FIRE RISK ASSESSMENT OF HOUSEHOLDS IN URBAN AREAS OF FAISALABAD, PAKISTAN

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in

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by

Muhammad Awais Nisar (00000276068)

Department of Urban and Regional Planning

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST) Islamabad

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This is to certify that the

Thesis titled

FIRE RISK ASSESSMENT OF HOUSEHOLDS IN URBAN AREAS OF FAISALABAD, PAKISTAN

Submitted by **MUHAMMAD AWAIS NISAR** (00000276068)

has been accepted towards the partial fulfillment

of the requirements for the degree of

Master of Science in Urban and Regional Planning

Dr. Irfan Ahmad Rana

Thesis Supervisor,

Department of Urban and Regional Planning,

School of Civil & Environmental Engineering-(SCEE),

National University of Sciences and Technology, Islamabad

ACCEPTANCE CERTIFICATE

Certified that the final copy of the MS thesis written by **Mr. M. Awais Nisar** (Registration No 00000276068) of **SCEE/NIT/URP** (School/College/Institute) has been vetted by the undersigned, found complete in all respects as per NUST Statutes / Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for the award of MS degree. It is further certified that necessary amendments, as pointed out by GEC members of the scholar, have also been incorporated in the said thesis.

Signature: ______________________________

Name of Supervisor: **Dr. Irfan Ahmad Rana**

Date: __________________________________

Signature (HOD): _______________________

Date: __________________________________

Signature (Dean/Principal): _______________

Date: _________________________________

DEDICATION

This work is dedicated to my Beloved Mother who supported and encouraged me throughout my research.

I also dedicate this work to My Thesis Supervisor, Dr. Irfan Ahmad Rana without whom it was impossible to achieve this milestone.

And finally, I dedicate this work to the Almighty Allah, who gave me healthy life to meet and complete such targets in my life

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(Muhammad Awais Nisar)

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CHAPTER 1:

Introduction

1.1 Background:

The Discovery of fire is a key feature of human evolution. Throughout history, fire has been shaping our specie in various ways. Charles Darwin believed that human evolutionary success could be attributed to three traits apart from our intelligence which led to so much else. He considered fire the greatest discovery made by man, except for language (Wrangham & Carmody, 2010). Recent anthropologists support this theory of Darwin, as it is evident from the archeological records that control of fire was an even greater feat achieved by early humans than the using tools (BRACE, 2009).

Domestication of fire is far more ancient than the domestication of wild animals. Fire a natural force that is wild and with incalculable risks was tamed to a certain degree. Although the process of taming the fire is still going on, the risks associated with fire will be with us even in the far future (Goudsblom, 1986). With the rise of urbanization fire protection has remained one of the "urban problems". In early 18^{th} century American cities, the fire hazard agitated the municipal authorities to impose fire safety regulations like constructing chimneys and keeping the water bucket to fight fire ignition. However, the fire hazard continued to stir the municipal authorities which made way for volunteer fire companies, this increasing involvement of stakeholders in the urban fire safety made way for further innovations like Franklin's lightning rod and the fireplace stove (Schlesinger, 1940). However, the fire hazard and its reduction could not be limited to just technological innovation. Fire has been studied most comprehensively in sociological approaches like urban theory, urban ecology, urban sociology, and economics. These approaches have provided a better understanding of the complex interdependencies of human systems and organizations in the case of urban fire hazards. Like other urban hazards, fire can be considered the product of social and structural factors (Jennings, 1999).

Each of these ecological factors can contribute to the fire problem. For example, heating is required for colder climates with the constant threat of fire ignition. Also, these factors influence successful firefighting by improving the capacity of firefighting institutions. The social-physiological understanding enhances better perception and preparedness against fire hazards in urban dwellers (Hazen & Hazen, 2014). Disastrous fires are very rarely started naturally. In almost all cases human factors are involved in starting a fire. This makes these incidents predictable with the application of scientific methods (Sufianto & Green, 2012). This research also explores the scientific methods to understand the ecological dimensions of urban fire hazards and reduce the fire disaster risks.

1.2 Problem statement:

A longstanding complex issue among the general public is the lack of understanding of residential fire safety regulations. These regulations are rather common and well elaborated in many cases but their implementation is a much more complex. Traditional fire safety codes provided by the institutions involved with the fire safety of buildings have incorporated the fire safety technologies like fire safe architectural and engineering standards, and firefighting equipment. Also, fire safety education provides little motivation and participation (DeChamplain et al., 2012). Fire remains a huge issue for the world. Fire losses cost 1% of the total GDP of the world every year which is approximately US$857.9bn (The Geneva Association, 2014). it causes more than 44000 death annually throughout the world. The highest number of these causalities occur in developing countries (Brushlinsky et al., 2009). The interpretation of fire safety in buildings has been shifted from technology to a more behavioral perspective at the end of the 20th century (Kobes et al., 2010b). In the local context, the fire safety measures don't account for the contemporary fire risks in buildings. They focus on the fire safety features with the least involvement of human behavioral aspects. This fire safety improvement features both active (automatic fire detection and extinguishing systems) and passive (structural and non-structural building components) are costly (Kodur et al., 2019). In the case of developing countries like Pakistan, general practice in the fire design of buildings has the only goal of getting approval from the regulatory authorities (Maluk et al., 2017). Furthermore, it is common that building control authorities don't perform their mandatory inspections after the construction has been completed. Let alone in the case of old buildings, buildings have rarely been abandoned or rehabilitated to minimize the fire risk (Akhter et al., 2014).

1.3 Rational and justification of study:

Pakistan is a country that has seen rapid urbanization in recent decades. With this rapid growth of cities, the role of urban development authorities in regulating building control also spreads thin. Historically, several development authorities have been involved in urban management in the typical cities of Pakistan (Rana & Bhatti, 2018). Building safety codes have kept changing with time. A serious change in the building safety codes has taken place after the earthquake of 2005 with the inception of national and provincial disaster management authorities. Building code of Pakistan- Fire Safety Provisions- 2016 has provided the by-laws vested in the authorities with jurisdiction over each city of the country (G. Pakistan, 2016). Pakistan is in the category of countries that face the highest number of casualties due to fire (10000-25000 per year) and the second highest number of fire incidents (100,000- 600,000 per year) (Brushlinsky et al., 2009). Research is required to analyze the level of implementation of FSP- 2016. Also, understanding the behavioral perspective of the fire hazard is essential to create effective feedback for FSP- 2016, which is to be reviewed and updated after five years.

1.4 Research questions:

- How much are the households' fire vulnerability and exposure in established built-up, urban and peri-urban areas?
- How much are the fire safety preparedness and capacities of communities?
- How much is the fire risk perception level of the communities?
- What mitigation strategies ensure the safety of life and property against fire hazards?

1.5 Research objectives:

- To assess the fire vulnerability and exposure of households in established built-up, urban and peri-urban areas.
- To measure the fire safety preparedness and capacities of communities.
- To assess the fire risk perception of the community.
- To suggest mitigation strategies to ensure the safety of life and property against fire hazards.

1.6 Scope of the study:

On average fire, incidents kill 16500, injure 164000 people and leave property damage and incurrence claims worth 400 billion each year in Pakistan (The Nation, 2012). Lack of clear reporting on these incidents after the lack of prevention and mitigation of fire incidents in the country. Pakistan is yet to adopt a National Fire Safety Policy. Although guidance is being provided in the building codes, fire incidents are also recorded where these building codes are formally implemented. This indicates that there is a lack of understanding and properly implementing of the fire safety codes. Adequacy of these codes should also be tested. There is a lack of information on fire hazard perception and awareness of the safety measures for the residents. These issues call for research on this matter. The scope of this study is limited to the fire risk assessment of household units. Only internal factors are considered for the assessment of household fire risk. The study focuses on the household units in established built-up areas, urban and peri-urban areas of a city. It analyses the fire safety situation of the existing household units in each part of the city.

CHAPTER 2:

Literature Review

2.1 Disaster Risk Reduction (DRR):

The definition of disaster given by Asian Disaster Risk Reduction (2003) as:

“A serious disruption of the functioning of society, causing widespread human, material or environmental losses which exceed the ability of affected society to cope using only its resources”.

Humans have been dealing with disasters since the start. According to the reviewed types of disasters, it is found that natural, human-made, and hybrid disasters cover all types of disasters. Disasters stemming from external (topological), internal (geological), metrological or hydrological, and biological phenomena are called natural disasters (Mohamed Shaluf, 2007). In the case of human-made disasters, human decisions result in catastrophic events. They can be short-term disasters like crop failure, production failure, and public place failure or long-term like national or international conflicts (Mohamed Shaluf, 2007). Hybrid disasters are subsequently triggered by human-made and natural disasters. Disasters resulting from natural, man-made, and hybrid hazards like earthquakes, floods, volcanic eruptions, forest fires, droughts, crop failure, wars, fire, landslides and development in hazard-prone areas hamper development in many ways. They destroy communication networks, critical infrastructures and lifelines which cause huge life, economic and environmental losses. These disasters can divert capital from other vital economic functions to rescue and rehabilitation, thus disabling development procedures. Resulting into spreading poverty, loss of business and industrial activities (Bendimerad, 2005).

Disasters are the cause of the collapse of early human civilizations. Interpretations of these disasters were more metaphysical than natural or human-made. For most of our history, disasters have been considered the act of God. Their prevention was largely based on spiritual and religious rituals, which almost gave no results. Contrary to that, secular measures in disaster management are also evident from the historical records of some ancient civilizations. Most of these written records have many inaccuracies and exaggerations of the disasters (Dominey-Howes, 2002), but the disaster responses that the societies have adopted can be evident from the records (Forlin et al., 2020).

The debate on the various phases of disasters goes back to the early 20th century. Various scholars and disaster management professionals have theorized the phases of disaster, but in practicality, disaster management was majorly focused on the aid and relief after the disaster has struck (Lewis et al., 1976). The second half of the 20th century saw a drastic increase in disasters. The losses were also greater than in the previous decades. Disaster management professionals pondered new ways to better utilize capital rather than providing rescue and relief. A practical practice was pre-disaster planning which was a necessary addition to the field of disaster management (Lewis et al., 1976). A new mechanism was designed that illustrated the whole process of disaster and provided governments, private organizations, and civil societies a chance to plan a response during and after the disaster to reduce its impacts. This new approach was called disaster management cycle. This disaster management cycle has been subjected to various changes and adaptations according the different organizations and researchers (Coetzee & Van Niekerk, 2012).

This systematic approach to reducing disaster risk is widely understood and practiced by organizations. This makes applying disaster risk management (DRM) practical at different phases of disaster. However, the new approach to disaster risk reduction (DRR) is commonly used as a similar term to DRM but it differs in the broader sense at policy, strategy, and institutional levels. Traditional disaster management is based on a conceptual model of the ‘disaster cycle (before, during, and after the disaster). This linear approach to disaster management simplifies the allocation of tasks and resources for the organizations. But disasters have greater complexity and cannot be broken down into these simplified phases. DRR is a holistic approach that provides frameworks for disaster risk reduction, not limited to structural approaches to reducing risks of certain disasters at particular times (Twigg, 2015).

Hyogo framework for action 2005-2015 was presented in Kobe, Hyogo, Japan and was agreed upon by members of the United Nations in January 2005. This framework provided the action plan to build the resilience of the nations and communities by reducing vulnerabilities and risks of hazard. The situation of the world pointed toward a future where disaster would increasingly threaten the population, economy, and development, especially in the developing countries of the world. The systematic integration of disaster risk reduction in the policies, plans, and programs. Achieving sustainable development requires rigorous approaches at a holistic level. Hyogo framework has strategic goals:

- Sustainable development policies, programs, and plans must be effectively integrated with the disaster risk reduction considerations focusing on the prevention, mitigation, preparedness, and vulnerability reduction of the disasters.
- Building resilience to the hazards by the systematical strengthening of institutions, mechanisms, and capacities at all levels.
- Strengthening the disaster risk management process by systematical incorporation of risk reduction approaches at phases.

It also incorporated the general considerations of accounting for the importance of international partnership and cooperation, integrating policies, programs, and plans of sustainable development, rescue, aid, and rehabilitation with the multi-hazard approach to disaster risk management in countries at risk, and integration of gender perspective in all aspects, most vulnerable people should be taken into account in DRR planning, empowerment of communities and local authorities to manage the process of DRR, proactive measure in all phases of disasters to build resilience and DRR as an essential element of global developmental goals. Governments and civil society organizations have been using this framework nationally and locally.

At the 3rd UN world conference on Disaster Risk Reduction, The Sendai Framework for Disaster Risk Reduction 2015-2030 was adopted. Which was the successor of the Hyogo framework and has the following goals:

- Reducing the global disaster mortality rate sustainably by 2030.
- Reducing the global disaster effectiveness rate sustainably by 2030.
- Reducing the global disaster economic losses concerning global GDP by 2030.
- Reducing disaster damages to infrastructure and basic survives by 2030.
- Increasing the number of countries with national and local disaster risk reduction strategies by 2030.
- Complementing the implementation of national action plans of countries with enhanced international cooperation and support by 2030.
- Increasing the availability and access of DRR technologies, information, and assessment to people by 2030.

In the case of Pakistan, the earthquake of 2005 and the floods of 2010 and 2011 proved to be a wake-up call, which exposed the vulnerability of the Pakistani society and economy to disasters. Pakistan being a signatory state of the Hyogo Framework for Action (2005-2015) formulated the National Disaster Management Ordinance in 2006 which was replaced by the current National Disaster Management act 2010 and followed by National Disaster Risk Management Framework (2007-2012). This policy reviewed the existing frameworks, plans, and policies of DRR extensively. This policy was formed with the inclusive consultations of local and provincial governments, the national government, civil society stakeholders, and development partners. This policy shared all principles of the Hyogo and Sendai framework of DRR.

2.2 Fire hazard:

Fire hazard is the most common hazard. Fire is a combination of three things. Fuel, oxidant, and ignition. Fuel is a combustion-able material, which can be natural or artificial. Combustion-able material is anything that can start burning when it is ignited. For fuel to start burning, a certain temperature is required. In the case of solid fuels, the ignition temperature is usually high, and in the case of liquid, it is usually low. In most cases of fire, the oxidant is usually oxygen. Oxidants are substances that can oxidize (loss of electrons due to a chemical reaction) other substances. In the case of fire, the combustion-able materials are oxidized under oxygen or other oxidants.

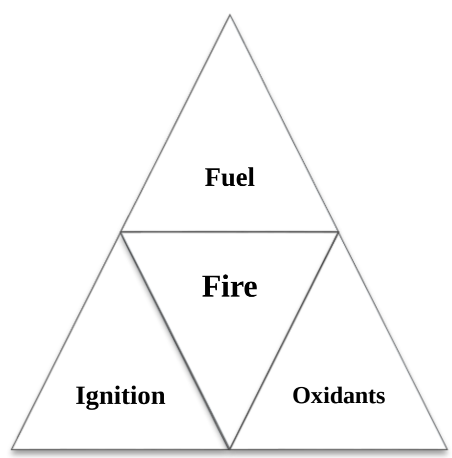

Figure 1 The fire triangle

According to the (UNSDL, 2004), the definition of fire hazard is “Any condition of the material that may start or contribute to the spread of fire”. Fire hazard includes flames, sparks, hot objects, flammable chemicals, and chemical accelerants (which can increase the spread rate of fire). In a broader context, a fire hazard is the presence of any materials, functions, or conditions which can impede the function of a fire protection system. Fire hazard is not only limited to the ignition or spread of fire. The presence of any phenomena can hamper the safe fire behavior like any obstructions in the safe evacuation (Safeopedia, 2021). The probability of the occurrence of a fire and the severity of its harm is called the fire risk. In short, the probability of a fire hazard is called fire risk (Safeopedia, 2021). the understanding of fire hazards may change over time and place. For example, a certain material or condition may be considered safe at one place and hazardous at another place. The assessment of fire risk and analysis of fire hazard can only be done by limiting the scope to a location or condition; for example, workplace, building, community, city, and wild-land.

Different types of fire pose different types of hazards. The types of fire depend upon different types of fuel. These types of fire are called fire classes.

Class A - Fire invloving solid materials such as wood, paper or textiles.	**Class B -** fires involving flammable liquids such as petrol, diesel or oils.
Class C - fires involving gases.	**Class D -** fires involving metals.
Class E - fires involving live electrical apparatus.	**Class F -** fires involving cooking oils such as in deep-fat fryers.

Figure 2 Classes of fire (Decagon, 2016)

These classes of fire are excessively used in firefighting practices. Different types of fire extinguishing materials are required to fight different classes of fire. Assessment of the risk associated with different classes of fire requires different approaches. Usually, residential and workplace fire belongs to class A fire. Class B and C fires can occur in industries, gas stations, and oil refineries. Class F fire can occur in restaurants and food industries. Fire associated with buildings can also be the combination of different classes of fire.

The primary objective of fire risk assessment is the assessment of the risks associated with human life. The risk of economic loss like property damage, an environmental loss like loss of forest cover, and biodiversity loss like loss of the number of animal species due to forest fire are a few examples of risks. In general, the risk assessment of buildings has two dimensions: expected risk-to-life (ERF), and fire cost expectations (FCE) in fire risk assessment models of CESARE and FIRECAM. The expected number of deaths over the design life of the building divided by the total number of residents of the building over the design life of the building is ERF. FCE can be defined as the total economic loss due to fire divided by the total cost of the building (Hadjisophocleous & Fu, 2004). Another approach is assessing the fire risk to individuals and society (Frantzich, 1998). The fire risk assessment of buildings is set to assess the fire risk of a building in comparison with a building with an acceptable level of risk. The acceptable level of fire risk of a building can be different, depending upon the fire safety codes applied to that building (Hadjisophocleous & Fu, 2004). These codes are usually prescriptive-based; they are comparatively convenient to be implemented by authorities. But these prescriptive-based codes are not derived from the strict scientific methodologies, research, and engineering disciplines. Rather they are derived from the method of trial and error over time. These rigid codes don't cater to the issue of different types of buildings. The basic consideration of these codes is that all buildings are subjected to the same level of fire risk (Meacham, 2000). A more reliable practice is performance-based fire safety codes. These codes have sets of flexible fire safety objectives and functional requirements. Performance-based codes are proved to be more successful than perspective-based codes in terms of cost-effectiveness, flexibility, equity, and innovativeness (Bwalya, 2008). Other types of fire hazard analysis or fire risk assessment are urban fire spread modeling, forest fire spread modeling and fire spread modeling of an urban-forest interface (T. W. Collins, 2005; Patac & Vicente, 2019; Zhao, 2011).

The development process of fire inside a typical room consists of incipient, growth, burning, and decay. The temperature during this process grows at the start and eventually decreases in the decay period as shown in the figure. The evolution of the temperature of household fire concerning time depends upon a wide range of variables for example; ventilation, compartmentation, fuel load characteristics, etc. In general, compartmental fire is categorized into three phases; pre-flashover fire and post-flashover fire. The incipient stage consists of flameless combustion and ignition called pre-flashover. The flashover stage occurs when fire rapidly grows and a steep increase in temperature is observed. In post-flashover, the temperature keeps increasing, which involves the burning of combustion-able material. After this fire starts to cool down (decay). Life safety considerations should focus on the pre-flashover fire stage, and structural safety considerations should focus on post-flashover fire (Kodur et al., 2019).

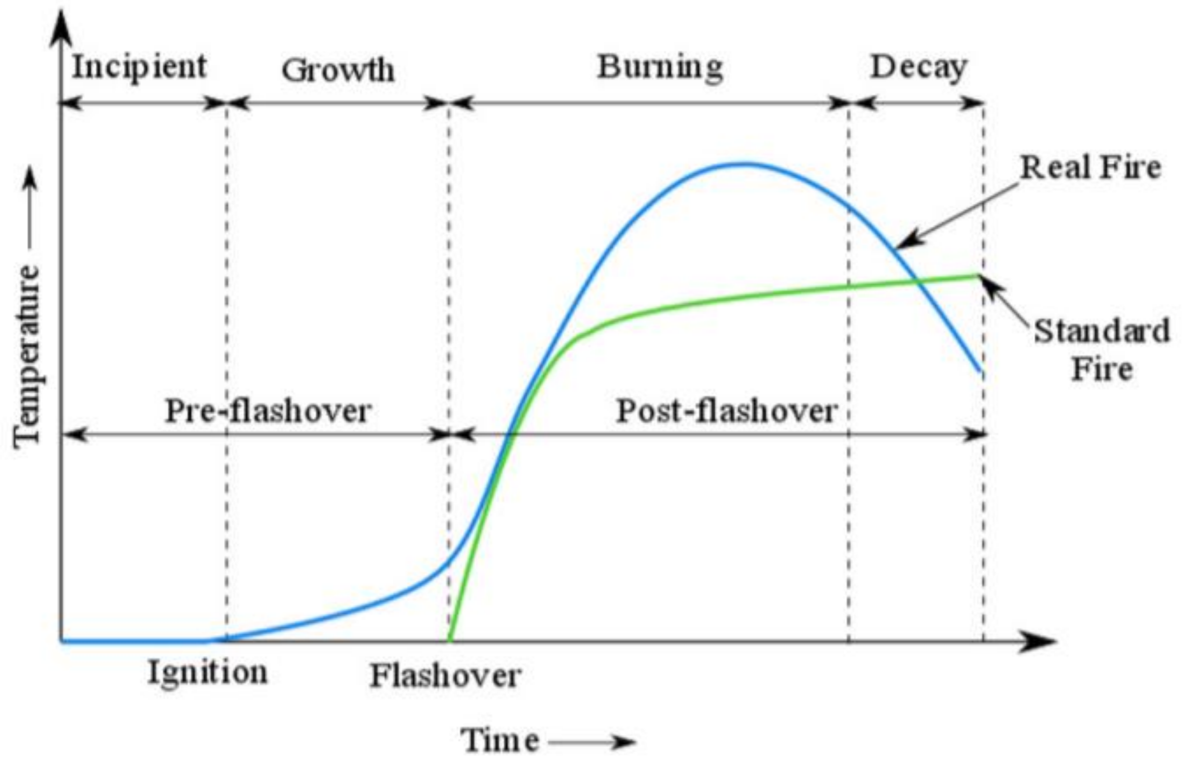

Figure 3 Uninterrupted building fire development process inside a typical room (Kodur et al., 2019)

Fire can reach up to the temperature of 1,000°C during the fully developed stage. It can cause significant damage to the structure of the building. It can compromise the structural integrity by melting the steel reinforcement, decreasing the stiffness properties of concrete, and completely burning down structural components made with wood (Kodur et al., 2019). Complete collapse of the load-bearing members of the structure can happen during or after the fire. Even if the building does not collapse, fire can permanently damage these structural members and make the building structurally vulnerable (Kodur et al., 2019). Fire can cause direct losses of life, property, and the cost of firefighting and rescue. Even if the fire does not cause such direct losses, there are always indirect losses like the cost of repair and maintenance, relocation, insurance, and environmental contamination.

2.3 Fire vulnerability:

It is hard to find a single definition of vulnerability that has been agreed upon by all researchers and practitioners. The simple working definition of vulnerability is the degree of loss resulting from the occurrence of a phenomenon. Accurate prediction of the loss due to a disaster can be made only with an accurate forecast of relevant scenarios. Fire vulnerability can be defined as the degree of loss that can be caused in the case of a fire. The main focus of fire vulnerability assessment is life and property in cases of urban fire hazards.

(Nehal A. H., Hasan M. R., 2019) explained in his research that fire is a disastrous event, and it originated from mostly human activities in an urban area. If an urban fire is not controlled, it can cause huge losses to life and property, especially in vulnerable areas. The study area was Chittagong, the second largest city in Bangladesh with a population of roughly 4009,423 in 2011. GIS is used for mapping the fire vulnerability of the city. With the help of remote sensing the vulnerability elements measured were the buildings in close vicinity of power transmission lines, the existence of fire sources, the width of streets, building material type, and floor area ratio. Critical analysis of this data indicated low to moderate fire vulnerability of critical facilities like hospitals and rescue departments, moderate fire vulnerability of economic features of the city, low fire vulnerability of the environmental features of the city, low fire vulnerability of residential areas, and low vulnerability for large fire incidents in the city.

