ASSESSMENT OF DIFFERENT HAZARDS AND VULNERABILITIES WITH SPARSE DATA IN COASTAL CITY OF KARACHI, PAKISTAN

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ASSESSMENT OF DIFFERENT HAZARDS AND VULNERABILITIES WITH SPARSE DATA IN COASTAL CITY OF KARACHI, PAKISTAN

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ABSTRACT

ASSESSMENT OF DIFFERENT HAZARDS AND VULNERABILITIES WITH SPARSE DATA IN COASTAL CITY OF KARACHI, PAKISTAN

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The coastal city of Karachi is the financial capital of Pakistan while being the most populous in the country. It was originally inhabited as a fishing village, which later became an important port during British rule. Almost all the major infrastructure, key facilities, slums, and housing schemes are located on or near the coast. The city was not known to pose risk of any major disaster until recently. With about twenty million people living in the city, it makes the inhabitants exposed and vulnerable to hazards than ever before. Although the city lies close to some on-shore faults, but the main concern is about off-shore faults in Makran Subduction Zone off the Karachi coast. The city has been hit by a Tsunami during 1945 earthquake with wave height of 1.5 m. Furthermore, the city has chronic problem of urban flooding hazard, mostly due to monsoon rain, which often put city at standstill and cause causalities. Even though the mega city faces risk of several hazards, there has not been any significant research to understand the type or extent of hazards it is likely to face. In this study, vulnerability analysis of Karachi metropolitan is carried out by taking into account the disasters which affected the city in past. It includes both geophysical and climate-related hazards such as earthquake, tsunami, and flooding. Because of scarcity of data, methodology relies heavily on expert knowledge and judgement with selection and weight of hazard indicators are given using Delphi method. Hazard vulnerability assessments are realized by using GIS based multi criteria decision analysis (MCDA).

Final vulnerability maps of Karachi obtained from Multi Criteria Decision Anlaysis reveal that the areas at South and West of Karachi near the shore with high population density are at grave danger against tsunami. Earthquake vulnerability map, however, shows that most of the areas, especially ones with high population density, households, and located on alluvial deposits, have either very high or high vulnerability to earthquake. That is because three parameters (geology, population density, and number of households) carry significant weights in earthquake vulnerability mapping. Lastly, flood hazard vulnerability map identifies district east, central, west, and parts of Korangi having high to very high vulnerability to flooding. These are generally the areas, which are often hit with floods by the rivers (Malir and Lyari), apart from being low altitude, and high population density.

Keywords: Multi Hazards, Vulnerability Assessment, Multi Criteria Decision Analysis, Karachi, Analytical Hierarchy Process, Flood

ÖZ

KIYI METROPOLİTAN ŞEHRİ KARACHİ'NİN CBS TABANLI ÇOK KRİTERLİ KARAR ANALİZİ İLE HASAR GÖREBİLİRLİK DEĞERLENDİRMESİ

Jawad Ahmed Nizamani

Yüksek Lisans, Jeodezi ve Coğrafi Bilgi Teknolojileri

Tez Yöneticisi: Prof. Dr. Ahmet Cevdet Yalçıner

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Pakistan'ın finans başkenti Karachi aynı zamanda ülkenin en kalabalık şehri özelliğini korumaktadır. Bir balıkçı köyü iken İngiliz yönetimi zamanında önemli bir liman şehri haline gelmiştir. Şehrin hemen hemen tüm büyük altyapı, kilit tesisler, gecekondu mahalleleri ve konut alanları kıyıyda ya da kıyıya yakın alanlarda bulunmaktadır. Şehrin yakın zamana kadar büyük bir felaket riski taşıdığı bilinmemekteydi. Şehirde yaşayan yaklaşık yirmi milyon insanın her zamankinden daha fazla afet tehlikesine maruz olduğu ortaya çıkmıştır. Bazı kıyı faylarına yakın olmasına rağmen, asıl endişe, Karaçi'nin Makran Dalma Batma zonundaki açık deniz faylarının etkileri altında olmasıdır. Şehir, 1945 depreminde 1.5 m yüksekliğindeki tsunami dalgaları tarafından etkilenmiştir. Bunlara ek olarak Karaçi şehri çoğunlukla muson yağmurlarından dolayı kronik kentsel sel tehlikesi sorununu da yaşamaktadır. Karaçi şehri çeşitli tehlikelerle karşı karşıya kalsa da, şehrin farklı tehlikelere karşı hasar görebilirlik analizi ayrıntılı olarak yapılmamıştır. Bu tez çalışmasında, Karaçi metropolünün kırılganlık analizi, geçmişte kenti etkileyen felaketler (Deprem, tsunami ve sel) ve iklimle ilgili tehlikeler dikkate alınarak, mevcut veriler ışığında, Coğrafik Bilgi Sistemleri (CBS) temelli Çok Kriterli Karar Analizi (MCDA) uygulanmaya çalışılarak gerçekleştirilmiştir.

Karaçi şehri için MCDA metodu yardımı ile elde edilen nihai kırılganlık haritalarına göre, yüksek nüfus yoğunluğuna sahip kıyıya yakın Karaçi'nin güneyinde ve batısındaki alanların tsunamiye karşı ciddi tehlike altında olduğunu ortaya koymaktadır. Ayrıca deprem hasar görebilirlik haritası, özellikle nüfus yoğunluğu yüksek olan, alüvyon yataklarında bulunan yerleşimlerin çoğunun depreme karşı çok yüksek veya yüksek düzeyde hasar görebilirlik durumunda olduğunu göstermektedir. Bunun nedeni jeoloji, nüfus yoğunluğu ve hane sayısı parametrelerinin deprem hasar görebilirlik haritalamasında önemli ağırlıklar taşımasıdır. Son olarak, taşkın tehlikesi için elde edilen hasar görebilirlik haritasında Karaçi şehrinin, doğu, orta, batı ve Korangi bölgelerinde (Malir ve Lyari) nehirlerinden taşkınlara karşı yüksek ve çok yüksek hasar görebilirlik düzeyleri olduğu ortaya çıkmaktadır.

Anahtar Kelimeler: Çoklu Afetler, Hasar Görebilirlik, Çok Kriterli Karar Analizi, Karaçi, Analitik Hiyerarşi Süreci, Taşkın

To my beloved family,

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The contribution of local experts for this study has been immense in achieving hazard maps of Karachi. For that, I would like to thank all those local experts from University of Sindh, University of Karachi, NED University, and Geological Survey of Pakistan. Also, I would like to thank Higher Education Commission of Pakistan who sponsored my study at METU.

I would like to mention friends of mine whose positivity and support has been of great motivation. Ilir Sheraj and Saeed Ahmed Khan are two humble people I spent great time with. I have great memories of several coffees and refreshing discussions on various topics outside of library with them.

Lastly, I would like to thank my family by dedicating this thesis to them. I have no words to thank for their love, support, and patience during my hard times and endeavor to complete this degree. These amazing people include my parents, and wife Esengül Güngör whose vital support helped me get over the line. Presence of my son Yusuf has always kept me motivated and energetic and now finally submitting this thesis I would like to spend all the time and attention to welcome the second child in coming days.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AHP:	*:Analytical Hierarchy Process*
DEM:	*:Digital Elevation Model*
GIS:	*:Geographic Information System*
GSP:	*:Geological Survey of Pakistan*
MCDA:	*: Multi Criteria Decision Analysis*
MSZ:	*:Makran Subduction Zone*
NDMA:	*:National Disaster Management Authority*
INFORM:	*: Index for Risk Management*
PAEC:	*:Pakistan Atomic Energy Commission*
PBS:	*: Pakistan Bureau of Statistics*
USGS:	*:United States Geological Survey*

CHAPTER 1

INTRODUCTION

Natural hazards, with increased exposure, pose a great danger to life, and environmental degradation. Earthquakes followed by Tsunami, have proven to be extremely fatal, such as, 2004 Indian ocean seismic event which caused hundreds of thousands of casualties with billions of dollars in economic losses. Around 14 countries were affected by the 2004 Tsunami, except India, none had the nuclear power plants. Such hazards may cause accidents when interacted with man-made systems, which may lead to catastrophic damages to life and environment. One such example was the 2011 Tōhoku earthquake and the following Tsunami which caused the Fukushima Daiichi nuclear disaster. Nuclear fallout from the disaster affected around 32 million people. Soil contamination, marine radioactivity, and environmental effects have been studied by Yasunari et al. (2011), Buesseler et al. (2011), Povinec et al. (2013) and many other researchers.

Karachi is located on the southern coastline of Pakistan along a natural harbor on Arabian sea and is the most populous city of Pakistan with an estimated population of about 20 million. The city was initially inhabited by a community which used the natural harbor for fishing which later turned into a trading port doing business with regional countries. Fishing and trading has brought a lot of prosperity to Karachi, which generates around 60% of revenue in taxes collected by the Federal Board of Revenue (FBR) and 15% of GDP. Karachi Metropolitan Corporation (KMC) budget is hardly 0.5% of national budget while most of it goes to salaries and pensions of KMC employees.

Karachi and the surrounding areas have been significantly affected by climate change phenomenon. Research showed that Karachi's surrounding areas have gone through sea water intrusion (Zia et al. 2017), deaths due to the extreme heat

(Ghumman and Horney, 2015), while flash flooding is also common and often paralyzes the city.

Apart from the climate-change related issues, Karachi is at risk of significant geophysical hazards. Overused infrastructure and facilities with various vulnerable communities makes it even more prone to damaging effects of any natural hazard. The city experienced major earthquake followed by a devastating Tsunami in 1945. With its history of such disasters, researches have shown that Karachi is at potential risk of earthquake and the Tsunami far more damaging than the 1945 event (Hafeez, 2007; Bilham et al., 2007).

General terminology of hazard assessment and its components is summarized in Table 1.1.

Table 1.1 Literature Terminology of Hazard, Risk, Disaster, Vulnerability & Social vulnerability

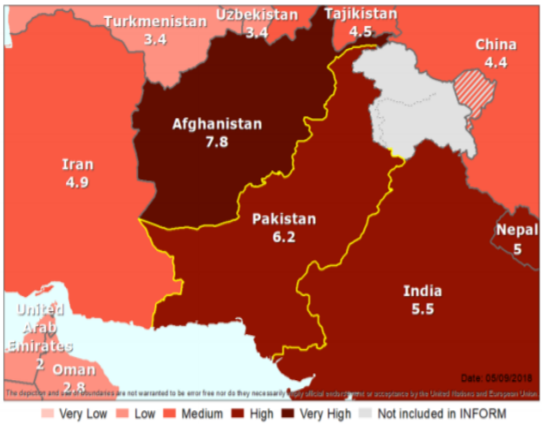
Term	**Definition**	**Source**
Hazard	Any event or trend which may cause harm to life, livelihood, property, infrastructure or ecosystem.	IPCC, 2014
Risk	Interaction of hazards with physical, socio-economic and environmental vulnerabilities and population exposure.	UNISDR, 2013
Disaster	Combination of hazards, exposure, and vulnerability resulting in terms of damage to life, property, infrastructure, natural resources, and manmade	IPCC, 2014

	or ecological system.	
Vulnerability	Circumstances or characteristics of an individual, group, asset or system making it susceptible to damaging effects of a hazard.	UNIDSR, 2009
Social Vulnerability	Combination of characteristics or experiences which enables an individual of the community or group of those individuals to respond and recover from a disaster.	Cutter et al. 2003
Multi-Hazard	-More than one hazard event threatening same exposed element with or without temporal coincidence. -Hazards may have same temporal coincidence or one following the other resulting in cascade effect.	Carpignano et al. 2009; EC, 2010; Marzocchi et al. 2012

Together, both hazards and vulnerability, can be summarized to have two main approaches categorized as multi-hazard risk assessment (Kappes et al. 2012), and multi-risk assessment for natural and technological hazards (Carpignano et al. 2009; Gallina et al. 2016). The multi-hazard risk assessment aggregates hazards as multi-hazard index and takes the total territorial vulnerability into consideration (not the hazard-dependent vulnerability). On the other hand, in more complex multi-risk assessment approach, multi-risk index is obtained when each risk is analyzed separately (i.e. each hazard taken into account with specific exposure and vulnerability individually). This study utilizes methodologies considering multi-hazard risk assessment.

The aim of this study is to assess and analyze vulnerabilities and various hazard risks posed to Karachi through a comparative analysis of identical risks posed or faced by Japan. According to Index of Risk Management (INFORM 2019), Pakistan and Japan are very high risk countries in terms of hazard & exposure with score of 7.6 and 5.8 respectively (Figure 1.1). However, in terms of overall risk profile of countries, Japan ranks much better with low score of 2.0 than Pakistan with score of 6.2. Disaster impacts are not only about the exposure, rather on coping capacity, resilience, and recovery from its effects (Greiving et al., 2006). Hence, such contrasting difference between two countries is primarily because of the higher vulnerability and lack of coping capacity of Pakistan (INFORM 2019).

	Value	*Rank*	*Trend (3 years)*
INFORM Risk	6.2	18	→
Hazard & Exposure	7.6	13	→
Vulnerability	5.7	37	→
Lack of Coping Capacity	5.6	59	→



	Value	*Rank*	*Trend (3 years)*
INFORM Risk	2.0	153	→
Hazard & Exposure	5.8	32	→
Vulnerability	0.9	185	→
Lack of Coping Capacity	1.5	180	→

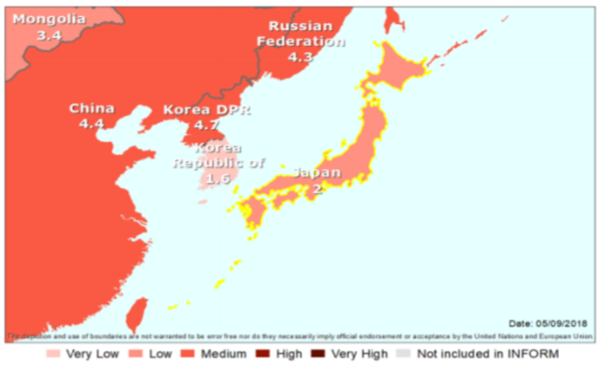


Figure 1. 1 Risk Index of Pakistan and Japan (INFORM 2019)

This comparative study shall provide improved vulnerability maps and increase knowledge of urban resilience to hazards for Karachi by learning from Japanese experiences. It includes identifying and examining various types of hazards city of Karachi may experience, extent to which city's infrastructure and population might be exposed to such hazards, level of awareness and readiness by population & administrators, and assessing overall vulnerability of the city. Same types of hazards are chosen from Japan with their hazard mitigation strategies and policies with their consequent success and failure during the last decades. Hazards geophysical, climatological, and technological nature which include Tsunamis, urban flooding, cyclones, and nuclear accident are of significant importance for this comparative study. Although Karachi faces significant hazard vulnerabilities but there are hardly any notable studies or mitigation plan for the population of more than 20 million. This study shall result in better understanding and awareness of vulnerabilities and encourage more research in disaster resilience of Karachi metropolitan.

The present study aims to demonstrate the following objectives:

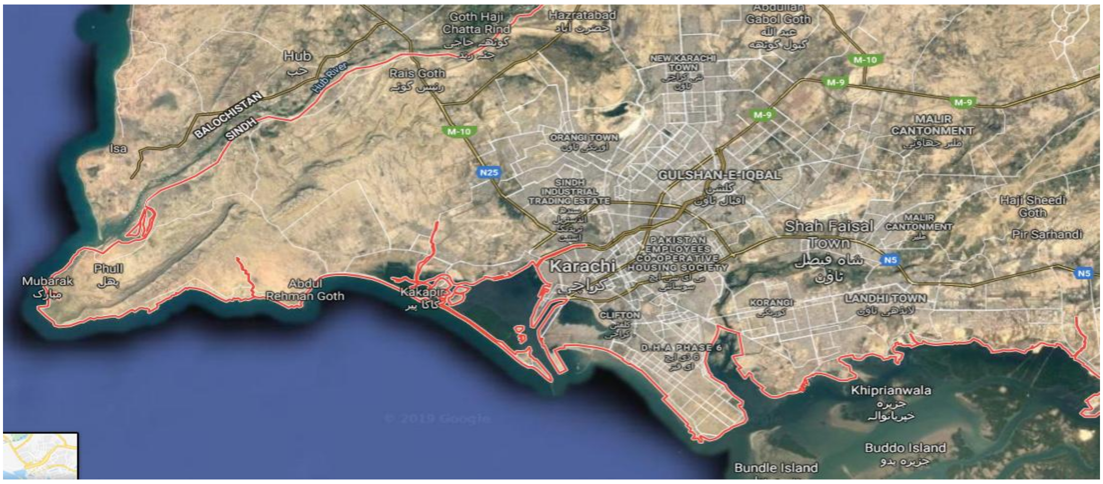
- To assess various geophysical, climatic, technological and social hazards and their exposure to the city infrastructure and population.
- To investigate vulnerabilities of Karachi and the population
- To determine potential natural hazards such as earthquake, Tsunami, flood and others the metropolitan city might encounter.
- To look for any man-made hazards like industrial accidents, factory fires etc.
- To identify identical hazards of Karachi and Japan, and comparing them to deduce a useful comparison.
- To construct a nascent multi-hazard risk map of the city.

According to the importance of Karachi city and the threat by different types of disasters, the multi hazard assessment using recent methods and approaches become an important issue for Karachi. Although initial aim of this thesis did include technological hazards of city, especially nuclear ones, but it was opted out after initial work because of non availability of detailed data and information needed to carry out such a sensitive hazard assessment properly. Hence the scope of the study is limited to natural hazards but technological hazards are also discussed to motivate further research in that area.

1.1. Study Area

The study area for this research is the metropolitan city of Karachi which is the capital of Sindh province of Pakistan (Figure 1.2). It is subtropical maritime desert like place which is divided as (a) hilly area, (b) lower alluvial valleys of Lyari, Malir, and Hub rivers, (c) mud or swamps type area along the coast (Chaudhri, 1967). It is the only developed city along the thousand kilometer coastline of the country and played a significant role the only port city responsible for all the imports and exports of Pakistan since independence. As a result, population increased exponentially soon after independence and increased city's financial activities. Currently, it is the most populous city with 14.9 million (2017 census) and plays a very significant role in the GDP of the country by being the financial capital. Most of the population is concentrated in south of the city along the coast with Arabian Sea. It is divided in six administrative districts as Karachi central, Karachi east, Karachi south, Karachi west, Korangi, and Malir. It hosts country's major civilian and air force airports, two sea ports, nuclear power plant, fuel storage facilities and many industries.

(a)



(b)

Figure 1. 2 (a) Google Earth image of Pakistan, (b) Google Earth image of Karachi

City's proximity to plate boundary and to several tectonically active structures exposes it to potential earthquakes within its boundaries (Bilham et al., 2007). Karachi lies around 150 kilometers east of makran subduction zone (MSZ) which is a triple junction between the Arabian, Indian, and Eurasian plates. MSZ has an extremely thick sediment layer of 7 km, which is one of the largest accretionary wedges in the world (Kopp et al. 2000). Such sediment layers are likely to fail, generating large undersea tsunamigenic slides **(**Heidarzadeh et al., 2008). MSZ has several active mud volcanoes (**(**Heidarzadeh et al., 2008) and they probably being the world's largest mud volcanoes developed along several of its weak anticlinal axes (Snead, 1967).

1.1.1 Geology of the Study Area

Karachi is located close to a plate boundary while earthquakes generated by many seismically active sources have the potential to affect the city. Period of rock formation is very recent, either quaternary or tertiary (Figure 1.3). The main population areas are in the central and southern parts of the city which consists of predominantly alluvial deposits. Three main formations are Nari, Gaj, and Manchar. Significant chunk of the population is also located on Korangi Conglomerate, grey stones of Manchar formation, and limestone and clay of Gaj formation.Most of the area of Karachi does not have any or significant population and such areas (especially in north east and north west) are covered by Pir Mangho, Hab, and Mol members of sandstone, limestone, and clay.

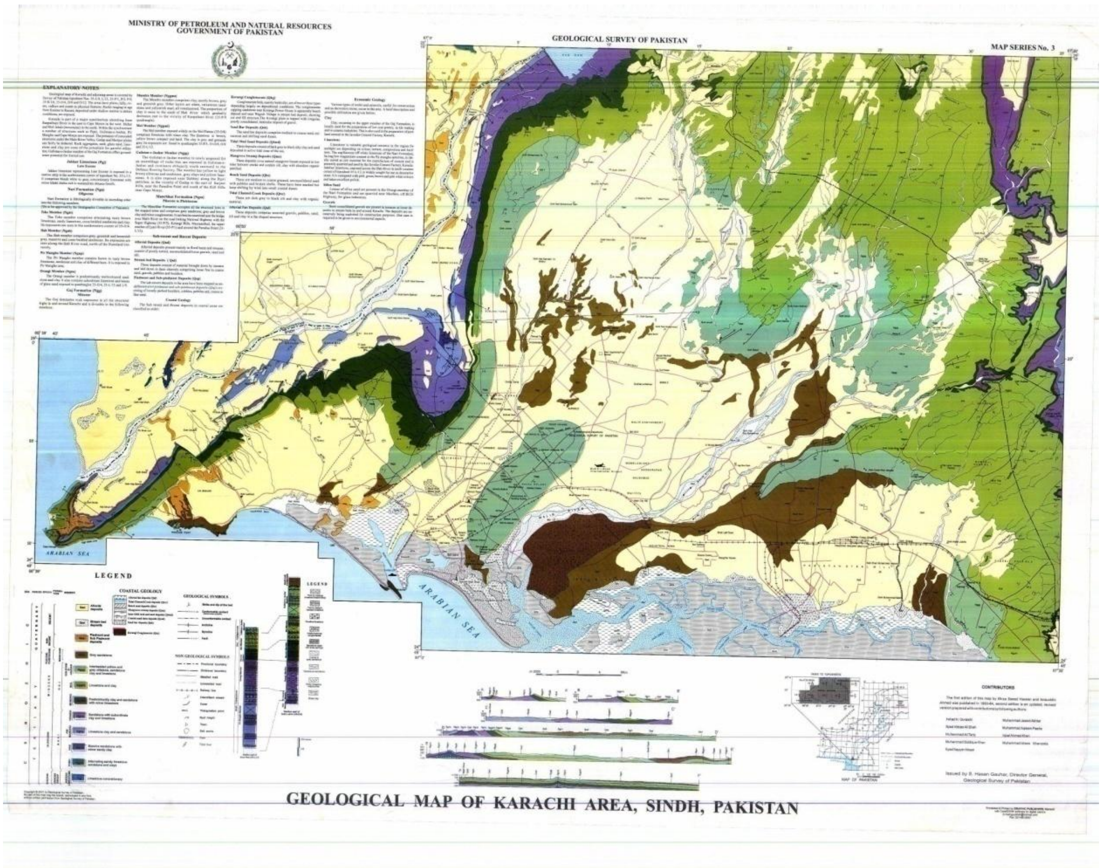


Figure 1. 3 Geological map of Karachi

1.1.2 Seismicity of Karachi

Most of the faults in Pakistan are present in North, West, and South-West of the country (Figure 1.4). Nearest fault to Karachi is Ornach Nal fault 130 km west of the city has the potential to produce an earthquake of up to M7 or larger (Bilham et al., 2007).

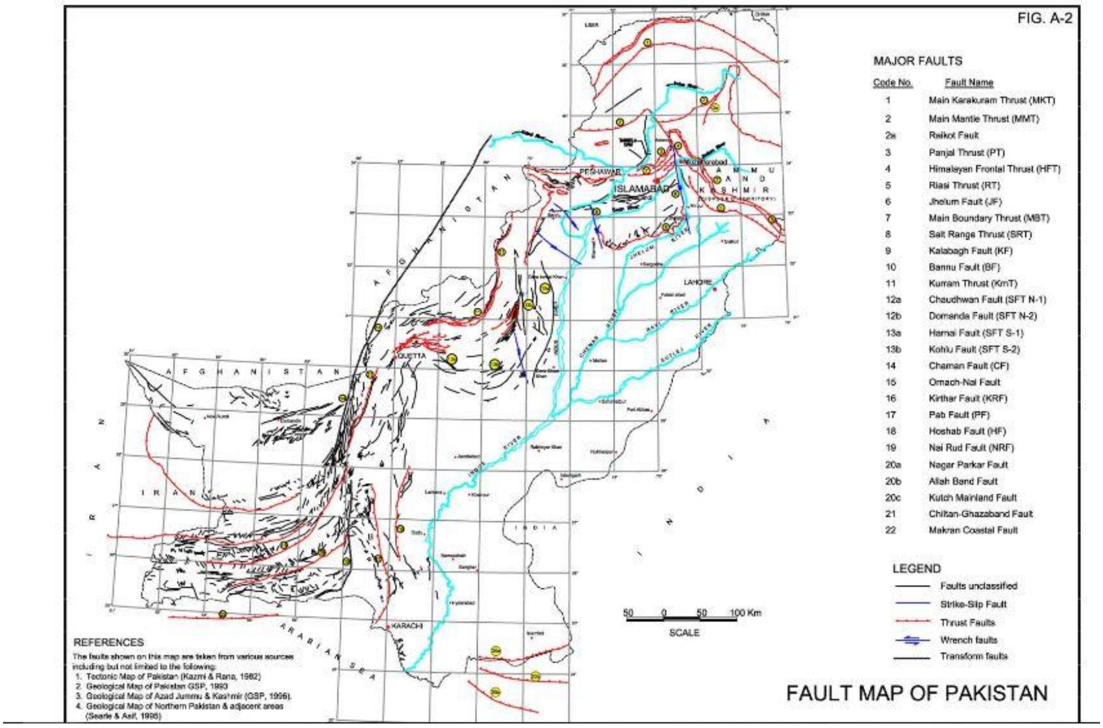


Figure 1. 4 Fault map of Pakistan (Building Code of Pakistan, 2007)

Makran Subduction Zone (MSZ) which has the length of 900 km lies offshore between south-western Pakistan near Karachi to south-eastern Iran in Strait of Hormuz (Heiderzadeh et al. 2009). It has formed as a result of convergence between Arabian and Eurasian plates, with length approximately 900 to 1,000 kilometers (Figure 1.5).

During the 1945 Tsunami, where Tsunami waves were highest at Makran, i.e. 12m while at Karachi the waves were up to 1.5m high. Calculations of Murty and Rao showed Tsunami waves as high as 15m in Gulf of Kach. While (Heiderzadeh et al., 2009) model showed that Karachi may experience waves as large as 1.5m high in future Tsunamis.

Evidence shows that there have been infrequent but major earthquakes, some of which, followed by destructive tsunamis in the MSZ during the last centuries (Berninghausen, 1966).

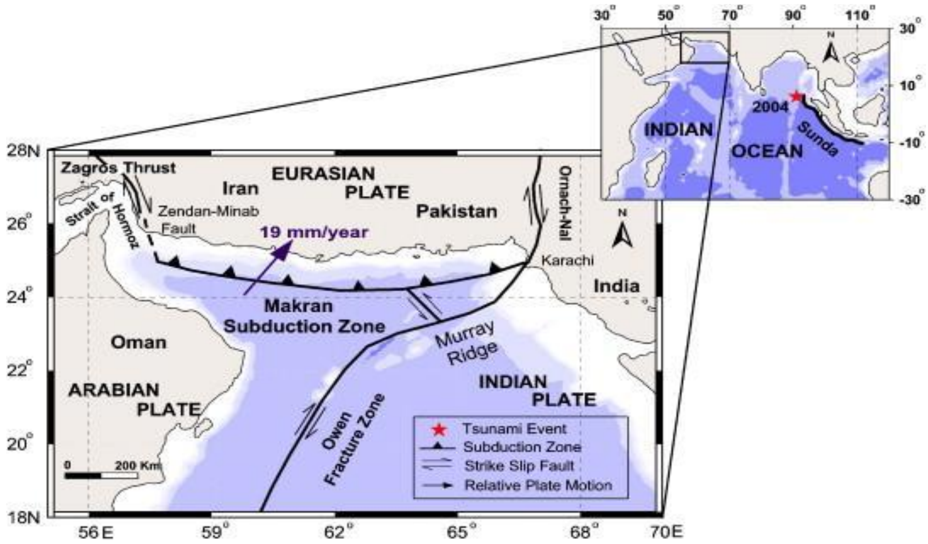


Figure 1. 5 Tectonic map of the MSZ at the northwestern Indian Ocean (Heidarzadeh et al., 2008)

MSZ seemingly has two different sections, where western section is apparently aseismic or locked, and eastern section is apparently more active which caused 1945 M_w 8.2 earthquake generating a deadly Tsunami which affected neighboring countries of the Arabian Sea (Yeats, 2012). It is confined between two fault systems, on west it has right-lateral Minab-Zendan fault, and while on eastern side it has left-lateral Ornach Nal fault. The MSZ is in the middle of two active continental collision of the Himalayas and the Zagros mountains while having one of the largest accretionary wedges in the world, formed by a thick layer of sediment deposit of approximately 7 km (Kopp et al., 2000).

1.2 Available Dataset and Methodology

1.2.1 Available Dataset

In order to create vulnerability map of Karachi, both physical and social vulnerability parameters were collected. Data from the following sources is used for this study:

- SRTM 1 Arc-Second data from United States Geological Survey (USGS) explore database is used to create Digital Elevation Model for Karachi. The spatial ground resolution is 30x30 meters.

- Open Street Maps for data related to transportation network, buildings, and infrastructure.
- USGS earthquake database
- Census Data, Pakistan Bureau of Statistics (PBS) 2017. This data is used to create thematic maps to be used for social vulnerability analysis and includes district-wise population, population density, age, sex etc.
- Historical data of disasters from literature including past earthquakes, tsunamis, floods, and tropical storms of Karachi.
- Weather data from Pakistan Meteorological department and Weather Underground to understand the temperature and precipitation trends.
- Published statistical reports: PBS, Pakistan Engineering Council (PEC), UNDP, WFP, and World Bank.

For the production of physical vulnerability parameters, three different datasets obtained from various sources have been used: (1) vector dataset covering almost all structures and infrastructures of Karachi, (2) digital elevation model of Karachi produced SRTM 1 arc-second resolution elevation dataset of USGS, and (3) geological map of whole Karachi digitized through available dataset of USGS.

Spatial data obtained from various sources followed different datum and projection systems. Uniformity across all spatial datasets is essential to get error free analysis using GIS tools; hence all the datasets are projected to Zone 42 North of Universal Transverse Mercator with WGS-84 datum.

1.2.2 Methodology

This study follows a methodology considering various parameters and provides a comprehensive risk assessment map (Figure 1.6). It includes Indicators and their sub components which are converted into the risk component. The indicators of both vulnerability and hazard are weighted according to Delphi method.

The main characteristics of the methodology can be highlighted as below:

- Identifying, ranking, and weighting hazards, hazard parameters, and vulnerability parameters by engaging with local experts.

- Collecting, digitizing, and storing data related to historical hazards and vulnerability parameters in a format workable on GIS platform.
- Utilizing the existing data and expert knowledge to attempt to create first ever hazard risk map of the city.

Sections of the methodology are briefly described below, while details can be realized in subsequent chapters.

