TOPOGRAPHICAL ASPECTS OF SEISMIC HAZARD

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

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MASTER OF TECHNOLOGY

in

DISASTER MITIGATION AND MANAGEMENT

By

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CENTRE OF EXCELLENCE IN DISASTER MITIGATION AND MANAGEMENT
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Declaration

I hereby declare that the work that is being presented in this **Dissertation**, entitled "***TOPOGRAPHICAL ASPECTS OF SEISMIC HAZARD***" in partial fulfillment of the requirements for the award of the Master of Technology in Disaster Mitigation and Management degree, submitted to the Centre of Excellence in Disaster Mitigation and Management of Indian Institute of Technology Roorkee, India, is an authentic record of my work and where others' ideas or words have been included, I have adequately cited and referenced the original sources.

I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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CERTIFICATE

This is to certify that the above mentioned statement made by the candidate is correct to the best of my knowledge.

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Abbreviations

GMPE- Ground Motion Prediction Equation
ISRO- Indian Space Research Organization
KSSZ- Kangra Seismogenic Source Zone
MBT- Main Boundary Thrust
MCE- Maximum Credible Earthquake
MCT- Main Central Thrust
MHD Catalogue- Merged, Homogenized, Declustered Catalogue
$M_{max,cal}$ - Maximum Calculated Magnitude
$M_{max,obs}$ - Maximum Observed Magnitude
PGA - Peak Ground Acceleration
SoI- Survey of India
SSZ1- Seismogenic Source Zone 1

Abstract

Many seismic hazards, like landslides, occur mostly in regions of high topographical elevations. A quantitative assessment of topography can be a useful tool for identifying zones of active landslides, particularly those associated with seismic hazards. The main objective of this study was to estimate slope angles in the vicinity of earthquakes in known seismogenic source zones, so that landslide potential can be estimated. The Kangra Seismic Source zone (KSSZ), (Mridula et al., 2014), which is the most active seismic source zone in western Himalaya, is the study area. It is located between latitude 31°-35°N and longitude 75°-78°E in the Western Himalayas, and covers parts of Jammu & Kashmir and Himachal Pradesh.

Several earthquakes, with M_W range 6.2 to 8.0 for the period 1905 - 1945, and ISRO topographical sheets 52D, 52H and 43P were used for obtaining elevations in the study area. Hazard parameters (M_c, b, a, λ_m, M_{max}) estimated in Kangra SSZ were 3.8, 1.93, 0.51, 0.982 and 8.71, respectively, and return periods estimated for 8.0, 7.0, 6.0 magnitude earthquakes were 141 years, 44 years and 14 years, respectively. Topographical aspect related to maximum and minimum elevation was considered within a pre defined buffer zone drawn around each epicenter, and slope angles were computed to assess landslide hazard. This study indicates that landslides will compound the disaster if the probability of occurrence of a great earthquake in the next 50 years is considered as per hazard parameters.

Chapter 1

INTRODUCTION

1.1 SEISMIC HAZARD

Hazard is the probability of occurrence of an earthquake or earthquake effects of a certain severity, within a specific period of time, at a given location or in a given area, (Coburn and Spence, 2002, p 317-318). Seismic hazard is a physical phenomenon, such as surface faulting, ground shaking, landslides, liquefaction, tectonic deformation, tsunamis, or seiches, which are associated with an earthquake and may produce adverse effects on the normal activities of the people (source: Indian Metrological Department). It can also be defined as the property of an earthquake that can cause damage and loss to human lives and to the environment (McGuire, 2004).

Seismic hazard assessment involves the quantitative estimation of ground shaking hazards at a particular site. Seismic hazards can be analyzed deterministically as and when a particular earthquake scenario is assumed, or probabilistically, in which uncertainties in earthquake size, location, and time of occurrence is explicitly considered (Kramer, 2009).

For sources and patterns of earthquake occurrence, geology and seismic setting of the region is examined both in depth and at the surface. Then the impacts from these sources to the local geologic rock and soil types, slope angle and groundwater conditions are assessed. Seismic hazard varies from place to place depending on many other factors. For example if a structure is built on soft swamp, it is more likely to experience damage than the neighbor on solid rock. Areas with high ground motion due to soil conditions are often subject to soil failure due to liquefaction. Soil failure can also occur due to earthquake induced landslides in steep topography. Landslides can also occur on rather gentle slopes depending on the soil condition.

