Journal of Bangladesh Institute of Planners ISSN 2075-9363
Vol. 9, 2016 (Printed in April 2018), pp. 113-124, © Bangladesh Institute of Planners

# Fire Hazard Risk Assessment of Mixed Use Chemical Storage Facilities: A Case Study of Chemical Warehouses in Old Dhaka

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**Abstract**

The aim of this study is to explore the level of fire hazard risk associated with coexistence of chemical warehouses with residential units in Dhaka, the capital city of Bangladesh. The concept is to analyse fire hazard risk for such type of land use mix through a fire hazard risk index developed for this specific context. In the paper, the authors propose the construction of a fire hazard risk index for determining the risk level. The proposed index is applied to a study of fire hazard risk assessment of a high concentration chemical warehouse zone in the old parts of Dhaka. Consultation with several stakeholder groups in the study area and survey techniques were employed to assess the level of fire hazard risks. The results showed that fire hazard risk was a result of storing and handling flammable chemical products in mixed use buildings, the structural inefficiency of buildings for fire safety and a lack of awareness of the buildings' users regarding fire safety rules and safe handling of chemical products.

## Introduction

In 2010, a deadly fire took life of 117 people in Nimtali, a densely populated ward in Dhaka, the capital city of Bangladesh (Alam, 2010). Investigation report says that the fire was originated from a chemical warehouse situated on the ground floor of the residential building and spread to surrounding buildings (Mamun et. al. 2011). In 2016, a temple in Kerala, India was on fire and 98 people were killed (The Indian Express, 2016). This time,spark from an ongoing firework inside the temple complex ignited a magazine of stored fireworks(The Indian Express, 2016). Local police confirmed that the temple authority did not have authorised permission to store or display fireworks. In both the cases fire hazard was originated because of negligence to fire safety measures, incompatible land use, failure to adhere to fire safety regulations and building code, demographic characteristics of people on the scene, and unplanned zone development in fast growing cities. Fire safety rules and regulations are not adequate to address the risk in many cases because the rules state minimum requirements of fire safety on site, it does not take into account of surrounding land uses, and it does not address risk arising from of cumulative impacts of storing different hazardous materials together. There is not a lot of study available looking into fire hazard risk in urban areas causing from incompatible land uses and demographic characteristics of those areas. This paper intends to extend conceptual understanding of fire hazard risk in fast growing urban areas in a developing world context using a case study from Dhaka, Bangladesh.

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## Some Terminologies Related to Fire Risk Assessment

Fire starts when heat source comes into contact with flammable materials and oxygen. So to ensure public safety, it is necessary to keep apart the sources of heat and possible flammable materials (Government of UK, n.d.). To develop fire risk index for chemical warehouses basic terminologies related to fire hazard and chemical substances were looked into and some of the key terms are described in the upcoming section.

### Fire in a Chemical Disaster

A chemical incident is the uncontrolled release of toxic substances which is harmful to public health and environment. It can have different appearances with different triggering events (natural or anthropogenic) (World Health Organization, 2009). Fire is defined as a steady state of exothermic, self-catalysed chemical reaction. It has the distinctive ability to spread through a combustible medium, usually a fuel and an oxidizer which is in most cases atmospheric oxygen (Haq, 2011). Fire produces injuries through heat and toxic substances including combustible products. A secondary effect of fire may be an explosion. All major fire can be considered a chemical incident.

Chemical disasters are the occurrence of fire or explosions involving one or more hazardous chemicals. Such disasters may happen during industrial activity or storage or transportation or due to natural events, leading to serious effects inside or outside the installation and likely to cause loss of life and property and adverse environmental effect (South Asian Disaster Knowledge Network, n. d.).

### Flammable Material

It is imperative to know about different classes of chemicals based on their level of flammability for ensuring fire safety from chemical handling. "Any solid, liquid, vapour or gas that ignite easily and burn rapidly is a flammable material" (Lewis, 1997). Flammability rating according to National Fire Protection Authority(National Fire Protection Association, n.d., 2005) has been used as the standard criteria for this study.

### Type of Fire and Fire Hazard Materials

Fires and combustible materials are classified into five groups from class A to Class D and a class K. Class A fires involve ordinary combustible materials like wood, cloth, rubber, paper and plastics (Haq, 2011). Class A fires require water or certain dry chemicals for fire extinguishing. Class B fires causes from flammable or combustible liquids and flammablegasses, and the method of extinguisher of such fires involves obstruction of the oxidization process (Haq, 2011). Class C fires include fire from electrical equipment. Class D Fires involve combustible metals which cannot be extinguished by Class A and B extinguishing agents (Haq 2011). Class K fires are ignited from cooking appliances and requires dry or wet chemicals for extinguishing (Haq, 2011).