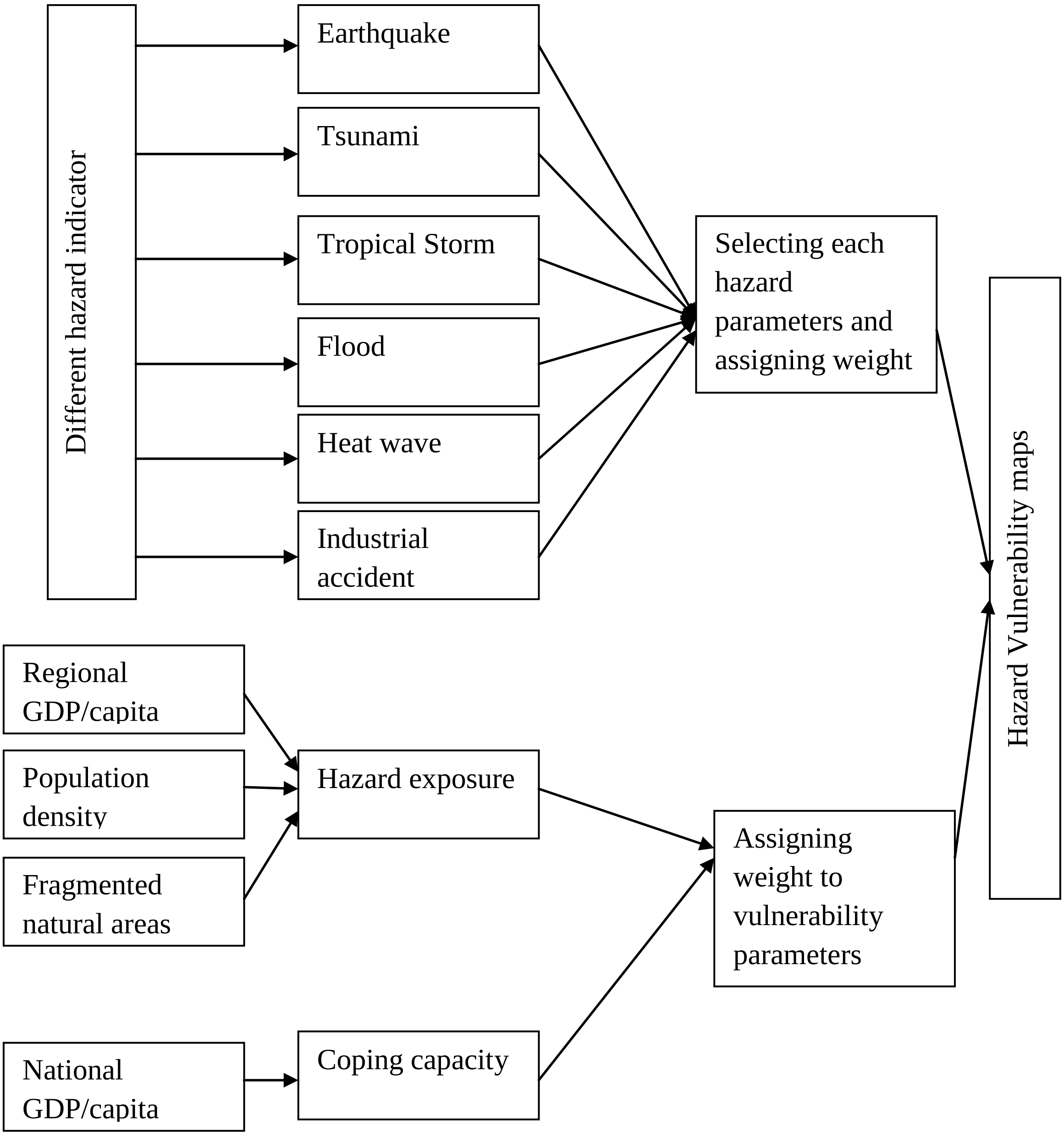


Figure 1. 6 Flow chart of the methodology

Delphi method is used in this study as it compensates well in the absence of quality data, hazard maps, and related literature on the Karachi's vulnerabilities and hazards. As Delphi method is heavily subjective which makes it practical and very useful in applying to areas where there is low availability of data for quantitative study. Delphi method in hazard and vulnerability applications incorporates the knowledge and experience of experts relevant to the study area.

In this study, experts from Sindh province were contacted and surveyed via online questionnaires and with telephonic feedback to rank the hazards and vulnerability indicators. The combination of Delphi survey accompanied with telephonic feedback proves to be effective approach in creating hazard indexes related to any type of hazard (De Brito et al. 2017).

CHAPTER 2

LITERATURE SURVEY

There are several hazards which can be devastating individually. The hazard is defined as a dangerous phenomenon, substance, human activity, or condition that may cause casualties with any other health impacts, property damage, loss of livelihood and services, environmental damages or socio-economic disruptions. It transforms into a disaster when it affects vulnerable population which lacks proper mitigation systems (Chadha et al., 2007). Most of the disaster events in human history have been believed to originate from a natural trigger, but during modern human history many of these events are the consequence of human activities and developmental process. Natural hazards are classified as geophysical, meteorological, climatological, hydrological, and biological (Figure 2.1).

Disaster Subgroup	Definition	Disaster Main Type
Geophysical	Events originating from solid earth	Earthquake, Volcano, Mass Movement (dry)
Meteorological	Events caused by short-lived/small to meso scale atmospheric processes (in the spectrum from minutes to days)	Storm
Hydrological	Events caused by deviations in the normal water cycle and/or overflow of bodies of water caused by wind set-up	Flood, Mass Movement (wet)
Climatological	Events caused by long-lived/meso to macro scale processes (in the spectrum from intra-seasonal to multi-decadal climate variability)	Extreme Temperature, Drought, Wildfire
Biological	Disaster caused by the exposure of living organisms to germs and toxic substances	Epidemic, Insect Infestation, Animal Stampede

Figure 2. 1 Types of disasters (Vos et al. 2010)

Alcántara-Ayala, 2002 studied natural hazards and vulnerability for prevention of natural disasters in developing world. According to the study, natural hazards are converted to disasters when their associated consequences impact society, and/or infrastructure. Such natural events are often sudden but expected with an impact on natural and human systems. It concludes that exposure and magnitude of natural and human vulnerability determines the spatial and temporal impact of natural events.

Studying hazard vulnerability is not enough in understanding hazards completely. It is essential to consider social vulnerability dimension in order to get proper hazard assessment.

Most pioneer and initial work on social vulnerability and their integral link in understanding natural hazards was carried out by Balikie et al. 1994. Balikie et al., 2005 has detailed and comprehensive work on natural hazards, vulnerability, and disasters. Authors address several natural hazards and type of people vulnerable to it. They are of the view that the vulnerability of people is the result of social, economic, and political processes that defines in which way and intensity hazard would affect people. They stress on the point that root causes of the disasters lie in social, economic, and political origin.

IPCC, 2014 report on impacts, adaptation, and vulnerability observes that climate change has impacted natural and human systems on all continents in recent decades. Many regions of the world are already experiencing altered hydrological system because of varying rainfall, melting snow and ice. Additionally, as a result of ongoing climate change, several water-borne and terrestrial species have changed their migration patterns, geographic ranges, and seasonal activities. The report also observes that changes in climate have negative impact on crop yields in many regions, including South Asia.

Godschalk, 2003 in studied on urban hazard mitigation in order to create resilient cities. Paper explains the importance of urban area and the threats they face from natural hazards. It describes resilient city as the combination of physical systems and human communities. Physical system constitutes infrastructure, buildings, topography, geology etc while human communities contains social and institutional component which act as brain of the city. It suggests that design of urban resilience against disaster should be the combination of strength and flexibility, efficiency and redundancy, diversity and interdependence, planning and adaptability, and collaboration and autonomy.

Pelling, 2012 in his book of vulnerability of cities, puts forth the point that hazards have been thought of a rural thing that is why social aspects of urban disasters lack the developed critical assessment. He contradicts the rural approach of certain hazards such as flooding and drought. It stresses that such hazards have rather become more and more urban in nature like drought as an emergency problem for cities in South America. However, in cities there is a perception that society can control of physical environments like diseases can be controlled, food can be accessed, floodwaters can be channeled away, and temperature can be moderated. That is why, except rich cities, it is unusual to find database related areas or population at risk of identified hazards. Pelling, 2012 gives an example of Seoul and Dhaka, where several lives are lost to floods neither city accumulates data on hazard experience which is an important part of risk mitigation.

Ciurean at al. 2013, in their writing of conceptual frameworks of vulnerability assessment endorses vulnerability as a component of hazard and risk. It identifies three main types of methods of vulnerability assessment outcome as qualitative, semi quantitative and quantitative. It stresses that there is no quantitative vulnerability assessment without an expert judgment, hence qualitative assessment always have some sort of contribution.

De Brito et al. 2017 have used Delphi method for flood vulnerability, coping capacity, and exposure indicators which was concluded as a very viable in creating flood-related indexes. Despite the fact that area has significant flood events, the amount of information available for hazard impacts and resistance of elements at risk is very limited. Amount of available data had many issues like it was difficult to access, not digitized and even in some cases the relevant agencies showed reluctance in releasing the data. Hence the authors opted to use Delphi method to accommodate the lack of data which has been scarce to the area.

Previously, several hazard and susceptibility studies have been carried out with scarce data, especially in flood and landslide domain. Falah et al. 2019, Kanani-Sadat et al. 2019 and Khaing et al. 2019; recently carried out flood hazard mapping in data-scarce areas while Lee et al. 2018 and others carried out similar study for landslides with limited data in their hands. In all of these studies, the common thing is scarcity of data which is complemented by heavy use of GIS and input of expert knowledge in assessing the hazards or the susceptibility of a natural event.

CHAPTER 3

HAZARDS AND METHODOLOGY

3.1. Geophysical hazards

There have been increasing studies focusing on geophysical conditions and the social system (Dow, 1992; Montz and Tobin, 2003; Chang&Shinozuka, 2004).

3.1.1 Earthquakes

Since the formation of solid earth, tectonic plates underneath the crust slowly move over, under, and past relative to each other. At times these plates are locked together, disabling their movement, which accumulates strain for a long time. Abrupt release of strain causes sudden violent movement of ground. Earthquake is most unpredictable types of natural hazard whose temporal accuracy in terms of hazard mapping is very low, which makes it very devastating and horrific. Although predicting precise timeline of earthquakes is not yet possible, however, marking the locations of earthquakes and measuring their sizes with accuracy has been possible.

3.1.2 Volcanic Eruptions

One of the most violent and dramatic natural hazards, volcanic eruptions, may cause drastic changes in land and water bodies tens of kilometers within its radius. Also, molecules of sulfuric acid in the form of tiny droplets injected in stratosphere through eruptions can temporarily change regional or global climate. Volcanic eruptions prompt force evacuation and abandoning of homes and land around it, which sometimes becomes indefinite with people not being able to return and settle in affected areas. People living in farther areas may avoid large scale destruction but their cities, agricultural land, infrastructure, industrial facilities, and electrical grids and poles may still be affected by lahars, tephra, and flooding. Apart from volcanic eruption on surface, if an eruption occurs under seas, it may trigger Tsunami which is a significant hazard posing threat to population living along coastal areas.

3.1.3 Tsunamis

International Tsunami Information Center defines Tsunami as successive waves of large height having very long wavelength and period generated by impulsive disturbance of sea water. Such impulsive disturbance may be caused by earthquakes, volcanoes or undersea landslides. However, historical records of Tsunamis have shown that their main triggering factor was earthquakes (Satake et al., 1996). Tohoku earthquake of 2011 with following Tsunami and its impact on Fukushima-Daiichi has highlighted the major risks posed by nuclear reactors on the coast. (Rodriguez-Vidal et al., 2012) located one nuclear site at risk of Tsunami at the coast of Pakistan.

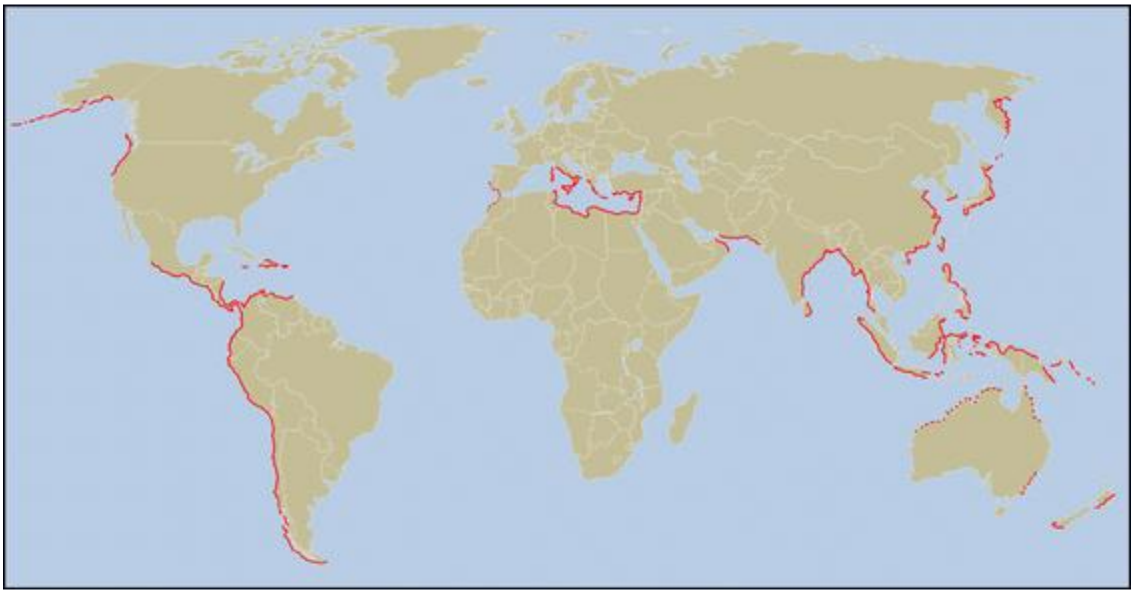


Figure 3. 1 Worldwide coastline at risk of large tsunamis produced by marine earthquakes in active subduction zones. Shoreline at risk (red line) (Rodriguez-Vidal et al., 2012)

3.2 Weather and Climatological Hazards

Weather and climatogical hazards floods, tropical storms, droughts, and storm surges have serious consequences for society and the economy as it disrupts transportation, impede construction work, destroy agriculture, production capacity, and human health (Rogers &Tsirkunov, 2013).

3.2.1 Floods

Flooding is the most common and widespread type of natural hazards, except fire. Ever since humans built first permanent settlements along the great riverbanks of Asia and Africa during the agricultural revolution, seasonal flooding has been an integral part of their lives. In densely populated urban areas the situation is dire as traditional approach which emphasizes on improving drainage capacity by up-gradation and expansion of existing storm drainage system has proven to be costly, unsustainable and in many cases, impractical (Qin et al, 2013). During 1979-2004 in the United States, floods and storms had been deadlier with 2,741 casualties than 2,644 casualties of seismic and lightning disasters combined (Thacker et al., 2008).

3.2.2 Drought

Drought is a recurrent feature of climate which occurs in nearly all the regions of the world. Meteorologically it is defined as long-term precipitation departure from normal, however threshold for minimum period of precipitation absence vary among professionals. This complex disaster affects more people than any other hazard but is least understood among all natural hazards (Hagman, 1984; Wilhite, 2000). Stats from Emergency Events Database reveal that droughts make up 5% of all natural disasters while losses from it are up to 30% of losses among all disasters. With millions of human and livestock deaths and billions of dollars in damages, it is by far the most damaging natural hazard.

3.2.3 Heat Waves

Although there is no universal definition of heat waves but it can be defined as extreme events which occur when hot temperatures during summer months last for a relatively longer period than usual, while temperature also exceed the threshold of daytime high and night-time low (Welle et al., 2014; Vescovi et al., 2005). It has the potential to cause human mortality and mobility, and significant impacts on economy and ecosystem (Meehl and Tebaldi, 2004). European heat wave of summer 2003 showed the extent of threat by such an extreme event to public health (Kovats etl al., 2004). In that event, more than 35,000 mortalities were estimated, while in

France alone there were more than 14,000 deaths (Fouillet et al., 2006; Kosatsky, 2005).

3.3 Hazard comparison of Pakistan and Japan

Pakistan and Japan have several comparable hazards which can be destructive and affect both socially and economically. Hazards in Japan are comparatively well studied while in Pakistan there have not been hazards understanding to the level of a Japan. Table 3.1 summarizes some of the common hazards between two countries.

Table 3.1 Comparison of hazards between Pakistan and Japan

Pakistan			Japan	
Hazard	Frequency	Impact	Frequency	Impact
Earthquake	High	High	High	High
Tsunami	Low	Moderate	High	High
Flood	High	High	High	Moderate
Tropical Cyclone	Low	Moderate	High	Moderate

3.4. Hazards of Pakistan

Pakistan has the population of over 200 million and has experienced various disasters in the past including earthquakes, landslides, floods, tsunami etc. It is a country with high peaks of the Himalaya mountains, plains of Indus valley, desert in its south east and 1,046 km coastline in South. Half of it lies over one of the most active tectonic plates, i.e. Indian Plate which has made country exposed to seismic hazards. Seasonal flooding in the plains of Indus valley affects both the life and country’s main sector, agriculture. Drought in the desert region has a history of affecting people and livestock of south eastern part of Pakistan. While most recently, there have been increasing warnings of Tsunami on the coast south of the country which is going through increasing rate of urbanization from Karachi to Gwadar.

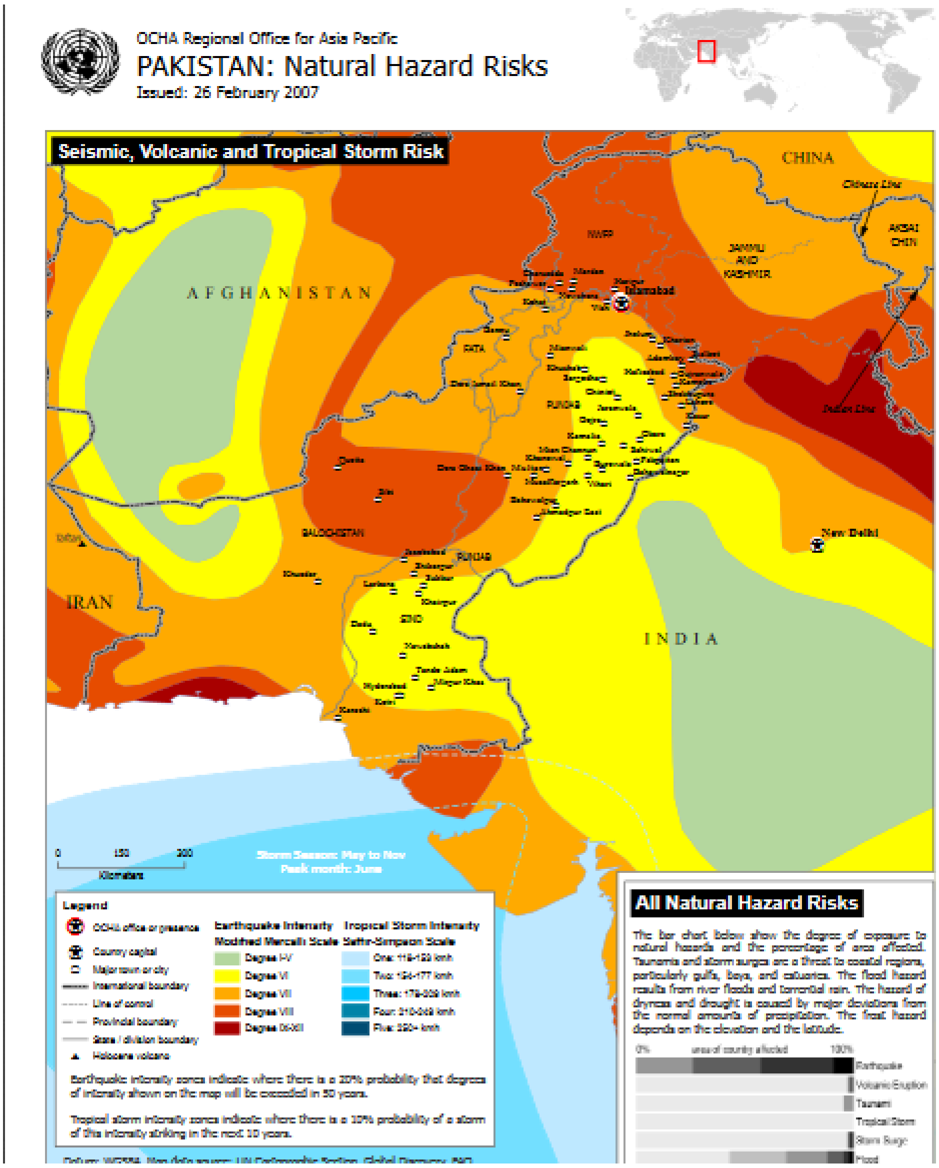


Figure 3. 2 Natural Hazard map of Pakistan by UN OCHA, 2007. (https://www.preventionweb.net/files/4178_OCHAPAKHazardv1070226.pdf)

3.4.1. Earthquake hazard of Pakistan

(Rafi et al, 2012) pointed out that regions such as northern Pakistan, Kashmir and Quetta are at greater risk of seismic hazards and it is likely that those regions will have more destructive earthquakes in future. Presence of several active faults in north-western Himalayas are likely to trigger a series of earthquakes and a few of those might even be greater than the region experienced in the past such as 2005 Kashmir earthquake(Shah & Malik, 2017). There have several recorded earthquakes of the past with intensity of 5+, and most of which are located in North and West of the country while some significant earthquakes also occurred in the south-west of the country (Figure 3.3).

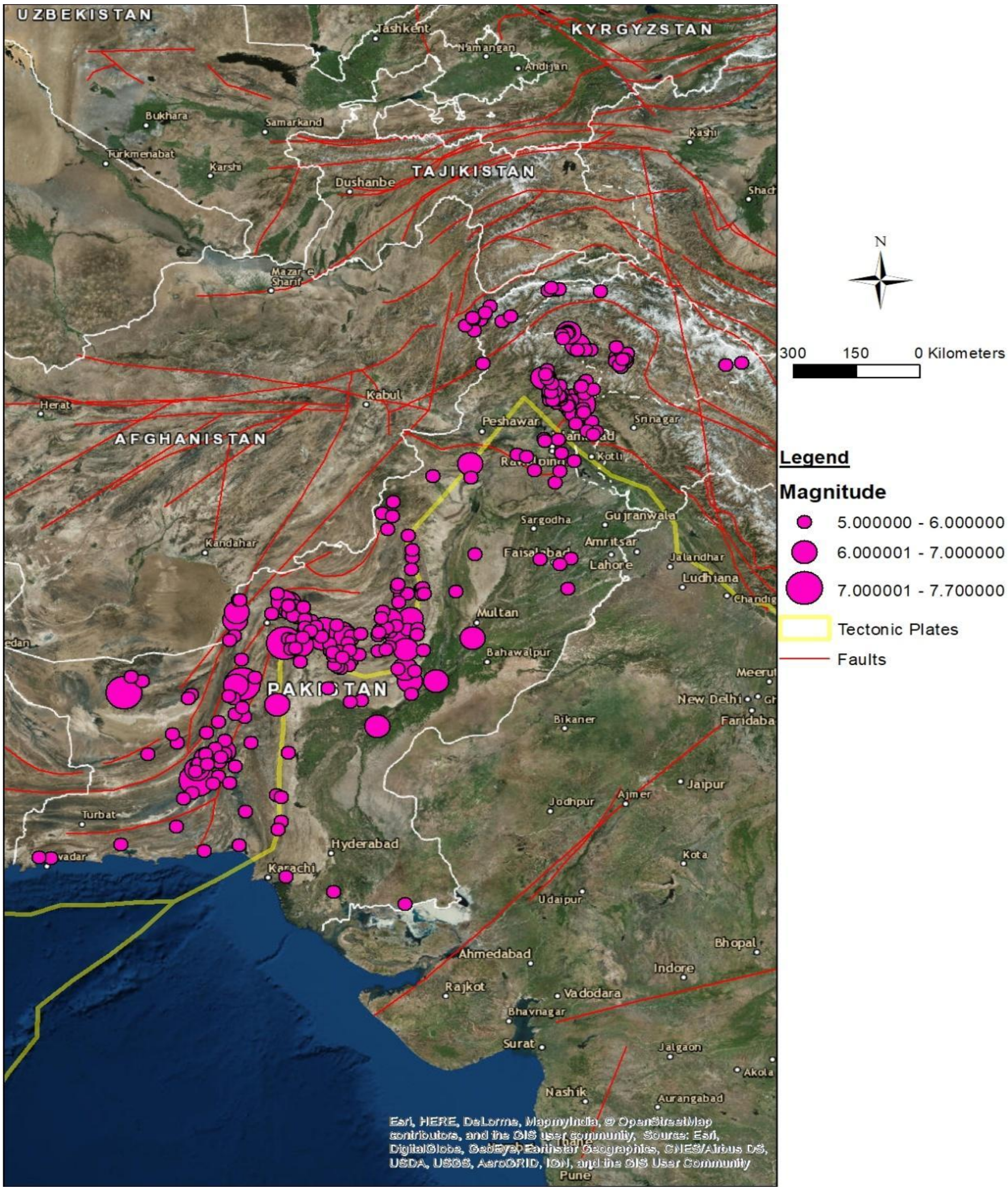


Figure 3. 3 Historical earthquakes of Pakistan, 1905 to 2018. (Produced by dataset from USGS earthquake catalogue)

According to seismic zonation of the country in 2007 by Building Code of Pakistan (BCP), most of the high seismicity zones (Zone 3 & 4) lie in North and West of the country while zones of medium seismicity (Zone 2B) lie in North-West and South-West (Figure 3.4).

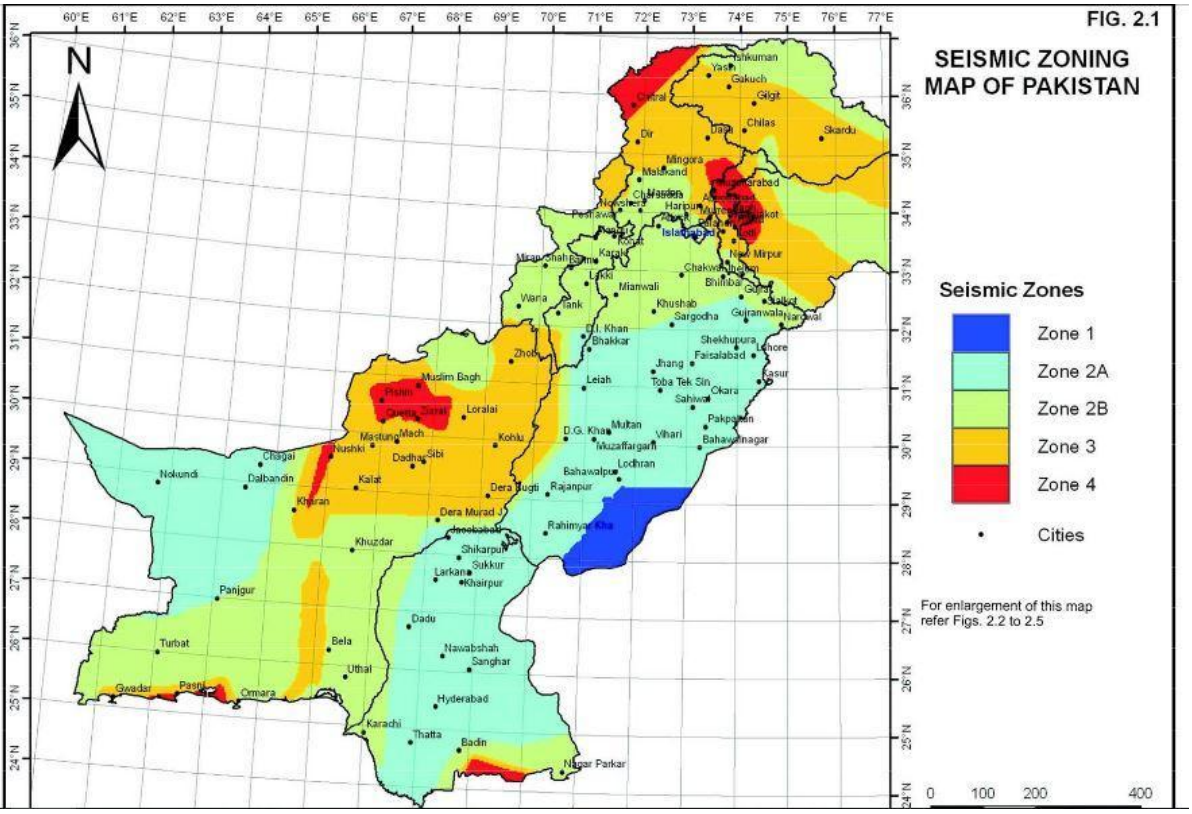


Figure 3. 4 Seismic Zone of Pakistan (Building Code of Pakistan; 2007). Blue color implies no or very little seismic activity while Red color means very high seismic activity.

Most areas of the Sindh province are in Zone 2A with low seismicity except Karachi, Badin, and Nagarparkar which are located in the zone 2B possessing significant seismic threat (Figure 2.6).Potential threat to Karachi is because of the presence of a thrust fault, namely Ornach Nal fault, in its vicinity (Figure 3.5). Ornach Nalfault which is just 130 km west of Karachi has the potential to produce an earthquake of up to M7 or larger (Bilham et al., 2007).

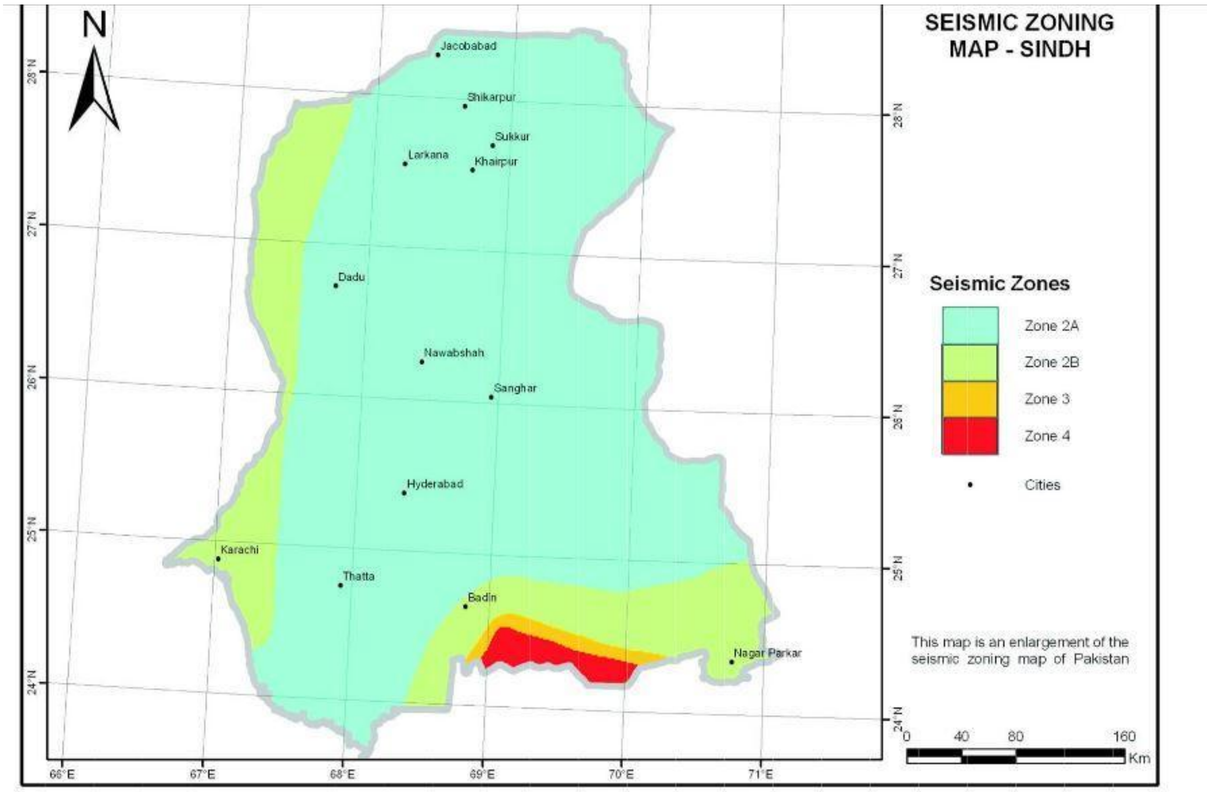


Figure 3. 5 Seismic Zoning Map of Sindh (BCP; 2007)

3.4.2. Flood Hazard Map of Pakistan

Monsoon precipitation alongside melting glaciers swell the rivers and canals in Pakistan, which often ends up flooding cities, farmland, and other life line of country. Such floods are frequent and devastating, occurring each year during monsoon season.

The 2010 flood caused around 2,000 deaths and several thousand injured while economic damages are estimated to be over US$ 40 billion. The phenomenon repeats each year with hundreds of casualties and economic losses in terms of property, crop, and livestock damages. Later flood events in 2011, 2013, and 2014 also caused significant damage to life and agriculture. Most of the times, these are areas along both banks of river Indus that are affected by flooding. Central and southern parts of Pakistan have very high while northern parts have high vulnerability to flood hazards (Figure 3.6).