(Granda & Ferreira, 2019) worked on the fire risk assessment of historical centers in an old urban area of Guimaraes. The complexity of the old urban areas in case of fire vulnerability is due to the historical and cultural significance. The fire vulnerability associated with the old buildings is generally due to the presence of combustion-able material, high density of construction, narrow streets, the inadequate adaption of the buildings, and the presence of an old electrical transmission system. Fire Risk Index (FRI) was used to assess the risk of fire. Fire Risk Index is composed of two global factors: global risk factor (FGR) and global efficiency factor (FGE). The sub-factors in the FGR are devoted to evaluating the vulnerability in the fire ignition phase (SFI), fire propagation phase (SFP), and evacuation phase (SFE). The vulnerability at the fire combat phase (SFC) is the only sub-factor of the global efficiency factor (FGE). Their overall relation is shown in the following mathematical equation

$$FRI = \frac{(1.2xSFI + 1.1x\ SFP + SFE + SFC)/4}{FRR}$$

Eq 1 Fire Risk Index (Granda & Ferreira, 2019)

FRR: Reference risk factor = $0.19+25F_C$ (for residential buildings).

F_C: Correction factor assuming the value of 1.1, 1.2 or 1.3 for a building of <3, <7 and 7+ floors. This analysis showed that only 6% of the buildings in the historical center of Guimaraes have low fire risk and all other buildings showed moderate to high vulnerability to fire.

(T. W. Collins, 2005) analyzed the social aspects of fire vulnerability of the communities of the wildland-urban interface. The study was based on household surveys of the forest ranches located in California. Social determinants of fire risk used are risk perception, amenity value conflicts, institutional incentive structure, and political-economic constraints. Inadequate practices to address the fire hazard in wildland-urban interface communities show the potential policy gaps. The necessary household-level fire vulnerability assessment would determine the potential of households to cause and suffering from this biophysical fire hazard. The fire vulnerability indicators used in household surveys were sectioned into socio-economic, ignitability, level of implementation of mitigating measures, and perception about the wildland-urban fire. For house ignitability the radius of maintenance and cleaning around the house, house in the approximate of the fire hydrant, availability of water supply for firefighting, fire rating of the material used in the exterior of houses, and accessibility of evacuation passageways used as indicators. For the level of implementation of mitigation measures, indicators used were residents' understanding of safety codes, their affordability of mitigation measures, their perception of the mitigation measures, and their overall perception of the responsibility of wildland-urban fire. The results indicated that the wildland-urban communities were highly vulnerable to fire because of being underdeveloped. The intervention was needed to implement the fire safety codes and build infrastructure to protect against this bio-physical hazard.

(Kobes et al., 2010a) Analyzed the building safety and human behavior in case of fire. People rely on themselves or wait to be rescued by others in close vicinity in case of fire. The most crucial feature of the fire safety of a building is the possibility of safe escape. Other main fire safety aspects of a building are Prevention of fire, limiting the speed of spread of fire and smoke, and arrangements for extinguishing the fire. Depending upon the type of building there can be extra aspects of fire safety. For example, in the case of hospitals, the provision of escape locations inside the building is important. The architectural features for the fire safety of a building are adequate width of evacuation passageways, stairs, and maximum flow rate capacity for fire exits. These architectural features are predominately technology-based. However, safe escape doesn't only depend on these features. Human behavior majorly determines the vulnerability in case of fire. The behavior of humans in the smoky environment is different and personal characteristics like age, disabilities, drug influence, or dizziness may also determine the deviation from the expected response. Emotional attachments to place and people also determine behavior. In most cases of a house fire, the residents tend to return to the house after escaping first to save other family members and precious possessions. In residential fires, people try to extinguish them by themselves in 74% of the cases. If the fire becomes out of control, people tend to self–evacuate. In most cases of deaths and injuries caused by fire, the main reason is delayed action for escape. People who are active and experienced tend to escape early. In the case of people who find themselves responsible like the head of the family, staff, or security personnel tend to be most vulnerable. The research suggested that the fire safety policy should be in line with the actual behavior of people and its interaction with the characteristics of the building.

(Kodur et al., 2019)

2.4 Fire Perception:

The perception of residents of the fire hazard plays a key role in the risk assessment of household fire. Various studies have analyzed the connection of fire risk with the preparedness of communities against fire. (T. W. Collins, 2005) Analyzed the correlation of fire vulnerability in the forest ranches with the fire risk perception of their residents. Variables were constructed to accurately assess the hazard perception based on the level of adoption of safety practices in the community. The difference between fire preparedness and perception indicated the accuracy of estimated risk by the residents.

(Kobes et al., 2010a) studied that in the initial phase of the fire human behavior determines the chances of survival. Human behavior can be defined as the action people take in case of fire based on their perception of this hazard. Also, their intentions and considerations for the situation determine their behavior. The ability of an individual to perceive, and interpret danger and decisions for surviving the fire determines their action. These perceptible traits can result in the early discovery of fire by smelling, seeing, or hearing. Personality traits like knowledge, mobility, experience, and observation determine the role during the escape. Most people adopt the role of follower during the escape from fire. This is because they don't detect the fire early and respond to danger early. Beliefs and assumptions also determine the vulnerability during the escape. Most people assess the intensity and speed of fire incorrectly. Common response during escape is that most people try to escape from the main entrances instead of safe exists due to the familiarity with routes.

(Subramaniam, 2004) studied the current fire safety conditions in residential colleges in Malaysia. For fire safety, the occupants depend on the developer of the building. Despite the presence of fire safety elements in the buildings, occupants were expected to know how to use those safety features. The assessment of the influence of human factors on safety features namely: portable fire extinguisher, hose reel system, fire alarm system, the exit sign, and the staircase was carried out. Human factors are termed as fire safety behavior and lifestyle, which includes sub-factors predisposing (knowledge, attitude, beliefs, values, and perception), reinforcing (feedback, social influence, social opportunities, modeling, and repercussion), and enabling (resources, access, policies, and skills). The data for this research was divided into two parts first was a safety audit which was based on the safety standards and the second was questionnaires. The questionnaires were divided into five sections. Four sections covered the above-mentioned human factors and the fifth covered the demographic data. The survey revealed that the predisposing and reinforcing factors positively contributed to fire safety behavior. Although populations' beliefs, values, perceptions, and knowledge may negatively contribute to fire safety in other cases and make communities more vulnerable. Therefore, the right beliefs in fire safety and values of achieving high standards for communities should be instilled in the population. For the fire safety of communities, the number of management staff would never be enough. The practical solution is to invest in well-trained staff, effective communication of the threat, and enable responsible decision making.

(Wolski et al., 2000) analyzed that the prescriptive-based building fire safety codes are influenced by a fire risk perception of several stakeholders. The difference in the perception levels of these stakeholders is a key issue in developing the most effective safety codes. The solution is to assess the existing fire risk of the buildings and categorize them into classes of low, medium, and high risk. Each class will be provided with a risk adjustment factor based on their perception level. For example, a building with low fire risk but high perceived risk should be provided by the level of fire safety interventions with a risk adjustment. This can help in more efficient use of resources.

2.5 Fire preparedness:

Preparedness against a disaster is indicated as the capacity to cope. Capacity is the measure of the resilience of an individual or a group against disaster. It is the total internal and external strength to manage and reduce disaster risks. Capacity can be assessed by identifying gaps and improvements against desired goals in the current situation of the selected community. Different approaches to assess the preparedness for fire hazards are adopted in literature, depending on different goals and local conditions. (Wilkinson & Eriksen, 2015) studied how the availability of water could improve the capacity of a community against bushfire. The State Mine fire in the Blue Mountains, New South Wales, Australia happened due to the unavailability of the main grid water supply in the area. The study suggested effective water distribution and storage planning in the communities exposed to bush fire. (T. Collins, 2008) considered the social-economic factors of people to assess the mitigation capacity of a community against fire hazards. Lower-income houses were found to be less prepared as compared to higher-income households. Place dependency played a key role as house owners were independent of resource utilization for fire mitigation as compared to tenants. The study suggested incorporating a fire mitigation strategy in the agreement of house owners, tenants, and residential property management institutes.

(Poudel, 2019) explored the relationship between vulnerability and preparedness against disasters at the household level. The attributes of the resilient families and vulnerabilities were assessed by evaluating their resources and assistance. The study suggested that exposure, marginalization, and poverty remained barriers to the resilience of households against hazards. (Paton & Fantina, 2013) analyzed the existing forest fire management strategist in Portugal and suggested the incorporation of the preparedness of the communities. Better communication of fire risk in vulnerable communities can increase their preparedness. Also, fire management institutions should actively facilitate the capacity-building process of the community.

CHAPTER 3:

Methodology:

This study assesses the fire risk of households in an urban area of Pakistan. This model of fire risk assessment of households is being implemented in a typical city in Pakistan.

3.1 Study Area Selection:

A typical industrial city of Faisalabad was selected for risk assessment of household fire. Faisalabad is a relatively new city founded in 1890 during the colonial era of India. According to the latest census, the population of Faisalabad city is around 3.7 million (PBS, 2017). Further three areas were identified based on their urban structure and selected for further study. Digluspura was initially named Dogluspura, it was built as a residential area around 1920. Digluspura is a settled urban area with the oldest built houses in the city. Madina town became a municipally administered area in 2005, a planned residential area. Sitara-sapna is a peri-urban area designed as a housing society and was established recently. All three of these areas have distinct built-up patterns. Comparative analysis of household fire vulnerability of three distinct residential areas will result in a better understanding of the fire risk of households in the whole city of Faisalabad.

Map 1 Study area Faisalabad city

Map 2 Study area Digluspura

Map 3 Study area Madina town

Map 4 Study area Sitara-sapna city

3.2 Sampling:

Three communities; Digluspura (settled urban area), Madina town (Planned urban area), and Sitara-sapna city (sub-urban area) were subjected to in-depth Interviews based on a questionnaire survey from individual households conducted. A total of 231 households comprising 90 from Digluspura, 61 from Madina town, and 80 from Sitara-sapna city were sampled for this study using the random sampling method.

3.3 Data Collection:

The responses were recorded during different times of the day. Mostly the household heads volunteered to respond on behalf of their household. In some instances, household members collaborated in answering the questionnaire. Special Ccovid-19 precautionary measures were taken in collecting the responses. The survey team showed professionalism and patience in explaining the intentions of the questions as people were reluctant to respond to very personal but necessary questions for this study.

3.4 Data Analysis:

Primary data from three different areas within the city were collected during the year 2021 and assessed through an index-based approach for measuring vulnerability, preparedness, and perception of household fire hazards. Vulnerability is measured for different stages of household fire. For the comparative analysis of each dimension, the assessed vulnerability was classified as low, moderate, high, and very high. The intervals between these categories were based on their standard deviation values. ANOVA was used for the variance analysis to determine the difference between three study areas, where *p* shows the level of significance.

3.5 Social Profile of Respondents:

Most responses were given by the age group of 19 to 35 years. 66.7% of responses collected from DIgluspura community was from age group of 19 to 35 years. Most responses (34.4%) collected from Madina town community was from the age group of 36 to 50 years. From Sitara-sapna community the most responses were given by the age group of greater than 51 years (52.5%). Monthly income of the most of the surveyed households in Digluspura was between 30,000 to 1,30,000 rupees (66.7%), in Madina town was greater than 3,30,000 rupees (42.6%) and in Sitara-sapna was also greater than 3,30,000 rupees (50%). Maxim education level of households' heads in Digluspura was mostly Matric (51.1%), in Madina town was graduation (50%) and in Sitara-sapna was also graduation (57.5%). Overall 81% of the people own a business as the source of income. 27.8% houses in Digluspura were rental as compared to none in Madina town and Sitara-sapna. 87.8% houses in Digluspura were less than 5 Marla in area. Most houses in Madina town were between 11-15 Marla size (41%). Most houses in Sitara-sapna were between 16-20 Marla size (42.5%). Overall 83.1% households did not have any insurance. Most households in Digluspura had only one earning member (37.8%). Most households in Madina town had two earning members (41%). Most households in Sitara-sapna had one earning member (57.5%). Overall 31.6% households had only one child. 10% households in Digluspura had persona with disabilities as compared to 4.9% in Madina town and 1.3% in Sitara-sapna. Overall 74.9% households had elderly people. Only 10% of surveyed households had infants.

Table 1 Socio-economic profile of respondents															
S. No	Indicators	Classes	Digluspura		Madina town		Sitara-sapna city		Total		Mean	SD	x2	p
			Fr	%	Fr	%	Fr	%	Fr	%				
1	Age of the respondents (in years)	≤18	1	1.1	0	0	0	0	1	0.4	41.9	13.815	53.207	0.000
		19—35	60	66.7	15	24.6	12	15	87	37.7				
		36—50	16	17.8	21	34.4	26	32.5	63	27.3				
		≥51	13	14.4	25	41	42	52.5	80	34.6				
2	Monthly income (in rupees)	≤30000	30	33.3	1	1.1	0	0	31	13.4	293575.76	337990.715	60.711	0.000
		30000—130000	59	64.8	13	21.3	3	3.8	75	32.5				
		130000—230000	1	1.1	14	23	17	21.3	32	13.9				
		230000—330000	0	0	7	11.5	20	25	27	11.7				
		≥330000	0	0	26	42.6	40	50	66	28.6				
3	Household head's educational qualification	Illiterate	5	5.6	0	0	0	0	5	2.2	—	—	47.561	0.000
		Under-metric	25	27.8	0	0	0	0	25	10.8				
		Metric	46	51.1	25	41.7	25	31.3	96	41.6				
		Graduate	11	12.2	30	50	46	57.5	87	37.7				
		Post-graduate	3	3.3	5	8.3	9	11.3	17	7.4				
4	Household head's occupation	Informal	0	0	1	1.1	2	2.5	3	1.3	—	—	3.517	0.031
		Job	24	26.7	7	11.5	10	12.5	41	17.7				
		Own-business	66	73.3	53	86.9	68	85	187	81.0				
5	House ownership	Rental	25	27.8	0	0	0	0	25	10.8	—	—	14.915	0.000
		Leased	1	1.1	1	1.6	2	2.5	4	1.7				
		Owned	64	71.1	60	98.4	78	97.5	202	87.4				
6	Size of the house (in Marla)	≤5	79	87.8	5	8.2	1	1.3	85	36.8	—	—	212.54	0.000
		6—10	11	12.2	7	11.5	11	13.8	29	12.6				
		11—15	0	0	25	41	27	33.8	52	22.5				
		16—20	0	0	13	21.3	34	42.5	47	20.3				
		≥20	0	0	11	18	7	8.8	18	7.8				
7	Insurance	Not-insured	73	81.1	46	75.4	73	91.3	192	83.1	—	—	3.336	0.037
		Health-insurance	1	1.1	2	3.3	2	2.5	5	2.2				
		Life-insurance	12	13.3	12	19.7	4	5	28	12.1				
		Property-insurance	4	4.4	1	1.6	1	1.3	6	2.6				
		Fire-insurance	0	0	0	0	0	0	0	0.0				
8		0	5	5.6	2	3.3	4	5	11	4.8	1.77	1.106	7.637	0.001

	No. of employed persons in the household	1	34	37.8	20	32.8	46	57.5	100	43.3				
		2	25	27.8	25	41	26	32.5	76	32.9				
		3	19	21.1	10	16.4	3	3.8	32	13.9				
		≥4	7	7.8	4	6.6	1	1.3	12	5.2				
9	No. of children (less than 18 y/o)	0	0	0	0	0	0	0	0	0.0	1.48	1.389	3.11	0.046
		1	29	32.2	17	27.9	27	33.8	73	31.6				
		2	12	13.3	20	32.8	20	25	52	22.5				
		3	22	24.4	17	27.9	18	22.5	57	24.7				
		4	13	14.4	5	8.2	11	13.8	29	12.6				
		≥5	14	15.6	2	3.3	4	5	20	8.7				
10	The person with disabilities in household	Yes	9	10	3	4.9	1	1.3	13	5.6	—	—	2.321	0.1
		No	81	90	58	95.1	79	98.7	218	94.4				
11	Elderly in the household (more than 60 y/o)	Yes	54	60	52	85.2	67	83.8	173	74.9	—	—	9.484	0.000
		No	36	40	9	14.8	13	16.3	58	25.1				
12	Infants in household	Yes	12	86.5	3	4.9	8	10	23	10.0	—	—	2.373	0.095
		No	77	13.5	58	95.1	72	90	207	89.6				

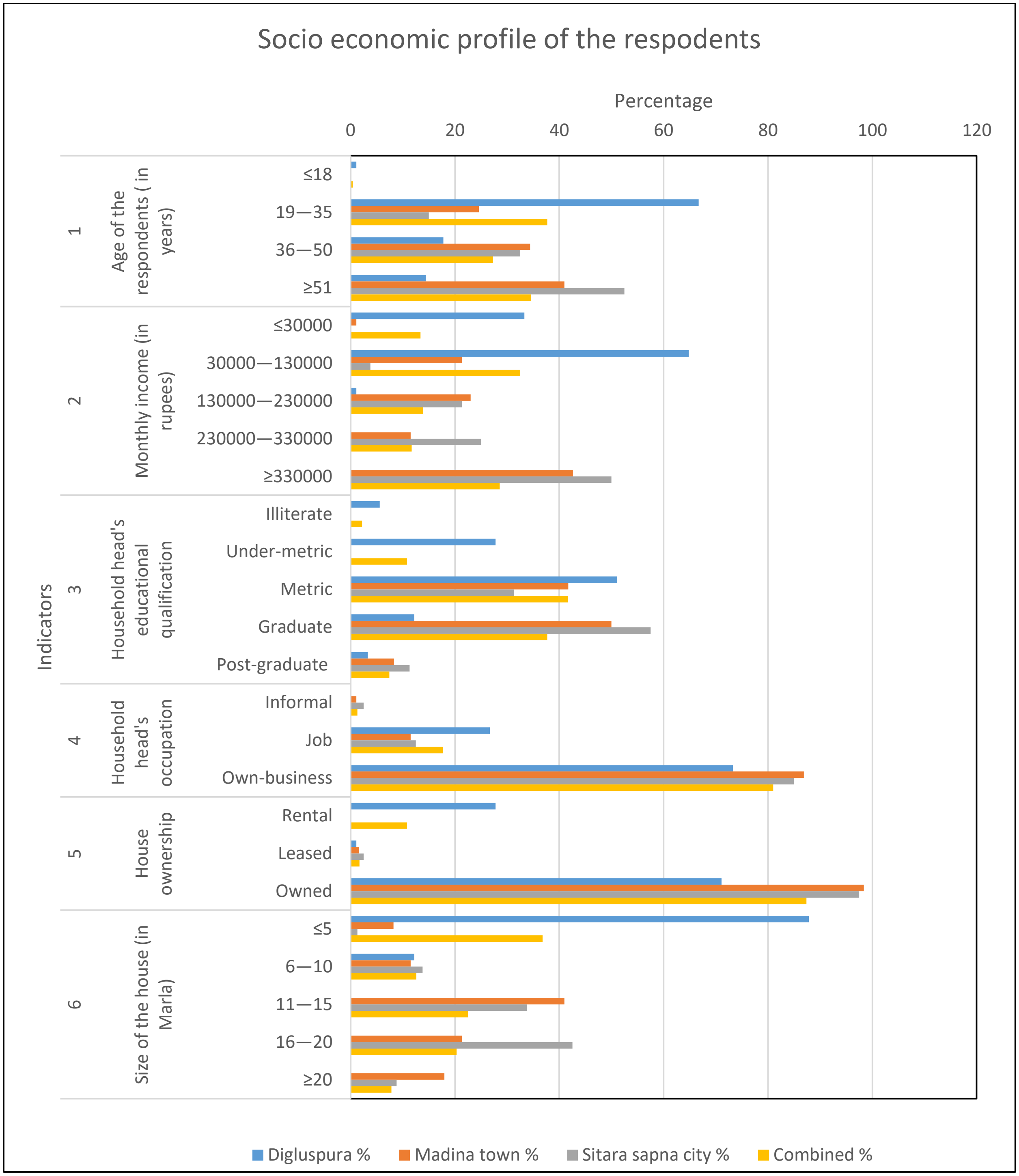

Figure 4 Socio-economic profile of the respondents

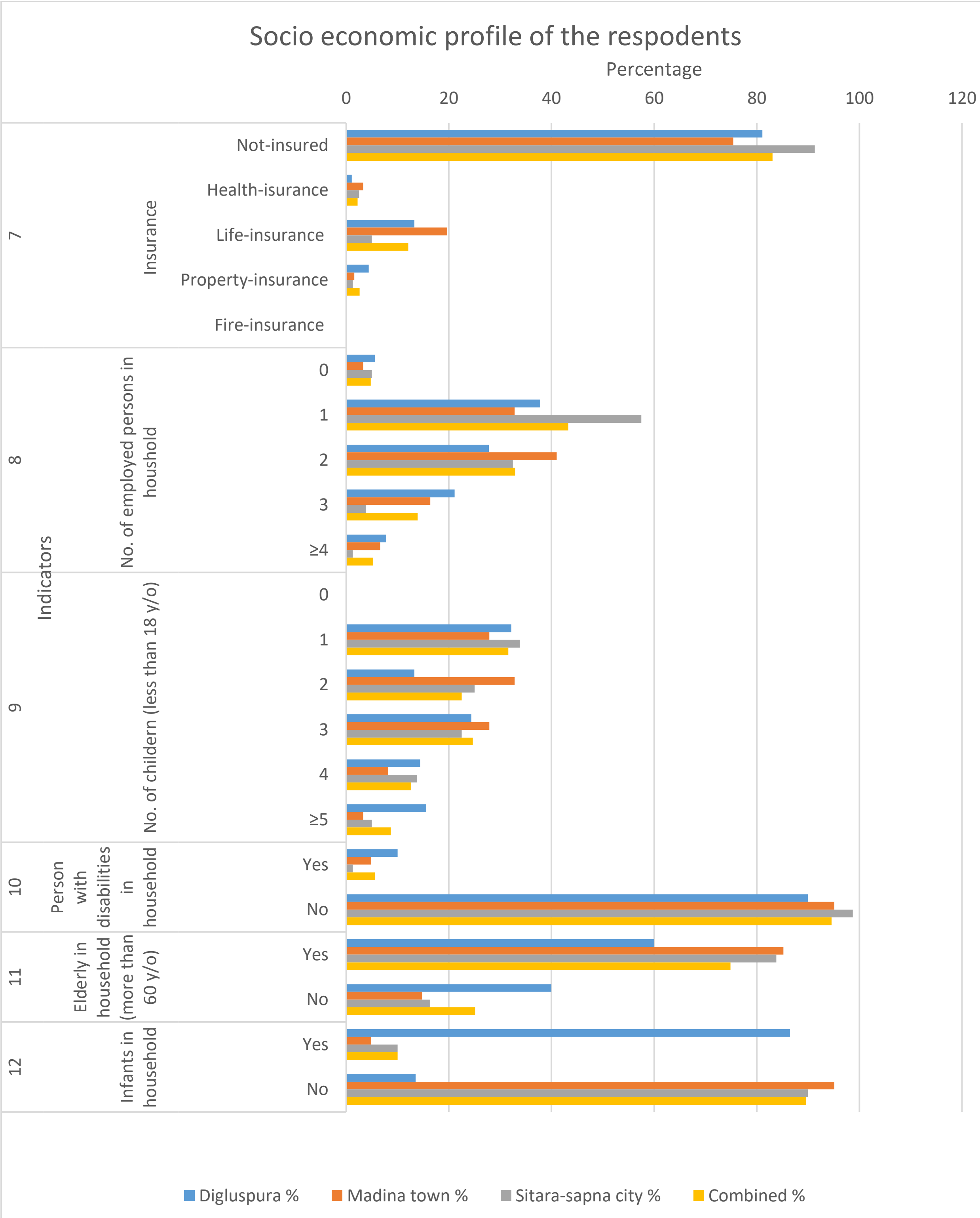

Figure 5 Socio-economic profile of the respondents

3.6 Methodological Framework:

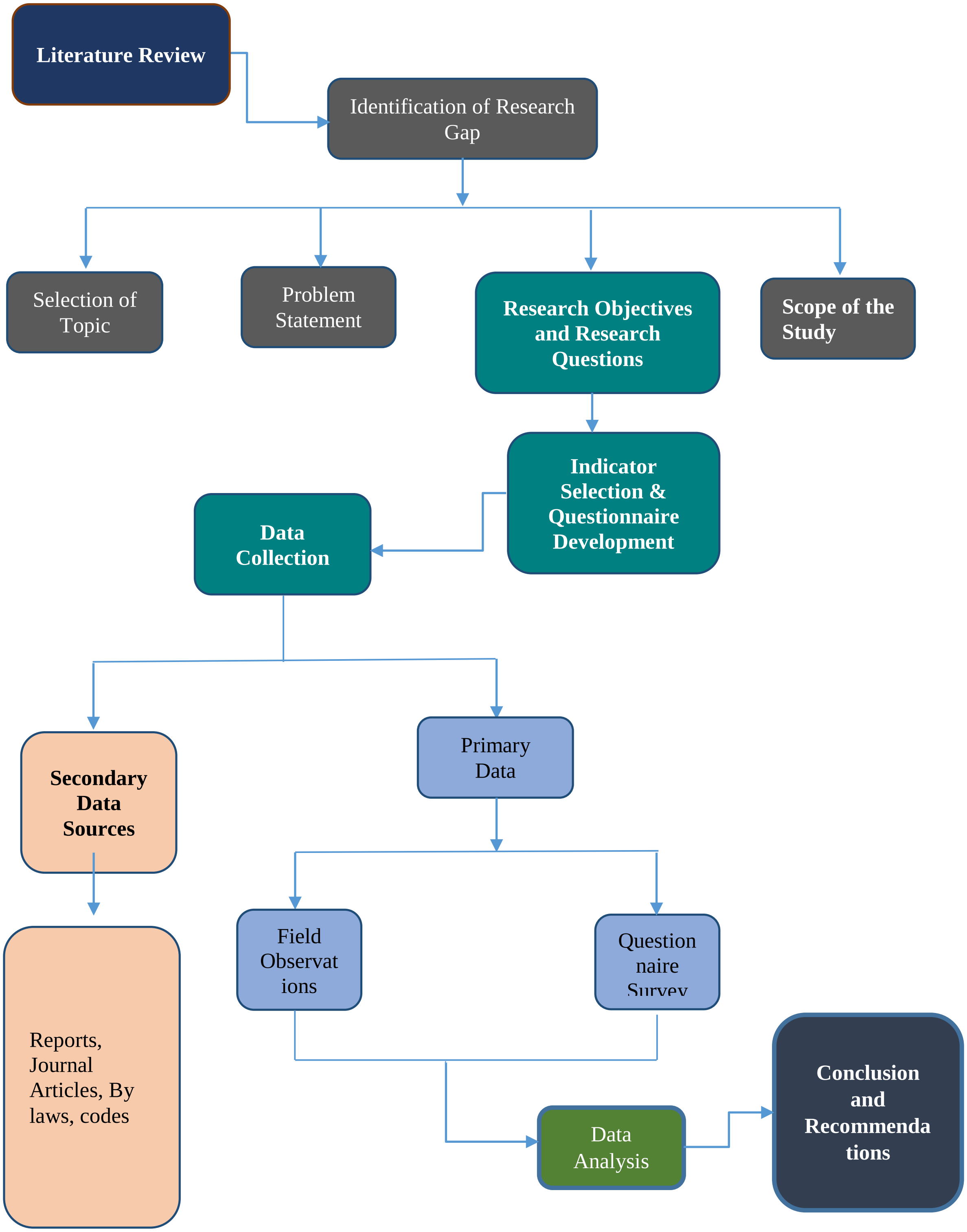

Figure 6 Methodological flowchart

CHAPTER 4:

