neighbourhoods were higher. Fire risk maps of the Chiang Mai Municipality, in Thailand were generated by using a GIS based approach for fire risk assessment and Analytical Hierarchy (AHP) technique by Srivanit [7]. Yagoub and Jalil [8] used GIS technologies to map fire incidents in Sharjah city, UAE. Similarly, Chhetri and Kayastha [9] generated fire potential zonation maps for Kathmandu City, Nepal. This study was conducted to assess the impact of spatial-temporal variations on fire vulnerability in the S-W Division of Delhi. Geo-spatial technologies and statistical tools have been used to analyze fire emergencies, fire types and occupancies involved in fire incidents during period 2013–2016.

## 2 STUDY AREA

Delhi covers an area of 1,483 sq. km. Delhi's geographical position lies between latitudes 28°24'–28°53' N and longitudes 76°50'–77°20' E. The total width and length of Delhi's area are 48.48 km and 51.9 km respectively. The elevation of Delhi varies from 213–305 meters above the mean sea level. Seven fire stations under three sub-divisions of South-West (S-W) have been chosen for this study (Fig. 1).

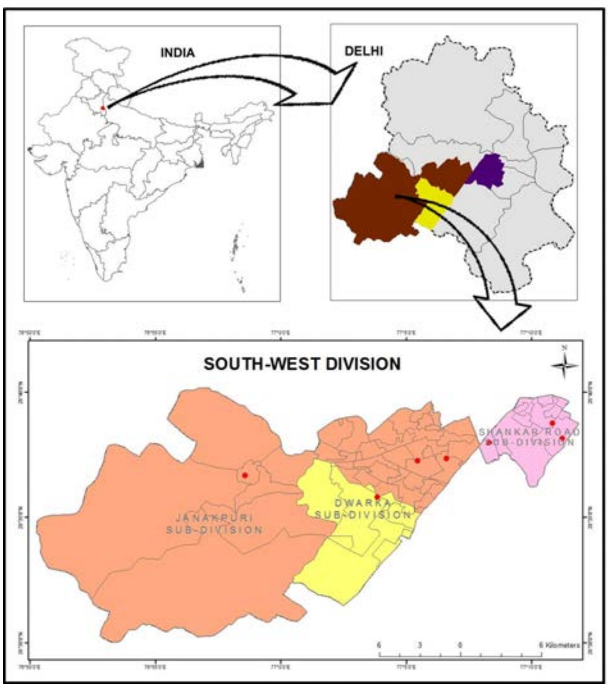


Figure 1: Location of the S-W Division of Delhi Fire Service.

## 3 MATERIAL AND METHODS

Data needed for the generation of a fire potential map for the S-W Division of Delhi Fire Service were collected from different sources:

- Municipal wards boundary map of Delhi from Geo-spatial Delhi Limited (GSDL), Government of National Capital Territory of Delhi, Delhi;
- Population data of each municipal ward of Delhi for the year 2011 from Geo-spatial Delhi Limited (GSDL);
- Location of fire stations: jurisdiction of fire Sub-Division and Division boundaries in the S-W Division and number of fire incidents, type/category of fire incidents and number of casualties (dead and injured) in fire incidents from Delhi Fire Service; and
- Land use-land cover map from the Delhi Jal Board.

Different fire stations receive diverse numbers of fire incident calls during different months of the year. Month wise fire incidents for seven fire stations were collected and recorded and all fire incidents have been classified in three broad categories as structural fire incidents (residential, educational, institutional, assembly, business, mercantile, industrial, storage and hazardous); temporary structure fire incidents (Jhuggi clusters, Huts, Pandals, etc.); non-structural fire incidents. Further, all fire incidents during the period under study were divided into two categories based on the material involved in fire incidents as:

- Fire incidents under electrical category;
- Fire incidents under non-electrical category.