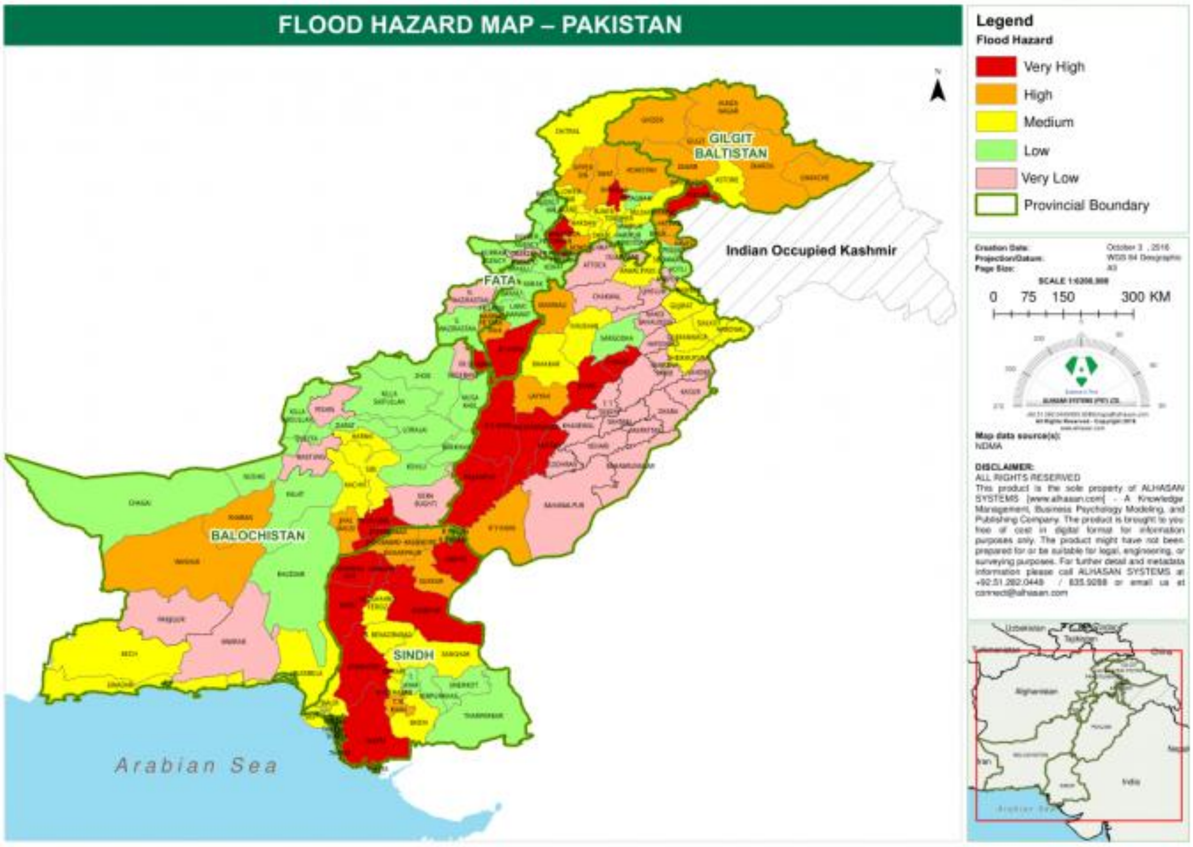
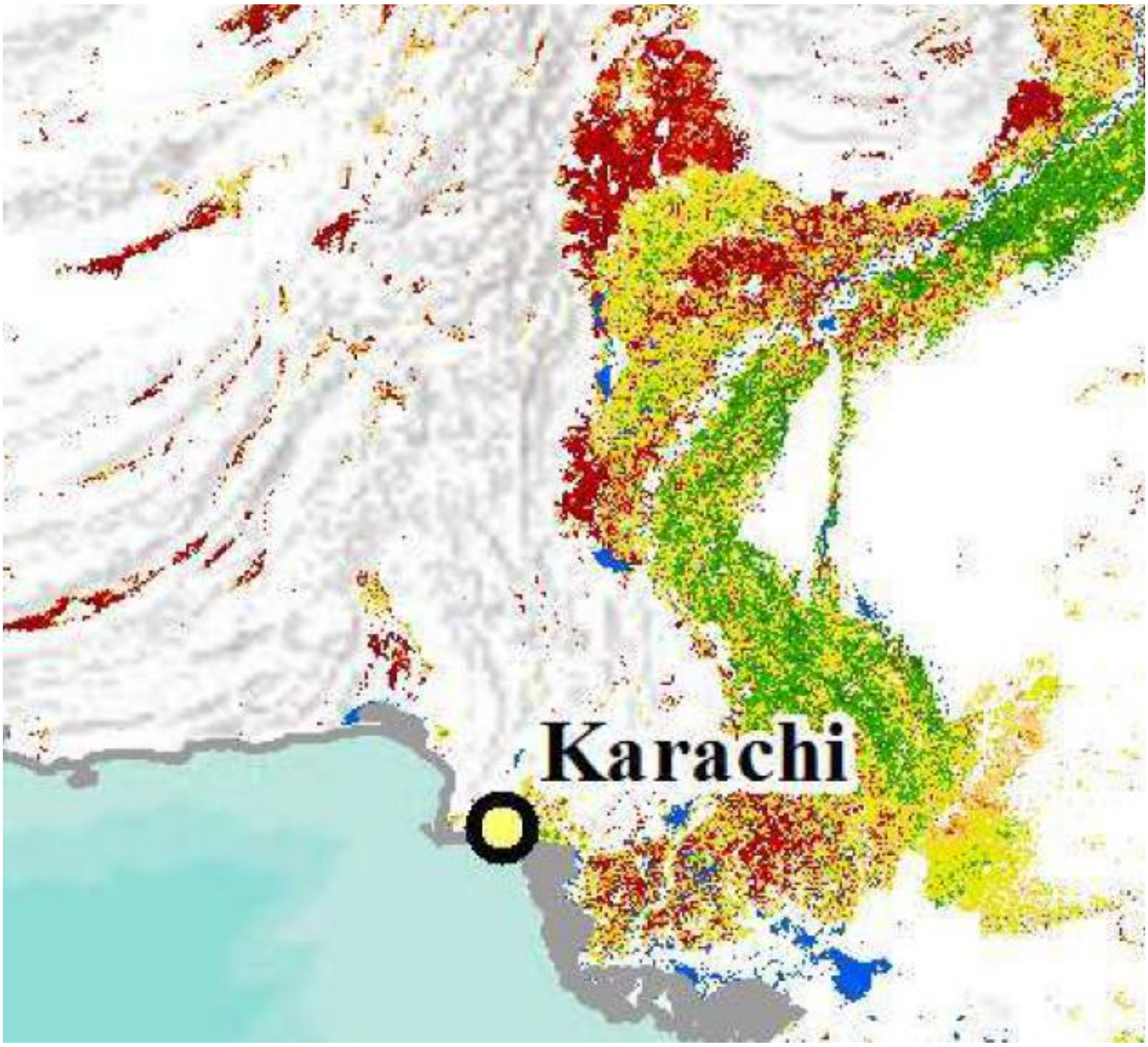


Figure 3. 6 Flood map of Pakistan (https://reliefweb.int/sites/reliefweb.int/files/resources/FLOOD%20HAZARD%20MAP%20%E2%80%93%20PAKISTAN.pdf)

3.4.3. Drought Hazard Map

Tharparkar region has a history of being hit with extreme droughts causing deaths of people and livestock with forced migration of the population. It has also affected the most vulnerable segment of the population, the children, causing hundreds of deaths due to famine and malnutrition with 1,800 casualties from 2011-2016 (Relief Web, 2017). Drought risk for Karachi is not zero and there is some level of vulnerability to the drought when it is surrounded by the areas either with no agriculture or areas under the threat of drought (Figure 3.7).



■Extreme Drought ■Severe Drought ■Moderate Drought■Stress ■Watch■Normal
■Healthy □ Non Agricultural ■Water Body ■Flood Pixels

Figure 3. 7 Drought Map of Pakistan. (International Water Management Institute IWMI)

3.4.4. Food Insecurity Map

During the last two decades, Pakistan has been governed by four different regimes, each vowed to address the issue of food insecurity. Although there have been evident progress in food production recently, however more than half of the population remains food insecure. Most of the western, southern, and south-eastern parts of the country have high vulnerability to food insecurity (Figure 3.8).

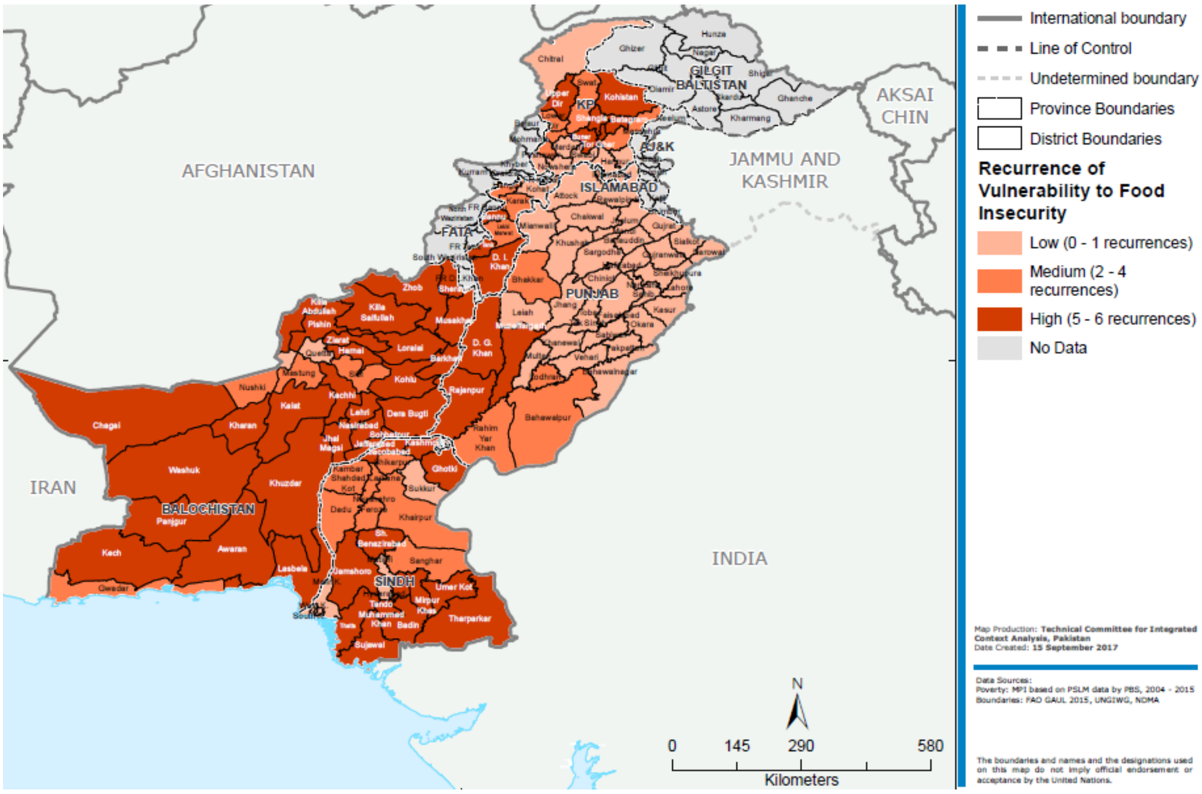


Figure 3. 8 Food insecurity Map of Pakistan (NDMA, 2017)

3.5. Hazards of Japan

The island state of Japan is located on a very vulnerable geographical and geological location, facing a wide range of hazards such as floods, typhoons, mudslides etc. However, the seismological hazards have proven to be the most devastating in Japanese history, including both the earthquakes and Tsunamis. Natural Hazard risk of Japan is very high with most parts of the country have high vulnerability to hazards (Figure 3.9).

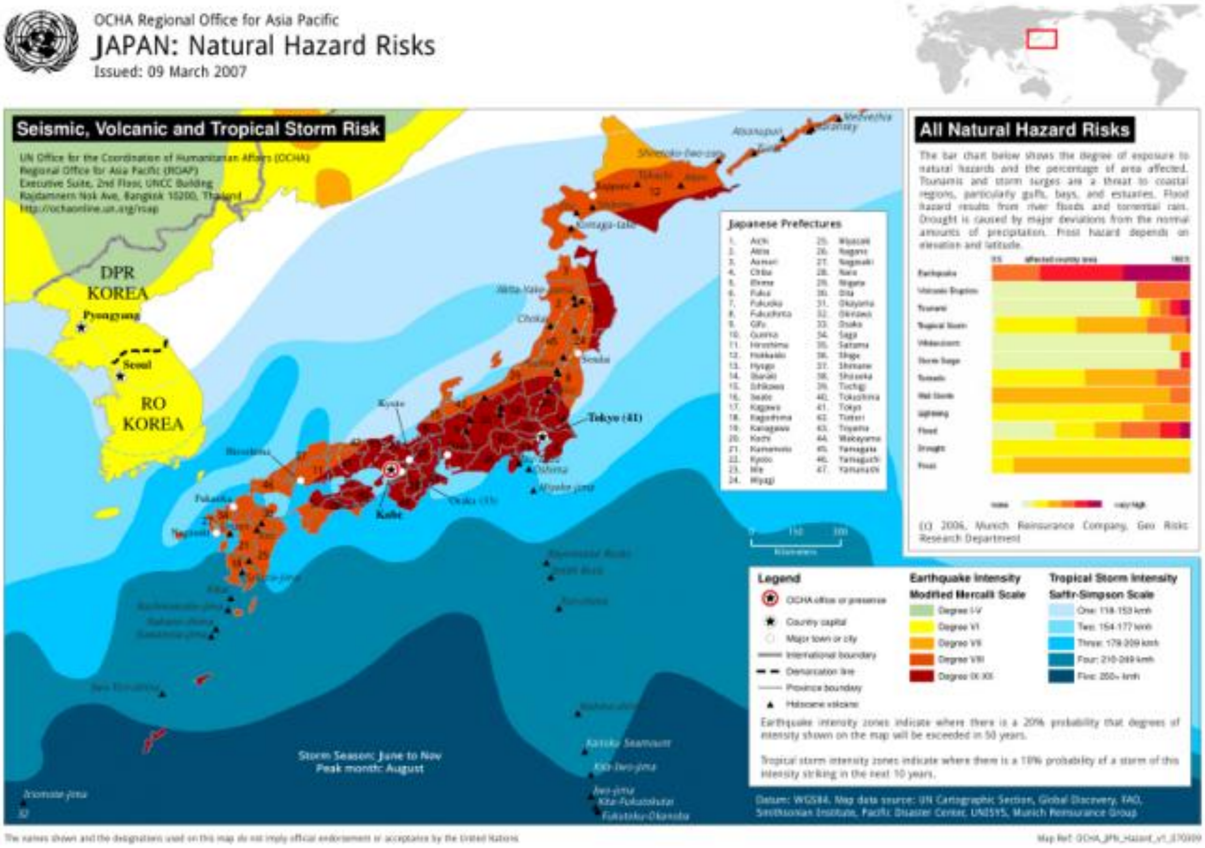


Figure 3. 9 Japan Natural Hazard Risks UNOCHA, 2007)

Human and economic cost of disasters has been huge for Japan and only Tohoku earthquake and Tsunami of 2011 ruined 23,600 hectares of farmland and 3%-4% of the rice production (Martin, 2011). Consequent impact of Tsunami on Fukushima Daichii nuclear power plant resulted in overhaul of nuclear energy policy, review of safety measures, shut downs of nuclear power plants in Belgium and Germany (Wittneben, 2012; Kunsh & Friesewinkel, 2014; Ming et al., 2016).

During last decade, Japan faced major disasters killing thousands of people and damaging even more dwellings (Table 3.2).

Table 3.2 Major disaster by earthquake, storm, flood from 2004-2014 (modified Statistics Bureau of Japan)

Date of Outbreak	Disaster	Magnitude	Damage to Persons		Damage to Dwelling	
			Killed	Injured	Ruined	Half-Ruined
June-Oct-2004	Concentrated downpour, typhoon, flooding	-	220	2,925	1,471	16,669
23 Oct 2004	Mid Niigata Earthquake	6.8	68	4,805	3.175	13,810
Dec 2005 – Mar 2006	Damage by snow	-	152	2,145	18	28
20 Mar 2005	Earthquake off the coast of Fukoka	7.0	1	1204	144	353
25 Mar 2007	Noto Hanto Earthquake	6.9	1	356	686	1,740
16 July 2007	Niigataken Chuetsu-oki Earthquake	6.8	15	2346	1331	5,710
14 June 2008	Iwate-Miyagi Nairiku Earthquake	7.2	17	426	30	146
24 July 2008	Earthquake off the coast of Iwate	6.8	1	211	1	-
11 Aug 2009	Earthquake of Suruga Bay	6.5	1	319	-	6
Nov 2010-Mar 2011	Damage by snow	-	131	1,537	9	14

11 Mar 2011	Tohoku Earthquake	9.0	19,074	6,219	127,361	27,3268
July-Oct 2011	Concentrated downpour	-	106	519	485	5,735
Nov 2011-Mar 2012	Damage by snow	-	133	1,990	13	12
Nov 2012-Mar2012	Damage by snow	-	104	1,517	5	7
7 Dec 2012	Earthquake off Sanriku	7.3	1	15	-	-

3.5.1. Seismic Hazard

Island nation of Japan is located in the Pacific Ring of Fire which is one of the most active volcanic zones in the world that experiences about 90% of the world's earthquakes. It is home tens of active volcanoes, experiences several major earthquakes some of which cause destructive Tsunamis. During the last century several earthquake events have killed and injured hundreds of thousands of people, most prominently, 1923 Tokyo earthquake, 1995 Great Hanshin earthquake and more recently, 2011 Tohoku earthquake which triggered a large Tsunami and affected significant areas in north-eastern Japan (Figure 3.10).

Tohoku earthquake and the following Tsunami caused a nuclear crisis at the Fukushima nuclear power plants.

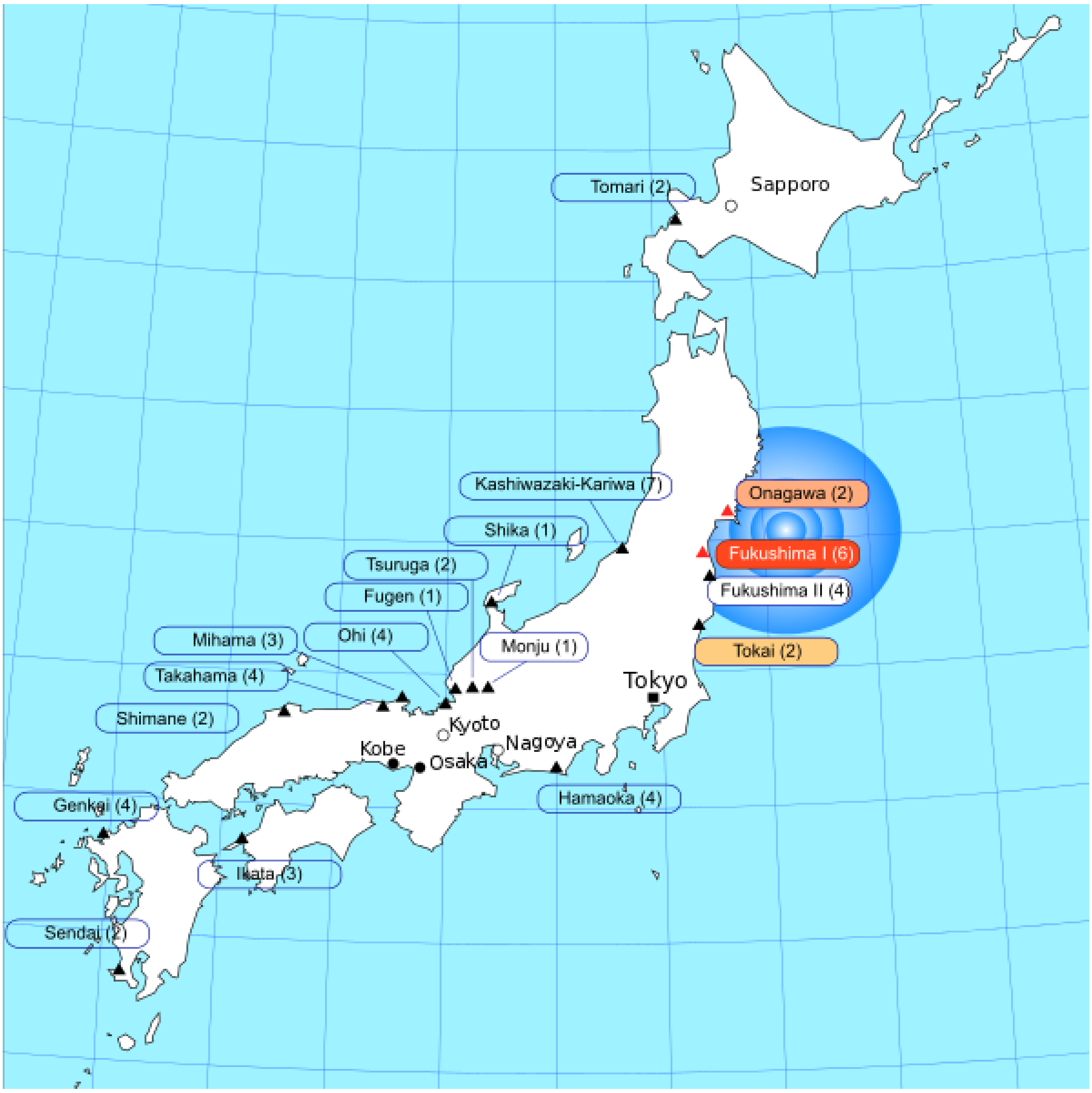


Figure 3. 10 Extent of 2011 Tsunami on Fukushima and surrounding power plants. (Wikimedia Commons)

Prior to 2011 Tohoku earthquake, the only known normal faulting earthquake was the M~8.5 Sanriku earthquake of 1933 (Kanamori, H., 1971). Maximum run-up height, affected stretch of coastline, and the general size and intensity of Tohoku tsunami was much bigger than assumed as tsunami modeling considering historical records proved inefficient (Mori et al., 2011), with 4-7% of estimated probability for 30 year repetition in literature.

3.5.2. Flooding

Almost half of the population and 75% of the property are contained in floodplains, facing serious flood hazard (Zhai et al., 2007). Japan has been hit with severe floods in recent past such as flooding and landslides followed by July 6, 2018 heavy rainstorm which killed more than 100 and injured 400 people with thousands of buildings destroyed (Ohshimo et al. 2018). Flash flooding in urban areas has resulted in disaster with famous past flooding of June 1953 and July 2012 has caused severe consequences with thousands of casualties (Duan et al 2014, Chicago Tribune Archives website). Flood management policy has gone through some drastic changes, such as usage of green dams has shown to be successful in reducing loss of life and property (Zhai et al., 2007; Luo et al., 2015).

3.5.3. Cyclones

Physical exposure of cyclones is as same as severe as Tsunamis (INFORM 2019). Tropical cyclones (TC) are very frequent hazard in Japan and other countries of northwestern pacific region with most recent hazards as Typhoon Jebi (2018), Typhoon Talas (2011), and Typhoon Morakot (2009) being of significant nature with very high winds and extreme rainfalls (Takemi, 2019). There is increasing trend of frequency of TCs in North Pacific Ocean and South China Sea region (Figure 3.11).

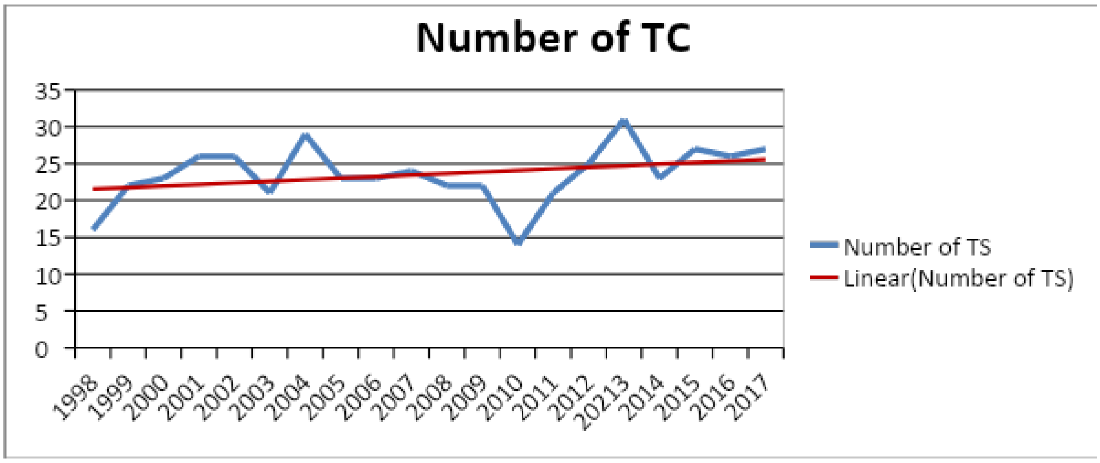


Figure 3. 11 Annual frequency of Tropical Cyclones in western North Pacific Ocean and South China Sea for 1998 – 2017. (Reproduced, Japan Meteorological Agency, 2017)

A recent study carried out by (Mei & Xie, 2016) estimates that the annual number of category 4-5 cyclones have increased by two while the proportion of intense TC against all other types of TC has more than doubled. The frequency and intensity of TC in warmer climate of northwest Pacific Ocean is expected to increase resulting in more exposure and damage of lives and properties (Emanuel, 2005; Mei & Xie, 2016; Yamada et al. 2017).

3.5.4 Case study of a disaster in Japan considering impact, recovery, and lessons learned

In order to better understand Japanese approach to a multi-disaster scenario, we considered the recent experience of Tohoku earthquake and how it challenged and changed the disaster management capacity and approach to similar disaster in future. Study by (Kajitani et al. 2013) finds that Tohoku earthquake of 2011 had significant damaging impact on the areas it struck. The earthquake together with tsunami and nuclear accident's direct damages cost around US$211 billion, making it costliest natural disaster. Japan has a total of 47 prefectures which are further grouped into eight regions namely: Chubu, Chugoku, Hokkaido, Kanto, Kinki, Kyushu, Shikou, and Tohoku. Out of nine affected prefectures the four of those prefectures (Aomori, Iwate, Miyagi, and Fukushima) are located in Tohoku region were the highest affected areas during the 2011 Tohoku earthquake event. Extent of areas affected by earthquake had been the largest, causing damage to buildings, infrastructure and industrial facilities while the tsunami affected key infrastructure of land, sea, and air transportation which aggravated the fuel shortages in first weeks of the event.

Government of Japan provided funding and compensation for the disaster hit areas. Government funding was US$221 billion presented through three supplementary budgets and covered key areas from agriculture and fishery, disaster relief and loans to grants to local governments and for public infrastructure projects. In Japan and overseas, the most disaster payouts are done by earthquake insurance companies which in case of Japan is limited to ¥10 million for property damage (household goods) and ¥50 million for building damage caused by ground motion or tsunami (MOF, 2012). One of the largest earthquake insurance payouts in the history of

Japan valuing just over ¥1,200 billion, while second largest was being ¥883.2 billion by Japan Agriculture fraternal insurance (Kajitani et al. 2013). While

3.5.5 Lessons learned from 2011 Tohoku earthquake

The case study of Tohoku earthquake of 2011 has been a landmark event in changing the approaches of disaster management and mitigation in Japan. Soon after that devastating event, several meetings and committees were hold to review the disaster and recommend any potential change in policy. (Imamura & Anawat, 2011) quote a report of an expert panel on future countermeasures against tsunami by Central Disaster Prevention Council which points out the limitations of previous approaches which are mostly prediction based while suggesting to ever more prioritize the residents' evacuation planning and land use. It argues that although predictions are useful to protect the population but for once in a millennium tsunami, measures to support immediate evacuation are much more crucial as accurate prediction of maximum possible magnitude of tsunamis is not practical. While another report by Committee for Technical Investigation on Countermeasures post-2011 Tohoku earthquake which concludes the requirement of developing two levels of tsunami countermeasures; (1) the level 1 for very damaging high frequency tsunamis but with low tsunami height, coastal protection facilities should be developed with main focus being protecting human life, assets, stabilization of regional economy and protection of vital industrial bases. Level 2 considers very damaging tsunamis with maximum height but with low frequency while the countermeasures should largely be focused on evacuation of local population while using every possible instrument.

3.6 Hazard Risk Assessment

When more than one hazard occurs at the same time, they have proven to be deadly. Investigating two or more hazards is very crucial whenever one hazard triggers another one, for example, earthquakes leading to Tsunamis (Satake et al., 1996; Billi et al., 2008; Uri et al., 2009; Polonia et al., 2013; Lay et al., 2005; Maeda et al., 2011). It is essential to carry out the hazard risk assessment with multi hazard approach which shall contribute in overall hazard risk reduction.

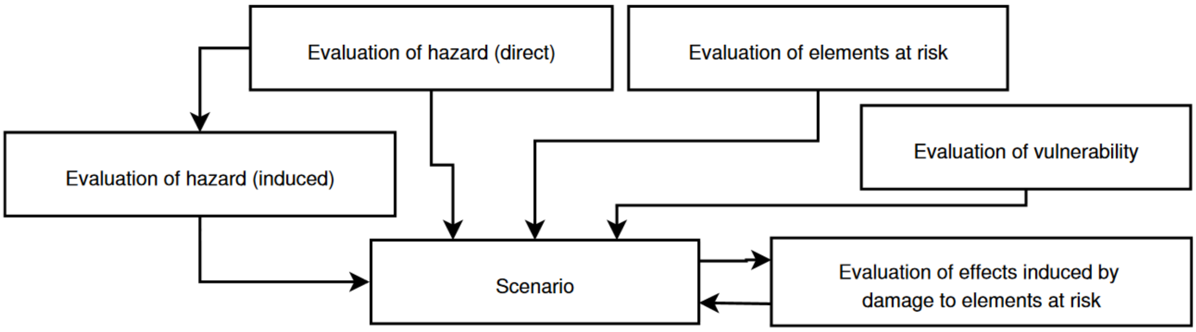


Figure 3. 12 Main aspects involved in risk assessment (Douglas, 2007)

Figure 3.12 describes the main aspects involved in risk assessment.

Economy of a country plays an important role to curb the impact of disaster in many ways. According to INFORM methodology, the Human Development Index (HDI) covers social and economic development of a country. HDI of countries with higher GDP per capita is better than those with lower GDP per capita (UNDP HDR, 2019). By comparing INFORM and UND HDR, it can be said that GDP per capita of an economy does impact human vulnerability.

3.6.1 Socio-Economic factors in Hazard Risk Assessment

Pakistan is one of the most populous countries in that world with GDP per capita being at the low end with turbulent GDP growth each year (Table 3.3). Turbulence in GDP has put exports in negative, hence increase in current accounts deficit resulting in devaluation of currency and increase in inflation.

Table 3.3 Pakistan economic profile (WorldBank, 2018)

Pakistan						2017
Population, million						207.7
GDP, current US$ billion						305
GDP per capita, current US$						1547
	2012	2013	2014	2015	2016f	2017f
Real GDP growth, at constant market prices	3.5	4.4	4.7	5.5	5.5	5.4
Private consumption	2.0	2.1	5.4	3.6	5.6	5.7
Government Consumption	7.3	10.1	1.5	16.0	3.1	3.1
Gross Fixed Capital Investment	2.4	2.6	4.2	8.2	7.0	7.0
Exports, Goods, and Services	-15.0	13.6	-1.6	-2.7	-0.9	0.5
Imports, Goods, and Services	-3.1	1.8	0.2	-1.2	0.8	2.5
Real GDP growth, at constant factor prices	3.8	3.7	4.0	4.2	4.5	4.8
Agriculture	3.6	2.7	2.7	2.9	2.9	3.0
Industry	2.5	0.6	4.5	3.6	4.4	4.8
Services	4.4	5.1	4.4	4.9	5.2	5.5
Prices						
Inflation(Consumer Price Index)	6.0	7.0	6.9	3.5	5.1	5.5
Inflation(Consumer Price Index)	11.0	7.4	6.9	3.5	5.1	5.5
Current Account Balance(% of GDP)	-2.1	-1.1	-1.3	-0.8	-0.8	-1.0
Fiscal Balance (% of GDP)	-8.8	-8.3	-4.7	-5.1	-4.0	-3.5

The latest figures from the International Monetary Fund (IMF) suggest that the real GDP growth of Pakistan has been 5.5 and 3.3 in 2018 and 2019 respectively. However, IMF estimates that economy will contract and the real GDP growth will be in negative as -1.5 for the year 2020 (Figure 3.13).

