PROBABLISTIC ESTIMATION OF EARTHQUAKE INTENSITY AND DESIGN OF EARTHQUAKE EARLY WARNING SYSTEM

FINAL YEAR PROJECT UG 2012

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This is to certify that the

Final Year Project titled

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submitted by

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has been accepted towards the requirements
for the undergraduate degree

in

CIVIL ENGINEERING

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ABSTRACT

PROBABLISTIC ESTIMATION OF EARTHQUAKE INTENSITY AND DESIGN OF EARTHQUAKE EARLY WARNING SYSTEM

The project focuses on estimating the intensity of earthquake by analyzing previous available seismic data of maximum annual intensity of earthquake recorded on Richter scale and designing an earthquake early warning system. The data is analyzed for the various seismically active zones of Pakistan which is located at almost the juncture of Indian and Eurasian tectonic plates. The results are derived based on the assumption that the natural hazards such as earthquake follow a fixed pattern and are based on the probabilistic seismic hazard theory. The Gaussian transformation and Pearson Type III distributions were used for the analysis of data. The results are plotted on log probability paper. This research provides sound basis for designing an earthquake early warning system for seismically active areas of Pakistan. The study contributes to mitigation of earthquake risk and the pre earthquake effective and economical design of mega structures and skyscrapers.

DEDICATION

This project is dedicated to all the people of Pakistan who have lost their valuable lives due to earthquakes. It is an earnest effort to pay a tribute to them by utilizing and implementing such techniques which could mitigate the losses caused by earthquakes. This research is to make sure that their losses never go in vain and such incidents could never get repeated.

ACKNOWLEDGEMENTS

We would like to express our deepest gratitude to all those people who have extended their assistance for the success of this project. It wouldn’t have become possible without the help of many individuals and instructors.

We are thankful to our supervisor, Dr. Syed Ali Rizwan for his support, guidance, advices, valuable comments, words of encouragement, suggestions and valuable provisions that benefited us in the completion of this study. We would like to extend our gratitude to all the faculty members of NUST for their continuous support and encouragement.

In the end we would like to thank Pakistan Meteorological Department (PMD) for cooperating with us throughout the project and providing us useful data needed in the accomplishment of this project.

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ABBREVIATIONS

ARE	Annual Rate of Exceedance
JMF	Japanese Meteorological Agency
OCHA	Office for the Coordination of Humanitarian Affairs
SUPARCO	Pakistan Space and Upper Atmosphere Research Commission
KPK	Khyber Pukhtoonkhwa
PDMA	Provincial Disaster Management Authority
SDMA	State Disaster Management Authority
GBDMA	Gilgit Baltistan Disaster Management Authority
URM	Unreinforced Masonry
PMD	Pakistan Meteorological department
IRIS	Incorporated Research Institutions for Seismology
WMO	World Meteorological Organization
USGS	United States Geological Survey
ISC	International Seismological Centre
IASPEI	International Association of Seismology and Physics of Earth Interior
SNR	Signal-to-noise ratio
Mw	Moment Magnitude
Mb	Body wave Magnitude

Ms	Surface wave Magnitude
m	Maximum Magnitude
g	Skew coefficient
k	Frequency factor
P_n	Probability of Exceedance
WWSSN	World Wide Standard Seismogram Network
NDMA	National Disaster Management Authority
EEW	Earthquake Early Warning System
CISN	California Integrated Seismic Network

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Pakistan makes it to the list of most seismically active countries of the world. According to estimation, 2/3rd of Pakistan is considered being resting on fault lines. Pakistan's each one of the four provinces is vulnerable to earthquake that can occur anytime in this area of high plate activity. Chaman Fault line grips the south west of the country and plate activity in Hindu kush looms over the north, North West and capital of the country. Additionally, there also exist four faults in and nearby Karachi and other parts of deltaic Indus and Makran coast.

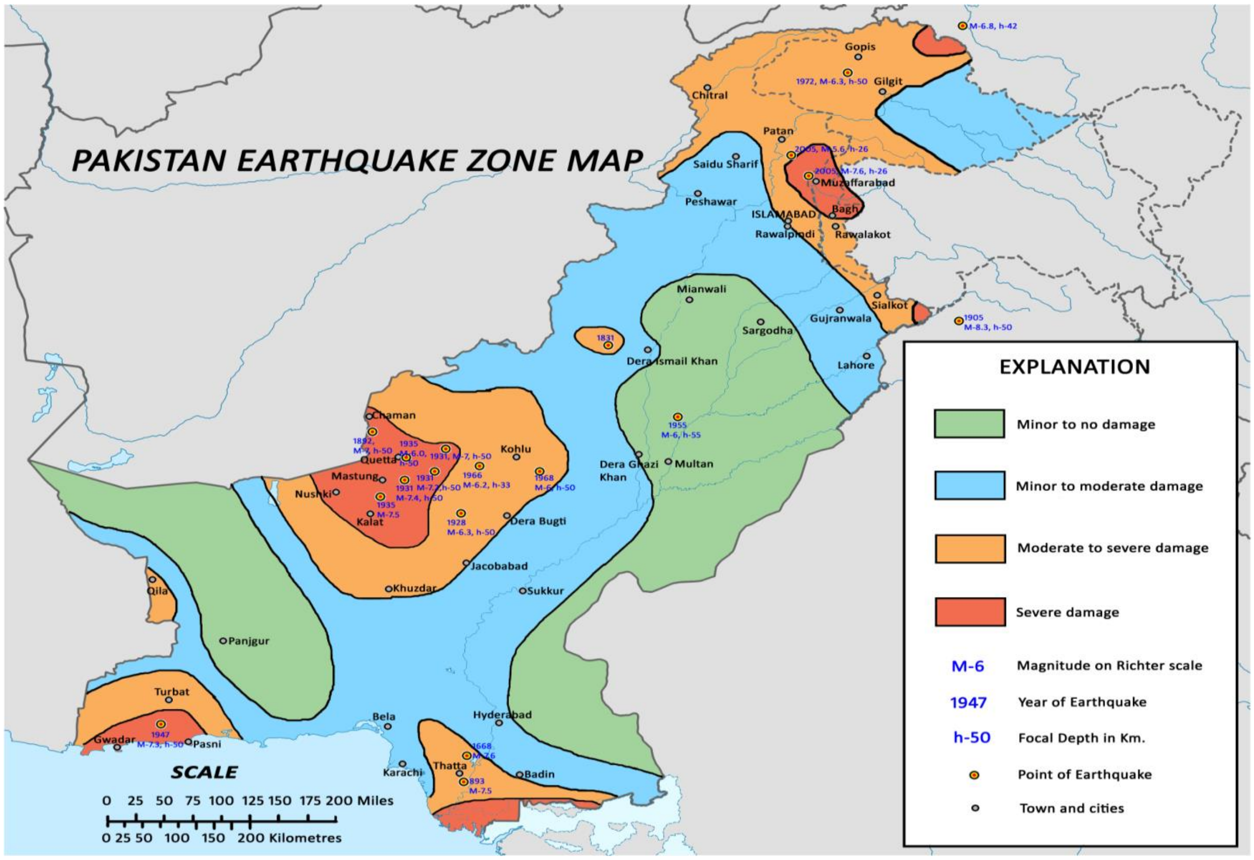

Figure 1.1 Earthquake Hazard zones in Pakistan (Wikipedia, 2011)

Figure 1.1 sheds light on the hazards zones in Pakistan. Figure explicitly envisages the fact that approximately more than 60% of the country is prone to damage caused by earthquakes.

Several deadliest earthquakes have hit Pakistan causing numerous casualties, capping economic activities, damaging and destroying infrastructure and utility services in the affected area. For instance, an earthquake of magnitude 7.5 jolted major cities of Pakistan in October, 2015 leaving more than 200 dead and number exceeding 1000 as injured. The epicenter was reported to be Hindu Kush mountain range as shown in the figure below.

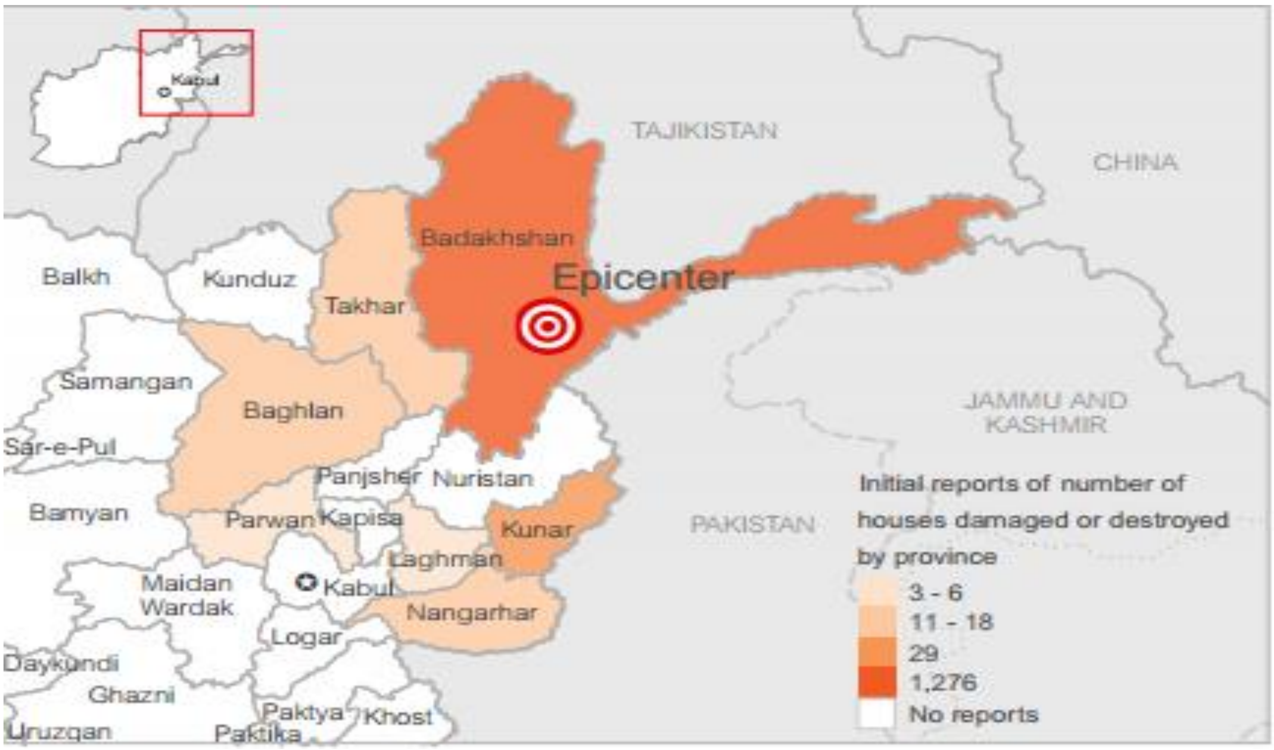

Figure 1.2 Epicenter of the Badakhshan Earthquake (OCHA)

Similarly, a violent and ruthless 7.7 magnitude shook Baluchistan, a province in south west of Pakistan, on 24 September, 2013 leaving more than 217 people dead, more than 350 people injured and affecting 30000 families. Its epicenter was 120 kilometers south-west of Khuzdar District, at a depth of 10 kilometers (Figure 1.3). In addition to that, a 7.6 magnitude hit Pakistan on 8th October, 2005 killing more than 73000, injuring more than 128000 and leaving around 3.5 million people homeless.

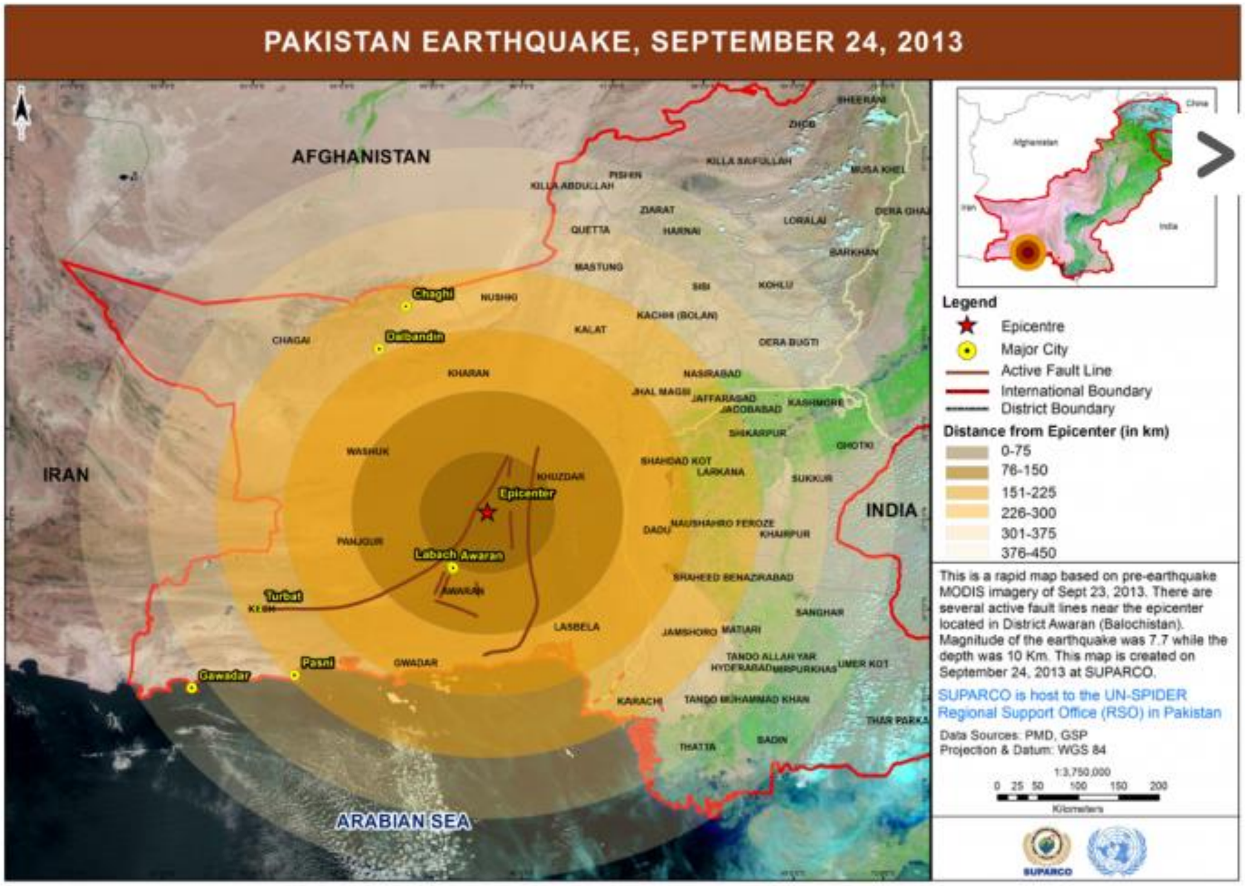

Figure 1.3 Epicenter of Baluchistan, 2013 (SUPARCO)

Recent activation of Hindu Kush fault line and the propagation of few very deadliest earthquakes from it which caused hundreds of casualties across Pakistan and neighboring countries have created ripples across the country and a fear exists that earthquakes can occur in future from the Hindu Kush mountain ranges affecting Pakistan and Afghanistan.

Traditionally, the buildings designed in Pakistan solely base upon gravity loads and a very meager development has been made to strengthen the buildings seismically. If the buildings are designed and constructed keeping in view the earthquake intensity in the area that can occur, the cost can be considerably reduced vis-à-vis saving hundreds of human lives could be made possible.