Based upon the two categories, the total number of fire incidents has been regrouped and recorded. Thematic maps depicting fire stations boundaries, sub divisional boundaries and locations of severe category fire incidents have been generated. Ward wise population has been recorded and compiled for analysis. Total number of fire incidents in each of the nine occupancies described in the National Building Code of India [10] has been recorded separately from 2013–2016 and percentage wise comparison was made to adjudge the effect of different occupancies on fire incidents. Total fire incidents received during the study period, under all occupancies, were segregated and recorded in four time interval zones, i.e. (i) 00.00 am–06.00 am; (ii) 06.01 am–12.00 am; (iii) 12.00 am–06.00 pm; and (iv) 06.00 pm–12.00 pm for analysis. A Geographical Information System (GIS) has been used in this study for assessment of fire and life risk in the study area. Different thematic maps were prepared for the analysis. Relevant spatial and non-spatial data for constructing various thematic maps has been collected and compiled using ArcGIS software, ArcMap version 10. The number of deaths and injuries in fire incidents were identified in each ward for preparation of a thematic map. Ward wise fire incidents were identified and recorded for the preparation of a thematic map. Locations of severe fire incidents have been identified and their coordinates were recorded for preparation of the maps.

## 4 RESULTS AND DISCUSSION

Fire incidents under seven fire stations (S-W Division) over a period of four years, from 2013–2016, were recorded and analysed for various parameters.

### 4.1 Station wise distribution of fire incidents

A large difference was noticed in the number of fire incidents amongst the seven fire stations of the S-W Division. The highest numbers of fire incidents were recorded in the Janak Puri fire station followed by the Dwarka and the Najafgarh fire stations. The Janak Puri fire station received the maximum number of fire incident calls (30.35%), whereas the Naraina fire station received the minimum (5.16%) of fire outbreak incident calls.

### 4.2 Effect of month on fire incidents

Fire incidents over a period of four years from 2013–2016 show a similar month wise pattern, except for a slight variation in the year 2014. A steep rise in fire incidents was noticed. The maximum fire incidents were recorded in the month of May and the minimum in February. The number of fire incidents appear to declines decline in month of July up to September and rises again in the month of October. As per the record of the Delhi Fire Service fire incidents increase significantly on day of Diwali (a Hindu festival of lights). The month wise breakup of fire incidents is shown in Table 2.

### 4.3 Effect of occupancy on fire incidents

Non-structural fire incidents were found to be around 48% of the total fire incidents, whereas structural fire incidents were 51%. Temporary structure fire incidents were found to be below 1% of the total fire incidents in the S-W Division. Under structural fire incidents, residential occupancy is found to be mostly involved in fire incidents. The occupancy wise breakup is shown in Table 3.

Table 1: Fire incidents, S-W Division, 2013–2016. *(Source: [14].)*

| Fire Stations | Total fire incidents 2013–2016 | % |
|---|---|---|
| Janak Puri | 2,803 | 30.35 |
| Najafgarh | 1,436 | 15.55 |
| Hari Nagar | 1,058 | 11.46 |
| Dwarka | 1,579 | 17.10 |
| Naraina | 477 | 5.16 |
| Shanker Road | 641 | 6.94 |

Table 2: Total fire incidents, S-W Division, 2013–2016. *(Source: [14].)*

| 2013–2016 | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No | 547 | 481 | 507 | 1,000 | 1,494 | 1,148 | 779 | 654 | 613 | 774 | 733 | 506 |
| % | 5.92 | 5.21 | 5.49 | 10.83 | 16.18 | 12.43 | 8.43 | 7.08 | 6.64 | 8.38 | 7.94 | 5.48 |

Table 3: Occupancy wise fire incidents, S-W Division, 2013–2016. *(Source: [14].)*

| 2013–2016 | Non-structural | Temporary structural | Residential | Educational | Institutional | Assembly | Business | Mercantile | Industry | Storage | Hazardous |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | 4,390 | 80 | 3,579 | 66 | 30 | 32 | 216 | 587 | 180 | 73 | 3 |
| % of total | 47.53 | 0.58 | 39.02 | 0.714 | 0.32 | 0.34 | 2.33 | 6.35 | 1.94 | 0.79 | 0.03 |

### 4.4 Fire vulnerability profile

The nature and extent of fires have been determined by first identifying the fire hazards in the study area. The number of actual fire incidents in each ward was recorded and a thematic map of fire risk-prone areas was obtained. The study area was classified in four risk zones as: low, moderate, high and very high (Fig. 2). As per the results, the Matiala ward (No. 136), under the Dwarka fire station, was found to be the most fire risk potential ward in the S-W Division.