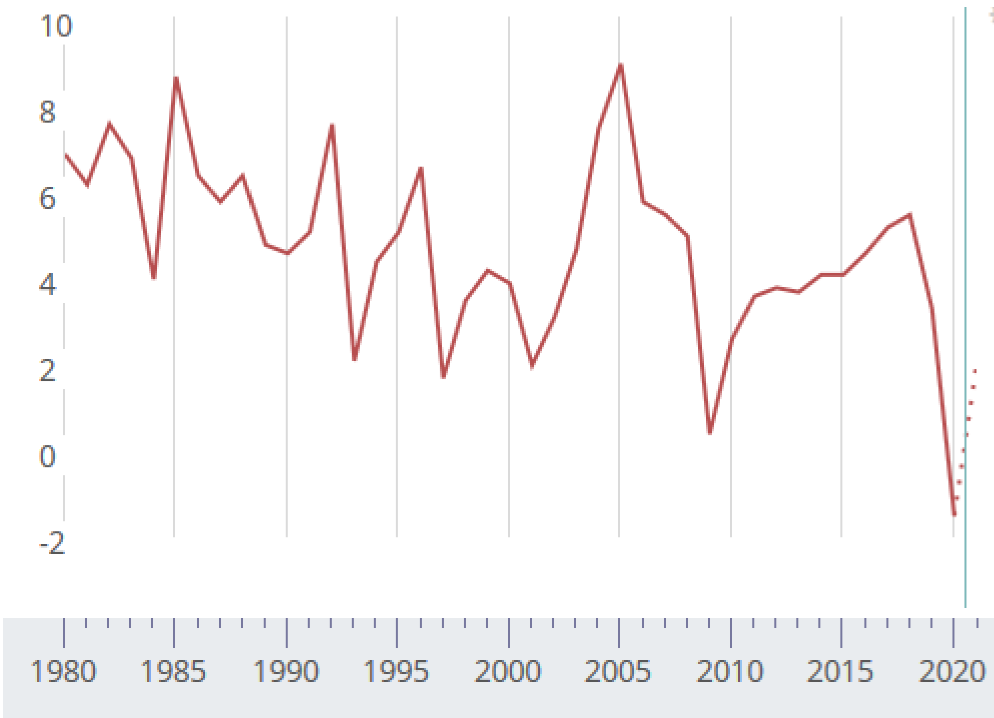


Figure 3. 13 Real GDP growth of Pakistan (IMF.org website datamapper)

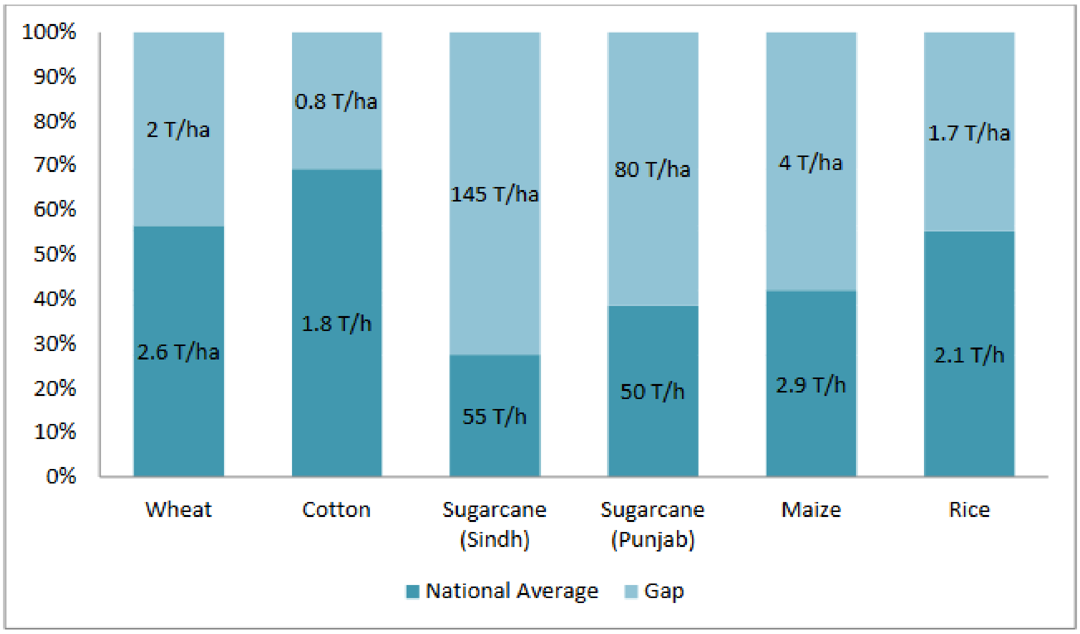


Figure 3. 14 Average National Yields and Yield Gaps as Percentages of Progressive Farmer Yields (Ahmed & Gautam, 2013)

World population was less than a billion until the 18th century and almost two billion during 1927 and had a "population explosion" since then (weeks, 2014). According to the United Nations estimation, the world population is over seven billion in 2017. Developing countries saw the most explosive growth of population. In these countries, urbanization has been on the rise for last decades and according to the United Nations figures, the urban population of developing countries is to reach 50% by the year 2020 while it can see as much as seven billion by 2030 (Figure 3.15).

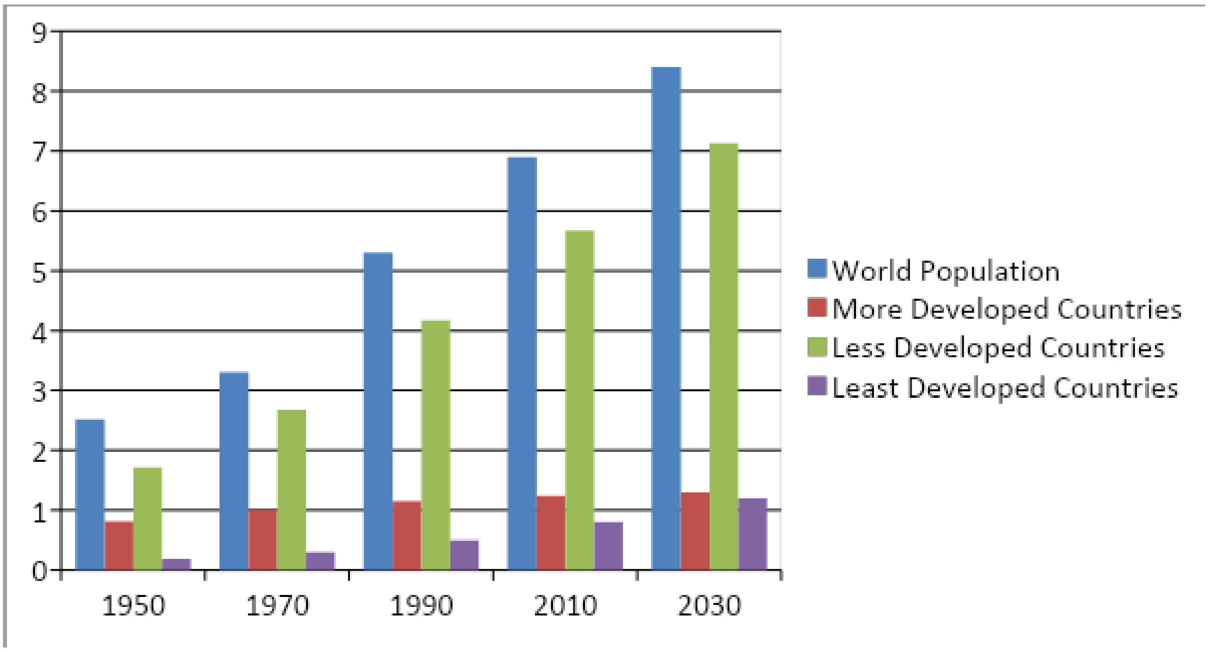


Figure 3. 15 United Nations Urban Facts and Figures UNCHS (Habitat, 2001)

3.6.1.1 Population of Pakistan and Karachi

Pakistan is world's sixth most populous country with a population estimated at two hundred and seven (207) million (Table 3.4). With an average growth rate of 2.40, UN population division ranks Pakistan the fourth most populous country on the globe by 2050.

Table 3.4 Provisional province-wise population by sex and rural/urban (PBS Census-2017)

Administrative Units		Households	Population-2017			
			Male	Female	Transgender	All Sexes
Pakistan		32,205,111	106,449,322	101,314,780	10,418	207,774,520
	Rural	20,012,797	67,300,171	64,886,593	2,767	132,189,531
	Urban	12,192,314	39,149,151	36,428,187	7,651	75,584,989
Sindh		8,585,610	24,927,046	22,956,478	2,527	47,886,051
	Rural	4,185,828	11,919,109	11,056,183	301	22,975,593
	Urban	4,399,782	13,007,937	11,900,295	2,226	24,910,458
Punjab		17,103,835	55,958,974	54,046,759	6,709	110,012,442
	Rural	10,714,102	35,197,990	34,425,030	2,124	69,625,144
	Urban	6,389,733	20,760,984	19,621,729	4,585	40,387,298

Khyber Pakhtunkhwa		3,845,168	15,467,645	15,054,813	913	30,523,371
	Rural	3,104,154	12,495,278	12,298,236	223	24,793,737
	Urban	741,014	2,972,367	2,756,577	690	5,729,634
Balochistan		1,775,937	6,483,653	5,860,646	109	12,344,408
	Rural	1,301,212	4,690,099	4,253,393	40	8,943,532
	Urban	474,725	1,793,554	1,607,253	69	3,400,876
FATA		558,379	2,556,292	2,445,357	27	5,001,676
	Rural	542,255	2,481,840	2,377,911	27	4,859,778
	Urban	16,124	74,452	67,446	0	141,898
Islamabad		336,182	1,055,712	950,727	133	2,006,572
	Rural	165,246	515,855	475,840	52	991,747
	Urban	170,936	539,857	474,887	81	1,014,825

Karachi is the most populous city of Pakistan with about 15 millions excluding significant number of workers, migrants from other parts of the county and people living in slums (Table 3.5). There was significant number of internally displaced people to Karachi during last decade. Also, there is an increasing trend of economic migrants from other cities and also people from rural areas moving to the metropolitan areas. It has caused the city to be overcrowded, more strain on city infrastructure and other resources.

Table 3.5 Population of major cities (PBS Census-2017)

	POPULATION	
	Census-2017	Census-1998
Karachi City	14,910,352	9,339,023
Lahore City	11,126,285	5,143,495
Faisalabad M.Corp.	3,203,846	2,008,861
Rawalpindi City	2,098,231	1,409,768
Gujranwala M.Corp	2,027,001	1,132,509
Peshawar City	1,970,042	982,816
Multan City	1,871,843	1,197,384
Hyderabad City	1,732,693	1,166,894
Islamabad Metropolitan Corp	1,014,825	529,180
Quetta City	1,001,205	565,137

Karachi is divided into several administrative units (districts) as Central, East, West, South, Korangi, and Malir (Table 3.6). District East and the Central are highly concentrated residential areas while district South hosts governor house, secretariat, high court, legislative and other administrative buildings. District West is the most populous with population of about 4 million and it has large industrial areas of the country. District Korangi lies on eastern bank of Malir river and has significant number of population with mixed ethnic groups. District Malir is the largest by area but smallest by population which hosts military cantonment area with most of the district comprises of rough terrain with steep slopes.

Table 3.6 District-wise population by sex and rural/urban Karachi (PBS Census-2017)

Administrative Units	Households	Population-2017			
		Male	Female	Transgender	All Sexes
Karachi Division	2,770,074	8,439,659	7,610,365	1,497	16,051,521
Rural	193,871	606,588	534,499	82	1,141,169
Urban	2,576,203	7,833,071	7,075,866	1,415	14,910,352
Karachi Central District	538,983	1,543,950	1,427,349	327	2,971,626
Rural	-	-	-	-	-
Urban	538,983	1,543,950	1,427,349	327	2,971,626
Karachi East District	509,239	1,528,019	1,379,225	223	2,907,467
Rural	-	-	-	-	-
Urban	509,239	1,528,019	1,379,225	223	2,907,467
Karachi South District	327,518	943,546	848,010	195	1,791,751
Rural	-	-	-	-	-
Urban	943,546	943,546	848,010	195	1,791,751
Karachi West District	634,459	2,065,847	1,848,553	357	3,914,757
Rural	44,051	149,220	134,014	13	283,247

Urban	590,408	1,916,627	1,714,539	344	3,631,510
Korangi District	421,618	1,284,015	1,172,737	267	2,457,019
Rural	-	-	-	-	-
Urban	421,618	1,284,015	1,172,737	267	2,457,019
Malir District	338,257	1,074,282	934,491	128	2,008,901
Rural	149,820	457,368	400,485	69	857,922
Urban	188,437	616,914	534,006	59	1,150,979

People with fragile or no income are affected more by disasters as they cannot afford housing resilient to hazards (earthquake, fire, flooding, tsunami) which results in reduction of capacity to deal with natural hazards (Gaillard, 2010). Hence, number of unemployed people has significant consequences for social vulnerability (Table 3.7).

Table 3.7 Percentage Distribution of civilian (Urban Sindh) labour force 10 years of age and over by age, sex, area, and nature of activities 2017-18 (Pakistan Bureau of Statistics 2017-2018)

Age Group (YEARS)	**CIVILIAN LABOUR FORCE (URBAN SINDH)**								
	TOTAL LABOUR			**EMPLOYED**			**UNEMPLOYED**		
	Total	Male	Female	Total	Male	Female	Total	Male	Female
Total 10 years and over	100.00	90.68	9.32	92.73	85.66	7.07	7.27	5.02	2.25
10-14	0.76	0.64	0.12	0.74	0.62	0.12	0.02	0.02	0.00
15-19	8.33	7.81	0.52	7.39	6.88	0.51	0.95	0.94	0.01
20-24	16.03	14.40	1.62	13.30	12.19	1.11	2.72	2.21	0.51

25-29	14.31	12.67	1.64	12.93	11.92	1.02	1.37	0.75	0.62
30-34	13.46	11.67	1.79	12.23	11.35	0.88	1.22	0.32	0.91
35-39	12.47	11.38	1.09	12.25	11.19	1.06	0.22	0.19	0.03
40-44	10.26	9.43	0.83	10.10	9.27	0.83	0.17	0.17	0.00
45-49	8.55	7.84	0.71	8.39	7.76	0.63	0.17	0.08	0.08
50-54	7.40	7.03	0.37	7.24	6.90	0.34	0.16	0.13	0.03
55-59	4.78	4.52	0.26	4.60	4.34	0.26	0.18	0.18	0.00
60-64	2.31	2.11	0.20	2.27	2.08	0.19	0.04	0.03	0.01
65 Years and over	1.34	1.18	0.16	1.28	1.16	0.12	0.06	0.02	0.04

Karachi has significant number of rural population, so taking rural ratio of unemployed people is useful understanding overall social vulnerability (Table 3.8).

Table 3.8 Percentage Distribution of civilian (Rural Sindh) labour force 10 years of age and over by age, sex, area, and nature of activities 2017-18 (Pakistan Bureau of Statistics 2017-2018)

Age Group (Years)	**CIVILIAN LABOUR FORCE (RURAL SINDH)**								
	TOTAL LABOUR			**EMPLOYED**			**UNEMPLOYED**		
	Total	Male	Female	Total	Male	Female	Total	Male	Female
Total (10 years≥)	100.00	82.94	17.06	97.29	81.05	16.24	2.71	1.88	0.83
10-14	5.21	4.21	0.99	5.08	4.11	0.97	0.13	0.10	0.02
15-19	14.06	12.18	1.88	13.22	11.39	1.83	0.84	0.79	0.05
20-24	12.92	10.83	2.09	12.03	10.27	1.76	0.89	0.56	0.33
25-29	12.42	10.15	2.28	12.06	9.97	2.09	0.36	0.17	0.19
30-34	11.03	8.79	2.24	10.93	8.74	2.18	0.11	0.05	0.06
35-39	11.73	9.31	2.42	11.59	9.28	2.31	0.13	0.03	0.11
40-44	9.52	7.53	1.99	9.49	7.53	1.96	0.03	0.00	0.03
45-49	8.75	7.33	1.42	8.69	7.29	1.40	0.06	0.04	0.02
50-54	6.35	5.42	0.93	6.31	5.38	0.92	0.05	0.04	0.01

55-59	3.96	3.49	0.47	3.92	3.45	0.47	0.04	0.04	0.00
60-64	2.43	2.20	0.24	2.38	2.15	0.23	0.06	0.05	0.01
65 YEARS ≥	1.61	1.49	0.12	1.60	1.48	0.11	0.02	0.01	0.01

Studies show that level of education has added effect on social vulnerability with countries and regions having lower education level tend to have high social vulnerabilities. Among all disaster management approaches the common thing is that they are preventive and fundamental approach in it is the level of education which is the most important factor in reducing disaster damages (Gerdan, 2014). Social vulnerability assessment of US south-eastern coastline to natural disasters was carried out by (Yoon, 2012), and the study concluded that level of education among other factors plays a critical role in high vulnerabilities.

In South Asia, Pakistan has the lowest literacy rate with only 70% going in primary schools (Figure 3.16).

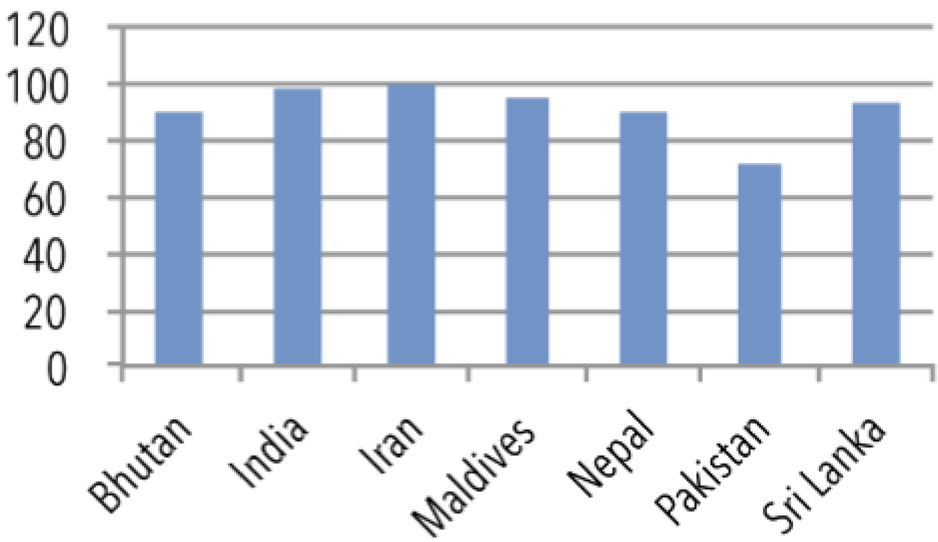


Figure 3. 16 Primary Education Adjusted NER – 2011 (UNESCO)

Actual population end up graduating with formal education is significantly low with only30% having primary and barely 10% having high school education (Figure 3.17).

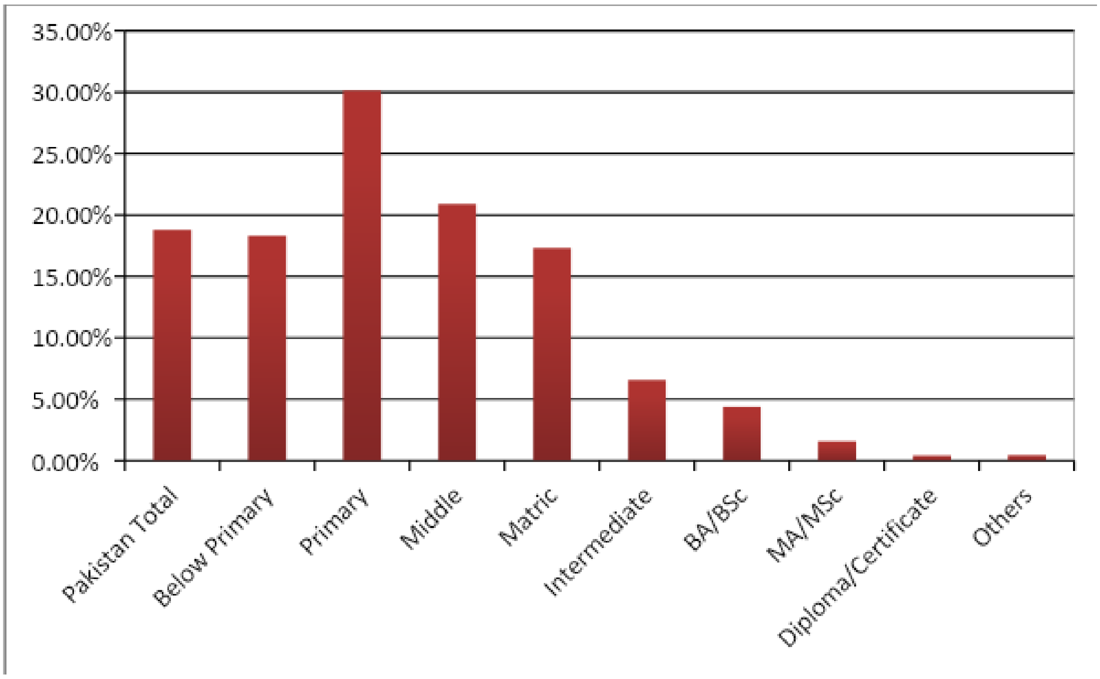


Figure 3. 17 Pakistan Total population and level of education (PBS, 2017).

Literacy rate of Sindh, whose capital is Karachi, been on lower side in terms of global standards but does fairly well at nearly 25% compared to other provinces (Figure 3.18).

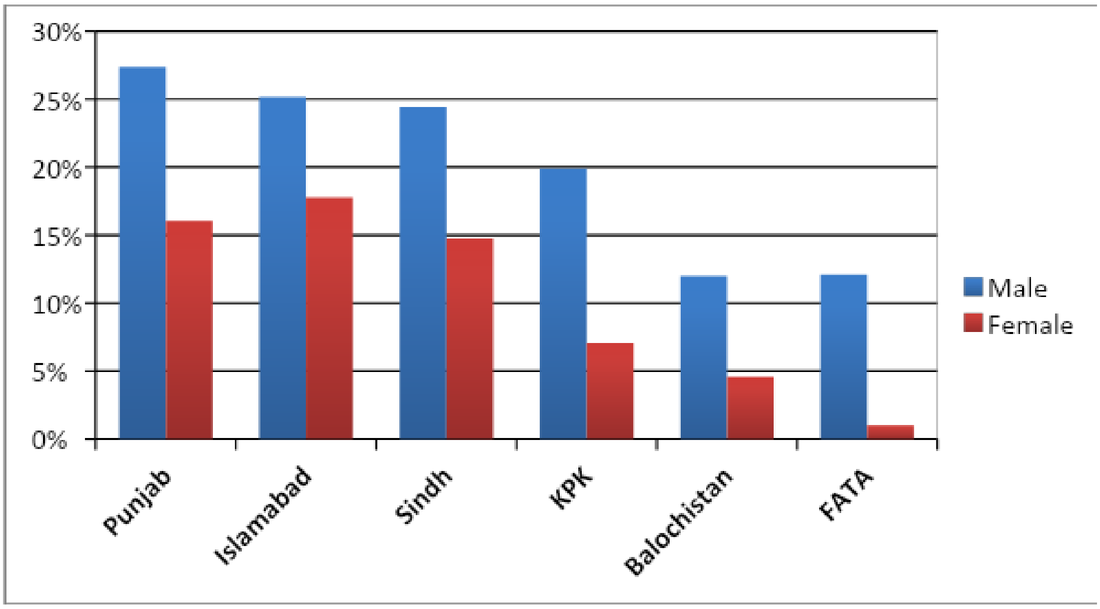


Figure 3. 18 Provincial-wise literacy rate (PBS, 2017)

3.6.1.2 Energy sector of Pakistan

Most of the Pakistan's electricity system is based on expensive source of thermal (fossil fuel) energy while hydroelectric also has significant portion followed by low input from nuclear and renewable energy (Figure 3.19).

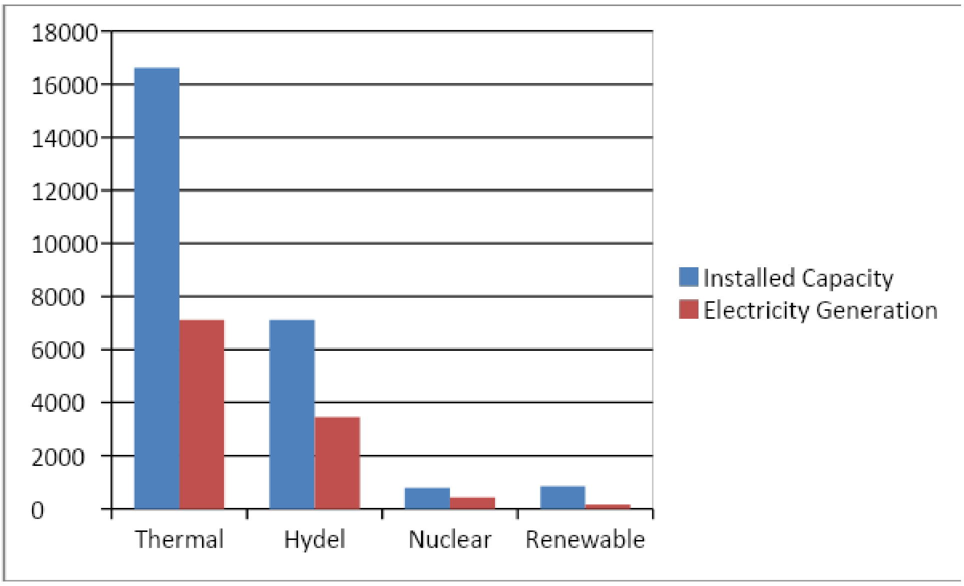


Figure 3. 19 Pakistan electricity installed Vs generation capacity. (NEPRA, State of the industry report, 2016. pp 21)

Data shows that about 63% of electricity is generated by oil and gas resources, chunk of which is imported from other countries (Figure 3.20).

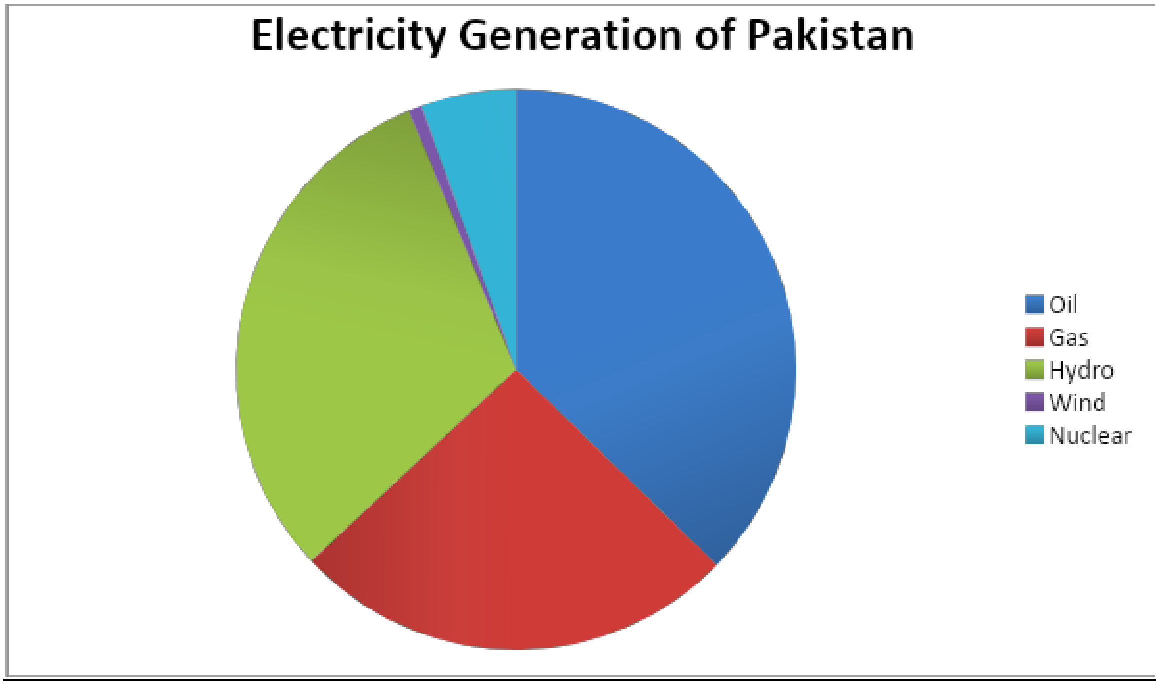


Figure 3. 20 Electricity Generation of Pakistan by energy sources. (International Energy Agency Electricity Generation, 2015)

Since last decade energy sector of Pakistan has been under strain because of sharp increase in electricity demand against low generation (Figure 3.21).

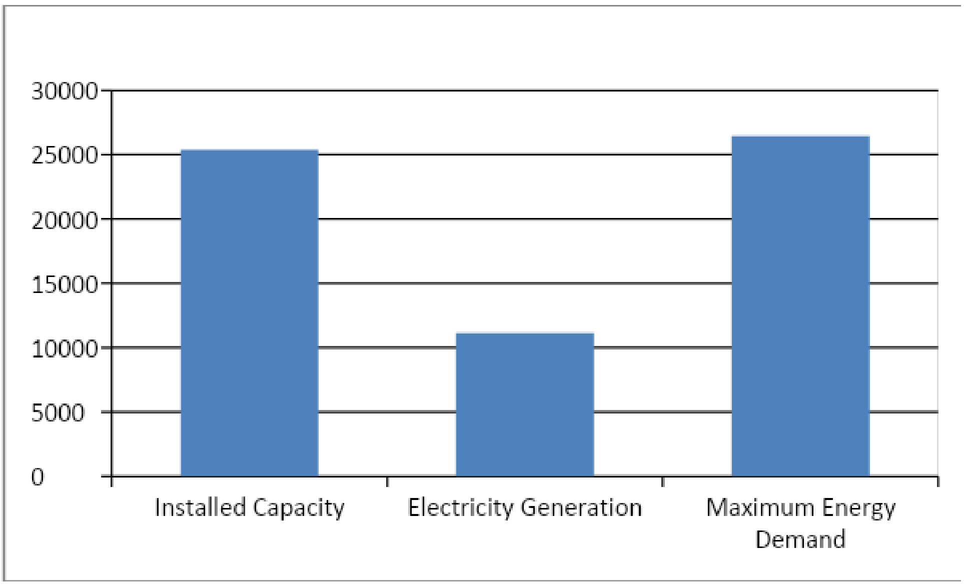


Figure 3. 21 Pakistan electricity capacity, generation and demand. (NEPRA, State of industry report, 2016. pp 135)

Pakistan is increasingly committed on enhancing electricity generation through nuclear power plant and there has been significant progress in constructing new NPPs. However, current share of nuclear energy has been low at 6.22% only (Figure 3.22).

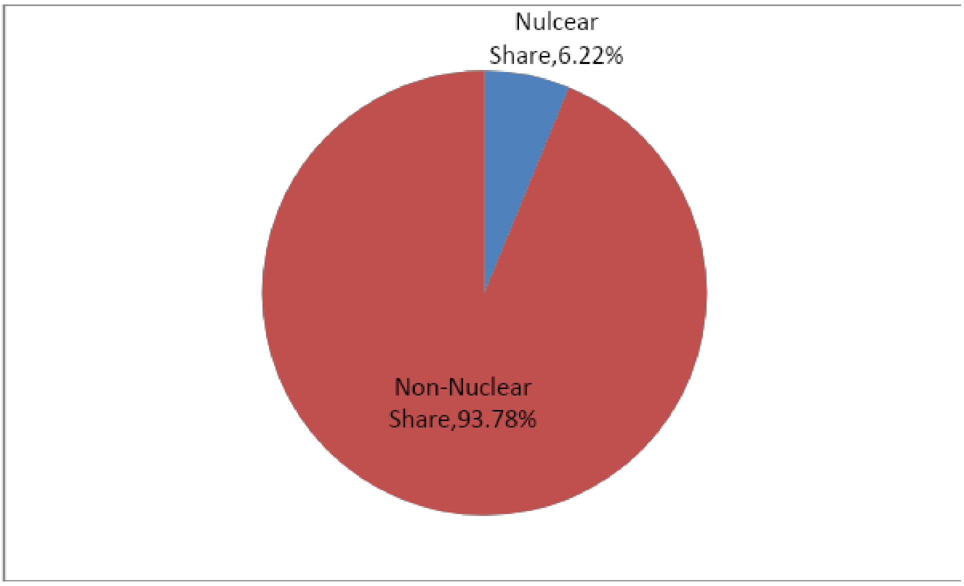


Figure 3. 22 Electricity Production Share in 2017. (produced, NEPTA industry report, 2016)

Pakistan is not able to generate electricity it requires to maintain uninterrupted supply of power. As Figure 3.19shows the massive share of thermal sources which is over 60% of its total electricity generation. Most of that fuel is imported in the form of oil, coal and liquefied natural gas (LNG) through Karachi port. Very high dependency of power sector on imports which are managed through a single port of Karachi city makes the sector extremely vulnerable in case of port shutdown or inaccessibility under unavoidable circumstances.

Apart from electricity generation, up gradation and maintenance of the infrastructure is needed to make it resilient against any disaster. K-electric which is responsible for supplying electricity and improving the related infrastructure has failed to make any major improvement.

3.7 Risk

According to the United Nations, the risk is the probability of harmful consequences which result from interactions between hazards (natural or human-induced) and vulnerable conditions. The harmful consequences can in form of casualties, damaged property, lost livelihoods, disrupted economic activity, and damage to the environment.

Risks can be classified as economic, environmental, societal, technological, geopolitical, and natural hazard risks. The most fatal among all are natural hazards which are uncontrollable and unpreventable. Intersecting point of hazard, exposure and vulnerability triggers a disaster (Figure 3.23).