Fire Vulnerability Assessment:

4.1 Assessment methodology:

Fire vulnerability assessment in a residential unit is done by analyzing the factors of vulnerability at all stages of household fire. The ignition phase is the initial phase of the fire when a spark initiates the fire. During the development phase the combustion-able materials start burning, this stage is comprised of two sub-stages growth and burning. During the growth, stage fire spread and encapsulates other combustion-able materials around it. In the burning stage, all the available combustion-able material within the range of fire keeps burning until it reaches the final phase of decay, where the material is eventually completely burnt. During these stages, multiple factors affect the vulnerability of the house and its occupants as shown in Fig 7. An index-based model was established considering the different stages of household fire. Indicators for vulnerability were chosen from empirical studies of household fires and scrutinized to the local conditions. Indicators were also chosen from the disaster management and climate change studies for the socio-economic vulnerability subjected to household fire.

For this study 11 indicators of socio-economic vulnerability, 27 indicators of vulnerability during the fire ignition phase, 7 indicators of vulnerability during fire combat, 18 indicators of vulnerability during the fire development phase, and 11 indicators of vulnerability during the fire escape phase were selected. These indicators represent both infrastructural and behavioral factors of vulnerability during stages of household fire. These five phases were given equal weightage for calculating the multi-phase vulnerability index. Computation of these indicators was done through the subjective weighting technique (Rana & Routray, 2018a) shown in Table 2. Original values of the indicators are transformed to 0-1 based on the intensity of vulnerability, where 0 is considered the lowest and 1 is the highest. A composite index of vulnerability is then derived for each dimension of household fire through the formula shown in Eq 2.

Eq 2 Composite Index = $(W_1+W_2+W_3+\ldots W_n)/n$

$$= \sum_{i=1}^{n} Wi/n$$

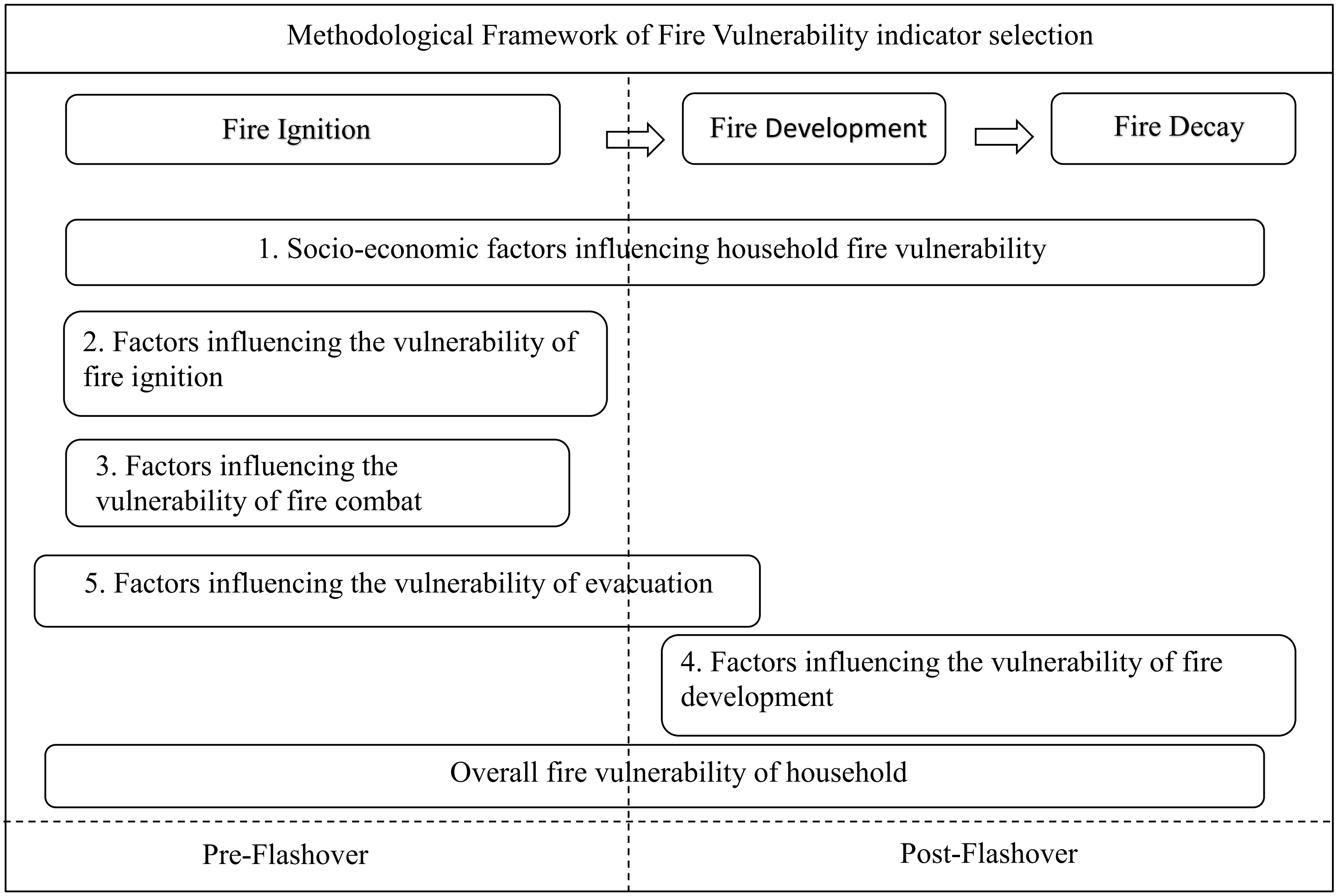

Figure 7 Factors affecting vulnerability during the household fire

Where CI is the composite index, W_1 to W_n are the respective transformed values of the indicators used to drive the composite index.

Following the same equation Socio-economic Vulnerability Index (SEVI), Fire Ignition Phase Vulnerability Index (FIPVI), Fire Combat Phase Vulnerability Index (FCPVI), Fire Development Phase Vulnerability Index (FDPVI), and Fire Escape Phase Vulnerability Index (FEPVI) were calculated. Multi-phase Vulnerability Index for each household was calculated according to *Eq 2*.

Eq 3 $\text{Socio} - \text{Economic Vulnerability Index} = \sum_{i=1}^{11} \frac{\text{SEVWi}}{\text{n}}$ $(n = 11)$

Eq 4 $\text{Fire Ignition Phase Vulnerability Index} = \sum_{i=1}^{27} \frac{\text{FIPVWi}}{\text{n}}$ $(n = 27)$

Eq 5 $\text{Fire Combat Phase Vulnerability Index} = \sum_{i=1}^{7} \frac{FCPVWi}{n}$ $(n = 7)$

Eq 6 $\text{Fire Development Phase Vulnerability Index} = \sum_{i=1}^{18} \frac{\text{FDPVWi}}{\text{n}}$ $(n = 18)$

$$\text{Eq 7 Fire Escape Phase Vulnerability Index} = \sum_{i=1}^{11} \frac{\text{FEPVWi}}{n} \qquad (n = 11)$$

$$\text{Eq 8 Multi} - \text{Phase Fire Vulnerability Index} = \frac{\text{SEVI+FIPVI+FCPVI+FDPVI+FEPVI}}{5}$$

4.2 Indicators for fire vulnerability:

Table 2 Indicators and transformed values for phases of vulnerability to household fire hazards in Faisalabad, Pakistan

S#	Ind.	Indicators	Classes	Transformed values	Explanation	Empirical references
Socio-economic Vulnerability						
1	W_1	Monthly income (in rupees)	≤30000	1	The higher the household income lesser might be the vulnerability	(Cutter et al., 2003), (Balica et al., 2009)
			30000—130000	0.8		
			130000—230000	0.6		
			230000—330000	0.4		
			≥330000	0.2		
2	W_2	Household head's educational qualification	Illiterate	1	Low literacy will render less understanding of safety protocols	(Hahn et al., 2009), (Pandey & Jha, 2012), (Armaş, 2012)
			Under-metric	0.8		
			Metric	0.6		
			Graduate	0.4		
			Post-graduate	0.2		
3	W_3	Household head's occupation	Unemployed	1	A secure stream of income will decrease the vulnerability	(Rana & Routray, 2018b)
			Employed	0.67		
			Own-business	0.33		
4	W_4	House ownership	Rental	1	Occupants of rented houses are less prepared as compared to owned houses	(Cutter et al., 2003), (Rana & Routray, 2018b)
			Leased	0.67		
			Owned	0.33		
5	W_5	Insurance	Not-insured	1	Type of insurance ensures preparedness against the relevant hazard	(Warner, Koko; Ranger, Nicola; Surminski, Swenja; Arnold, Margaret; Linnnerooth-Bayer, Joanne; Michel-Kerjan, Erwann; Kovacs, Paul; Herweijer, 2009)
			Health-insurance	0.8		
			Life-insurance	0.6		
			Property-insurance	0.4		
			Fire-insurance	0.2		
6	W_6	No. of employed persons in the household	0	1	More employed persons in a household mean a greater level of shared responsibilities in case of disasters	(Balkenhol et al., 2009)
			1	0.8		
			2	0.6		
			3	0.4		
			≥4	0.2		
7	W_{22}	No. of children (less than 18 y/o)	0	0	More children mean greater vulnerability in case of household fire	(Pollack-Nelson et al., 2006), (Shokouhi et al., 2019)
			1	0.2		
			2	0.4		
			3	0.6		
			4	0.8		
			≥5	1		
8	…….. W_{35}	The person with disabilities in household	Yes	1	Persons with disability are more vulnerable in escaping the fire	(Fernández-Vigil & Echeverría Trueba, 2019), (Runyan et al., 1992)
			No	0		
9	W_{36}	Elderly in household	Yes	1		

			No	0	Elderly persons are more vulnerable in case of fire	(Fernández-Vigil & Echeverría Trueba, 2019)
10	W_{37}	Infants in household	Yes	1	Infants are more vulnerable in case of fire	(Lal & Bhatti, 2017)
			No	0		
11	W_{38}	Other people at most risk in household	Yes	1	For example people with an illness, fatigue, or other health issues	(Fernández-Vigil & Echeverría Trueba, 2019)
			No	0		
Vulnerability in the fire ignition phase						
1	W_7	Smoking inside house	Yes	1	Cigarettes are a contact risk of igniting the fire	(Ahrens, 2019)
			No	0		
2	W_8	Electrical wiring earthed	Yes	1	An electric system that is not earthed can cause electric shock and fire	(Ahrens, 2016)
			No	0		
3	W_9	Short-circuit switch in the electrical system	Yes	1	The Presence of short-circuit switch prevents short circuit fires	(Ahrens, 2016)
			No	0		
4	W_{10}	Cracks, bends, or heat marks on electric wires	Yes	1	Faulty wires can cause sparking and fire	(Ahrens, 2016)
			No	0		
5	W_{11}	Electric items left switched on permanently	Yes	1	Long-term use of electric equipment can cause overheating and fire	(Ahrens, 2016)
			No	0		
6	W_{12}	Use of wooden or coal stove	Yes	1	Fire fumes from wooden and coal stoves can initiate fire	
			No	0		
7	W_{13}	The permanent presence of combustion-able material near the stove (within 70 cm height)	Yes	1	Fumes can ignite the fire in combustion-able material located within the height of 70 cm	(Chow & Xiaomin, 2014)
			No	0		
8	W_{14}	Regular maintenance of the stove	Yes	0	Maintenance of stove can prevent fire ignition	(Chow & Xiaomin, 2014)
			No	1		
9	W_{15}	More than 1 functional stove	Yes	1	More stoves mean more vulnerability	
			No	0		
10	W_{16}	Excessive use of stove (more than 3 times per day)	Yes	1	Excessive use of the stove, cooking for longer periods and unattended cooking adds more vulnerability	
			No	0		
11	W_{17}	Gas leakage (smell)	Yes	1	Leaked gas can catch fire abruptly	(Campbell, 2021)
			No	0		
12	W_{18}	Use of candle or other burning sources of light	Yes	1	A constant source of fire risk	(Miller, 2005)
			No	0		
13	W_{19}	Regular use of candle	Yes	1	Regular use of candles means more risk	
			No	0		
14	W_{20}	Placing a candle in a non-combustion-able pan (while using)	Yes	0	Unsafe use of candles means more fire risk	(Miller, 2005)
			No	1		
15	W_{21}		Yes	0		(Miller, 2005)

		Placing a candle in a safe place	No	1	Unsafe use of candles means more fire risk	
16	W_{23}	Children playing with fire	Yes	1	Children not being sensitized to the risks of playing with fire adds to more vulnerability	(Miller, 2005)
			No	0		
17	W_{24}	Children's awareness about fire hazard	Yes	0	Children not being sensitized to the risks of playing with fire adds to more vulnerability	Kodur and Kumar (2019)
			No	1		
18	W_{25}	Wood or coal heaters	Yes	1	Fumes from wood or coal heater can ignite the fire	
			No	0		
19	W_{26}	No. of heater units	0	0	More heater units mean more vulnerability	
			1	0.25		
			2	0.5		
			3	0.75		
			≥4	1		
20	W_{27}	Presence of flammable items (proximity of 1m of heaters)	Yes	1	Combustion-able material in 1m proximity of heaters can catch fire	(Campbell, 2021)
			No	0		
21	W_{28}	Pilot light working in heaters	Yes	0	The pilot light can prevent gas leakages	
			No	1		
22	W_{29}	Discolored walls in heater	Yes	1	Faulty heaters are a constant threat to fire	
			No	0		
23	W_{30}	Regular use of heater (during winter)	Yes	1	More use of heater means more vulnerability	
			No	0		
24	W_{31}	Regular maintenance of heaters	Yes	0	Less maintenance of heaters means more vulnerability	(Campbell, 2021)
			No	1		
25	W_{32}	No. of electrical washing machines	1	0.33	A washing machine is a heavy-duty electric appliance that can cause a fire in a supply board	(Miller, 2005)
			2	0.67		
			≥3	1		
26	W_{33}	No. of electrical irons	0	0	Iron is a heavy-duty electric appliance that can cause a fire in a supply board	(Miller, 2005)
			1	0.33		
			2	0.67		
			≥3	1		
27	W_{34}	No. of other heavy-duty electric machines	0	0	Heavy-duty electric appliances can cause a fire in the supply board	
			1—2	0.2		
			3—4	0.4		
			5—6	0.6		
			7—8	0.8		
			≥9	1		
Vulnerability at fire combat phase						
1	W_{39}	No. of active household members	0	1	More the number of active household	(Kobes et al., 2010a)
			1—3	0.8		

			4—6	0.6	members can better detect and defuse fire at the ignition stage, lesser will be the fire vulnerability	
			7—8	0.4		
			≥9	0.2		
2	W_{40}	No. of household members who know the use of fire-fighting equipment	0	1	More the number of household members who can use fire-fighting equipment, the lesser will be the fire vulnerability	(Kobes et al., 2010a)
			1	0.8		
			2	0.6		
			3	0.4		
			≥4	0.2		
3	W_{41}	No. of household members who have used the fire-fighting equipment before	0	1	More the number of household members who are trained to use fire-fighting equipment, the lesser will be the fire vulnerability	(Kobes et al., 2010a)
			1—2	0.8		
			3	0.6		
			4—5	0.4		
			≥6	0.2		
4	W_{42}	No. of household members who can detect the early signs of fire (smell of smoke)	0	1	More the number of household members who can detect the fire ignition, the lesser will be the fire vulnerability	(Kobes et al., 2010a)
			1—3	0.8		
			4—6	0.6		
			7—8	0.4		
			≥9	0.2		
5	W_{43}	No. of household members who have successfully detected the signs of early fire	0	1	More the number of household members who have experience in detecting the fire at the ignition stage, the lesser will be the fire vulnerability	(Kobes et al., 2010a)
			1—3	0.8		
			4—6	0.6		
			7—9	0.4		
			≥10	0.2		
6	W_{44}	No. of active members who have successfully extinguished the early fire in past	0	1	More the number of household members who have experienced extinguishing the fire at the ignition stage before, the lesser will be the fire vulnerability	(Kobes et al., 2010a)
			1	0.8		
			2	0.6		
			3	0.4		
			≥4	0.2		
7	W_{45}	How often do active members stay at home	24 hours	0.33	The longer the active members stay, the lesser will be the fire vulnerability	(Kobes et al., 2010a)
			12 hours	0.67		
			less than 12 hours	1		
Vulnerability in the fire development phase						
1	W_{46}	Presence of an automatic fire extinction system	Yes	0	The presence of an automatic fire extinction system means less fire vulnerability	(Xin & Huang, 2013)
			No	1		
2	W_{47}	The covered area of automatic fire extinction system	None	1	More the area of the house is covered by an automatic fire extinction system, less will be the fire vulnerability	(Xin & Huang, 2013)
			Most vulnerable rooms (kitchen)	0.67		
			Major rooms	0.33		
			Whole house	0		
3	W_{48}	Type of fire-fighting equipment available in the house	None	1	Availability of better type of fire-extinction equipment means less fire vulnerability	(Islam & Adri, 2008)
			Water buckets	0.75		
			Sand buckets	0.5		

			Fire-extinguishers	0.25		
4	W_{49}	Age of house (years)	0—1	0.2	The older the house is, the more will be the fire vulnerability	(Granda & Ferreira, 2019)
			2—18	0.4		
			19—36	0.6		
			37—53	0.8		
			≥54	1		
5	W_{50}	Area of the house (Marla)	0—3	1	Smaller the area of the house, smoke will spread quickly. This means more vulnerability	
			4—14	0.8		
			15—26	0.6		
			27—37	0.4		
			≥38	0.2		
6	W_{51}	No. of rooms in the house	0—3	1	More rooms mean better compartmentation against fire and smoke. This means lesser vulnerability	(Littlewood et al., 2017)
			4—6	0.8		
			7—8	0.6		
			9—11	0.4		
			≥12	0.2		
7	W_{52}	No. of stories in house	1	0.33	More number of stories equates to more structural load. In the case of fire, it means more structural vulnerability	(Littlewood et al., 2017)
			2	0.67		
			≥3	1		
8	W_{53}	No. of sides having a common wall with the neighboring house	0	1	Common walls with neighboring houses cause the spread of smoke and fire. This means more vulnerability	
			1	0.75		
			2	0.5		
			3	0.25		
9	W_{54}	Structural system in the house	RCC	0.33	The structural system which is less resistant to fire adds more vulnerability	(Prager et al., 2020)
			Steel girders	0.67		
			Wooden	1		
10	W_{55}	Fire-load (number of combustion-able items)	≤13	0.2	More the fire load the more will be the fire vulnerability	(Wei et al., 2018)
			14—23	0.4		
			24—33	0.6		
			34—43	0.8		
			≥44	1		
11	W_{56}	Thickness of walls	≤9	1	The lesser the thickness of the walls, the lesser will be the compartmentation. This means more fire vulnerability	(Wei et al., 2018)
			10—14	0.67		
			≥15	0.33		
12	W_{57}	Wall covering (plastering)	Yes	0	A plastered wall can resist fire and radiate lesser heat on the opposite side. This means lesser fire vulnerability	(Industry Association, 2008)
			No	1		
13	W_{58}	Type of bricks	Concrete (non-hollowed)	1	Better fire resistance of the material of	(Industry Association, 2008)
			Clay	0.67		

			Concrete (hollowed)	0.33	bricks means lesser fire vulnerability	
14	W_{59}	Total No. of exterior openings (vents, windows, doors,, androof openingss)	≤9	1	The more more the number of exteropeningsnings, the more will be the chances of sescapingping. And, lesser will be the fire vulnerability	(Wei et al., 2018)
			10—13	0.8		
			14—17	0.6		
			18—21	0.4		
			≥22	0.2		
15	W_{60}	Total No. of interior openings (vents, windows,, and doors)	≤10	0.2	The more more the number of exteopeningsenthe ing, the more will be the chances of smoke spreading within the unit. And, more will be the fire vulnerability	(Wei et al., 2018)
			11—45	0.4		
			46—81	0.6		
			82—116	0.8		
			≥117	1		
16	W_{61}	Water connection	None	1	A consistent water connection in a house reduces its fire vulnerability	(Occupational Safety and Health Administration, 2015)
			Municipal	0.67		
			Ground	0.33		
17	W_{62}	Size of water storage tank (liters)	≤100	1	More quantity of water storage in the house reduces its fire vulnerability	(Occupational Safety and Health Administration, 2015)
			101—137	0.8		
			138—178	0.6		
			179—480	0.4		
			≥481	0.2		
18	W_{63}	Availability of water storage in adjacent neighbors	Yes	0	Availability of stored water in close vicinity to the house can reduce its fire vulnerability	
			No	1		
Vulnerability in the fire escape phase						
1	W_{64}	No. of exit doors in the house	1	1	A greater number of exit doors means greater chances of evacuation. This means less fire vulnerability	(Wei et al., 2018)
			2	0.67		
			≥3	0.33		
2	W_{65}	Length of exit corridor (foot)	≤8	0.2	Lesser length of evacuation passageways means lesser fire vulnerability	(Wei et al., 2018)
			9—12	0.4		
			13—17	0.6		
			18—21	0.8		
			≥22	1		
3	W_{66}	Availability of immoveable stairs that can be used for evacuating from upper floors	Yes	0	The availability of fire escape stairs can reduce fire vulnerability	
			No	1		
4	W_{67}	Availability of passageway that can be used for evacuating from upper floors (escape route to neighbor's roof)	Yes	0	Availability of escape passageways to neighboring buildings can reduce fire vulnerability	
			No	1		
5	W_{68}	Width of exit corridor (foot)	≤2.5	1	More the width of exit corridor, lesser changes	(Wei et al., 2018)
			2.6—3.5	0.8		

			3.6—4.5	0.6	of crowding. This means lesser fire vulnerability	
			4.6—5.5	0.4		
			≥5.6	0.2		
6	W_{69}	Width of exit doors (foot)	≤2.5	1	More the width of the exit door, it will be easier to escape. This means lesser vulnerability	(Wei et al., 2018)
			2.6—3.5	0.8		
			3.6—4.5	0.6		
			4.6—5.5	0.4		
			≥5.6	0.2		
7	W_{70}	The direction of the opening of the exit door	Inwards	1	Outwards opening system of exit doors presents better chances of safe escape. This means lesser vulnerability	(Wei et al., 2018)
			Outwards	0		
8	W_{71}	Presence of hurdles in the evacuation passageway	Yes	1	Hurdles in the evacuation passageway reduce the chance of safe escape. This means more vulnerability	(Wagner & Agrawal, 2014)
			No	0		
9	W_{72}	Availability of ladder (that can be used for evacuation)	Yes	0	Moveable stairs can be used in escaping from upper floors. This means lesser vulnerability	(Wei et al., 2018)
			No	1		
10	W_{73}	Availability of ladder in neighborhood (that can be used for evacuation)	Yes	0	Moveable stairs can be used in escaping from upper floors. This means lesser vulnerability	(Wei et al., 2018)
			No	1		
11	W_{74}	Width of street (feet)	≤4	1	More width of the street means more room for avacuation. This means lesser vulnerability	(Occupational Safety and Health Administration, 2015)
			5—11	0.8		
			12—17	0.6		
			18—24	0.4		
			≥25	0.2		

4.3 Socio-economic vulnerability:

Surveyed houses in Digluspura were of small size mostly under 1400 sq. ft (86.8%) and 71.1% of houses were owned. The income source of most of the households in Digluspura was small businesses (73.3%), and 18.9% of household heads were making equal to or less than minimum wage (PKR 25000/- per month). 73% of households had no insurance of any kind in Digluspura. 10% of households had persons with disabilities, 14.4% infants, and overall 57.8% of households considered one or more persons at most risk in case of household fire in the Digluspura community. Surveyed houses in Madina town were large mostly over 2800 sq. ft (80.3%) and 98.4% of houses were owned. Residents of Madina town were mostly business owners (86.9%) with an average monthly income of more than PKR 450000/-. 75.4% of households in Madina town had no insurance of any kind. 4% of households had a person with disabilities, 85.3% had one or more elderly persons and overall 65.6% of households considered one or more persons at most risk in case of household fire in the Madina town community. 76.3% of houses in Sitara-Sapna city community had an area of more than 2800 sq. ft with 97.5% ownership. Only 8.8% of the household had insurance, and 85% of households owned a business with a mean income of more than PKR 450000/- per month. 37.6% of households had more than one earning member. Overall 90% of households considered one or more person at most risk in case of household fire in Sitara-Sapna city community.