### 4.5 Fire and life risk vulnerability

The vulnerability profile of fire emergencies of the S-W Division has been assessed, based on international practice of risk assessment, using ward wise data of fire incidents, number of persons injured, number of persons died and severe category fire incidents. Furthermore, the existing conditions of vulnerability in terms of deaths and injuries and severe fire categories in each ward have been evaluated. Data of fire incidents (A), injuries (B), deaths (C) and severe category fire incidents (D) have been recorded separately for each ward and classified as scores in Table 4.

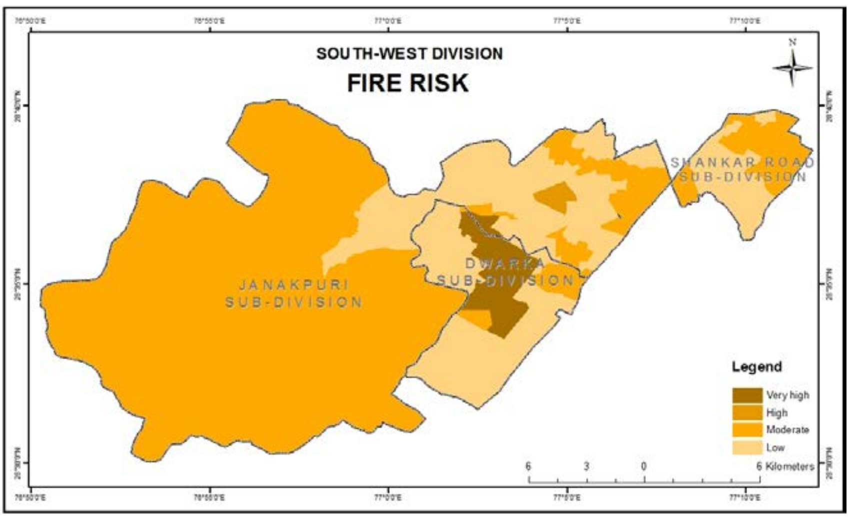


Figure 2: Ward wise fire incidents in S-W Division, 2013–2016.

Table 4: Criteria for calculating risk score.

| Fire incidents | | Injured in fire incidents | | Dead in fire incidents | | Severe category fire incidents | |
|---|---|---|---|---|---|---|---|
| Number of fire incidents | Score (A) | Number of injured | Score (B) | Number of dead | Score (C) | Category | Score (D) |
| 0–200 | 1 | 1–6 | 1 | 0–1 | 1 | 4 | 1 |
| 201–400 | 2 | 7–12 | 2 | 2–3 | 2 | 6 | 2 |
| 401–600 | 3 | 13–18 | 3 | 3–5 | 3 | 8 | 3 |
| 601–1,000 | 4 | 19–24 | 4 | 6–14 | 4 | 10 | 4 |

The level of risk in the S-W Division based on the analysis of the above findings has been classified into four categories as low, moderate, high and very high, based on the overall score reached by individual wards (i.e. A+B+C+D). Based on the number of actual fire incidents in each ward, the number of injured persons, the number of persons who died and the severe category of fire incidents, a thematic map of risk profile of the S-W Division was derived by classifying the study area into four zones (Fig. 3). The results of this study show that only 4.35% of the study area falls under the very high fire and life risk potential zone, while 5.55% falls under the high fire and life risk potential zone, 35.41% falls under the moderate fire and life risk potential zone, and finally 54.88% falls under the low fire and life risk potential zone. Two wards, Matiala (No. 136) and Parsad Nagar (No. 95), have scored the highest in terms of overall fire and life risk in the S-W Division. Six severe category fire incidents have occurred in Matiala, out of which four were in a factory; however, the designated land use of this area is not industrial. Three medium-10 category fire incidents have occurred in ward number 95, in high rise office buildings.

Fire and life risk were found very high in the Matiala Ward (No. 136). Many residential colonies were developed in an unplanned way. Basic civil amenities were provided later by authorities in these colonies.