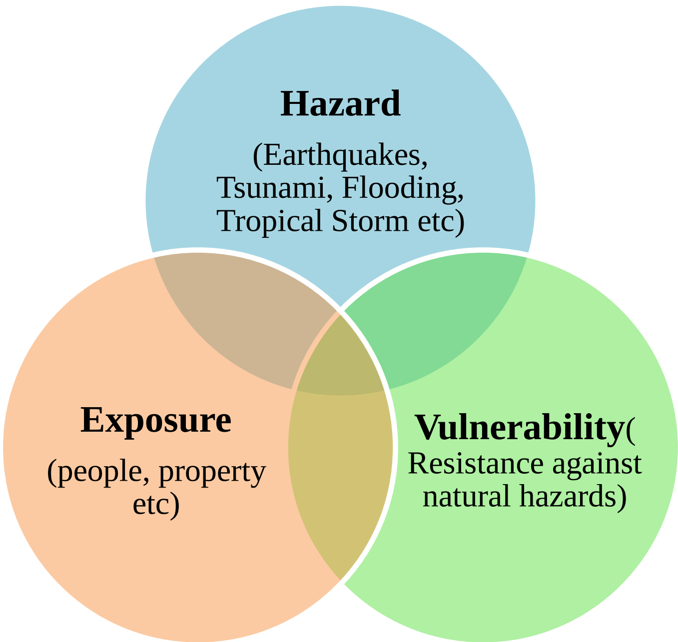


Figure 3. 23 Mechanism of Disaster occurrence

3.7.1 Urban Risk Assessment

With the increase in population and settlements, and important life lines over the hazardous locations are causing the impact of natural disasters rise (Rosenfeld, 1994; Alexander, 1995). In the near future, urban population will face more casualties from the disaster like earthquake than in the past (Bilham, 2009).Natural hazards are not the only reason to cause disasters, rather it is the social, economic, preparedness and political aspects responsible for hazards to become disasters (Burton et al., 1993; Blaikie et al., 1994; Alexander, 2002; Schneiderbauer and Ehrlich, 2004; Smith and Petley, 2009). While disaster risks management approach has changed from solely being relief and response to risk management between various sectors of a country (Yodmani, 2001). The World Bank's Urban Risk Assessment provides three factors being the very foundation of understanding the urban risks are hazard impact assessment, an institutional assessment, and a socioeconomic assessment.

3.8 Risks in Karachi

The city is one of the worst affected by global climate change phenomenon. Frequent heat waves in summer, monsoon flooding, and cyclones are some of the direct risks faced by Karachi. Additionally, there are geophysical hazard risks, such as earthquake and Tsunami. Apart from the risks posed by natural phenomenon, there are human originated risks in the form of communal and sectarian violence alongside years of gang wars among various factions.

3.8.1 Earthquake

Bilham et al. 2007 made a comprehensive review of seismicity based on historical earthquakes in and around Karachi and concluded that city is within the distance of one or more Mw 8 earthquakes originated by subduction zone in the west, $6 < M_w < 8$ in east (Kutch region), M_w 7.9 strike rupture to northwest, while M_w 6 earthquakes near or beneath the city. There have been several earthquakes recorded in and around Karachi and they have been of significant nature, especially in the subduction zone off the coast of Karachi (Figure 3.24).

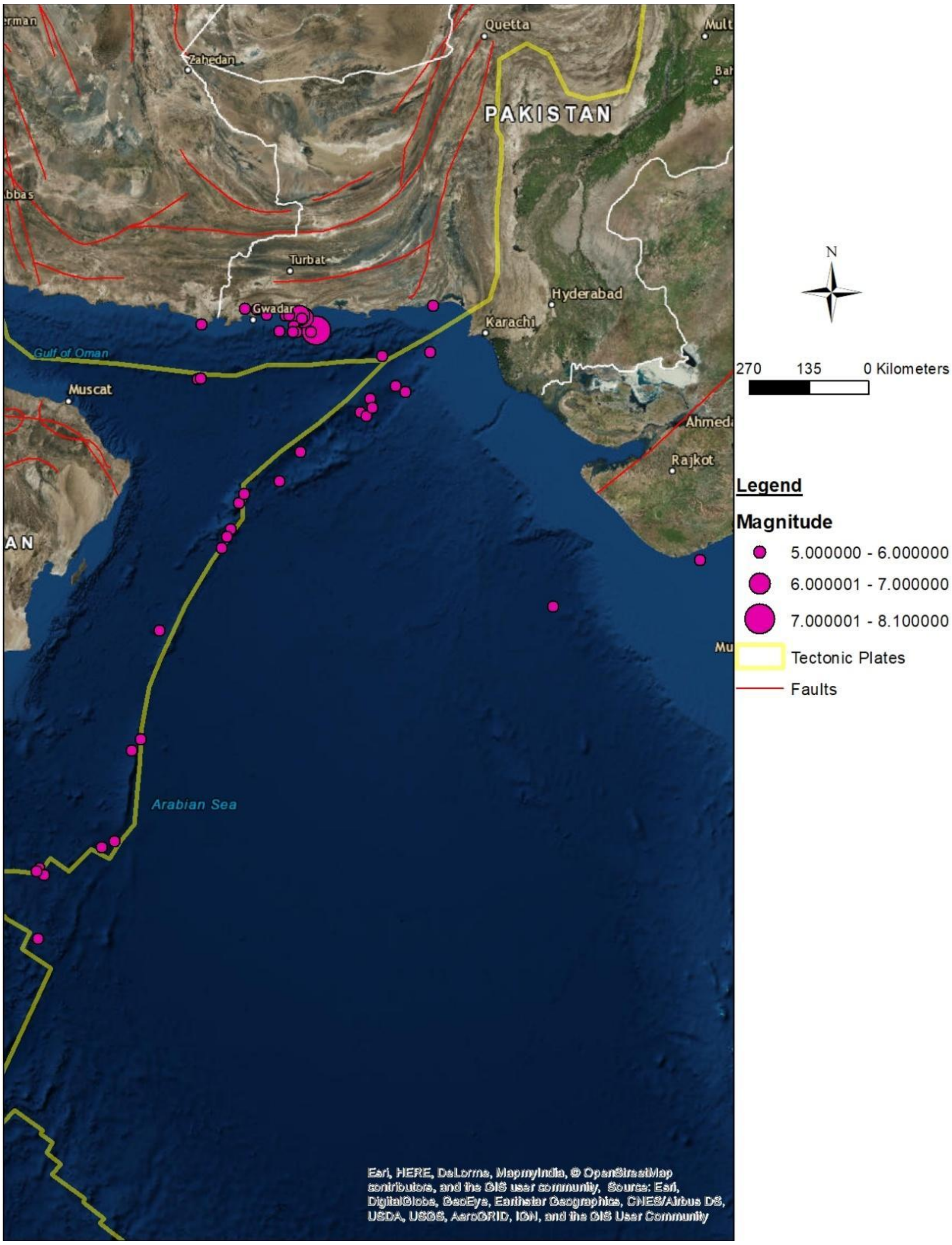


Figure 3. 24 Earthquakes of M_w>5 in-and-around Makran Subduction Zone, 1945-2018 (Produced by author)

The earthquake of 1945 is one of the kinds which occurred in the subduction zone off the coast of Karachi which generated large Tsunami in the region (Figure 3.25).

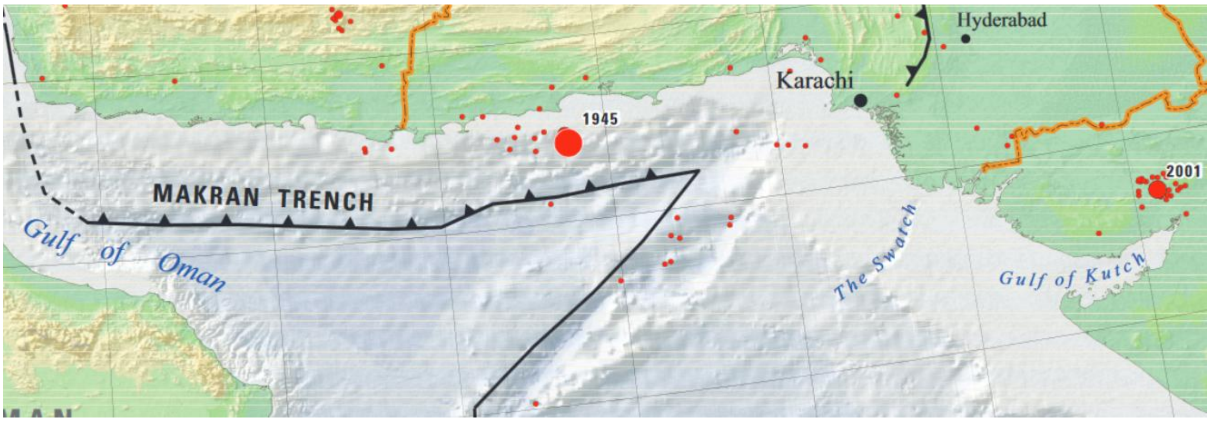


Figure 3. 25 Tectonic setting of Makran Subduction Zone

There is at least one earthquake of Mw 6.0 or more in MSZ each decade and that temporal pattern is repetitive (Figure 3.26).

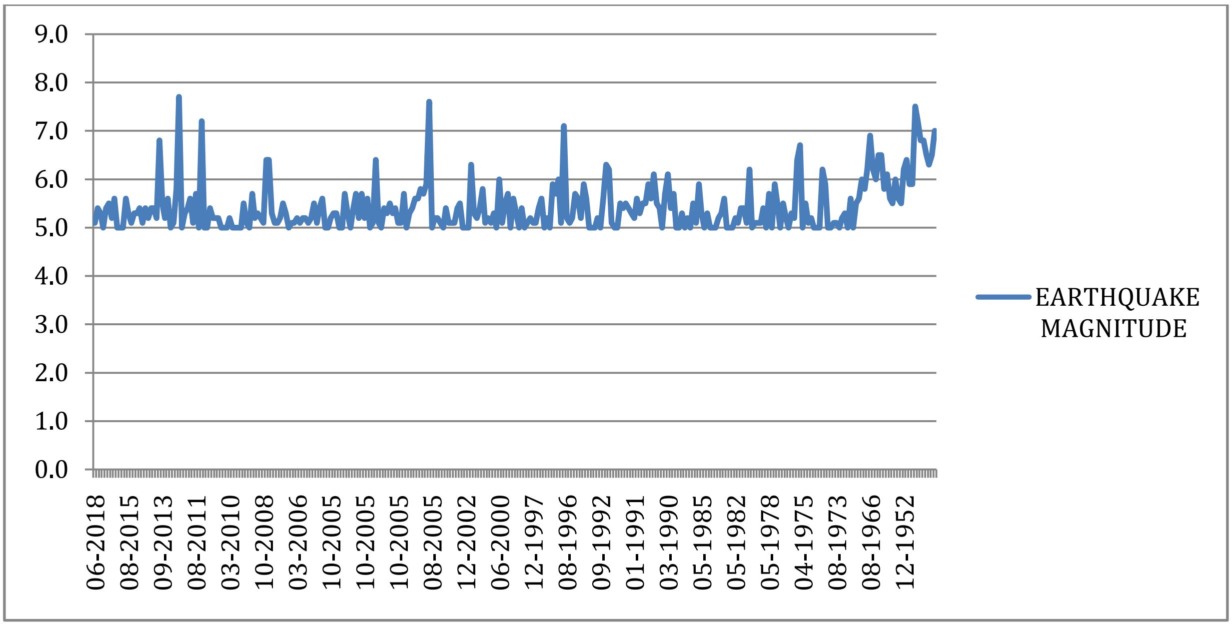


Figure 3. 26 Earthquakes magnitude pattern (<5) around Makran Subduction Zone from 1945-2018. (https://earthquake.usgs.gov/earthquakes/search/)

3.8.2 Tsunami

Heidarzadeh et al., 2008 recorded several historical earthquakes and Tsunami in MSZ area from literature and compiled them as in Table 3.9.

Table 3.9 Significant historical earthquakes and tsunamis in the MSZ (Heidarzadeh et al., 2008)

No	Year	Source Coordinates	Focal depth (km)	Magnitude	Intensity (MM)[a]	Tsunami Intensity
1	326 BC	24N-67.30E				2
2	1008	25N-60E			8-9	4
3	1483	24.90N-57.90E			10	
4	1524	-	-	-	-	2
5	1668	25N-68E			8-9	
6	1765	25.40N-65.80E			8-9	
7	1851	25.10N-62.30E			8-9	
8	1897	25N-62.30E	-	-		2
9	1927	27N-62E		6.5		
10	1929	26.40N-62.60E		6.5		
11	1934	27.43N-62.59E	35	7.0		
12	1945	24.50N-63E	25	8.3		5
13	1947	25.10N-63.40E	35	7.6		
14	1969	27.90N-60.10E	35	6.5		
15	1983	27.79N-62.05E	64			

The Tsunami Intensity 6-point intensity scale of Sieberg-Ambraseys, which classifies a tsunami as, 1: very light while scale 6 being disastrous.

In 326 BC, Macedonian fleet belonging to the military of Alexander the Great, encountered a Tsunami, which said to have destroyed the fleet and that earthquake's magnitude is believed to be between 7 and 8 (Heidarzadeh et al., 2008).

The 1008 earthquake whose epicenter was western MSZ in the Persian Gulf caused several casualties with several ships being sunken (Ambraseys and Malville, 1982; and Rastogi and Jaiswal, 2006).

(Rastogi and Jaiswal, 2006) have compiled the catalog of historical Tsunamis in the Indian ocean and have noted that an earthquake occurred near the coast of Dabhol in 1524 AD which caused damage to a Portuguese fleet present in the area, while numerical modeling of (Heidarzadeh et al., 2008) points to MSZ as the likely cause of Tsunami.

(Ambraseys and Melville, 1982) described an event as possible ocean storm in 1897 near Gwadar which reportedly brought hundreds of tons of fish to the coast of Makran. However, (Heidarzadeh et al., 2008) doubts the reason being an ocean storm as it is unlikely for such storm to bring massive quantity of dead fish to shore, and rather claims the likely reason behind that are the submarine volcanic activities.

The deadliest Tsunami of Arabian Sea which was caused by an earthquake on November 28th, 1945 in the makran subduction zone affected several countries including Iran, Pakistan, Oman, and India. Seismic waves were recorded in stations located in New Delhi and Mumbai, while several studies carried out later and estimated the earthquake was of 8.3 scale (Page et al., 1979). Run-up height of this Tsunami is reported to be 12-15 m by Pendse (1946), Berninghausen (1966), and Snead (1967) and 7-10 m by (Page et al., 1979).

3.8.3 Nuclear Accident

The thirty years design life of the nuclear power plant has already expired in 2002, while the plant is still operational with frequent extensions. Karachi has the Pakistan’s first ever nuclear power plant, namely KANUPP-1, since 1971. The 125 MWe capacity power plant, which completed nominal design life of thirty years in 2002 is still under operation with reduced electricity production of only 90 MWe. With these facts in sight, government planned to replace KANUPP-1 and start construction of KANUPP-2 and KANUPP-3 in 2015 and 2016 respectively. These new reactors have the electricity production of 1,014 MWe, making them Pakistan's biggest reactors.

Our study domain is the Karachi Nuclear Power Plant (KANUPP), which has one of the highest numbers of population within 30 kilometers diameter,i.e.8.3 million (Lévêque, 2013). KANUPP was constructed for peak ground acceleration (pga) of 0.1g, however, according to the building code of Pakistan (2007)), the area is classified in zone 2B with pga value of 0.25g which necessitates to perform further vulnerability and risk analysis for the NPP vulnerable to earthquake hazard with potential of a Tsunami as well.

3.8.4 Industrial Accident

Unlike countries in the EU and the US, Asia still lags behind in chemical safety domain and it has experienced significant chemical disasters such as Bhopal in India (1984), Jilin in China (2005), Gumi in South Korea (2012), and Rayoug in Thailand (2012) causing deaths and economic losses (Mannan et al., 2005; Asian Disaster Preparedness Center, 2015; Lee et al., 2016).

Karachi has a history of industrial accident which resulted in loss of human lives and capital.

Scale and intensity of industrial accident can significantly be reduced if proper safety standards are followed, which includes fire equipment availability and training, mock drills, and emergency plan.

(Mirza & Bashir, 2015) carried out a survey of several industries, namely, garment, textile mills, plastic & leather manufacturing, and pharmaceutical companies in Pakistan including Karachi. Survey included a questionnaire to investigate fire safety in major industries (Table 3.10). That survey gives a dreadful picture of industrial safety regulations in the country with large cache of safety equipment being out of order and the majority of workers are not able to use those equipment in case of emergency.

Table 3.10 Fire safety survey results of major industries of Pakistan (Mirza & Bashir, 2015)

Question-1 Do employees have knowledge regarding the location and use of fire safety equipment? (n=90)	
Employees know the location and use of safety equipment	37 (41%)
Employees do not have any idea about safety equipment	53 (59%)
Question-2 What is the present situation of fire safety equipment? (n=90)	
Equipment functioning properly	34 (38%)
Equipment out of order	56 (62%)
Question-3 Does your organization properly display fire safety evacuation plan in the building? (n=90)	
There is an evacuation plan	38 (42%)
No evacuation plan	52 (58%)
Question-4 Are emergency exit paths part of building structure in your organization? (n=90)	
Emergency exit paths are part of this building	39 (43%)
No exit paths in this building	51 (57%)
Question-5 Is safety equipment in your organization properly maintained and updated? (n=90)	
Maintenance of safety equipment is done as a matter of routine	21 (23%)
No formal system for safety equipment maintenance	69 (77%)
Question-6 Are employees in your organization properly trained to face fire emergency? (n=90)	
Properly trained	28 (31%)
No training provided	62 (69%)
Question-7 Are the signs/symbols to indicate emergency exits properly displayed in	

your organization? (n=90)	
Properly displayed	40 (44%)
Not displayed	50 (56%)

It is evident from recent accidents across many industries that most of those buildings were not safe for gathering of high numbers of workers, such as Ali Enterprise factory where more than 250 people died because of fire, had only one accessible exit (Campaign, 2013). Similarly, majority of the workers lack training and do not follow safety standards as was in the case where one worker slipped into tank of a chemical factory followed by three workers jumped one by one in the tank to save the colleague which resulted in the death of all four inhaling chemical fumes (Dawn, 2017). Such recent reported industry accidents are compiled in Table 3.11.

Table 3.11 Recent reported industry accident

Location	**Year**	**Description**
Ibrahim Hyderi (Dawn 2019)	2019	Three workers died after falling into a pit carrying toxic chemicals and animal waste.
Landhi (Dawn, 2018)	2018	Six workers died because of the explosion at the factory's furnace.
Bin Qasim area (Dawn, 2017)	2017	Four workers died after falling into an underground chemical tank one after another in an effort to rescue a fallen worker.
Korangi Industrial Area (Dawn, 2016)	2016	Three men descended into a chemical tank to rescue four men inside, it resulted

		in the death of five workers inhaling toxic fumes of a polythene bags factory.
Baldia Town, SITE	2012	More than 250 workers died when fire engulfed the garment factory.

3.8.5 Flooding

Karachi has two, Malir and Lyari, seasonal rivers which are used for the purpose of draining untreated industrial and municipal waste into the sea (Akhtar et al. 1997). These rivers are critical to drain out rain water but are not draining efficiently anymore because of increasing encroachments along their banks (Zafar & Zaidi, 2016). Lyari river drains most of the city's sewage and industrial waste to Arabian sea, while during monsoon season it makes the slum population of 0.8 million living both sides of river vulnerable to flooding (Mansoor & Mirza 2007; Irfan et al. 2018). Malir river on the other hand, is the largest and passes through the most populous areas of the city and has been the reasons of worst flooding in the past (Ahtar & Dahnani, 2012).

Table 3.12 Major floods of Karachi (Zafar & Zaidi, 2016)

Flood Date (dd-mm-yyyy)	Rainy hours	Rainfall (mm)	People Killed
07-08-1953	24	278.1	-
01-07-1977	24	207	248
2003	48	284.5	-
17-08-2006	-	77	13
21 to 26-06-2007	-	110.2	228
09 to 11-08-2007	-	191	21
22-08-2007	-	80	-
18-07-2009	4	245	20
31-08-2009	-	147	-

13-09-2011	-	145	-
13-08-2013	-	150	50

Historical records in Table 3.12 show that recurrent flooding in metropolitan occurring more frequently while preventive measures seem to prove insufficient because of large casualties.

3.8.6. Cyclone

In a study carried out by – which cited PMD and JTWC as sources, states that from 1999-2000, four severe tropical cyclones 02A (1999), 01A (2001), Yemiyn (2007), and Phet (2010) struck the coast of Pakistan. During those tropical cyclones (TC), about 1,700 either died or went missing while over one billion dollars of damages across Oman, Pakistan and parts of India with significant impact on Karachi (Sarfaraz & Dube, 2012). Future trends indicate that Arabian Sea will have increasing cyclone frequency, especially during the months of June and October (Hussain et al. 2011). Frequency of cyclones in Arabian Sea is listed in Table 3.13.

Table 3.13 Frequency of Arabian Sea cyclone data 1891-2010 (Hussain et al. 2011)

Cyclone data (120 years)	Frequency
Total annual	194
January	01
February	00
March	00
April	08
May	33
June	45
July	09
August	02
September	11
October	43
November	37
December	09

3.8.7 Extreme Heat

Karachi has increasingly fluctuating temperatures with changing climate where city is seeing colder winters, and hotter and humid summers. Lowest recorded temperature was recorded as on 21st January of 1934 and highest temperature of 47.8 on 9th May of 1938 (Table 3.14).

Table 3.14 Temperature and Precipitation data of Karachi from 1931-2018 (Pakistan Meteorological Department)

	Temperature (°C)		Monthly Heaviest
Month	Highest Maximum *(dd/yyyy)*	Lowest Minimum *(dd/yyyy)*	Rainfall in mm *(yyyy)*
January	**32.8***(16/1965)*	**0.0***(21/1934)*	**89.3***(1995)*
February	**36.5***(28/2016)*	**3.3***(11/1950)*	**96.0***(1979)*
March	**42.2***(20/2010)*	**7.0***(09/1979)*	**130.0***(1967)*
April	**44.4***(16/1947)*	**12.2***(29/1967)*	**52.8***(1935)*
May	**47.8***(09/1938)*	**17.7***(04/1989)*	**33.3***(1933)*
June	**47.0***(18/1979)*	**22.1***(03/1997)*	**110.2***(2007)*
July	**42.2***(03/1958)*	**22.2***(22/1938)*	**429.3***(1967)*
August	**41.7***(09/1964)*	**20.0***(07/1984)*	**262.5***(1979)*
September	**42.8***(30/1951)*	**18.0***(23/1994)*	**315.7***(1959)*
October	**43.3***(01/1951)*	**10.0***(30/1949)*	**98.0***(1956)*
November	**38.5***(02/1994)*	**6.1***(29/1938)*	**83.1***(1959)*
December	**35.5***(03/2011)*	**1.3***(14/1986)*	**63.6***(1980)*
Annual	**47.8***(09/05/1938)*	**0.0***(21/01/1934)*	**713.0***(1967)*

Temperature of Karachi has been rising and having a severe impact on the city life by causing extreme heat. It was found that city's temperature has increasing trend when analyzed the data from 1999-2018 (Figure 3.27).

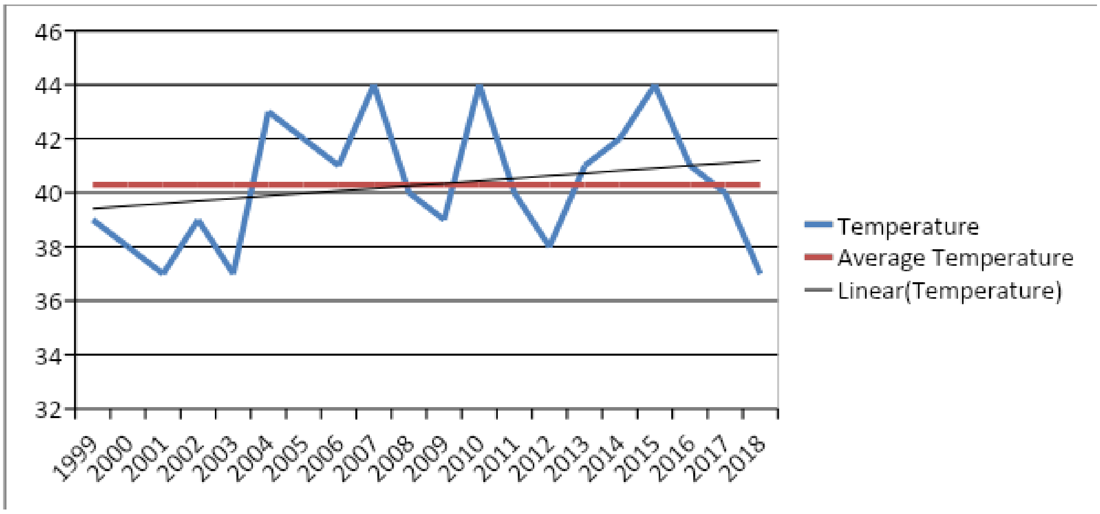


Figure 3. 27 Temperature trend of Karachi city from 1999-2018 (Reproduced using Weather Underground data)

Analysis of temperature and heat index for the period between years 1973-2015, it was observed that in Karachi the daily maximum heat index was about 7°C-12°C (Wehner et al. 2015). Monthly average temperature during June 2014 was 31.1°C, while during extreme heat of June 2015 monthly average was 37.7°C and maximum temperature reaching 45°C (Ghumman & Horney, 2016). Table 3.15 gives extraordinary figures of causalities during 2015 heat wave in Karachi. In comparison to death by heat a year before, 2015 had far greater number of loss of lives.

Table 3.15 Total death toll during 2015 Karachi Heat Wave against June 2014 Reference Period (Ghumman & Horney, 2016)

	Reference Period	**Heat Wave Period**	**Excess Deaths**
Gender:			
Female	21	382	361
Male	48	838	790
Age:			
≤50	16	320	304
>50	53	900	847
Income:			
>20,000 (196	49	693	644

USD)			
≤20,000	20	527	507
Home Sufficiency:			
No	47	737	690
Yes	22	483	461
Education:			
<5th Grade	43	582	539
≥5th Grade	26	638	612
Religion			
Other	9	201	192
Muslim	60	1019	959
Total	69	1220	1151

There were 1,151 excessive mortalities during the heatwave of 2015 with people of older age, mostly men, had the most deaths (Ghumman & Horney, 2016).

3.8.8 Fire

Fire is one of the risks faced by the population and businesses of Karachi with number of fire incidents in the city recently (Masood Rafi et al, 2012). Building codes are not followed in Karachi, in fact they are never enforced effectively in the country (Masood Rafi et al, 2012; Bilham et al. 2007).

3.8 Vulnerability

For different scientific groups, vulnerability means differently but when explaining in disasters context, it has two basic elements, i.e. exposure and susceptibility. Exposure is determined based on the living and working place of the people relative to a hazard while susceptibility involves physical, social, economic, political, environmental and psychological variables that determine the impact of hazard on people of same exposures (White et al., 2005). The dynamic and complex nature of social vulnerability changes through time and space and it can be realized by identification of susceptible population, which may not possess the capacity to cope with, resist and recover from a natural hazard (Cutter & Finch, 2008, Otto et al., 2017). The main factors generally used for social vulnerability in literature are found to be as age, education, gender, employment status, public health and infrastructure condition, socioeconomic status, and access to resources. Children and elderly people can be the most disadvantageous in emergency or the recovery phase while the situation for female population can be very challenging as they are generally linked to higher mortality rate in disasters compared to their male counterparts (Cutter et al., 2003; Fatemi et al., 2017; Wisner et al., 2004). Marginalized groups such as religious, migrant or ethnic minorities living in risky areas can be related to higher social vulnerability (Carnelli and Frigerio, 2016).

Index for Risk Management (INFORM) further classify vulnerability as in Figure 3.28.

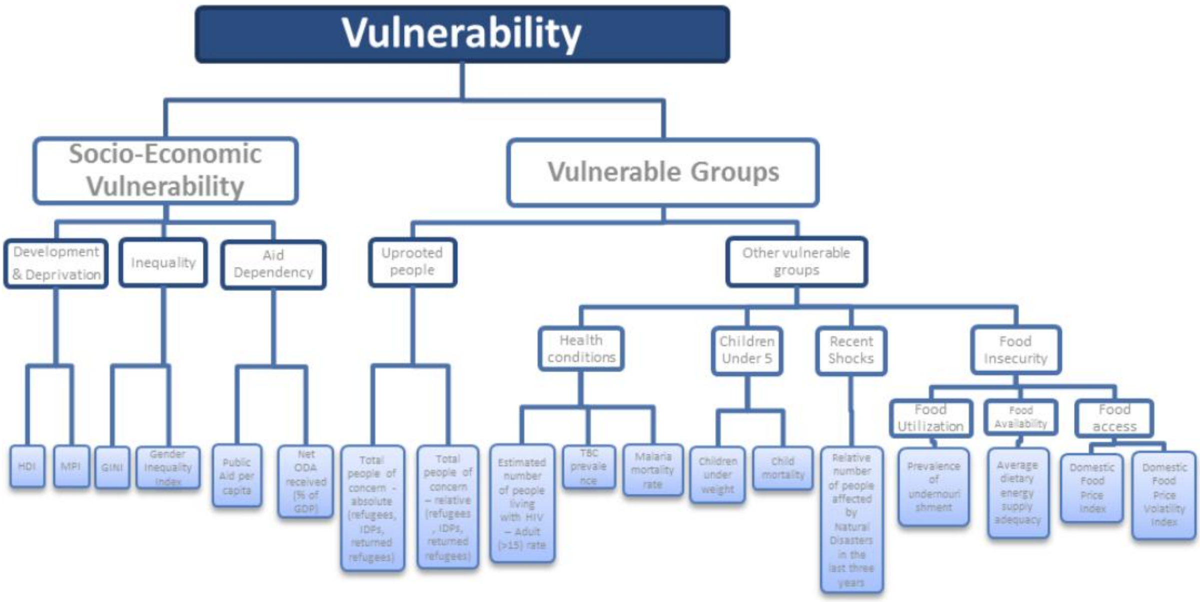


Figure 3. 28 Graphical presentation of vulnerability dimension (Marin Ferrer et al. 2017)

Social vulnerability has several variables which are key in determining overall vulnerability of a society (Table 3.16).

Table 3.16 Variables used in social vulnerability index for Italy (Frigerio et al.2018)

Variables	Indicators	Impact on Social Vulnerability
Family with more than 6 members	Family structure	Increase
High education Index	Education	Decrease
Low education Index		Increase
Quality of buildings	Socioeconomic status	Decrease
Commuting rate		Increase
Employed female labor force	Employment	Decrease
Employed labor force		
Unemployment rate		Increase
Rate of children < 14 years	Age	Increase
Rate of elderly > 65 years		
Aging index		
Dependency ratio		
Population density	Population growth	Increase
Built-up areas		
Crowding Index		
Foreign residents	Race/Ethnicity	Increase

Overall resilience is the combination of several sub-types such as social resilience, economic resilience, institutional resilience, infrastructure resilience, and community capital (Table 3.17).

Table 3.17 Types of resilience

Category	Variable	Reference
Social Resilience		
Educational equity	Ratio of the pct. population with college education to the pct. population with no high school diploma	Norris et al. 2008 Morrow 2008
Age	Percent non-elderly population	Morrow 2008
Communication capacity	Percent population with a telephone	Colten et al. 2008
Health coverage	Percent population with health insurance coverage	Heinz Center 2002
Economic Resilience		
Housing capital	Percent homeownership	Norris et al. 2008 Cutter et al. 2008a
Employment	Percent employed	Tierney et al. 2001
Income and equality	GINI coefficient	Norris et al. 2008
Single sector employment dependence	Percent population not employed in farming, fishing, forestry, and extractive industries	Berke & Campanella 2006 Adger 2000
Health Access	Number of physicians per 10,000 population	Norris et al. 2008
Institutional Resilience		
Municipal services	Percent municipal expenditures for fire,	Sylves 2007

	police, and EMS	
Previous disaster experience	Number of paid disaster declarations	Cutter et al. 2008a
Infrastructure Resilience		
Housing type	Percent housing units that are not mobile homes	Cutter et al. 2003
Shelter capacity	Percent vacant rental units	Tierney 2009
Medical capacity	Number of hospital beds per 10,000 population	Auf de Heide and Scanlon 2007
Access/ evacuation potential	Principle arterial miles per square mile	NRC 2006
Housing age	Percent housing units not built before 1970 and after 1994	Mileti 1999
Sheltering needs	Number of hotels/motels per square mile	Tierney 2009
Recovery	Number of public schools per square mile	Ronan and Johnston 2005
Community Capital		
Place attachment	Net international migration	Morrow 2008
Political engagement	Percent voter participation in the 2013 election	Morrow 2008
Social capital – civic involvement	Number of civic organizations per 10,000 population	Morrow 2008 Murphy 2007

3.8.1. Gender

Only 24.3% of Women in Pakistan contribute to workforce while males contribute 82.2% (UNDP 2016), it causes the reduction in resources women can access. Inequality in education stands at staggering high at 44.4% making significant portion of female population illiterate.