The socio-economic vulnerability index for the Digluspura community was ranged from 0.30 to 0.75 with a mean value of 0.54, for Madina town the range of socio-economic vulnerability was found to be from 0.35 to 0.61 with a mean value of 0.47 and for Sitara-sapna city community the range of socio-economic vulnerability was found to be from 0.37 to 0.66 with a mean value of 0.50.

There is a serious need to increase the insurance cap of all three study areas. Digluspura being the most socioeconomically vulnerable needs more attention in elevating the household fire vulnerability.

Table 3 Socio-economic vulnerability to household fire in Diglus Pura, Madina Town and Sitara-sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)								
Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.45	0.46−0.54	0.55−0.63	≥0.64		Min =0.30	*F =14.690*
	No. of HHs	14	35	23	18	90	Max =0.75	df =2
	%	15.6	38.9	25.6	20	100	Mean =0.54	*p value =0.00*
							SD =0.09110	
Madina Town	Range	≤0.41	0.42−0.48	0.49−0.54	≥0.55		Min =0.35	
	No. of HHs	12	14	26	9	61	Max =0.61	
	%	19.7	23	42.6	14.8	100	Mean =0.4751	
							SD =0.05996	
Sitara-sapna city	Range	≤0.44	0.45−0.50	0.51−0.56	≥0.57		Min =0.37	
	No. of HHs	14	25	30	11	80	Max =0.66	
	%	17.5	31.3	37.5	13.8	100	Mean =0.5015	
							SD =0.06096	
Total	No. of HHs	40	74	79	38	231		
	%	17.3	32	34.2	16.5	100		

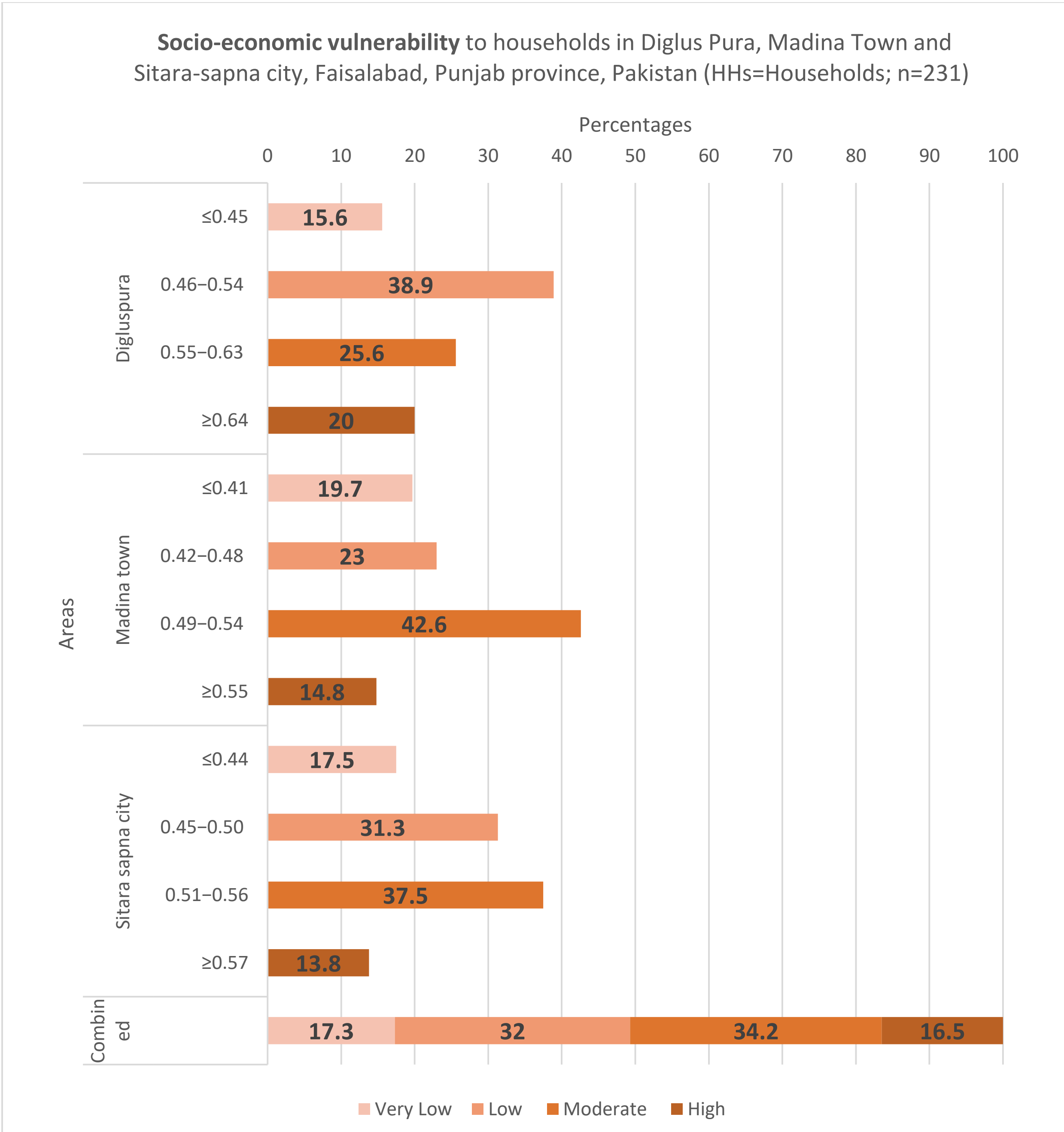

Figure 8 Socio-economic vulnerability

4.4 Fire ignition phase vulnerability:

Fire ignition phase vulnerability involves the physical and attitudinal indicators of vulnerability for fire ignition. 21.1% of households in Digluspura, 60.7% in Madina town, and 65% in Sitara-sapna city community had members who smoke inside the house. The electrical system of the house was not earthed in most of the surveyed houses in all three communities (90% in Digluspura, 100% in Madina town, and 93.8% in Sitara-sapna city). 42.2% of houses in Digluspura, 3.3% of houses in Madina town, and 5% of houses in Sitara-sapna city had faulty electrical wiring. In all 3 communities, people had a habit of keeping one or more electrical items switched on all the time. Due to load shedding, 80% of houses in Digluspura used a burning source of light like candles and oil lamps, and 14.5% of them were not observing necessary safety practices for using candles and oil lamps. Overall vulnerability at the fire ignition stage in the three communities was significantly different (F=45.7 and p value=0.00). In the Digluspura community vulnerability at the ignition stage varied from 0.22 to 0.60 with a mean value of 0.3794, in the Madina town community it varied from 0.34 to 0.55 with a mean value of 0.4547 and in Sitara-sapna city community it varied from 0.35 to 0.57 with a mean value at 0.4613. Overall, 32.5% of houses were moderately vulnerable and 15.6% were highly vulnerable.

Table 4 Fire ignition phase vulnerability of households in Diglus Pura, Madina Town, and Sitara-sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)								
Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.30	0.31−0.38	0.39−0.46	≥0.47		Min =0.22	*F =45.702*
	No. of HHs	12	37	25	16	90	Max =0.60	df =2
	%	13.3	41.1	27.8	17.8	100	Mean =0.3794	*p value =0.00*
							SD =0.08175	
Madina Town	Range	≤0.42	0.43−0.45	0.46−0.49	≥0.50		Min =0.34	
	No. of HHs	7	25	22	7	61	Max =0.55	
	%	11.5	41.0	36.1	11.5	100	Mean =0.4547	
							SD =0.03923	
Sitara-sapna city	Range	≤0.41	0.42−0.46	0.47−0.51	≥0.52		Min =0.35	
	No. of HHs	17	22	28	13	80	Max =0.57	
	%	21.3	27.5	35	16.3	100	Mean =0.4613	
							SD =0.04686	
Total	No. of HHs	36	84	75	36	231		
	%	15.6	36.3	32.5	15.6	100		

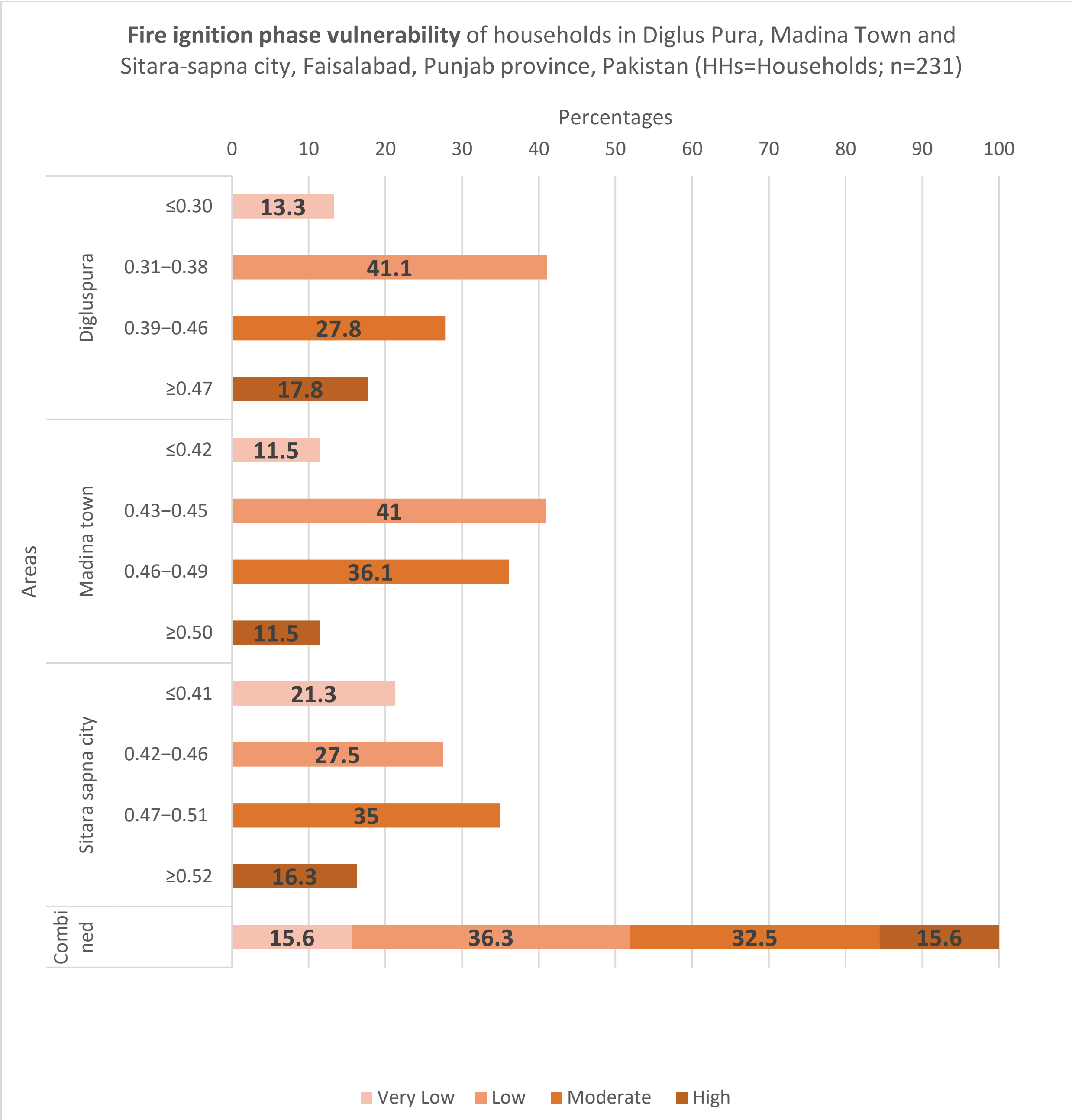

Figure 9 Fire ignition phase vulnerability

4.5 Fire combat phase vulnerability:

Fire combat phase vulnerability was assessed through the capacity of residents to detect and extinguishing the fire at an early stage. 97.8% of households in the Digluspura community claimed to have one or more active members who could fight the early fire, and 95.6% of these active members knew how to use the basic firefighting equipment. 83.3% claimed to have experience in using firefighting equipment, 92.2% were confident that they could detect the early fire inside their house, 85.6% claimed to have successfully detected early fire in the past, 80% claimed to have successfully extinguished the early fire in the past. In 66.7% of households, these active members stayed home for less than 12 hours during the day.

100% of households in the Madina town community claimed to have one or more active members who could fight the early fire, and 96.7% of these active members knew how to use the basic firefighting equipment. 57.4% claimed to have experience in using firefighting equipment, 65.6% were confident that they could detect the early fire inside their house, 60.7% claimed to have successfully detected early fire in the past, 60.7% claimed to have successfully extinguished the early fire in the past. In 85.2% of households, these active members stayed home for less than 12 hours during the day.

98.7% of households in the Sitara-sapna city community claimed to have one or more active members who can fight the early fire, and 96.2% of these active members knew how to use the basic firefighting equipment. 95% claimed to have experience in using firefighting equipment, 87.5% were confident that they could detect the early fire inside their house, 97.5% claimed to have successfully detected early fire in the past, and 100% claimed to have successfully extinguished the early fire in the past. In 88.8% of households, these active members stayed home for less than 12 hours during the day.

A significant difference was seen among the three communities in overall fire combat vulnerability (F=7.284 and p=0.001). Highly vulnerable households in Digluspura, Madina town, and Sitara-sapna city were 7.8%, 11.5%, and 12.5% respectively.

Table 5 Fire combat phase vulnerability of households in Diglus Pura, Madina Town and Sitara-sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)

Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.68	0.69−0.75	0.76−0.81	≥0.82		Min =0.46	*F =7.284*
	No. of HHs	8	24	51	7	90	Max =0.91	df =2
	%	8.9	26.7	56.7	7.8	100	Mean =0.7527	*p value =0.001*
							SD =0.06290	
Madina Town	Range	≤0.74	0.75−0.79	0.80−0.84	≥0.85		Min =0.65	
	No. of HHs	8	18	28	7	61	Max =0.88	
	%	13.1	29.5	45.9	11.5	100	Mean =0.7871	
							SD =0.04881	
Sitara-sapna city	Range	≤0.72	0.73−0.76	0.77−0.81	≥0.82		Min =0.64	
	No. of HHs	13	33	24	10	80	Max =0.91	
	%	16.3	41.3	30	12.5	100	Mean =0.7660	
							SD =0.04766	
Total	No. of HHs	29	75	103	24	231		
	%	12.5	32.5	44.6	10.4	100		

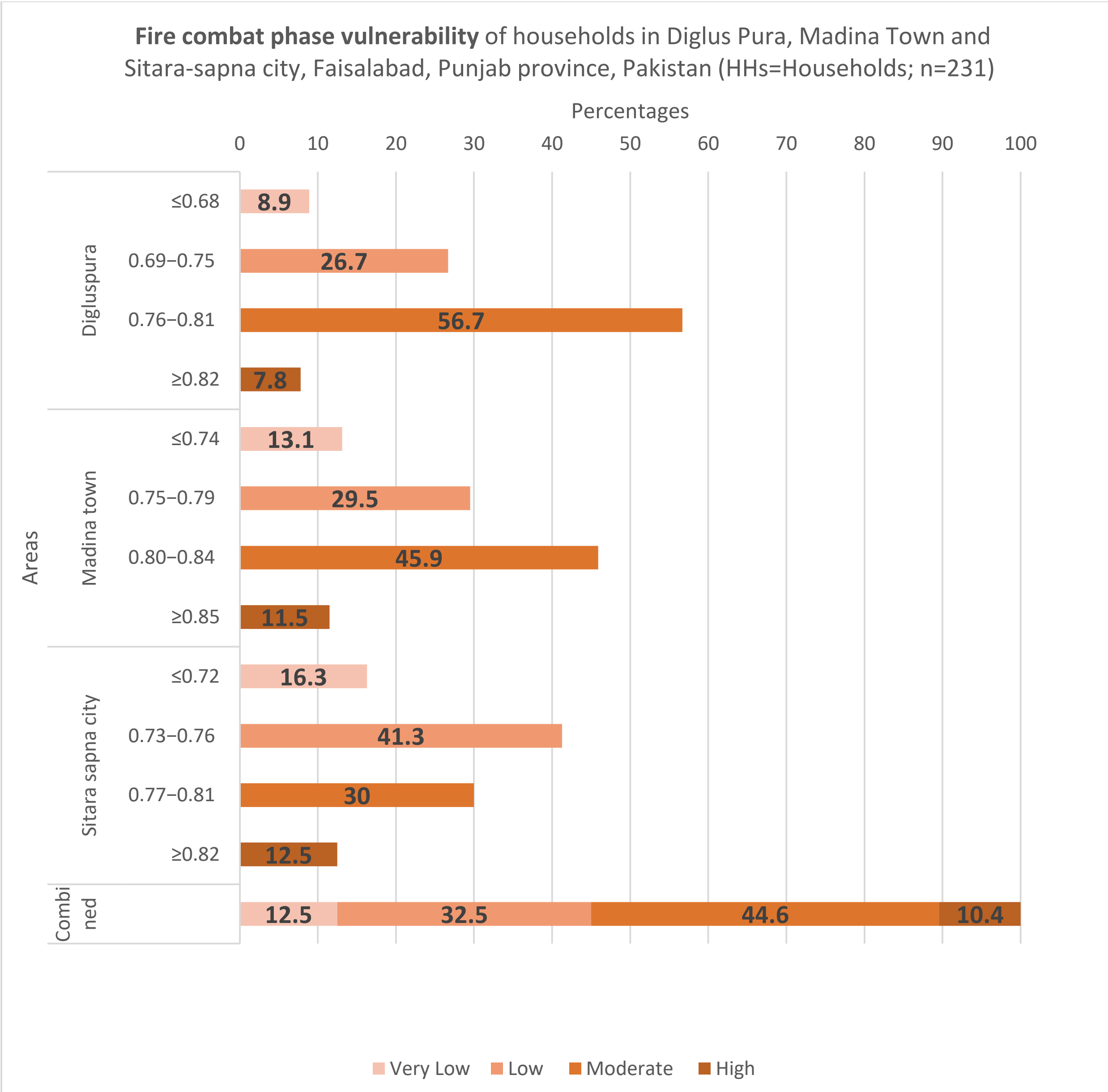

Figure 10 Fire combat phase vulnerability

4.6 Fire development phase vulnerability:

Overall only 0.4% of the houses have fire extinguishers. The rest of the houses would rely on water and sand buckets to fight the fire. Most of the houses were relatively new total of 39.8% of houses were older than 20 years. 77.5% of houses had more than 5 rooms, thus had better compartmentation against the spread of fire. 85% of houses have more than one story which was making them more structurally vulnerable in case of fire. 100% of houses had a common wall with their neighbors, indicating that fire can spread between units. A total of 53.4% of houses had higher than average fire load (MJ/m^2). 87.9% of houses pumped groundwater for their domestic use and 61.5% had water tanks less than 200 gallons in size. 97.4% of houses were constructed with burnt clay bricks which provide comparatively less insulation than hollow and concrete bricks. The walls of 38.8% of houses were not plastered. For smoke to escape from the burning building 38.5% of houses had 10 or fewer exterior openings. The number of interior openings in 54.1% of houses was more than average, thus making their residents more vulnerable to the spread of smoke inside the unit. For structural stability against fire, 16% of houses had wooden structures, 19% had T-iron and steel girders and 64.9% had reinforced concrete structures on their roofs.