### Fire Extinguisher

Fire extinguishers can be fixed or portable. Examples of fixed fire extinguishers include foam extinguishing system, $CO_2$ extinguishing system, halogenated extinguishing system, dry chemical, and wet chemical extinguishing system(National Fire Protection Association, 1998). According to Bangladesh National Building Code (BNBC), 'Portable Fire Extinguishers' should be installed in kitchen, public areas, storages, electrical distribution points of a building (Dhaka House and Building Research Institute, 2006).

## Major Focus of Bangladesh National Building Code (BNBC)

### Fire Resistance Rating and Construction Type

According to the BNBC, chemical storage should not coexist in the same building used for residential purposes as per Part 3 - general building requirements, control and regulation of Bangladesh National Building Code (Dhaka House and Building Research Institute, 2006, The BNBC also states that fire resistance rating denotes the property of a building construction material and or construction itself and is expressed as a period of time during which the materials or constructions are:

a) resistant to collapse due to fire,

b) resistant to flame penetration, and

c) resistant to excessive temperature rise on the unexposed surface.

In Table 1, fire resistance rating for various thickness of brick wall is provided as per Part 4 - fire protection of Bangladesh National Building Code (Dhaka House and Building Research Institute, 2006).

Table 1: Fire resistance rating of common construction elements

| Structural elements | Fire resistance rating |
|---|---|
| 75 mm thick walls of clay brick | 0.75 hours |
| 125 mm thick walls of clay brick | 1.5 hours |
| 250 mm thick walls | 3 hours |

Source: BNBC 2006, pp. 4-4

All the buildings or structures are classified in following three categories based on fire resistance of construction elements:

Type 1: Highest degree of fire resistance

Type 2: Intermediate degree of fire resistance

Type 3: Lowest degree of fire resistance

## Fire Hazard Risk Assessment

There are many methods for fire risk indexing. In order to develop a fire risk index for chemical warehouses, existing risk index methods was studied. One commonly used method for risk indexing is ranking method. In the ranking methods or semi-quantitative methods, a group of experts identify every single factor that affects the level of safety or risk (European Commission, 2003). The importance of each factoris decided by assigning a value based on the knowledge and the experience of experts.All the assigned values are then used to develop an arithmatic function to achieve an index value, which can be called as a “risk index” (Fire Risk Assessment Method (for) Enginerring, 2012). It is a measure of the level of safety or risk in the object and it is possible to compare this to other similar objects (European Commission, 2003).Advantages of fire ranking methods are their simplicity, cost effectiveness, and ease of use as a structured tool for decision making(Fire Risk Assessment Method (for) Enginerring, 2012). But a disadvantage of ranking methodis that it can only be used for a specific type of building or process etc (European Commission, 2003).

The Fire Risk Index Method (FRIM) is a well-accepted tool in the Nordic countries and was used by Larsson for timber frame multi-storey apartment building (Larsson, 2000). The Fire Risk Index Method (FRIM) can be applied to all types of ordinary apartment buildings. A high risk index for buildings represents a high level of fire safety and a low risk index a low level of fire safety. The theoretical value is from 0.0 to 5.0 (Larsson, 2000).

In FRIM, Delphi technique was followed to estimate the appropriate weights of different risk factors. The members had to assign weights to the Objectives, strategies, and parameters and give their opinions on the parameter grades and they had to provide weights again in round 2 to reach consensus (Larsson, 2000).

## Research Methodology

### Delphi Panel Exercise for Risk Index Development

Delphi technique was developed by a California-based firm named, the RAND Corporation in the 1950s (RAND Corporation, 2012). The intuitively available information of the participating experts is used in this approach. This approach consists of a structural survey conducted in two or more rounds(Cuhls, 2004). In the second round, all the participants are provided with the results of the first round so that they can alter their original assessments if they want to or stick to their previous opinion (Cuhls, 2004).

