EARTHQUAKE RISK ASSESSMENT OF KHYBER PAKHTUNKHAWA PROVINCE, PAKISTAN

By

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DEDICATED

TO

MY PARENTS AND MY FAMILY

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ABSTRACT

Kashmir 2005 and recent earthquakes in Baluchistan 2013 demand the earthquake hazard and risk assessment of whole country. Assessing the risk associated with earthquake is challenging as well as very essential component for earthquake risk mitigation. Many researchers have already work on hazard assessment of the whole or part of country but the earthquake risk assessment has not been carried out at national or provincial level. Therefore Earthquake Risk Assessment (ERA) of Khyber Pakhtunkhawa (KPK) was selected for this study. ERA framework developed by Khan (2011) has been used in hazard and risk calculation. Seismic hazard in terms of Peak Ground acceleration (PGA) was estimated for period of 100 years using Probabilistic method. Ambarasey's 2005 Ground Motion Prediction Equation (GMPE) was used in the hazard assessment considering the local soil effects in term of shear wave velocity, while building inventory was developed from projected census data. Maximum PGA of 0.39 g occurred in region of district Mansehra, district Battagram and some parts of district Shangla across Indus River. It was observed that average risk per $1000 ranged between $(5 -145) depending upon the type of building and its location. It has been concluded that most of the risk is concentrated in six districts in order of severity i.e Masehra, Battagrarm, Kohistan, Swat, Chitral and Abbottabad due to high hazard and vulnerability of building stock. Seismic risk estimated was compatible with seismo-tectonic of area, exposure and vulnerability of building stock. Insurance premium was calculated for the study region and risk mitigation recommendations are made for the study region.

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ABBREVIATIONS

ADB-WB	Asian Development Bank and World Bank
AS	Adobe Structures
AJ&K	Azad Jammu and Kashmir
BCP	Building code of Pakistan
CRED	Centre for Research on the Epidemiology of DF Damage Factor
DSHA	Deterministic Seismic Hazard Assessment
EQ-RACY	Earthquake Risk Assessment Cyprus
ERA	Earthquake Risk Assessment
ERM	Earthquake Risk Management
ERRA	Earthquake Reconstruction and Rehabilitation Authority
FBS	Federal Bureau of Statistics
FEMA	Federal Emergency Management Agency
GESI	Global Earthquake Safety Initiative
GIS	Geographic Information System
GSHAP	Global Seismic Hazard Assessment Program
GSP	Geological Survey of Pakistan
HAZUS	Hazard United States
IDNDR	International Decade for Natural Disaster Reduction
ISC	International Seismological Centre
MDF	Mean Damage Factor
MHW	Ministry of Housing and Works
MMI	Modified Mercali Intensity
NDMA	National Disaster Management Authority
NESPAK	National Engineering Services Pakistan

NGA	Next Generation Attenuation
NIBS	National Institute of Building Science
NUST	National University of Sciences and Technology
PGA	Peak Ground Acceleration
PMD	Pakistan Meteorological Department
POE	Probability of Exceedance
PSHA	Probabilistic Seismic Hazard Assessment
PTHA	Probabilistic Tsunami Hazard Assessment
RADIUS	Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters
RC	Reinforced Concrete
RCF	Reinforced Concrete Framed Structures
RCI	Reinforced Concrete Frames with Masonry Infills
REC	Randomized Earthquake Catalogue
RMS	Risk Mitigation Strategy
RSM	Rubble Stone Masonry
SHA	Seismic hazard assessment
URM	Unreinforced Brick Masonry
UC	Union Council
USA	United States of America
USGS	United States Geological Survey
WHE	World Housing Encyclopaedia

NOTATIONS

a	acceleration, constant for seismic source
b	constant for the seismic source
Db	total number of collapsed buildings for building class b
F_N	Normal Fault
Fo	Other Fault
Hi	seismic hazard (i=1 to n).
i	event number
j	location number
LF	Load Factor to cover taxes
M_w	moment magnitude,
M_0	Seismic Moment
M1	population per building
M2	occupancy at Time of Earthquake:
M3	occupants trapped by collapse:
M4	Injury distribution at collapse:
M5	post collapse mortality:
Mb	body wave magnitude
Ms	Earthquake Surface Wave Magnitude
Mb	Earthquake Body wave Magnitude
M_{max}	maximum magnitude
Ms	earthquake surface wave magnitude
RA	rupture area
RLD	subsurface rupture length
RW	rupture width

S	shaking intensity, soil parameter
V_{S30}	average shear-wave velocity
S_A	stiff soil factor
Ss	soft soil factor

Chapter # 1

INTRODUCTION

1.1 INTRODUCTION

The seismic risk assessment is the foundation for risk mitigation strategies, a major step in risk management. Government and large organization in related industries (i.e. Insurance industry) analyze the seismic risk to allocate their resources in best possible way to utilizing constrained funds for retrofitting of existing structures or other risk mitigation measures such as emergency planning. In computing risk monetary losses, causality assessment and socio-economic losses due to infrastructure damage are considered. The, road, water supply systems, lifelines and other facility are also considered along with direct building damage for risk calculations. Insurance industry utilizes the results of seismic risk in their operations, to confirm suitable insurance rates, to screen over-gathering of strategies in a little range, and to buy re-insurance.

Seismic risk is normally resolved utilizing seismic modeling computer software's, which uses the seismic hazard inputs and combines them with the known vulnerabilities of structures and facilities, such as buildings, bridges, lifeline, Gird stations, etc. The result gives probabilities for economic damage or casualties, for example the RADIUS computer program. The results obtained from these studies could be utilized as a general measure of seismic risk for sorts of edifices; the real seismic risk for single building may shift respectably and will hinge on its correct design, structural plan and condition. Acquiring the particular information for a singular building or office is a standout amongst the most unmanageable and challenging parts of seismic risk estimation.

Earthquake risk is the potential losses and number of people that are expected to be hurt or killed if a likely earthquake on a particular fault or area occurs.

Earthquakes occur due to sudden release of energy by seismic waves that generates due to movement of Earth's crust. At the Earth's surface, earthquakes produce vibration, shaking and sometimes displacement of the ground. Only in the 1^{st} decade of twenty first century, nearly 60 per cent of the people killed by natural disasters died because of earthquakes (CRED, 2009). Earthquakes are not only dangerous because of the ground shaking they produce but because of the secondary events that they generate, such as building collapse, Landslides, fires, tsunamis (seismic sea waves) and volcanoes.

The earthquake will remain a serious threat for huge number of people all over the world as many of the most populated cities in the world lies on earthquake fault-lines. i.e(Loss Angles, Madrid, Tehran, Mansehra, Muzaffarabad).We cannot prevent or accurately predict an earthquake but life and economic losses can be significantly reduced by earthquake risk mitigation. The optimum level of risk management could only be achieved when the risk is known. This provides the need for earthquake risk assessment (ERA) that is loss estimation through a loss estimation model that combines seismic hazard and vulnerability models with building inventories to estimate the extent of future damage and the socio-economic consequences from seismic events.

In terms of losses Asia is the continent that has been struck again and again by earthquakes by large earthquakes. In developing countries either buildings are not designed or design without seismic detailing. Also Poor quality of construction practices and materials make the building stock highly vulnerable. A large number of pre-code buildings exist in these countries. These factors with high population density and ever growth of building stock make the risk assessment a necessity.

Earthquake Risk Assessment (ERA) of whole Pakistan is needed at this stage but ERA of whole Pakistan is overwhelming task so the work is divided into many MS thesis. In this report ERA of Khyber Pakhtunkhawa (KPK) province is selected as MS thesis .The scope of thesis includes the calculation of the financial risk and insurance premium of the building stock in KPK province.

Pakistan is situated in South Asia between longitudes 61º & 76º E and latitudes 24º & 37º N having a total area of 796,095 sq. km. Tectonically, the Pakistan region comprises of diverse nature of geological/tectonic features as it lies at the junction of Indian, Eurasian and Arabian plate boundaries. (Rafi et al., 2011)

The study region is located in the north-west of Pakistan. The capital of KPK province is Peshawar. The province consists of 24 districts with approximate estimated total population of 25,956,829(FBS, 2012). Hindukush and Some portion of Himalayas range are in KPK which make it seismically active region. Kashmir 2005 earthquake that claimed the lives of more than 85,000 people and a devastation of financial loss of approximately $3.5 billion (ADB-WB, 2005) severely affected some areas of KPK province. Approximately 3.5 million people became homeless, bereaving them of food and shelter (ERRA, 2007)

A number of risk assessment software are available that include HAZUS (USA), RADIUS (Japan), RISK-UE (Europe) etc. These softwares are good for developed countries where seismo-tectonic data and building inventories are easily available but in developing country like Pakistan limited availability of data required by these software make them difficult to calculate the seismic risk. So, for the purpose the ERA framework developed by Khan (2008) will be used that uses lesser number of data variables suitable for a developing country like Pakistan. The need for this study could be ascertained by the fact that the risk assessment is considered to be the first step towards the formulation of risk mitigation strategies (Khan, 2011). Assessment of damage costs due to an earthquake is also an important issue for the insurance industry and the ERA results may be used to determine the insurance premium rates. The ERA of the study region will also prove to be a source of reference and comparison for further studies using different ERA software.

1.2 AIMS & OBJECTIVES

The main aim of this thesis is to calculate earthquake risk of KPK Province. Following are the main objectives for this thesis.

- To apply ERA framework to study region (KPK province) and calculate the seismic hazard and risk at Union Council (UC) level.
- Highlight the high risk areas
- Estimate the annual insurance premium for the study region
- To determine various Risk Mitigation Strategies (RMS) for study region.

1.3 STRUCTURE OF PROJECT REPORT

This thesis presents Earthquake risk assessment of KPK Province, Pakistan.

Chapter 2 deals with the literature review and discusses the Probabilistic seismic hazard methodology.

Chapter 3 discusses the data required for risk assessment. This chapter also presents the data collected and sources of data.

Chapter 4 describes the methodology uses in current study.

Chapter 5 describes the hazard and risk estimated in current study. In this chapter the ERA framework is validated using Kashmir Earthquake data.

Chapter 6 presets conclusion of study and recommendation for study area.

Chapter # 2

LITERATURE REVIEW

2.1 INTRODUCTION

Earthquake Risk Assessment is essential for risk mitigation. ERA is carried out for different part of world and assessment in progress for certain regions. ERA consists of three components: Earthquake Hazard, Vulnerability assessment and Risk Assessment. The literature review discusses ERA, Seismic Hazard Assessment (SHA) and Seismology of study region, vulnerability assessment and building inventory development.

2.2 EARTHQUAKE RISK ASSESSMENT (ERA)

2.2.1 Introduction

Although damaged caused by earthquake to human life is decreasing with time but the Socio-economic loss has increased many times in last decades (Vacareanu et al., 2004). The number of deaths and economic losses are dependent upon the earthquake magnitude, distance of populated area from origin of earthquake and building stock of area. The damages causes by earthquakes are more sever in developing countries due to lack of awareness, preparedness and high vulnerability of building stock (Khan, 2011).

Earthquake Risk Assessment (ERA) is the essential step in developing Risk Management Strategies (RMS) as it gives estimate of likely maximum loss that can occur due to a future destructive earthquake. ERA can be used in risk mitigation programs such as seismic strengthening and seismic code preparation & implementation (Kythreoti, 2002). Risk mitigation programs based on ERA can reduce the fatalities, injuries and damaged infrastructure and economic losses that may occur due earthquake (Dowrick, 2009). The future disasters can be reduced through Risk Mitigation Strategies (RMS).

2.2.2 Seismic Risk

Seismic risk is the loss which an earthquake will result in region for certain period of time. According to Dowrick (2009) Seismic Risk can be defined as:

$$\text{Seismic risk} = (\text{Seismic hazard}) \times (\text{Vulnerability}) \times (\text{Value}) \quad (2.1)$$

Where:

Seismic hazard is the expected ground motion or other physical consequence of earthquake like liquefaction or landslides,

Vulnerability is the amount of damage induced by a given degree of hazard, and expressed as a ratio of the Value of the damage to the total cost of the item under consideration.

Value is the amount of cost of exposed infrastructure.

A more comprehensive expression as given by Kythreoti (2002) for seismic risk R is

$$R = \sum_{i=1}^{n} \sum_{j=1}^{m} (H_i * V_{ij}) * C_j \quad (2.2)$$

Where H_i is the Seismic Hazard (i = 1 to n).

V_{ij} is the Vulnerability, of each element j at risk for each hazard i.

C_j is the Value of element j at risk, e.g. buildings, economic activities; Public services in the area are under consideration.

2.3 SEISMIC RISK ALL OVER THE WORLD

A compilation of global investigation tells us that the number of earthquake risk assessment programs have been carried out and some program are still active. Earthquake risk assessments with different titles have been carried for number of cities.

In Japan Oyo Corporation and INDAR RADIUS has carried out the risk assessment in Kawasaki City, Saitama Prefecture, Knagawa prefecture, Quito, Tehran (Komaru et al. 1995). EPEDAT (The Early Post –Earthquake Damage Assessment Tool) is a GIS based system capable of estimating earth risk for building and lifelines was used for ERA of different cities. Earthquake risk assessment for Istanbul was carried out by M Edrik (2003). European Union has launched program for ERA for different major cities.

2.4 SEISMIC HAZARD

The probability of earthquake shaking reaching or exceeding a certain intensity (or macro seismic intensity) during a certain period determines the seismic hazard for a specific area. Other parameters, which can also determine the seismic hazard, are maximum acceleration, velocity or displacement. It can be calculated as annual frequency of exceedance of different ground level motions.

Seismic hazard calculation required the detail information about seismo-tectonic, active fault system in the region and earthquake recurrence relationships, geological & geotechnical details of study area and suitable ground motion prediction equation (GMPE) for study region.

2.5 EARTHQUAKE AND SIESMO-TECTONICS

Earth crust is divided into number of part having thickness of few km to 100km. These plates are known as tectonic plates and these palates are always in motion. Some plates collided with each other and other are moving away from each other. The relative motion of tectonic plates accumulates strain energy which is rebounded by these plates in the form of seismic waves results an Earthquake. Hence the earthquakes occur at boundary of these plates. This is known as elastic rebound theory first proposed by Reid (1910) and demonstrates well the formation of faults, large geological features and mountain ranges.

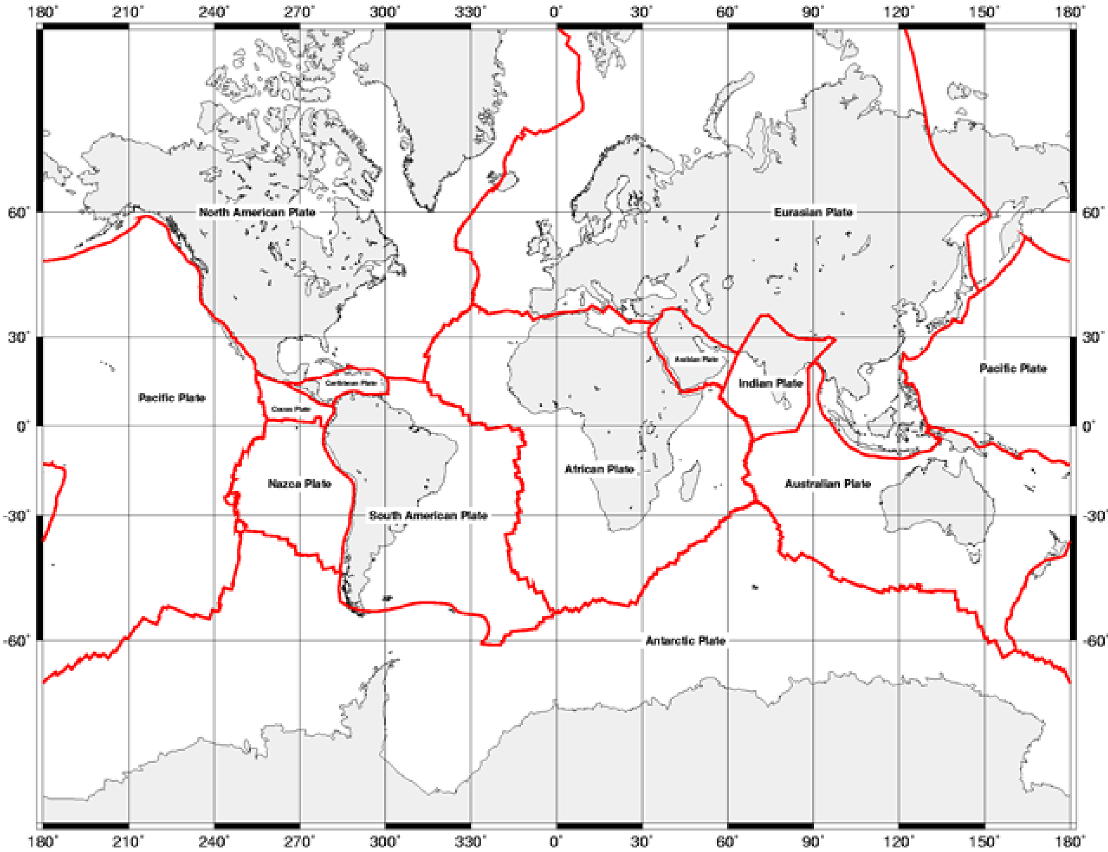

Figure 2.1 – Tectonic Plate Setting of Earth

2.5.1 Tectonic setting of the region

Pakistan is situated on north- west of Indian plate that pushes into Eurasian plate. The verge of these two plates is a concurrent limit. The Indian subcontinent has been impacting Eurasian sub mainland in the course of the last 30-40 million years (Aitchinson et al; 2007). Throughout this period monstrous mountains runs on Northern, Western and in addition Southern Pakistan are framed because of shortening of lithosphere. This greatly animated seismic zone is enlarged in Kashmir, Northern India and Afghanistan. Seismic tremors along dynamic blames in Pakistan, Afghanistan and India are the immediate consequence of the movement of Indian subcontinent northward and impacting the Eurasian landmass at a rate of in the ballpark of 5cm/year (T.G Sitharam et al., 2013). Before this impact, this plate was moving with the most noteworthy rate of 20cm/year (Kumar et al., 2007). The most elevated mountain tops on the planet incorporating the Himalayan, the Karakoram, the Pamir and the Hindu Kush ranges are because of elevate initiated by the this major tectonic collision (A.Q Bhatti et al.,2011). Some of most amazing mountains processed because of crashes of these are; Himalayas, Karakoram, Kirthar and Suleman ranges in Pakistan, Arakan-Yoma mountains in Burma and Naga hills of Asam India, Hindukush Mountains in Pakistan-Afghanistan boarder.

Most of the earthquakes occur in Pakistan along this plate boundary. Study area lies in this zone and hence seismically active.

2.6 SEISMIC HAZARD ANALYSIS TECHNIQUES

Seismic Hazard Analysis (SHA) is defined as the probability that a ground motion or other consequences of earthquakes (Land slide, Liquefaction etc) of certain amplitude exceeds at a given area during a certain period. There are two methodologies for seismic hazard assessment of an area that are mentioned below.

2.6.1 Deterministic Method

In deterministic earthquake hazard approach a single event is selected then hazard/ ground motion is calculated at site due to this single event using suitable attenuation relationship. This process is repeated for all seismic events and the event with Maximum hazard at site is the controlling event.