1.2 Problem Statement

The study focuses on calculating the probability of occurrence of an earthquake of certain magnitude in a particular area, and designing an early warning system based on the graphs plotted with respect to the distance from epicenter. To start with, 4 areas have been chosen which include areas with high number of earthquakes in the past, the areas that are most vulnerable and big cities of the country. The areas include Muzaffarabad, Peshawar, Islamabad and Quetta.

Observing the trends from the past earthquakes, poor construction techniques and inadequate design have added to the losses caused by these earthquakes. High number of deaths has been reported in less developed, backward areas with poor designs. A few preliminary losses/ damages have been shown in Figure 1.4.

PRELIMINARY LOSSES / DAMAGES EARTHQUAKE 2015

	INJURED	DEATHS	HOUSES DAMAGED
Khyber Pakhtunkhwa	1,486 (89.4%)	202 (81.4%)	3,952 (89.9%)
Gilgit Baltistan	30 (1.8%)	9 (3.5%)	90 (3.6%)
Punjab	78 (4.6%)	5 (2.2%)	44 (1.7%)
Azad Jammu & Kashmir	12 (0.7%)	2 (0.8%)	6 (0.2%)
FATA	59 (3.6%)	30 (13.2%)	300 (11.9%)
Sindh	0	0	-
Balochistan	0	0	-
	1,665	248	4,392

Figure 1.4 Preliminary Losses/ Damages in Pakistan due to Earthquakes in 2015 (PDMA, SDMA & GBDMA)

After the 7.6 magnitude earthquake that hit northern region of Pakistan in 2005, 73000 people lost their lives, 128000 were injured. It is estimated that in Muzaffarabad, 30-50% of the buildings were either destroyed or badly damaged in the main event. Most of the buildings in those areas are of non-engineered unreinforced masonry (URM) wall construction.

The study would enable engineers and designers to design structures that would withstand the earthquake expected in that particular area. Figure 1.5 shows the poor state of un-engineered wall after the devastating earthquake of 2013 in Baluchistan. Thousands of people have lost their lives owing to the collapse of buildings.


Figure 1.5 The Collapsed Weak Wall After the Earthquake (OCHA)

The study would also cap the economic losses that incur to Pakistan due to the earthquake. The earthquake of 2005 caused Pakistan a loss of around $5.2 billion. Similarly, a large portion of country's money is wasted in overdesigning structures where they are not needed. The study would help to reduce such wastage of money and resources by predicting the probability of occurrence of an earthquake of certain magnitude in a particular area.

Earthquakes catch people by shock. And earthquakes prove to be more destructive when people are not prepared for the menace. An early warning system aims at warning the dwellers of a particular area when a rupture starts and resulting in providing general population the time to evacuate to a safer place.

Prediction of probability of occurrence of an earthquake of certain magnitude in a particular area together with designing an early warning system would subsequently result in reducing loss of human lives, providing the people with tens of seconds before they feel the shocks, lesser financial losses, minimizing wastage of money and protection of utility services in a country.

1.3 Significance of Study

The research is a significant and a pioneer step for providing safety to dwellers, saving cost of construction and possible positive contributor to the economy of the country. Study of probabilistic estimation of earthquake intensity and design of an early warning system using that probability has never been carried out in Pakistan. Results obtained through this research will greatly help in reducing casualties during an earthquake by preparing the designers for the earthquake their buildings might encounter in the most vulnerable areas, metropolitans and big cities. Similarly, harm to human lives will also reduce by warning people in the locus of an earthquake using an alarming system, allowing them to evacuate to a safer area. This in turn will save cost of over designing structures and help economy of the country grow by minimizing economic aspect of earthquake losses. This will also prove to be helpful in designing of high funding projects like dams, barrages, bridges and nuclear plants.

1.4 Scope and Limitations

Earthquakes have caused severe damages in Pakistan in the last few years. Starting from the devastated earthquake of Muzaffarabad in October 2005, Pakistan has faced a number for earthquakes that shook it seriously, claiming hundreds of lives and posing a major threat to the economy of Pakistan. The destruction due to earthquakes needs to be minimized. This study of Probabilistic estimation of earthquake intensity and design of an early warning system for the seismically active and densely populated areas of Pakistan provides a firm ground for the design of a system for the mitigation of losses caused by severe earthquakes. However the limitation is the unavailability of useful historical data. For the purpose of study and carrying out the necessary analysis, earthquake occurrence data of past 40 years has been used obtained from Pakistan Meteorological department (PMD) and Incorporated Research Institutions for Seismology (IRIS). The soil profile of the areas under study is unknown therefore the speed of body waves is assumed uniform and taken as average. Further study in this regard is needed to improve the accuracy of results and design of more efficient system.

1.5 Salient Features of Study

The study of carrying out probabilistic estimate of earthquake intensity for a demarked area and laying out an early warning system for it stands to be of greater significance in a country of vulnerable economy. The study would accompany following benefits:

- First and most important of all it would allow people living or working in vulnerable places to evacuate to a safer one by providing time in tens of seconds. This would result in protection of precious human lives.
- Secondly, an easy-to-understand graph would allow designers in a particular area to get probability of earthquake in that area with respect to time. This means they can have earthquake's probability during the course of life of structures. This is particularly useful for sensitive sites such as nuclear plants, bridges and barrages. For example, Fukushima Daiichi Nuclear Power Plant was destroyed by the Tsunami caused by 9.0 magnitude earthquake in Japan in 2011.
- This study would also lead to cost saving by discouraging designers to overdesign an earthquake resistant structure in an area which is not supposed to encounter earthquake which would cause impact on buildings. Cost saving is the most influential driving force affecting construction techniques and materials being used in subsequent construction of structures.
- The drawing of graph would save engineers and designers from carrying long, time consuming calculations leading to time saving.

CHAPTER 2

LITERATURE REVIEW

2.1 Lee, W. H. K., Shin, T. C., & Teng, T. L. (1996, June). Design and implementation of earthquake early warning systems in Taiwan. In Proc. 11th World Conference on Earthquake Engineering, Acapulco, Mexico.

An earthquake early warning system has the capacity for the quickest return of benefit to the society. Such a system can minimize loss to property and lives, provide critical information regarding direct rescue operations and to prepare for retrieval from earthquake damage. This earthquake early warning system can estimate the maximum expected ground motion caused by an earthquake so that emergency quick response teams can be deployed where they needed most. Because such type of a system monitors earthquake in real time and information on the earthquake sequence will be readily available while the events are in progress. The physical principle of an earthquake early warning system is very simple, as strong ground motion caused by shear (S) waves. Seismic waves travelling speed is lower than electromagnetic waves. The seismic wave velocities P-waves and S-waves have been taken as 6km/s and 3km/s respectively. If an earthquake is located at 100 km away from the city, the P-wave reaches in the city at about 17 seconds and S-wave at about 29 seconds. If a dense seismic network in the earthquake source area that has a capability of locating and determining the size of the event in about 10 seconds is deployed, then it will take about 5 seconds to issue a warning before the P-wave arrives, and have almost 17 seconds before the most destructive S-waves and surface waves arrive at the city. Here the assumption is that it takes very little time of about 2 seconds to send a signal from a seismic network to the city.

This above mentioned earthquake early warning system study has been conducted in Taiwan. We recommend similar quake early warning system on the grounds of the analysis which has been done to figure it out that which areas are more prone to earthquake hazards. So this research paper has played a significant role in the 2^{nd} part of the project which relates to the recommendations.

2.2 Application of probability theory in the Earthquake Risk Assessment and its consequent possible reduction by Rizwan, S. A., khan, Muhammad A., Debaj

Analysis of available previous seismic data related to maximum annual intensity of earthquakes on Richter scale for an area of Cholen situated in Baluchistan has been done in this research paper. The objective of this study was to project this analysis to know future earthquakes intensity and return period required for making decision regarding the design of lifeline systems and other structures. Earthquake is a natural hazard and it follows an almost fixed cycle like other natural hazards which provide the grounds for its suitability for analysis by using normal or Gaussian distribution and specially Pearson's type III distribution. This concept got its support by seismic gap theory according to which big earthquakes are generated due to tectonic movements and follows a cycle. The results of analysis are plotted on log probability paper which contains very useful information required for the decision making for design of the lifeline supported systems and other structure and also it brings safety and economy in design.

We took an idea from this study for our project and select the potential cities of Pakistan which are Islamabad, Peshawar, Quetta and Muzaffarabad. This analysis of available previous seismic data covered part I of our project which relates to the probabilistic earthquake estimation and followed by the part II which is recommendations for that particular area.

2.3 Böse, M., Allen, R., Brown, H., Gua, G., Fischer, M., Hauksson, E., ... & Maechling, P. (2014). CISN ShakeAlert: An earthquake early warning demonstration system for California. In Early Warning for Geological Disasters (pp. 49-69). Springer Berlin Heidelberg.

The demonstration of feasibility of earthquake early warning system (EEW) in California has been done by developing and implementing the CISN shake alert demonstration system. CISN (California Integrated Seismic Network) is a software package which quickly receives earthquake information which would be distributed by seismic networks operating in the United States. This application was developed mainly for emergency management 24/7 operation centers. It is equipped with map displays of earthquake locations, magnitudes and time of happening and can notify users of the happening of an earthquake event. For larger earthquakes its Display may also display maps describing the extent and extremity of ground motion in the pompous region i.e. Shake Map. So a decision module integrate estimates and uncertainties determined by three algorithms performed in parallel τc – Pd Onsite, Virtual Seismologist and ElarmS are there to measure and outline at a given time the probable quake magnitude and location, and the chance of correct alarm. A user end receives the instant warning messages in the run time and also calculates the anticipated local shaking intensity, and presents the information on a map.

This earthquake early warning system also provided grounds for the 2^{nd} part of our project which relates to the recommendations and early warning system is a major portion of our recommendations.

CHAPTER 3

EARTHQUAKE AND FAULT LINES

3.1 Earthquake

Earthquake is transient, perceptible and violent shaking of the surface of the earth that follows a dissemination of energy in the Earth's crust. Once the internal stresses arising, due to accumulated strain, reaches the strength of rock, faulting takes place thus releasing accumulated strain and stresses. If this strain accumulation takes place on stronger and bigger rocks then bigger and more powerful would be the earthquake upon its faulting. In the phenomena of rupturing of the rocks certain type of vibrations which are called seismic waves are originated. These seismic waves travel outward from the origin of the earthquake and move along the surface and through the Earth with different speeds which depends on the material through which they travel.

In order to get an Earthquake

- A mechanism is needed to supply the energy and stress the material
- Brittle material should be present
- The material should be able to store significant amounts of energy

3.1.1 Size of Earthquake

The Richet Magnitude scale was developed in early twentieth century to compare the magnitudes of earthquakes. It is determined from the logarithm of amplitude of waves which are recorded by seismographs. According to this magnitude scale, earthquakes with magnitude of 2 or less are called micro earthquakes and these earthquakes are generally not felt by people and recorded on a seismographs. This scale is not commonly used now rather it has been superseded by another scale called the moment magnitude scale which is more accurate in measuring the size of earthquake.

3.1.2 Hypocenter of Earthquake

Hypocenter is the point where faults start to begin or point in earth where strain energy released which stored in earth surface. This occurs directly under the epicenter, at a distance which is known as the focal or hypo central depth. This focal depth can be calculated from seismic wave phenomena measurements.

3.1.3 Epicenter of Earthquake

Epicenter is the point on the surface of earth that is straight above the hypocenter or the point where earthquake originates. It is the area of greatest damage.

3.1.4 Fault Plane

The fault plane is the flat surface along which there is a slip during an event of earthquake. Fault plane formed between two rocks that slip one with the other during an earthquake. The edge of the fault plane can be seen on the land as fault line.

3.2 Seismic waves

Seismic waves are caused by the sudden breaking of rock within the rock or explosion and these waves are called as the waves of energy. They are the energy carriers that travel through the earth and is recorded on seismographs. Seismic wave velocity depends upon the density and elasticity of the medium. This velocity varies from 2km/s to 8 km/s in the Earth's crust and approximately up to 13 km/s in deep mantle.

3.2.1 Body Waves

Body waves are the waves that traveling through the interior of the earth, body waves arrive before the surface waves emitted by an earthquake. These waves are of a higher frequency than surface waves.

a) P-Waves

This is the fastest kind of seismic wave and consequently the first to arrive at a seismic station. The P wave can move through solid rock and fluids like water or the liquid layers of the earth. It pushes and pulls the rock it moves through just like sound waves push and pull the air. P wave is also known as compressional waves, is a seismic body wave that shakes the ground back and forth in the same direction and the opposite direction as the direction the wave is moving.

b. S-Waves

An S wave is a seismic body wave that vibrates the ground back and forth perpendicular to the direction of the wave movement.

3.2.2 Surface Waves:

Surface waves are of a lower frequency than body waves and are easily recorded on a seismogram as a result. They reach after body waves, it is surface waves that are completely responsible for the damage and disaster linked with earthquakes.

a) Love waves

This is the quickest moving surface wave and moves the ground from side-to-side. It is confined to the surface of the crust, love waves produce completely horizontal motion.

b) Rayleigh Waves:

A Rayleigh wave rolls along the ground just like a wave rolls across a lake or an ocean. It moves the ground up and down and side-to-side in the same direction that the wave is moving. Most of the shaking felt from an earthquake is due to the Rayleigh wave, which can be much larger than the other waves.

3.3 Plate Tectonics

The tectonic plates are the large, thin, relatively rigid plates that move relative to one another on the outer surface of the earth. The lithosphere is made up of large slabs of rock which fit in as a jigsaw puzzle. Tectonic plates move because the lie over a thick liquid. The movement of plates causes strains in the plates and hence due to these strains, stresses are released resulting in earthquakes.

3.4 Fault

A fault is a fracture or zone of fractures between blocks of rocks. Faults allow blocks of rocks to move relative to each other. This movement may be in the form of creep or sudden in the form of earthquakes. Most faults produce repeated displacements over geological time.

3.4.1 Normal Fault

A dip-slip fault in which the block above the fault has moved downwards relative to the block below.

3.4.2 Thrust Fault

A dip-slip fault in which the upper block, above the fault plane, moves up and over the lower block. This type of faulting is common in areas of compression.

3.4.3 Strike-slip fault

A fault on which two blocks slide past one another. The San Andreas Fault is an example.

a) Left-lateral strike slip fault

A fault on which the displacement of the far block is to the left when viewed from either side.

b) Right-lateral strike slip fault

A fault on which the displacement of the far block is to the right when viewed from either side.