TOPOGRAPHY

Topography can be defined as the art or practice of graphic delineation in detail, usually on maps or charts, of natural and man-made features of a place or region especially in a way to show their relative positions and elevations, for example topographical surveying. Topographic analysis cannot be ignored if seismic activities and tectonic features are described to assess seismic hazard. Topography itself may signal tectonic activities at depth that is not well recorded by short-term satellite measurements. Direct field documentation of active deformation provides critical corroboration.

Topographic assessment can act as a guide to identify the region of high seismic hazard. Although researchers are often quick to rightly point out difficulties in the interpretation of tectonics from topography, it can be estimated that topographical analysis can help with the initial identification of active structures and, in some cases, provide constraints on the nature of deformation along them. Since many seismic hazards like landslides occur mostly in regions of high topographical elevations, a quantitative topographic assessment can be a quick and useful tool for identifying zones of active rock uplift and the seismic hazards associated with them. Such analyses can be particularly insightful above blind or hidden faults, in remote mountainous landscapes.

1.2 OBJECTIVE

The objective of this study is to estimate topographical aspects from satellite imageries, to estimate seismic hazard. In this study an estimate is made of slopes, so that potential of landslides can be estimated, based on slopes. This has immense implications in seismic hazard assessment.

1.3 STUDY AREA

The Himalayan mountain region extends all along the northern border of the country. From the eastern border of West Pakistan to the frontiers of Burma, the Himalayas run for a distance of about 2,400 km in the east-west direction in the shape of an arc. Himalayas cover an area of about 500,000 km^2. The Western Himalayas cover the states of Jammu & Kashmir and a part of Himachal Pradesh. The part between Satluj and Kali River is known as Kumaon Himalayas, the Nepal Himalayas lie between the Kali River and the Tista River. The area between the Tista and the Brahmaputra Rivers is known as the Assam Himalayas.

CLIMATIC CONDITION

The climatic condition in the Himalayas varies depending on the elevation and location. Climate ranges from subtropical in the southern foothills, with average summer temperatures of about 30° C (about 86° F) and average winter temperatures of about 18° C (about 64° F); warm temperate conditions in the Middle Himalayan valleys, with average summer temperatures of about 25° C (about 77° F) and cooler winters; cool temperate conditions in the higher parts of the Middle Himalayas, where average summer temperatures are 15 to 18° C (59 to 64° F) and winters are below freezing temperature; to a cold alpine climate at higher elevations, where summers are cool and winters are severe. At elevations above 4880 m (16,000 ft) the climate is very cold with below freezing temperatures and the area is permanently covered with snow and ice. The eastern part of the Himalayas receives heavy rainfall; the western part is drier.

MAJOR RIVERS AND DRAINAGE SYSTEM

The major rivers of north India that originate from Himalayas are the Indus, Satluj, Ganga, and the Brahmaputra. Being snow fed, these rivers are perennial and carry large amount of water and sediments. The origin of the Indus, the Satluj and the Brahmaputra is near the Kailash Mansarovar region. Besides the snow covered peaks, glaciers and pristine rivers, Himalayas are known for beautiful valleys the world over. The valleys of Kashmir, Kulu, Kangra, and Khasi and Garo hills are known for their scenic beauty and salubrious climate attracting millions of tourists every year.

STUDY AREA

As per Mridula et al (2014b), a region bound by latitude 29.0° N to 36.0° N and longitude 73.0° E to 80.0° E was divided into nine Seismogenic Source Zones. These were Kangra SSZ, Uttarakhand SSZ, Syntaxes SSZ, Kaurik SSZ, Kashmir SSZ, Western Tibet SSZ, Karakoram SSZ, Jhelum SSZ, and Indo Gangetic SSZ. Kangra SSZ was the most vulnerable SSZ in terms of return period and magnitude which is further crosschecked for topographical change.

1.4 KANGRA SEISMOGENIC SOURCE ZONE (KANGRA SSZ)

Kangra SSZ is the area demarcated by Main Boundary Thrust (MBT) in the south, Main Central Thrust (MCT) in the north, Kishtwar fault in west and Sundarnagar fault in the east. It has a dense cluster of seismicity within this zone. The great Kangra earthquake is part of this cluster.

The regions which are in Kangra SSZ are parts of the state of Jammu and Kashmir and Himachal Pradesh and a small portion of Punjab. Border States of Jammu & Kashmir: To its north and east lies Tibet. On the South and South-West lie the states of Punjab and Himachal Pradesh. On the west is the North West Frontier Province of Pakistan. Border States of Himachal Pradesh: It is surrounded by Jammu and Kashmir in the north, Tibet on north east, Uttarakhand in the east and south east, Haryana in south and Punjab in south west and west.