2.6.2 Probabilistic Method:

It is well realized that uncertainties are key in the meaning of all components that go into seismic risk dissection, specifically since the questionable matters regularly drive the outcomes, and progressively so for low-exceedance probabilities. As could be expected this can at times lead to challenging decisions for decision makers. Objective answers for predicaments postured by lack of determination could be dependent upon the use of some type of probabilistic seismic peril investigation. Rather than the normal deterministic dissection, which makes utilization of discrete single-esteemed events or models to land at the obliged portrayal of seismic events, the probabilistic assessment permits the utilization of multiple model parameters. Of most criticalness, the probability of diverse extent of earthquakes happening is incorporated in the dissection. An alternate preference of probabilistic seismic peril examination is that it brings about an evaluation of the probability of ground motions or other harm measures happening at the area of investment. This considers a more advanced consolidation of seismic hazard into seismic risk; probabilistic seismic peril appraisals might be stretched to characterize seismic risk.

Cornell (1968) was the 1st to propose the methodology used in most probabilistic seismic hazard analysis (PSHA) carried out today. In the present work EQRAM a computer code prepared by Khan (2010) used for earthquake hazard assessment. The EQRAM code has user-friendly interface and it accommodates uncertainty in a number of seismicity model parameters.

2.7 PREVIOUS WORK ON HAZARD & RISK ASSESSMENT FOR KPK

Many studies have been carried out for the study region or the study region remains part of the large study area. A seismic hazard assessment of Pakistan based on a probabilistic approach was carried out under the Global Seismic Hazard Assessment Program (GSHAP) for the whole world (Rafi, 2011). Few studies have been carried out on hazard assessment of selected parts of the Khyber Pakhtunkhawa Province (Ali Q, 2005; Monalisa et al., 2007; PMD-NORSAR, 2007; Ahmed, 2008; Khan, 2011). But no broad scale study is done so far on Earthquake Risk Assessment (ERA) in Pakistan on national or provincial level. Therefore, the ERA of the Khyber Pakhtukhawa province is selected. KPK is located in the north-west of Pakistan (Shown in Figure 1). The capital of KPK province is Peshawar. The province consists of 24 districts with approximate estimated total population over 25 million (FBS Pakistan, 2012).

Pakistan Metrological Department (PMD) and NORSAR have carried out the seismic study of Pakistan after Kashmir earthquake (NORSAR and PMD 2006) and carried out the seismic zoning of Pakistan. Study area and surrounding are divided in to 19 Seismic source zones. Ambraseys et al. (2005) attenuation relationship is used. Computer software CRISIS 2003-CL, ver, 3.0.2 (Ordaz et al., 2003) is used.

Risk Assessment of Un- reinforced brick masonry structures for Mansehra has been carried out by Ahmed (2011). He carried out the site specific PSHA of Mansehra city. For 475 year return period a PGA of 0.25g on soil site estimated. He reported that 5% of the total single storey URBM buildings will collapse, 20% of the buildings will attain heavy damages and 21% buildings will be in repairable damages. Only 54% buildings of the will have no damage and estimated total loss of about US$ 7.64 million. Total injuries of 2294 ±459 people and fatalities of 29±6 will be expected for the exposure of 50years.

UNDP had overviewed 14240 structures in Muzaffarabad, something like 11047 edifices in Mansehra, 3000 structures in Quetta, 2500 in Chitral and in the vicinity of 1500 in Murree city for Earthquake Risk Assessment (ERA) in 2008. However literature is available on Hazard assessment of study area. Khan (2010) has carried out study for Pakistan in 2010 and compared results with work done by PMD & NESAPK (2007). In this study the Seismic hazard has been calculated based on PSHA methodology proposed by Khan (2010).

In 1992 1st hazard map for Pakistan was developed by PMD.

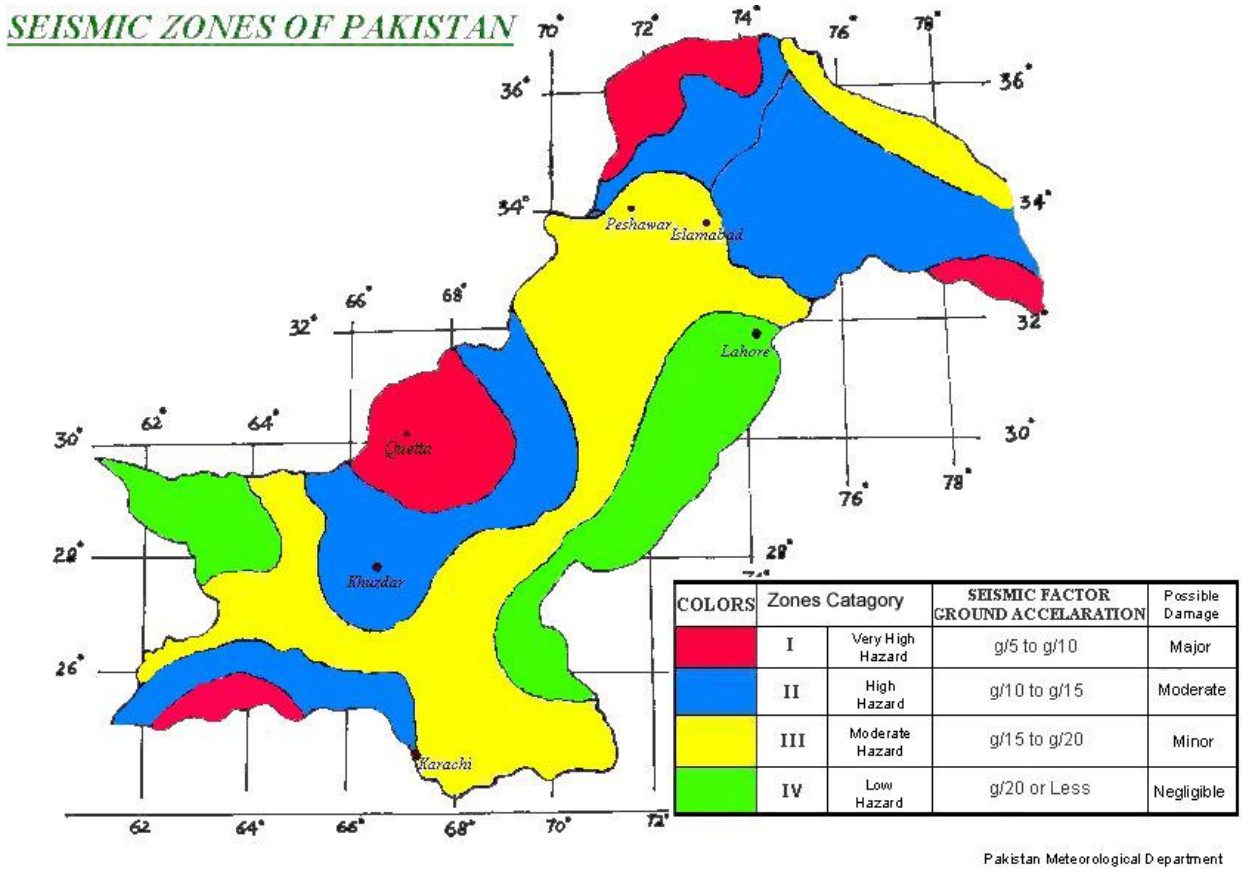

Figure 2.2 – 1st hazard maps for Pakistan (PMD,1992)

Hazard assessment and micro-zonation of Peshawar city using PSHA methodology was carried out (Ali, 2004). PMD carried out seismic hazard assessment of Whole country and developed hazard map.

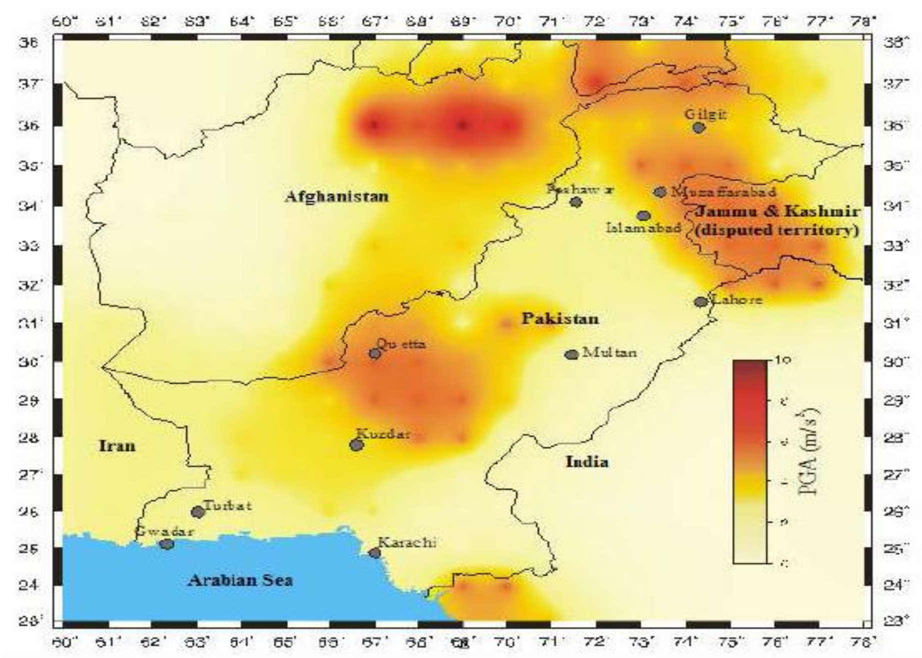

Figure 2.3 – PMD Hazard Map (2006)

Monalisa et al (2007) used areal source and historical seismicity to carry out the seismic hazard analysis of NW Himalayans region.

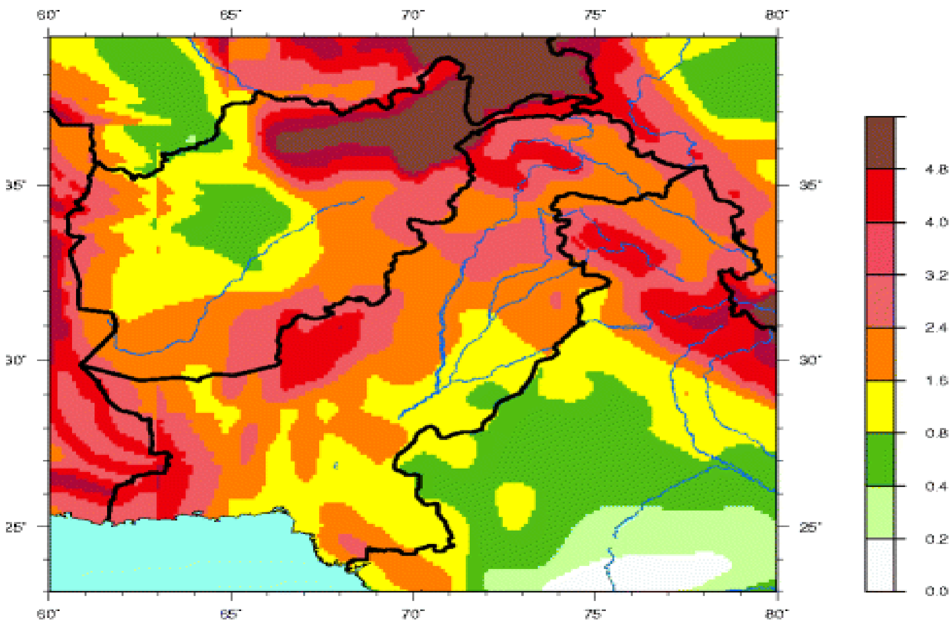

Figure 2.4 – USGS (GSHAP) Hazard Map for Pakistan for for 10% POE in 50 years (GSHAP, 2006)

After Kashmir Earthquake Ministry of Housing and Works has engaged NESPAK to develop seismic code for Pakistan. NESAPK with the help of national and international experts developed seismic Hazard map for Pakistan in 2007.

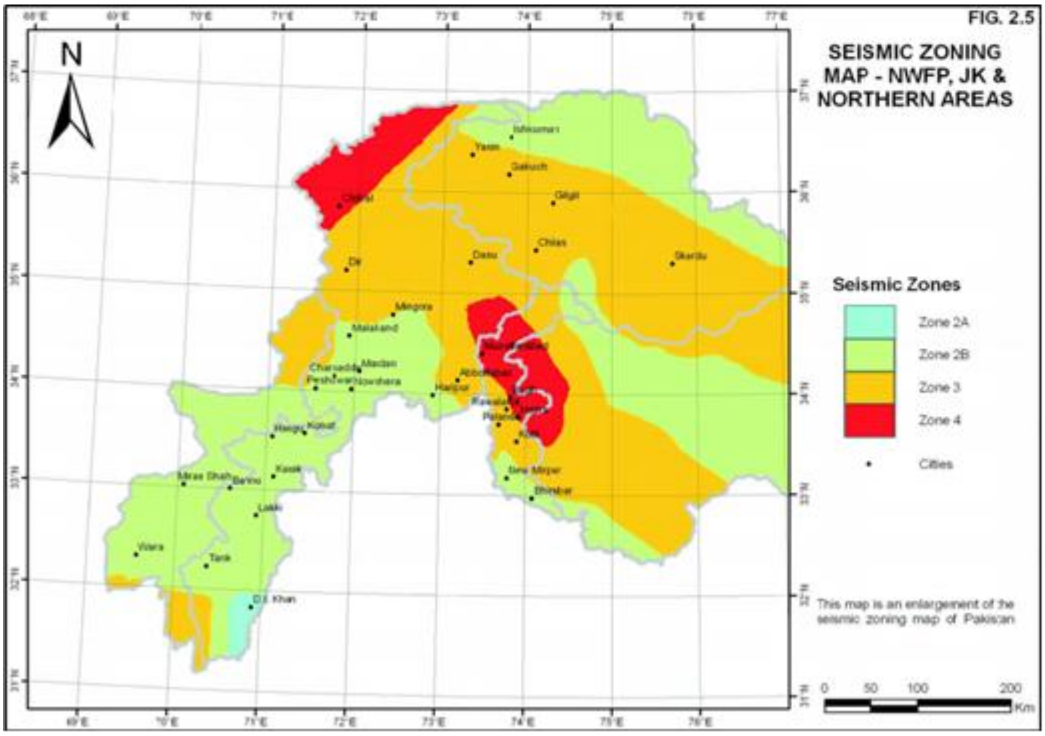

Figure 2.5 – BCP (2007) Seismic Hazard Map (10% POE in 50 years) of KPK, AJK & Northern Areas (BCP, 2007)

2.8 MODERN PSHA METHODOLOGY

Earthquake hazard assessment can be characterized of following components, the event (cause, time, location) and the resulting ground motion (amplitude, duration, frequency).

Probabilistic seismic hazard analysis (PSHA) include the above these part furnishing a technique to represent the connection among earthquake sources, ground motion variable associated to these sources, and exceedance of particular ground motion with time quantitatively.

2.8.1 Source Geometry

Seismic sources characterization portrays the rate at which seismic event of given size and magnitude occurs at a given area (Godinho.J, 2007). Identification and modeling the geometric properties of potential source is the first step of the source characterization. This incorporates defining the source, evaluating the source extents, and assigning uncertainty distribution to the source.

2.8.2 Types of Sources

2.8.2.1 Areal Sources

Due to inadequate geological data of a known fault, areal sources along with historical seismic data were initially used in hazard assessment. Uniform source properties both in space and time are assumed in case of such seismic zones. Areal sources are still in use in regions with unknown fault setting (Abrahamson, 2006).However today faults sources are used for most of hazard studies. Monalisa et al. (2007) used areal sources and historical seismicity to carry out the Seismic hazard analysis of NW Himalaya region.

2.8.2.2 Fault Sources

Identification and location of fault lines has become easy due to the availability of geological data. Most fault sources are of multi-planar features and ruptures, which were earlier modeled as linear, are now assumed to be dispersed over surface of fault plane (Abrahamson, 2006).

2.8.3 Estimation Fault Rupture Dimensions

Estimation of fault rupture length is very important as the wave motion generation and attenuation vary with rupture dimension. Dimension of fault rupture may either be estimated by the size of the fault rupture plane or by the size aftershock zone (Wells &

Coppersmith, 1994; Henry & Das, 2001). The corner frequency of the source spectra may also be used to estimate the rupture dimensions (Beresnev, 2002; Molnar et al, 1973; Savage, 2012). Evaluating fault rupture measurements straightforwardly requires the estimation of the length (L) of the fault and the seismogenic zone (correspond to the width, W) (Godinho.J, 2007). It becomes difficult especially in cases of no surface rupture. To distinguish between the tectonic rupture i.e. the primary source and the secondary accompanying fractures adds to the difficulty of application of the method (Wells & Coppersmith, 1994). Difference in the primary source rupture and secondary source rupture is that primary rupture directly occurs due to tectonic activity. Secondary rupture are fractures occurs due to causes associated with the primary rupture such as shaking of ground, landslides because of this shaking, or ruptures occurs from earthquakes triggered on neighboring faults (Wells & Coppersmith, 1994).

Spatial pattern of aftershocks are used to determine the length of the subsurface rupture in case of second method. This may also be used to determine the width of the rupture. This method is reliable but has uncertainties due to some factors (Godinho.J, 2007). As the aftershock zone expands with respect to time, so, time of application of the method is also very important (Henry & Das, 2001). The application of the method even after one day of the main event, estimates good results (Henry & Das, 2001). In light of above, the first method is being used in current study.

2.8.4 Uncertainty of Sources

Expected seismic events are assumed to be consistently dispersed along the fault strike; this assumption is supported by drawing hypocenter locations for different strike and dip-faults (Henry & Das, 2001). Despite the fact that other studies have prescribed that hypocenters of large earthquakes associated with sub-duction fault typically be found at the ends of ruptures. (Henry & Das, 2001)

2.8.5 Source Seismicity

Once the geometry of a seismic source is characterized the following step is to gauge the appropriation of all conceivable size events that can happen inside the source extents. This includes selection of suitable magnitude scale and representing the source seismicity by magnitude recurrence relation.

2.8.6 Magnitude Scales:

While dealing with seismicity it is significant to give careful consideration to magnitude scales. Case in point, there are some diverse approaches to express the extent of a quake, the most well-known utilizing surface, body and moment magnitudes. These earthquake magnitudes were determined using scales based on the estimation of seismic wave amplitudes at a selected period.

2.8.6.1 Surface wave Magnitude (Ms)

Surface wave magnitude represented by Ms is measured using the amplitude of surface Raleigh waves at a period of 20 sec. (Gutenberg & Richter, 1936).

2.8.6.2 Body wave magnitude, m_b

Body wave magnitude m_b, generally used for deeper earthquakes in which the surface waves are small enough to measured. It is associated to the amplitude of the first few cycles fastest body wave (P-waves) and is measured at of 1 sec period (Gutenberg, 1945).

2.8.6.3 Local magnitude, ML

The local magnitude, M_L developed by Richter (1935) to measure shallow, neighborhood earthquakes in state California is additionally measured at a time of around 1 sec. Earthquake magnitude scales that are measured in this time period range are frequently used and are often considered as better measures of seismic damage. This is in light of the fact that most regular structures have a natural time period which lies near to 1 sec.