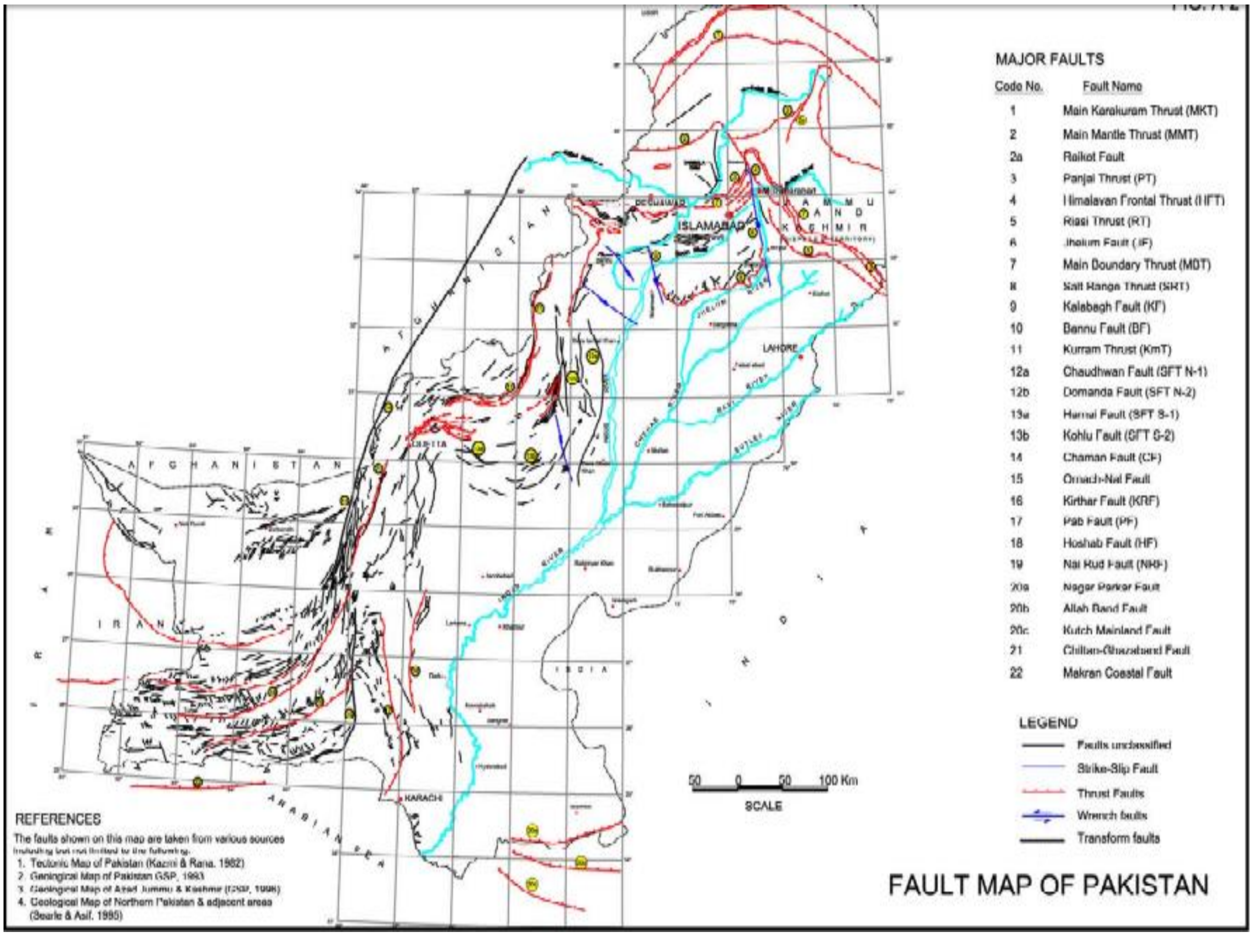

Figure 3.1 Fault line Map of Pakistan

3.5 Causes of Earthquakes

Earthquakes are very dangerous natural hazards because they occur without or with a little warning. There are several causes of earthquakes which are shown in figure below:

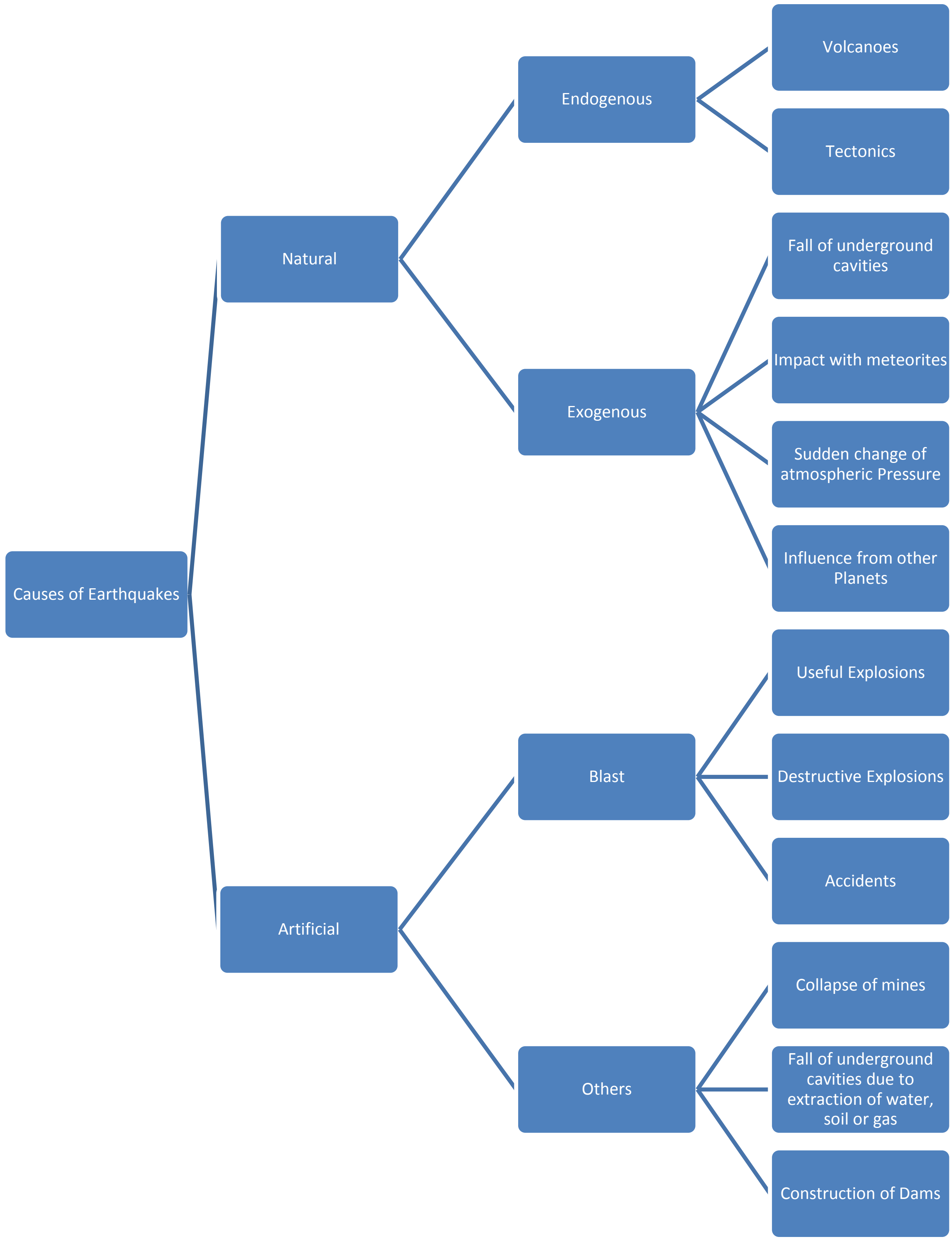

Figure 3.2 Causes of Earthquake

3.6 Seismic waves

Seismic waves are the waves of energy which caused by the sudden breaking of rock within the rock or explosion. They are the energy carriers that travel through the earth and is recorded on seismographs.

3.7 Seismic Hazard

Seismic hazard is the probability that a certain earthquake will occur in a given area within certain time period with ground motion intensity exceeding a certain threshold. The maximum acceleration during earthquake, velocity and displacement are also used to calculate seismic hazard.

3.8 Seismic Risk

Although there is a huge difference between seismic risk and the seismic hazard but in the literature they are both used in the same context. It refers to the damage to life, property, buildings and other infrastructure caused by the earthquakes.

According to Dowrick,

Seismic Risk = (Seismic Hazard) x (Vulnerability) x (Value)

The seismic risk would be zero if there is a no population area or the area in which there is no urbanization. Seismic risk can be improved if the probability of occurrence of earthquakes is known.

CHAPTER 4

AREA SELECTION

4.1 Islamabad

Islamabad is the capital city of Pakistan with a population of 20 lacs. Islamabad is located in the Potohar range in the northeastern part of the country. This region has been a part of the crossroads of Punjab and Khyber Pakhtunkhwa with the Margalla Pass acting as the bridge between the two regions. The city was built during the 1960s to become a capital of Pakistan and replacing Karachi which was previously the capital of the country. Islamabad is a well-managed international city divided into many different sectors and zones. It is regarded as the most developed city in Pakistan.

Figure 4.1 A view of Islamabad city

It is situated near the Hindu Kush range of mountains due to which it has faced many earthquakes in the past. The culture of high rise buildings in the city has turned its exposure to earthquake damage and hazard. On 8 Oct 2005, the Margalla Tower of Islamabad collapsed due to 7.6 magnitude earthquake. More than 250 people were buried alive.

4.2 Peshawar

Peshawar is the provincial capital of Khyber Pakhtunkhwa province of Pakistan and according to 1998 census it was ninth largest in country. It is a metropolitan city and administrative and economic center for Federal Administered Tribal Areas of Pakistan. Peshawar history goes back to 539BC which makes it the oldest city of Pakistan.

Not farther but Peshawar was recently hit by an earthquake of 7.6 magnitude on 26th October 2015. At least 42 people died and many were reported injured. Pakistan Meteorological department believe that this earthquake may have reactivated certain dormant fault lines in the area.

Figure 4.2 A view of Peshawar city

4.3 Quetta

Quetta is the provincial capital of Baluchistan which is the largest province of Pakistan by area. Quetta is ninth biggest city of Pakistan with a population of 2,000,000 and area of 2656 km^2. The city is known as Fruit Garden of Pakistan and also called Little Paris in past due to its beauty location. Quetta is a trade and communication hub between Pakistan and Afghanistan. It situated on Bolan Pass and was the only pathway from Central Asia to South Asia.

Quetta is amongst the most active seismic regions of Pakistan and lies on Chaman and Chiltan fault. On 31st May 1935, Quetta was hit by a devastating earthquake of 7.7 magnitude earthquake having focal depth of 17km. The earthquake caused 35000-60000 deaths and injured thousands more in the region.

Figure 4.3 A view of Quetta city

4.4 Muzaffarabad

Muzaffarabad is the capital of Azad Jammu and Kashmir, Pakistan. It is located on Neelum and Jhelum river banks with population of 96,000 and area of 6117km^2. It is surrounded by Khyber Pakhtunkhwa in west, disputed Jammu and Kashmir in east and Neelum valley in the north.

There are two forts and their names are Red and Black Fort and they are located on the opposite sides of river Neelum. The Neelum River flows through the town, joins the river Jhelum at Domel and plays a decisive role in the climate and economy of Muzaffarabad on a micro level.

Muzaffarabad has seen one of the deadliest earthquakes of Pakistan's history. On the morning of 8 Oct, 2005 it was hit by an earthquake of 7.6 magnitude having depth of around 15km, the epicenter of which was around 19km northeast of Muzaffarabad. The devastating earthquake left over 100,000 people dead, over 138,000 injured and more than 3500000 were homeless. It is observed that around 70% of all casualties of Pakistan occurred in the area of Muzaffarabad.

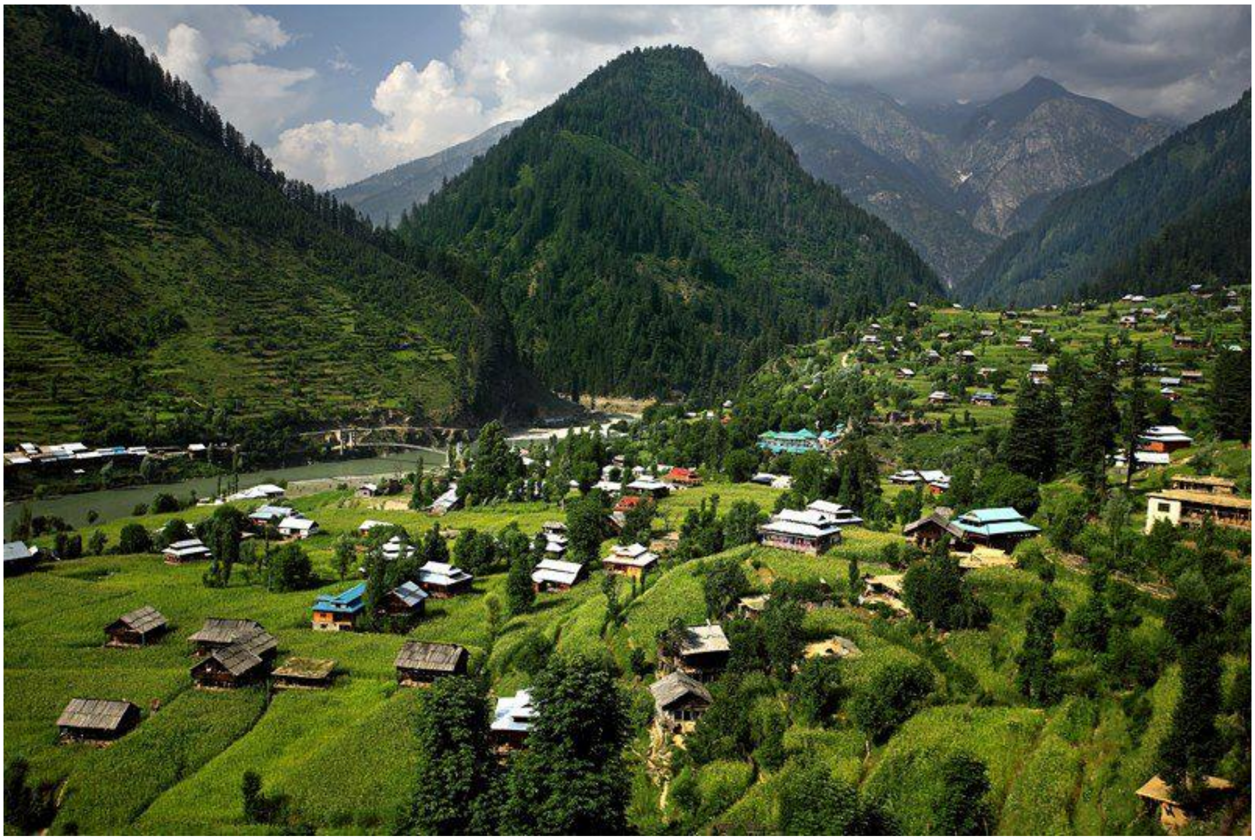

Figure 4.4 A view of Muzaffarabad City

CHAPTER 5

DATA PROCESSING

5.1 Data Collection

A good catalogue is necessary for the balance quantification of seismicity. The data required for the calculation of earthquake intensity is obtained from the various sources which are listed below

5.1.1 Pakistan Meteorological Department

Pakistan Meteorological Department (PMD) is a scientific and a sevice department which provide information on weather, climate, mitigation of disasters and provides services in area of Hydrology and Seismicity. PMD operated under World Meteorological Organization (WMO) umbrella as 198 members of states and act as National Meteorological and Hydrological services of Pakistan.

Figure 5.1 PMD logo

Main objectives are to provide information on climate, weather and geophysical phenomena with purpose of traffic safety in air, land and sea, reduction of disasters, agricultural development based on the climate potential of country, climate change, impact assessment and future projections of climate and adaption options in different sectors.

5.1.2 Incorporated Research Institution for Seismology

IRIS is non-profit association of more than 120 US universities with purpose of acquisition, management, and distribution of seismological data. IRIS is leading in discovery, research and education in seismology to benefit the society by understanding our planet.

IRIS provides management and access to observed and derived data to the world community. Data includes ground motion, infrasonic, atmospheric, hydrological and hydro-acoustic data. Its mission is to advance knowledge and understanding of seismology and earth sciences. It has multiple online tools that help in learning about global and local seismicity.

Figure 5.2 IRIS logo

5.1.3 United States Geological Survey Department

USGS is a research and a scientific agency of Unites States of America which provide well-grounded seismic awareness and data full of information to describe and understand the earth; reduce loss of life and property form calamites like quakes, intensify and protect the status of life and manage resources.