Unified Building Bye Laws [11], applicable to National Capital Territory of Delhi has been notified on 2nd March 2016 by the Government of India and prior to this notification, Building Bye Laws, Delhi 1983 were in force.

### 4.6 Effect of land use on severe category fire incidents

A fire scene is assessed, in terms of severity of the fire and the numbers of fire tenders/fire units required to control the fire, by the officer in-charge. There are six categories of the severe fire incidents starting from category-4 (Make-IV) up to category-14 (Major). The severe category fire incidents have been categorized as per standard operating procedure of Delhi Fire Service as shown in Table 5.

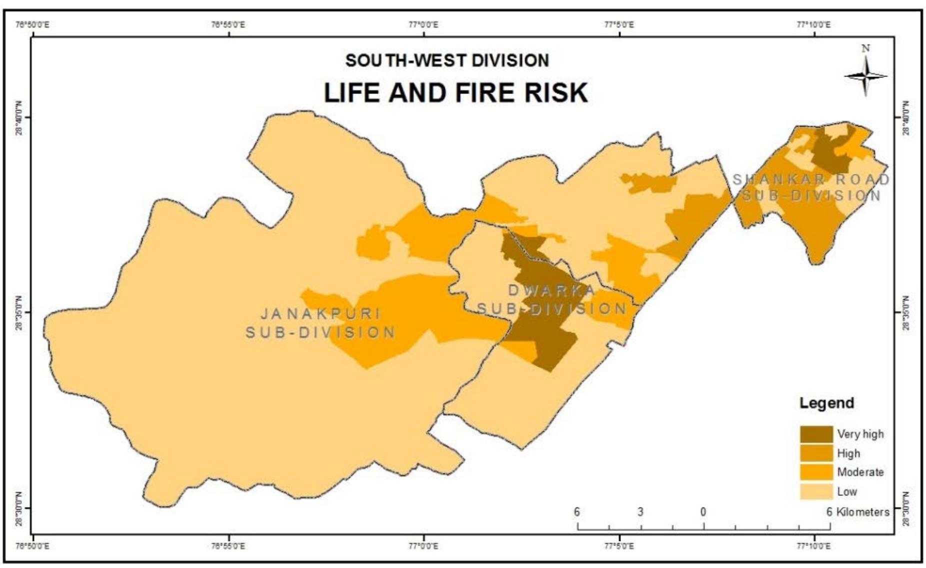


Figure 3: Fire and life risk map, S-W Division, 2013–2016.

Table 5: Severe fire categories. *(Source: [14].)*

| Severe category fire incidents | No of fire tenders/ fire units | Officer-in-charge |
|---|---|---|
| Category-4 (Make-IV) | 7–8 | Assistant Divisional Officer |
| Category-6 (Make-VI) | 11–14 | Divisional Officer |
| Category-8 (Make-VIII) | 16–20 | Divisional Officer |
| Category-10 (Medium) | 22–28 | Deputy Chief Fire Officer |
| Category-12 (Serious) | 30–36 | Chief Fire Officer |
| Category-14 (Major) | 40–48 | Director |

Severe category fire incidents have been recorded in the fire reports by the Delhi Fire Service as per the categories described above. The severe category fire incidents have been analyzed as per land use/land cover and population factors. Various analytical maps, using different information layers in geospatial environment, were generated for risk analysis. It has been observed that only few number of severe category fire incidents have actual happened in designated industrial areas, whereas in most of the cases of factory fires, the authorized land use was built-up residential i.e. small industrial units that were being operated in unplanned residential areas (Fig. 4). Further analysis revealed that the category-10 (Medium) fire incidents have mostly occurred in a commercial land use (ward no. 95).