Table 6 Fire development phase vulnerability of households in Diglus Pura, Madina Town, and Sitara-sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)

Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.56	0.57−0.60	0.61−0.64	≥0.65		Min =0.51	*F =68.000*
	No. of HHs	14	37	24	15	90	Max =0.71	df =2
	%	15.6	41.1	26.7	16.7	100	Mean =0.6032	*p value =0.00*
							SD =0.03832	
Madina Town	Range	≤0.50	0.51−0.54	0.55−0.58	≥0.59		Min =0.42	
	No. of HHs	10	18	25	8	61	Max =0.63	
	%	16.4	29.5	41	13.1	100	Mean =0.5370	
							SD =0.04187	
Sitara-sapna city	Range	≤0.54	0.55−0.57	0.58−0.59	≥0.60		Min =0.49	
	No. of HHs	10	25	33	12	80	Max =0.61	
	%	12.5	31.3	41.3	15	100	Mean =0.5662	
							SD =0.02259	
Total	No. of HHs	34	80	82	35	231		
	%	14.7	34.7	35.5	15.1	100		

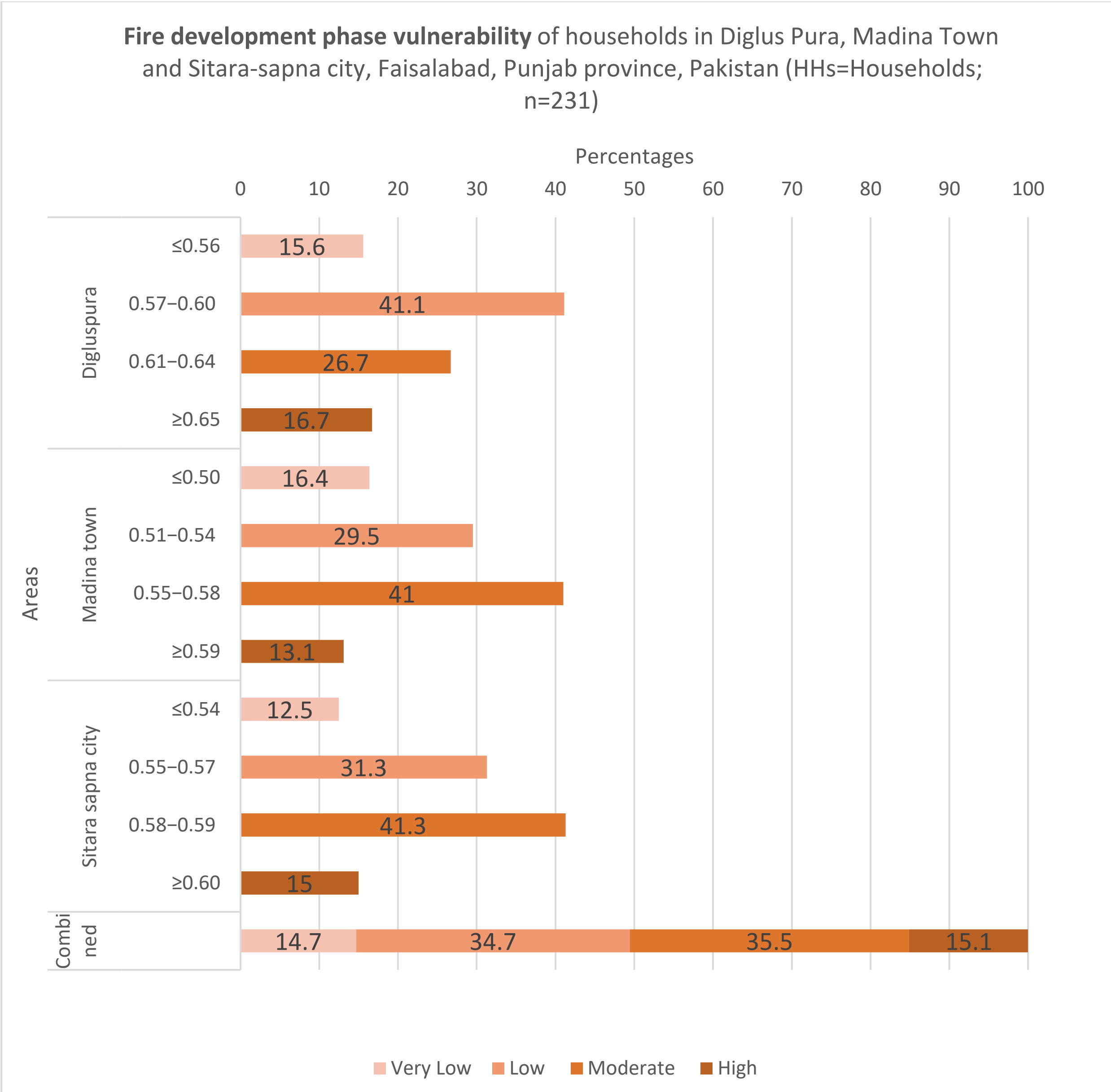

Figure 11 Fire development phase vulnerability

4.7 Fire escape phase vulnerability:

Overall 48.9% of houses have only one exit door. 81% of houses have only one set of stairs and no fire escape stairs. 76.6% of houses have no evacuation passageway that can be used to evacuate to neighboring houses from upper floors. Overall 16.9% of houses have less than 1m wide exit corridor which is the minimum required width of exit corridors (Occupational Safety and Health Administration, 2015). 65.8% of doors in houses open inwards, which threatens to escape the fire inside the building. 84.8% of houses have no ladders that can be used for evacuating the upper floors. 87.4% of houses were located on the street less than 20ft wide which is the minimum requirement for fire truck and rescue vehicles to work as per (Occupational Safety and Health Administration, 2015).

A significant difference was seen among the three communities in overall fire combat vulnerability (F=15.318 and p=0.000). Highly vulnerable households in Digluspura, Madina town, and Sitara-sapna city were 5.6%, 14.8%, and 8.8% respectively.

Table 7 Fire escape phase vulnerability of households in Diglus Pura, Madina Town, and Sitara-sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)

Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.53	0.54−0.66	0.67−0.79	≥0.80		Min =0.31	*F =15.318*
	No. of HHs	13	21	51	5	90	Max =0.84	df =2
	%	14.4	23.3	56.7	5.6	100	Mean =0.6569	*p value =0.00*
							SD =0.12997	
Madina Town	Range	≤0.38	0.39−0.55	0.56−0.71	≥0.72		Min =0.20	
	No. of HHs	14	12	26	9	61	Max =0.80	
	%	23	19.7	42.6	14.8	100	Mean =0.5337	
							SD =0.1704	
Sitara-sapna city	Range	≤0.51	0.52−0.63	0.64−0.75	≥0.76		Min =0.18	
	No. of HHs	7	20	46	7	80	Max =0.80	
	%	8.8	25	57.5	8.8	100	Mean =0.6325	
							SD =0.11871	
Total	No. of HHs	34	53	123	21	231		
	%	14.7	23	53.3	9	100		

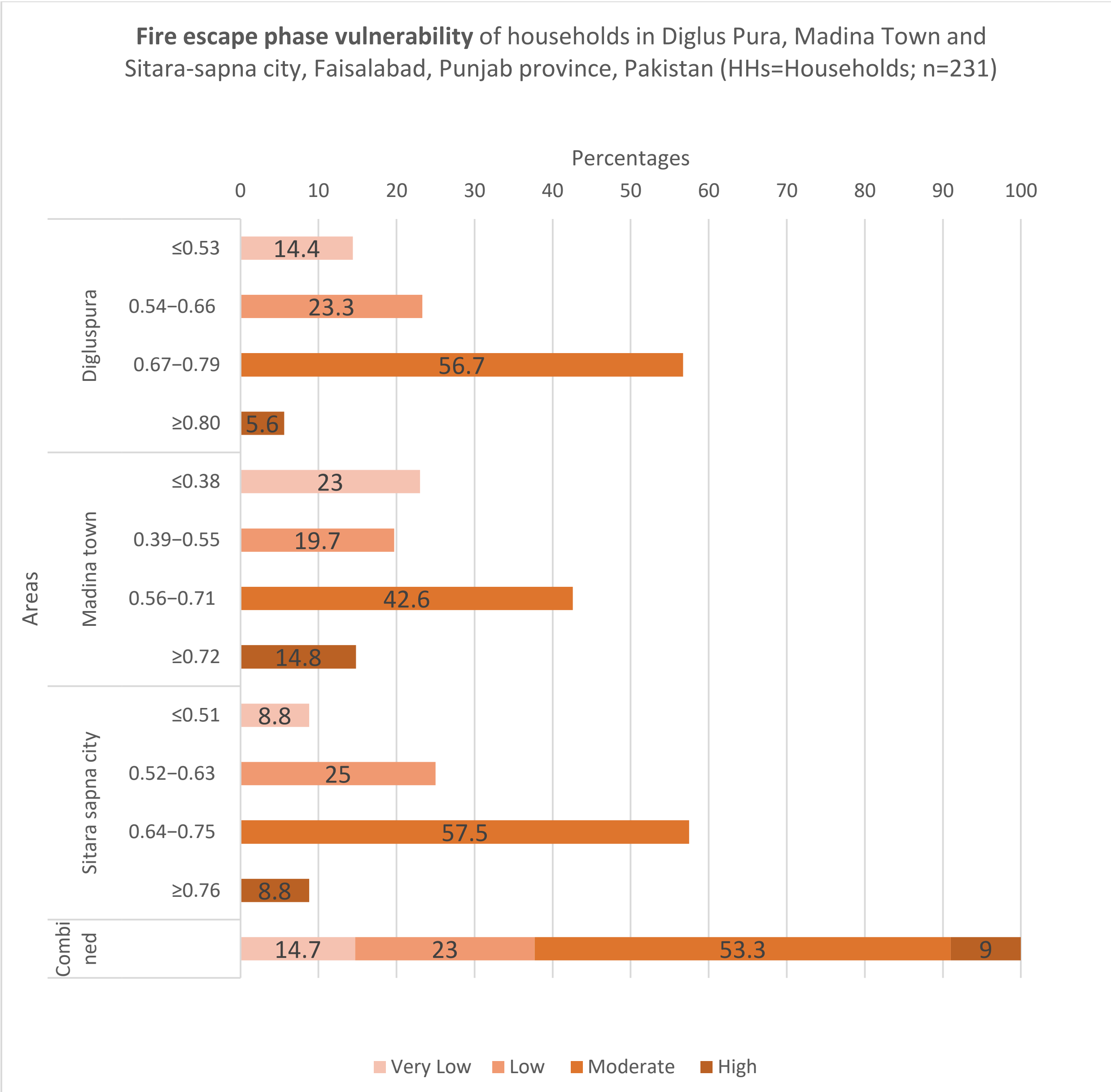

Figure 12 Fire escape phase vulnerability

4.8 Multi-phase fire vulnerability:

Overall in Digluspura, 38.9% of households are moderately and 14.4% are highly vulnerable to fire. In Madina town, 32.8% of households are moderately and 21.3% are highly vulnerable to fire. In Sitara-sapna city 26.3% of households are moderately and 16.3% are highly vulnerable to fire. This shows an alarming situation as more than 50% of houses in all three communities are vulnerable to household fire. Madina town community can be deemed the most vulnerable community as it has most houses with high vulnerability to fire. A significate difference in vulnerability was observed between the three communities with (F=10.28 and p=0.000).

Table 8 Fire multi-phase vulnerability of households in Diglus Pura, Madina Town, and Sitara-sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)

Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.50	0.51−0.53	0.54−0.57	≥0.58		Min =0.44	*F =10.208*
	No. of HHs	15	27	35	13	90	Max =0.61	df =2
	%	16.7	30	38.9	14.4	100	Mean =0.5321	*p value =0.00*
							SD =0.03709	
Madina Town	Range	≤0.48	0.49−0.52	0.53−0.56	≥0.57		Min =0.46	
	No. of HHs	14	14	20	13	61	Max =0.60	
	%	23	23	32.8	21.3	100	Mean =0.5210	
							SD =0.03672	
Sitara-sapna city	Range	≤0.52	0.52−0.55	0.56−0.58	≥0.59		Min =0.45	
	No. of HHs	13	25	29	13	80	Max =0.61	
	%	16.3	31.3	36.3	16.3	100	Mean =0.5471	
							SD =0.02900	
Total	No. of HHs	42	66	84	39	231		
	%	18.1	28.6	36.4	16.9	100		

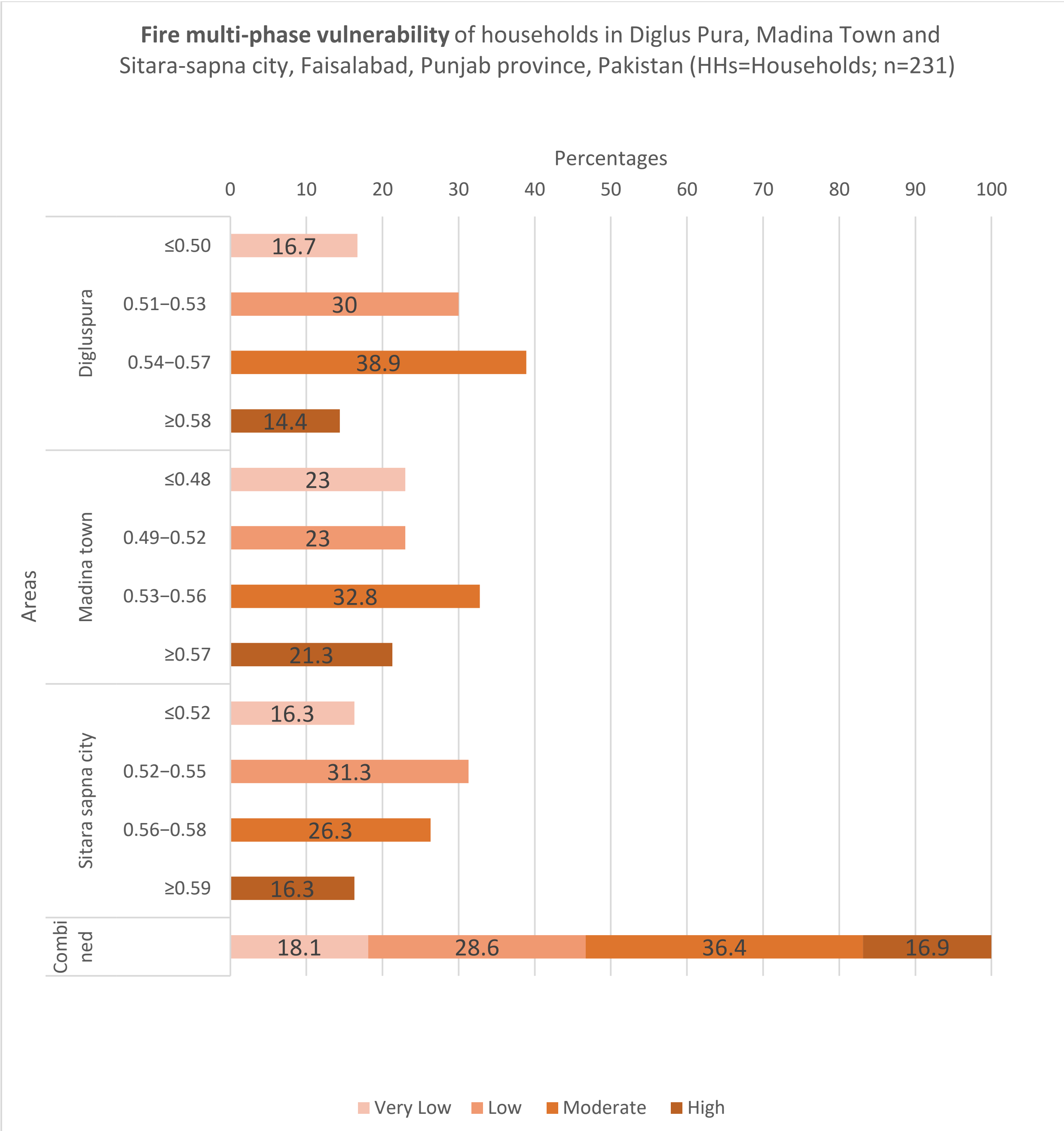

Figure 13 FIre multi-phase vulnerability

Chapter 5:

Fire Risk Preparedness

5.1 Assessment methodology:

Fire risk preparedness assessment in a residential unit is done by analyzing the factors of the capacity of both physical and behavioral aspects. For this study, 5 indicators of economic capacity specific to fire risk were selected. Physical capacity indicates the presence of physical features inside the building which can help in reducing the fire risk, 10 indicators were selected to assess physical capacity. Attitudinal capacity shows the fire safety practices of household members; 12 indicators were selected to assess this. The firefighting capacity of the household's members was assessed by 7 indicators of their firefighting knowledge and experience. 5 indicators were selected to assess the structural capacity of the house against fire. 3 indicators were selected to assess the architectural capacity of the house against fire and its spread. Water supply capacity was assessed through 3 indicators. The capacity to escape the fire was assessed through 11 different indicators. All these factors of capacity were given equal weightage. Computation of these indicators was done through the subjective weighting technique (Rana & Routray, 2018a) shown in Table 9. Original values of the indicators are transformed to 0-1 based on the level of capacity, where 0 is considered the lowest and 1 is the highest. A composite index of preparedness is then derived for each factor of capacity against household fire through the formula shown in Eq 9.

Eq 9 Composite Index $= (C_1+C_2+C_3+\ldots C_n)/n$

$$= \sum_{i=1}^{n} Ci/n$$

Where CI is the composite index, C_1 to C_n are the respective transformed value of the indicators used to drive the composite index.

Following the same equation Economic Capacity Index (ECI), Physical Capacity Index (PCI), Attitudinal Capacity Index (ACI), Firefighting Capacity Index (FCI), Structural Capacity Index (SCI), Architectural Capacity Index (ARCI), Water Supply Capacity Index (WSCI) and Fire Evacuation Capacity Index (FECI).

$$\text{Eq 10 Economic Capacity Index} = \sum_{i=1}^{5} \frac{\text{ECI}}{\text{n}} \qquad (\text{n} = 5)$$

$$\text{Eq 11 Physical Capacity Index} = \sum_{i=1}^{10} \frac{\text{PCI}}{\text{n}} \qquad (\text{n} = 10)$$

$$\text{Eq 12 Attituddional Capacity Index} = \sum_{i=1}^{12} \frac{ACI}{n} \qquad (n = 12)$$

$$\text{Eq 13 Firefighting Capacity Index} = \sum_{i=1}^{7} \frac{\text{FCI}}{\text{n}} \qquad (\text{n} = 7)$$

$$\text{Eq 14 Structural Capacity Index} = \sum_{i=1}^{5} \frac{\text{SCI}}{\text{n}} \qquad (\text{n} = 5)$$

$$\text{Eq 15 Architectural Capacity Index} = \sum_{i=1}^{3} \frac{\text{ARCI}}{\text{n}} \qquad (\text{n} = 3)$$

$$\text{Eq 16Water Supply Capacity Index} = \sum_{i=1}^{3} \frac{\text{WSCI}}{\text{n}} \qquad (\text{n} = 3)$$

$$\text{Eq 17 Fire Evacuation Capacity Index} = \sum_{i=1}^{11} \frac{\text{FECI}}{\text{n}} \qquad (\text{n} = 11)$$

$$\text{Eq 18 Overall Preparedness Index} = \frac{\text{ECI+PCI+ACI+FCI+SCI+ARCI+WSCI+FECI}}{8}$$

5.2 Indicators of household capacity against fire:

Table 9 Indicators and transformed values for capacity of households against fire hazards in Faisalabad, Pakistan

S. No	Ind	Indicators	Classes	Transformed values	Explanation	Empirical References
Economic						
1	C_1	Total household income per month (Pkr)	≤30000	0	Households having higher incomes can better prepare themselves against fire	(Cutter et al., 2003), (Balica et al., 2009)
			30000—130000	0.2		
			130000—230000	0.4		
			230000—330000	0.6		
			≥330000	0.8		
2	C_2	Main income source of household	No. permanent source	0.33	A secure stream of income will increase the capacity	(Rana & Routray, 2018b)
			Job	0.67		
			Business	1		
3	C_3	House ownership	Rental	0	Occupants of rented houses are less prepared as compared to owned houses	(Cutter et al., 2003), (Rana & Routray, 2018b)
			Leased	0.33		
			Owned	0.67		
4	C_4	Insurance	Not-insured	0	Type of insurance ensures preparedness against the relevant hazard	(Warner, Koko; Ranger, Nicola; Surminski, Swenja; Arnold, Margaret; Linnnerooth-Bayer, Joanne; Michel-Kerjan, Erwann; Kovacs, Paul; Herweijer, 2009)
			Health-insurance	0.2		
			Life-insurance	0.4		
			Property-insurance	0.6		
			Fire-insurance	0.8		
5	C_5	No. of employed persons in the household	0	0	More employed persons in a household mean a greater level of shared financial responsibilities in case of disasters	(Balkenhol et al., 2009)
			1	0.2		
			2	0.4		
			3	0.6		
			≥4	0.8		
Physical						
1	C_6	Short-circuit switch in the electrical system	Yes	1	Short circuit switches reduce the risk of short circuit fires	(Ahrens, 2019)
			No	0		
2	C_7	Cracks, bends, or heat marks on electric wires	Yes	0	Good quality wires reduce the risk of overheating and sparking	(Ahrens, 2016)
			No	1		
3	C_8	Gas leakage (smell)	Yes	0	Gas can collect inside the house and get ignited	(Campbell, 2021)
			No	1		
4	C_9	Pilot light working in heaters	Yes	1	The pilot light can prevent gas leakages	
			No	0		
5	C_{10}		Yes	0		

		Discolored walls in heater	No	1	Discolored walls on the heater are a sign of danger	
6	C_{11}	Presence of an automatic fire extinction system	Yes	1	The presence of an automatic fire extinction system can extinguish the fire before it's spread	(Xin & Huang, 2013)
			No	0		
7	C_{12}	The covered area of the automatic fire extinction system	None	0	More the covered area of the automatic fire extinction system will be the fire extinguishing capacity	(Xin & Huang, 2013)
			Most vulnerable rooms (kitchen)	0.33		
			Major rooms	0.67		
			Whole house	1		
8	C_{13}	Type of fire-fighting equipment available in the house	None	0	The better type of equipment helps fight the fire more efficiently	(Islam & Adri, 2008)
			Water buckets	0.25		
			Sand buckets	0.5		
			Fire-extinguishers	0.75		
9	C_{14}	Age of house (years)	0—1	0.8	Old houses have less capacity against fire hazard	(Granda & Ferreira, 2019)
			2—18	0.6		
			19—36	0.4		
			37—53	0.2		
			≥54	0		
10	C_{15}	Fire-load (number of combustion-able items)	≤13	0.8	More the combustion able items in a house more intense the fire will be	(Wei et al., 2018)
			14—23	0.6		
			24—33	0.4		
			34—43	0.2		
			≥44	0		
Attitudinal						
1	C_{16}	The practice of not smoking inside the house	Yes	0	Smoking inside the house is a constant threat of fire ignition	(Ahrens, 2019)
			No	1		
2	C_{17}	Keeping flammable material at a safe distance from the cooking stove	Yes	1	Flammable material can catch fire due to fumes or constant heat transfer from a stove	(Chow & Xiaomin, 2014)
			No	0		
3	C_{18}	Regular maintenance of the stove	Yes	1	Gas can be gas leakages inside the stove if it is not maintained regularly	(Chow & Xiaomin, 2014)
			No	0		
4	C_{19}	Use of candle or other burning sources of light instead of safer alternatives	Yes	0	Candles are a constant threat of fire ignition	(Miller, 2005)
			No	1		
5	C_{20}	Regular use of candle in case of load shedding	Yes	0	Regular use of candles increases the threat level	
			No	1		

6	C_{21}	Placing a candle in the non-combustion-able pan (while using)	Yes	1	responsible use of candles	(Miller, 2005)
			No	0		
7	C_{22}	Placing a candle in a safe place	Yes	1	responsible use of candles	(Miller, 2005)
			No	0		
8	C_{23}	Children often play with fire	Yes	0	Children are often unaware of the dangers of playing with fire	(Miller, 2005)
			No	1		
9	C_{24}	Use of wood or coal for heating instead of natural gas	Yes	0	Natural gas heaters are a safer option	
			No	1		
10	C_{25}	Keeping flammable items at safe distance from heaters (proximity of 1m of heaters)	Yes	0	Flammable material can catch fire due to fumes or constant heat transfer from the heater	(Campbell, 2021)
			No	1		
11	C_{26}	Regular use of heater (during winter)	Yes	0	Regular use of candles increases the threat level	
			No	1		
12	C_{27}	Regular maintenance of heaters	Yes	1	Regular maintenance of the heater can reduce the risk of fire	(Campbell, 2021)
			No	0		
Firefighting ability of individuals						
1	C_{28}	No. of active household members	0	0	More household member who can actively detect and fight the fire means the more prepared the household is against fire	(Kobes et al., 2010a)
			1—3	0.2		
			4—6	0.4		
			7—8	0.6		
			≥9	0.8		
2	C_{29}	No. of household members who know the use of fire-fighting equipment	0	0	A household member who can use the firefighting equipment in a safe and effective manner	(Kobes et al., 2010a)
			1	0.2		
			2	0.4		
			3	0.6		
			≥4	0.8		
3	C_{30}	No. of household members who have used the fire-fighting equipment before	0	0	Household members who have some sort of training in fire fighting	(Kobes et al., 2010a)
			1—2	0.2		
			3	0.4		
			4—5	0.6		
			≥6	0.8		
4	C_{31}	No. of household members who can detect the early signs of fire (smell of smoke)	0	0	Household members who have some sort of training in fire fighting	(Kobes et al., 2010a)
			1—3	0.2		
			4—6	0.4		
			7—8	0.6		
			≥9	0.8		
5	C_{32}	No. of household members who have	0	0	A household member who has experience in	(Kobes et al., 2010a)
			1—3	0.2		

		successfully detected the signs of early fire	4—6	0.4	successfully detecting the early fire in past	
			7—9	0.6		
			≥10	0.8		
6	C_{33}	No. of active members who have successfully extinguished the early fire in past	0	0	A household member who has experience in successfully extinguishing the early fire in past	(Kobes et al., 2010a)
			1	0.2		
			2	0.4		
			3	0.6		
			≥4	0.8		
7	C_{34}	How often do active members stay at home	24 hours	1	Most benefits can come from the long stay of active members at home in their daily routine	(Kobes et al., 2010a)
			12 hours	0.67		
			less than 12 hours	0.33		
House structure						
1	C_{35}	No. of stories in house	1	1	More number of stories equates to more structural load. Also in case of fire, it will be harder to evacuate upper floors	(Littlewood et al., 2017)
			2	0.67		
			≥3	0.33		
2	C_{36}	Structural system in the house	RCC	1	RCC structures perform much better in case of fire	(Prager et al., 2020)
			Steel girders	0.67		
			Wooden	0.33		
3	C_{37}	Thickness of walls	≤9	0	Greater thickness means lesser chances of heat transfer in other rooms	(Wei et al., 2018)
			10—14	0.67		
			≥15	0.33		
4	C_{38}	Wall covering (plastering)	Yes	1	Covered walls provide better insulation	(Industry Association, 2008)
			No	0		
5	C_{39}	Type of bricks	Concrete (non-hollowed)	0.33	Hollowed bricks provide better insolation	(Industry Association, 2008)
			Clay	0.67		
			Concrete (hollowed)	1		
House Architecture						
1	C_{40}	Compartmentalization	0—3	0	More number of rooms means better compartmentalization of fire which reduces the spread rate	(Littlewood et al., 2017)
			4—6	0.2		
			7—8	0.4		
			9—11	0.6		
			≥12	0.8		
2	C_{41}	Total No. of exterior openings (vents, windows, doors, and roof openings)	≤9	0	The more exterior opening will ventilate the toxic smoke out of the house	(Wei et al., 2018)
			10—13	0.2		
			14—17	0.4		
			18—21	0.6		
			≥22	0.8		
3	C_{42}		≤10	0.8		(Wei et al., 2018)