For this study, a fire risk index has been developed by scoring various factors associated with fire risk.The weight of these factors has been set by the Delphi panel. Each of the chemical storage and shops selected for survey gets a rating according to the risk index. The first step was to develop a preliminary structure. Each of the panel members is asked to give their opinion on the tentative structure of the risk index, and then they are asked to give appropriate weighting factors to the components and sub-components of the index. After completing the 1$^{st}$ round questionnaire, the level of consensus among their opinion is checked with standard deviation. Then, the structure of the index is corrected according to their suggestions. Finally, the 2$^{nd}$ round has been conducted in the same manner to reach consensus on the weighting factors and hence the Delphi is run in a loop until a consensusis reached. The total duration of Delphi exercise was two months. Time difference between 1$^{st}$ round and 2$^{nd}$ round was one month. The table 2 shows the weighing factors derived from the Delphi exercise.

The risk index has three major components comprising of Risk related to construction type, building facilities and content, Risk related to incompatible land use and general fire-fighting facilities, and Risk related to occupants. Each risk evaluation component has several sub-components. Specific parameters for the sub-components were developed from the existing relations of BNBC and Fire safety rules and in the absence of local standards international best practices were looked into, and the parameters were finalized through the Delphi panel. The following formula was developed to calculate the risk index for each warehouse to be surveyed.

Table 2: Summary of weighing factors after Delphi exercise

| Major Risk Components | Weight | Subcomponents | Weight(w) |
|---|---|---|---|
| C1: Risk related to construction type, building facilities and content | 0.352 | C1-1: Type of chemicals (based on flammability) | 0.21004 |
| | | C1-2: Portable Fire extinguisher | 0.10364 |
| | | C1-3: Amount of chemical stored | 0.16846 |
| | | C1-4: Construction type | 0.1088 |
| | | C1-5: Fire detector and Alarm | 0.151 |
| | | C1-6: Means of Escape | 0.15216 |
| | | C1-7: Ventilation | 0.1059 |
| C2: Risk related to incompatible land use and general fire-fighting facilities | 0.37 | C2-1: Main activities other than warehouse | 0.21062 |
| | | C2-2:Minimum separation distance from adjacent buildings | 0.12888 |
| | | C2-3: Source of fire | 0.16986 |
| | | C2-4: Accessibility of fire fighters | 0.18186 |
| | | C2-5: Response time of fire service | 0.1759 |
| | | C2-6: Presence of overhead tank, underground reservoir and other source of water | 0.13288 |
| C3: Risk related to occupants | 0.278 | C3-1: Awareness of owner and worker | 0.2878 |
| | | C3-2: Awareness of inhabitants of the building | 0.3298 |
| | | C3-3: Population composition (based on age) | 0.17076 |
| | | C3-4: Density of occupants | 0.21164 |

Source: Delphi survey, 2012

$$\textbf{Risk Index} = W_{C1}*(\sum W_{C1\text{-}i}*S_{C1\text{-}i}) + W_{C2}*(\sum W_{C2\text{-}j}*S_{C2\text{-}j}) + W_{C3}*(\sum W_{C3\text{-}k}*S_{C3\text{-}k}) \qquad (5.1)$$

Where, W = weight of components and subcomponents

S = risk score for parameters under subcomponents

i = subcomponents of C1

j = subcomponents of C2

k = subcomponents of C3

The index was named as 'Fire Risk Index for Chemical Warehouses' i.e. FRICW. According to this index, highestrisk score for any warehouse will be 4 and lowest risk score will be zero. The final score of index was classified into following risk levels, and the classification was adapted from the National Fire Protection Association hazard rating of chemicals as shown in Table 3 (National Fire Protection Association, n.d.).