## 4.7 Effect of population on fire incidents

The fire incidents for years 2013–2016, under the S-W Division were separated as per municipal ward boundaries and average fire incidents per ward were calculated. A correlation test was conducted between ward population and average fire incidents. The relationship between population and average number of fire incidents in wards was found significant. The result of the correlation study is given below:

$$r\,(40) = 0.460,\ p = 0.003,$$

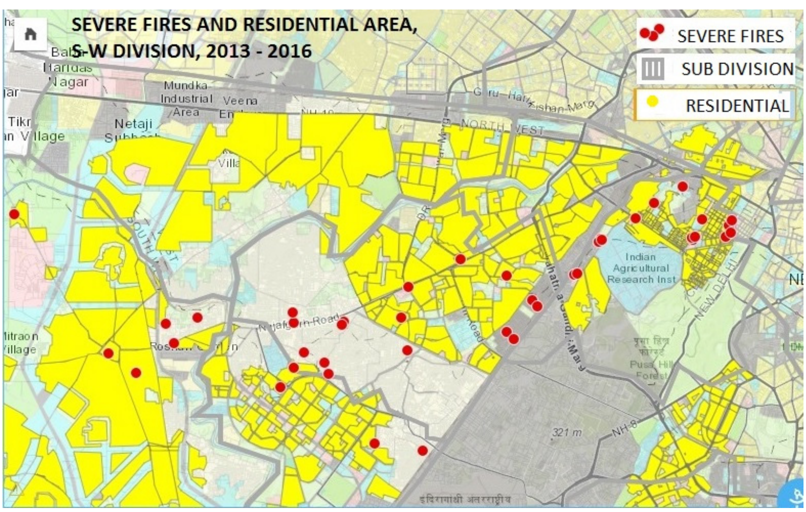


Figure 4: Severe fires and residential areas 2013–2016. *(Source: [14].)*

where “p” is the p-value and “r” is the correlation. The ward population was found to be significantly associated with the average fire incident occurrence.

### 4.8 Deaths and injuries

The total number of deaths and injuries suffered in fire incidents during the study period in the S-W Division was recorded. It was also observed that the number of injuries due to fires was higher during cold winter months, and fire incidents were more frequent during 18:00 hrs–24:00 hrs. The number of fire deaths was much higher between midnight and 6 am. The localities of these premises were identified using a GIS platform. Fig. 5 shows the colony type distribution of injured in fire incidents. The maximum injuries occurred in Type G category of colonies. The economic status of residents of these colonies is lower than that of residents of Type A and B colonies.

### 4.9 Fire incidents injuries – fire type

Analyses using geospatial technologies have been utilized in identification of majority of the fire types that have been causing high numbers of injuries amongst citizens. It was found that, out of the total of injuries in fire incidents, about 34% persons got injured due to fires involving LPG. A consolidated map of severe fires and injuries sustained during fire incidents (2013–2016) in the S-W Division was generated using a GIS platform (Fig. 6).

## 5 CONCLUSIONS

The present study analyzed the impact of spatial-temporal variations on fire vulnerability in the S-W Division of Delhi. The fire incidents data from the year 2013–2016 were recorded and analyzed under the jurisdiction of seven fire stations to evaluate the variation. It was found that the Janak Puri fire station received the maximum number of fire incident calls (30.35%), whereas the Naraina fire station received the minimum (5.16%). A large difference was also observed for fire incidents occurred during different months of the year. Out of the total fire incidents during the period 2013–2016, the maximum fire incidents (16.18%)