		Total No. of interior openings (vents, windows, and doors)	11—45	0.6	The more interior opening will spread fire and smoke at a higher rate inside the house	
			46—81	0.4		
			82—116	0.2		
			≥117	0		
Water supply						
1	C_{43}	Water connection	Non-traditional	0.33	A steady supply of water helps in putting out the fire	(Occupational Safety and Health Administration, 2015)
			Municipal	0.67		
			Ground	1		
2	C_{44}	Size of water storage tank (liters)	≤100	0.2	A larger storage capacity of water will increase the chances of firefighting	(Occupational Safety and Health Administration, 2015)
			101—137	0.4		
			138—178	0.6		
			179—480	0.8		
			≥481	1		
3	C_{45}	Availability of water storage in adjacent neighbors	Yes	1	Stored water in the neighboring house can help fight the fire	
			No	0		
Fire evacuation						
1	C_{46}	No. of exit doors in the house	1	0.33	More exit doors will provide more escape routes	(Wei et al., 2018)
			2	0.67		
			≥3	1		
2	C_{47}	Length of exit corridor (foot)	≤8	0.8	The lesser the length of the exit route more instant will be the evacuation	(Wei et al., 2018)
			9—12	0.6		
			13—17	0.4		
			18—21	0.2		
			≥22	0		
3	C_{48}	Availability of a second set of stairs that can be used for evacuating from upper floors	Yes	1	Usually, there are two sets of stairs in houses in urban areas of Faisalabad, they can provide better evacuation chances from the upper floors	
			No	0		
4	C_{49}	Availability of passageway that can be used for evacuating from upper floors (escape route to neighbor's roof)	Yes	1	Most houses in urban areas of Faisalabad share their walls with neighbors, there can be routes to evacuation to the neighbor's roof from the upper floors	
			No	0		
5	C_{50}	Width of exit corridor (foot)	≤2.5	0	Wider exit corridors can provide a more efficient evacuation route	(Wei et al., 2018)
			2.6—3.5	0.2		
			3.6—4.5	0.4		
			4.6—5.5	0.6		
			≥5.6	0.8		
6	C_{51}		≤2.5	0		(Wei et al., 2018)

		Width of exit doors (foot)	2.6—3.5	0.2	There are better chances of evacuation from wider exit doors	
			3.6—4.5	0.4		
			4.6—5.5	0.6		
			≥5.6	0.8		
7	C_{52}	The direction of the exit door opening	Inwards	0	Outwards opening exit doors can be opened with much ease during the evacuation	(Wei et al., 2018)
			Outwards	1		
8	C_{53}	Presence of hurdles in the evacuation passageway	Yes	0	The evacuation passageway should be hurdle free	(Wagner & Agrawal, 2014)
			No	1		
9	C_{54}	Availability of ladder in the house (that can be used for evacuation)	Yes	1	Ladders can be used for the evacuation from the upper floors	(Wei et al., 2018)
			No	0		
10	C_{55}	Availability of ladder in the neighborhood (that can be used for evacuation)	Yes	1	Ladders can be used for the evacuation from the upper floors	(Wei et al., 2018)
			No	0		
11	C_{56}	Width of the street (foot)	≤4	0	Wider streets provide more room for rescue services	(Occupational Safety and Health Administration, 2015)
			5—11	0.2		
			12—17	0.4		
			18—24	0.6		
			≥25	0.8		

5.3 Economic capacity:

The overall monthly income of households ranges from 15000 – 2000000 pkr with an average of approximately 450000 pkr. 51.9% of households have more than 1 earning member. Most houses are owned only 11.3% of houses are rentals. Madina town and Sitara-sapna city communities showed good economic capacity as most of the residents from these communities belong to the higher middle class. 78.9% of surveyed households in the Digluspura community showed low to very low economic capacity against fire risk. Earning source of most of the households in Digluspura were small to medium-scale businesses.

Table 10 Economic capacity of households against fire in Diglus Pura, Madina Town, and Sitara-sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)

Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.29	0.30−0.39	0.40−0.49	≥0.50		Min =0.11	*F =53.226*
	No. of HHs	26	45	13	6	90	Max =0.59	df =2
	%	28.9	50	14.4	6.7	100	Mean =0.3306	*p value =0.00*
							SD =0.104	
Madina Town	Range	≤0.29	0.30−0.39	0.40−0.49	≥0.50		Min =0.17	
	No. of HHs	4	13	18	26	61	Max =0.63	
	%	6.6	21.3	29.5	42.6	100	Mean =0.4597	
							SD =0.089	
Sitara-sapna city	Range	≤0.29	0.30−0.39	0.40−0.49	≥0.50		Min =0.25	
	No. of HHs	2	17	40	21	80	Max =0.55	
	%	2.5	21.3	50	26.3	100	Mean =0.4450	
							SD =0.0609	
Total	No. of HHs	32	75	71	53	231		
	%	13.9	32.5	30.7	22.9	100		

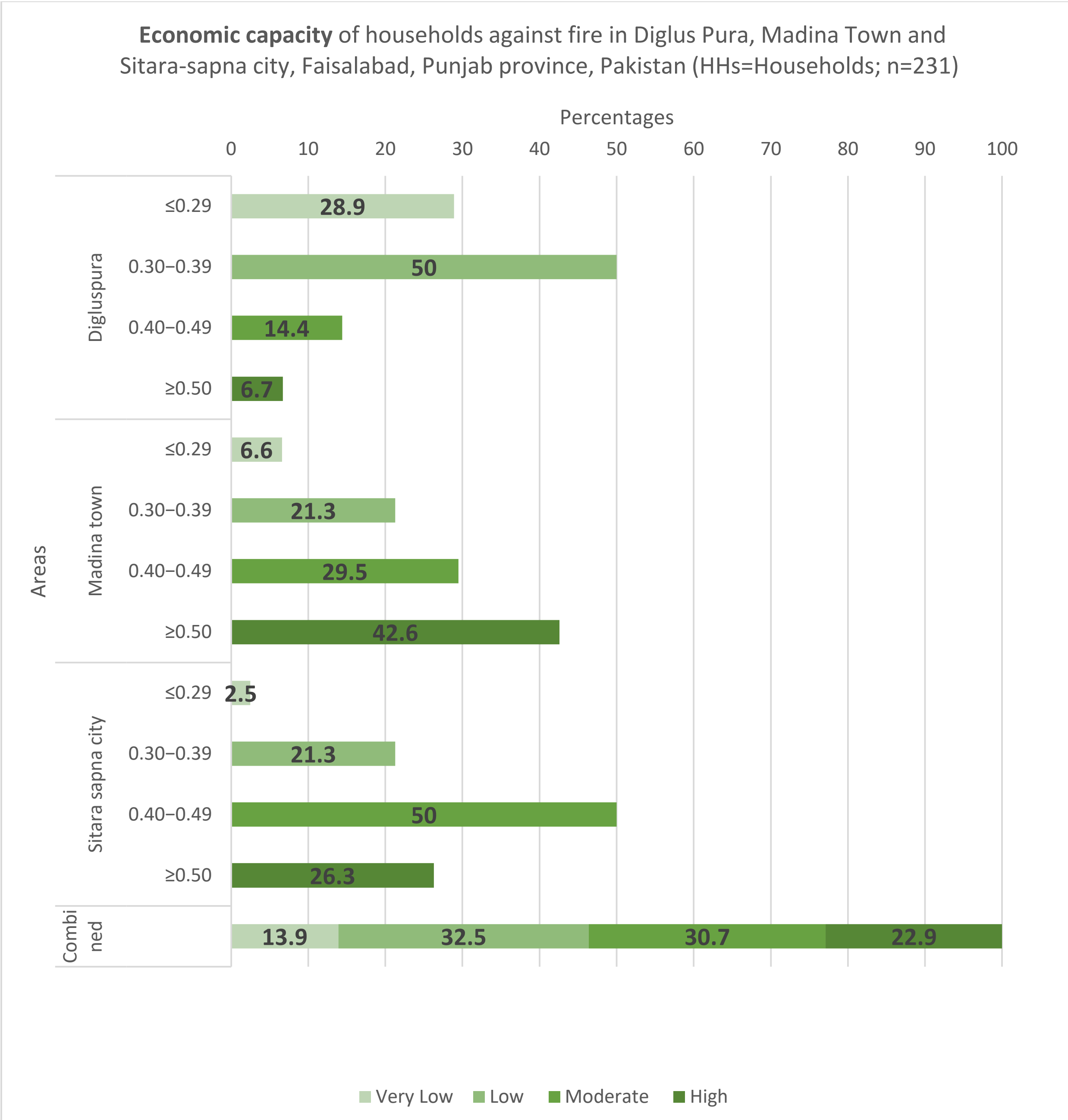

Figure 14 Economic capacity

5.4 Physical capacity:

Overall 48.9% of houses have a short circuit protection switch. 62.8% of houses use wood or coal heaters in winters. 9.5% of houses have leakage in their natural gas supply system. A total of 53.4% of houses had higher than average fire load (MJ/m^2). Surveyed households in Digluspura showed better physical capacity against fire as compared to Madina town and the Sitara-sapna community. Overall Madina town had the lowest physical capacity against fire. Strict action is required by the authorities in mobilizing these communities by using fire safety technologies.

Table 11 Physical capacity of households against fire in Diglus Pura, Madina Town, and Sitara-Sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)

Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.39	0.40−0.48	0.49−0.57	≥0.58		Min =0.21	*F =3.399*
	No. of HHs	13	17	40	20	90	Max =0.74	df =2
	%	14.4	18.9	44.4	22.2	100	Mean =0.4946	*p value =0.035*
							SD =0.0986	
Madina Town	Range	≤0.39	0.40−0.48	0.49−0.57	≥0.58		Min =0.36	
	No. of HHs	3	25	33	0	61	Max =0.54	
	%	4.9	40.9	54.1	0	100	Mean =0.4711	
							SD =0.0433	
Sitara-sapna city	Range	≤0.39	0.40−0.48	0.49−0.57	≥0.58		Min =0.22	
	No. of HHs	6	26	30	18	80	Max =0.72	
	%	7.5	32.5	37.5	22.5	100	Mean =0.5068	
							SD =0.0801	
Total	No. of HHs	22	68	103	38	231		
	%	9.5	29.4	44.6	16.5	100		

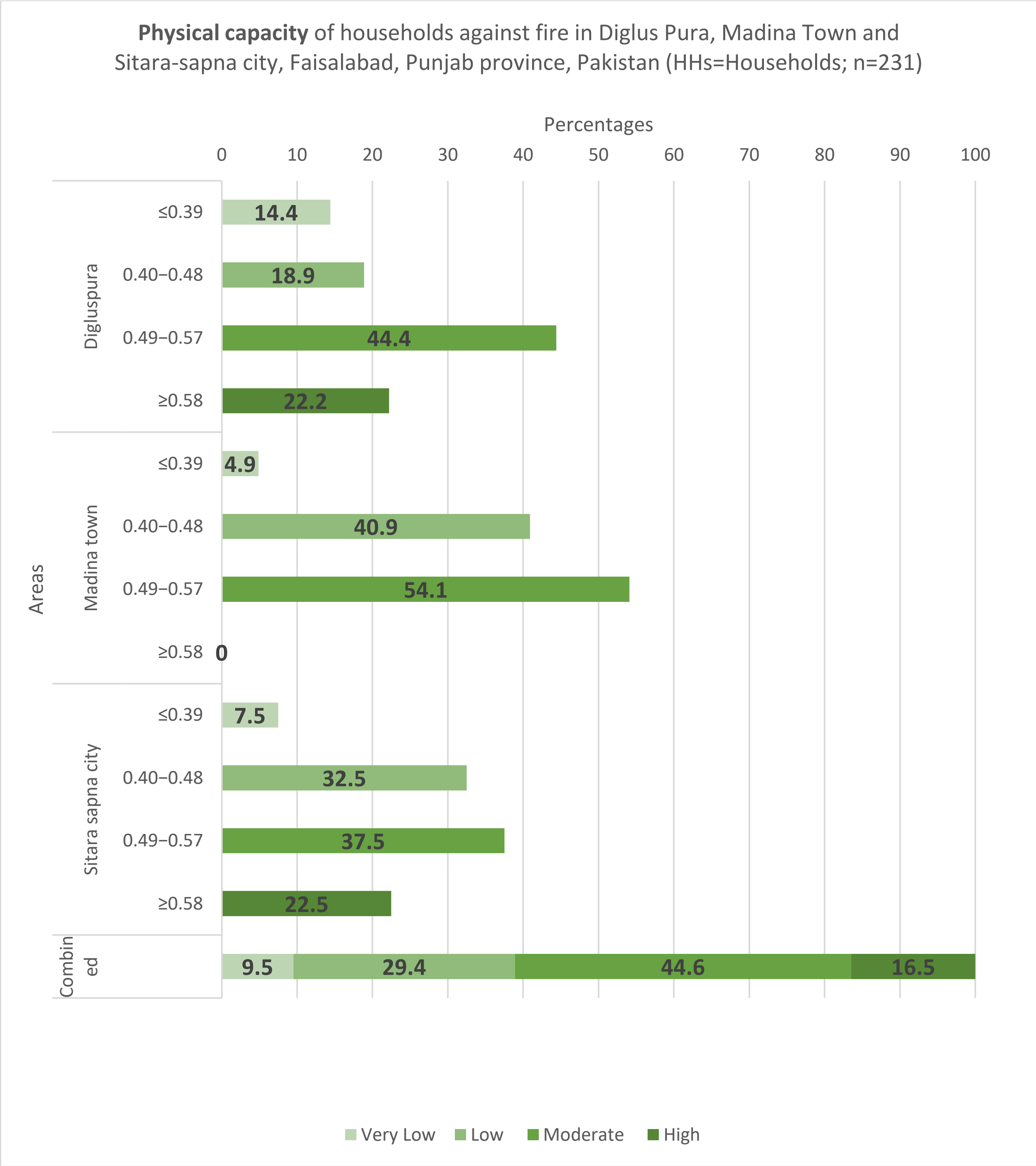

Figure 15 Physical capacity

5.5 Attitudinal capacity:

Overall 7.8% of households reported that their children often play with fire. 25.5% of households reported that they neglect the safety protocols during the use of heaters (keeping combustion-able materials 1m away from heaters). 88.3% of households claimed that their heaters are regularly maintained. 92.2% of households claimed that they regularly clean and maintain their cooking stoves. Surveyed houses in Digluspura showed much better attitudinal capacity against household fire as compared to the other two communities. Sitara-sapna community showed the least attitudinal capacity against fire. Strong mobilization is required to improve the fire safety behaviors of residents.

Table 12 Attitudinal capacity of households against fire in Diglus Pura, Madina Town and Sitara-sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)

Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.59	0.60−0.71	0.72−0.83	≥0.84		Min =0.33	*F =13.3*
	No. of HHs	17	4	28	41	90	Max =1.00	df =2
	%	18.9	4.4	31.1	45.6	100	Mean =0.7398	*p value =0.00*
							SD =0.148	
Madina Town	Range	≤0.59	0.60−0.71	0.72−0.83	≥0.84		Min =0.50	
	No. of HHs	4	13	29	15	61	Max =0.83	
	%	6.6	21.3	47.5	24.6	100	Mean =0.7404	
							SD =0.0747	
Sitara-sapna city	Range	≤0.59	0.60−0.71	0.72−0.83	≥0.84		Min =0.42	
	No. of HHs	29	25	22	4	80	Max =0.83	
	%	36.3	31.3	27.5	5	100	Mean =0.6594	
							SD =0.0901	
Total	No. of HHs	50	42	79	60	231		
	%	21.6	18.2	34.2	26	100		

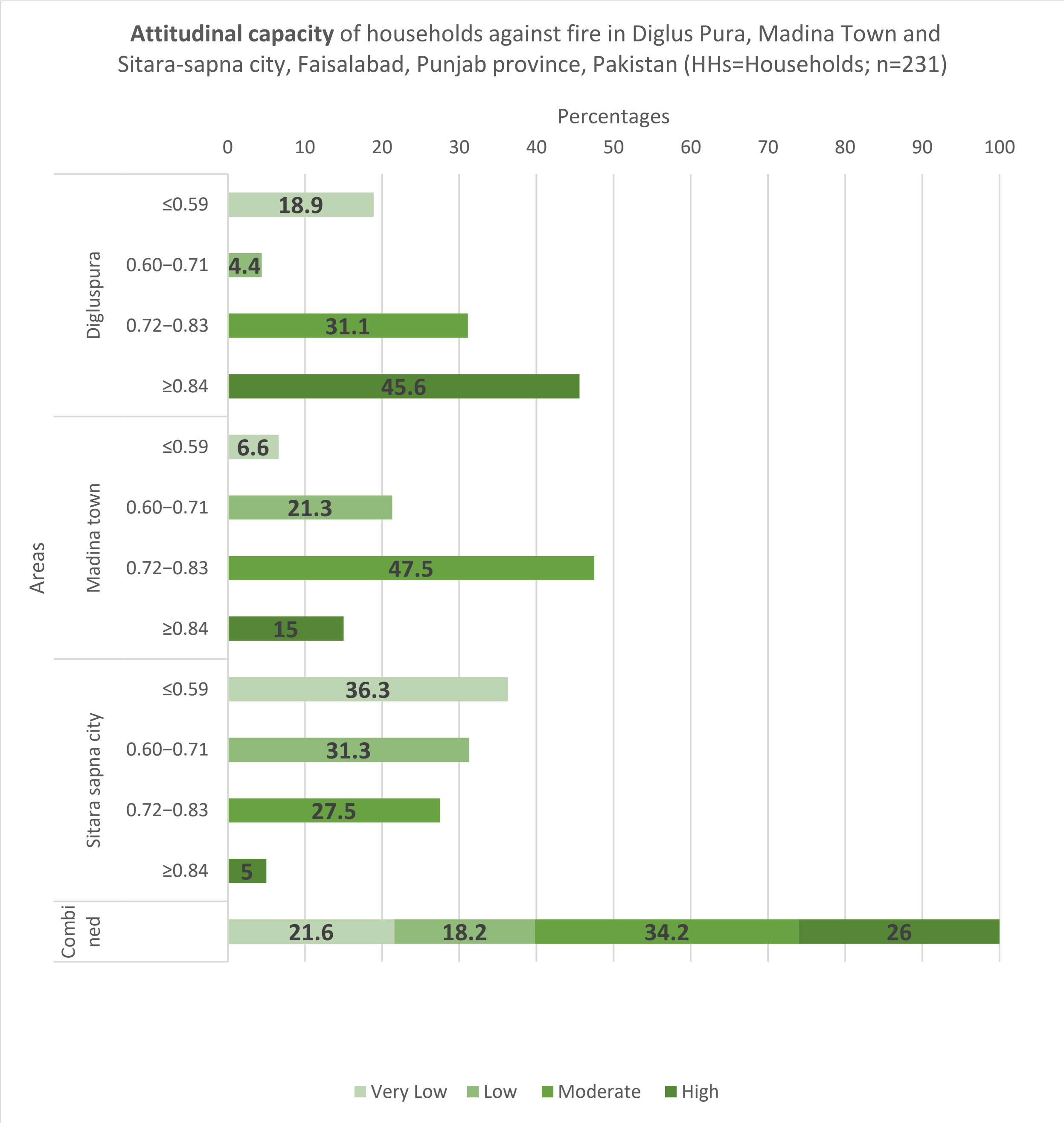

Figure 16 Attitudinal capacity

5.6 Firefighting capacity:

Overall 96% of households claimed that at least one of their member knows the use of firefighting equipment. 80%, 60.7%, and 100% of households in Digluspura, Madina town, and Sitara-sapna city have claimed that they have successfully distinguished the early fire before. DIgluspura community showed comparatively better firefighting capacity as compared to the other two communities. Intervention is required by the firefighting institutes in training the communities against household fire and the use of basic firefighting equipment.

Table 13 Firefighting capacity of household members in Diglus Pura, Madina Town, and Sitara-sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)

Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.20	0.21−0.26	0.27−0.33	≥0.34		Min =0.09	*F =7.284*
	No. of HHs	9	56	18	7	90	Max =0.54	df =2
	%	10	62.2	20	7.8	100	Mean =0.2473	*p value =0.001*
							SD =0.0629	
Madina Town	Range	≤0.20	0.21−0.26	0.27−0.33	≥0.34		Min =0.12	
	No. of HHs	26	27	7	1	61	Max =0.35	
	%	42.6	44.3	11.5	1.6	100	Mean =0.2129	
							SD =0.0488	
Sitara-sapna city	Range	≤0.20	0.21−0.26	0.27−0.33	≥0.34		Min =0.09	
	No. of HHs	10	53	15	2	80	Max =0.36	
	%	12.5	66.3	18.8	2.5	100	Mean =0.2340	
							SD =0.0477	
Total	No. of HHs	45	136	40	10	231		
	%	19.5	58.9	17.3	4.3	100		

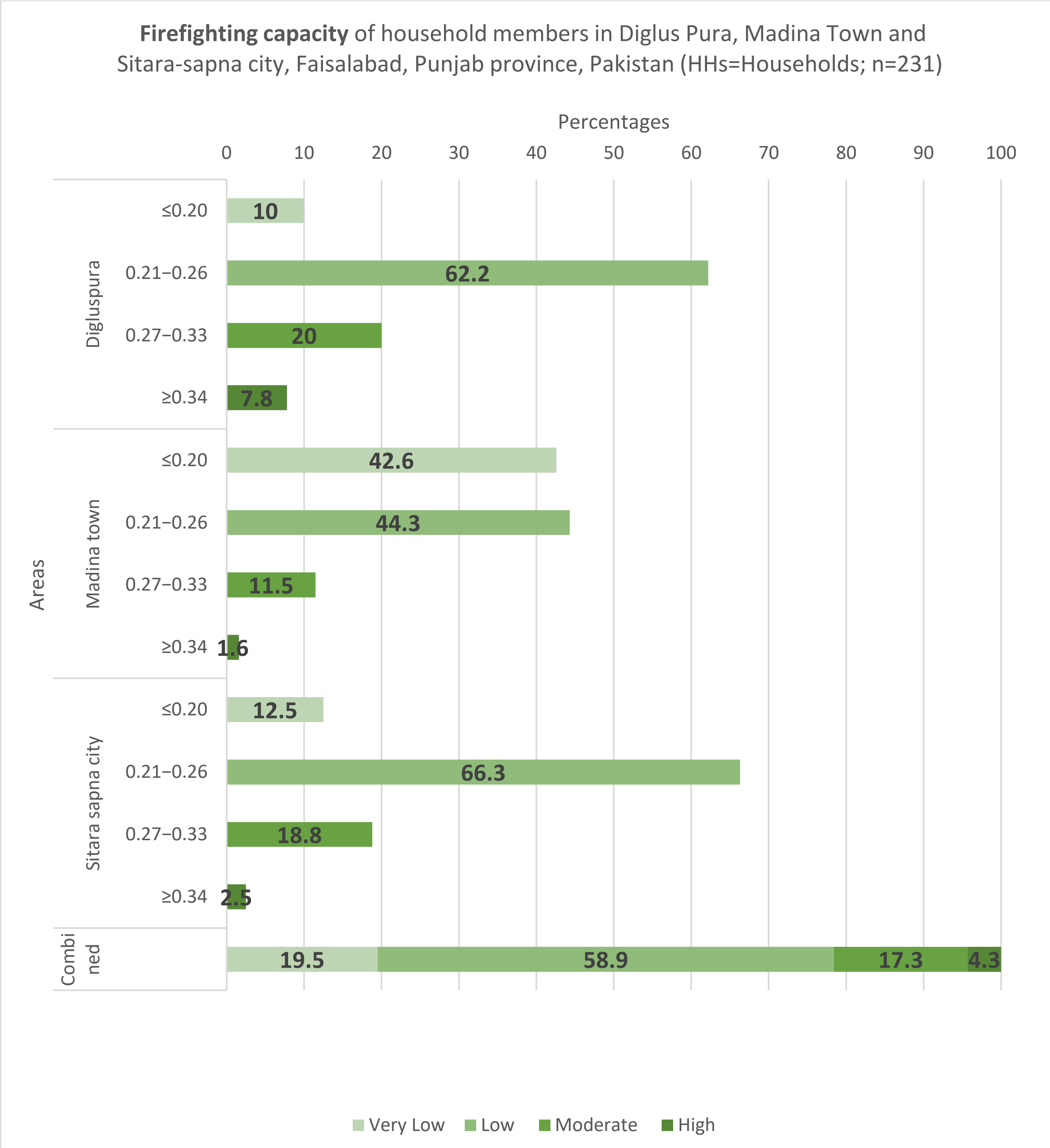

Figure 17 Firefighting capacity

5.7 Structural capacity:

Overall 85.7% of houses have more than 1 story. Most of the houses have 9in thick walls 83.1%. Surveyed houses in Digluspura and Madina town showed a different types of construction practices. A number of building codes applied in these areas over the years. Houses in Sitara-Sapna city showed a similar kind of construction pattern as this community is relatively new and was subjected to a single building code. However, all three communities showed overall bad structural capacity against fire. This calls for an inclusive fire safety code for construction, which can also cover the existing houses and improve their structural capacity against fire.