The scale present above are not true representative of actual damage of an earthquake because these magnitude are related to shaking intensity of an earthquake, not the total energy released. The ground shaking parameters do not change at same rate as the total energy, scale saturation occurs for great earthquakes (Kramer, 1996).

2.8.6.4 Moment Magnitude – (Kanamori 1977, Hanks & Kanamori 1979)

A requirement of better presentation of earthquake magnitude scale was fulfilled by Hanks & Kanamori (1979) and developed moment magnitude (M_w), which is the most broadly utilized scale today, Mw, as defined by Hanks & Kanamori (1979) is related to the total energy released during an earthquake and function of seismic moment M_0 (Aki, 1966) which is the most major physical parameter of a seismic source that communicates the measure of a earthquake.

$$M = \frac{2\log(\mathrm{Mo})}{3} - 10.7 \qquad (2.3)$$

The seismic moment is of the product of earth rigidity μ, the fault rupture surface area A of that slips and the geological average slip u might be identified with the strain energy that is released during an earthquake by source,

$$M = \mu A u \qquad (2.4)$$

Where

μ = Shear modulus of earth crust (3×10^{11} dyne / cm)

A = Area of fault rupture plane

u = Average slip on rupture surface

2.8.7 Magnitude Recurrence Relations

After defining source geometry and selection of suitable earthquake magnitude scale the next step toward the SHA is to express the source seismicity through recurrence equation which is the average rate at which earthquake of magnitude greater than or equal to certain selected magnitude occur at on source (Godinho.J, 2007).

2.8.8 Magnitude Distribution

Probability density function is required to characterize the randomness in the amount of different size earthquakes that will happen on a given source. Two sorts of models are commonly used for magnitude distribution, the truncated exponential model & characteristic model. Despite the fact that the exponential model works well for extensive areas in which the peril is not regulated by one specific deficiency, studies have demonstrated that the characteristic model is more proper for portraying singular sources (Youngs & Coppersmith, 2000). A few models exploit a consolidated magnitude distribution, utilizing the truncated exponential model for the dispersion of little to-direct seismic events and the characteristic model for huge size events. (Youngs & Coppersmith, 2000).

a) Truncated Exponential Model

The Gutenberg-Richter developed this relationship (Gutenberg-Richter, 1956) and is expressed as:

$$\log \lambda m = a - bm \qquad (2.5)$$

The a-value presents the activity rate of the source which is the absolute rate of occurrence of earthquake with magnitude more than zero. b- value is identified with the relative probability of events with different sizes and ranges between 0.8-1.0. The exponential distribution of earthquake magnitudes shows that the mean recurrence rate for small magnitude earthquakes is higher than that of large magnitude earthquakes.

In spite of the fact that the standard Gutenberg-Richter relation could be connected to a vast reach of extents, it is in like manner practice to apply limits at minimum and maximum size. This is since seismic sources are generally associated with an ability to produce some maximum size earthquake M and for engineering purposes earthquake of small sizes that don't cause harm to structures are not of interest (Abrahamson, 2006). At the same time some fault systems inside seismic source don't comply with the Gutenberg-Richter law up to maximum magnitudes (Wenousky et al., 1994 & Dahmen et al., 1998).

b) Characteristic Earthquake Models

Characteristic models are dependent upon the presumption that unique fault have a tendency to create same size (within ½ size of one another), or "characteristic“quakes. characteristic model was initially proposed by Schwartz and Coppersmith (1985), before 1980's the magnitude connected with the characteristic events was dependent upon the assumption that only some portion of the fault length might rupture (e.g. ¼-½) (Abrahamson, 2006). Now complex fractures are considered in rupture and this multi-planner rupture in addition to single rupture is known as "cascading" (Abrahamson, 2006). One manifestation of the characteristic model, otherwise called extreme magnitude models, do not represent small to-medium sized estimated quake events along the fault.

c) Composite Model

Many studies have been carried out using combine approach. The model developed by combing the truncated exponential and characteristic model suit well to small and large magnitudes (Youngs & Coppersmith, 1985).

2.8.9 Activity Rates

While earthquake magnitude distribution models give the relative rate at different magnitudes, absolute rate of earthquake above a base magnitude is required to completely represent source seismicity through a recurrence model, reputed to be the activity rate. There are two methods to decide the activity rate of a seismic source, either through authentic seismicity or through geographical information.

2.8.10 Historical & Instrumental Seismicity

In seismically dynamic areas, in which there is sufficient historical data is accessible; it is conceivable the activity rate is dependent upon data recorded in earthquake catalogues. Historical seismicity is combined with truncated exponential distribution model to estimate activity rate. Statistical analysis of data is required to fit the data on exponential distribution model. Normally these values are calculated using regression analysis.

Earthquake records should be carefully examine to check that the record consist of independent event only because the accuracy of activity rate is wholly solemnly dependent on the accuracy of earthquake records. All Aftershocks and foreshock should be eliminated from the catalogues (Abrahamson, 2006). This is in light of the fact that probabilistic models utilized within the investigation ordinarily accept that all events are autonomous, and including these events might damage that presumption. Moreover, since all earthquake events might not have been accounted for in the index, especially small size events, the completeness of the catalogues must be evaluated. This could be accessed through method, for example, that created by Stepp (1973) which inspects the stationary nature of the activity rate. If all above conditions satisfy then we can calculate b-value and activity rate.

2.8.11 Geological Information (i.e. slip rate)

Historical earthquake record is suitable for estimation of activity rate when truncated exponential model is used, however the geological slip rate, can be useful to estimate activity rates for characteristic earthquake model (Youngs & Coppersmith, 1985). This method allows better estimate of earthquake frequency when historical & instrumental earthquake records are not available for some seismic area but he require a reliable estimate of geological slip rate (Youngs & Coppersmith, 1985).

2.8.12 Magnitude Occurrence with Time

Earthquake occurrence with time is a significant input in estimation of risk, particularly if event model keeps the memory of an occurrence or it is memory-less". According to Reid (1911) an earthquake is a result of the progressive accumulation of strain energy in the rock contiguous flaws. The assemble up of strain energy is an aftereffect of the relative displacement of the tectonic plates which cause shear stress accumulation at planes on the boundaries of tectonic plates. The point when the shear strength of rock is overcome, the rock breaks suddenly and the amassed strain energy is released. For ductile and weak rocks the smaller event occurs as the strain energy build-up will be slowly released. (Kramer, 1996).

2.8.12.1 Model without Memory

Most Probabilistic studies are based on this method .In this analysis earthquake process is assumed as memory less. That an event occurs today can occur at as the same location tomorrow .i.e there is no memory of occurrence with time location & magnitude. This implies that probability of occurrence in future is independent of the time elapsed since previous earthquake. It means the earthquake process follow the Poisson law. The accuracy of Poisson assumption is check by many researchers. In most practical cases the application of Poisson assumption is considered as the appropriate (Cornell & Winterstein, 1988).

2.8.12.2 Model with Memory

Some model keeps the memory of the earthquake location and magnitude. These model produce underestimates of hazard.

2.8.13 Attenuation Relations for Study Region

An attenuation relationship is the requirement for calculating ground motion at the site due an earthquake event at a distance. Boomer after detailed study on attenuation equations concluded that there is not a single equation even from nearby countries that can be used for SHA of Pakistan (Mona Lisa et al., 2005). For Pakistan there is no specific attenuation relationship established (PMD-NORSAR 2007) but relationship for similar region can be used. Khan (2011) compared different available attenuation model with PGA obtained at different station in 2005 Kashmir earthquake and found that Ambraseys et al. (2005) attenuation curve gives good results at distances greater than 100 km. For distances less than 100 km it gives lower PGA values as compared to those derived from observed intensities. However, the attenuation curve by Ambraseys et al. (2005) matches better with the instrumentally recorded PGA values (Khan, 2011). Ambraseys et al., (2005) Equation is used current study because:

a. Comparison of results of different available Attenuation equation with actual data of Kashmir Earthquake shows that Ambraseys (2005) relationship gives very closer results. (Khan.2011)
b. Data from Himalayan region is used for development of this equation.(Zhaid Rafi et al.2011)
c. Current Study area has shallow earthquakes same like the areas i.e Middle East and Europe, from where the data is used for development of this equation.
d. Tectonic settings of the Mediterranean are the almost similar to those of our region.
e. Earthquake data from the Himalayan region is used in development of this equation. This equation has been used in SHA of Mangla dam previously by Mona Lisa (Mona Lisa et al 2005).

f. This equation is preferred for Pakistan by PMD and NORSAR.(A.Q Bhatti et al.2011)

g. This is the most suitable equation for Pakistan when compared with different relationship specially some developed by Indian researcher (Zhaid Rafi et al.2011)

2.8.14 Monte Carlo Simulation

This is technique developed to solve complex problems. It calculates the probability suing random variables by simulation. The Monte Carlo simulation method has been previously used for PSHA (e.g. Shapira 1983, Koyanagi, 1988). This method generates synthetic earthquake catalogues using Monte Carlo process (using controlled random number). Each catalogue represents the next 100 year period in study region, and these new events are generated anywhere in region. A synthetic earthquake event is generated from recurrence relationship for N years (N=50 or 100) by randomizing magnitude and epicenter for each new event. An attenuation relationship is used to represent ground motion for each event in catalogue. The highest value of ground motion for each year in the catalogue is saved. Above three steps are repeated R times, where R is selected in such way that product of R and N is greater than 10^3 x return period.

2.8.15 Seismic Vulnerability

Vulnerability can defined as the sensitivity of the exposure to seismic hazard(s). The vulnerability of any structural or non structural element is usually presented as a percentage damage for a given hazard severity level (Coburn et al., 1994). In case of building stock, a group of large number of elements, vulnerability may be defined in terms of the damage potential to a class of similar structures subjected to a given seismic hazard.

Vulnerability analysis describe the damageability of the structure(s) under changing intensity or magnitudes of ground motion. More than one damage states are typically investigated in the analysis and height of building,

Seismic vulnerability is expressed as Mean Damage Ratio (MDR), which the ratio of cost of damage item to the replacement cost of same item.

$$\text{MDR} = \frac{(\text{Cost of Damage to item})}{(\text{Replacement Value of item})} \qquad (2.6)$$

Vulnerability can be defined as a relationship between MDR and earthquake intensity. Vulnerability assessment can be done using empirical method and analytical method. The empirical method is based on statistical evaluation of damage caused by past earthquakes some time know as fragility. The analytical method uses computational analysis of structure. In many developing countries like Pakistan there is no previous vulnerability assessment done on the building stock. Many researchers in Pakistan are currently working on development of vulnerability relationship of different building classes. Rafi (2012) has recently developed fragility curve for Adobe building. Work is also in progress at NICE NUST under the supervision of Dr. Shaukat Ali Khan, however the vulnerability relationship for all for different building classes in not yet developed. Due to this reason vulnerability curve for similar type of region will be used.

2.8.16 Value

Value represents the cost or property value which is exposed to risk. The more construction in a study region more is the risk of damage induction.

For example, a rural area with less population density might be having less risk as opposed to highly populated metropolitan. Since Risk is the product of Hazard, Vulnerability and Value, so it is directly proportional to risk.

2.8.17 Methods for Developing Building Inventory

Building inventories are a key element of disaster preparedness and response activities. Building inventory is important for ERA, since risk is dependent upon the value of the structure. Inventory will identify the most vulnerable structures in the region. Risk is also proportional to hazard and hazard varies spatially and the infrastructure to be mapped for the calculation of spatial risk.

There are no national databases characterizing built environment. There are number of sources of urban inventory information for analysis like Census department, World Housing Encyclopedia and others.

i. Remote sensing techniques

Remote sensing techniques involve all types of airborne and space borne plate forms with active or passive sensors to capture details about the surface of Earth. Passive sensors use sunlight as source of illumination and active sensor has its own illumination setup. The benefits of using remote sensing are,

- Depending upon resolution detailed building inventory data could be acquired.
- Using information from above step image processing can be done.
- Repeated images obtained over a specific region can provide information about urban growth and land use pattern.

Passive sensors use optical and infrared band at high resolution. Active sensors use microwave or laser pulses and measure the time taken for the signal to be reflected and its intensity. Synthetic Aperture Radar (SAR) uses microwave pulses and record both phase and amplitude information. Light Detection and Ranging (LIDAR) emits laser pulses receive their reflection. The spatial data produced from these techniques may be stored, processed and analyzed in GIS.

ii. Building Inventory Estimation Method

Another method of developing building inventory is through using a method of field survey and or inspection of construction documents. But this method is expensive and time consuming and often low relative to the frequent changes in the study region because each time full survey cannot be conducted if there is modification, retro-fits or demolition in the study region.

iii. Inventory development from Census Data

Building inventory development for large region is quite difficult task. Any method you use need lot of computation and time. Very simple approach to this problem is use of census data. In this study projected census data is used with field verification.

2.8.18 Seismic Hazard Assessment by Kythreoti

Kythreoti (2002) developed an ERA framework EQ-RACY and applied it using Cyprus as case study. In this framework seismic hazard and vulnerability were treated as probabilistic and Monte Carlo simulations were used to include variability of parameters. This framework was developed for the region with low to intermediate seismicity and considers spatial characteristic that affect hazard and risk assessment. For ERA to be accurate the model and information should be continuously revised. The parameter those effect hazards were: epicentral location, magnitude, geology, epicentral depth, and attenuation relationships.

Monte Carlo simulation method was used for hazard and risk calculation. The past century seismicity was used to generate synthetic earthquake catalogue. Past century seismicity was compared with historical seismicity to make sure that instrumental is in consistence with historical seismicity. This method used 100 years data and randomized the error in magnitude, depth, location and geology and new catalogue was created. The assumption made in this method is that earthquake spread uniformly from focal point of earthquake. Due to this intensity distribution is circular with its center at epicenter.

Synthetic earthquake catalogues were created by randomizing error in magnitude, depth, location and geology. Kythreoti used basic vulnerability curves along with population density and building inventory. The framework was finally used to determine the distribution of earthquake intensities, produced a seismic map for risk calculation and predicted the risk of injuries and death. The variations of key hazard parameter to include uncertainties were selected for low magnitude earthquake where direction and length of faults can be ignored. This method gave good result for Cyprus or the region of low seismic active region and simple tectonic settings.

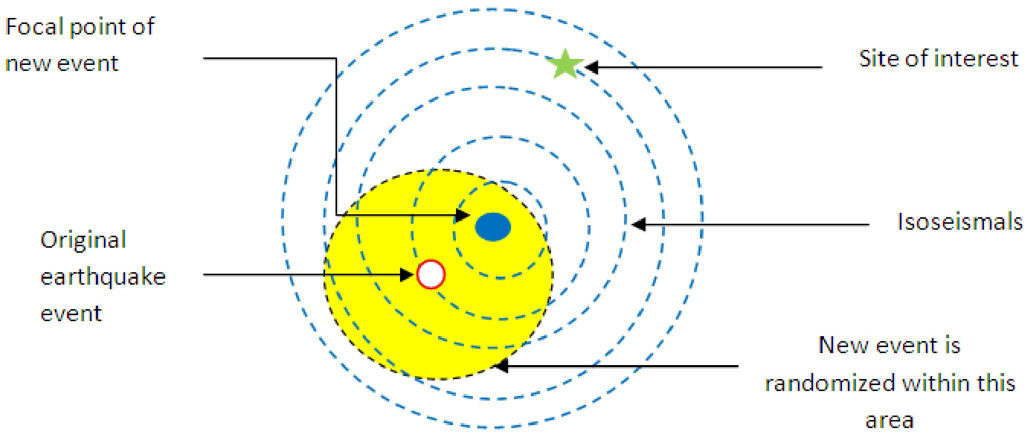

Figure 2.6 – Spread of seismic intensity from earthquake focal point (Kythreoti)

2.8.19 Risk Assessment Frameworks

2.8.20 HAZUS

HAZUS (HAZards U.S.), developed for the Federal Emergency Management Agency (FEMA) by the National Institute of Building Sciences (NIBS), is geographic information system (GIS) based, standardized, nationally applicable multi-hazard loss estimation methodology and software. FEMA (Federal Emergency Management Agency) is committed to mitigation as a means of reducing damages and, both, the social and economic impact from earthquakes in 45 states. FEMA, in agreements with the National Institute of Building Sciences, has developed HAZUS (NIBS, 1997, 1999 and 2002), a standard, nationally applicable methodology for assessing earthquake risk.

2.8.21 RADIUS

The United Nations General Assembly designated the 1990s, as the "International Decade for National Disaster Reduction (IDNDR). The IDNDR secretariat launched the RADIUS initiative (Risk Assessment tools for Diagnosis of Urban Areas against Seismic Disasters) in 1996, with the help of Japan, aiming at the reduction of urban seismic risk, focusing on developing countries. The main incentive of RADIUS is to increase awareness and understanding of Earthquake Risk. *RADIUS* is not based on Probabilistic Seismic Hazard Assessment (PSHA).

2.8.22 RISK-UE

The European RISK-UE was launched in 1999 dealing with vulnerability and assessment of historical building as well as existing structures. The hazard assessment was based upon all Europe while risk assessment was carried out for seven cities (Barcelona, Bitola, Bucharest, Catania, Nice, Sofia and Thessaloniki).

2.8.23 EQ-RAM

EQ-RAM is an ERA framework for the developing countries. This framework comprises of hazard due to earthquake and their consequences, vulnerability assessment of structures taking in account the building methods of developing countries and mapping of building inventory using satellite imagery and field survey.

EQ-RAM is based on probabilistic assessment, used for regions having high seismicity and well defined fault lines. It uses simple and cost effective mapping of building inventory for developing countries. It consists of three parts;

- Hazard assessment
- Risk assessment
- Causality Assessment

Value and spatial distribution of elements at risk are required, as risk is the product of hazard and hazard varies spatial.

Chapter # 3

DATA REQUIRED FOR RISK ASSESSMENT

3.1 SELECTION OF STUDY AREA

KPK Province is selected for Risk Assessment.KPK province is situated in seismically highly active region of world. Kashmir Earthquake (2005) severely damaged the northern part of the province. Risk Assessment of whole province has never been carried out so far, therefore it has been decided to carry out the ERA of KPK province.

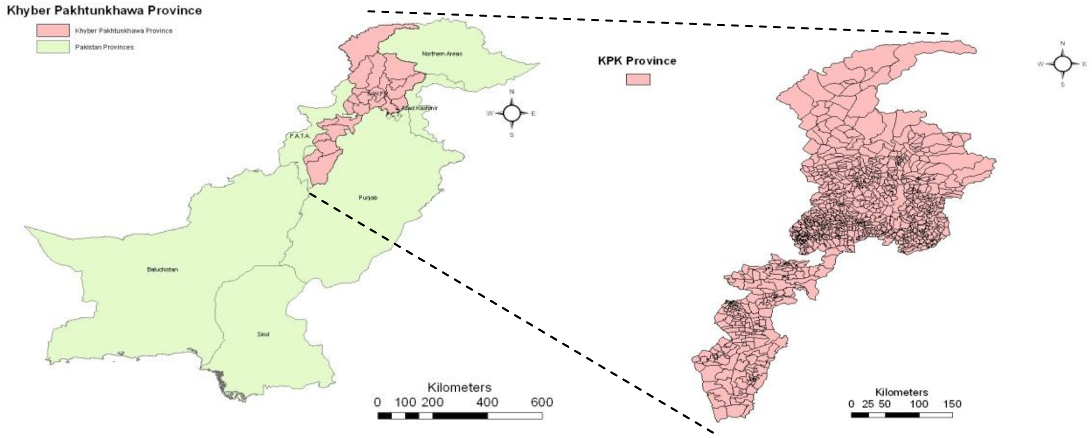

Figure 3.1 - Study Area –Khyber Pakhtukhawa (KPK) Province Pakistan

3.1.1 Division of Study Area

The study area needs to be divided into smaller units to carry out the analysis as at micro level. Digitized map of the Study area at Union Council (UC- Smallest administrated unit) level collected from PDMA. Then ERA framework calculates the coordinates of the centriod of the UCs and uses these coordinates to calculate the epicentral distances. The number of buildings of different classes will also be calculated for each UC.