As the Nation's leading water, earth, and biological science and civilian mapping agency, USGS gathers, monitors, analyzes, and provides science about natural resource conditions, issues, and problems. Their diverse expertise enables them to carry out large-scale, multidisciplinary investigations and provide impartial scientific information to resource managers, planners, and

Figure 5.3 USGS logo

other customers.

5.1.4 International Seismological Centre

ISC is set up with the help of UNESCO (United Nations Educational, Scientific and Cultural Organization) in 1964 to collect, archive and process seismic stations and networks and providing and distributing the seismic summary to world.

Figure 5.4 ISC logo

They have maintained ISC bulletin which is the biggest continuous definitive summary of World seismicity, International seismographic station registry and IASPEI (International Association of Seismology and Physics of Earth Interior) reference event list. The ISC relational database recently collects approximately 90 GB of unique data. The ISC Bulletin has over 4 million seismic events: earthquakes, chemical and nuclear explosions, mine blasts and mining induced events. The Bulletin contains about 50 million individual seismic station readings of arrival times, amplitudes, periods, SNR, slowness and azimuth, reported by approximately 17,000 seismic stations.

5.2 Data Conversion

The data obtained from the various sources were in different formats. The data from the PMD was mostly in moment magnitudes (Mw) format, the data from the IRIS was mixed in body wave magnitude (Mb) and surface wave magnitude (Ms). The hazard estimation in this project is based on the Mw so it is necessary to convert all other magnitudes into Mw scale using Harvard catalogue.

CHAPTER 6

SELECTION AND IMPLEMENTATION OF METHOD

The Gutenberg-Richet relationship and Pearson Type iii distribution are used for the analysis of data. To calculate future frequency or probability of seismic events statistical analysis is applied in earthquake engineering based on the information contained in previous seismic records.

6.1 Pearson Type iii Distribution

The Pearson Type iii Distribution is one of the most popular distributions for earthquake probability analysis. It is a statistical technique for fitting frequency distribution data to predict hazard at some place. Once the statistical information is calculated for a specific site, a frequency distribution can be made. The probabilities of earthquakes of different sizes can be obtained from the curve. The benefit of this unique technique is that extrapolation can be made of the values for events with return periods well beyond the observed earthquake events.

The Log-Pearson Type III distribution explains you the likely values of earthquakes to expect at various recurrence intervals based on the available historical record. This is helpful when designing structures in or near the seismic area. It is also handy while designing structures to protect against the largest expected event. For this reason, it is customary to perform the earthquake frequency analysis using the instantaneous peak magnitude data.

For the convenience of calculations excel sheets are developed. The Pearson Type iii co-ordinates are used for the computation of magnitude in standard deviation from mean for exceedance percentage.

6.1.1 Procedure of plotting of curves

i. Obtain the maximum magnitude data and organize information in table.
ii. Rank the data from 1 to n where n being the total number of values in database.
iii. Take the log of maximum magnitude in next column.
iv. Calculate Average maximum Magnitude 'm' and average of log (m).

v. Calculate **(log (m)-avglog(m))^2** in next column.

vi. Similarly, Calculate **(log (m)-avglog(m))^3** in next column.

vii. Calculate the sum of **(log (m)-avglog(m))^2** and **(log(m)-avglog(m))^3**.

viii. Calculate the standard deviation, variance and skew co-efficient as follows:

$$\text{Variance}=\frac{\sum_i^n(\log m-\text{avg}(\log m)^\wedge 2}{n-1}$$

$$\text{Standard Deviation} = \sigma \log m = \sqrt{\text{Variance}}$$

$$\text{Skew Coefficient 'k'} = \frac{n \times \sum_i^n(\log m-\text{avg}(\log m))^\wedge 3}{(n-1)(n-2)(\sigma \log m)^\wedge 3}$$

Table 6.1 Pearson Type-iii Distribution for Peshawar

Rank	Year	Magnitude	Ranked peak Data	log (m)	(log(m)-avglog(m))2	(log(m)-avglog(m))3
1	1975	4.9	7.3	0.86332	0.02233	0.00334
2	1976	5	6.3	0.79934	0.00730	0.00062
3	1977	5.2	6.3	0.79934	0.00730	0.00062
4	1978	5	6.2	0.79239	0.00616	0.00048
5	1979	4.8	5.9	0.77085	0.00324	0.00018
6	1980	4.7	5.9	0.77085	0.00324	0.00018
7	1981	6.2	5.7	0.75587	0.00176	0.00007
8	1982	5.7	5.5	0.74036	0.00070	0.00002
9	1983	4.8	5.5	0.74036	0.00070	0.00002
10	1984	5.9	5.5	0.74036	0.00070	0.00002
11	1985	5.1	5.4	0.73239	0.00034	0.00001
12	1986	5.4	5.4	0.73239	0.00034	0.00001
13	1987	4.7	5.4	0.73239	0.00034	0.00001
14	1988	4.7	5.4	0.73239	0.00034	0.00001
15	1989	4.9	5.2	0.71600	0.00000	0.00000
16	1990	5.4	5.2	0.71600	0.00000	0.00000
17	1991	5.2	5.2	0.71600	0.00000	0.00000
18	1992	6.3	5.2	0.71600	0.00000	0.00000
19	1993	5	5.1	0.70757	0.00004	0.00000
20	1994	4.7	5.1	0.70757	0.00004	0.00000
21	1995	4.9	5	0.69897	0.00022	0.00000
22	1996	4.8	5	0.69897	0.00022	0.00000
23	1997	4.9	5	0.69897	0.00022	0.00000
24	1998	4.6	4.9	0.69020	0.00056	-0.00001
25	1999	5.9	4.9	0.69020	0.00056	-0.00001
26	2000	6.3	4.9	0.69020	0.00056	-0.00001

27	2001	4.8	4.9	0.69020	0.00056	-0.00001
28	2002	5.4	4.9	0.69020	0.00056	-0.00001
29	2003	5.1	4.9	0.69020	0.00056	-0.00001
30	2004	5.5	4.9	0.69020	0.00056	-0.00001
31	2005	7.3	4.8	0.68124	0.00107	-0.00003
32	2006	5.2	4.8	0.68124	0.00107	-0.00003
33	2007	4.9	4.8	0.68124	0.00107	-0.00003
34	2008	4	4.8	0.68124	0.00107	-0.00003
35	2009	5.4	4.8	0.68124	0.00107	-0.00003
36	2010	5.2	4.7	0.67210	0.00175	-0.00007
37	2011	4.8	4.7	0.67210	0.00175	-0.00007
38	2012	5.5	4.7	0.67210	0.00175	-0.00007
39	2013	5.5	4.7	0.67210	0.00175	-0.00007
40	2014	4.9	4.6	0.66276	0.00261	-0.00013
41	2015	4.9	4	0.60206	0.01251	-0.00140
			5.204878	0.71389	0.08695	0.00349

Variance = 0.0021738

Standard Deviation = 0.0466241

Skew coefficient = 0.905379336

Variance and standard deviation are required to fit the frequency curves. Computation of unadjusted frequency curves is accomplished by computing the logarithms of magnitudes corresponding to selected points on frequency tables. The number of points needed to define a curve depends on skew coefficient. For skew coefficient values near zero, fewer points are needed while for skewer coefficient near 1, all the points given in table C.1 will be needed. The selected exceedance frequency points are labeled as P_n.

ix. Find the value of ‘k’ using the skew co-efficient, given in Frequency factor tables, at several recurrence intervals. (see Appendix C)

x. Use the given equation to find the maximum magnitude in given recurrence intervals.

$$\log m = \text{avg}(\log m) + (K \times \sigma \text{logm})$$

xi. Plot the graph between Maximum Magnitude, exceedance Probability and Recurrence Interval.

Table 6.2 Results to be plotted on graph

Pn	k(0.9)	K(1.0)	slope	k(0.905379336)	M	Return Period 'I'
99	-1.66	-1.588	0.72	-1.6561269	4.33186152	1.0101
50	-0.148	-0.164	-0.16	-0.1488607	5.09271637	2
20	0.7691	0.758	-0.111	0.7685029	5.619798428	5
10	1.339	1.34	0.01	1.3390538	5.974783307	10
4	2.018	2.043	0.25	2.0193448	6.427470831	25
2	2.498	2.542	0.44	2.5003669	6.768108842	50
1	2.957	3.022	0.65	2.9604966	7.110832754	100
0.5	3.401	3.489	0.88	3.4057338	7.45897667	200
0.1	4.395	4.54	1.45	4.4028	8.301690937	1000

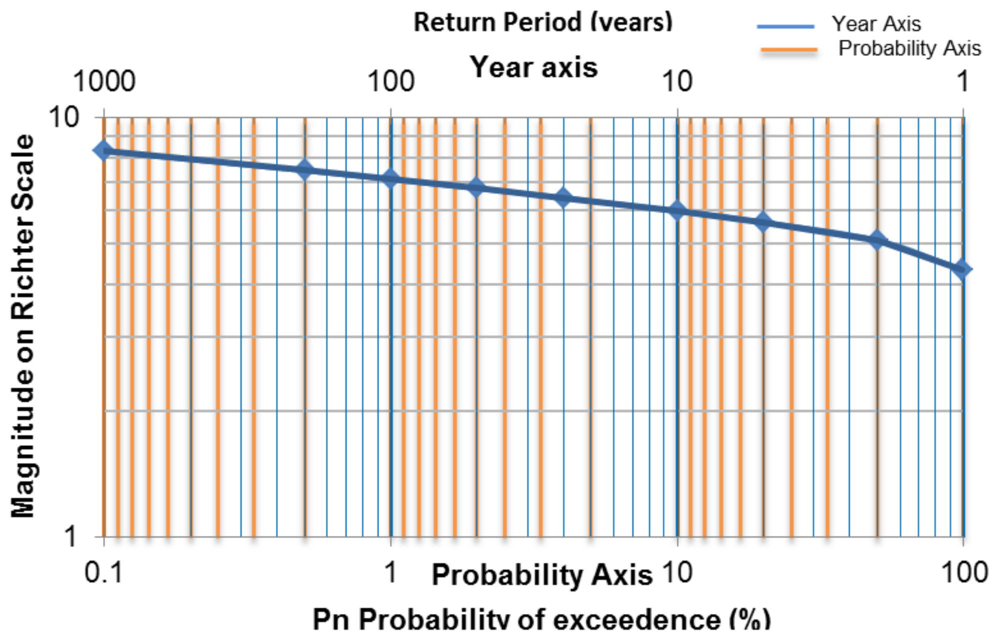

Figure 6.1 Probability Analysis of Earthquake Intensity for Peshawar

6.1.2 Discussion

It is very difficult to exactly predict the occurrence of major earthquake due to various factors involved. However, depending on the availability of data and limitations of frequency analysis, a reasonable estimate can be made on the recurrence of given magnitude of earthquake along with its return period can be determined easily.

6.2 Gutenberg- Richter Relationship

When plotting the results on a logarithmic graph is done then we get the required number of earthquakes greater than or equal to a given magnitude in a given period of time against that magnitude, a basic characteristic of the seismicity rate in an area the slope can be determined.

It expresses a relationship between magnitude and total number of earthquakes in a specified time and in any given area.

6.2.1 Procedure of plotting of curves

i. Calculate the frequency of occurrence of all earthquake magnitudes in given database.

Table 6. 3 Gutenberg- Richet Relationship for Peshawar

Magnitude 'Mw'	Number	Cumulative number 'N'	Midpoint of Magnitude Range	log (N)
2-3	107	2903	2.5	3.462847036
3-4	1770	2796	3.5	3.446537167
4-5	923	1026	4.5	3.011147361
5-6	98	103	5.5	2.012837225
6-7	4	5	6.5	0.698970004
7-8	1	1	7.5	0

ii. Plot the magnitude against log of number of earthquake occurrences.

iii. Draw the best fit line for the data points.

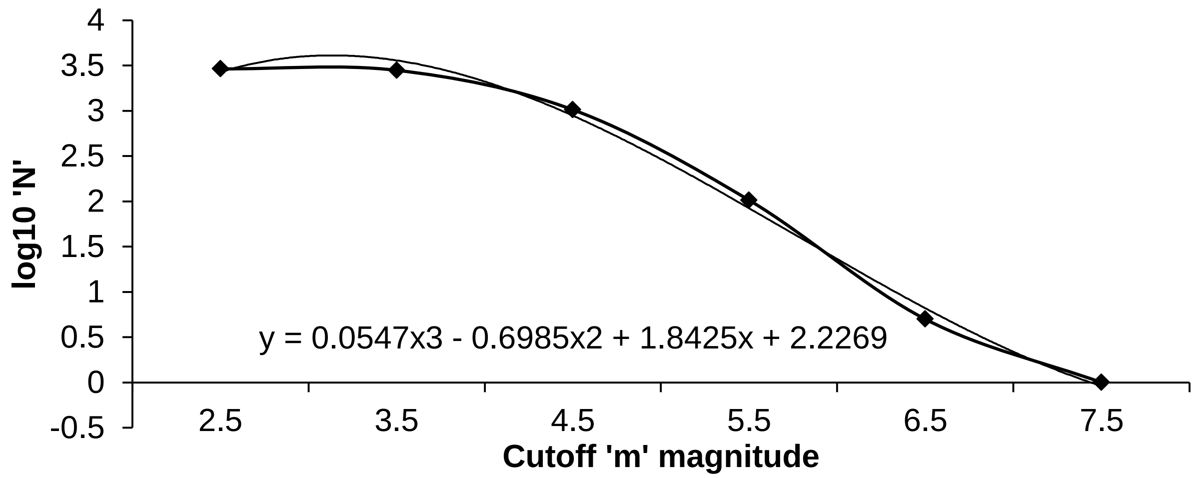

Figure 6.2 Gutenberg- Richet Relationship for Peshawar

iv. Use the equation of line to find out Number of future earthquakes.

Table 6.4 Results for Peshawar

Magnitude	Number of Earthquakes
2	3593.353968
3	880.6432284
4	83.50260034
5	6.522288425
5.5	2.146532656
6	0.893511199
6.5	0.517026139
7	0.45708819

v. Make a column graph with magnitude and Number of future earthquakes.