1.5 JAMMU AND KASHMIR

The entire State lies between latitude 32.17"-36.58" N and between longitudes 73.26" - 80.30"E. The average altitude of the valley is 1850m above mean sea level which is the Kashmir or Jhelum valley and the highest altitude which is the Karakoram ranges is 8615.17m above mean sea level.

The Indian administrated Jammu & Kashmir consists of three divisions: Jammu, Kashmir Valley and Ladakh, and is further divided into 22 districts. The districts of Jammu division are: Jammu, Doda, Kishtwar, Rajouri, Reasi, Udhampur, Ramban, Kathua, Samba and Poonch. The districts of Kashmir valley are: Srinagar, Anantnag, Kulgam, Pulwama, Shopian, Budgam, Ganderbal, Bandipora, Baramulla and Kupwara. And that of Ladakh division are Kargil and Leh.

The districts of Jammu & Kashmir which are in Kangra SSZ are: Kathua, Udhampur, Doda, Kishtwar, Anantnag and Pulwama.

CLIMATIC CONDITIONS OF JAMMU AND KASHMIR

The climate of Jammu and Kashmir varies greatly because of its rough topography. The climate of the state ranges from the burning and the scorching heat of the plains of (Jammu Division) to the snow-capped heights of Gulmarg (Kashmir) and the mud peak of Mount Godwin Austin (Ladakh) 21,265 feet above sea level, the second highest in the world. All these represent the three different climatic zones.

From Alpine (Ladakh region) to the sub tropical (Jammu region) the extreme variants of climate in Jammu and Kashmir are due to its location and topography. In the south around Jammu, the climate is typically monsoonal, though the region is sufficiently far west to average 40 to 50 mm of rain per month between January and March. In the hot season, Jammu city is very hot and temperatures can reach up to 40 °C whilst in July and August, very heavy though erratic rainfall occurs with monthly extremes of up to 650 mm. In September, rainfall declines, and by October conditions are hot but extremely dry, with minimal rainfall and temperatures of around 29 °C.

MAJOR RIVERS AND DRAINAGE SYSTEM OF JAMMU AND KASHMIR

The Jhelum is the main waterway of the valley of Kashmir. Its tributaries are Vishav, Romushi, Dudhganga, Sukhang, Lidar, Ferozpore Nullah, Sind Nullah and Flood Spill Channel. Its lakes are Wullar Lake, Dal Lake, Anchar Lake, Mansbal Lake, Harvan Lake, the Hokarsar Lake, The Konsarnag or Vishno Pad Lake, The Gangabal Lake, The Sheshnag Lake, The Neelang Lake, Tarsar Lake and Marsar Lake, Marsar Lake is the origin of the Canal Sharab Kohl, Sokh and Dokh are two frozen lakes situated at Harmukh Mountain.

1.6 HIMACHAL PRADESH

Himachal Pradesh is located between latitudes 30° 22' 40" to 33° 12' 20"N and longitudes 75° 45' 55" to 79° 04' 20" E. The altitude varies from 350m to 6975m above mean sea level. Himachal Pradesh is divided into 12 districts namely, Kangra, Hamirpur, Mandi, Bilaspur, Una, Chamba, Lahaul and Spiti, Sirmaur, Kinnaur, Kullu, Solan and Shimla.

The following districts of Himachal Pradesh are in Kangra SSZ: Chamba, western parts of Lahul & Spiti, major part of Kangra, north western part of Kullu, some parts of eastern Una, Hamirpur, major parts of Mandi and Bilaspur and some parts of north western Solan.

CLIMATIC CONDITIONS OF HIMACHAL PRADESH

Due to extreme variation in elevation, there is great variation in the climatic conditions of Himachal Pradesh. The climate varies from hot and sub-humid tropical in the southern tracts to, with more elevation, cold, alpine and glacial in the northern and eastern mountain ranges. The state has areas like Dharamshala that receive very heavy rainfall, as well as those like Lahaul and Spiti that are cold and almost rainless. Broadly, Himachal Pradesh experiences three seasons: Summer, winter and rainy season. Summer lasts from mid April till the end of June and most parts become very hot (except in alpine zone which experiences a mild summer) with the average temperature ranging from 28°C to 32 °C (82 to 90 °F). Winter lasts from late November till mid March. Snowfall is common in alpine tracts (generally above 2,200 meters (7,218 ft) i.e. in the Higher and Trans-Himalayan region).