3.2 SEISMIC SOURCE CHARACTERIZATION

As discussed in Literature review that the first step in probabilistic seismic hazard assessment is the seismic source characterization .i.e. Where seismic event can occur?

In this study PSHA is conducted using seismic source zone set by PMD & NORSAR (2007). Fault setting of study area and surrounding regions are shown in figure 3.2. It can be observed that almost whole country is surrounded by four major faults i.e Pamir Fault, Karakoram Fault, Chaman Fault and Heart Fault. The length of whose length is in thousands kilometers along this some major faults are either passing through are very near to KPK Province. 19 Seismic source zones shown in figure 3.3 based on fault direction, focal mechanism and seismicity of the area are defined.

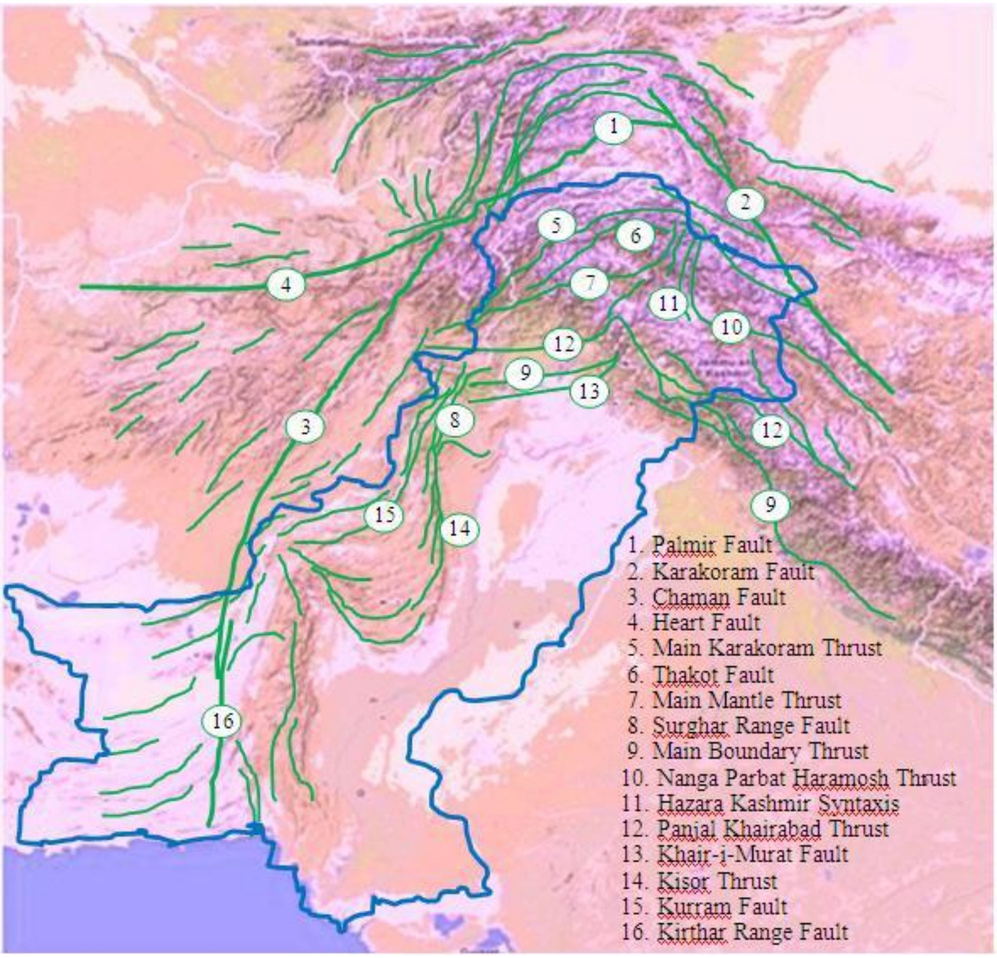

Figure 3.2 – Fault setting of the study area and surrounding regions.

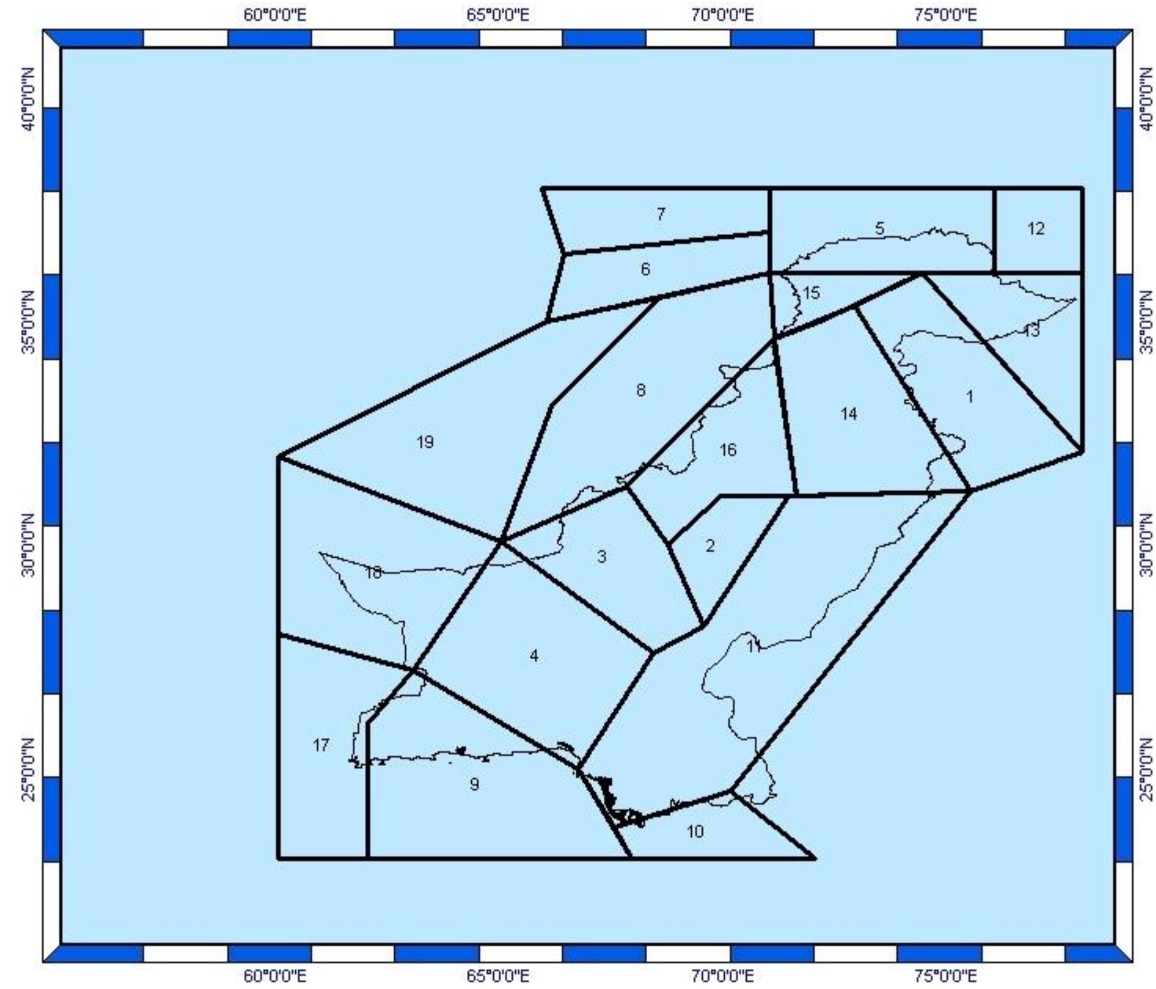

Figure 3.3 – 19 Seismic source zones.

Shape, size and orientation of the seismic source zones are used only to determine the fault type and direction of EFL. Shape, size and orientation of seismic source zones do not affect the hazard results, Since the original earthquake events are randomized in magnitude, location and depth according to the expected errors, the overestimation due to smearing (or distribution) of seismicity over the seismic source zones is reduced and Recurrences relationships are not directly used because complete Instrumental and historical seismicity is used to generate the synthetic catalogues.

3.3 SEISMICITY OF AREA

Study of the Earthquake record involved investigation of the historical seismicity, instrumental recorded earthquake record, Analysis of earthquake record and description of interpreted focal depths and mechanism.

3.3.1 Historical seismicity

Before the establishment of seismological observatories, which began at the beginning of 20th century, intensity data collected from the historical records was the only source of earthquake information. Historical earthquake data is a general account of damage to life (human and animal) and property. The historical pre-instrumental earthquake data has been collected from the description of the earthquakes given in the memoirs or records of travelers, historians and writers. Such earthquake catalogues have been compiled by Oldham, 1893, Heukroth and Karim, 1970, Ambraseys et al. 1975 and Quittmeyer and Jacob, 1979.

3.3.2 Instrumental Seismicity

The instrumental recording of earthquakes started in 1904 but very few seismic stations were established in the South Asian region until the 1960's. However with the installation of high quality seismographs under the World Wide Standard Seismograph Network (WWSSN) established by the U.S. Coast and Geodetic Survey in 1960, the quality of earthquake recording in this region improved and resulted in a better understanding of the seismicity of Pakistan. In Pakistan and most other parts of the world, the seismic record is too short and incomplete to develop a complete sample that is truly representative of the spatial and temporal distribution of shocks over a large period. Complete catalogues are not available in any of Pakistani organization therefore instrumental catalogue is obtained from International Seismological Centre (ISC) England. All events within an area between latitude:

22˚ – 38˚ N and longitudes: 57˚ – 78˚ E are collected. Details of record and number of events against different magnitudes are shown in table 3.1 and Figure. 3.3.

Table 3.1 - Earthquakes in the Study Area (Period 1904 to 2012)

Magnitude Mw	**Number of Events**
< 4	5425
4.0 to 4.9	10684
5.0 to 5.9	1650
6.0 to 6.9	171
> 7	30
Total Events	**17960**

This data set has been referred to as "Instrumental Catalogue" and is presented in Appendix – B. This catalogue comprises 12535 events having magnitude 4 and greater. The above mentioned reporting agency has given a variety of magnitude viz: Body-wave magnitude (mb), Surface-wave magnitude (Ms) etc. Since attenuation relationships are based on magnitude of given type, a single type must be selected. For data to be used in seismic hazard analysis, all the magnitudes were therefore converted to moment magnitude (Mw).Regression analysis was carried out to correlate these magnitudes.

All available types of magnitudes in the catalogue were converted into a uniform magnitude scale i.e., Mw (Moment magnitude)

The distribution of number of earthquakes of various magnitudes is shown in Figure 3.4 below.

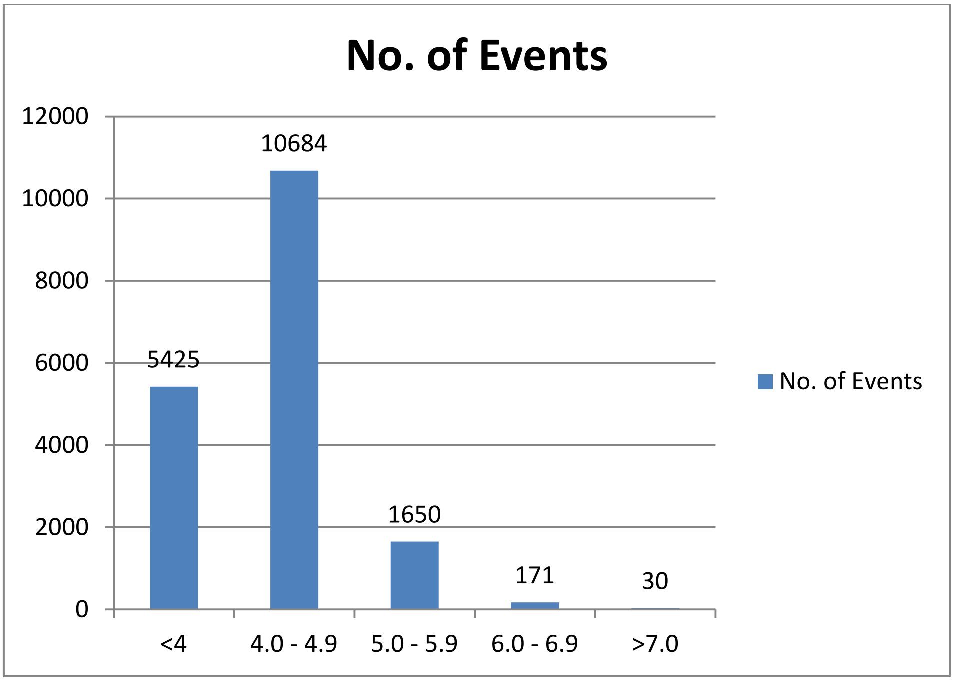

Figure 3.4 – Histogram showing number of earthquakes of different magnitude range

The reported focal depth of earthquakes included in the composite list range from 0 to 831 km. The deeper events are related to Hindukush seismic zone whereas other areas have focal depths less than 100 km.

The distribution of seismicity with respect to focal depth is shown in Fig. 3.4. From this figure it can be concluded that shallow seismicity (<70 km focal depth) dominates in the study area other than Hindukush region. This can be observed from the table 3.2.event with depth below 30km are 3690 and from the depth between 30 to 70 km, 5141 events were recorded whereas from the depth greater than 70 km, there are only 4685 events recorded and most of them lies in Hindukush region. The distribution of number of earthquakes of various depths is given in Table-3.2 below.

Table 3.2 - Focal Depth of Earthquakes in the Study Area (Period 1904 to 2012)

Focal Depth (km)	**Number of Events**
≤ 10	3990
Between 10 and 30	2557
Between 30 and 70	4883
Between 70 and 200	4880
>200	1650
Total Events	**17960**

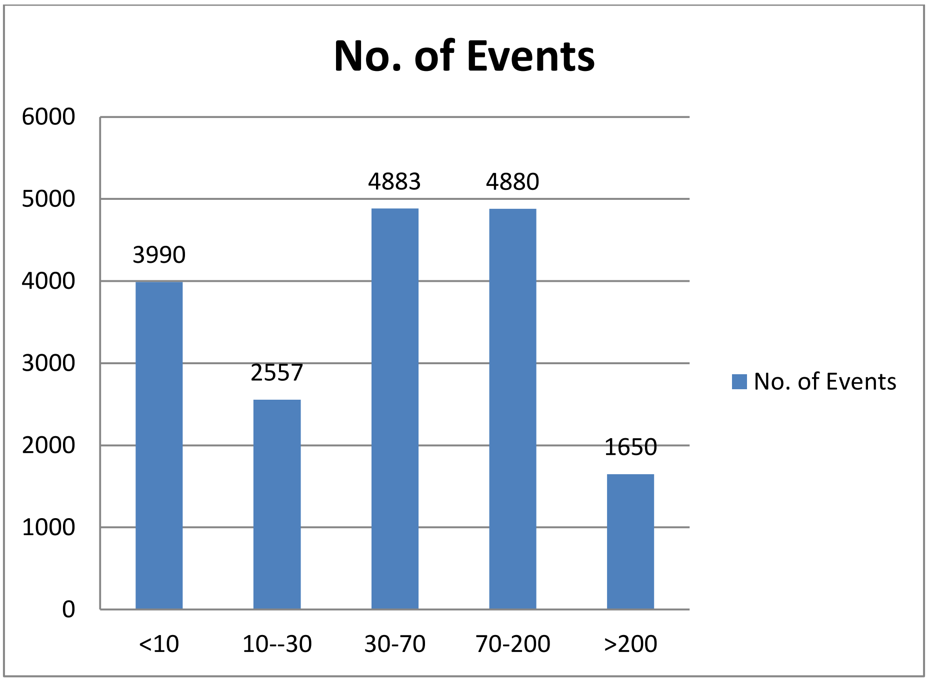

Figure 3.5 – Histogram showing distribution of seismicity with depth

Spatial distribution of earthquake shows that the most of the earthquake having focal depth less than 10 km are having magnitude between 4 -5 Mw.

3.3.3 Analysis of Earthquake Record

The spatial distribution of seismic rerecord in the study area is plotted on Figure 3.6. From this figures it can be inferred that maximum concentration of events having magnitudes

4-5 is north of Pakistan and medium magnitude events i.e between 5-6 are distributed along the plate boundary and larger magnitude earthquake above 6 -7 lies in Hindukash regions and near Quetta.