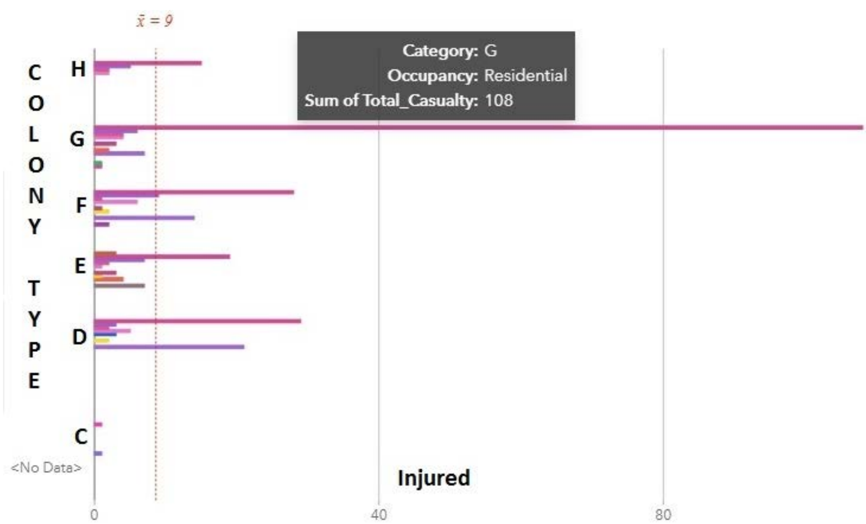


Figure 5: Colony type distribution of injured. *(Source: [14].)*

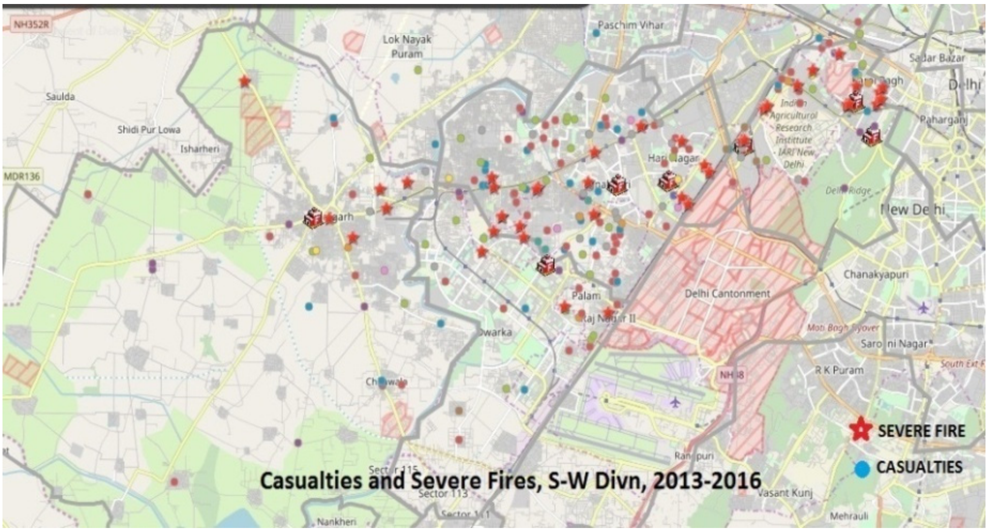


Figure 6: Total injuries and severe fire incidents, S-W Division, 2013–2016. *(Source: [14].)*

occurred in May and the minimum (5.21%) in February. Structural fires accounted for nearly 51%, whereas non-structural fires for 49%. Temporary structures such as hutment clusters did not contribute significantly to fire incidents in the S-W Division, owing to their total share being less than 1%. Under building fires, amongst all classes of occupancies, as prescribed in National Building Code of India, residential class (Sub category A-2 and A-4) buildings, less than 15 meters high, were found to be involved in the highest number (39%) of fire incidents. Fire incidents on national holidays were found to be fewer as compared to one month's average, except for the Diwali festival. The results of this study show that only 4.35% of the study area falls under the very high fire and life risk potential zone, while 5.55% falls under the high fire and life risk potential zone, 35.41% falls under the moderate fire and life risk potential zone, and 54.88% falls under the low fire and life risk potential zone. It was also observed that the number of injuries due to fires was higher during cold winter months, and fire incidents were more frequent during 6 pm and 12 pm. The number of fire deaths was much higher between midnight and 6 am. Furthermore, the population in a ward area is found to be significantly associated with fire incidents occurrence. Geo-spatial analyses showed that the highest number of severe fire incidents (Category 4, 6, and 8) took place in the land use designated as "residential". It has been observed that only a small number of severe category fire incidents has actually occurred in designated industrial areas whereas in most of the cases of factory fires the land use was built-up residential. The injuries sustained during fire incidents were found predominantly in D, E, F, G and H types of colonies but the highest injuries happened in type "G" category of colonies. LPG related fire incidents have resulted in most of the injuries in S-W Division. Male members of the family sustained more injuries than female members during the fire incidences. Analysis using GIS and statistical tools did and can help in the adoption of fire prevention policies, the formulation of fire-fighting strategies, enhancing resources (equipment and manpower) and in organizing fire safety awareness programmes with community participation for mitigating the effects of fire incidents in vulnerable areas.

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