RIVERS AND MAJOR DRAINAGE SYSTEM OF HIMACHAL PRADESH

The drainage system of Himachal includes both rivers and glaciers. Himachal Pradesh provides water to both the Indus and Ganges basins. The drainage systems of the region are the Chandra Bhaga or the Chenab, the Ravi, the Beas, the Sutlej and the Yamuna. These rivers are perennial and are fed by snow and rainfall. They are protected by an extensive cover of natural vegetation.

Area of Study

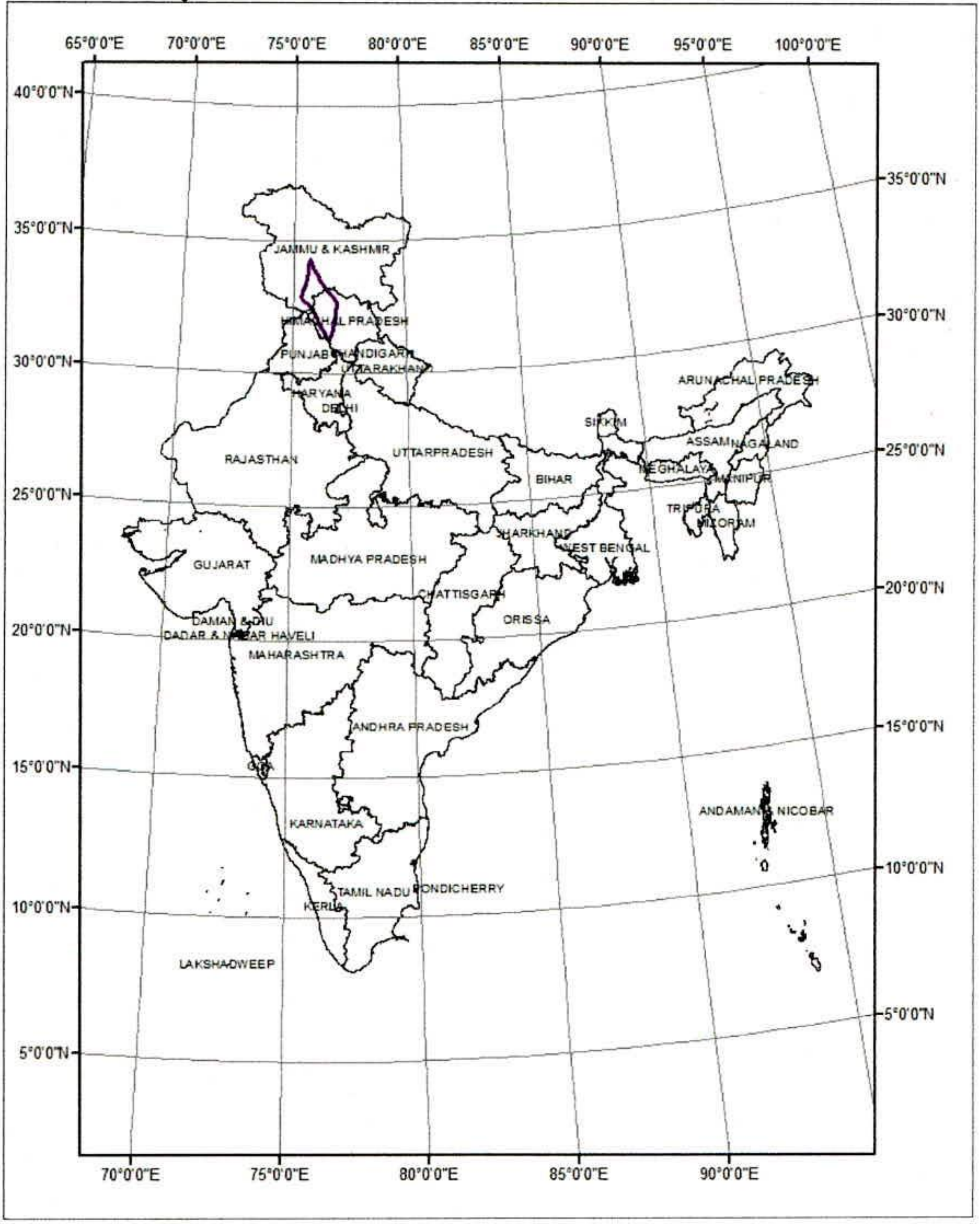


Figure 1: Map of India showing area of study: Kangra Seismogenic Source Zone, KSSZ (personal communication, Mridula)