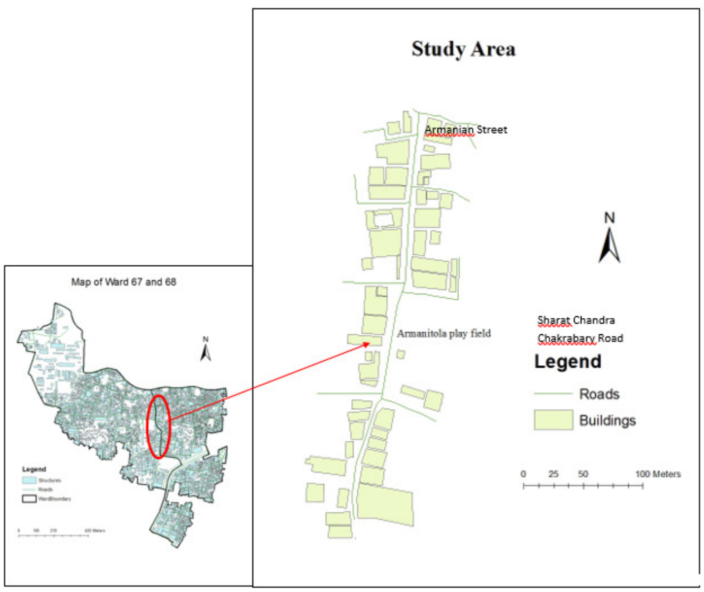
Table 3: Classification of risk level

| Risk score | Risk level |
|---|---|
| 0 to <1 | Minimal risk |
| 1 to <2 | Slight risk |
| 2 to <3 | Moderate risk |
| 3 to <4 | Serious risk |
| 4 | Extreme risk |

Source: National Fire Protection Association, 2005.

## Study Location

The study area was selectedconsidering the concentration of chemical warehouses, high population density and previous history of fire. Armanianstreet and Sharat Chandra Chakrabarty road is locatedat the middle part of 67 and 68 number ward of Dhaka South City Corporation (DSCC) area. The study area is located near the river Buriganga as shown in Figure 1.




Source: CDMP

Figure 1: Map of the study area

A cluster of chemical warehouses exists in the areas of Mitford, Babu Bazar, Sharat Chandra Chakrabarty road, and Armanianstreet. This selected study area is situated in between ward no. 67 and 68. It extends from Sharat Chandra Chakrabarty road to the end of Armanian Street. Warehouses situated on both side of the street were subjected to detail survey. Following are the reasons that led to selection of this study area:

- Reconnaissance survey showed that this area has 238 chemical shops/ warehouses which are around 34% of total 702 chemical warehouses of Old Dhaka (Rashid, 2011)

- Very high population density
- Several fire incidents had occurred in this area

**Secondary Data Collection**

Secondary data needed for the study have been collected from Dhaka City Corporation, The Comprehensive Disaster Management Programme (CDMP), Fire Service and Civil Defence and other relevant sources. Physical copies of maps and demographic data of Ward 67 and 68 were collected from Dhaka City Corporation. GIS maps of both wards were collected from CDMP. Data of previous fire incidents (i.e. Nimtali fire and other incidents) and a list of chemical warehouses in the study area were collected from the Fire Service and Civil Defence Directorate.

**Primary Data Collection**

***Sample Size Determination for Survey***

The total number of chemical warehouses in the study area is 238. In total 147 chemical storages have to be randomly selected for surveying to satisfy 95% confidence level and 5% precision. However due to data availability and a higher concentration of warehouses on 'Armanian Street' and Sharat Chandra ChakrabartyRoad, in total 153 warehouses were selected to survey for the study purpose.

***Field Survey***

Primary data has been collected through field survey. The first step in data collection is a reconnaissance survey of the study area to know the location of chemical warehouses and general characteristics of the area. Necessary data according to the risk index has been collected through questionnaire survey and check-list from the study area.

## Analysis and Discussion

The Fire Risk Index for Chemical Warehouses (FRICW) was used to determine the risk level of warehouses of the Armanian Street and Sharat Chandra Chakrabarty road. The data was collected through questionnaire survey and check-list has been used to rank the warehouses for level of fire risk. Later, the warehouses were classified for the level of fire risk according to the risk index.

Ward 67 and 68 contain mixed type of occupancy of dwelling units. The selected study area falls in between both these wards and shares the same characteristics. Occupancy types found in the study area were categorizedin Table 4 according to the Bangladesh National Building Code(2006) typology (Dhaka House and Building Research Institute, 2006)

According to the classification in BNBC (2006), mostly the structures of Ward 67 and 68 are of Type 2 and Type 3 construction type meaning intermediate and low level of fire resistance rating (Field survey, 2011). Separation distance between two buildignswere found to be less than the minimum requirement of 10 feetwhich is the minimum requirement stated in BNBC (Dhaka House and Building Research Institute, 2006).