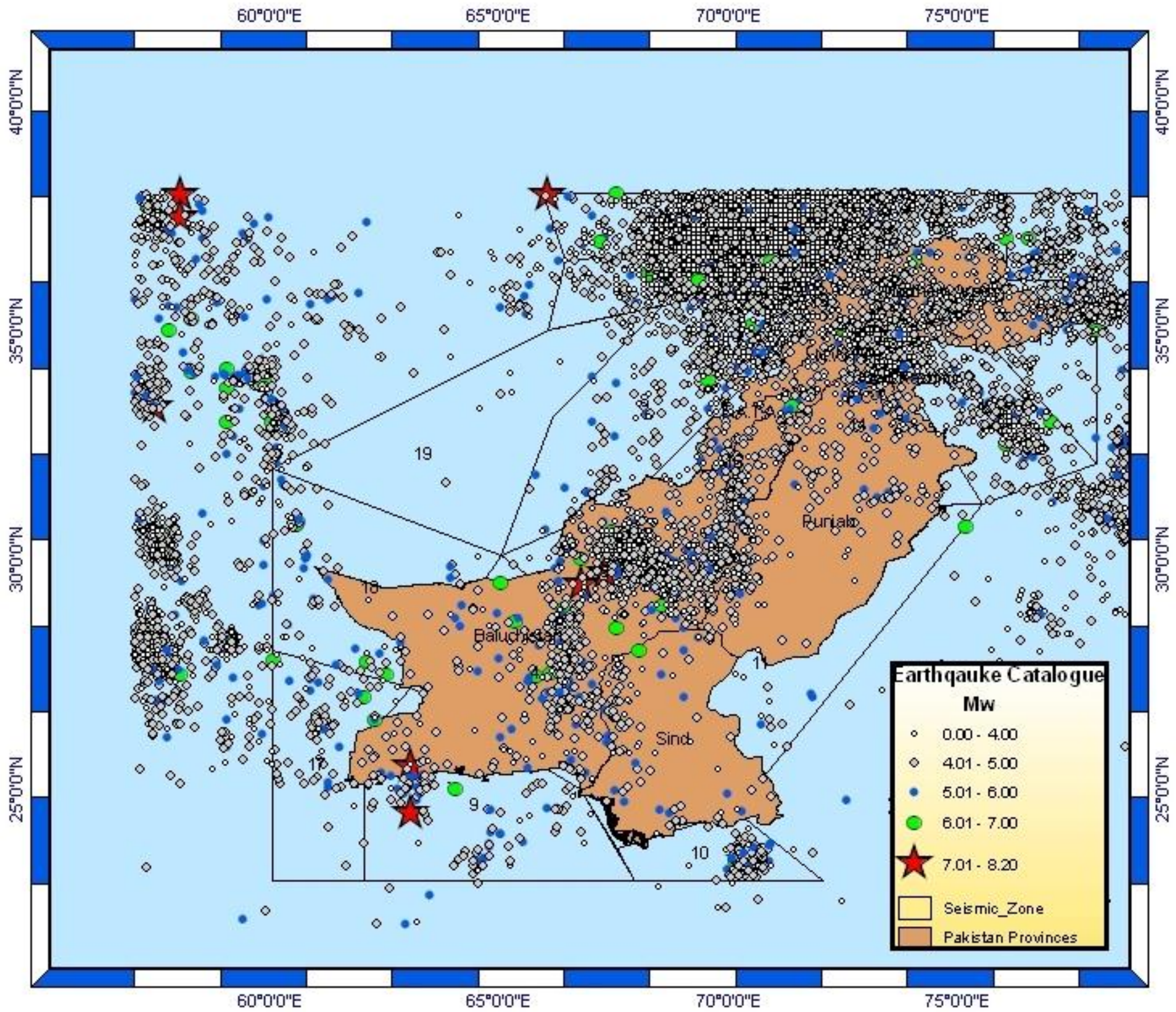

Figure 3.6 – Spatial distribution of Instrumental Seismicity

3.4 ESTIMATING THE RUPTURE DIMENSION:

Rupture dimension are estimate based of direct fault rupture plane. Well & Coppersmith 1994 relationship is used for this purpose.

$$Log\ (RLD) = -2.44 + 0.59M_w \qquad (3.1)$$

Where

RLD =subsurface rupture length

3.5 GEOLOGY /LOCAL SOIL OF THE STUDY REGION

The site response to an earthquake is varied by the type of soil at the site. Thick soil layers may greatly amplify the ground shaking from an earthquake (PMD-NORSAR, 2006). The Ambraseys et al (2005) attenuation relation could be written as

$$Log\ (a) = f\ (M_W, d, F_N, F_T, F_O) + 0.137S_s + 0.05S_A \qquad (3.2)$$

Ambraseys et al (2005) relationship considers soil types based on shear wave velocity. Details shown in below table:

Table 3.3 - Values of Ss and SA for different soil type in study area

Soil Type	**Shear wave velocity**	**Ss**	**SA**
Soft Soil (S)	Sv30< 360m/Sec	1	0
Stiff Soil(A)	360<Sv30< 750/Sec	0	1
Rock (R)	750m/Sec <Sv30	0	0

The soil type of study region is determined from study carried by USGS. For this purpose shear wave velocity calculated by USGS at distance of 1km grid from instrumental earthquake records is plotted as shape file in ArcGIS and overlaid by UCs to get values of Ss and S_A.

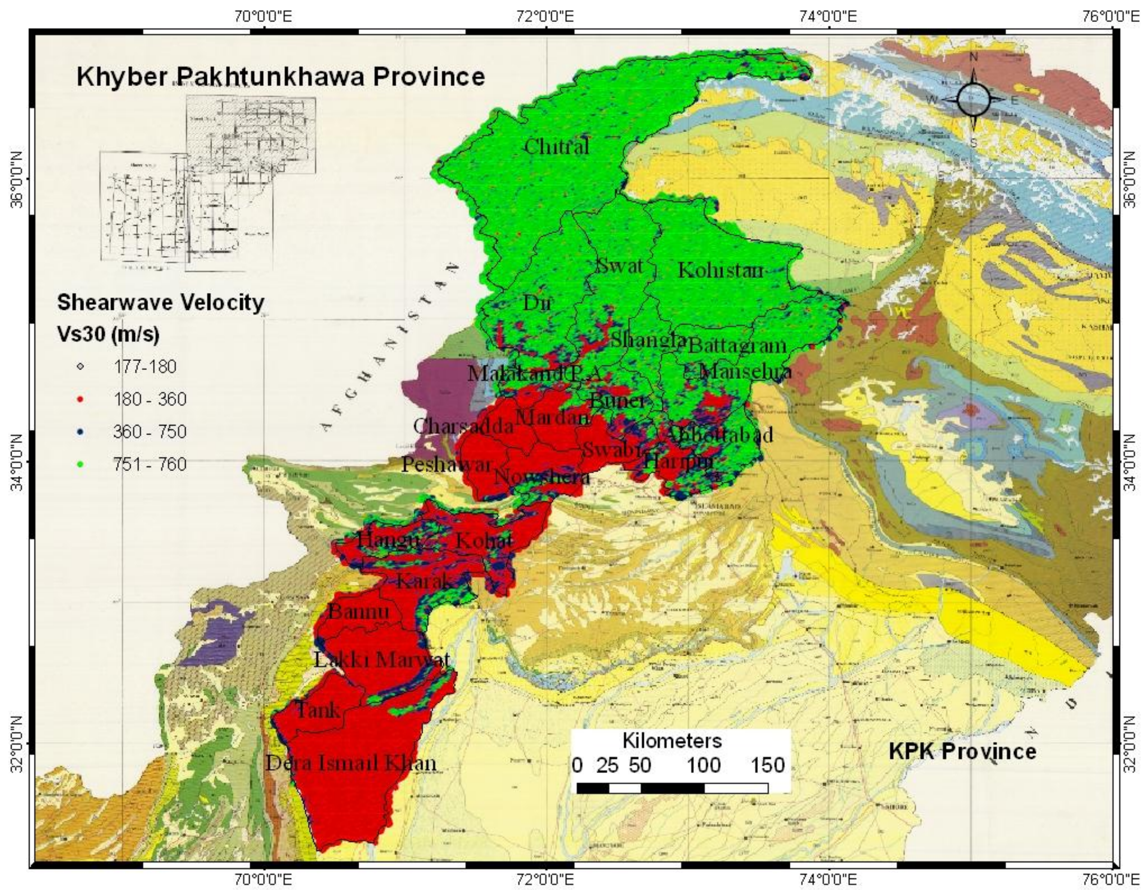

Figure 3.7 – Shear wave velocities (Vs30) through different soil types

To verify the soil types Geological maps of Pakistan obtained from Geological Survey of Pakistan is overlaid by UCs with in the study region shown by figure 3.8 .Various soil formations in the study region are identified. It was found that the shear wave velocity calculate by USGS matches well with Geological maps of Pakistan. Northern KPK has rock type of soil profile having shear wave velocity above 750 m/sec, whereas the south-west of the province mostly contains soft soil having shear wave velocity below 360 m/sec.

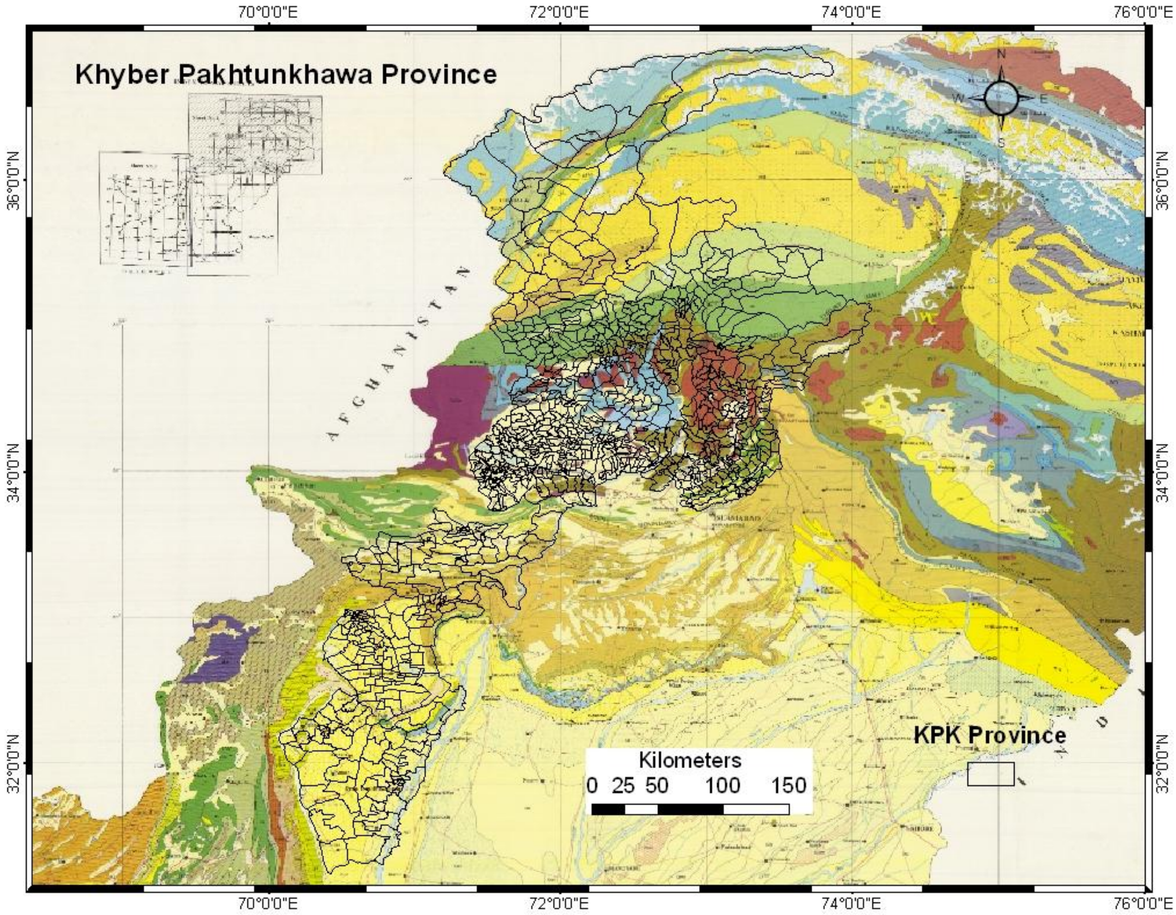

Figure 3.8 – Study area overlaid by Geological Map of Pakistan

3.6 VULNERABILITY

Vulnerability relations give the relation between PGA and Mean Damage Ratio (MDR). MDR is then used to calculate the financial loss. The GESI vulnerability curves will be used for the purpose. These were developed by the GeoHazad International (GHI, 2001). These use a scoring system of various factors to determine appropriate vulnerability curve. These factors are the type of building and its quality.

3.7 BUILDING TYPES IN STUDY REGION

Following types of building exist in the study region

3.7.1 Reinforce Concrete Frame (RCF)

Reinforced concrete frame exist as commercial units in the urban area and their height may varies from 5 to 10 storeys. Large numbers of these building are 3-5 stories.These type of building perform better during earthquake if properly design and detailed, but poor performance has been observed in Kashmir (2005) Earthquake due to lack of seismic design, soft storey, poor detailing and poor quality of materials.

3.7.2 Reinforced Concrete Frame with infill masonry (RCI)

Building Stock in the study area contains large number of this type building. These building consist of 3-6 storeys. Reinforce concrete framed with infill masonry is common building type for residential and commercial building in urban areas in study region. Most of buildings are non-engineered and more vulnerable than the RCF due to lack of detailing, poor quality of construction and materials. Performance of these building remained very poor in Kashmir (2005) Earthquake.

3.7.3 Un-Reinforced Masonry (URM)

This the most common type of residential building throughout the Pakistan as well as in the study region. Brick masonry with Cement-sand Mortar (CSM) is used for this type of building. These building are 1 to 3 storeys with RCC roofing and equally used for residential and commercial purposes. This type of building performed better than RCI and RCF in Kashmir (2005) earthquake.

3.7.4 Rubble Stone Masonry (RSM)

Dry Rubble or Rubble stone building are not only available in certain rural areas but the construction of these building is still in use in some urban area as well. People used locally available stone without dressing for the construction of houses. For rural constructions, i.e. residential buildings, bearing walls are built in rubble stone masonry in which undressed stone units are laid randomly in mud mortar or simply placed in dry form, (Ahmad, N et al. 2012) whereas half-dressed stone units laid in cement mortar are employed for urban constructions, i.e. public buildings. The buildings are provided with wooden floors in case of rural constructions, whereas reinforced concrete slab floors and roofs are used in the case of urban constructions (Ali and Mohammad, 2006; Gupta et al., 2008).This type of building is highly vulnerable to earthquake and has shown very poor performance in Kashmir (2005) earthquake.

3.7.5 Dhajji Structures (DS)

This structure mainly consists in Northern areas of Pakistan and Kashmir. Wooden framed with masonry infill. Different bracing pattern usually followed. These structures performed very well in Kashmir (2005) earthquake and in Rehabilitation phase ERRA recommended to use these structures and more than 100 thousands housed are built using this technique.

Figure 3.9 – Dhajji Structures in Study area

3.7.6 Adobe Structures or Mud Wall Structures (AS)

This is non-engineered and low cost building. These are mud structure or mud brick with mud mortar to bind these brick. This type of building exists in rural area of Pakistan. In

KPK these type of building exist in rural area of Abbottabad, Mansehra, Battagram ,Shangla ,Kohistan ,Peshawar, Nowshera, Bannu, Lakki Marwat ,Kohat ete. This building type is highly vulnerable.

Chapter # 4

METHODOLOGY

4.1 INTRODUCTION

This chapter discusses the essential component of ERA Framework that includes the hazard assessment (PSHA), vulnerability assessment and Risk assessment.

4.2 SEISMIC HAZARD

The ERA model is divided into three main parts, hazard assessment, risk assessment and causality assessment. Most of computer programs or ERA framework discussed are based on PSHA methodology initially proposed by Cornall(1968).These computer program model seismicity with in seismic zone using spatial or kernel approach for occurrence rate. Although these program are in use worldwide but these gives accurate result for developed countries where seismo-tcetonic data is readily available.

Khan (2008) developed innovative approach for PSHA to address the problems in existing PSHA methodology while developing ERA Framework.

a) Shape, size and orientation of seismic source zones is subjective, user can change these depending upon available seismicity and tectonic information resulting different hazard estimates (Khan, 2011).

b) An earthquake recurrence relationship is based on a power law distribution such as the Gutenberg-Richter relationship (Gutenberg and Richter, 1954). However, for strong earthquakes earthquake recurrence does not always follow the power law (Wesnousky et al., 1994). Therefore, Hazard calculated from power law recurrence relationships may lead to inaccurate results (Dahmen and Ertas, 1998).

c) In conventional PSHA methods, the historical seismicity is assumed to be uniformly distributed over source zones or is smoothed spatially (Beauval et al. 2006). Therefore, the seismicity is sometimes smoothed over large regions which spread the possible occurrence of earthquakes in regions without historical seismicity. This may lead to lower seismicity in locations near the area source, whilst overestimating the seismicity of regions with little or no historical earthquakes (Abrahamson, 2006).

d) Maximum magnitudes M_{max} and minimum magnitude M_{min} are sources of over and under-estimation and hence omitted in new methodology

In this new methodology instrumental seismicity of past 100 years is used with seismo-tectonic information.

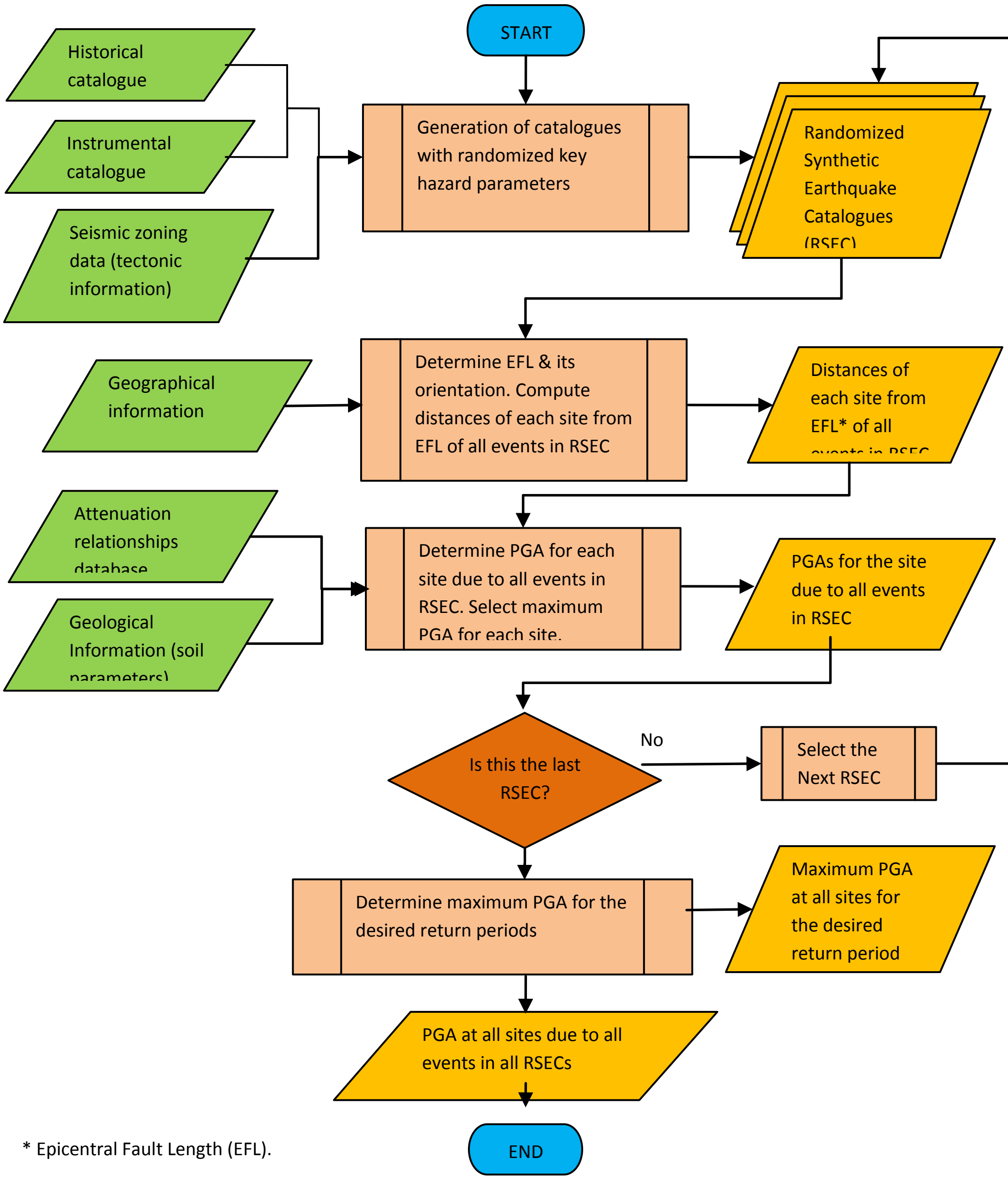

Figure 4.1 – Flowchart of the proposed PSHA process (Khan, 2011)

The process will begin with SHA where new earthquake events will be generated from past (20th) century instrumental seismicity and historical seismicity and hazard is calculated at the center of UC in the study region. Mont-Carlo simulation will be used to determine the probabilistic seismic hazard by generation new synthetic randomized catalogues (REC).