3.8.2 Age

Population group of 15 to 64 years 53.09% while 5-64 years of age makes up 81.61% of total population. Such a high percentage of youth population is likely to contribute in social vulnerability if they are not educated and employed properly.

3.8.3 Education

More than half of the population is categorized illiterate while 46.70% are considered literate with only 14.09% of the population has acquired primary education (PBS 2013-14).

3.8.4 Employment

Unemployment rate in Pakistan stands around 6% with province of Sindh has lower than national unemployment rate at 4.6% (PBS, 2015).

3.8.5 Health

Healthcare system of Pakistan is one of the most strained ones in the world and rapid increase in population is making things even worse. As per World Health Organization (WHO) there are only 0.98 physicians per 1,000 people while only 20 beds for 10,000 people.

3.8.6 Disadvantaged Communities

There are hundreds of thousands of people who do not have access to basic services as any other Pakistani. There are communities like Bengalis, Burmese and Biharis, whose population is well over two million, cannot have access to basic education, health, and labor market because of their status in the country. As they are often categorized as stateless people, they do not possess the same rights as any other country man would, hence being abused and exploited without any access to the justice system of the country.

3.8.7 Tsunami disaster preparation and drills

For any city which is susceptible to Tsunami hazard needs to have Tsunami evacuation plan which shall be tested by frequent evacuation drills (Scheer et al. 2012). Such drills are particularly important in places like schools. Japan tend to be very sensitive with Tsunami evacuation plan and carry frequent drills for that purpose. Before 2011 Tsunami, Okawa primary school, near the mouth of a river, did not conduct any drills, the consequence of that was that out of 108 children, 74 died while remaining survived by climbing a mountain behind the school (Suppasri et al. 2013).

National Disaster Management Authority (NDMA) has several volumes of booklets, none of which explicitly contain any Tsunami and/or Nuclear disaster plan for Karachi. Human Resource Development Volume-1 of NDMA mentions about Tsunami evacuation drills conducted in coastal area of Balochistan but no mention of such drills carried out in Karachi. PMD which relies on Geo Forcheng Zentrum, is not able to have real-time monitoring of Tsunamis in Arabian sea (national disaster management plan volume Volume-II). It is reported that Tsunami generated by 1945 MSZ earthquake hit the coast in less than 20 minutes. There is absence of any Tsunami hazard, inundation or risk map of Karachi and absence of such a map leads to inadequate planning, policy and management of a disaster. Also, in non-existence of tsunami or earthquake evacuation plan, it is very likely that residents and the authorities of Karachi metropolitan will find themselves taken by surprise like Sumatra was in 2004 earthquake followed by a Tsunami.

3.8.8. Traffic and Terrain

Karachi has a history of severe traffic congestions during rush hours and it gets worse in case of torrential rain when roads are quickly inundated with water. Disasters like earthquake cause serious deterioration of roads and disruption of traffic on that, causing delays or complete abandonment of essential logistics to reach the intended areas. During Fukushima, because of damages to transportation system and traffic congestion, Off-site Center (OFC), 5 km southeast of the plant, could never be fully staffed. Also, when Tokyo Electric Power Co. (TEPCO) sent eleven power supply trucks equipped with emergency generators towards Fukushima Daiichi, 250 km away, it immediately got stuck in traffic. Roads which were not affected by earthquake or tsunami were being flooded with people fleeing the disaster sites.

3.9 Methodology

This research applies various methods and techniques to assess various hazards and vulnerabilities posed by Karachi with constraints of sparse data. Also, the purpose of such hazard assessment is not only to spatially locate hazards but to be able to quantitatively or qualitatively deduce significance of those risks (Smith, 2003). As a result, all the risks related to a country, region, or a city need to be taken into account for risk assessment of spatial nature (Greiving, et al. 2006).

3.9.1 Multi-Hazard Risk Assessment Methods

The term multi-hazard as defined in Table 1.1 is the occurrence of more than one hazard with or without temporal coincidence while it may have cascading effects when hazards have temporal coincidence or shortly following each other. Any resultant risks posed by more than one hazard define the term multi-hazard risk.

In applying hazard risk assessment methods, it is important to have the data about consequences of various hazards (losses due to hazards) to the study area. Consequence analysis requires the elements at risk and vulnerability of element at risk. In order to quantify the vulnerability of elements at risk, it is essential to understand interaction between a certain hazard and affected elements. Elements at risk refer to population, buildings, road networks, infrastructure, so on (Van Westen, 2006).

There are different methods to assign weights, this study uses the Delphi method (Greiving 2006; Greiving et al. 2006; Olfert et al. 2006; Schmidt Thomè 2006). Delphi method has been extensively used in many fields while in hazard domain it has been river floods, earthquakes, forest fires, technological accidents and so on (Greiving et al. 2006; Elmer et al. 2010; Peng et al. 2012; Lee at al. 2013; Alshehri et al. 2015).

3.9.2 GIS-based MCDA

Multi-criteria decision analysis (MCDA) has been extensively used over past decades with increasing application areas in natural and social sciences (Velasquez & Hester, 2013). There has also been increasing use of MCDA in GIS-based hazard and vulnerability mapping of landslides, earthquakes, floods, and Tsunamis.

3.9.3 Analytical Hierarchy Process –AHP

The AHP is an essential tool which is used to measure vulnerability in terms of indicators as exposure, sensitivity, and coping capacity of Karachi. These indicators are further divided as: exposure (earthquake, tsunami, nuclear accident, flood, fire, extreme heat, chemical accident, and cyclone); (2) sensitivity (population density, slums, pumping stations, marginal workers, migrants); (3) coping capacity (literacy rate, water availability, electricity supply, health facilities, fire stations). These indicators are selected depending on the availability of data. Disaster vulnerability assessment is based on ranking all the indicators, each with different weight.

There are different methods to assign weight, this study uses the Delphi method (Greiving 2006; Greiving et al. 2006; Olfert et al. 2006; Schmidt Thomè 2006). Delphi method has is useful for study areas for which the data is scarce.

As Karachi is a mega city, which is exposed to multiple hazards, an integrated risk assessment is indispensable. Such spatially multi hazard risk assessment, namely, integrated risk assessment, proposed by (Greiving, et al. 2006) addresses both natural and technological hazards.

Method proposed by Greiving, et al. 2006 (Figure 3.29), when fully applied, gives a comprehensive integrated risk map. However, for the full application of this method, extent and the quality of data needed would be much higher.

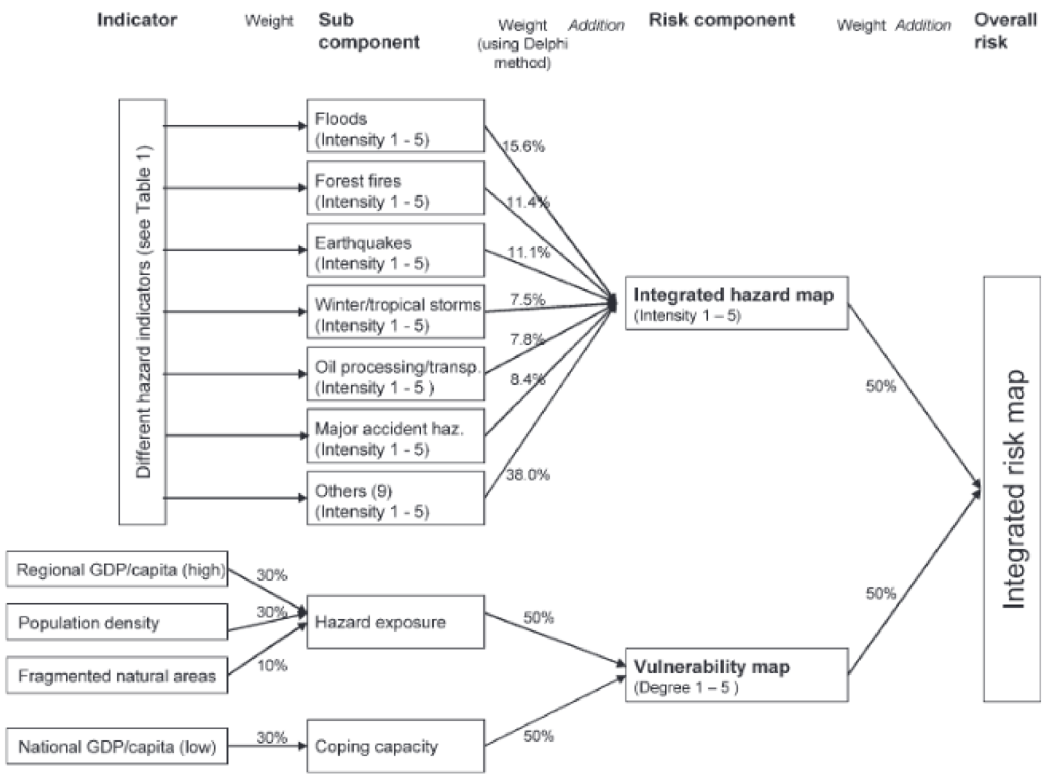


Figure 3. 29 Flow chart of the methodology (Greiving et al. 2006)

Ideally, separate studies of vulnerability and hazard assessment followed by comprehensive risk map would be done to achieve integrated risk maps. However, in the scope of this thesis, ideal target of integrated risk map was not achieved as my case study area was with limited data. Hence, the study is limited in creating hazard vulnerability maps utilizing the limited data in best possible ways.

Comprehensive survey and discussion was carried out with local experts with the knowledge of geology, geomorphology, geography, social and governance, and various hazards. The experts were asked to estimate the relevance and give weight to parameters of different hazards (Schmidt-Thomé et al. 2006). This weighting process has also considered vulnerability indicators and the obtained result had been sum of 100%.The mean result of the estimates were considered for the further process. Figure 3.30 shows the adopted procedure for assessing hazards and vulnerabilities.

Figure 3.30 shows the framework followed in this study. The raw data was collected, processed and digitized in GIS environment to make full use of it in the analysis.

After selecting and giving proper weight to each indicator, the weighted overlay method in ArcGIS was applied for each hazard type.

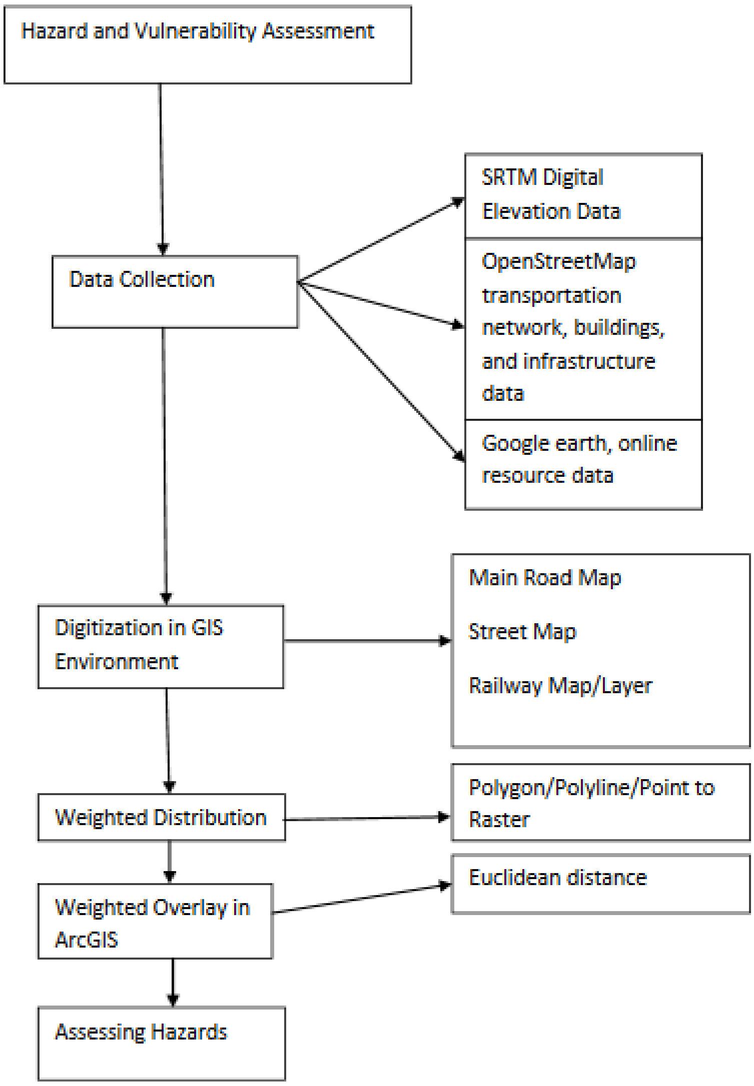


Figure 3. 30 Framework of adopted procedures for assessing hazards and vulnerabilities

3.10 Production of Parameters Map and Datasets

In order to assess and create hazards and vulnerability maps, dataset mentioned in section 1.2.1 has been used. That includes 30x30 meters DEM, raw and basic geological maps of Karachi from USGS. However the raw geological map (Figure 4.8) was manually digitized (Figure 4.9) and added more details to be used more efficiently for the analysis.

The vector dataset mostly comes from Open Street Maps with various layers such as roads, buildings, and railway. The shoreline of Karachi was manually digitized in vector format which was later converted in raster format to calculate Euclidean distances from shoreline to mainland.

Social and census data of each district of Karachi was collected from Pakistan bureau of statistics and added as separate layer to aid in vulnerability assessment.

Data derived from the primary data sources is described in Table 3.18.

Table 3.18 Primary data sources and the type of data extracted for this study

Primary Source	**Data Extracted**
USGS SRTM	Digital Elevation Model
Open Street Map	Buildings, roads, and infrastructure
USGS Earthquake Catalog	Historical seismic activity
USGS Geological Maps	Geological map of Karachi
Pakistan Bureau of Statistics	Census and Social
Weather Underground	Temperature and Precipitation

Availability and access of data for this study has been a crucial and challenging part. Similar to many other developing countries, data availability is low and access to data is difficult in Pakistan. Table 3.19 categorizes the data used in this study (open source) and other desired data either did not exist or was available commercially.

Table 3.19 Types of data for Karachi: freely available Vs not-available or paid data

Freely available data	**Either not-available or paid data**
Digital Elevation Model	Detailed Geological map
Vector data of roads, building, infrastructure etc	Flood inventory data
Census data	Bathymetry data
Land cover images	Land cover images with higher spatial resolution from commercial satellite
Basic weather data (Weather underground)	Detailed weather data (Pakistan Meteorological Department)
Social Data	Socio-Economic Data at district level
Past seismic activity (USGS)	Building inventory

However, it was the main objective to have the data on right column of Table 3.19 as that data would have made this study achieve the original idea and aim of creating more detailed integrated hazard risk map of Karachi.

CHAPTER 4

MULTI HAZARDS VULNERABILITY ASSESSMENT FOR KARACHI

For hazards vulnerability assessment there are certain assumption which needs to be taken into account as its base, these assumptions are listed below:

4.1 Assumptions of Vulnerability assessment of Karachi Metropolitan

Several assumptions are included in order to assess the vulnerability of the city:

- Any significant earthquake in Karachi is most likely to originate from Makran Subduction Zone. While any large earthquake in MSZ has the potential to trigger a Tsunami.
- The only recorded large Tsunami in modern history of Karachi occurred in 1945 which was triggered by 8.1 M_w earthquake in MSZ. Potential of any future Tsunami is likely to originate in MSZ.
- There have been several irregular, illegal, and low quality constructions since 1945. Earthquake of similar magnitude as of 1945 may damage several buildings across the city.
- Earthquake tremors would not be perceived as warning of Tsunami as population does not have any previous experience or knowledge of Tsunami. It is likely that communication lines go offline after an earthquake, hence local mosques' speakers and sirens are used for evacuation in coastal areas.
- Because of encroached roads, congested traffic, and damaged buildings debris in the city, evacuation by vehicles is not possible. Evacuation only by motor bicycle and by foot can be recommended.
- People are advised to stay away from river Malir and river Lyari as river overflow can deteriorate the situation.

- Coastal areas of Karachi are prone to storms developed in Arabian Sea.
- Southern parts of the city can be affected significantly due to storm surge.
- Heavy rains following the storm often result in flash flooding. Most of the damage is due to the fall of billboard, electric transmission line and due to electrocution in the city.

This study considers three aspects of risk as vulnerability, and hazard and exposure (Table 4.1). Vulnerability part takes into account the socio-economic factors while hazard and exposure considers various types of hazards faced by Karachi and areas of the city exposed to those hazards. INFORM model (2017) is used for this study.

Table 4.1 Model used to asses overall risk

Dimension	Hazard & Exposure						Vulnerability			
Categories	Natural					Human	Socio-Economic		Vulnerable groups	
Component	Earthquake	Tsunami	Tropical Cyclone	Flood	Heat Wave	Industrial Accidents	Development Deprivation	Inequality	Uprooted People	Other vulnerable groups

4.2. Calculating Risk

UN International Strategy for Disaster Reduction (UNISDR) expresses rick as equation 4.1. It comprises two components of risk as potential event as hazard and vulnerability as the degree of susceptibility of element exposed.

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability} \qquad (4.1)$$

However, INFORM improves the equation 1 by splitting vulnerability variable and updates it as:

$$\text{Risk} = \text{Hazard \& Exposure} \times \text{Vulnerability/Coping capacity} \qquad (4.2)$$

4.3 Vulnerability at Location

Karachi, a southwestern city (Figure 4.1) occupies only 0.47% of Pakistan's land while it accommodates over 7.5% of its population. The city's infrastructure as well as the population is potentially vulnerable to hazards. There are several factors which make Karachi vulnerable, these are explained as:

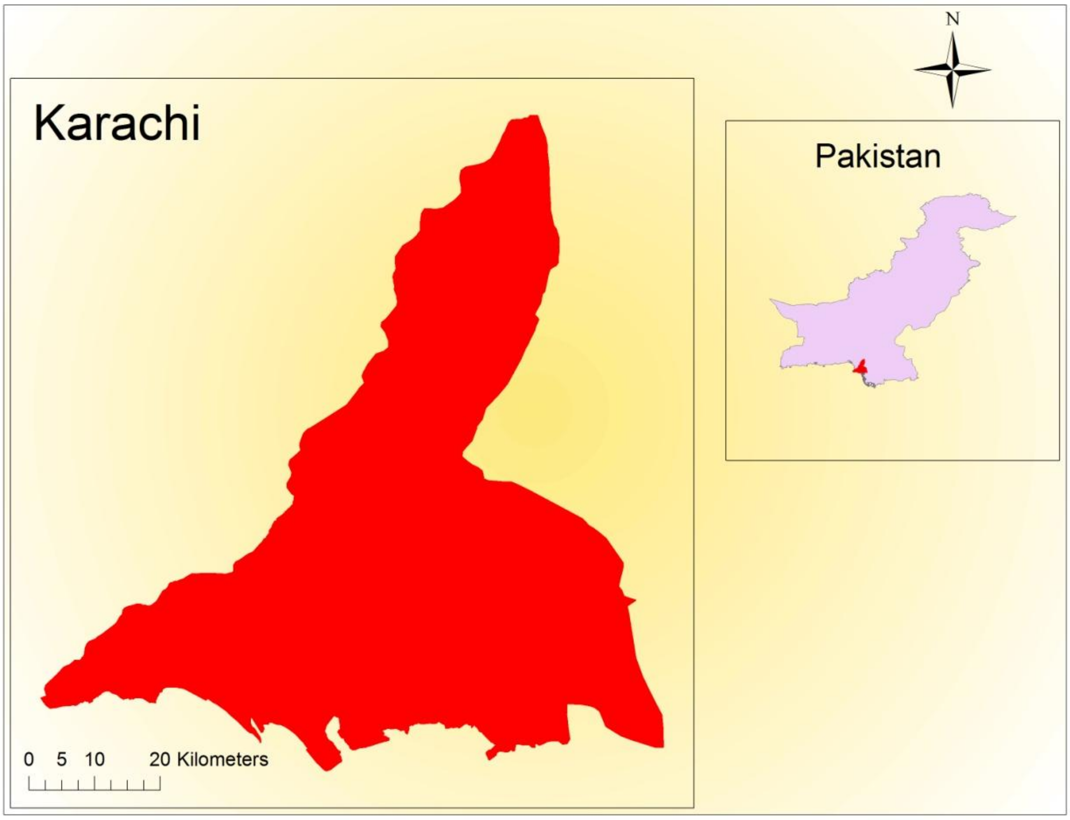


Figure 4. 1 Area of Study, Karachi city (Produced by author)

4.3.1 Parameter map of Vulnerability at Location

Several squalid or slums are spread across the city with one of them the largest in the world, i.e. Orangi Town. World Economic Forum, Agenda 2016 puts population of Orangi Town at staggering high of 2.4 million

Population map (Figure 4.2) of each district was constructed based on the latest census data of 2017. Based on this population data, district-wise population density map (Figure 4.3) was produced with Malir district having lowest and district south having highest population density of 662 and 52,734 respectively. District Central, East, Korangi, and South are the most densely populated.

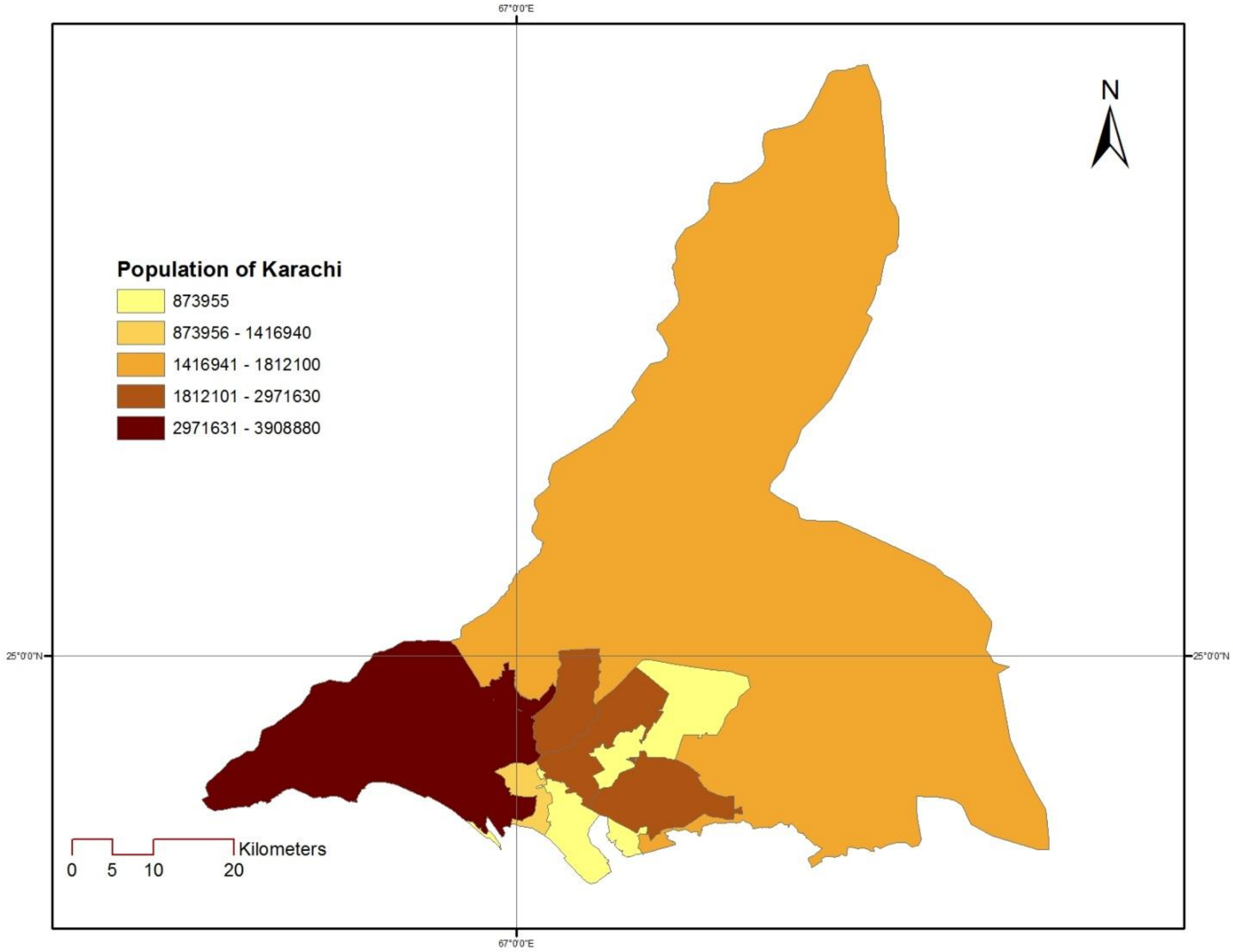


Figure 4. 2 District-wise population map of Karachi (Produced by author)

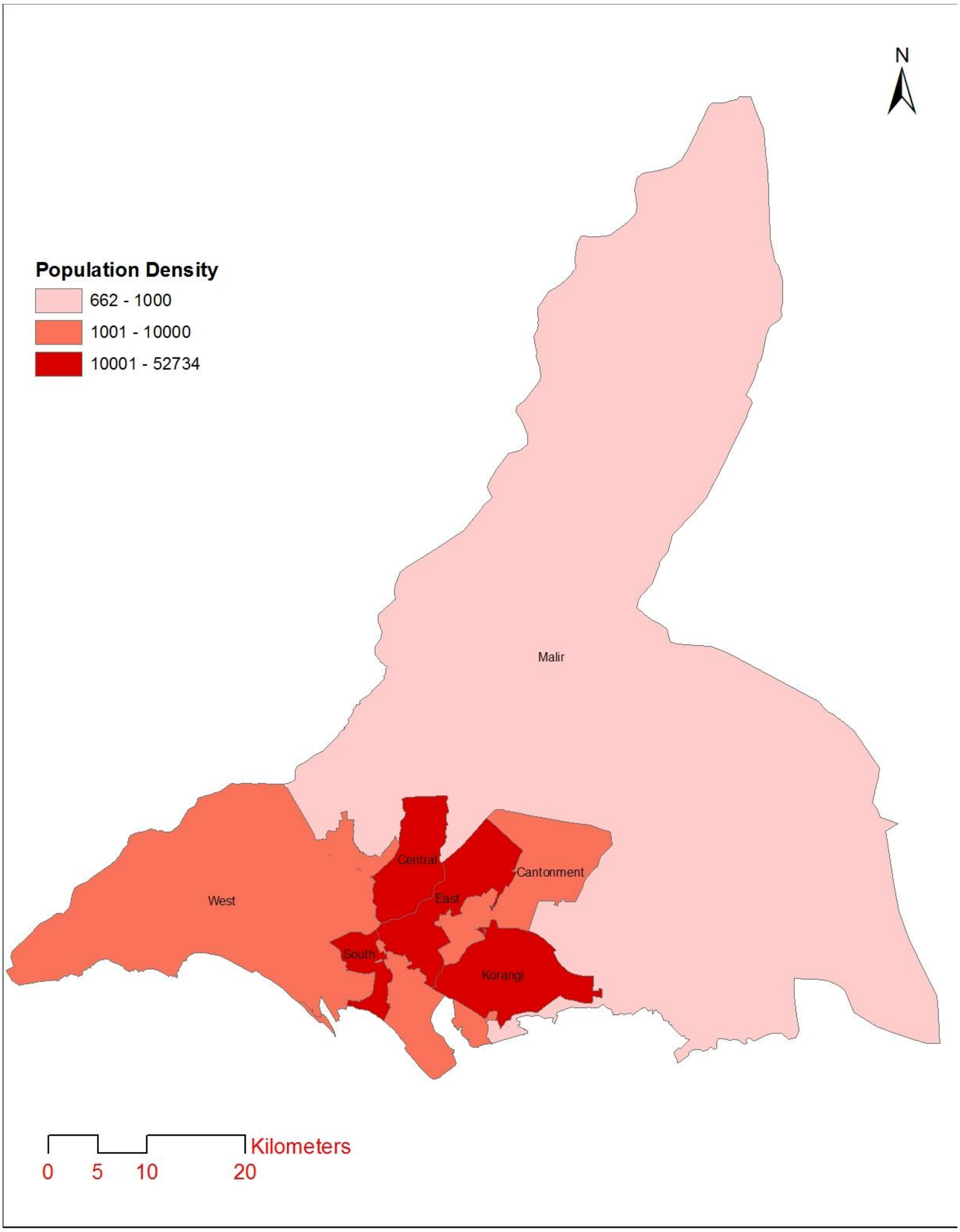


Figure 4. 3 District-wise population density map of Karachi (Produced by author)

4.3.2 Hospitals

Hospital data of Karachi was obtained through Open Street Map database and imported in ARCMAP to create a hospital layer (Figure 4.4). Most of the hospitals are located in the densely populated central districts of the city.

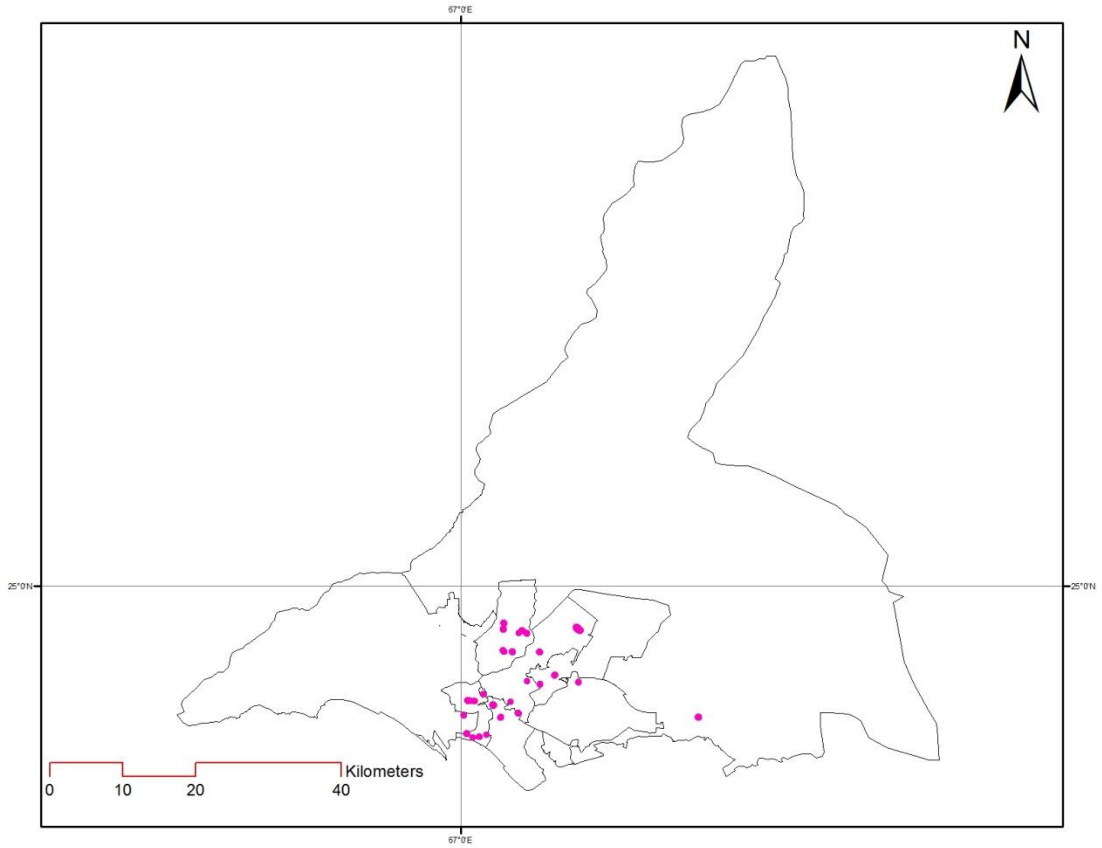


Figure 4. 4 Spatial distribution of hospitals across Karachi (Produced by author)

4.3.3 Distance from the shore

In case of a Tsunami, the areas closer to shore tend to posses higher risk of being affected by the event. Use of any building or infrastructure near the shoreline during Tsunami will make people severely vulnerable. This vulnerability decreases as distance from the shoreline increases. Therefore, the distance from the shore is a key parameter to analyze vulnerability.

In order to acquire the raster map of distance from shoreline, the shoreline of Karachi has been digitized in vector format (Figure 4.5). Through that vector format, the distance from the shoreline to each location of Karachi has been represented in raster format (Figure 4.6).