Table 4: Type of occupancies in the study area

| Occupancy Type | Sub-division | Nature of use or Occupancy |
|---|---|---|
| A: Residential | A1 | Detached single family dwelling |
| | A2 | Flats and apartments |
| F:Business and mercantile | F1 | Office |
| H: Storage | H1 | Low fire risk storage |
| | H2 | Moderate fire risk storage |
| J:Hazardous | J1 | Explosion hazard building |
| | J2 | Chemical, biological or radiation hazard building |

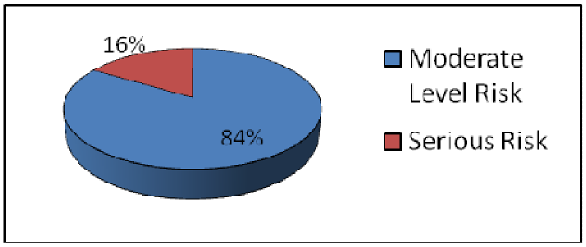
Source: Field survey, 2011

Survey results revealed that warehouse owners in the study area had stored chemicals with a flammability rating of non-flammable to hazard level 3 (Table 5). All the warehouses located in residential buildings exceeded the limit of approved amount to be stored in a residential building according to the National building code of Bangladesh. 86.9% of these warehouses did not have a portable fire extinguisher and 100% of these storage facilities did not have fire detectors, alarms and a designated fire escape route. These warehouses were running their operation with complete disregard to the BNBC and fire safety rules. 84% of the warehouses are at serious risk due to nature of products stored and in-house fire safety features (Figure 2).

Table 5: Major findings under nature of products stored in the warehouse and in-house fire safety feature (Component C1)

| **Factors considered under nature of products stored in the warehouse and in-house fire safety feature** | **Major findings** |
|---|---|
| Type of chemical stored | Varied from non-flammable (0) to hazard level three (3).<br>In 57.5% warehouses hazard level 1 and 2 chemicals were found |
| Amount of chemical stored | 100% warehouses exceeds the exempted amount of chemical stored described in BNBC (2006, pp. 3-44) |
| Portable fire extinguisher | No portable fire extinguisher in 86.9% warehouses<br>1.3% warehouses have dry chemical powder (DCP) extinguisher |
| Construction type | 97.4% warehouses are situated in buildings with intermediate degree of fire resistance |
| Fire detector and Alarm | None of the warehouses contain fire detector and alarm |
| Means of Escape | No designated fire escape in any warehouse.<br>In 29.4% casesstair cases are obstructed. |
| Ventilation system | 90% warehouses have no ventilation system |

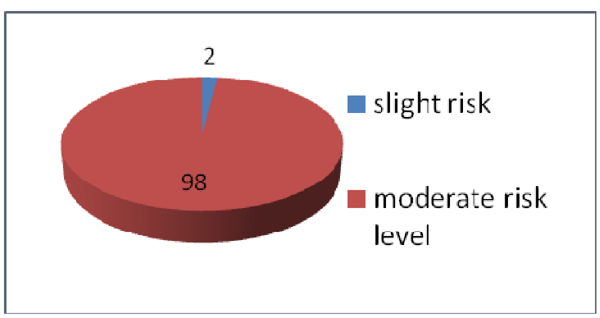
Source: Field survey, 2011




Source: Field survey, 2011

Figure 2: Level of risk of the surveyed ware houses due tonature of products stored and in-house fire safety features C1

The study area had 238 chemical shops which was around 34% of total 702 chemical warehouses of Old Dhaka (Rashid, 2011). Table 6 provides summary of findings under the risk component to incompatible landuse and general of firefighting facilities. The length of the roadway from Armanianstreet to Sharat ChandraChakrabarty road was 348.45 meter. Road width varied from 15 to 25 feet (Field survey, 2011). However, the effective road width was much less than the actual right of way. Large number of trucks and pickups were often parked along both sides of the roads and loading-unloading consignment of chemical materials took place all day long. Access roads connecting houses on Armanian street to Sharat ChandraChakrabarty road were even narrower and some of them were 5 to 6 feet wide (Field survey, 2011). Overhead cables of telephone and power grid were hanging at an altitude of 13 feet or less, which is less than the required vertical clearance for fire trucks. The area had a very high population density. Population density of ward 67 was 63,447 persons per square kilometer and for ward 68 population density per square kilometer was 1,34,424 persons (Bangladesh Bureau of Statistics, 2001). Record of fire service and civil defense office showed that 3 small fire incidents had occured in this area in the time period of 2011-2012.Average level of risk of warehouses in the study area according to the combined index was measured to be inmoderate risk of fire hazard. Risk of warehouses under different subcomponents of the developed fire risk index is discussed in the following sections.Almost 98% of the warehouses face moderate risk due to incompatible land use and lack of general fire-fighting facilities (Figure 3).