4.2.1 The Creation of New Synthetic Randomized Earthquakes

It is assumed that the future seismicity will be consistent with the past century's instrumental seismicity (Kyhthroti, 2002) but for a country like Pakistan with diverse tectonic setting and high magnitude seismicity, only the past century's seismicity is not representative so historic seismicity must also be included(Khan,2010). The ERA framework includes historic seismicity in such a manner that the probability of instrumental data is not distorted. Random events are picked up form historic data and put in place of instrumental catalogues by replacing a random event of same magnitude.

The magnitude of new virtual earthquake is varied randomly by the ERA framework from the original with $\pm 0.20M_w$ (Khan, 2008).The magnitude determination error ranges from 0.15 to 0.36 (Kagan, 2003).This is for magnitudes already reported in M_w. For magnitudes that need conversion the randomization from original is $0.41M_w$ (Khan, 2008). This is to account for the errors in magnitude conversion in addition to errors in magnitude determination. The variation in the location is done due to the errors in location determination and that depends upon the depth and magnitude of earthquake and range between 20 km and 40 km (Kagan, 2003).The ERA framework randomized the new position of the earthquake within 25 km of the Epicentral Fault Line (EFL) with the original epicenter as the starting point and the direction of it will be parallel to well defined fault. It is assumed that PGAs attenuate from fault line rather than focal point of the earthquake as explained in relevant section. The error in depth is varied by 15% (Kythrioti, 2008)

4.2.2 The Calculation of Epicentral Distances

The simplest model when modeling ground motion distribution is assuming that the source is concentrated at a point and attenuation radiate radial this assumption is satisfactory for small earthquake events but for large magnitude events the intensity of earthquakes spread perpendicular to the line of rupture than the focal point (Garcia-Fernfindez and Egozcue, 1989).

The length of fault rupture due to earthquake depends upon the magnitude of earthquake which is given by the following relations and these are parallel to the fault line (Wells and Coppersmith, 1994). On these the Epicentral Fault Length (EFL) depends.

$$Log\ (RLD) = -2.44 + 0.59M_w \qquad (4.1)$$

Where,

RLD = Subsurface rupture length

The distances in these equations are in km. The ERA Framework randomized the new position of the earthquake within 25 km of the Epicentral Fault Line (EFL). The EFL of the new synthetic virtual earthquake is oriented parallel to the fault length with epicenter at the starting point. This method requires minimum information about regional seismo-tectonics and historic seismicity.

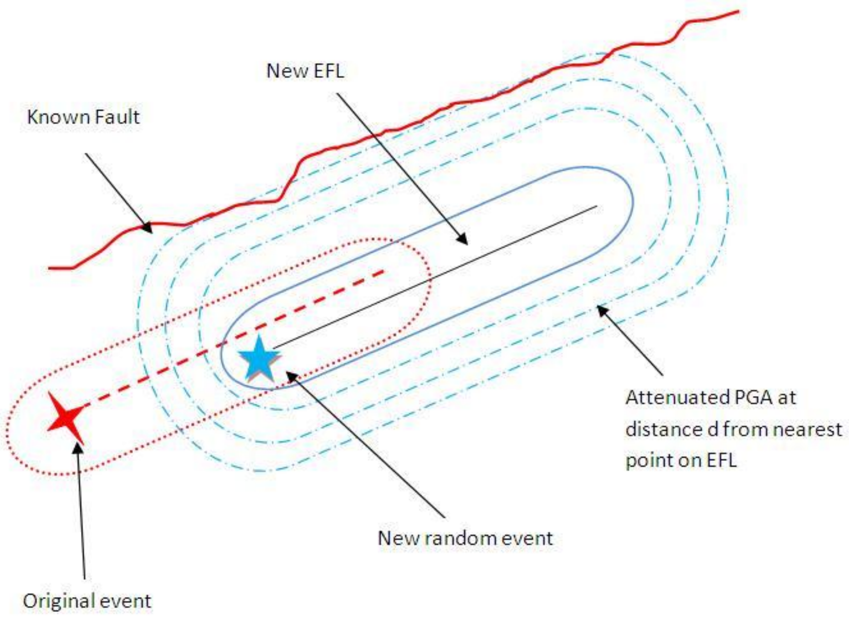

Figure 4.2 – PGA distribution around the EFL for a new seismic event

The ERA framework uses the geodetic coordinates of the World Geodetic System (WGS) and the epicentral distances are calculated using from these geodetic coordinates.

It is assumed that the PGAs are attenuated around the EFL of the new synthetic virtual earthquake. The epicentral distances (d) are calculated for the center of each UC. The epicentral distance is perpendicular distance from an offset of 25 km for all centers of grids that face the length of the EFL and radial distances starting from the tip of the semicircle to the center of the UC that do not face the length of EFL. To avoid exaggerating the effect of earthquake the minimum epicentral distance should not be less than 25-30 km (Smith &Ekstrom, 1997).

4.3 VULNERABILITY

The different building classes are discussed in section 3.7 and their vulnerability curves developed by using GESI methodology as discussed below. Curves developed are shown in figure (4.3).

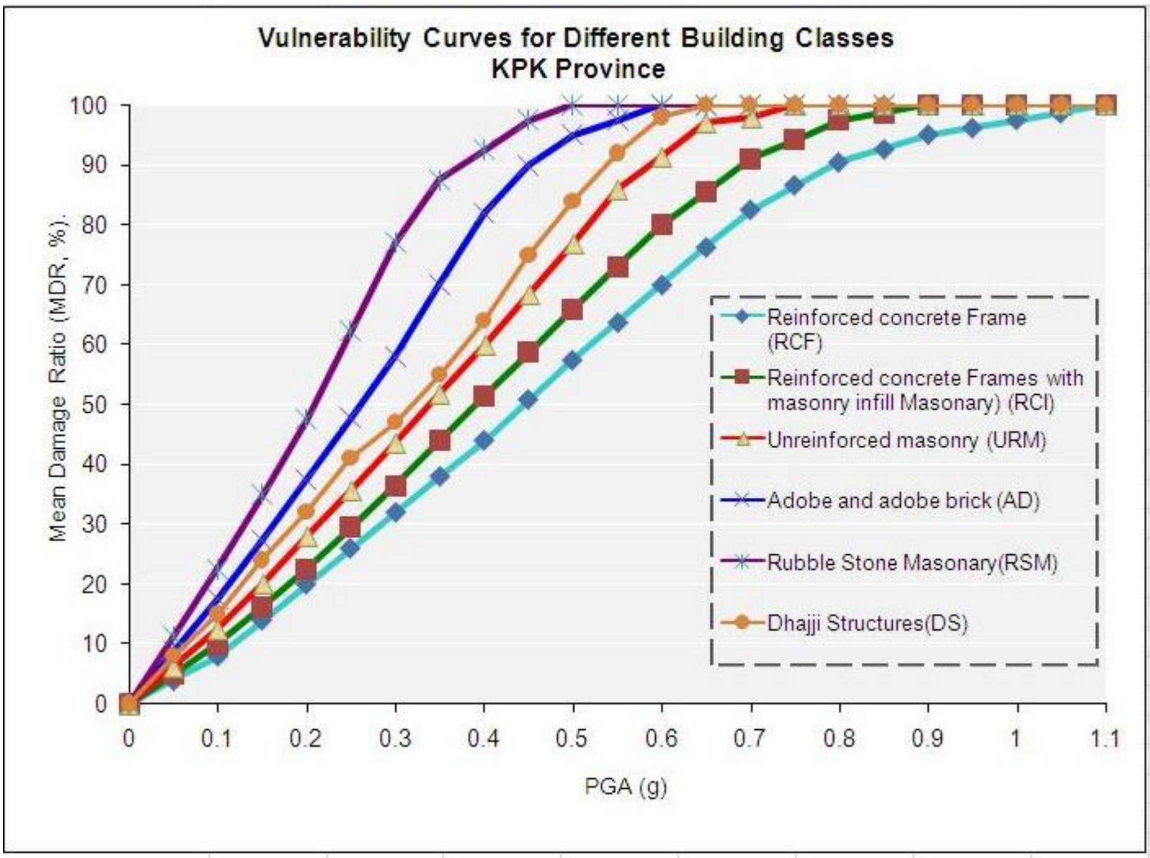

Figure 4.3 – Vulnerability curve for Building stock of KPK

The different types of buildings have already been defined so, each building class will have a different vulnerability curve. The GESI vulnerability curves could be obtained from GESI Program which is Microsoft Excel software. The following steps are followed to obtain values for vulnerability curve. Firstly select the number of building type from the following chart.

Table 4.1 - Values for type of buildings

0	Wood
1	Steel
2	Reinforced Concrete
3	Reinforced Concrete Infill
4	Reinforced Masonry
5	Unreinforced Brick Masonry
6	Adobe

Appropriate values of 0, 2, 3, 4, 5, and 6 will be given RCF, RCI, UBM and adobe. Secondly to define the quality of construction choose values from the following tables

Table 4.2 - To define the quality of design

0	Engineered with Seismic Design
1	Engineered without Seismic Design
2	Non-Engineered without Seismic Design
3	Non-Engineered, no Seismic Design and Poor Proportions

Table 4.3 - To define quality of construction

0	Excellent quality with good supervision of Seismic elements
1	Good quality with some supervision of Seismic elements
2	Moderate quality with no supervision of Seismic elements
3	Poor quality with no supervision of Seismic elements and unskilled workers

Table 4.4 - To define quality of material

0	Good quality material
1	Poor quality material of poor maintenance of building

Appropriate values will be given for each building class based upon the general practices in Pakistan. By providing these; vulnerability curves are obtained that will give different values of Mean Damage Ratio corresponding to different PGA values. The vulnerability curves are input to the risk assessment module.

4.4 VALUE OF ELEMENT AT RISK

By applying the above procedure relationships of mean damage ratio with PGAs have been obtained. As discussed in literature review mean damage ratio is the ratio of damage incurred with the total cost. The hazard module of ERA Framework has calculated a number PGA values at each UC. By co-relating these values the ERA Framework calculates mean damage ratio for a building class in the union council. If this mean damage ratio is multiplied with the cost of one building of the said building class, the damage on the building could be calculated. So, the cost is one building of each building class needs to be calculated. The cost of a building will be calculated by multiplying the average area of the buildings in the building class with the average cost per area of the said building class. As it is the damage cost so only the cost of construction is included in average cost per area that is the cost of land is excluded in determining the cost of building per area.

Average cost of building per area could be obtained by averaging the costs of similar constructions in the study area or it could be also be obtained by averaging the costs of similar construction without prejudice of area because a sample of data will give also the average of area. Similarly it could be assumed if the person has sufficient knowledge of the construction in the area.

4.5 PSHA

The historic earthquake catalogue and the instrumental earthquake catalogue have been developed from appropriate source for the study region and saved in historic.csv and InstCatA.csv containing date and time of occurrences, geographical co-ordinates, magnitude and depth of the respective earthquakes contained. Union Councils of the study region are saved in area layer file of GIS and will be properly geo-referenced so that co-ordinates of centroid of the UC are obtained. Data of seismic zones will be provided in zones.csv file which would contain the co-ordinates of the corners of seismic zones, general fault direction (azimuth) and fault mechanism (thrust, normal or odd fault) in the right format readable by the ERA framework.

Value of Ss and S_A for different soil types in the study area is entered in UCSoil.csv file. The ERA Framework will then randomize the magnitude and the location of earthquakes from the instrumental earthquake catalogue after inclusion of historic seismicity from historic earthquake catalogue and thus generating a catalogue of new synthetic randomized earthquakes in the folder "RandCat". After calculating the epicentral distances from each randomized earthquake that will have any effect to the center of each UC using the co-ordinates of center of UC and EFL, the ERA Framework will calculate the PGA values for all the UCs for the earthquake. The framework calculates PGAs for all UCs for all randomized earthquakes generated in the randomized earthquake catalogue. The results are stored in the files AUC001.csv to AUCn.csv. These contain PGA values of each UC from all events in s number of simulations.

4.6 BUILDING INVENTORY DEVELOPMENT

The ultimate aim of the building inventory development is the calculation of the number of units of each building class in every Union Council. Projected Census data is used for this purpose with some field verification. These results are then saved in the coma separated file. This file is input in the Risk Assessment Module of the EQRAM.

4.7 EARTHQUAKE RISK ASSESSMENT

A separate module of the EQRAM deals with Seismic Risk Assessment. As discussed earlier seismic risk is the product of hazard, vulnerability and value. The methodology of hazard assessment has been discussed in the relevant section. The vulnerability and the value will be discussed in this section. In general earthquake risk may include calculation of financial loss due to PGA which may or may not include indirect losses due to fire, landslides etc. The ERA Framework includes only the loss due to PGA and does not include losses due to other indirect factors. Another type of risk is the risk of causality loss. The risk module of the ERA Framework calculates the material damage loss and also has the capability of calculating the causality losses.

The ERA framework will extracts the PGA value for a specified UC for a synthetic earthquake and co-relate it with the vulnerably relation and find MDR. Through MDR and the value of buildings of a building class in the UC it will calculate the probable financial loss in that UC due to the synthetic event and save it in the "damage database". The ERA will repeat the above actions for all synthetic events and will calculate the average damage for a building class in the UC. The same procedure is repeated for all building classes and for all UCs and storing it in the damage database. The damage database could be used to plot the damage distribution for the UCs.

4.8 CASUALTY MODEL BY COBURN AND SPENCE (1992)

Coburn and Spence (1992) have proposed a casualty model where the effects of response times and search and rescue efforts are taken into consideration. This model is suitable for use in the planning of earthquake preparation and response and rescue capacity development of a community. Coburn and Spence gave factors for the various components of the model that may be modified for the study region. According to the

Casualty model of Coburn and Spence, the number of fatalities due to structural damage can be represented by

$$K_{sb} = D_b x(M_1 x\, M_2 x M_3 x\{M_4 + \; M_5\,(1 - M_4)\} \qquad (4.4)$$

Where:

D_b is the total number of collapsed buildings for building class b and

M_1 to M_5 are modification factors to account for various parameters.

These parameters are explained in detail as follows:

4.8.1 M1, Population per building

The population per building depends on the location (country and urban/rural setting) and varies from time to time. M1 is equivalent to the average family size in each house for a residential building stock. In developing countries like Pakistan, etc. it is 6 to 9.The model uses population per building that can be determined from census data. This gives the user control on applying the model anywhere in the world.

4.8.2 M2, Occupancy at time of earthquake

The number of deaths during an earthquake depends on the time during the day at which the event occur .For example, in rural areas more population is indoors at night since during the day most occupants are outdoors. Similarly, in urban areas people move from residential to commercial buildings for work, schools, shopping malls, services etc. Moreover, the season (winter or summer) during which an earthquake strikes also affects occupancy. For example, in rural areas in Pakistan people sleep outside in summer due to the hot weather.

4.8.3 M3, Occupants trapped by collapse

During an earthquake, if a building collapses all the people may not be trapped inside. The number of people trapped inside will depend on the type of the building and the individuals. A certain percentage of people will escape before total collapse, or collapse may be partial, or even will rescue them. According to Coburn and Spence (1992), in general, the number of trapped occupants is less for fewer storeys in a building.

However, this does not include weak masonry buildings at the epicenter of strong earthquakes or cases were collapse is immediate.

Table 4.5 Estimated average percentage of occupants trapped by collapse.

Type of building	MKS intensity			
	VII	VIII	IX	X
COLLAPSED MASONRY BUILDINGS (UP TO 3 STOREYS)				
	5%	30%	60%	70%
COLLAPSED RC BUILDINGS (3 TO 5 STOREYS)				
Near field, high-frequency ground motion:				70%
Distant, long-period ground motion:				50%

The value of M3 in this model is based on shaking intensity and is multiplied by the number of collapsed buildings. If a building is in the collapsed damage state it does not make sense to associate this factor to the shaking intensity.

4.8.4 M4, Injury distribution at collapse

The injuries sustained by people caught in building collapses are of a wide range and of varying degrees. Some occupants are killed immediately when the collapse occurs and others sustain injuries of various degrees. According to Coburn and Spence (1992), the

M4 factor in the casualty model is the proportion of the immediate collapse fatalities.

Table A.2 presents one of the simplest, and most useful to emergency managers, injury severity scales (ISS) proposed for quantifying earthquake epidemiological studies (Coburn and Spence, 1992). It is based on a four-point standard triage classification of injuries.

Table 4.6 M4, Estimated injury distributions at collapse (% of trapped occupants) according to injury category

Triage	Injury Category	Un-Reinforced Masonry	RC	Rubble Stone
1	Dead or cannot be saved	20%	40%	20%
2	Life threatening cases needing immediate medical attention	30%	10%	25%
3	Injury requiring hospital treatment	30%	40%	30%
4	Light injury not necessitating hospitalization	20%	10%	25%

This factor is useful in a sense that a different number of occupants will sustain a certain severity of injury in different types of construction in various parts of the world.

4.8.5 M5, Post collapse mortality

It is evident that the individuals trapped in the rubble after structural collapse will pass away if they are not saved and given medical treatment required. Likewise those with extreme injuries will die at a quicker rate than the individuals who are not genuinely sting. In case of collapsed structures, time is of great importance. It is assessed that 90% of the trapped people protected from collapsed structures, are pulled rapidly from the remnants by consistent individuals display in the zone throughout the quake (Krimgold, 1987 , Coburn and Spence, 1992). The M5 factor depends on the effectiveness of the post-collapse rescue activities. Therefore, in cases of disasters where the majority of the population is affected (i.e. either killed or seriously injured) and there are not many people present to act as the initial rescue teams and this factor increases dramatically. Some of the factors that influence the effectiveness of the search and rescue procedures and, therefore, the rescue rates of victims are manpower, equipment, search techniques and transport resources. Further factors, which affect the fade-away time (perish rate of trapped victims) and consequently the M5 factor include the weather conditions in general and in particular the temperature and rainfall. Secondary consequences of main event like aftershocks, fire , landslides also affect the perish rate of trapped victims.

Table 4.7 M5, Percentage of trapped survivors in collapsed buildings that subsequently die (Coburn and Spence, 1992)

Situation	**Masonry**	**RC**
Community incapacitated by high causality rate	95%	99%
Community capable of rescue operation	50%	80%
Community + emergency squad after 12 hours	70%	85%
Community + emergency squads+ search & rescue expert after 36 hours	50%	70%

This is an important factor since it gives control over the level of preparedness and the ability to rescue a community. It can enable the identification of the effect of various response/rescue measures.

Injuries are estimated using the factor M4 which gives the percentage of injury severity according to the type of building. The injuries are determined for all damage states and added up.

Chapter # 5

ESTIMATION OF SEISMIC HAZARD AND RISK

Risk Assessment of KPK is carried out using ERA Framework developed by Khan (2011).As already discussed that the risk comprise of three component that. i.e Earthquake Hazard Assessment, Vulnerability and Value.

5.1 HAZARD ESTIMATES & DISCUSSION

The Earthquake Hazard Maps prepared from this study is shown in figure 5.1 & 5.2 below.