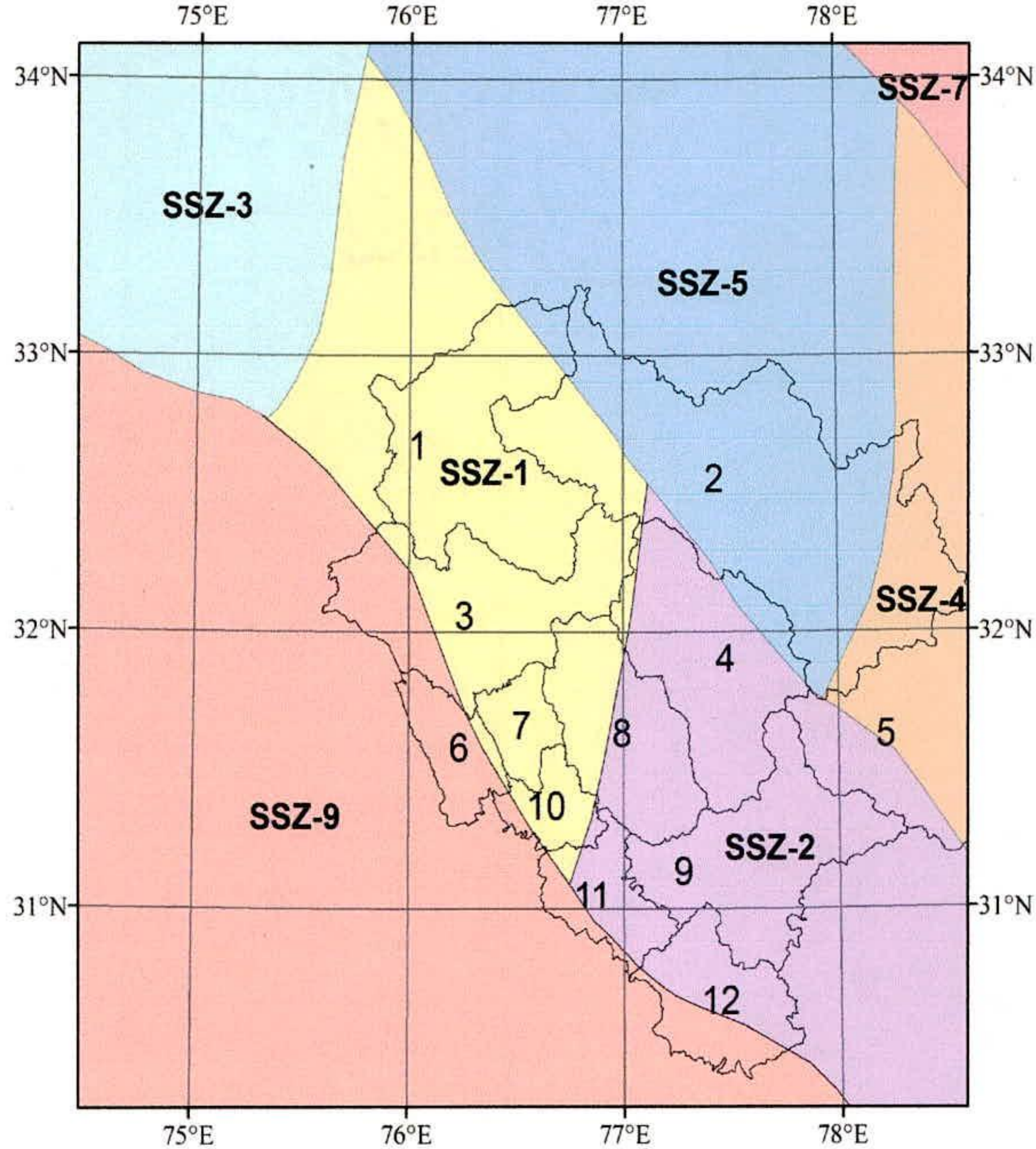


Figure 2: Map shows SSZ 1 surrounded by SSZ 3, SSZ 5, SSZ 4, SSZ 2, SSZ 7 and SSZ 9, (personal communication, Mridula), Outline of Himachal Pradesh, and Outline of districts of Himachal Pradesh: '1" represent Chamba, '2' represent Lahul & Spiti, '3' represent Kangra, '4' represent Kullu, '5' represent Kinnaur, '6' represent Una, '7' represent Hamirpur, '8' represent Mandi, '9' represent Shimla, '10' represent Bilaspur, '11' represent Solan, '12' represent Sirmaur.