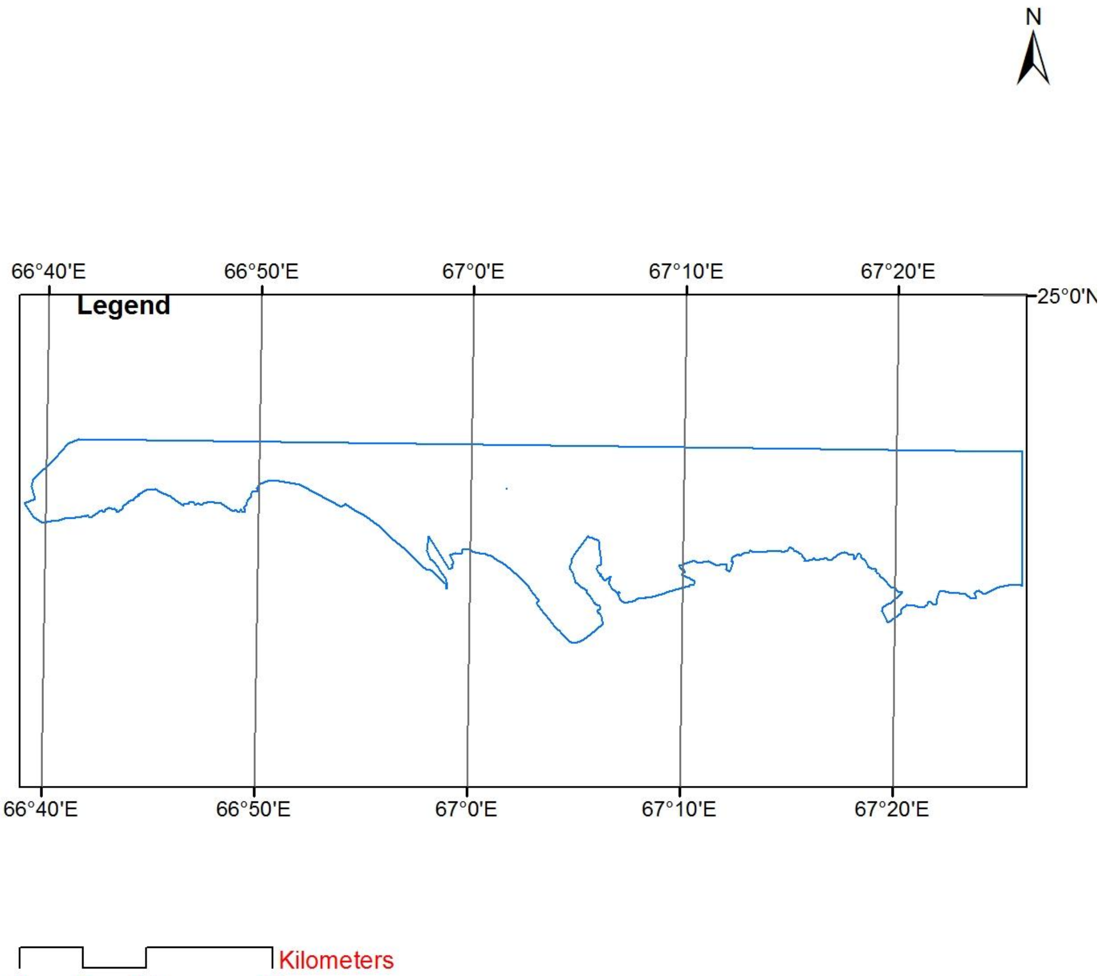


Figure 4. 5 Vector representation of shoreline of Karachi (Produced by author)

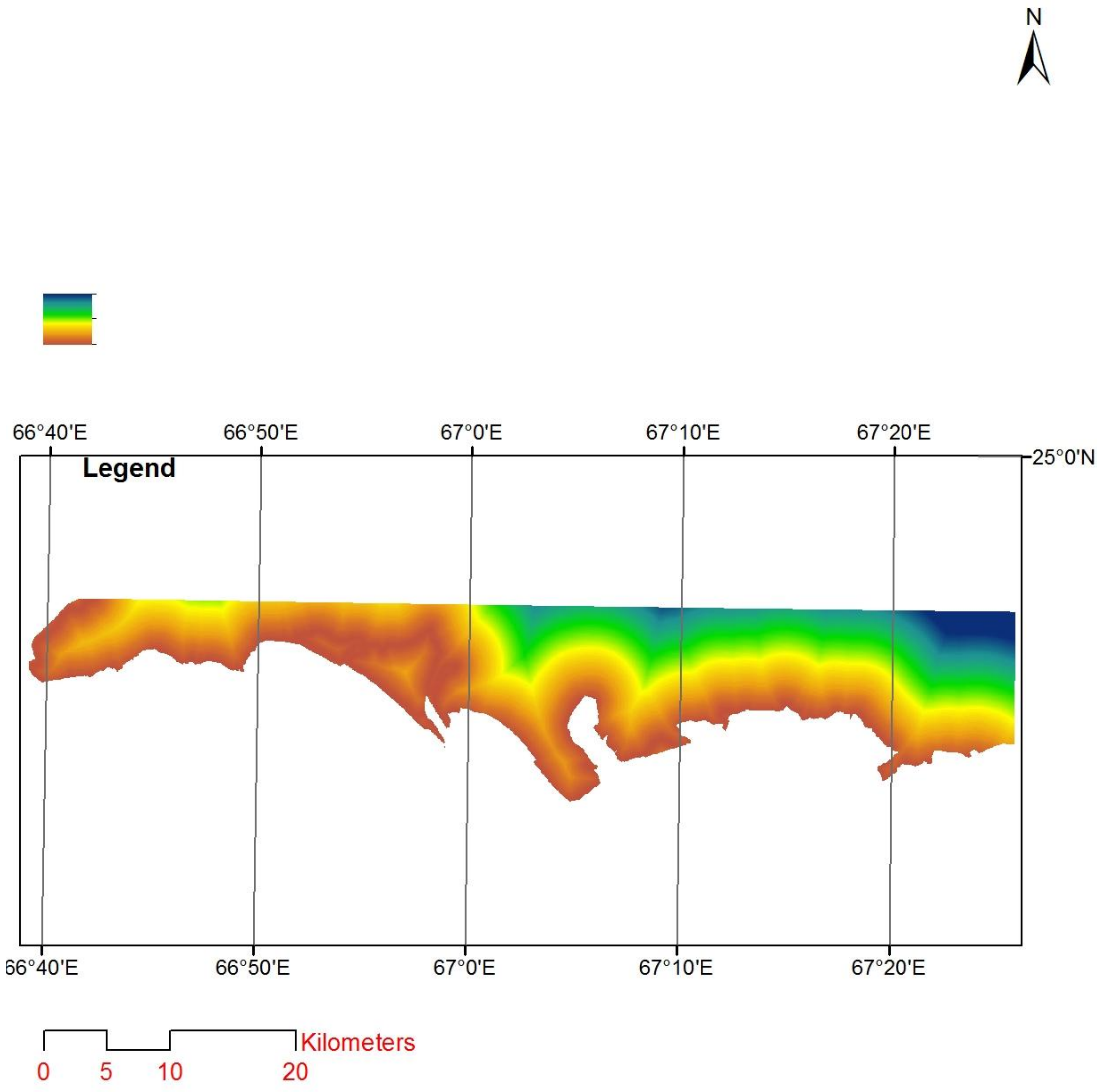


Figure 4. 6 Distance from the shoreline map parameter (Produced by author)

4.3.4 Metropolitan Use Layer

Metropolitan use layer (Figure 4.7) has been produced by using vector data of Open Street Map. Data contains points, polyline and polygon shape files featured as buildings, roads, railways, and natural places. These features are classified separately into following subgroups in Table 4.2.

Table 4.2 Classification of various features of Karachi according to their use

Classes of Metropolitan Use	Structure and Building Type
Important Places	Government Buildings
	Schools
	Religious Places
Infrastructure	Gas Stations
	Pumping Stations of KWSB
Assembly Areas	Sports Facilities
	Shopping Malls
Flat Areas	Railway Tracks
	Roads
	Parking Lots
	Parks and Forests
Buildings	Factories
	Residential Buildings
	Commercial Buildings
	Small Industries

According to the level of vulnerability level, those 15 attributes of table have been classified and labeled into 5 groups as important places (government buildings, schools, religious places), infrastructure (gas stations, water and sewerage pumping stations), assembly areas (sports facilities, shopping malls), flat areas (railway tracks, roads, parking lots, parks & forests), and buildings (factories, residential buildings, commercial buildings, small industries).

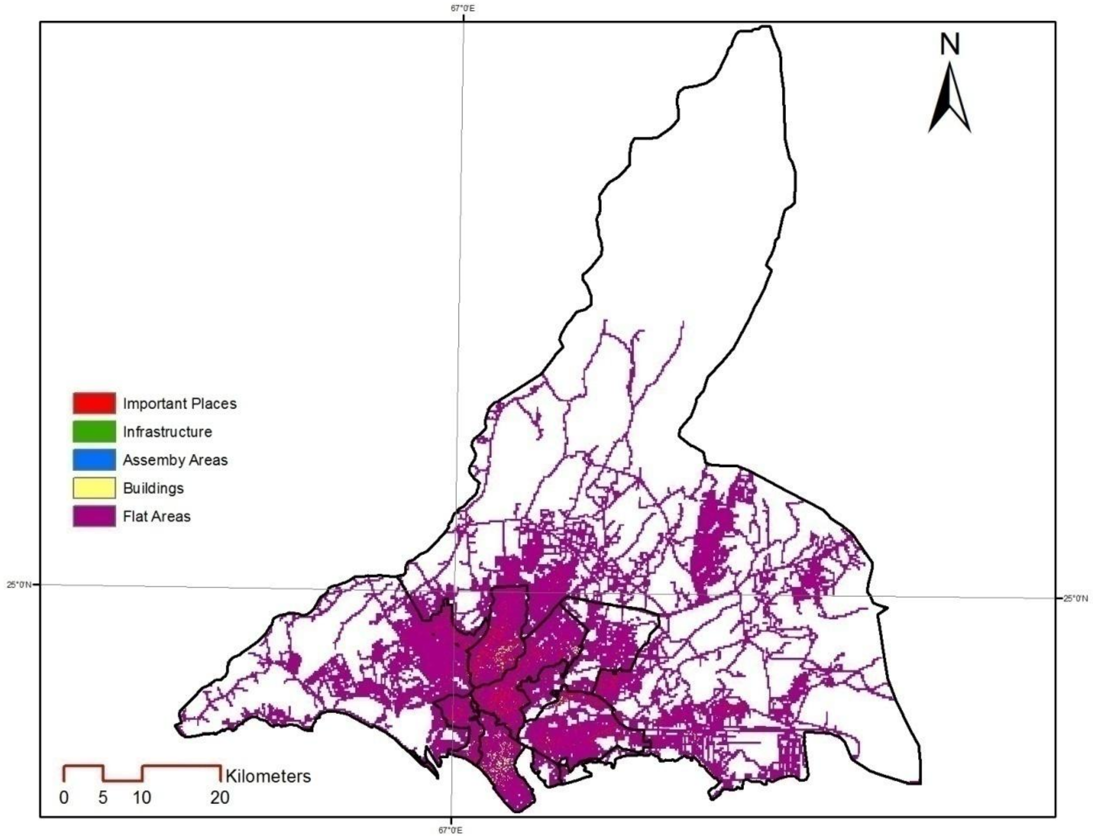


Figure 4. 7 Parameter map of metropolitan use layer (Produced by author)

Each class was then ranked from 1-10 and classifid according to vulnerability level from very low to very high vulnerability (Table 4.3).

Table 4.3 Classification and ranking of the metropolitan use layer

Metropolitan Use		
Class	Rank	Vulnerability Level
Buildings	1	Very Low
Flat Areas	7	High
Assembly Areas	8	High
Infrastructure	9	Very High
Important Places	10	Very High

4.3.5 Geology

Because of non-availability of geological map of Karachi in digital format, the map was self digitized for this study. A very basic geological map of the city was downloaded through USGS database which is represented in Figure 4.8.It includes three formations of Cenozoic time with period as Quaternary, Neogene, and Paleogene.

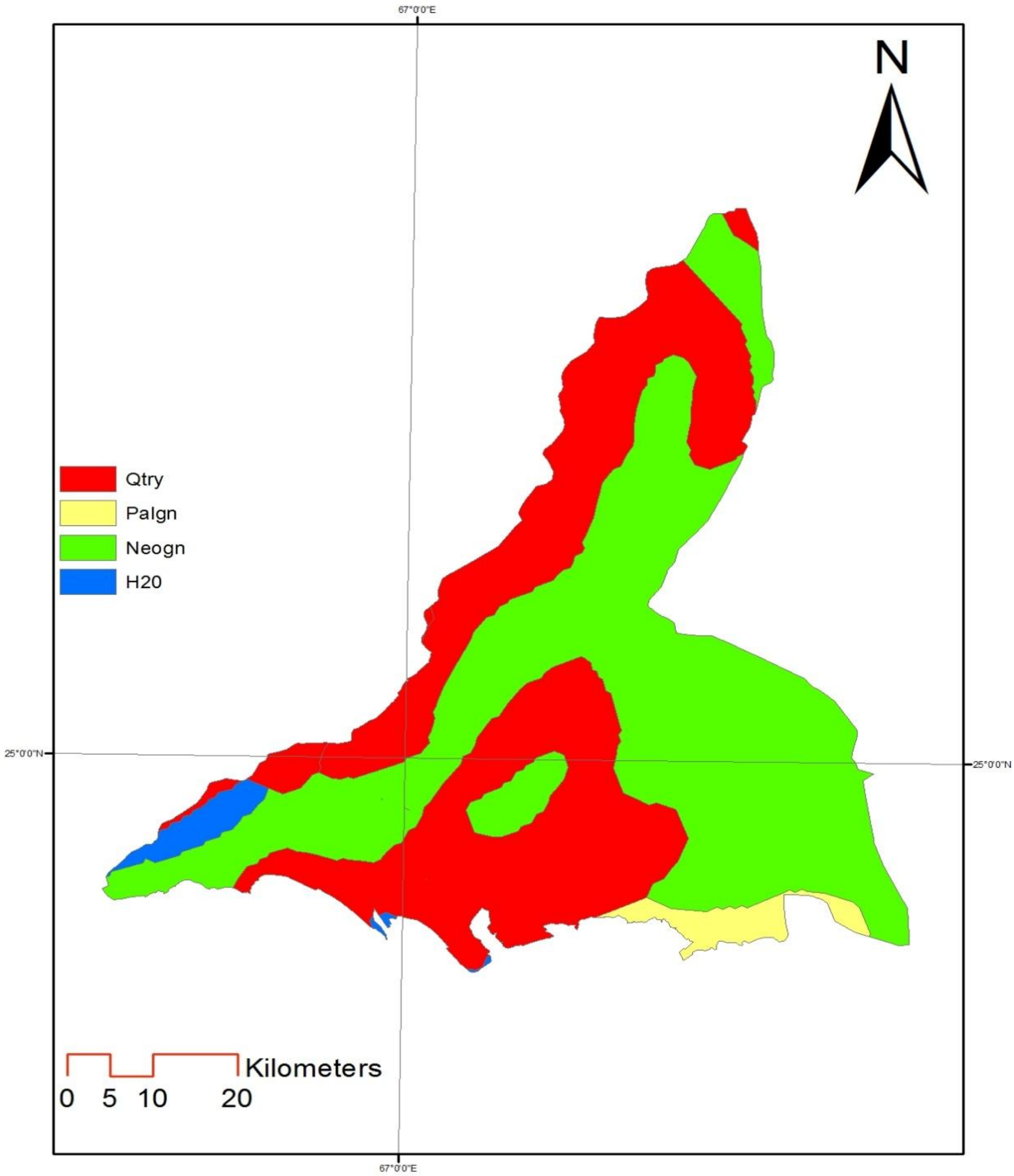


Figure 4. 8 Basic geological map of Karachi (Modified from USGS)

Map in Figure 4.8 was further digitized manually to include more geological details **(**Figure 4.9**)**.Karachi consists of several formations such as Manchar, Gaj, and Nari formations. Area-wise, most of Karachi is covered by alluvial deposits and Gaj formation of quaternary and tertiary periods. Gaj formation contains Mol, Mundro, and Gulistan-e-Jauhar member. Mol member consists of limestone and clay, Mundro is predominantly clay and sandstone with minor limestone, while Gulistan-e-Jauhar member is inter-bedded yellow and grey siltstone, sandstone clay and limestone. Most of the city’s population is sitting over alluvial deposits of recent quaternary period and gulistan-e-jauhar member of tertiary period.

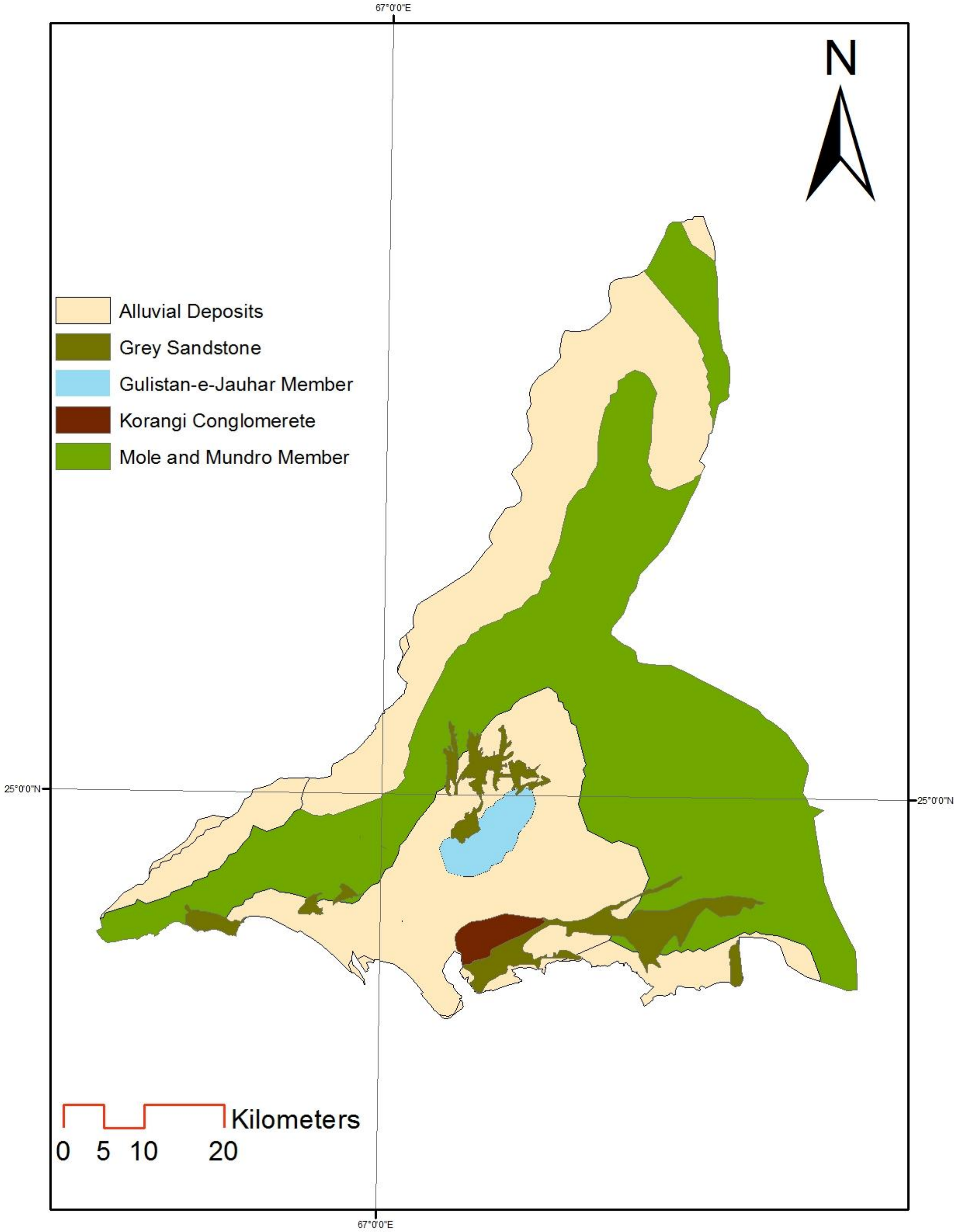


Figure 4. 9 Digitized geological map of Karachi (Produced by author)

Each class was further ranked from 10 (very high vulnerability level) to 2 (very low vulnerability level (Table 4.4). Alluvial deposits are ranked with very high vulnerability while Korangi Conglomerete with very low vulnerability (Figure 4.10).

Table 4.4 Classification and ranking of geological layer

Geology		
Class	Rank	Vulnerability Level
Alluvial deposits	10	Very High
Grey sandstone	8	Very High
Gulistan-e-Jauhar member	7	High
Korangi Conglomerete	2	Very Low
Mole and Mundro member	7	High

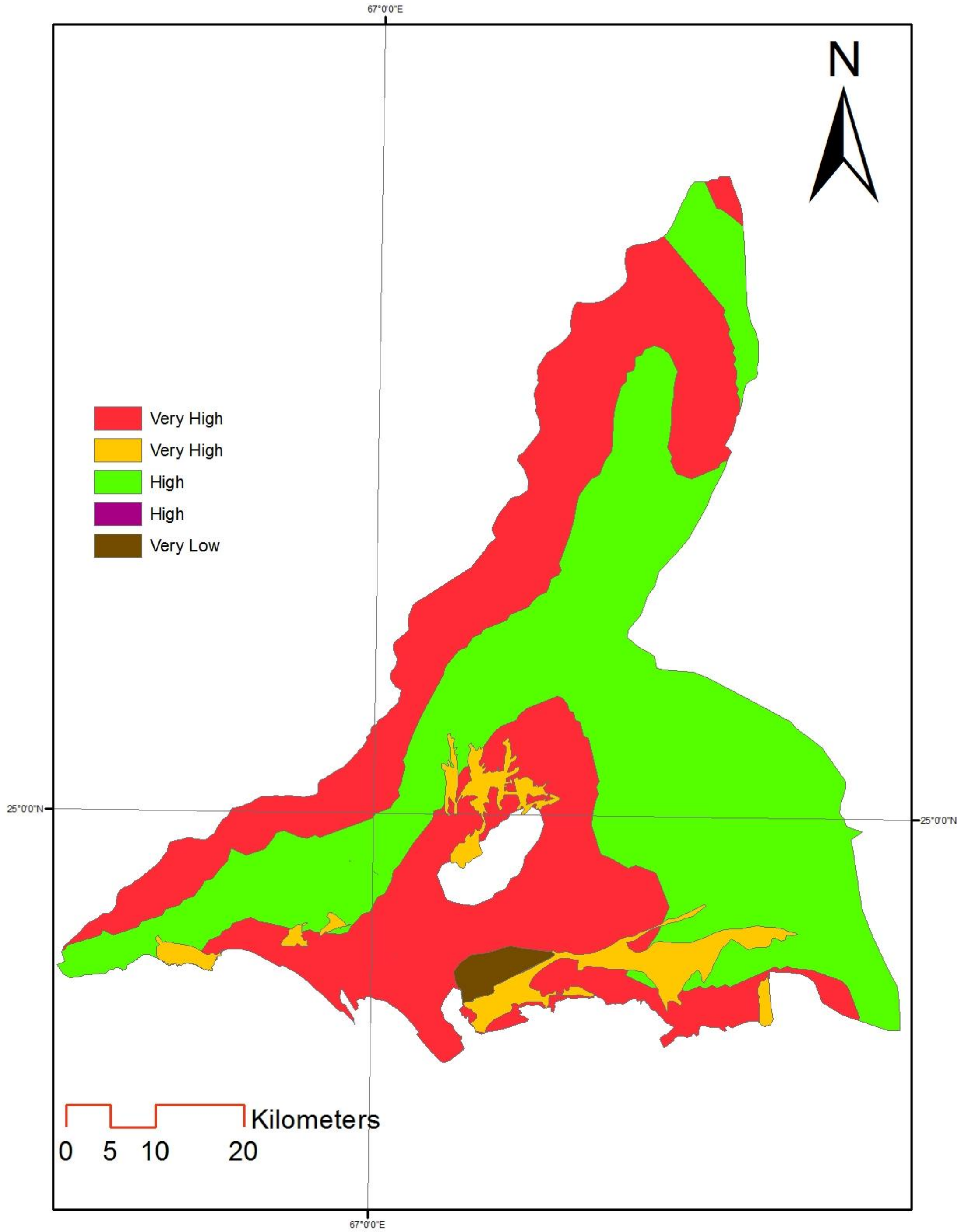


Figure 4. 10 Ranked map of Geological layer (Produced by author)

4.3.6 Elevation

Low lying areas tend to increase the vulnerability of Tsunami and flood disaster. Buildings, infrastructure, and the population located at higher elevation will have reduced effect against Tsunami waves or flood water. During 1945 Tsunami, few low lying areas along the coast of Keamari of Karachi were affected and inundated couple of compounds (Pararas-Carayannis, 2006). Past rainstorms has inundated low lying settled areas of Karachi, causing significant damage to life and property (Bakhsh et al. 2016, Paulikas& Rahman, 2015).

Digital Elevation Model (DEM) was created (Figure 4.11) by using SRTM data with acquisition date of year 2000 and resolution of 1 arc-second. The elevation values vary across many districts of Karachi between 0 and 535 meters. Highly populated districts such as west, south, central, and east has the lowest values indicating that most of the population lives in low lying areas. While, Malir district in north has the highest elevation with sparsely populated hilly areas.

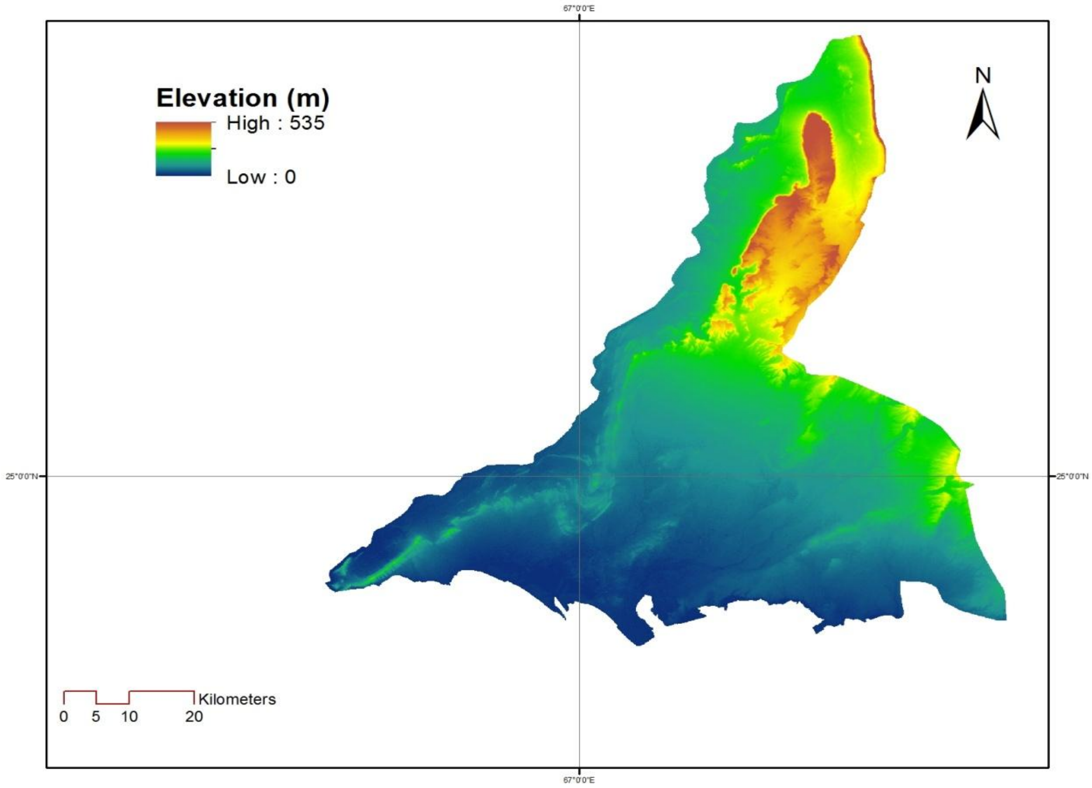


Figure 4. 11 Digital Elevation Model of Karachi (Produced by author)

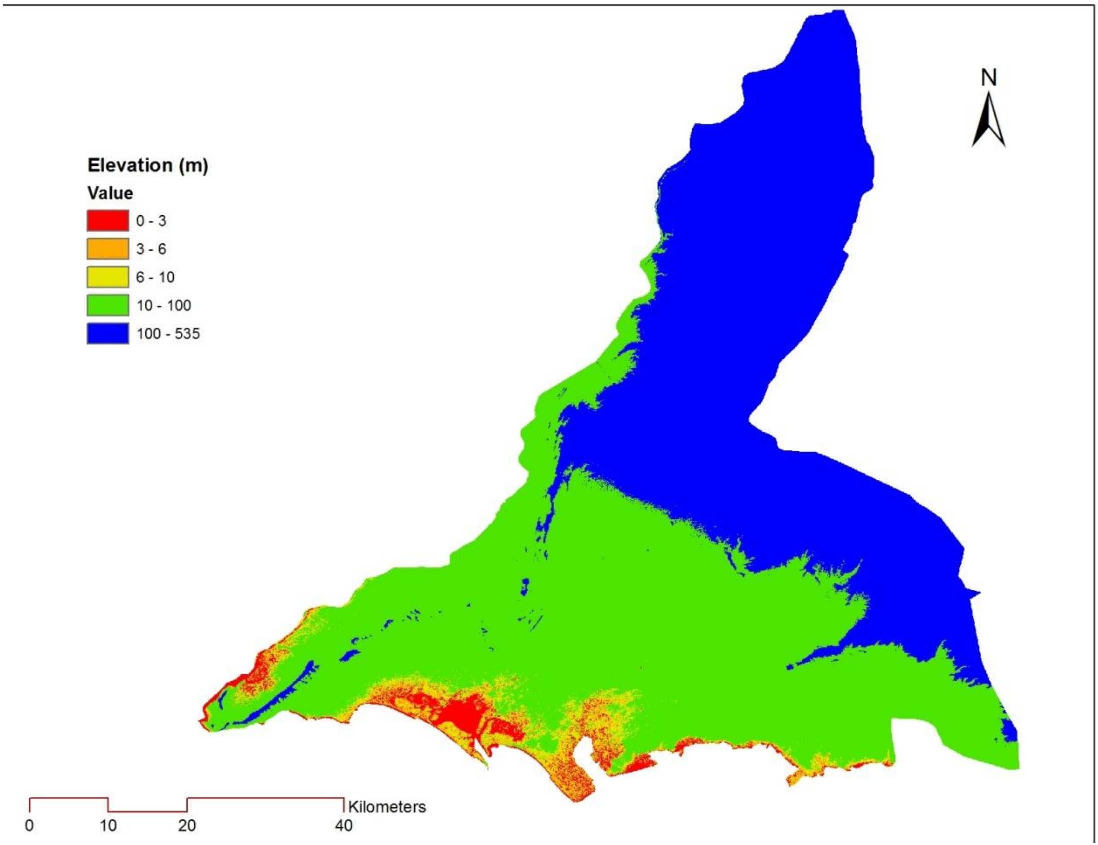


Figure 4. 12 Parameter map of elevation layer (Produced by author)

Karachi has elevation values ranging from 0 to 535, these values were classified and assigned values according to vulnerability level. Elevation values in Figure 4.12 show that coastal areas are at low elevation and would be at high risk of inundation due to tsunami or flooding while further away it gets steeper. Maximum elevation can reach over 500 meters in the northern part of Karachi which are very sparsely populated.

Table 4.5 Classification and ranking of elevation layer

Elevation		
Value in meter	**Rank**	**Vulnerability Level**
<2	10	Very High
2 – 4	8	Very High
4 - 6	6	High
6 – 8	3	Low
>8	1	Very Low

4.3.7 Past Tsunami Inundated areas

UNESCO's Indian Ocean Tsunami Information Center (IOTIC) website has several interviews with the survivors of great 1945 earthquake and Tsunami. Interviewees describe that sea level rose up and all area near the coast was inundated. One of the interviewee, Laal Mohammad, mentions of dead body found near Karachi mangroves while water inundation occurred as far as Jamaat Khana in Kharadar. Figure 4.13 shows areas of Jamat Khan which was inundated by sea water. It is likely that Tsunami water inundated through a water channel of Moosa Lane Nallah (MSL) flowing parallel to Kharadar area.

Figure 4. 13 Inundated area of Kharadar (in red) during 1945 Tsunami (Produced by author)

Other witness was quoted saying that half of the city was under water without specifying areas up to which water inundated. Another eyewitness, Haji Ismaeel who was around the age of 20 during Tsunami, said that Khadda market (Figure 4.14) was flooded and many people died while only few could survive.