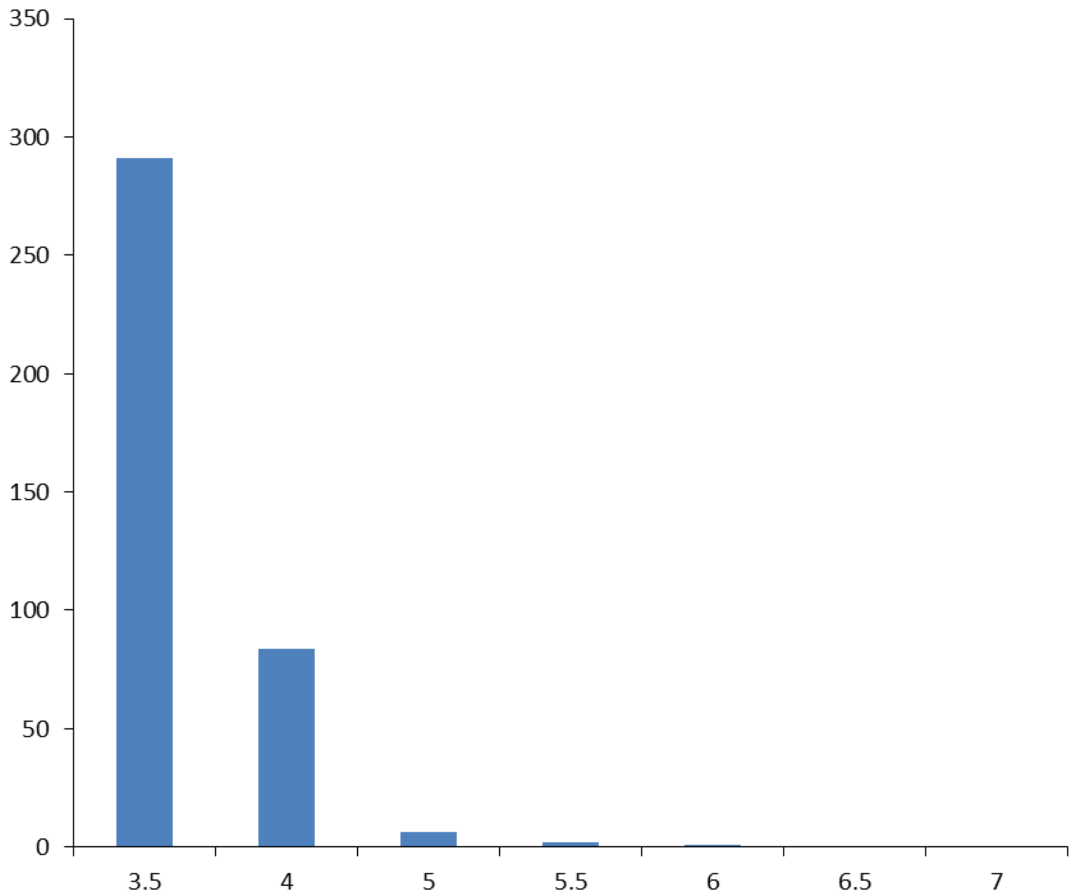

Figure 6.3 Bar chart for number of earthquakes in Peshawar

6.3 Comparison of Methods

Table 6.5 Comparison of both methods used

Pearson Type iii Distribution	Gutenberg –Richet Relationship
Gives the expected return period of Earthquakes	Gives the expected No. of Earthquakes
Need at least 40 years of data for analysis	Provide results for the same no. of years for which the data is provided.
Accuracy depends on size of sample	Accuracy is independent of sample size
It comprises of Mathematical calculations	It works on assumptions and sometimes data is so versatile that it is difficult to set a trend line.

6.4 Accuracy of Frequency Analysis

Many researchers and engineers believe that frequency curves based on Pearson functions and other graphical functions do not take into account the several important factors. There are others who have devoted lot of times on topic seeking in favor of method. According to tectonic plate theory, once the internal stresses arising, due to accumulated strain, reaches the strength of rock, faulting takes place thus releasing accumulated strain and stresses. If this strain accumulation takes place on stronger rocks, bigger would be the corresponding earthquake upon its faulting. Earthquakes are natural hazards and natural hazards follow an almost fixed cycle and are ideally suited for analysis by using Pearson's type-III distribution and other frequency analysis.

CHAPTER 7

Earthquake Early Warning System

7.1 Introduction

Pakistan has faced many disastrous earthquakes in the past which has affected the human lives and the economy of the country severely. A systematic approach is needed to counter the potential disaster and minimize the losses. Pakistan is located on a number of active fault lines, which makes it more susceptible to frequent earthquakes. Pakistan was hit by many earthquakes in the recent past, the majority of which had the epicenter located in Hindu Kush ranges or the Himalayas. These ranges lie at sufficient distance from metropolitan cities of Pakistan which have been remained victim of these earthquakes many times. An effective approach is needed to cater these earthquakes. One such approach and the technique is design of an early warning system for earthquakes. The concept of earthquake early warning system is relatively simple i.e. issuing a warning about the incoming earthquakes and providing sufficient time to people to take necessary measures. Alarming the people before the earthquake could help in mitigating the losses due to earthquakes.

7.2 Earthquake Waves Detection Sensors

The waves need to be detected on sensors to locate the earthquake and issue a warning. Pakistan has a wide range of seismogram stations installed by Pakistan Meteorological Department (PMD), but they need to be upgraded to design more efficient system. In 1954, United States Geological Survey installed World Wide Standard Seismogram Network (WWSSN) to monitor the seismic activities in Pakistan. In 1975, Micro Seismic Study Program of Atomic Energy Commission installed 30 seismic network stations in Pakistan which were later upgraded in the year 2005. These seismic stations were then capable of producing highly reliable data from 360 sec to 50Hz and had a large amplitude dynamic range.

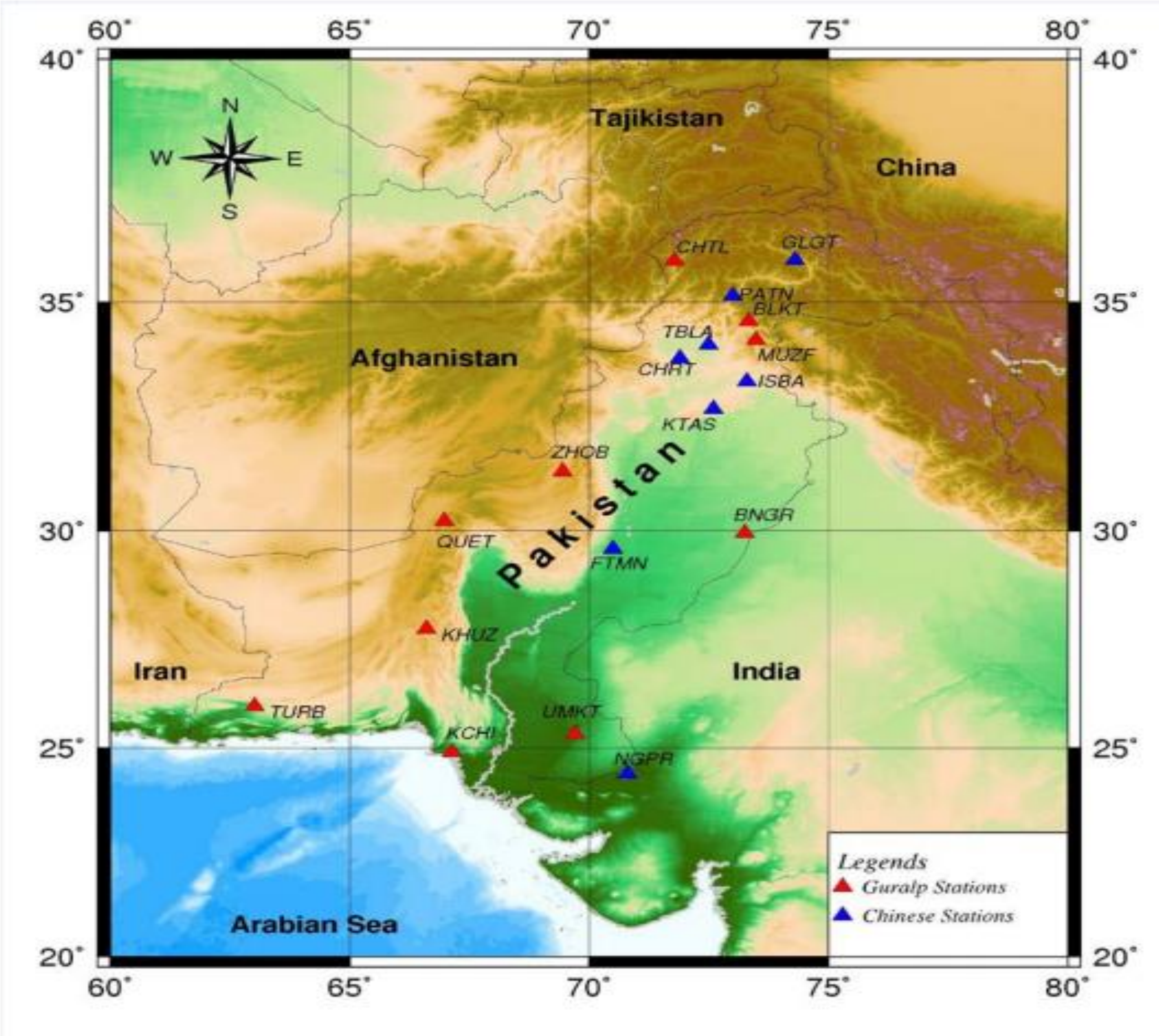

Figure 7.1 Seismic Monitoring Stations Network of Pakistan

7.3 Earthquake Alert Network

After the arrival of P-waves the signal will be sent to Earthquake Alert Networking Stations to issue the warning for the arrival of earthquake. This system needs to be efficient and alert as to save the time that is required for issuing a warning. It should be effective in a way that it must transmit the message urgently and properly. The user must get the message loud and clear so that he/she could take precautionary measures. The message can be transferred in various ways such as social media, news media, mobile phone services, radio, television, ringing an alarm, and so many other ways. The use of proper medium is an important part of issuing a warning and making the system more effective.

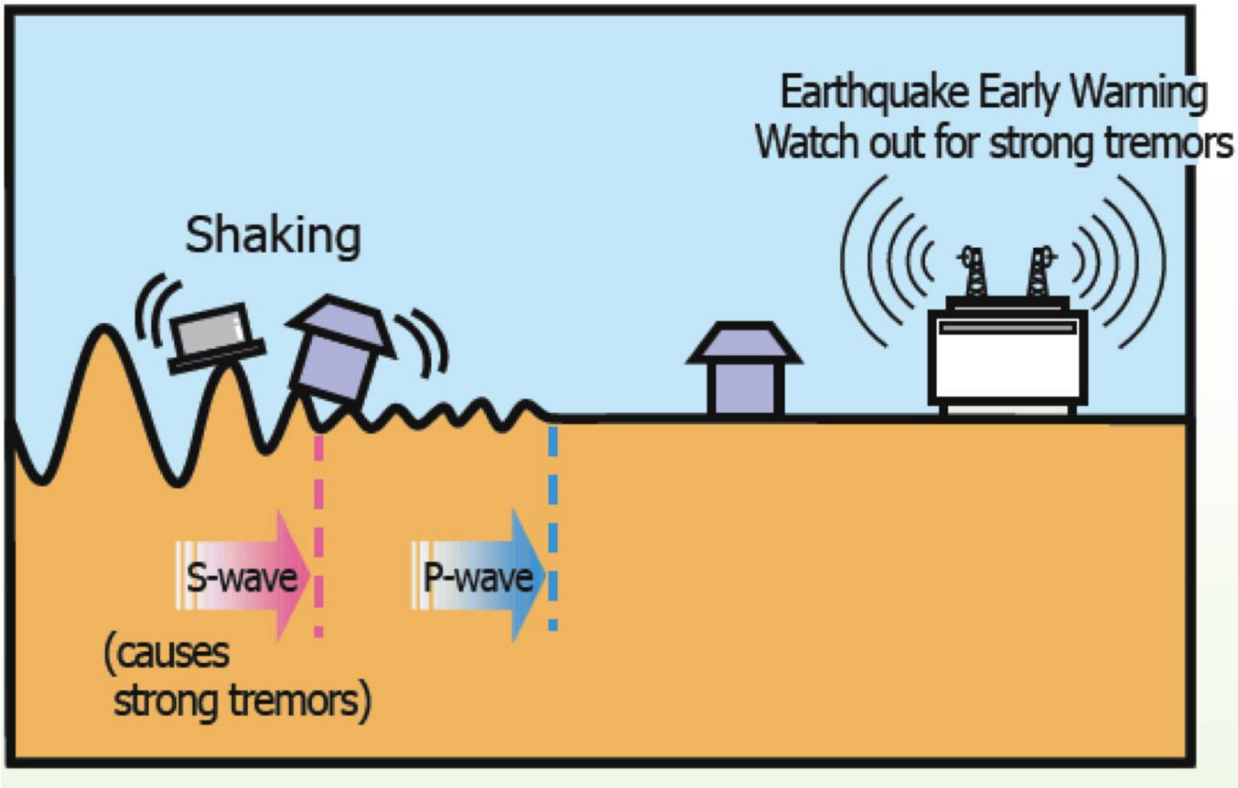

Figure 7.2 Earthquake Early warning Basics

7.4 Design of Earthquake Early Warning System

The design of an earthquake early warning system is based on two main aspects. First one is the distance at which the epicenter of an earthquake is located from the area of study, second is the speed with which the Primary "P" waves and the Secondary "S" waves travel. The velocity of P & S waves depend upon the type of material through which they travel. Earthquakes can occur at any depth from few kilometers to hundreds of kilometers. Therefore it is nearly impossible to find out the type of strata through which the P & S waves will travel. The velocity of P & S waves is assumed uniform for design purpose.

The design of an early warning system requires seismogram stations to record the arrival of body and surface waves and an alarm system that can issue the warning. Pakistan has a wide ranged network of seismogram stations installed by Pakistan Meteorological Department. Pakistan is seismically active zone. Two-third of its total area is located on the fault line. The most active being one passing through Hindu Kush ranges. Pakistan has faced a number of high intensity earthquakes in recent years, the epicenter of which is mostly located either in Himalaya or the Hindu Kush ranges. Table 7.1 shows the location of seismogram stations and the average distance from the common epicenter locations to the areas under consideration.

Table 7.1 Seismogram Station Data of area and the average epicenter distance

Code	**City Name**	**Latitude (N)**	**Longitude (E)**	**Sensor Type**	**Distance from Hindu Kush (km)**	**Distance from Himalaya (km)**
ISBA	Islamabad	33.7426	73.065	Geodevice BBVS & BBAS	330-380	50-100
QUET	Quetta	30.2333	66.9833	CMG 3T & CMG 5T	375-425	550-600
MUZF	Muzaffarabad	34.3646	73.4938	CMG 3T & CMG 5T	250-300	0-50
PESH	Peshawar	34.0133	73.1065	CMG 40T	125-175	75-125

An earthquake occurred in Tajikistan of magnitude Mw 7.3 at the depth of 10 km on 7th December, 2015. The epicenter was located at the distance of around 261 km from Islamabad. The earthquake occurred at 7:50:06; P waves were recorded at seismogram in Islamabad at 7:51:14 (68 seconds after the earthquake) and S waves arrival time was recorded as 7:52:05 (51 seconds after arrival of P waves). If we consider 10 seconds of recording and warning time we could have plenty of time to prepare for the potential disaster.