Source: Field survey, 2011

Figure 3: Level of risk of the surveyed ware houses due to incompatible landuse and general of firefighting facilities (components C2)

Table 6: Fire risk due to incompatible landuse and general of fire fighting facilities (Component C2)

| **Factors considered under incompatible land use and general firefighting facilities** | **Major findings** |
|---|---|
| Major use of buildings other than warehouses | In 50% of cases warehouses are found with residential uses |
| Separation distance | For 100% of the warehouses separation distance is below 10 feet<br>For 65.4% of the warehouses separation distance is below 5 feet |
| Nearby source of fire | Distance of cables is less than 4 feet for 14% cases<br>In 43% of the warehouses source of fire is in adjacent room (cooking stove in the kitchen) |
| Accessibility of fire fighters | Road width in front of 53% warehouses is less than 20 feet<br>Vertical clearance is less than 16 ft to 13.5 ft for 90% of warehouses (Below BNBC standard).<br>77% warehouses are situated in buildings with only one open side for fire fighting |
| Response time of fire service | On an average 20 minutes |

Source: Field survey, 2011

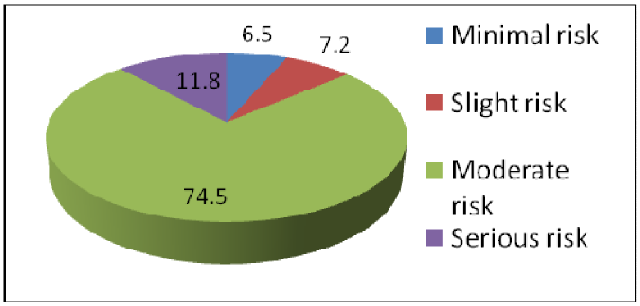
Findings on risk related to the type and awareness of occupants of the warehouse and the surrounding land uses are describedin table7.Literacy rate (+7 years) of ward 67 was 75.45% and that of ward no. 68 was 73.23%. It was quite higher than the national average adult literacy rate of 47.49% (BBS, 2001). However, none of the owners of the warehouses maintained material safety data sheet and never had participated in a fire drill. The owners of the buildings were unaware ofthe nature and flammability of chemicals being stored in their building. These implied a serious lack of concern regarding fire safety among the occupants and owners in the study area.

Table 7: Risk related to type and awareness of occupants of the warehouse and the surrounding land uses (Component C3)

| **Factors considered under Type and awareness of occupants of the warehouse** | **Major findings** |
|---|---|
| Awareness of owner and worker of warehouses | Warehouse owners do not maintain material safety data sheet and never had any experience of fire drill. They can read the symbols on containers and maintain phone number of fire service |
| Awareness of owners of warehouse buildings | None of the owners of the buildings has any idea about type of chemical being stored and fire drill in the warehouses they have let for rent. 4.5% building owners maintain emergency phone numberfor fire services |

Source: Field survey, 2011

There is variation in the level of fire risk for the risk related to occupants. Around 12% of the warehouses are in serious risk and 74.5% of the warehouses are at moderate risk of fire because of lack of concern and awareness among the occupants and owners of warehouses and the respective buildings in the study area (Figure 4).




Source: Field survey, 2011

Figure 4: Level of risk due to type and awareness of occupants of the warehouse and the surrounding land uses for component C3

From the discussion of risk scores for all the components it is understood that value of final risk score falls in moderate risk category, but all three major risk components vary from minimal to serious risk. So there is possibility of serious outcomes for any of the risk components in times of fire hazard. Warehouses in the study area were risky for the unsafe conditions described in the analysis of fire hazard risk assessment.

## Conclusion

The general findings of this study was that the risk of fire hazard developed in the study area due to failure to implement the national building code and fire safety rules of the country. High densityliving, unplanned urbanization, and lack of general awareness regarding proper handling and storage of chemical products and the risk associated with it created a situation where any fire incident can cause high level of fatality. Findings from this study shows that a large number of people were living in a constant threat of deadly fire hazard in the study area with minimal to no regard to fire safety. Lack of compliance of building code, and fire safety rules caused the risk of a fatal fire incident in the area. It necessitates the need to look into urban man made hazard and development of disaster preparedness plan for such hazards.

***Acknowledgement:*** *This study was conducted in partial fulfillment of the requirement for the degree of Bachelor of Urban and Regional Planning in the Bangladesh University of Engineering and Technology (BUET). We are grateful to Dr. Ishrat Islam for her guidance and supervision of the research and opinion on this paper.*

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