Table 14 Structural capacity of houses against fire in Diglus Pura, Madina Town and Sitara-sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)

Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.24	0.25−0.36	0.37−0.48	≥0.49		Min =0.07	*F =15.247*
	No. of HHs	22	31	35	2	90	Max =0.53	df =2
	%	24.4	34.4	38.9	2.2	100	Mean =0.3218	*p value =0.00*
							SD =0.1113	
Madina Town	Range	≤0.24	0.25−0.36	0.37−0.48	≥0.49		Min =0.20	
	No. of HHs	1	33	23	4	61	Max =0.60	
	%	1.6	54.1	37.7	6.6	100	Mean =0.359	
							SD =0.1071	
Sitara-sapna city	Range	≤0.24	0.25−0.36	0.37−0.48	≥0.49		Min =0.27	
	No. of HHs	0	80	0	0	80	Max =0.33	
	%	0	100	0	0	100	Mean =0.2753	
							SD =0.02325	
Total	No. of HHs	23	144	58	6	231		
	%	10	62.3	25.1	2.6	100		

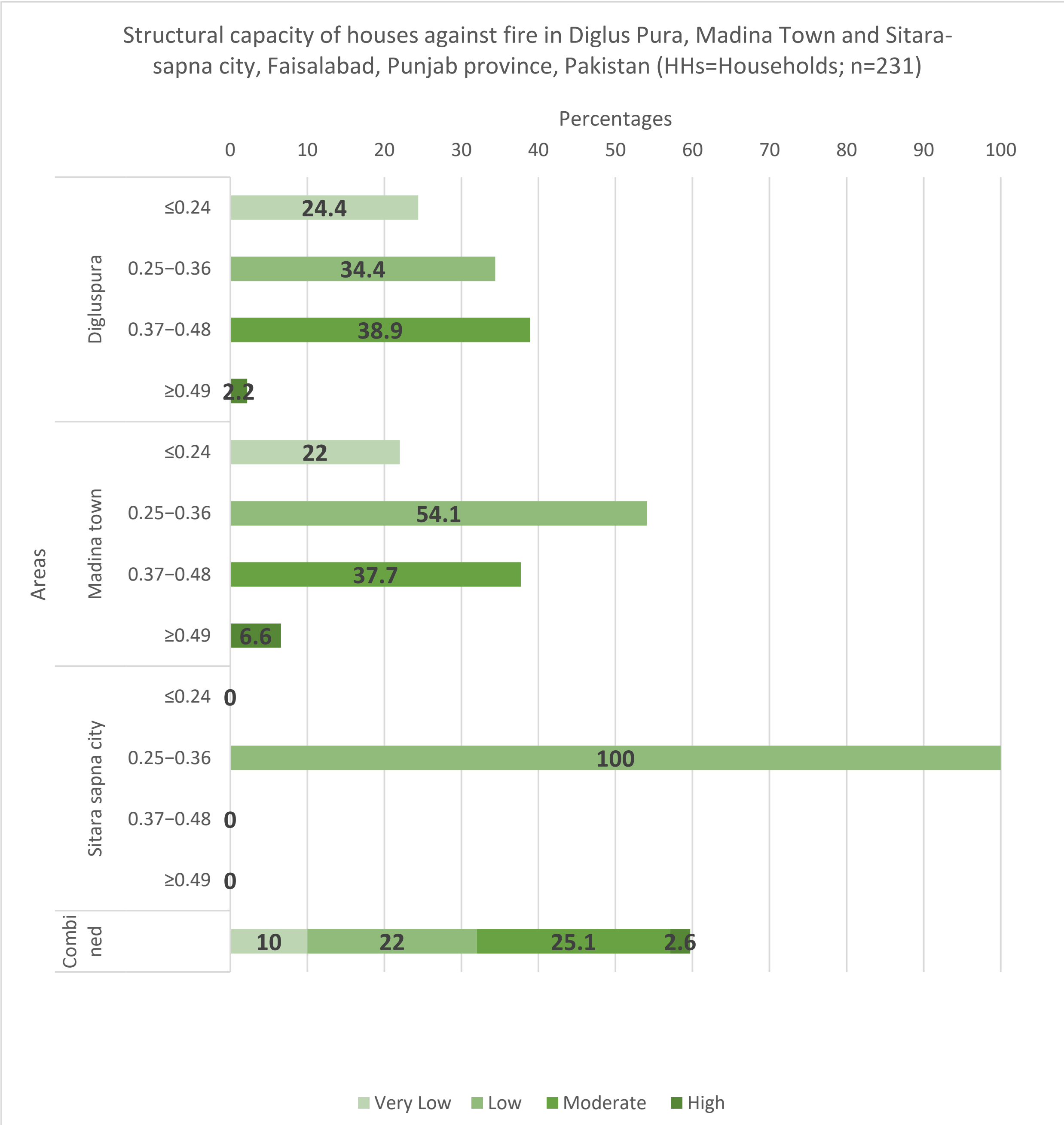

Figure 18 Structural capacity

5.8 Architectural capacity:

Overall 77.5% of houses have more than 5 rooms, thus have better compartmentation against the spread of fire. For smoke to escape from the burning building 38.5% of houses have 10 or fewer exterior openings. As the architectural capacity of the house against fire largely depends upon the covered area of the house, the results varied similarly between and within the communities. Houses in the Digluspura community showed the least architectural capacity against fire. A fire safety code with a separate focus on compartmentalization of fire and ventilation of smoke is required to improve the architectural capacity of houses.

Table 15 Architectural capacity of houses against fire in Diglus Pura, Madina Town and Sitara-sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)

Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.31	0.32−0.43	0.44−0.54	≥0.55		Min =0.20	*F =121.495*
	No. of HHs	31	51	8	0	90	Max =0.53	df =2
	%	34.4	56.7	8.9	0	100	Mean =0.3289	*p value =0.00*
							SD =0.0677	
Madina Town	Range	≤0.31	0.32−0.43	0.44−0.54	≥0.55		Min =0.27	
	No. of HHs	1	17	34	9	61	Max =0.67	
	%	1.6	27.9	55.7	14.8	100	Mean =0.4831	
							SD =0.0891	
Sitara-sapna city	Range	≤0.31	0.32−0.43	0.44−0.54	≥0.55		Min =0.33	
	No. of HHs	0	21	54	5	80	Max =0.60	
	%	0	26.3	67.5	6.3	100	Mean =0.4817	
							SD =0.0645	
Total	No. of HHs	32	89	96	14	231		
	%	13.9	38.5	41.6	6.1	100		

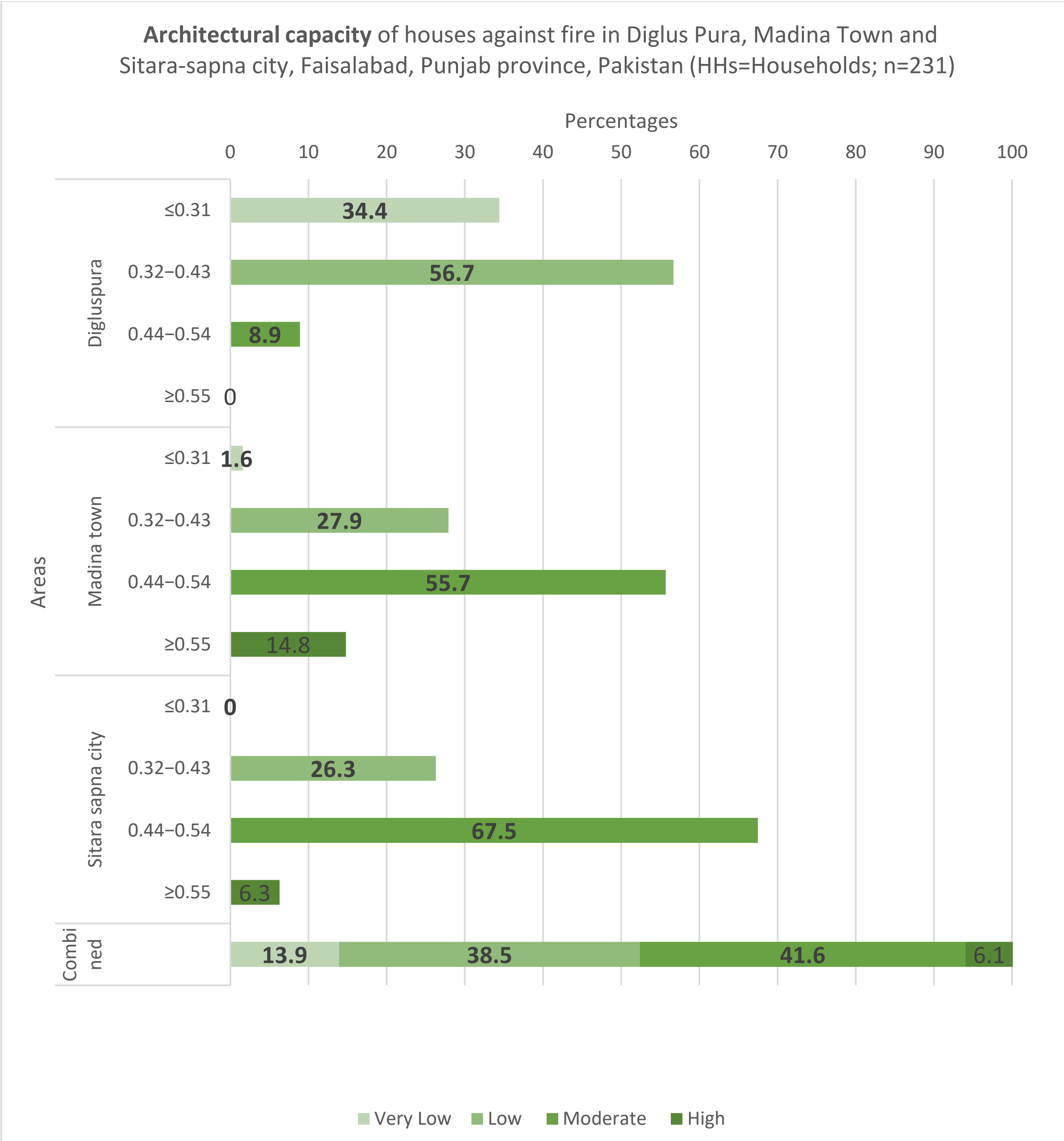

Figure 19 Architectural capacity

5.9 Water supply capacity:

87.9% of houses pump groundwater for their domestic use. 61.5% had water tanks less than 200 gallons' size. Madina town and Sitara-sapna city showed similar results as almost all of the houses were using groundwater and similar size of water tanks. In the Digluspura community, many houses also have a municipal supply of water.

Table 16 Water supply capacity of houses against fire in Diglus Pura, Madina Town and Sitara-sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)

Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.71	0.72−0.80	0.81−0.89	≥0.90		Min =0.3	*F =203.96*
	No. of HHs	36	47	6	1	90	Max =0.93	df =2
	%	40	52.2	6.7	1.1	100	Mean =0.7085	*p value =0.00*
							SD =0.0805	
Madina Town	Range	≤0.71	0.72−0.80	0.81−0.89	≥0.90		Min =0.70	
	No. of HHs	2	0	59	0	61	Max =0.87	
	%	3.3	0	96.7	0	100	Mean =0.8579	
							SD =0.0327	
Sitara-sapna city	Range	≤0.71	0.72−0.80	0.81−0.89	≥0.90		Min =0.80	
	No. of HHs	0	0	80	0	80	Max =0.87	
	%	0	0	100	0	100	Mean =0.8575	
							SD =0.0231	
Total	No. of HHs	38	47	145	1	231		
	%	16.5	20.3	62.8	0.4	100		

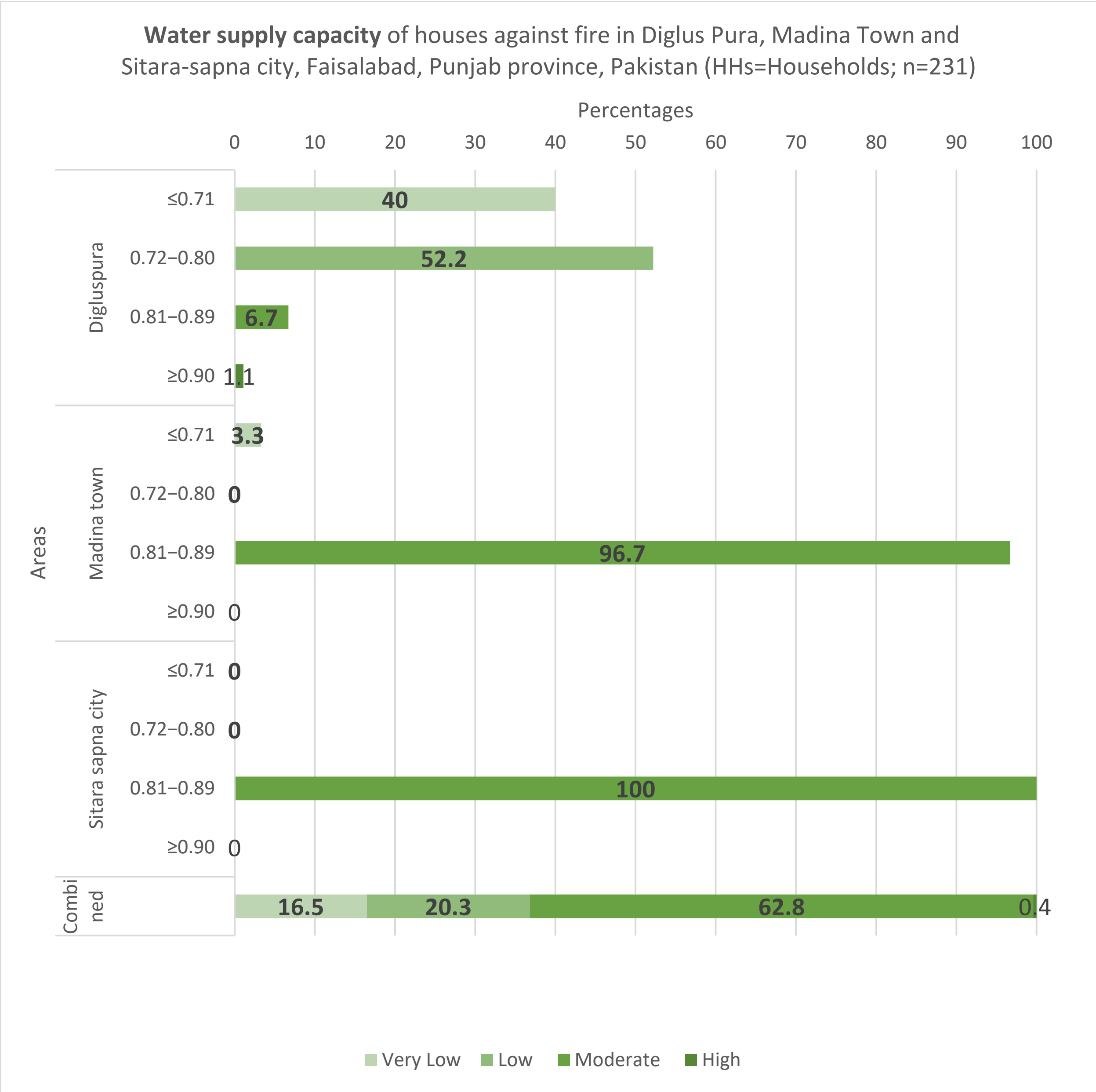

Figure 20 Water supply capacity

5.10 Fire evacuation capacity:

99.6% of households claimed to have no hurdles in their evacuation passageway. 97.4% of households claimed to have less than a 20 ft distance from the center of their house to the exit door. Results were varied between all three communities with (F=14.733 and p=0.000). Improvement in the building code is required to improve the fire escape properties of houses.

Table 17 Fire evacuation capacity of houses in Diglus Pura, Madina Town, and Sitara-sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)

Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.25	0.26−0.39	0.40−0.54	≥0.55		Min =0.16	*F =14.733*
	No. of HHs	20	47	13	10	90	Max =0.69	df =2
	%	22.2	52.2	14.5	11.1	100	Mean =0.3436	*p value =0.00*
							SD =0.1306	
Madina Town	Range	≤0.25	0.26−0.39	0.40−0.54	≥0.55		Min =0.20	
	No. of HHs	5	26	7	23	61	Max =0.80	
	%	8.2	42.6	11.5	37.7	100	Mean =0.4627	
							SD =0.1720	
Sitara-sapna city	Range	≤0.25	0.26−0.39	0.40−0.54	≥0.55		Min =0.20	
	No. of HHs	7	56	12	5	80	Max =0.82	
	%	8.8	70	15	6.3	100	Mean =0.3675	
							SD =0.1187	
Total	No. of HHs	32	128	33	38	231		
	%	13.9	55.4	14.3	16.5	100		

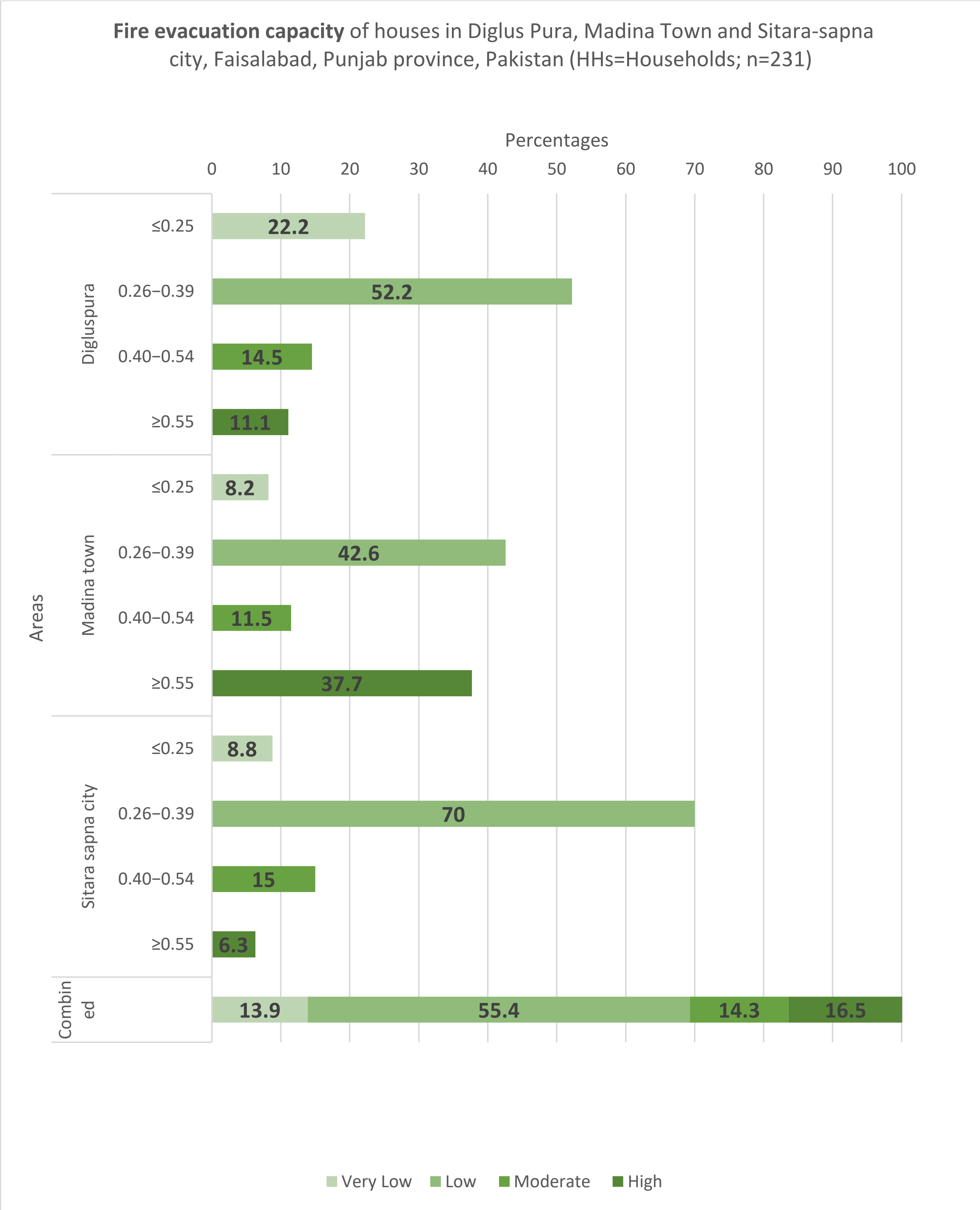

Figure 21 Fire evacuation capacity

5.10 Overall preparedness:

Overall the preparedness against household, fire is very low to low in 9.5% and 49.3% of households. With Sitara-sapna and Digluspura least prepared communities.