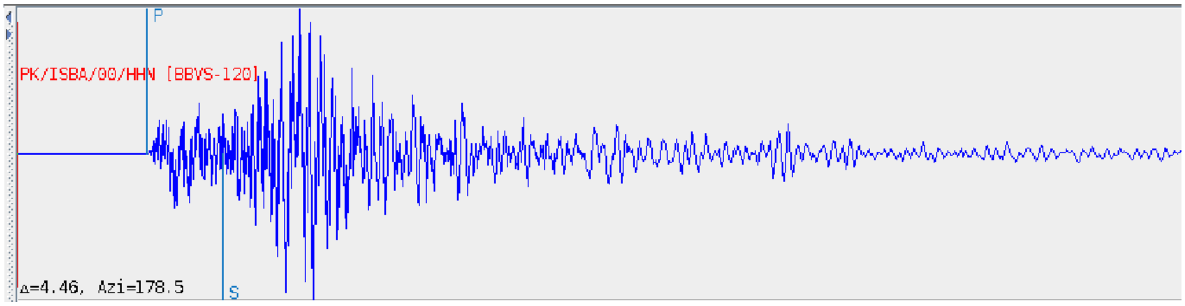

Figure 7.3 Acceleration recorded in Islamabad

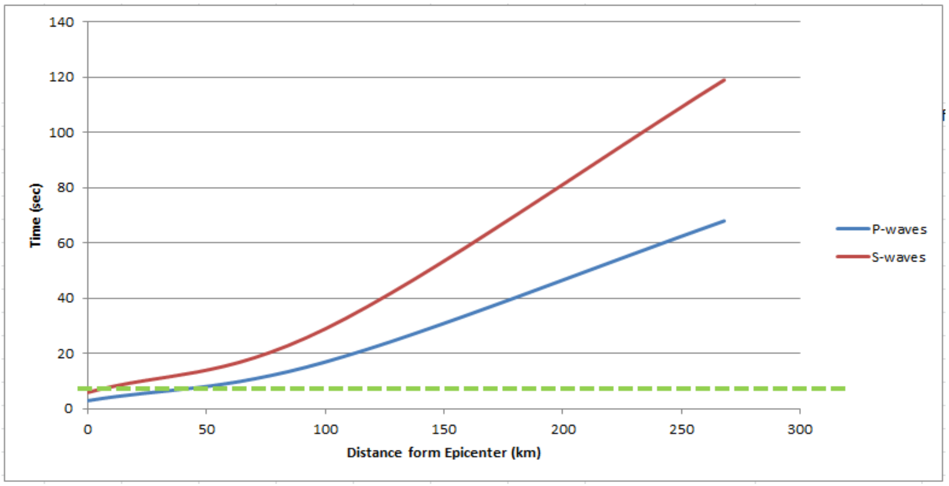

Figure 7.4 Relationship between Distances from epicenter of earthquake to the time required by P & S waves.

Fig 7.4 provides us with a measure of time available to prepare for the incoming earthquake waves and to take necessary measures. The time which is available after the issuance of warning is termed as Escape Time. Escape time can also be called as the response time. It depends highly on the strata through which the waves travel. The variation due to the geologic properties is adjusted by taking average of the escape time calculated. Fig 7.5 shows the relationship between average escape time available after issuance of warning. The escape time is negative for the earthquakes having epicenter within around 48km of the area, which means that early warning system is ineffective for the area under study if the earthquakes occur within 48kms of that area.

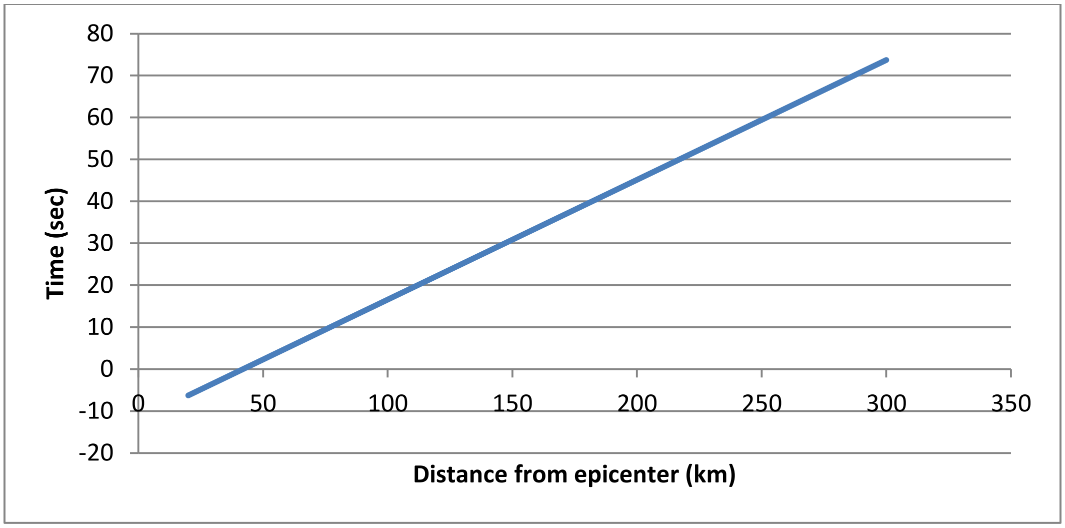

Figure 7.5 Net average time available to issue warning and take necessary measures after occurrence of earthquake.

7.5 Benefits of Earthquake Early Warning System

Earthquake early warning system provides critical information needed to minimize the damages caused by strong ground shaking. Such a system can help in minimizing losses to life and property, to direct rescue operations and to prepare for the immediate recovery from earthquake damages. The most efficient use of this system will be to activate automated system to provide useful seconds for evacuating large and hazardous buildings. It can help in minimizing the losses by issuing an early warning for slowing down high speed vehicles and trains to avoid potential derailment, to preserve the nuclear sites from possible damages, gas pipelines and other utilities can be shut down temporarily, emergency response teams can be deployed quickly at the affected sites, school children can either evacuate or hide under the tables before the actual ground shaking occurs, panic and chaos can be minimized. A few seconds of warning time can prevent a huge disaster.

7.6 Design and Implementation Considerations

Earthquake early warning system requires updated accelerometers, communication system, alarm system, seismograms and use of modern technology for its successful implementation. The concept of earthquake early warning system is relatively new in Pakistan. It has been under consideration for quite some time, but nothing has been practically done yet. In Pakistan, the most destructive earthquake may be those that occur at the lower depth and lesser distances of epicenter. Therefore, for the early warning system to be effective it must be able to detect and locate an earthquake within 10 seconds after it occurs. In a developing country like Pakistan, cost of initialization and maintenance of that facility has always been a major issue. The real time monitoring of earthquakes requires expanding the seismic network of Pakistan and equipping them with the modern accelerometers and real time data processing and communication system.

7.7 Reliability of Early Warning

System Earthquake early warning system has been implemented in several countries. Mexico has this system since 1991. Japan implemented this system in the year 2007. Other countries like Taiwan, China, Italy, Romania, Istanbul and Turkey have also successfully implemented this system. In Pakistan, Pakistan Meteorological Department (PMD) conducted a study in collaboration with National Disaster Management Authority (NDMA), but no actions were taken for the implementation of earthquake early warning system.

7.8 Limitations of the System

No system is 100% accurate. It won't be able to issue warning right at the epicenter. The system might send warnings for the earthquakes which are too small in size to cause any damage. The system might get too late in sending warnings or the waves might surpass the speed with which warnings are issued. All these can be improved by rigorous planning and improvising the technology used for issuing the warnings.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Pearson Type-iii Distribution

8.1.1 Results of Analysis

The results for the probabilistic estimation of earthquake intensity by Pearson Type III distribution are given in Table 6.3. The study provides sound knowledge about the seismicity of major areas of Pakistan, with Peshawar being most susceptible to face major earthquakes in near future.

Table 8. 1 Result of Analysis

Area of Study	Years of Record	Mean Earthquake	Variance	Skew Co-efficint	Maximum Expected Magnitude	Exceedance % probability for Maxima	Exceedance Chance % of average Earthquake
Peshawar	41	5.2	0.0022	0.905	8.3	0.1	38
Islamabad	41	5.1	0.0015	1.844	7.5	0.5	45
Quetta	41	5.2	0.002	0.667	7.7	0.1	40
Muzaffarabad	41	5.2	0.0015	1.8	7.6	0.5	42

Tables and graphs of other three cities are shown in Appendix A.

8.2 Gutenberg-Richet Relationship

8.2.1 Results of Analysis

The Gutenberg-Richet Relationship provides sound knowledge about the seismicity of major areas of Pakistan, with Peshawar being most susceptible to face major earthquakes in near future. It gives number of expected earthquakes in future.

Table 8. 2Expected Earthquakes in next 40 years

Area of Study	Earthquakes with magnitude > 5	Earthquakes with magnitude > 6
Peshawar	7	1
Islamabad	7	1
Quetta	2	0
Muzaffarabad	9	1

8.3 Recommendations for Future Work

- High intensity earthquakes can be predicted using probability and hence buildings to be constructed in a particular area can be designed according to the earthquake of expected intensity.
- Return period of an earthquake of a particular intensity can be compared with the design life of the structure which will result in economical design and construction.
- Using earthquake intensity, towns can be designed with a view to cause minimum disruption to services in case of any emergency.
- Using probability to acquire earthquake intensity can help in designing that could mitigate the damage to human lives and reduce financial losses.
- Future estimation can also help in building control in a town or city to reduce the damage that could harm people or infrastructure.
- In an area where there is a potential danger of triggering landslides, avalanches, mudslides and tsunamis due to earthquake, this method can prove to be extremely useful.

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APPENDIX

APPENDIX A

PEARSON TYPE-iii DISTRIBUTION

Table A. 1 Pearson Type-iii Distribution for Islamabad

Rank	Year	Magnitude	Ranked peak Data	log (m)	(log(m)-avglog(m))2	(log(m)-avglog(m))3
1	1975	5.2	7.3	0.86332	0.023473	0.003596
2	1976	4.6	6.3	0.79934	0.007961	0.000710
3	1977	5.2	6	0.77815	0.004629	0.000315
4	1978	5	5.7	0.75587	0.002094	0.000096
5	1979	4.8	5.6	0.74819	0.001450	0.000055
6	1980	5.2	5.4	0.73239	0.000496	0.000011
7	1981	5.1	5.4	0.73239	0.000496	0.000011
8	1982	5.4	5.4	0.73239	0.000496	0.000011
9	1983	4.8	5.4	0.73239	0.000496	0.000011
10	1984	5.3	5.3	0.72428	0.000201	0.000003
11	1985	4.8	5.3	0.72428	0.000201	0.000003
12	1986	4.6	5.2	0.71600	0.000035	0.000000
13	1987	4.7	5.2	0.71600	0.000035	0.000000
14	1988	4.8	5.2	0.71600	0.000035	0.000000
15	1989	4.7	5.2	0.71600	0.000035	0.000000
16	1990	5.3	5.2	0.71600	0.000035	0.000000
17	1991	5.2	5.2	0.71600	0.000035	0.000000
18	1992	6.3	5.2	0.71600	0.000035	0.000000
19	1993	5	5.2	0.71600	0.000035	0.000000
20	1994	4.7	5.1	0.70757	0.000006	0.000000
21	1995	4.9	5	0.69897	0.000124	-0.000001
22	1996	4.8	5	0.69897	0.000124	-0.000001
23	1997	5	5	0.69897	0.000124	-0.000001
24	1998	5	5	0.69897	0.000124	-0.000001
25	1999	5.2	5	0.69897	0.000124	-0.000001
26	2000	5	5	0.69897	0.000124	-0.000001
27	2001	5.2	5	0.69897	0.000124	-0.000001
28	2002	6	4.9	0.69020	0.000397	-0.000008
29	2003	4.7	4.9	0.69020	0.000397	-0.000008
30	2004	5.6	4.8	0.68124	0.000834	-0.000024
31	2005	7.3	4.8	0.68124	0.000834	-0.000024
32	2006	5.2	4.8	0.68124	0.000834	-0.000024
33	2007	4.9	4.8	0.68124	0.000834	-0.000024

34	2008	4.6	4.8	0.68124	0.000834	-0.000024
35	2009	5.4	4.7	0.67210	0.001445	-0.000055
36	2010	5.2	4.7	0.67210	0.001445	-0.000055
37	2011	5	4.7	0.67210	0.001445	-0.000055
38	2012	5.4	4.7	0.67210	0.001445	-0.000055
39	2013	5.7	4.6	0.66276	0.002243	-0.000106
40	2014	5	4.6	0.66276	0.002243	-0.000106
41	2015	5.4	4.6	0.66276	0.002243	-0.000106
			5.151220	0.710114	0.060617	0.004140

Variance = 0.001515434

Standard Deviation = 0.038928582

Skew coefficient = 1.84439956

Table A. 2 Results to be plotted on Log Probability Paper for Islamabad

P_n	k(1.8)	K(1.9)	slope	k(1.84439956)	m	Return period 'I'
99	-1.087	-1.037	0.5	-1.06480	4.66297	1.0101
50	-0.282	-0.294	-0.12	-0.28733	4.99952	2
20	0.643	0.627	-0.16	0.63590	5.43085	5
10	1.318	1.31	-0.08	1.31445	5.77143	10
4	2.193	2.207	0.14	2.19922	6.24778	25
2	2.848	2.881	0.33	2.86265	6.63060	50
1	3.499	3.553	0.54	3.52298	7.03490	100
0.5	4.147	4.223	0.76	4.18074	7.46215	200

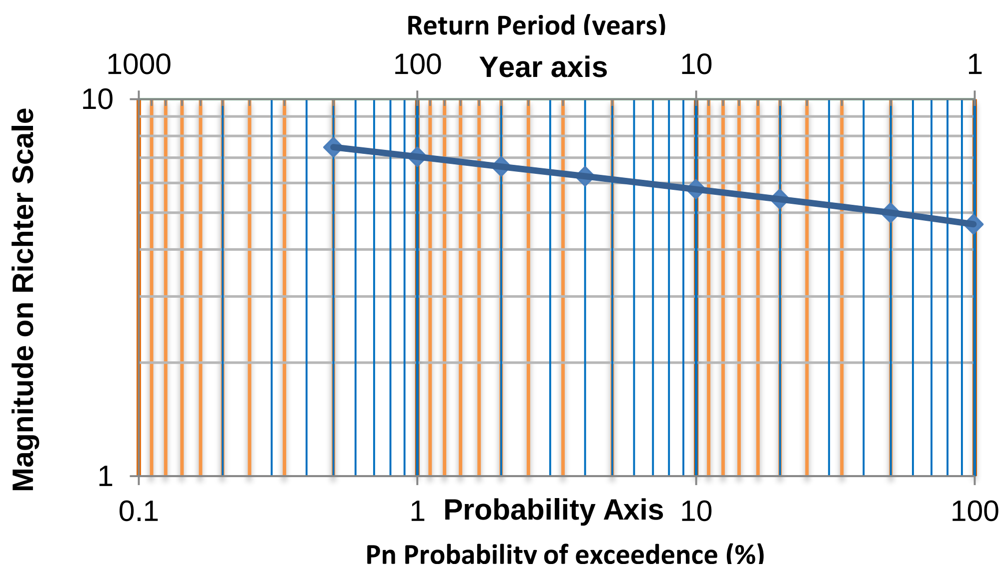

Figure A. 1 Probability Analysis of Earthquake Intensity for Islamabad

Table A. 3 Pearson Type III Distribution for Muzaffarabad

Rank	Year	Magnitude	Ranked peak Data	log (m)	(log(m)-avglog(m))2	(log(m)-avglog(m))3
1	1975	5	7.3	0.86332	0.02157	3.2E-03
2	1976	5	6.3	0.79934	0.00687	5.7E-04
3	1977	5.2	6.2	0.79239	0.00577	4.4E-04
4	1978	5	6	0.77815	0.00381	2.3E-04
5	1979	4.8	5.9	0.77085	0.00296	1.6E-04
6	1980	5.2	5.6	0.74819	0.00101	3.2E-05
7	1981	6.2	5.4	0.73239	0.00025	4.1E-06
8	1982	5.4	5.4	0.73239	0.00025	4.1E-06
9	1983	5	5.4	0.73239	0.00025	4.1E-06
10	1984	5.3	5.4	0.73239	0.00025	4.1E-06
11	1985	5.2	5.4	0.73239	0.00025	4.1E-06
12	1986	4.9	5.3	0.72428	0.00006	4.8E-07
13	1987	4.7	5.3	0.72428	0.00006	4.8E-07
14	1988	4.8	5.2	0.71600	0.00000	-8.9E-11
15	1989	4.8	5.2	0.71600	0.00000	-8.9E-11
16	1990	5.4	5.2	0.71600	0.00000	-8.9E-11
17	1991	5.2	5.2	0.71600	0.00000	-8.9E-11
18	1992	6.3	5.2	0.71600	0.00000	-8.9E-11
19	1993	5.3	5.2	0.71600	0.00000	-8.9E-11
20	1994	4.7	5.2	0.71600	0.00000	-8.9E-11
21	1995	4.9	5.2	0.71600	0.00000	-8.9E-11
22	1996	5.9	5	0.69897	0.00031	-5.3E-06
23	1997	5	5	0.69897	0.00031	-5.3E-06
24	1998	5	5	0.69897	0.00031	-5.3E-06
25	1999	5.2	5	0.69897	0.00031	-5.3E-06
26	2000	5	5	0.69897	0.00031	-5.3E-06
27	2001	5.2	5	0.69897	0.00031	-5.3E-06
28	2002	6	5	0.69897	0.00031	-5.3E-06
29	2003	4.9	5	0.69897	0.00031	-5.3E-06
30	2004	5.6	5	0.69897	0.00031	-5.3E-06
31	2005	7.3	4.9	0.69020	0.00069	-1.8E-05
32	2006	5.2	4.9	0.69020	0.00069	-1.8E-05
33	2007	4.9	4.9	0.69020	0.00069	-1.8E-05
34	2008	4.7	4.9	0.69020	0.00069	-1.8E-05
35	2009	5.4	4.8	0.68124	0.00124	-4.4E-05
36	2010	5.2	4.8	0.68124	0.00124	-4.4E-05
37	2011	5	4.8	0.68124	0.00124	-4.4E-05
38	2012	5.4	4.7	0.67210	0.00197	-8.7E-05