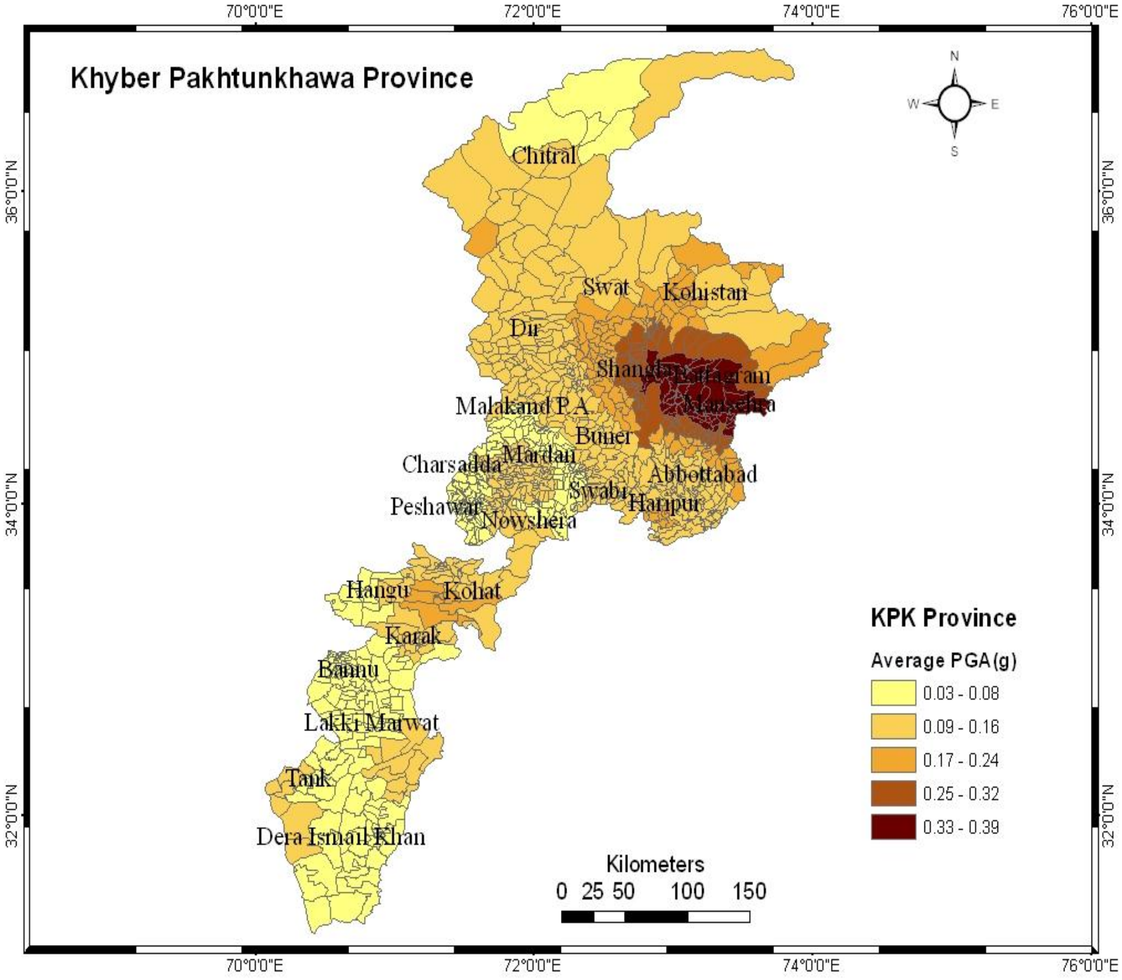

Figure 5.1 – Average PGA i.e Max PGA for 100 year for KPK Province.

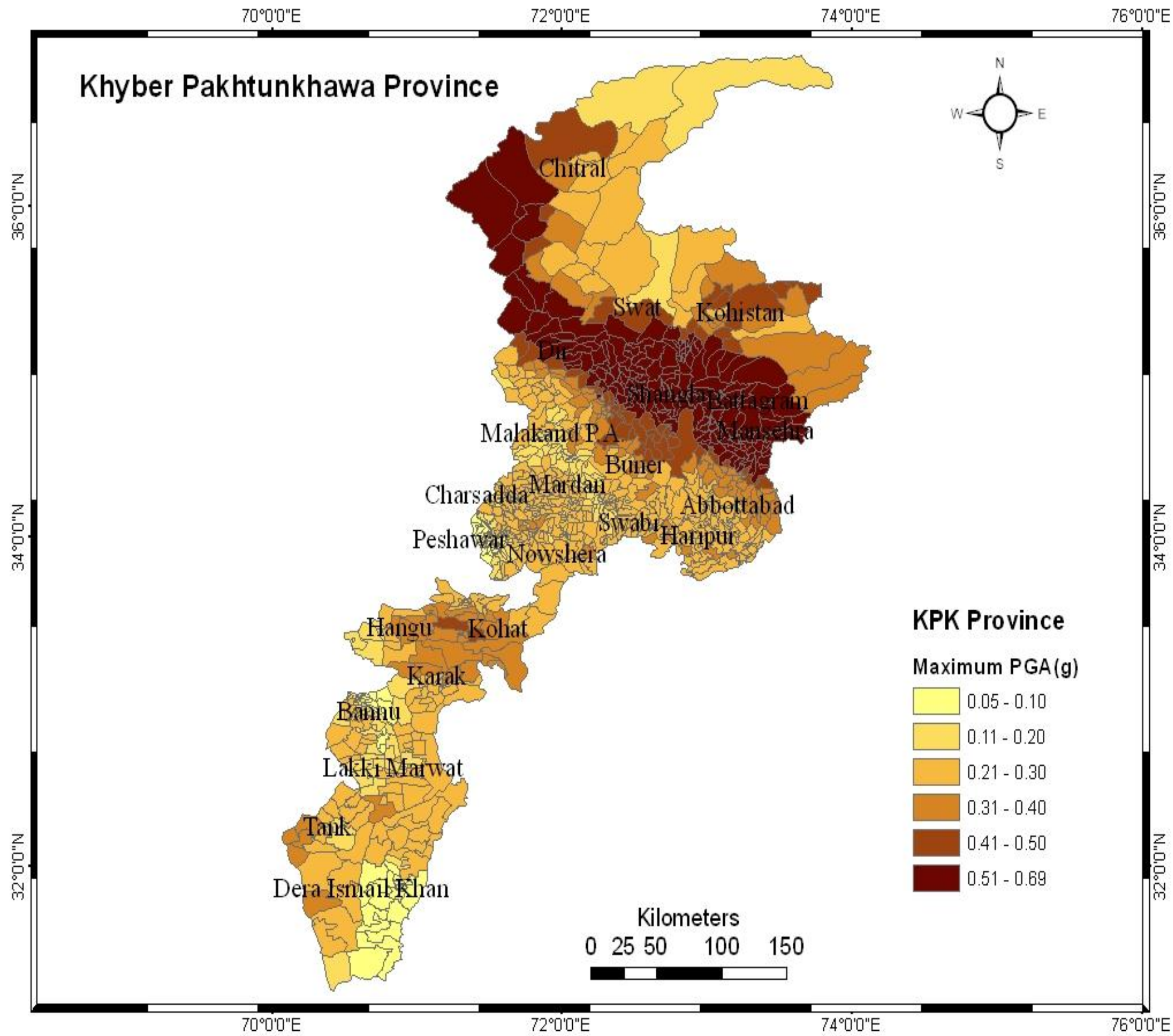

Figure 5.2 – Maximum PGA i.e Extreme Max PGA for 100 year for KPK Province

As shown in map that Max PGA is 0.39g in Some UC of Distrit Mansehra, Battagram and Shangla. Hazard map for 100 years shows that the general trend similar to study made by NESPAK for BCP 2007 (shown in figure 2.5). However the estimated hazard in this study is concreted at some districts contrary to smear hazard by BCP. BCP has overestimated the hazard and this overestimation is due to smearing of seismicity over a large area. PSHA maps of Pakistan by the BCP were produced by PSHA study, using different computer code, i.e. EZ-FRISK (McGuire, 1993). As the hazard calculate in this study is at micro level therefore the result are considered to be more accurate. Hazard in district Kohat is high as compared to nearby area. This is because of major historical earthquake of March 2, 1878. At Kohat several houses, public buildings and portion of the wall of the fort fell. At Peshawar it caused damage to houses and city walls. Estimated Intensity in MM was V11 (Ambraseys et al., 1975).

It is also clear that the high hazard at north of the province and extreme value of PGA i.e figure 5.2 is quite high in five districts but high hazard is diluted in average PGA map i.e Figure 5.1.

5.2 VALIADTION OF ERA FRAMEWORK & DATA

ERA Framework and collected data is validated using actual damage data of Abbottbad district in Kashmir Earthquake. Data containing number of collapsed and partially damaged building is collected from ERRA.

Kashmir earthquake event is simulated and building inventory is developed at time of Kashmir earthquake, by giving basic vulnerability relationship developed by GESI to buildings classes the total damage is estimated. This damage is compared with damage calculated by EQRAM and the two are plotted against distance from EFL and shown in figure 5.3. It is observed that up to the distance of 44 km from EFL the EQRAM has under estimated the damage, whereas after this distance the ERQRAM has over estimated the damage. The trend line of estimated damage is steeper than the calculated damaged by EQRAM. This difference in estimation is due to observed data; attenuation relationship and error in vulnerability relationships as basic vulnerability relationship are used.

Data in Estimate1 and Estimate 2 are derived from owner's claims to Government. Minor damages are excluded from this data as the compensation was not given to minor damages therefore these may not be accurate.

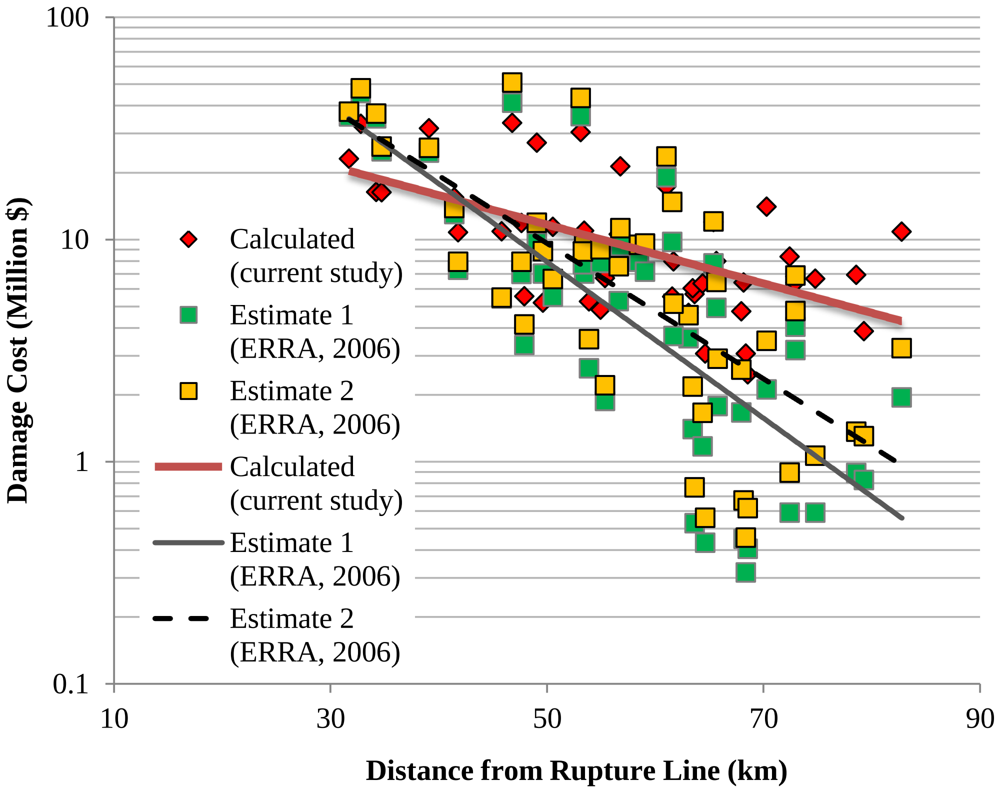

Figure 5.3 – Comparison of Calculated and Estimated losses in District Abbottbad for Kashmir Earthquake

When total losses are compared then it is observed that EQRAM calculated 17 % higher losses than Estimate 1 and only 5% higher than the Estimate 2.

Considering the fact that losses estimated from ERRA data are not very accurate and calculated losses can be improved using better model incorporating better vulnerability relationships and improved building inventory, it is can be concluded that EQRAM gives reasonable results and can be useful tool for risk assessment.

5.3 DISTRIBUTION OF BUILDINGS & RISK

It is observed in Figure 5.4 that buildings are cluster at some union council and this trend is followed almost all the cities of KPK province. This clustering of building exists even at smaller scale in rural areas.

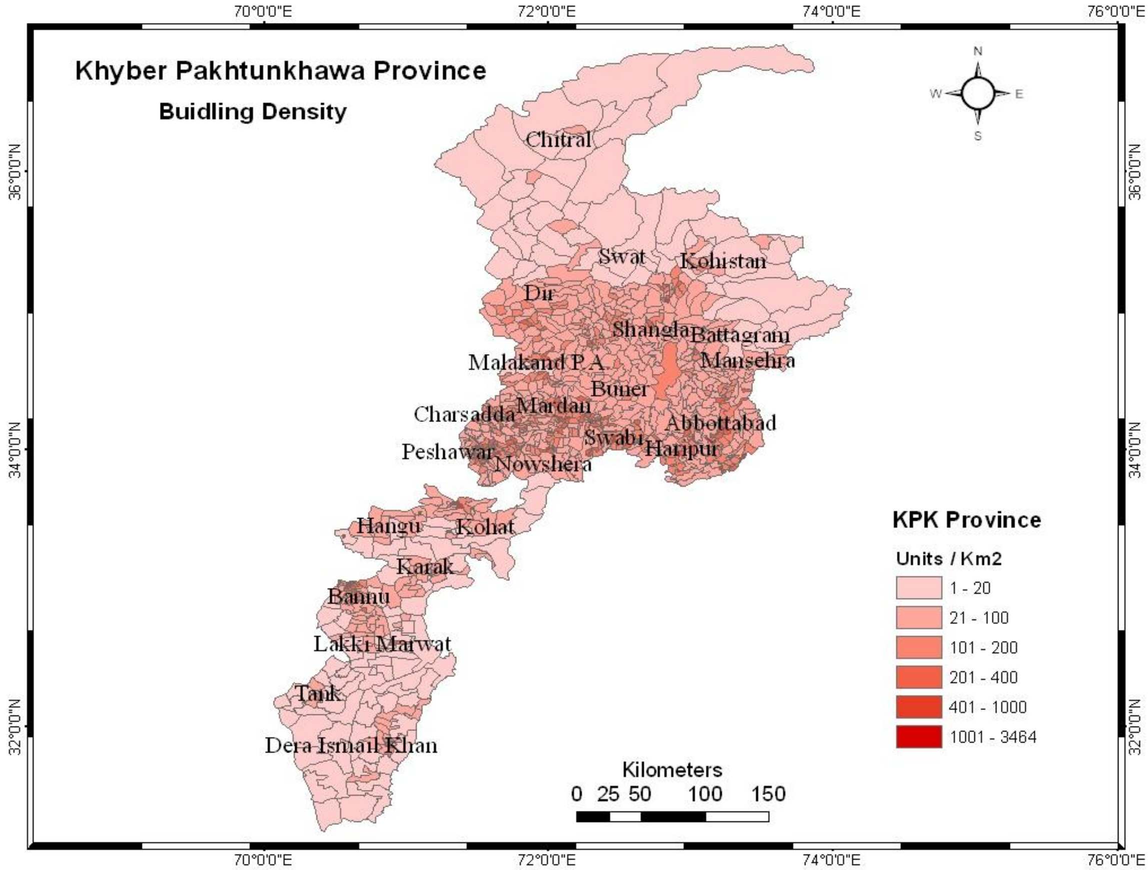

Figure 5.4 – Building densities in the study area

This concentration of buildings at small area can result high risk values. It is also observed from above figure that urban areas have high building density. Risk in $ per building is calculated and shown in Figure 5.5.

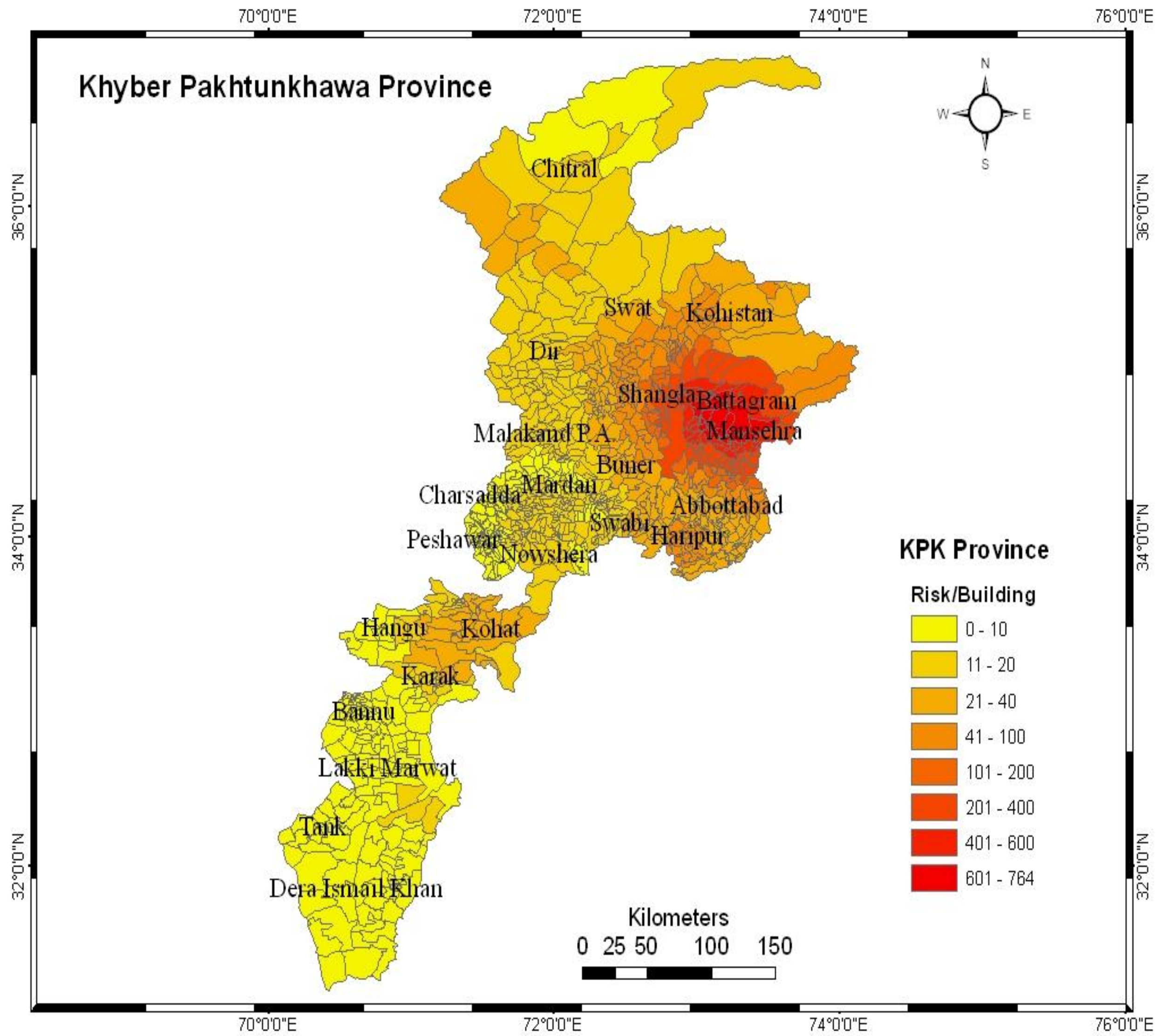

Figure 5.5 – Risk in $ per building for KPK Province

Table 5.1 shows the details of collapsed building in study region. In figure 5.6 the spatial distribution of these collapsed building is shown. Collapsed buildings are mostly consisting of Rubble stone masonry and Adobe buildings with small number of un-reinforced brick masonry buildings.