Table 18 Overall preparedness of households against fire in Diglus Pura, Madina Town, and Sitara-sapna city, Faisalabad, Punjab province, Pakistan (HHs=Households; n=231)

Area	Classes	Very Low	Low	Moderate	High	Total	Descriptive statistics	ANOVA
Diglus Pura	Range	≤0.43	0.44−0.48	0.49−0.52	≥0.53		Min =0.35	*F =26.552*
	No. of HHs	17	48	20	5	90	Max =0.56	df =2
	%	18.9	53.3	22.2	5.6	100	Mean =0.4590	*p value =0.00*
							SD =0.0417	
Madina Town	Range	≤0.43	0.44−0.48	0.49−0.52	≥0.53		Min =0.40	
	No. of HHs	1	19	19	22	61	Max =0.59	
	%	1.6	31.1	31.1	36.2	100	Mean =0.5045	
							SD =0.0453	
Sitara-sapna city	Range	≤0.43	0.44−0.48	0.49−0.52	≥0.53		Min =0.40	
	No. of HHs	4	47	24	5	80	Max =0.56	
	%	5	58.8	30	6.3	100	Mean =0.4686	
							SD =0.0308	
Total	No. of HHs	22	114	63	32	231		
	%	9.5	49.3	27.3	13.9	100		

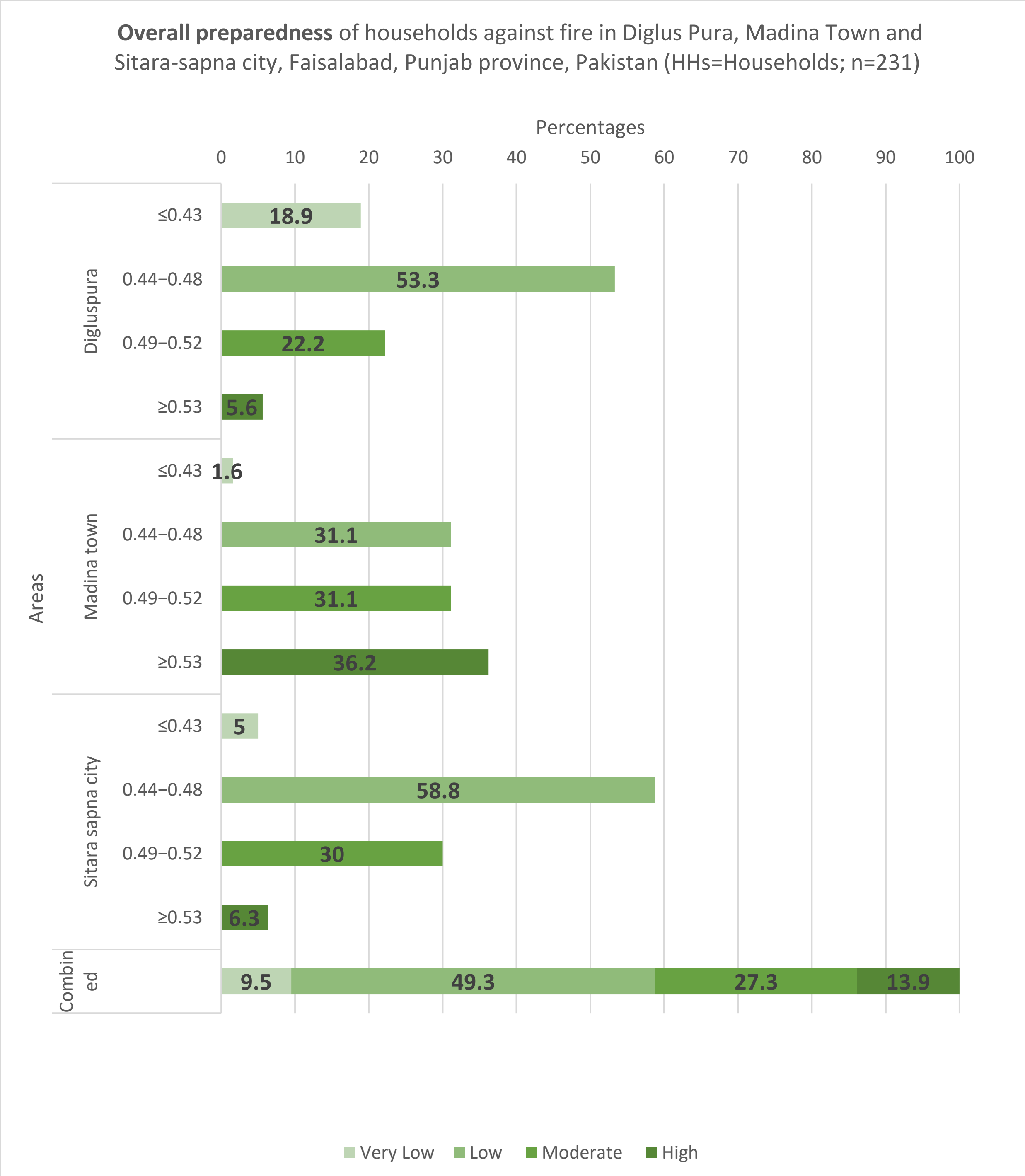

Figure 22 Overall preparedness

CHAPTER 6:

Fire Risk Perception:

6.1 Assessment methodology:

For the assessment of fire risk perception, 11 indicators were selected from 5 different studies. Likert scale was designed to record the responses of households. Original values were transformed to 0-1 based on their perception level as shown in Table 19.

6.2 Indicators of perception against fire:

Table 19 Indicators and transformed values for the perception of household fire hazards in Faisalabad, Pakistan

S. No	Ind	Indicators	Classes	Transformed values	Empirical References
1	P1	Perceived fire threat Question: Do you think that there can be a fire incident in your house?	Strongly disagree	0	(Kinateder et al., 2015)
			Disagree	0.25	
			Uncertain	0.50	
			Agree	0.75	
			Strongly agree	1	
2	P2	Perceived fear of fire Question: Do you think that you are afraid of fire?	Strongly disagree	0	(Paul & Bhuiyan, 2010)
			Disagree	0.25	
			Uncertain	0.50	
			Agree	0.75	
			Strongly agree	1	
3	P3	Perceived likelihood of severity of the fire Question: Do you think that fire can take a life?	Strongly disagree	0	(Paul & Bhuiyan, 2010)
			Disagree	0.25	
			Uncertain	0.50	
			Agree	0.75	
			Strongly agree	1	
4	P4	Perceived likelihood of personal damages due to fire Question: Do you think that your family and neighbors are at risk of fire?	Strongly disagree	0	(Kinateder et al., 2015)
			Disagree	0.25	
			Uncertain	0.50	
			Agree	0.75	
			Strongly agree	1	
5	P5	Perceived understanding of human error in fire ignition Question: Do you think that human carelessness causes fire ignition?	Strongly disagree	0	(Kobes et al., 2010b)
			Disagree	0.25	
			Uncertain	0.50	
			Agree	0.75	
			Strongly agree	1	

6	P6	Perceived likelihood of general economic damages due to fire	Strongly disagree	0	(Cvetković, 2019)
			Disagree	0.25	
		Question: Do you think that fire can cause huge damage?	Uncertain	0.50	
			Agree	0.75	
			Strongly agree	1	
7	P7	Perceived likelihood of own economic damages due to fire	Strongly disagree	0	(Kinateder et al., 2015), (T. W. Collins, 2005)
			Disagree	0.25	
		Question: Do you think that you can lose your house and valuable assets due to fire?	Uncertain	0.50	
			Agree	0.75	
			Strongly agree	1	
8	P8	Perceived preparedness against fire	Strongly disagree	0	(Wolski et al., 2000), (T. W. Collins, 2005)
			Disagree	0.25	
		Question: Do you think that you can deal with the household fire?	Uncertain	0.50	
			Agree	0.75	
			Strongly agree	1	
9	P9	Trust in firefighting institutions	Strongly disagree	0	(Kinateder et al., 2015)
			Disagree	0.25	
		Question: Do you have trust in the firefighting institutes?	Uncertain	0.50	
			Agree	0.75	
			Strongly agree	1	
10	P10	Trust in rescue institutes	Strongly disagree	0	(Kinateder et al., 2015)
			Disagree	0.25	
		Question: Do you have trust in the rescue institutes?	Uncertain	0.50	
			Agree	0.75	
			Strongly agree	1	
11	P11	Perceived understanding of fire safety protocols	Strongly disagree	0	(Wolski et al., 2000)
			Disagree	0.25	
		Question: Do you think that fire hazards can be managed with fire safety protocols?	Uncertain	0.50	
			Agree	0.75	
			Strongly agree	1	

6.3 Results:

Overall the fire risk perception level of all three communities was good. All three communities showed an almost similar perception of fire risk. The perception level of Sitara-sapna city was comparatively more than the other two communities.

Perceived fire threat (P_1), the belief that there can be a fire incident in the house explains that people understand the lack of overall preparedness measures against fire in their houses. The community of Sitara-sapna was perceiving the fire threat the most as compared to the other two communities. Perceived fear of fire (P_2), would theoretically compel people to prepare against the fire. The community of Sitara-sapna was perceiving the fear of fire the most with a mean value of 0.8719 as compared to 0.7951 and 0.7694 of Madina town and Digluspura. The perceived likelihood of severity of the fire (P_3), was intended to determine the understanding of the severity of fire to human life. The community of Sitara-sapna was perceiving the likelihood of the severity of fire better than the other two communities. Perceived likelihood of own economic damages due to fire (P_7), would determine the perception of risk to the own property loss. The community of Sitara-sapna was perceiving the loss of property more than the other two communities. A significant difference in perception level was recorded in perceived fire threat (P_1), perceived fear of fire (P_2), perceived likelihood of severity of fire (P_3), and perceived likelihood of own economic damages due to fire (P_7). For all other indicators, the perception level was more similar.

Table 20 Perception of household fire hazards in Faisalabad, Pakistan									
S. No	**Ind**	**Indicators**	**Descriptive statistics**	**Digluspura**	**Madina town**	**Sitara-sapna city**	**ANOVA (F-test)**	**Sig.**	**Combined (All Communities)**
1	P1	Perceived fire threat	Mean	0.7028	0.7377	0.8094	15.167	0.000	0.7489
			Std.Dev	0.13457	0.14014	0.10706			0.13493
2	P2	Perceived fear of fire	Mean	0.7694	0.7951	0.8719	15.367	0.000	0.8117
			Std.Dev	0.1075	0.14074	0.12575			0.13077
3	P3	Perceived likelihood of severity of the fire	Mean	0.7833	0.8197	0.8969	15.922	0.000	0.8323
			Std.Dev	0.11367	0.1654	0.12385			0.14084
4	P4	Perceived likelihood of personal damages due to fire	Mean	0.8278	0.8361	0.8719	2.669	0.071	0.8452
			Std.Dev	0.13326	0.12817	0.12575			0.1303
5	P5	Perceived understanding of human error in fire ignition	Mean	0.7806	0.7869	0.7969	0.348	0.706	0.7879
			Std.Dev	0.12889	0.15703	0.09819			0.12737
6	P6	Perceived likelihood of general economic damages due to fire	Mean	0.8083	0.8197	0.8031	0.261	0.771	0.8095
			Std.Dev	0.15475	0.14528	0.10291			0.13584
7	P7	Perceived likelihood of own economic damages due to fire	Mean	0.7889	0.8279	0.8594	5.985	0.003	0.8236
			Std.Dev	0.12934	0.14819	0.1248			0.13592
8	P8	Perceived preparedness level against fire	Mean	0.7528	0.7992	0.7969	3.864	0.022	0.7803
			Std.Dev	0.13247	0.12764	0.09819			0.12181
9	P9	Trust in firefighting institutions	Mean	0.8028	0.8279	0.8031	1.029	0.359	0.8095
			Std.Dev	0.12706	0.11673	0.10291			0.11645
10	P10	Trust in rescue institutes	Mean	0.8056	0.7992	0.8031	0.053	0.948	0.803
			Std.Dev	0.11719	0.12764	0.11033			0.11727
11	P11	Perceived understanding of fire safety protocols	Mean	0.8	0.7828	0.7719	1.57	0.210	0.7857
			Std.Dev	0.12542	0.1068	0.07109			0.10463

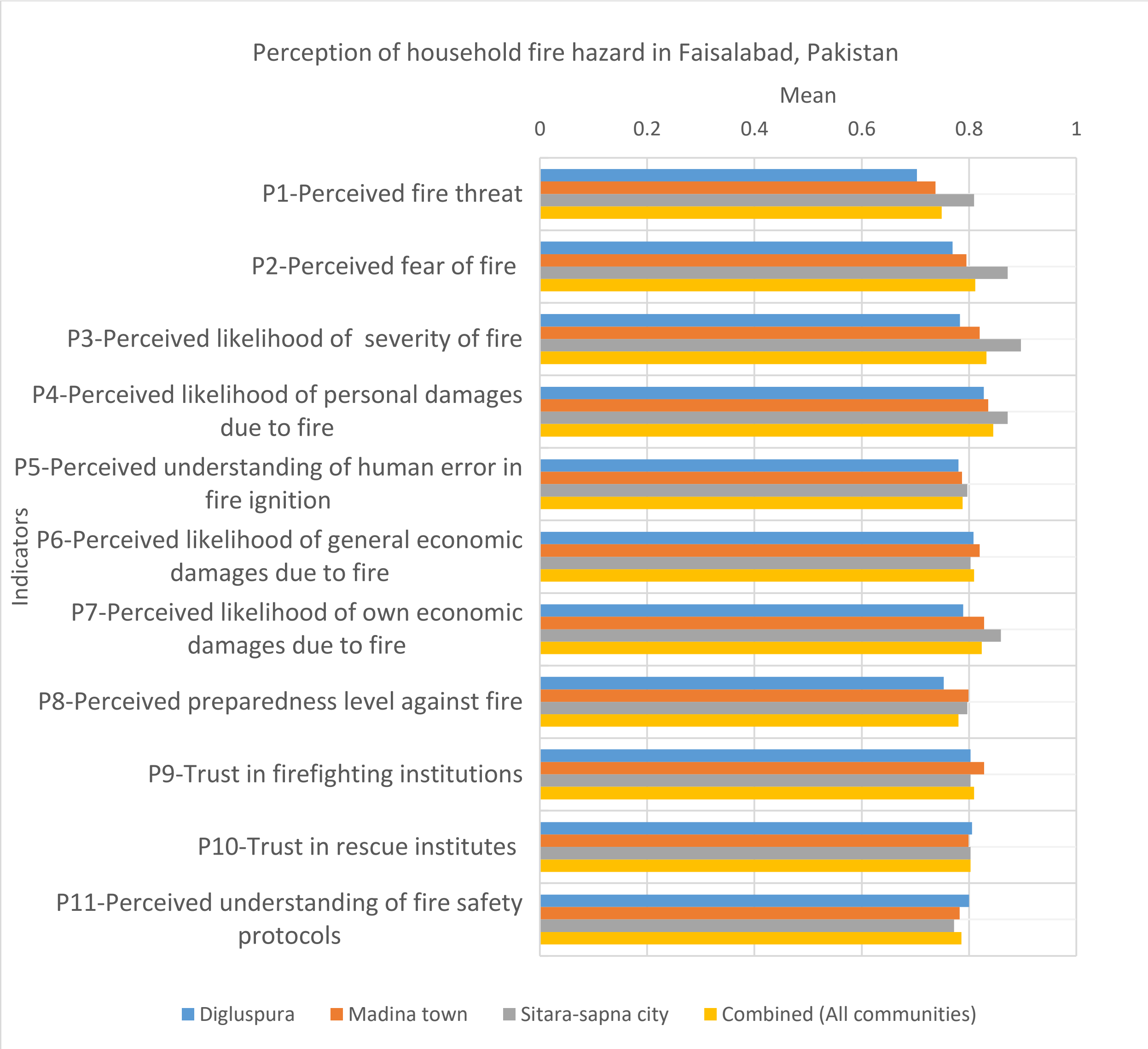

Figure 23 Perception of household fire hazard

Chapter 8:

Recommendations and conclusion:

This study was carried out to assess the risk of household fire in an urban area. Three distinct urban communities in the city of Faisalabad, Pakistan were selected for this study. These three urban communities Digluspura, Madina town, and Sitara-sapna city had established urban, newly administered, and peri-urban properties. Statistical tests analyzed results from these communities to establish the patterns of fire risk. This study contributes to the existing literature on fire risk assessment of households in an urban area. It represents the overall picture of household fire risk in urban areas of Pakistan. The results of this study can apply to similar communities across the country and region.

This study included the fire vulnerability, capacity, and perception assessment of households. Overall the fire posed a constant threat to households in the city. This study held its merits against the common misconceptions of fire being a threat to underdeveloped or underprivileged areas of the city.

Digluspura community was socio-economically most vulnerable area compared to the other two communities, and also showed more vulnerability in fire ignition and development. But, showed better stats in fighting the early fire and extinguishing it. Also, residents of the Digluspura community possessed a better ability to escape the fire, their vulnerability in the evacuation phase of household fire was less than the other two communities. Overall in Digluspura, fewer houses were highly vulnerable to household fire as compared to the other two communities. Communities of Madina town and Sitara-sapna city possessed less socio-economic vulnerability are found to be a bit relaxed about the fire. There is a need to instill fire-safe behavior in developed communities more.

There were different types of building practices observed in Digluspura and Madina town. Digluspura, the oldest established community, showed the most variation in the design of houses. Many of the houses in Digluspura were older than 100 years and some were newly constructed after demolishing of old structures. Building patterns showed the changing of building codes, jurisdiction authorities, and construction practices throughout the years. Madina town showed comparatively less variation in building design of houses as it is comparatively recently established. In the Sitara-sapna city community, the building design was found to be similar as all the houses were built recently and were subjected to the same building code.

The structural and architectural capacity of the houses against the fire varied similarly to the design and construction practices of the houses. Structural and architectural capacity was also bad in newly constructed houses. Physical and attitudinal capacity against household fire is also lacking especially in newly established urban communities. As fire hydrants are not provided in the communities of the urban area, the only reliable source of water to fight the early fire in houses of these communities is their water storage. Digluspura was partially supplied with the municipal water supply. However, the size of the water tank of the house determines the quantity of water available for extinguishing the early fire. There is a trend of renting out the upper floors of the house, so there is by default a separate staircase provided to the renters. This increases the fire escape capacity of the houses. But fire escape design of most of the houses was overall poor.

The fire safety code of Pakistan (Fire Safety Provisions, 2016) provides the bylaws for the fire safety of residential units. Many of these bylaws are referred to from the building codes of the United States of America, which makes it complex to implement as local conditions are much different. These bylaws are based on the best practices which are developed over time by trial and error. Most of the fire safety provisions in this code are technology based.

As this study pointed out that human behavior also adds to the vulnerability of household fire. Disaster management institutes should make inclusive fire safety policies. Other disciplines and institutes should also be incorporated into the fire safety planning of households. A building fire safety code should be made which can also cover the provisions of fire safety improvements in the existing houses. As two of the selected communities had better economic capacity than underprivileged areas of the city, the building code should not be generalized. The building code should incorporate the fire safety needs and available resources of different economic classes of the city. Other institutes like Rescue 1122 should also reach out to more citizens increase their understanding of fire hazards, and train them to fight the fire. A comprehensive strategy of fire safety training for the citizens should be made, including educational institutes and workplaces. The fire safety considerations for household items like cooking stoves, heaters, and electrical items should be made. Household items with the least fire risk should only be approved to sell.

This study can be replicated in other cities in Pakistan. This study can also help The fire risk management departments and local governments to develop an assessment framework for existing household fire risks across their jurisdiction areas.

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Annexures:

Questionnaire:

<u>Sr. No:</u>…………

Diglus pura / Madina Town / Sitara-sapna City

<u>National University of Sciences and Technology, Islamabad, Pakistan</u>

<u>School of Civil and Environmental Engineering (SCEE)</u>

<u>Department of Urban & Regional Planning</u>

Fire Risk Assessment of Household Units in established built-up, urban and peri-urban areas of Faisalabad city.

This questionnaire is designed to collect the data that will be used in assessing the fire vulnerability and exposure of households, measuring the fire safety preparedness and capacities of communities, and identifying the barriers and challenges faced by institutions against fire safety hazards. I would be very grateful for the valuable time you will spend to complete this questionnaire. This information will be kept confidential and used only for study purposes.

Socio Economic Profile:

1. Gender: Male / Female
2. Age:

3. Qualification: Informal education / Under Metric / Metric / Graduate / Higher
4. Household Size:
5. Employment status; Employed / Unemployed / Own-Business
6. Monthly income:
7. House Ownership: Owned / Rental / Leased
8. Do you have insurance: Health / Life / Property / Fire if other: ……….
9. Employed Person at Home:

Please fill in the following details of your living style:

10. Does anyone smoke inside your house?

    Yes/No

11. Is Electrical wiring in your house earthed?

    Yes/No

12. Is there a short circuit switch in the electrical system of your house?

    Yes/No

13. Are there any cracks, bends, or heat marks on your electrical wires?

    Yes/No

14. Do you leave electrical items switched on during the day and night?

    Yes/No How many:….

15. Do you have a wooden or coal stove? Yes/No

    Which:………

16. Is there any combustion able material permanently present

    Yes/No

    within 70 cm height of your stove?

17. Do you clean and check your stove regularly? Yes/No

How often:….

18. Do you have more than 1 functional cooking stove in your house?

Yes/No How many……:

19. Do you use the cooking stove more than 3 times during the day?

Yes/No How many (avg):..

20. Do you smell gas leakage in your house?

Yes/No

21. Do you use a candle or other burning source of light? Yes/No

22. Do you use a candle or other burning source of light regularly?

Yes/No How often:……

23. Do you place the candle in a non-combustion able pan while using it?

Yes/No

24. Do place a burning candle in a safe place?

Yes/No Where:

25. Do you have children less than 18 years old in your house?

Yes/No How many:

26. Do your children play with fire?

Yes/No

27. Do your children know about the fire hazard?

Yes/No

28. Do you have wood or coal heaters in your house?

Yes/No Which:

29. Do you have more than 1 heater unit?

Yes/No How many:

30. Do you keep flammable things 1 meter away from heaters?

Yes/No

31. Does the pilot light work in your gas heaters?

Yes/No

32. Are there any discolored walls in your gas heater?

Yes/No

33. Do you use heaters regularly during winter?

Yes/No How often:…….

34. Do you clean and maintain your heaters regularly?

Yes/No How often:……

35. Do you have an electrical washing machine?

Yes/No How many:…….

36. Do you have an iron?

Yes/No How many:……

37. Do you have other heavy-duty electrical machines?

Yes/No How many:……

Please fill in the following details of your household members:

38. The number of children less than 18 years old:

39. Do you have any household members who are at most risk in case of fire?

Yes / No

No. of persons with disabilities: ………..

No. of old: …………

No. of infants: ………….

No. of other people at most risk: ………….

40. Do your children know about the fire hazard?

Yes / No

41. How many active members in your house can fight the fire?

…………………………………………………………………………

42. How many household members know the use of fire-fighting equipment?

…………………………………………………………………………

43. How many household members have used the fire-fighting equipment before?

…………………………………………………………………………

44. How many household members can detect the early signs of fire like the smell of smoke or the noise of fire?

………………………………………………………………………….

45. How many members have successfully detected the early fire in past?

………………………………………………………………………….

46. How many members have successfully fought the fire in past?

………………………………………………………………………….

47. How often these active members stay at home?

a)24 hours, b)12 hours, c)less than 12 hours, d)other……………..

Please fill in the following blanks about your house:

48. Do you have an automatic fire extinction system?

a)Yes b)No

49. The covered area of the automatic fire extinction system?

a)whole house b)Major rooms c)Most vulnerable rooms d)other . . . …………..

50. Which type of fire-fighting equipment do you have?

a)Water buckets, b)Sand buckets, c)Fire extinguishers, d)other………………

51. How old is your house?

……………………..

52. What is the area of your house?

…………………….

53. How many rooms are there in your house?

…………………....

54. How many stories are there in your house?

………………….

55. On how many sides your house has a common wall with the neighboring houses?

…………………

56. Which structural system is used in your house?

a)RCC, b)Steel girders, c)wooden, d)other

57. Fill in the details for the following items in your house?

No. of Chairs ………….. Material…………

No. of Beds……………. Material…………

No. of Cupboards……… Material…………

Area of Carpets ……..

No. of other combustion-able items……………

Names………………………...

…………………………………………………………………………………………

……………………………..

58. What is the thickness of the walls in your house?

…………………

59. Which type of wall covering is there in your house?

a)Plastered, b)Un-plastered, c)other……………

60. What type of bricks did you use in your house?

a)Clay, b)Concrete, c)Hollow bricks, d)other……….

61. How many numbers of exterior openings in your house?

Vents…………..............

Windows………………...

Doors……………………

Roof openings………….

62. How many numbers of interior openings in your house?

Vents…………..............

Windows………………..

Doors……………………

63. What type of water supply does your house have?

a)Municipal water supply, b)Groundwater, c)other…………

64. What is the size of your water storage tank?

…………………

65. What are the sizes of water tanks in houses right, left, front, and back of your house?

…………………

66. How many exit doors in your house?

…………………

67. What is the distance of your nearest exit door from the last room?

(Total distance from the door of the last room to the nearest exit door in case of 1 story house, in case of more than 1 stories total distance from last room on the last floor to the nearest exit door including length of stairways)

…………………..

68. In case of more than 1 story, do you have immovable stairs that can be used for evacuating?

…………………..

69. In case of emergency do you have any evacuation passage for the upper floors? (Escape route to neighbor's roof)

…………………..

70. Give the specifications of your evacuation passageways:

Width of the passageways…………………….

Minimum width of the door in passageway…………………

Doors open (outwards or inwards)…………………..

Are there any obstacles present in the passageway………………. If yes which……………………..

71. Do you have moveable stairs in your house that can be used for evacuation?

…………………….

72. Do your neighbors have moveable stairs that can be used for evacuation?

……………………

73. What is the width of the street?

……………………

74. Your nearest fire fighting station?

…………………….

75. Fire brigade phone number?

…………………….

How much do you agree to the following statements?

No.	Statement	Strongly Disagree 1	Disagree 2	Uncertain 3	Agree 4	Strongly Agree 5
76	There can be a fire incident in your house?					
77	Are you afraid of fire?					
78	Fire can take a life?					
79	Fire is dangerous to your family and neighbors?					
80	Human carelessness causes fire ignition?					
81	Fire can cause huge damages?					
82	You can lose your house and valuable assets due to fire?					
83	You are able to deal with the household fire?					
84	You have trust in the firefighting institutes?					
85	You have trust in the rescue institutes?					
86	Fire hazard can be managed with fire safety protocols?					

Please give your valuable opinion:

87. Any other hazard?

…………………………………………………………………………………………

…..

88. Any suggestion related to this study:

…………………………………………………………………………………………

…..

89. Any recommendations:

…………………………………………………………………………………………

….