39	2013	4.7	4.7	0.67210	0.00197	-8.7E-05
40	2014	5	4.7	0.67210	0.00197	-8.7E-05
41	2015	5.4	4.7	0.67210	0.00197	-8.7E-05
			5.226829268	0.71645	0.06047	4.0E-03

Variance = 0.001511827

Standard Deviation = 0.038882224

Skew coefficient = 1.799414641

Table A. 4 Results to be plotted on Log Probability Paper for Muzaffarabad

P_n	k(1.7)	K(1.8)	slope	k(1.799414641)	m	Return Period 'I'
99	-1.14	-1.087	0.53	-1.08731024	4.722503687	1.0101
50	-0.268	-0.282	-0.14	-0.28191805	5.075604167	2
20	0.66	0.643	-0.17	0.643099511	5.513844134	5
10	1.324	1.318	-0.06	1.318035122	5.857300195	10
4	2.179	2.193	0.14	2.19291805	6.334536995	25
2	2.815	2.848	0.33	2.847806832	6.71704734	50
1	3.444	3.499	0.55	3.498678053	7.120094041	100
0.5	4.069	4.147	0.78	4.14654342	7.545294165	200

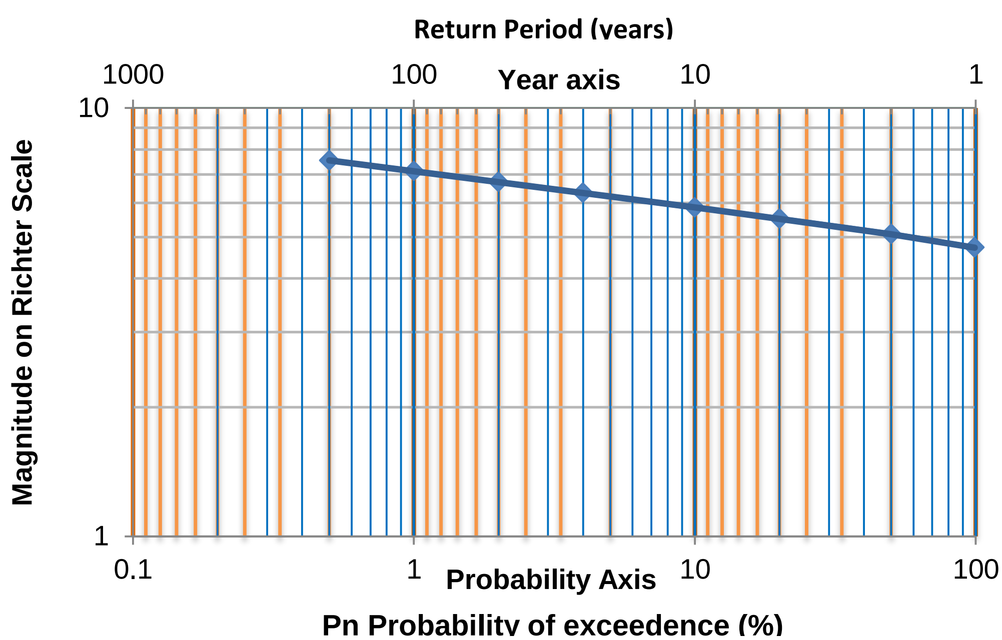

Figure A. 2 Probability Analysis of Earthquake Intensity for Muzaffarabad

Table A. 5 Pearson Type III Distribution for Quetta

Rank	Year	Magnitude	Ranked peak Data	log (m)	(log(m)-avglog(m))2	(log(m)-avglog(m))3
1	1975	5.8	7	0.84510	0.017924539	0.002399783
2	1976	5.3	6.3	0.79934	0.007766027	0.000684382
3	1977	5.1	6	0.77815	0.004480397	0.000299899
4	1978	5.5	5.9	0.77085	0.003556516	0.000212098
5	1979	4.8	5.8	0.76343	0.002726146	0.000142339
6	1980	5.1	5.6	0.74819	0.001366969	5.05403E-05
7	1981	5.2	5.5	0.74036	0.00084956	2.47623E-05
8	1982	5.1	5.5	0.74036	0.00084956	2.47623E-05
9	1983	4.7	5.5	0.74036	0.00084956	2.47623E-05
10	1984	5.5	5.5	0.74036	0.00084956	2.47623E-05
11	1985	4.8	5.4	0.73239	0.000448519	9.49887E-06
12	1986	4.6	5.4	0.73239	0.000448519	9.49887E-06
13	1987	4.3	5.3	0.72428	0.000170574	2.22776E-06
14	1988	5.4	5.3	0.72428	0.000170574	2.22776E-06
15	1989	4.7	5.3	0.72428	0.000170574	2.22776E-06
16	1990	5.9	5.2	0.71600	2.29236E-05	1.09755E-07
17	1991	4.9	5.2	0.71600	2.29236E-05	1.09755E-07
18	1992	5.5	5.2	0.71600	2.29236E-05	1.09755E-07
19	1993	5.4	5.2	0.71600	2.29236E-05	1.09755E-07
20	1994	4.6	5.2	0.71600	2.29236E-05	1.09755E-07
21	1995	5.2	5.1	0.70757	1.32883E-05	-4.84398E-08
22	1996	4.9	5.1	0.70757	1.32883E-05	-4.84398E-08
23	1997	7	5.1	0.70757	1.32883E-05	-4.84398E-08
24	1998	5.2	5.1	0.70757	1.32883E-05	-4.84398E-08
25	1999	5.6	5	0.69897	0.000149952	-1.83623E-06
26	2000	6	4.9	0.69020	0.000441815	-9.28669E-06
27	2001	4.7	4.9	0.69020	0.000441815	-9.28669E-06
28	2002	4.8	4.9	0.69020	0.000441815	-9.28669E-06
29	2003	4.2	4.9	0.69020	0.000441815	-9.28669E-06
30	2004	5.2	4.9	0.69020	0.000441815	-9.28669E-06
31	2005	4.9	4.8	0.68124	0.000898455	-2.69305E-05
32	2006	4.9	4.8	0.68124	0.000898455	-2.69305E-05
33	2007	5.5	4.8	0.68124	0.000898455	-2.69305E-05
34	2008	6.3	4.7	0.67210	0.001530189	-5.98573E-05
35	2009	5	4.7	0.67210	0.001530189	-5.98573E-05
36	2010	5.2	4.7	0.67210	0.001530189	-5.98573E-05
37	2011	5.1	4.6	0.66276	0.002348144	-0.000113786
38	2012	5.3	4.6	0.66276	0.002348144	-0.000113786

39	2013	5.3	4.5	0.65321	0.003364344	-0.000195142
40	2014	4.9	4.3	0.63347	0.0060446	-0.00046995
41	2015	4.5	4.2	0.62325	0.007738051	-0.000680687
			5.16829268	0.71122	0.074283608	0.002032143

Variance = 0.00185709

Standard Deviation = 0.04309397

Skew coefficient = 0.66736604

Table A. 6 Results to be plotted on Log Probability Paper for Quetta

P_n	k(0.6)	K(0.7)	slope	k(0.667366045)	m	Return Period 'I'
99	-1.88	-1.806	0.74	-1.8301491	4.288911583	1.0101
50	-0.99	-0.116	8.74	-0.4012208	4.942256573	2
20	0.8	0.79	-0.1	0.7932634	5.564169498	5
10	1.328	1.333	0.05	1.3313683	5.869342152	10
4	1.939	1.9672	0.282	1.95799722	6.245875954	25
2	2.359	2.407	0.48	2.3913357	6.520300772	50
1	2.755	2.824	0.69	2.80148257	6.791136911	100
0.5	3.132	3.223	0.91	3.1933031	7.060372063	200
0.1	3.96	4.105	1.45	4.05768077	7.692669108	1000

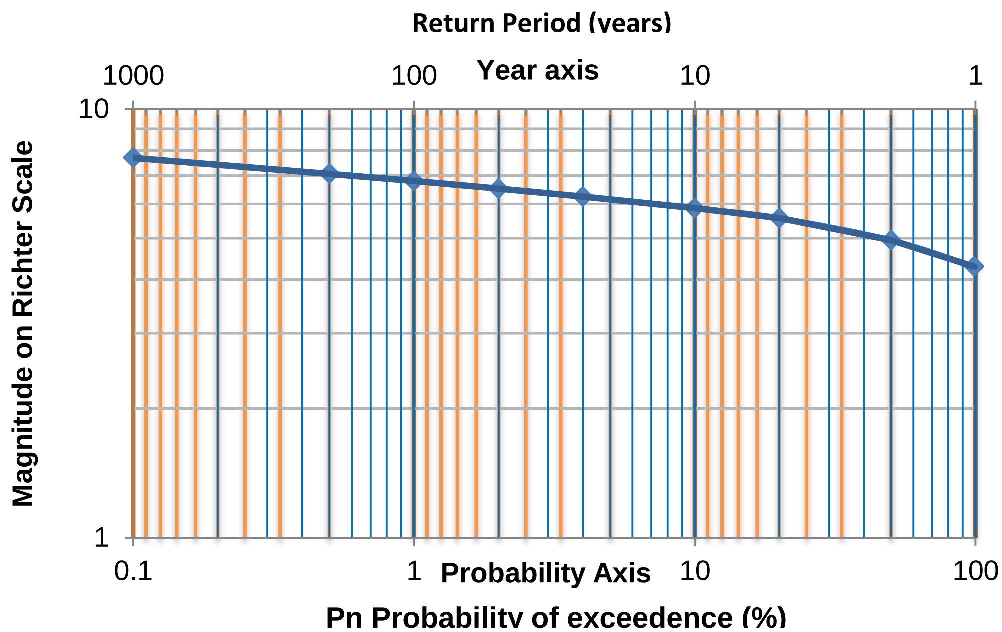

Figure A. 3 Probability Analysis of Earthquake Intensity for Quetta

APPENDIX B

GUTENBERG-RICHET RELATIONSHIP

Table B. 1 Gutenberg- Richet Relationship for Islamabad

Magnitude 'Mw'	Number	Cumulative number 'N'	Midpoint of Magnitude Range	log (N)
2-3	325	3073	2.5	3.48756256
3-4	1735	2748	3.5	3.439016728
4-5	890	1013	4.5	3.005609445
5-6	118	123	5.5	2.089905111
6-7	4	5	6.5	0.698970004
7-8	1	1	7.5	0

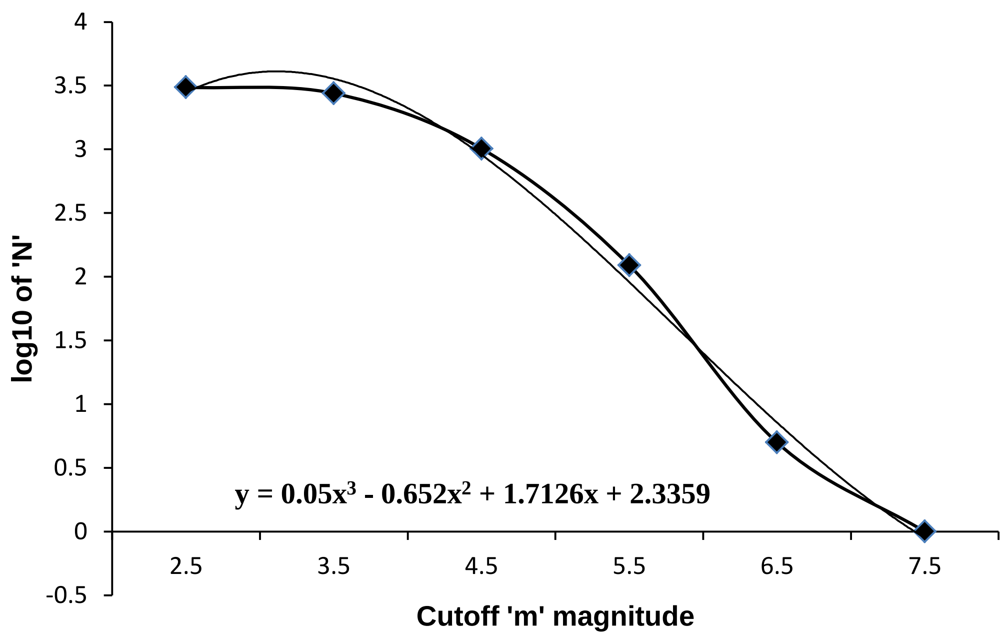

Figure B. 1 Gutenberg- Richet Relationship for Islamabad

Table B. 2 Results for Islamabad

Magnitude	Number of Earthquakes
2	3573.551127
3	903.0254703
4	90.01191471
5	7.061549374
5.5	2.243623602
6	0.869961433
6.5	0.448797057
7	0.33581493

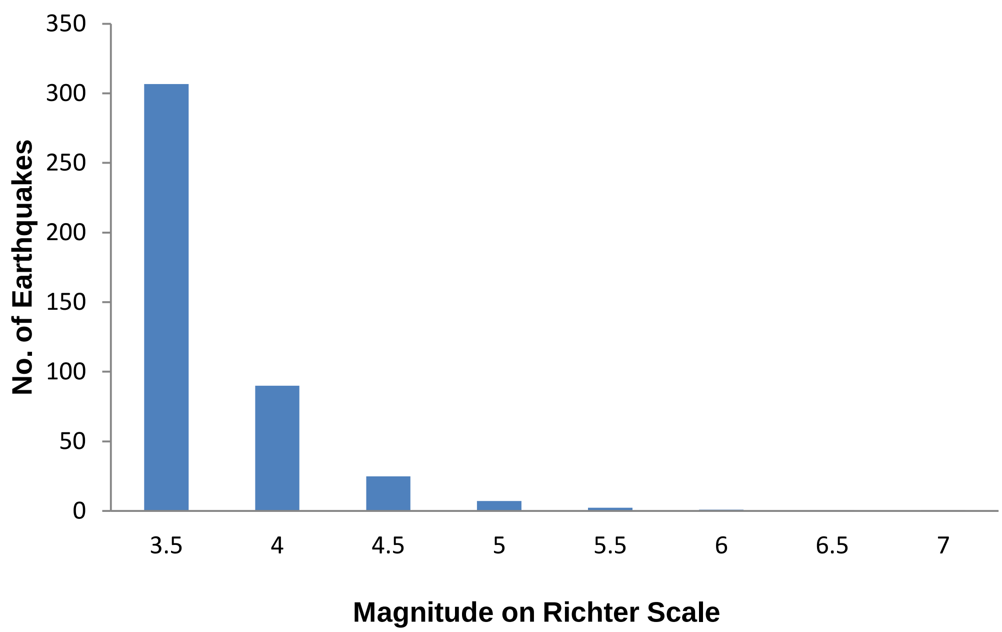

Figure B. 2 Bar Chart for Islamabad

Table B. 3 Gutenberg- Richet Relationship for Muzaffarabad

Gutenberg- Richet Relationship for Muzaffarabad				
Magnitude ‘Mw’	Number	Cumulative number 'N'	Midpoint of Magnitude Range	log (N)
2-3	193	3170	2.5	3.501059262
3-4	1792	2977	3.5	3.473778835
4-5	1036	1185	4.5	3.07371835
5-6	142	149	5.5	2.173186268
6-7	6	7	6.5	0.84509804
7-8	1	1	7.5	0