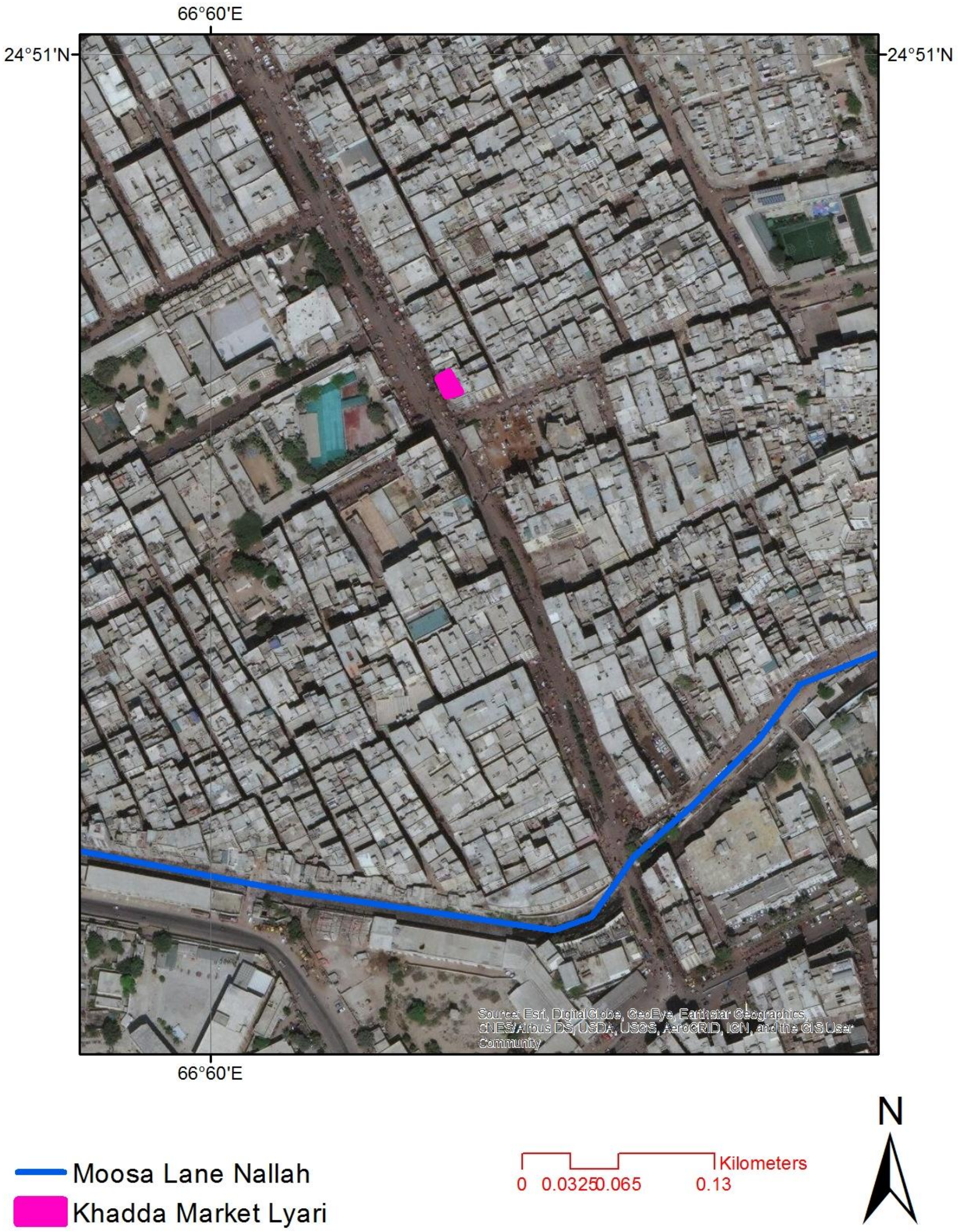


Figure 4. 14 Inundated area of Khadda Market during 1945 Tsunami (Produced by author)

With the inundation of Khadda Market of Lyari and Jamat Khana in Kharadar, while both areas are located deep inland it is safe to make a conclusion that Moosa Lane Nallah running between both areas carried sea water upstream and caused flooding in those areas (Figure 4.15).

Figure 4. 15 Inundated area of Karachi marked red and pink during 1945 Tsunami (Produced by author)

At the mouth of MSL exists the largest slum of Karachi, i.e. Machar Colony with over 3,000,000 inhabitants (Figure 4.16). It is possible that this whole area of Machar colony was inundated during the Tsunami. This colony only started populating during 1960s, whose one fourth is built on encroachment of mangroves. Most its residents are Bengalis who settled after 1971 and most of them do not right to health, education, and legal employment because of not having the citizenship of Pakistan. Colony lacks basic facilities, infrastructure, and sewerage which make it very vulnerable.

Figure 4. 16 Machar Colony location (Produced by author)

4.4 Hazard Vulnerability Analysis of Karachi

Parameters for hazard vulnerability analysis are divided as physical vulnerability and social vulnerability.

Physical vulnerability parameters include elevation, slope, fault proximity, vegetation, lithology, fire stations, chemical factories, nuclear power plant, weather, and traffic congestion. Moreover, social vulnerability parameters include population density, age, gender, level of education, gender inequality in education and jobs, health, minorities.

4.4.1 Tsunami Hazard Vulnerability Map

For Tsunami vulnerability at location, the methodology used by Tufekci et al. 2018 has been followed to most extent while the ranking and weights were assigned using Delphi method. Several parameters are used for that purpose including geology, elevation, distance from shore, past inundation, and population vulnerability. Each parameter was given a separate weight with distance from shore having the maximum weight of 30% while Geology and past inundation areas both having 20% each. Elevation had been given 10% weight while social vulnerability parameter of population density carries 20% weight. All the parameters were added in ARCMAP by using Weighted Overlay Method. Each given weight of the parameters was summed and reclassified to generate a Tsunami vulnerability map (Figure 4.17). Resulting map in Figure 4.18 show that most southern coast and south western parts of city are most vulnerable while central and southern areas of the city are significantly vulnerable because of several river flow from the city into the sea. During 1945 Tsunami, several parts of inner city were inundated with Tsunami water and caused several causalities.

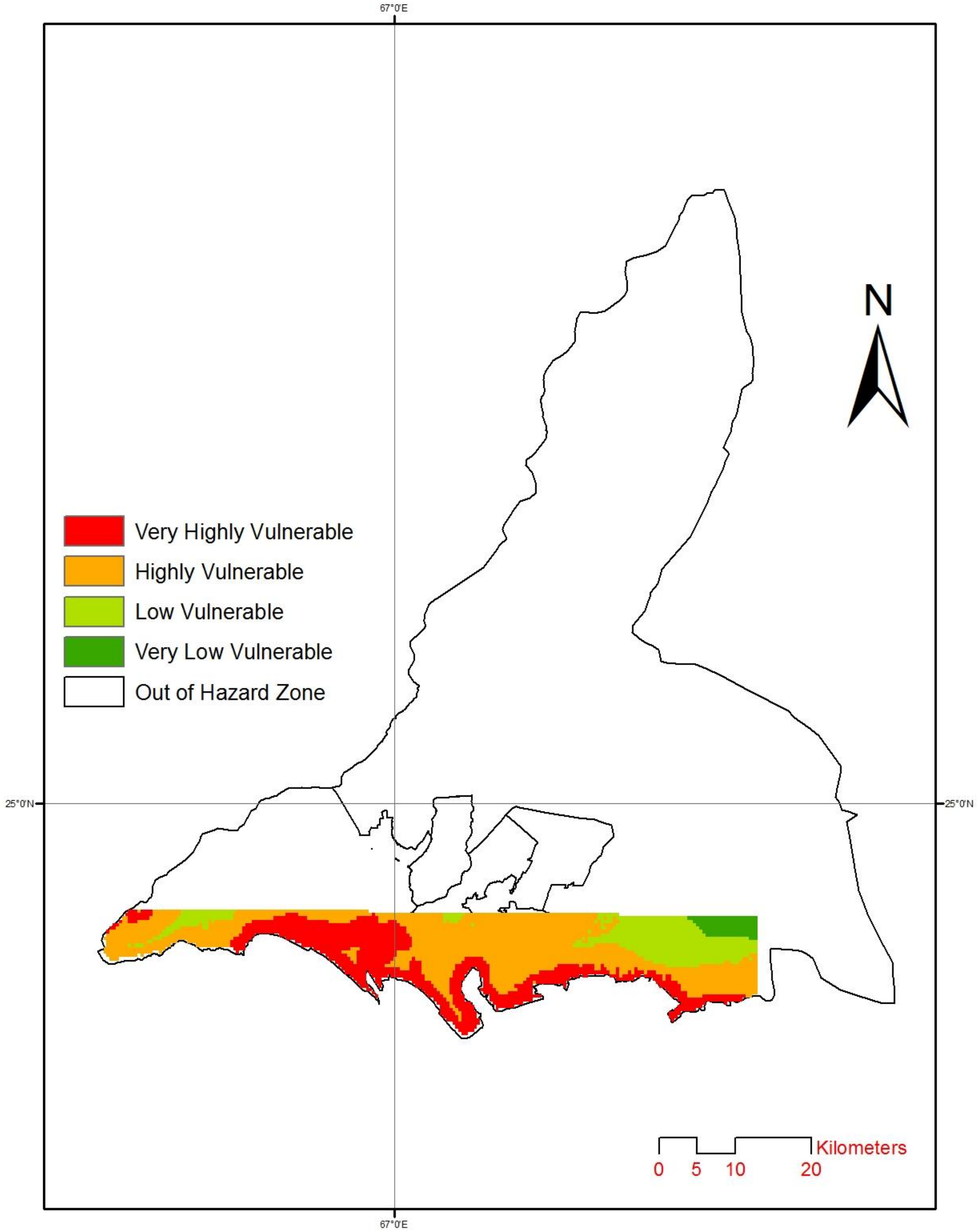


Figure 4. 17 Tsunami Risk Map of Karachi (Produced by author)

4.4.2 Earthquake Hazard Vulnerability Map

There are several studies for seismic hazard based on AHP and weights assigned to criteria based on expert opinion (Kaur et al., 2018; Nyimbili, 2018; and Nath, 2004). Those studies generally focused on seismic hazard vulnerabilities without taking any social vulnerability account. Earthquake hazard map vulnerability map of Karachi was prepared by taking into account geological as well as social factors with each factor having certain weight. Factors with given weight is as: Geology (40%), Peak Ground Acceleration (20%), elevation (10%), population density (15%), and number of household (15%). Central and Southern parts of Karachi have alluvial deposits with high population density and number of household, resulting in very high vulnerability for those areas (Figure 4.18). North and East of Karachi which are with very low population and household, and have got relatively stable geological formation have low vulnerability.

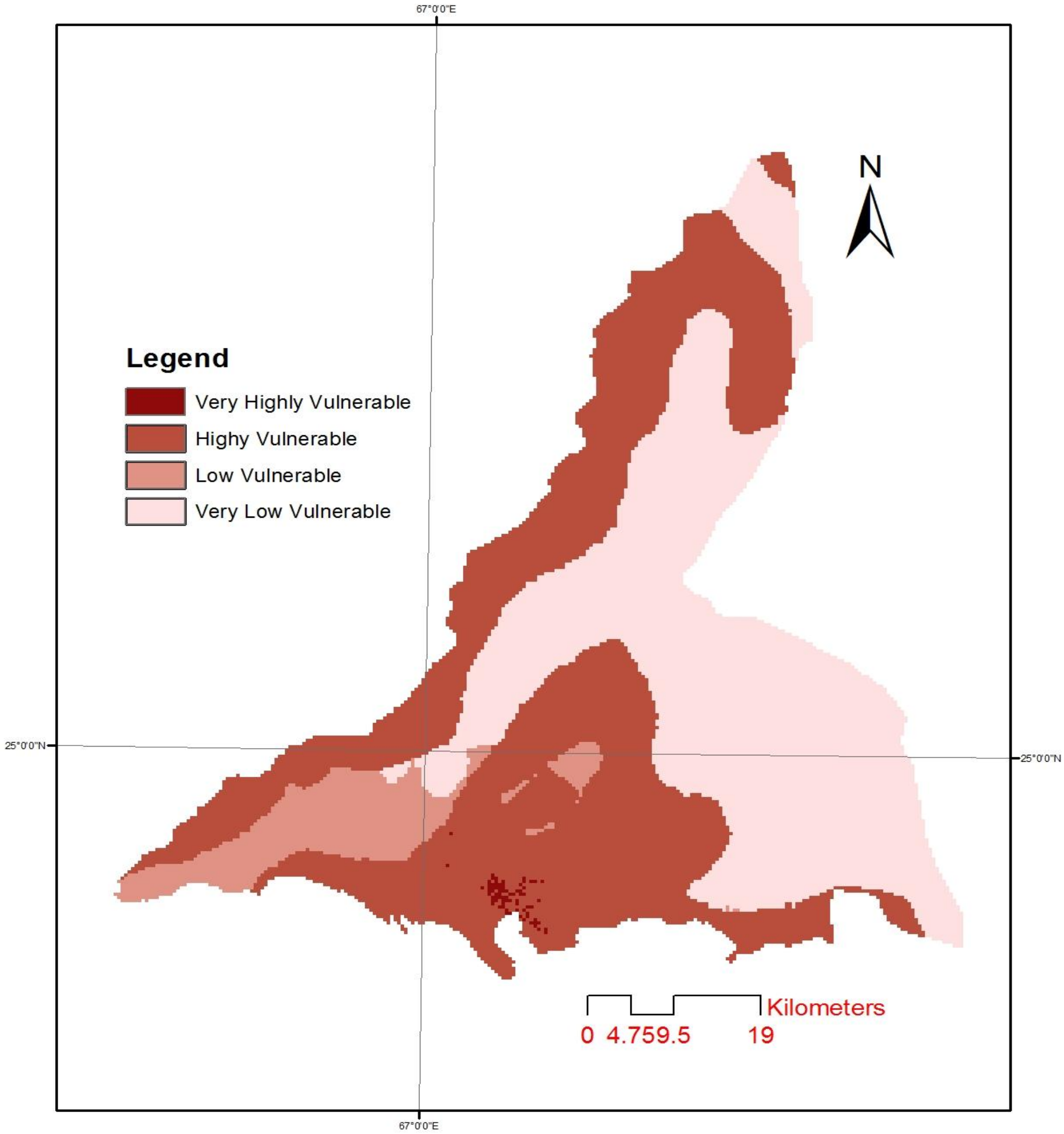


Figure 4. 18 Earthquake Hazard Map of Karachi (Produced by author)

4.4.3 Flood Hazard Vulnerability Map

In flood susceptibility mapping, weight of evidence method is being commonly used and many recent researches have implemented it (Hong et al., 2018; Shafapour Tehrany et al., 2017; and Tehrany et al., 2014). (Meyer et al., 2009) have used Multi-Attribute Utility Theory (MAUT) of MCDA which is based on assigning weights by decision maker (Velasquez & Hester, 2013).

However, for the purpose of flood hazard vulnerability, weights on each parameter were assigned with expert knowledge. Those parameters include both natural and social given as: Geology (30%), elevation (30%), flood frequency (20%), and population density (20%).

Obtained result puts most of district South and parts of district West, Korangi, and East with very high vulnerability. Almost all of the areas covered by aforementioned districts is highly vulnerable while other areas have low to very low vulnerability (Figure 4.19).The reason of these areas having vulnerability is because social factors such as population density is high while those areas had past flooding as well (flood frequency), both carry significant weight.

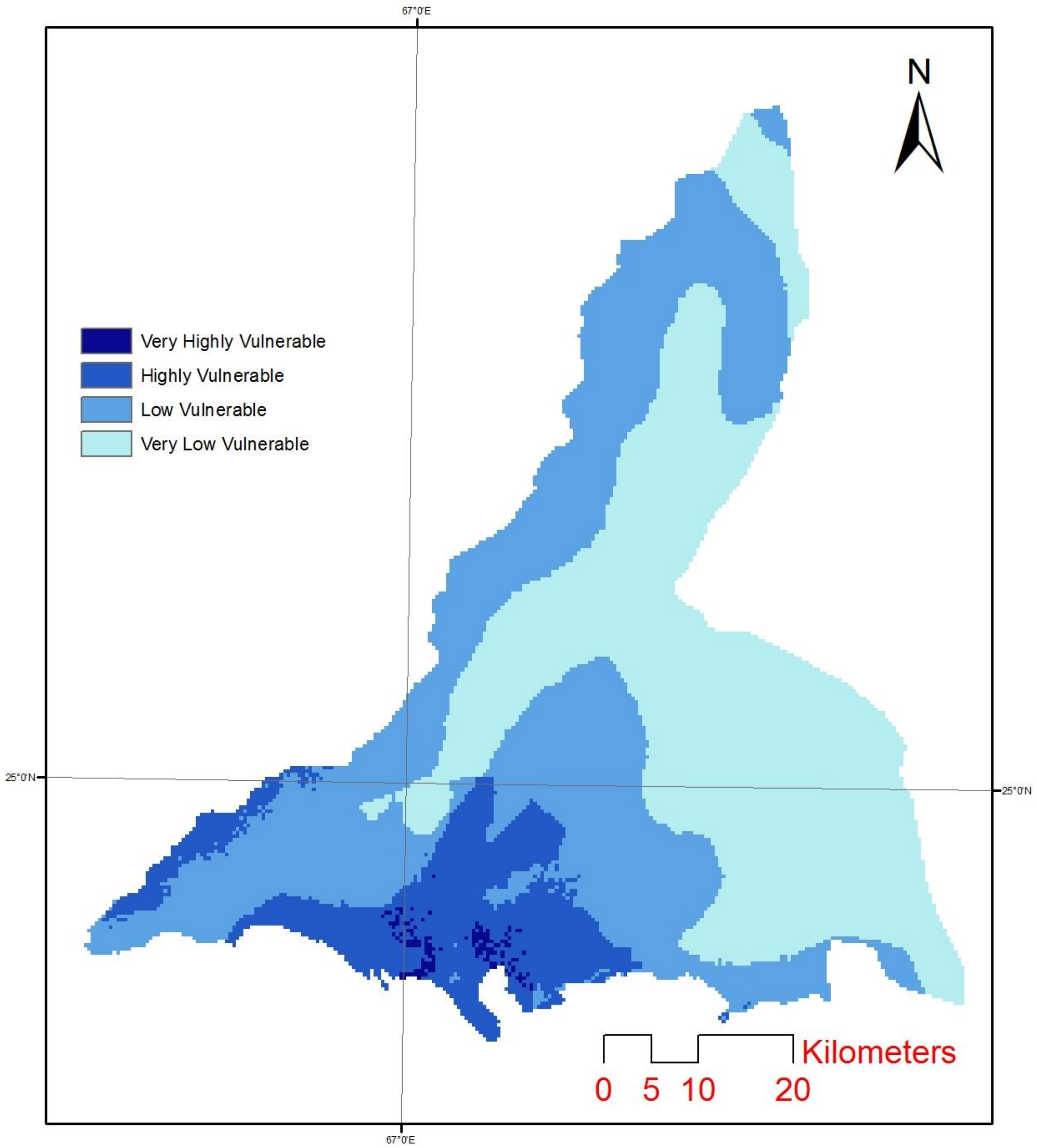


Figure 4. 19 Flood Hazard Map of Karachi (Produced by author)

Flood hazard map can be compared with flood event of 2009 which was mapped through a World Bank project (Figure 4.20). It can be seen that flood hazard map with very highly and highly vulnerable areas are extensively flooded during the flooding of 2009 in Karachi.

Figure 4. 20 Flooded areas of Karachi during 2009 flooding event mapped by World Bank Earth Observation for Sustainable Development | Data Catalog (2017, page 37. https://development-data-hub-s3-public.s3.amazonaws.com/ddhfiles/584086/eo4sd-urban_karachi_operations_report_v2-2_inclqc.pdf)

CHAPTER 5

DISCUSSION

Hazard vulnerability assessment is the core of disaster mitigation policy, strategies, and plans alongside emergency measures formulation. Current literature of vulnerability assessment takes various natural and technological hazards into consideration. However, there is no universal vulnerability assessment method which could be applied with great success in different spatio-temporal dimension. Varying socio-economic behaviors, trends, and growth cause added complexity in assessing vulnerability. Nevertheless, there are always some common factors and patterns in disasters of geographically and temporally different events. So, in order to mitigate, if not avoid, disaster it is useful to study and learn from spatially different past events. Further to this point, current study makes a comparison of hazards of Pakistan and Japan tried to assess vulnerability approach applied in each country. In case of Pakistan, we have considered the largest metropolitan city of country, i.e. Karachi. This is first of its kind, as there is no previous study which takes multi-hazard approach for such a large metropolitan city.

As it is known from the literature that Tohoku earthquake of 2011, triggered a Tsunami which inundated Fukushima Daiichi nuclear power plant with subsequent blasts resulting in release of radioactive material. This chain of disasters is inspiration to carry out further study – is particularly dangerous when it triggers a technological disaster. As technological disasters are sudden, they cause havoc and comparatively more damage because of surprise factor they bring, often leaving authorities and personnel off guarded. In case of Fukushima, the disaster was made worse because of unpreparedness of Japanese Government (Funabashi et al. 2012). Although technological disaster in Fukushima caused very few loss of life but had a significant impact on environment, ecology (marine and terrestrial), and agriculture. The deadliest event of Tohoku earthquake was the Tsunami which killed 15,641 while as many as 5,007 people missing (Moni et al., 2011).

Karachi faces both natural and technological disasters with a lot of similarity to Fukushima. Both are coastal cities with proven seismic activity and events such as earthquake and Tsunami. Both the cities are prone to cyclones and flooding with history of damages due to these disasters. They are also home to countries’ nuclear power plants with Karachi NPP being at very close proximity to densely populated city. In comparison to highly developed and institutionalized Japan, the coping capacity and lack of interdepartmental cooperation and cooperation drastically increases vulnerability of Karachi.

Literature related to risk and vulnerability assessment of Karachi is unusually scarce for a mega metropolitan. Also, non-availability of accurate digital data online by government agencies has been a big constraint to smoothly carryout this study. Hence, data was either obtained through open source platforms or digitized manually through long and cumbersome processes.

Data for metropolitan use was acquired through Open Street Map (OSM), while DEM was created by acquiring and processing SRTM images of Karachi through USGS database portal. Geological map was digitized manually by taking reference data of USGS and through some literature available online. Past earthquakes data was acquired through USGS earthquake catalogue page and was processed to create inventory of past earthquakes. For social vulnerability part, data was collected from PBS, UN portals, or private entities including World Bank etc. Several thematic maps such as population map, population density map, level of education, labor etc were created and then used in as input for socio-economic layer in ArcGIS to calculate overall hazard vulnerability.

Each layer and disaster was ranked according to the opinion of experts in the field. Vulnerability assessments are evaluated through multi-criteria decision analysis in GIS environment. For each hazard map, different natural and social parameters were taken into account such as; geology, elevation, distance from shoreline, population density, number of households etc. Parameters were assigned different weight for each hazard vulnerability maps.

For Tsunami vulnerability map maximum weight of 30% while Geology and past inundation areas both having 20% each. Elevation had been given 10% weight while social vulnerability parameter of population density carries 20% weight.

For Tsunami vulnerability map, physical and social parameters with their assigned weights are given as; distance from shore (30%), geology (20%), past inundation (20%), elevation (10%), and population density (20%).Resulting map reveals that areas in south and west of the city pose highest vulnerability. That is because of the fact that those areas are near the shore and had been inundated in past, also they possess high population density as well. Geology, which is assigned 20% weight, also has added role in Tsunami vulnerability as most of very highly vulnerable areas are on alluvial deposits. There is a careful assumption about past inundated areas that Machar Colony of district West, currently with over half a million populations, had no population during 1945 Tsunami and was inundated at that time. It is because of the fact that areas further inland from Machar Colony and as far as Khadda market in Lyari and Jamat Khana in Kharadar, were inundated during the Tsunami. Both the areas are in fact hundreds of meters away from the coast. Most likely scenario is that Tsunami water traveled through a water channel, namely Moosa Lane Nallah (MSL) and caused inundation on both sides of MSL. An illegal slum, Machar colony, along the coast and adjacent to MSL which had no one living during 1945 Tsunami but it is assumed that if areas further away were inundated then Machar colony had higher level of inundation during that Tsunami. This slum area has very high population density and most of the people do not posses legal land ownership. It started inhabiting only after 1960, which now has over half million people living, many are Bengalis and Burmese who do not have rights as other people in the city. This makes it highly vulnerable both socially and in terms of natural hazards.

For earthquakes there have been constraints in availability of data or hazard maps for Karachi in literature and on national agencies website or publication. Although Building Code of Pakistan categorizes Karachi at significant seismic danger and pga value of 0.25 g, but the lack of hazard mapping is a rare case for such a large city. In order to create a nascent earthquake hazard vulnerability map, several parameters were considered. Each parameter was assigned as: geology (40%), Peak Ground

Acceleration (20%), elevation (10%), population density (15%), and number of household (15%). Final hazard vulnerability shows that areas in district South and Central are likely to turn into disaster in case of a hazard, as both the districts posses very high vulnerability. In addition to that, parts of district West, East and Korangi have high vulnerability and are of serious concern. Major factor in driving vulnerability high is mostly because of the geology and the social factors such as population density and number of households. Areas with high population density, number of household which lie on lose alluvial deposits tend to show higher vulnerabilities. In case of district Malir which has lowest population density and number of household while of the district sits on non-alluvial deposits, show very low or low vulnerability.

Flooding is the most frequent natural hazards for Karachi which generally tend to be localized phenomenon within city which at times become city wide disaster. Most of the flooding occurs after short and heavy spell of rainfall as city's drainage gets choked. Such rain-triggered flash flooding is common and more frequent as there is no mechanism for early warning of such hazard in the city. Like any other coastal city, Karachi also faces tropical storm and storm surges, although not very frequent but very damaging. People who are socially vulnerable and economically not well off and living in slum areas, tend to be far more affected by flooding than those living in proper and well of neighborhoods and buildings in the city.

For flood hazard vulnerability mapping of Karachi includes both social and natural parameters with varying weights as: geology (30%), elevation (30%), flood frequency (20%), and population density (20%).

Obtained hazard vulnerability map puts most of the district South and parts of district West, Korangi, and East with very high vulnerability. Areas with very high vulnerability have very high population density, low elevation, and high flood frequency. However, most parts of district West and Malir have low or very low vulnerability; these are the areas with very low population density, low flood frequency, and higher elevation. Flood hazard vulnerability map of this study could be compared to a World Bank project (2017) which mapped the areas of Karachi flooded during 2009 events, the comparison reflects significant level of accuracy of our obtained map.

Lastly, I would like to summarize through Table 5.1, the original ideas about what I wanted to achieve at the beginning of this study, what I actually could achieve and what I could not achieve.

Risk assessment is a very broad term and to realize it in full sense for a metropolitan like Karachi needed much more data than it was made available. For technical hazards, such as nuclear, without the cooperation of relevant authorities it would lack authenticity and accuracy. While for a district-wise multi-hazard risk assessment, very detailed and quality data alongside field trips to verify, especially social data, would be necessary.

Table 5.1 List of initial aims of the study, the aims achieved, and the aims could not be realized

Wanted to achieve	**Could achieve**	**Could not achieve**
Tsunami Risk Assessment	Tsunami Hazard Vulnerability Assessment	Hazard Risk Assessment of Tsunami, Earthquake, Flood, Nuclear
Earthquake Risk Assessment	Earthquake Hazard Vulnerability Assessment	District-wise comprehensive multi-hazard risk assessment for Karachi
Flood Risk Assessment	Flood Hazard Vulnerability Assessment	
Nuclear Hazard Risk Assessment		
District-wise comprehensive multi-hazard risk assessment for Karachi		

CHAPTER 6

CONCLUSION, LIMITATIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

The aim of this research has been to carry out multi-hazard vulnerability assessment using GIS for Karachi metropolitan and comparing it with similar hazard assessment successfully implemented to minimize disasters in Japan. The type of study is unique for the city whose population of about 25 million is vulnerable to many hazards, both geophysical and climate-related. Damaging impacts of 2011 Tohoku earthquake were investigated alongside its recovery performance.

It is pertinent to stress that primary aim of this work is to attempt to create vulnerability maps considering various hazards for the city of Karachi in GIS-based environment with little basic data available to accurately create such maps. Due to data limitations, the analysis heavily relies on expert opinion and historical data (Van Westen et al. 2002). Because of that several assumptions and simplifications had to be made during the analysis. As this is first such effort, the accuracy of vulnerability maps would be better judged only when another similar study is carried out with high quality data at better scales, until such comparative study is carried out these maps should be considered with caution. When we compare Flood Hazard map (Figure 4.19) against the mapping of flooded area during 2009 flooding event (Figure 4.20), we see that our flood hazard map has significant level of accuracy in mapping the flood prone areas. In Tsunami vulnerability assessment, more emphasize should be given on Tsunami modeling and simulation of 1945 Tsunami considering the river streams which flow from densely populated areas to the sea. As historical record suggest that 1945 tsunami inundated several areas along Moosa Lane Nallah, it would be interesting to know by simulation that how much population would be affected by same tsunami events with current demographics.

The results of the study are explained comprehensively in terms of remarks listed below.

Karachi has faced at least one large and recorded Tsunami in 1945 while historical records reveal occurrence of several Tsunamis with varying intensity and damages in the past. There is also significant risk of earthquakes as city lies close to active faults. The main onshore fault of Ornach Nal is located just 130 km west of the city, while offshore faults lie in Makran Subduction Zone off the coast of Karachi. City also has the chronic problem of urban flood which is generally caused by heavy burst of monsoon rains and also during the storm surges which always disrupt city life and cause loss of life.

Hazard vulnerability which was carried by using multi-criteria decision analysis (MCDA) resulted in different maps for each hazards, namely, tsunami, earthquake, and flooding. Tsunami hazard vulnerability shows that areas near the shore with high population density are potentially at grave danger. Areas which are at high risk mostly present in district South and the West. Parts of both the districts had evidently been inundated during 1945 Makran Tsunami and killed many people in respective areas and were assigned higher weights because of past inundation. Machar Colony, a large slum, in district West is very highly vulnerable in case of a Tsunami and needs an immediate safeguard to be resilient to Tsunami hazard. This slum area has very high population density and most of the people do not possess legal land ownership. It started inhabiting only after 1960, which now has over half million people living, many are Bengalis and Burmese who do not have rights as other people in the city. This makes it highly vulnerable both socially and in terms of natural hazards. It is likely that in case of potential Tsunami, past inundated areas posses very high vulnerability and with its current state, it is an obvious disaster area proper measures need to be taken immediately to protect them.

Earthquake vulnerability map, however, shows that most of the areas in center and south of the city are vulnerable. It includes districts Center, East, South, Korangi and parts of district West which have high to very high vulnerability to earthquakes. It is because three parameter, namely geology, population density, and number of households carry significant weight in earthquake vulnerability mapping. As aforementioned districts lie on alluvial deposits with very high population density and number of households, it results in higher vulnerability for those areas.

Lastly, flood hazard vulnerability map indentifies district east, central, west, and parts of Korangi having high to very high vulnerability to flooding. These are generally the areas which are frequently hit with floods, posses' low altitude and high population density which alongside geology parameter were assigned more weight. Also, two rivers, namely Malir and Lyari, pass through these districts and have the potential to overflow during rainfall which may severely inundation, stranding most of the city population.

The limitations and constraints faced during this study are as below:

- This study was started with very high expectations in terms of realizing multi-hazard risk assessment but ended up with only hazards vulnerability due to constraints.

- Most maps and data being which could be essential in assessing both natural and technological hazards is considered classified and is not allowed to be shared with other entities or person.

- Non-availability or lack of identification of employee of local government having understanding of hazards who would contribute his opinion in hazard parameter selection and weight.

The recommendations for future studies, which can be considered in hazard vulnerability of Karachi, are listed below:

- Detailed geological map of the Karachi should be made available in digital format online, which shall help greatly in hazard mapping of the city.
- Tsunami simulation can be carried out to better understand level of potential inundation and run-off, which is likely to improve Tsunami vulnerability mapping.
- Building inventory, which shall include age, durability, number of storey, and construction type, should help estimate buildings vulnerable to earthquakes.
- Vector map of electric transmission lines should be obtained and used in flood vulnerability mapping as during monsoon rain and flooding, most people die because of electrocution.

- Inventory of flood hazards at town/sector level should be recorded and utilized to improve flood vulnerability.
- Accurate data of slums related to population and household should be acquired as these areas are the most vulnerable to hazards because of the socio-economic component.
- For resilience purpose, survey of hazard awareness and preparedness can be carried out with a questionnaire to public and responsible institutes.
- Presence of one Nuclear Power Plant and completion of two more units in near future should be intriguing for a region with an active subduction zone and proven history of tsunami. Any nuclear hazard risk assessment, by taking relevant authorities in confidence, should be of significant importance.

Because of several limitations, resulting vulnerability scores are only indicative and should not be considered as absolute vulnerability score. However, these vulnerability values do show the relative importance and trend of each type of hazard with likely to have certain degree of impact.

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