Table 5.1 .District wise details of collapsed buildings

District	Building Collapse
Battagram	5191
Mansehra	5163

Swat	3338
Shangla	3343
Kohistan	2204
Uper Dir	1734
Chitral	966
Buner	75
Abbottbad	73

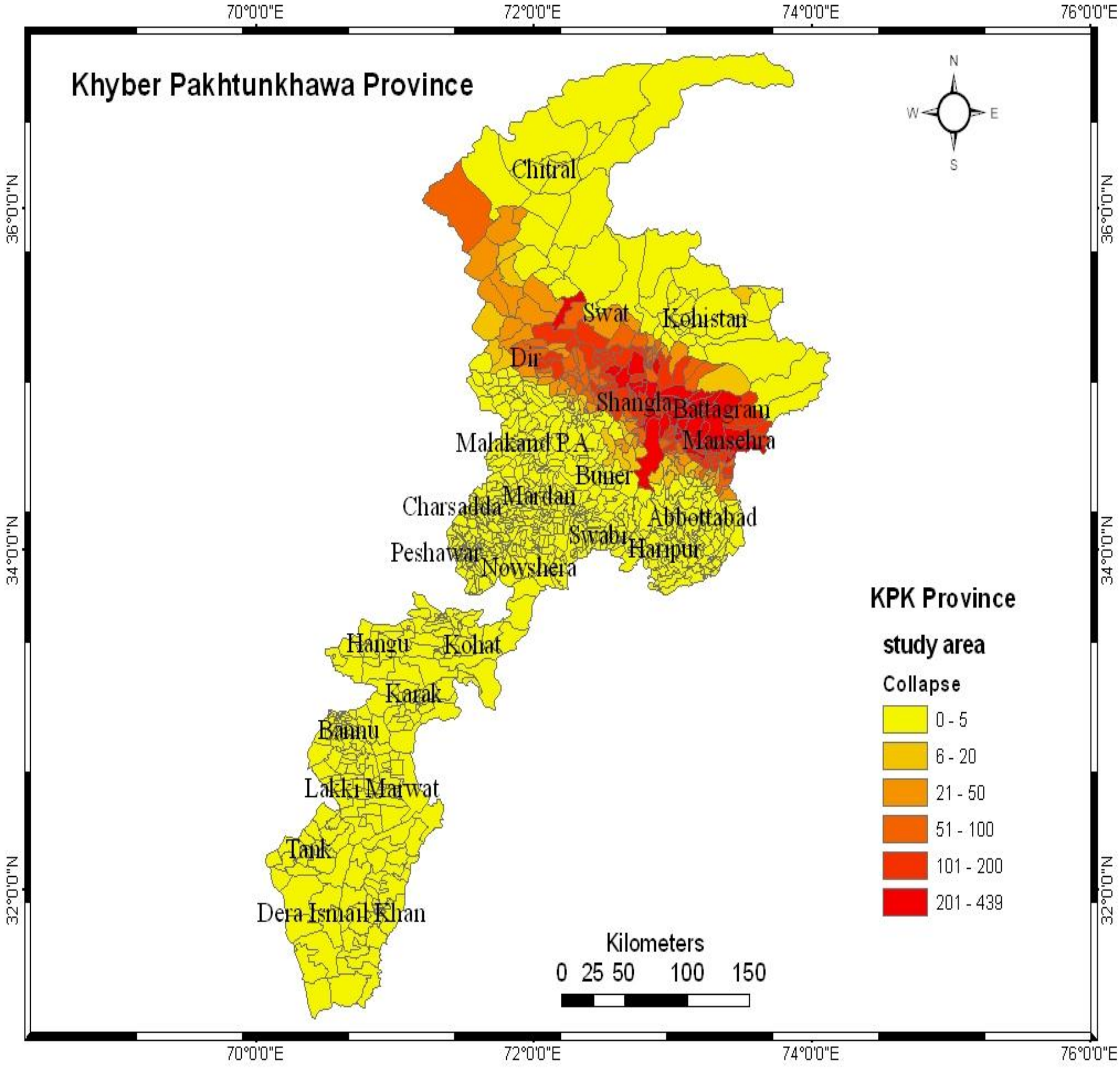

Figure 5.6 – Collapse of Building.

Seismic risk calculated and spatial representation of collapsed building shows that the risk is compatible with seismo-tectonic, exposure and vulnerability of building stock.

5.4 CAUSALITY ASSESSMENT

The below table shows the Fatalities and injuries for some district in the study region

Table 5.2 Fatalities and Injuries for some districts in the study region

District	**Fatalities**	**Injuries**
Mansehra	3487	8966
Battargam	3506	9015
Shangla	2285	5806
Abbottabad	49	127
Swat	2080	5875
Kohistan	1488	3828
Chitral	168	432
Upper Dir	1171	3011

The spatial representation of fatalities and injuries is shown in below figures.

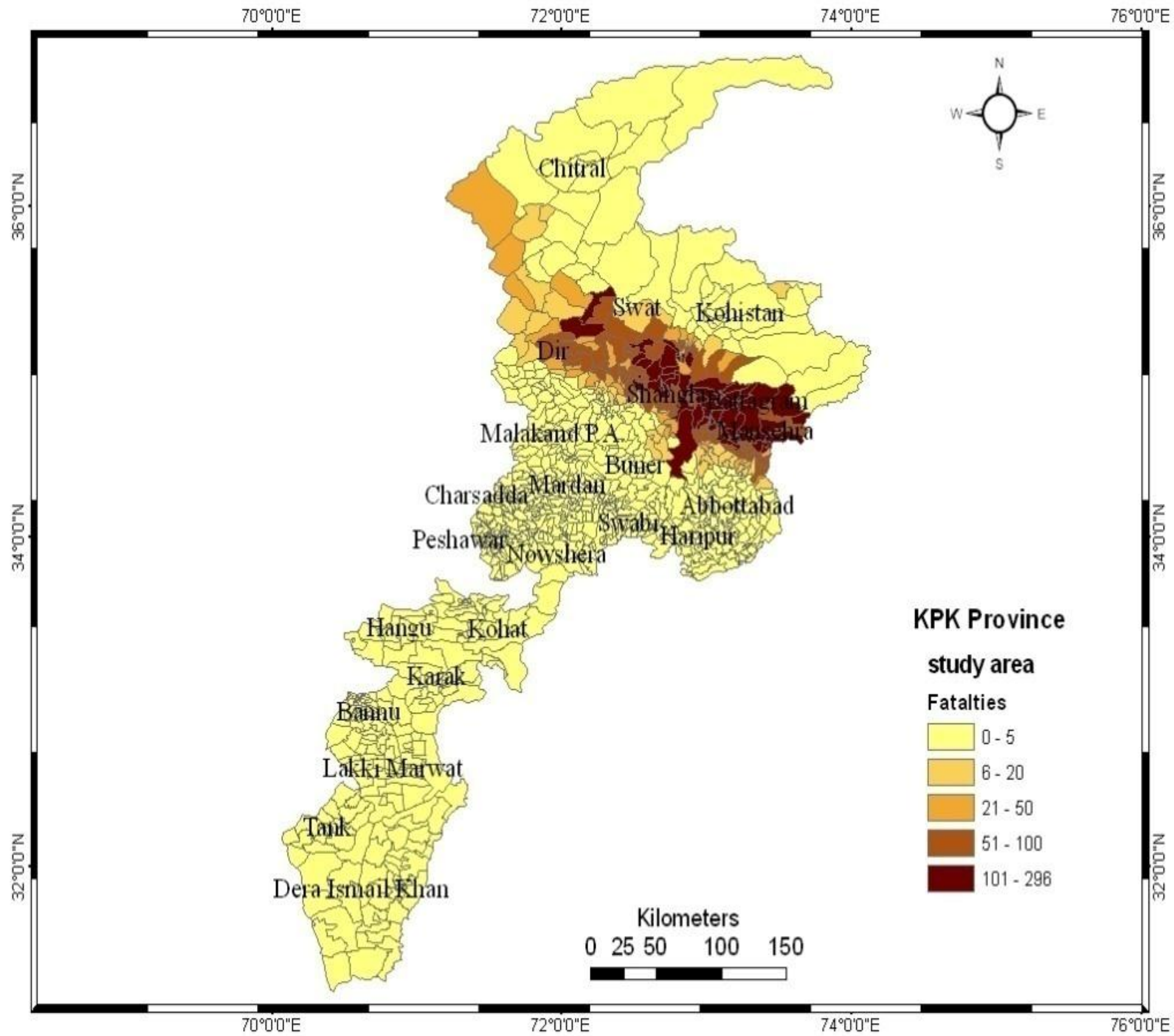

Figure 5.7 – Fatalities in 100 years

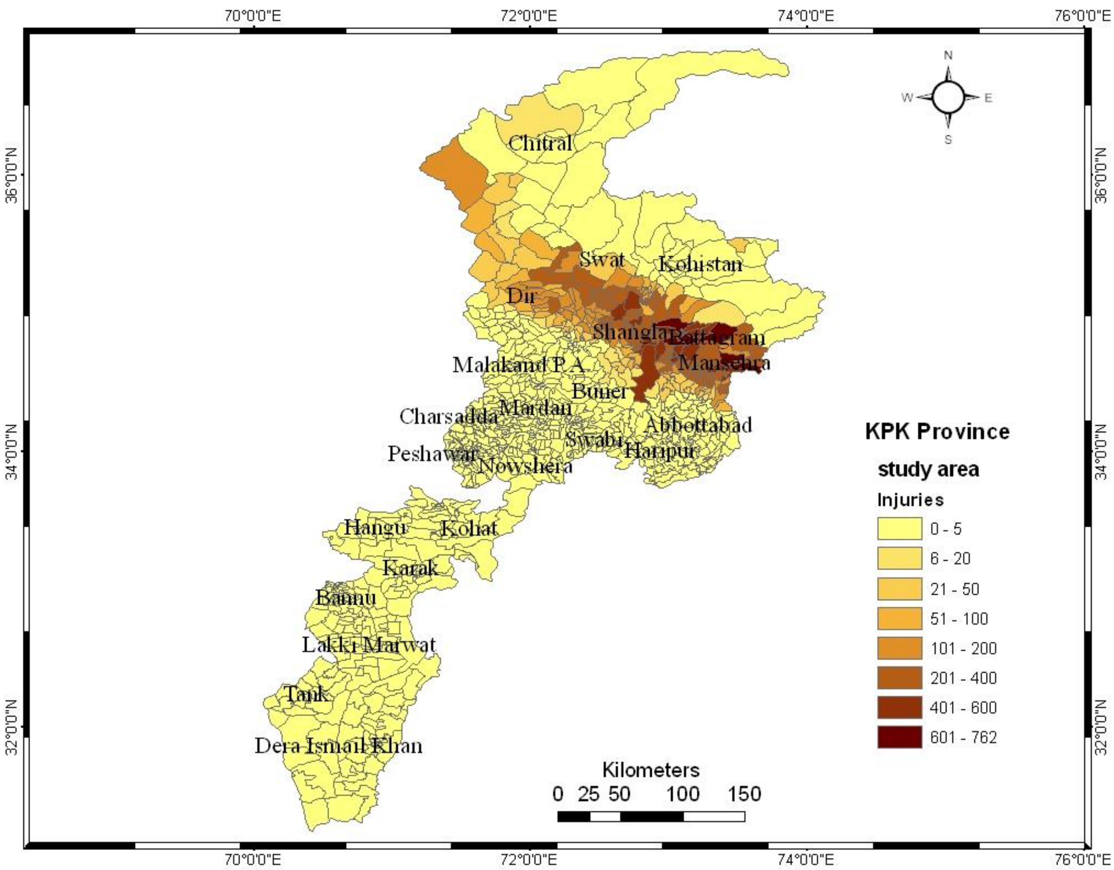

Figure 5.8 – Injuries in 100 years

5.5 INSURANCE PREMIUM FOR STUDY REGION

Insurance premium rate calculated from risk calculated in preceding section and these are average value for mentioned district. Insurance values are calculated for district because it is easy to implement. Insurance industry for construction in South Asian countries is not developed. Insurance calculation formula developed by Yucemen 2005 is used in current study. Yucemen carried out insurance premium calculation for Istanbul, Turkey.

$$Isurance\ Premiun = \frac{Risk}{1-LF} \qquad (5.1)$$

Spatial distribution of Insurance premium rate is shown in figure 5.8. Insurance Premium rate for some of district is given in table.5.3

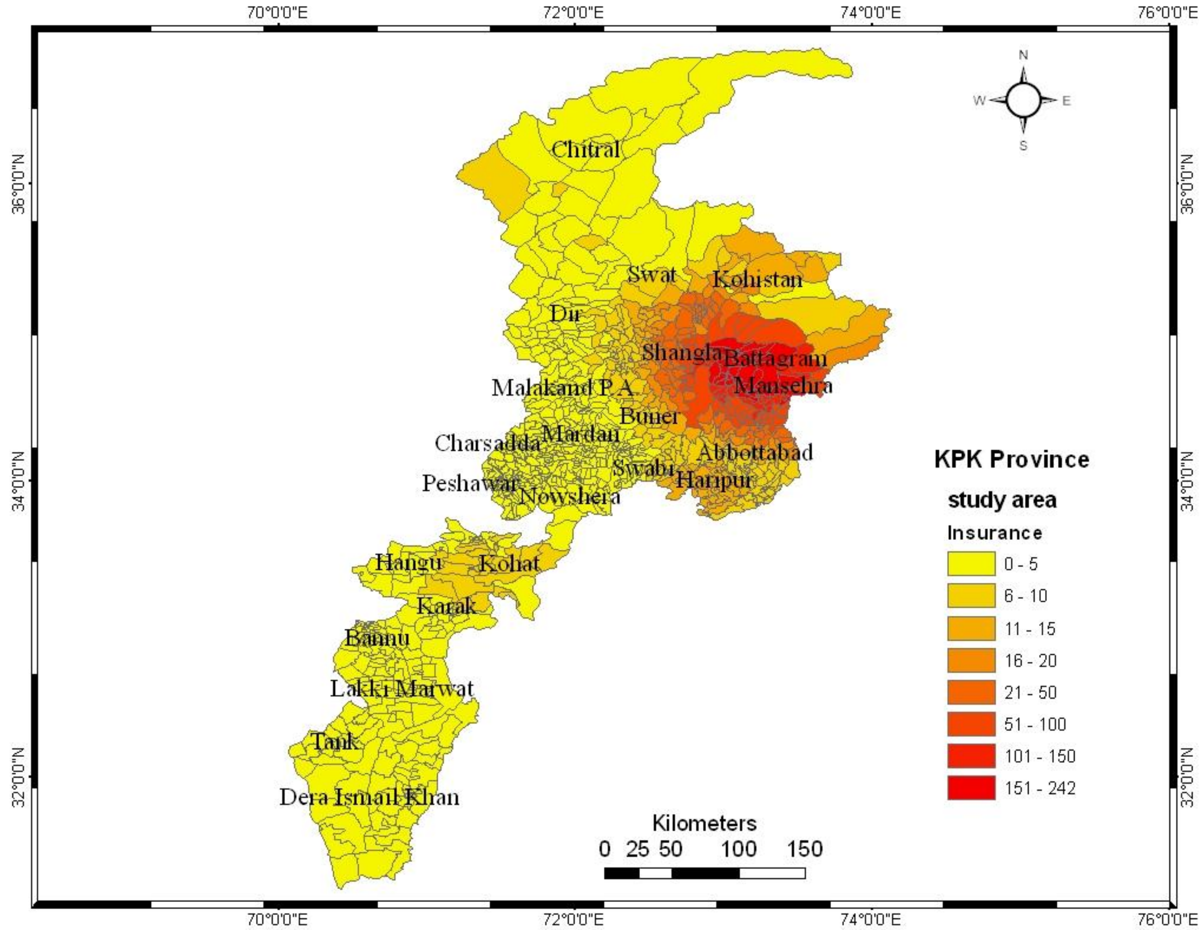

Figure 5.9 – Insurance Premium for Study region

Table 5.3 Insurance Premium for some districts in the study region

District	**Risk/1000 ($)**	**Insurance Premium ($)**
Mansehra	51	88
Battargam	107	170
Shangla	35	58
Abbottabad	7.4	12

Insurance premium rate calculated above are from risk calculated using PSHA methodology are these are average value for mentioned district.

Chapter # 6

CONCLUSIONS, RECOMMENDATIONS & FUTURE WORK

6.1 INTRODUCTION

This research work is part of larger project in the National University of Sciences & Technology (NUST) Islamabad, in which Earthquake Hazard and Risk Assessment of Whole country to be carried out. In this research the Earthquake hazard and Risk Assessment of KPK province is carried out using PSHA methodology.

In the following sections, the main conclusions of this study are given and recommendations for future work are suggested:

6.2 CONCLUSIONS

In this Probabilistic seismic hazard and risk assessment of KPK province is carried out. The following are conclusions of this study.

1. The Seismic hazard map giving Max. PGA 0.39g for 100 years returns period for some part of Mansehra, Batagram and District Shangla.
2. Risk assessment is carried out and it is concluded that average risk per $ 1000 ranges between $ (5 -145) depending upon the type of building and its location.
3. Insurance premium is calculated for different districts of KPK Province and Maximum amount of insurance premium is $ 170 for district Battagram where as insurance premium for Abbottbad is only $ 12.

6.3 RMS RECOMMENDATIONS FOR THE STUDY REGION

1. According to the risk Map few Union Councils of Mansehra, Battagram and Shangla are at high risk and hence only earthquake resistant construction should be allowed in these areas.
2. Seismic retrofitting is recommended for buildings in Abbottabad, Mansehra, Battagram, Shangla Swat and Chitral district.
3. Major contribution of collapsed buildings consists of Rubble stone masonry hence this type of construction is high seismic zone should be prevent.

6.4 RECOMMENDATION FOR FUTURE WORK

1. Hazard and Risk Assessment of other parts of Country should be done. Especially the Quetta and surrounding regions.
2. Attenuation relationship for Pakistan should be developed.
3. Open Source National data base need be developed for Building Inventory. (We can obtained this data in coming census)
4. The methodology for building inventory assessment needs to be further developed to utilize more sophisticated and automated image processing procedures.(IGIS)
5. Vulnerability assessment of industrial facilities and other infrastructure such as dams, power stations, lifelines etc. needs to be performed. This will help extend the ERA framework.
6. ERA Framework need to be enhanced to carry out the risk assessment of lifelines, communication towers, bridges etc.

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