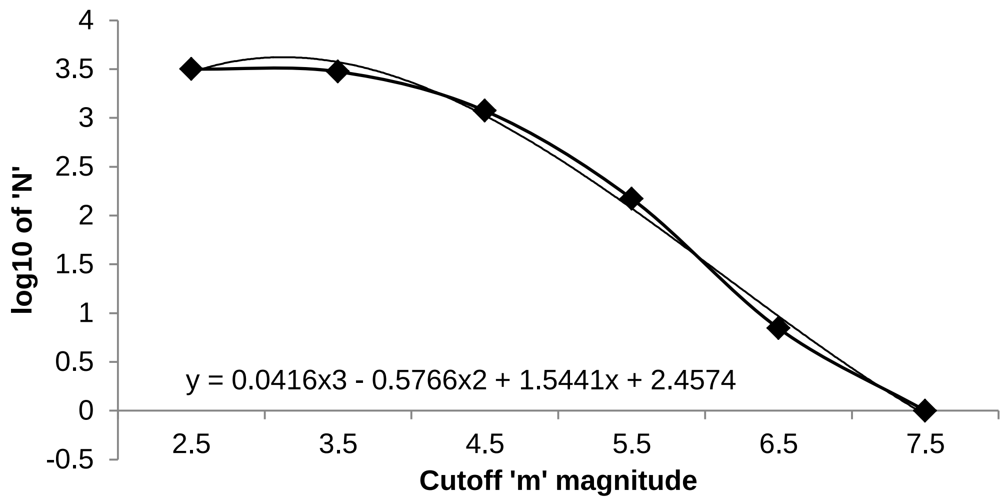

Figure B. 3 Gutenberg- Richet Relationship for Muzaffarbad

Table B. 4 Results for Muzaffarabad

Magnitude	Number of Earthquakes
2	3732.501578
3	1055.601503
4	117.6521858
5	9.181211669
5.5	2.685344446
6	0.891250938
6.5	0.360661679
7	0.191205332

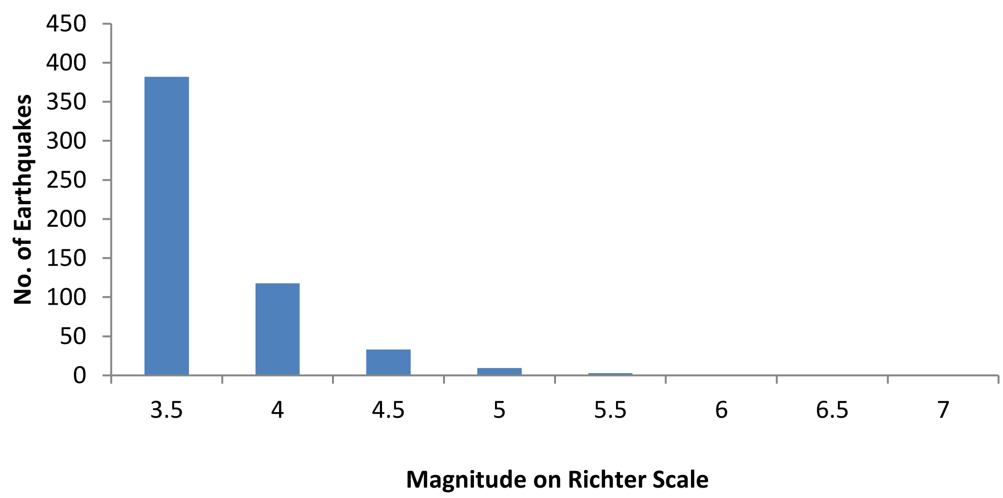

Figure B. 4 Bar-chart of Muzaffarabad

Table B. 5 Gutenberg- Richet Relationship for Quetta

Magnitude 'Mw'	Number	Cumulative number 'N'	Midpoint of Magnitude Range	log (N)
2-3	1	1123	2.5	3.050379756
3-4	586	1122	3.5	3.049992857
4-5	485	536	4.5	2.72916479
5-6	48	51	5.5	1.707570176
6-7	3	3	6.5	0.477121255

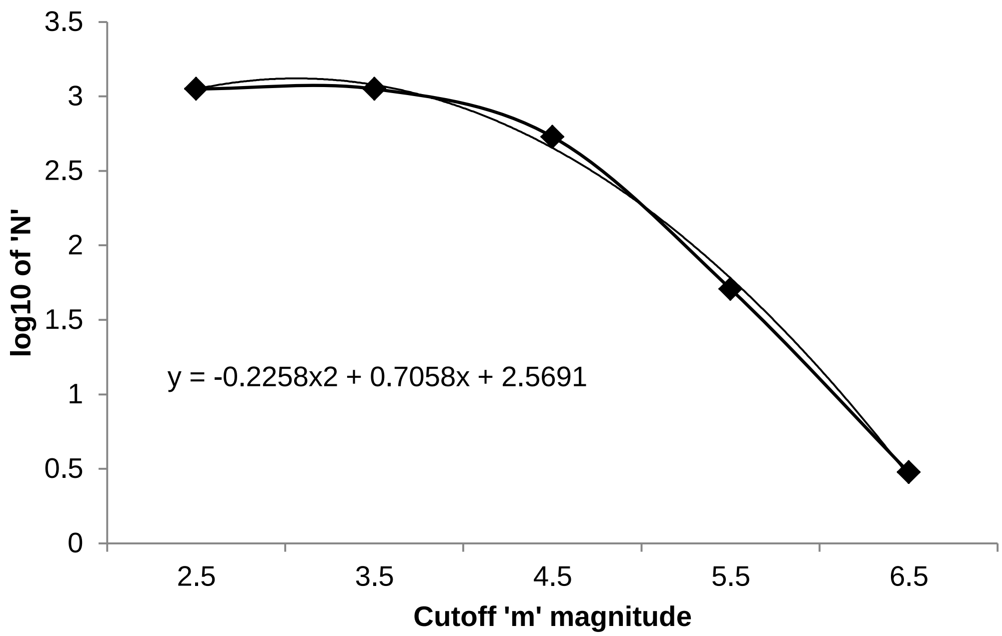

Figure B. 5 Gutenberg- Richet Relationship for Quetta

Table B. 6 Results for Quetta

Magnitude	Number of Earthquakes
2	1195.363526
3	451.1282253
4	60.18662629
5	2.838572559
5.5	0.41739765
6	0.047326022
6.5	0.004137614
7	0.000278933

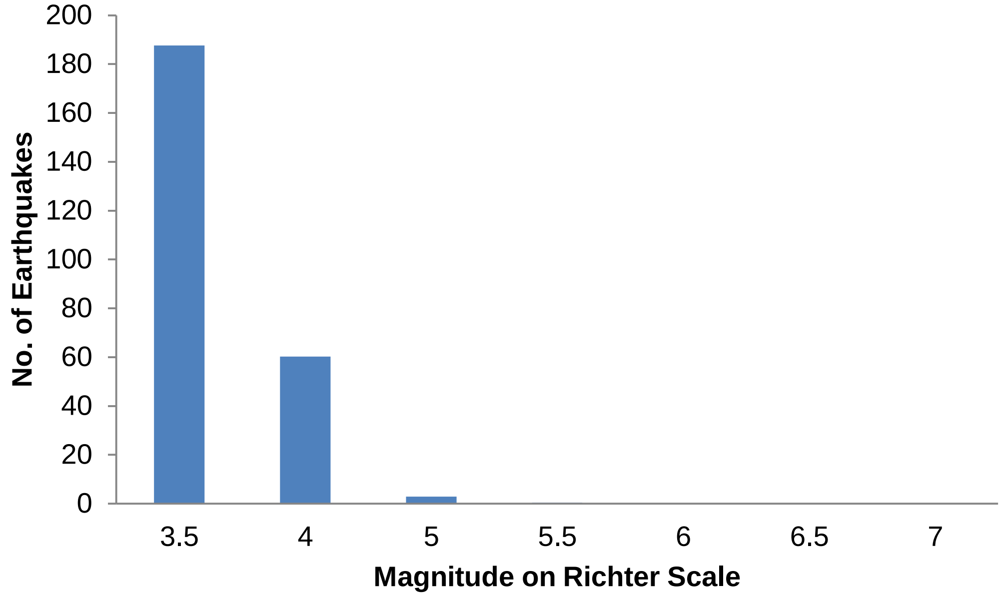

Figure B. 6 Bar Chart for Quetta

APPENDIX C

VALUE OF 'K'

SKEW COEFFICIENT Cs	Recurrence Interval In Years							
	1.0101	2	5	10	25	50	100	200
	Percent Chance (>=) = 1-F							
	99	50	20	10	4	2	1	0.5
3	-0.667	-0.396	0.420	1.180	2.278	3.152	4.051	4.970
2.9	-0.690	-0.390	0.440	1.195	2.277	3.134	4.013	4.904
2.8	-0.714	-0.384	0.460	1.210	2.275	3.114	3.973	4.847
2.7	-0.740	-0.376	0.479	1.224	2.272	3.093	3.932	4.783
2.6	-0.769	-0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.5	-0.799	-0.360	0.518	1.250	2.262	3.048	3.845	4.652
2.4	-0.832	-0.351	0.537	1.262	2.256	3.023	3.800	4.584
2.3	-0.867	-0.341	0.555	1.274	2.248	2.997	3.753	4.515
2.2	-0.905	-0.330	0.574	1.284	2.240	2.970	3.705	4.444
2.1	-0.946	-0.319	0.592	1.294	2.230	2.942	3.656	4.372
2	-0.990	-0.307	0.609	1.302	2.219	2.912	3.605	4.298
1.9	-1.037	-0.294	0.627	1.310	2.207	2.881	3.553	4.223
1.8	-1.087	-0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.7	-1.140	-0.268	0.660	1.324	2.179	2.815	3.444	4.069
1.6	-1.197	-0.254	0.675	1.329	2.163	2.780	3.388	3.990
1.5	-1.256	-0.240	0.690	1.333	2.146	2.743	3.330	3.910
1.4	-1.318	-0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.3	-1.383	-0.210	0.719	1.339	2.108	2.666	3.211	3.745
1.2	-1.449	-0.195	0.732	1.340	2.087	2.626	3.149	3.661
1.1	-1.518	-0.180	0.745	1.341	2.066	2.585	3.087	3.575
1	-1.588	-0.164	0.758	1.340	2.043	2.542	3.022	3.489
0.9	-1.660	-0.148	0.769	1.339	2.018	2.498	2.957	3.401
0.8	-1.733	-0.132	0.780	1.336	1.993	2.453	2.891	3.312
0.7	-1.806	-0.116	0.790	1.333	1.967	2.407	2.824	3.223
0.6	-1.880	-0.099	0.800	1.328	1.939	2.359	2.755	3.132
0.5	-1.955	-0.083	0.808	1.323	1.910	2.311	2.686	3.041
0.4	-2.029	-0.066	0.816	1.317	1.880	2.261	2.615	2.949
0.3	-2.104	-0.050	0.824	1.309	1.849	2.211	2.544	2.856
0.2	-2.178	-0.033	0.830	1.301	1.818	2.159	2.472	2.763
0.1	-2.252	-0.017	0.836	1.292	1.785	2.107	2.400	2.67
0	-2.326	0.000	0.842	1.282	1.751	2.054	2.326	2.576

Figure C. 1 Value of 'k' for positive value of skew-coefficient

	Recurrence Interval In Years							
	1.0101	**2**	**5**	**10**	**25**	**50**	**100**	**200**
SKEW COEFFICIENT	Percent Chance (>=) = 1-F							
Cs	**99**	**50**	**20**	**10**	**4**	**2**	**1**	**0.5**
0	-2.326	0.000	0.842	1.282	1.751	2.054	2.326	2.576
-0.1	-2.4	0.017	0.846	1.27	1.716	2.000	2.252	2.482
-0.2	-2.472	0.033	0.850	1.258	1.680	1.945	2.178	2.388
-0.3	-2.544	0.050	0.853	1.245	1.643	1.890	2.104	2.294
-0.4	-2.615	0.066	0.855	1.231	1.606	1.834	2.029	2.201
-0.5	-2.686	0.083	0.856	1.216	1.567	1.777	1.955	2.108
-0.6	-2.755	0.099	0.857	1.200	1.528	1.720	1.880	2.016
-0.7	-2.824	0.116	0.857	1.183	1.488	1.663	1.806	1.926
-0.8	-2.891	0.132	0.856	1.166	1.448	1.606	1.733	1.837
-0.9	-2.957	0.148	0.854	1.147	1.407	1.549	1.660	1.749
-1	-3.022	0.164	0.852	1.128	1.366	1.492	1.588	1.664
-1.1	-3.087	0.180	0.848	1.107	1.324	1.435	1.518	1.581
-1.2	-3.149	0.195	0.844	1.086	1.282	1.379	1.449	1.501
-1.3	-3.211	0.210	0.838	1.064	1.240	1.324	1.383	1.424
-1.4	-3.271	0.225	0.832	1.041	1.198	1.270	1.318	1.351
-1.5	-3.33	0.240	0.825	1.018	1.157	1.217	1.256	1.282
-1.6	-3.880	0.254	0.817	0.994	1.116	1.166	1.197	1.216
-1.7	-3.444	0.268	0.808	0.970	1.075	1.116	1.140	1.155
-1.8	-3.499	0.282	0.799	0.945	1.035	1.069	1.087	1.097
-1.9	-3.553	0.294	0.788	0.920	0.996	1.023	1.037	1.044
-2	-3.605	0.307	0.777	0.895	0.959	0.980	0.990	0.995
-2.1	-3.656	0.319	0.765	0.869	0.923	0.939	0.946	0.949
-2.2	-3.705	0.330	0.752	0.844	0.888	0.900	0.905	0.907
-2.3	-3.753	0.341	0.739	0.819	0.855	0.864	0.867	0.869
-2.4	-3.800	0.351	0.725	0.795	0.823	0.830	0.832	0.833
-2.5	-3.845	0.360	0.711	0.711	0.793	0.798	0.799	0.800
-2.6	-3.899	0.368	0.696	0.747	0.764	0.768	0.769	0.769
-2.7	-3.932	0.376	0.681	0.724	0.738	0.740	0.740	0.741
-2.8	-3.973	0.384	0.666	0.702	0.712	0.714	0.714	0.714
-2.9	-4.013	0.390	0.651	0.681	0.683	0.689	0.690	0.690
-3	-4.051	0.396	0.636	0.660	0.666	0.666	0.667	0.667

Figure C. 2 Value of 'k' for negative value of skew-coefficient