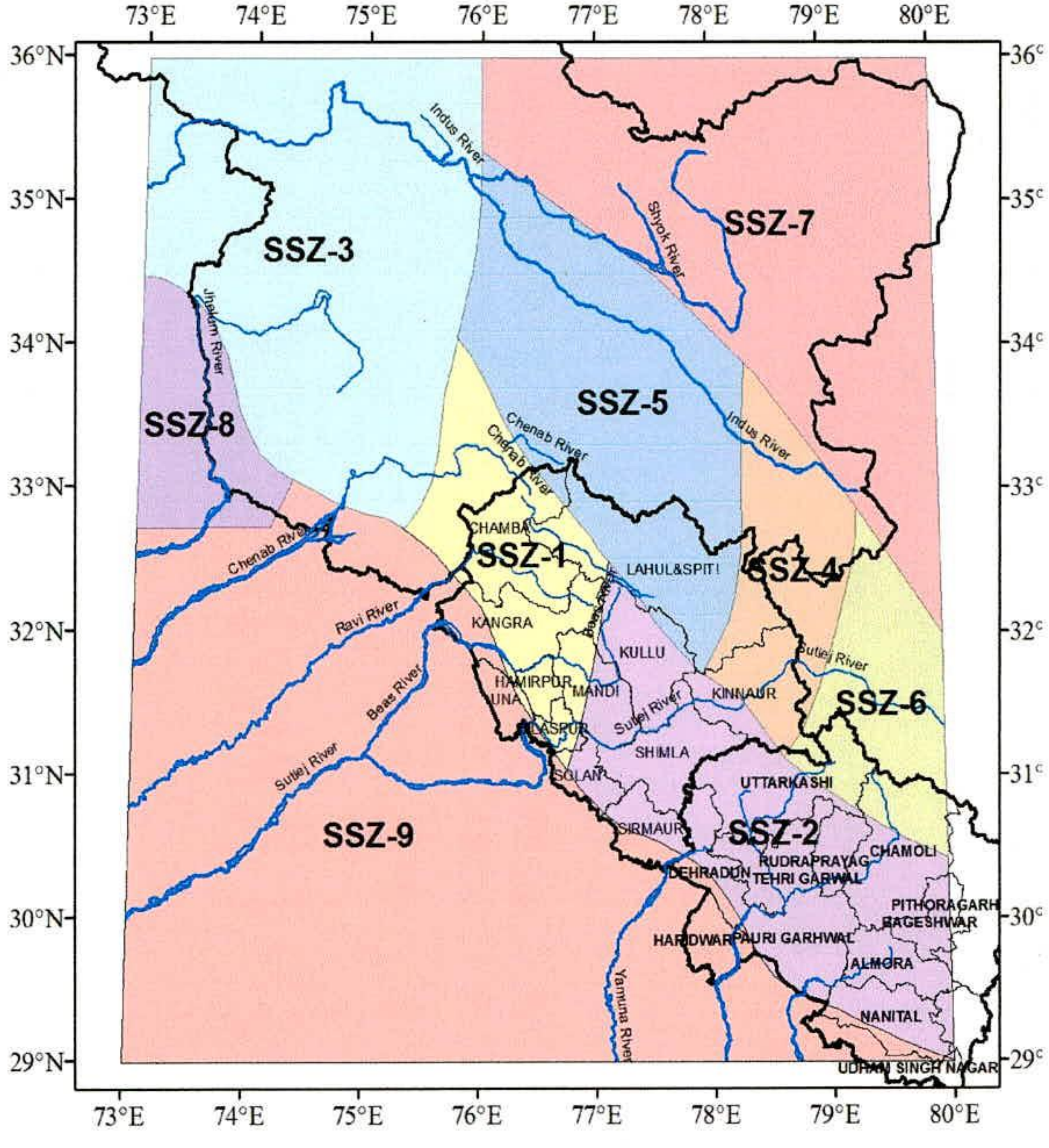


Figure 3: Map shows SSZ 1 surrounded by SSZ 3, SSZ 5, SSZ 4, SSZ 2, SSZ 7 and SSZ 9, (personal communication, Mridula), Outline of Indian states: Himachal Pradesh, Jammu & Kashmir and Uttarakhand, Major rivers and Drainage systems in and around Kangra seismogenic source zone (after Rashmi, et. al., 2014).

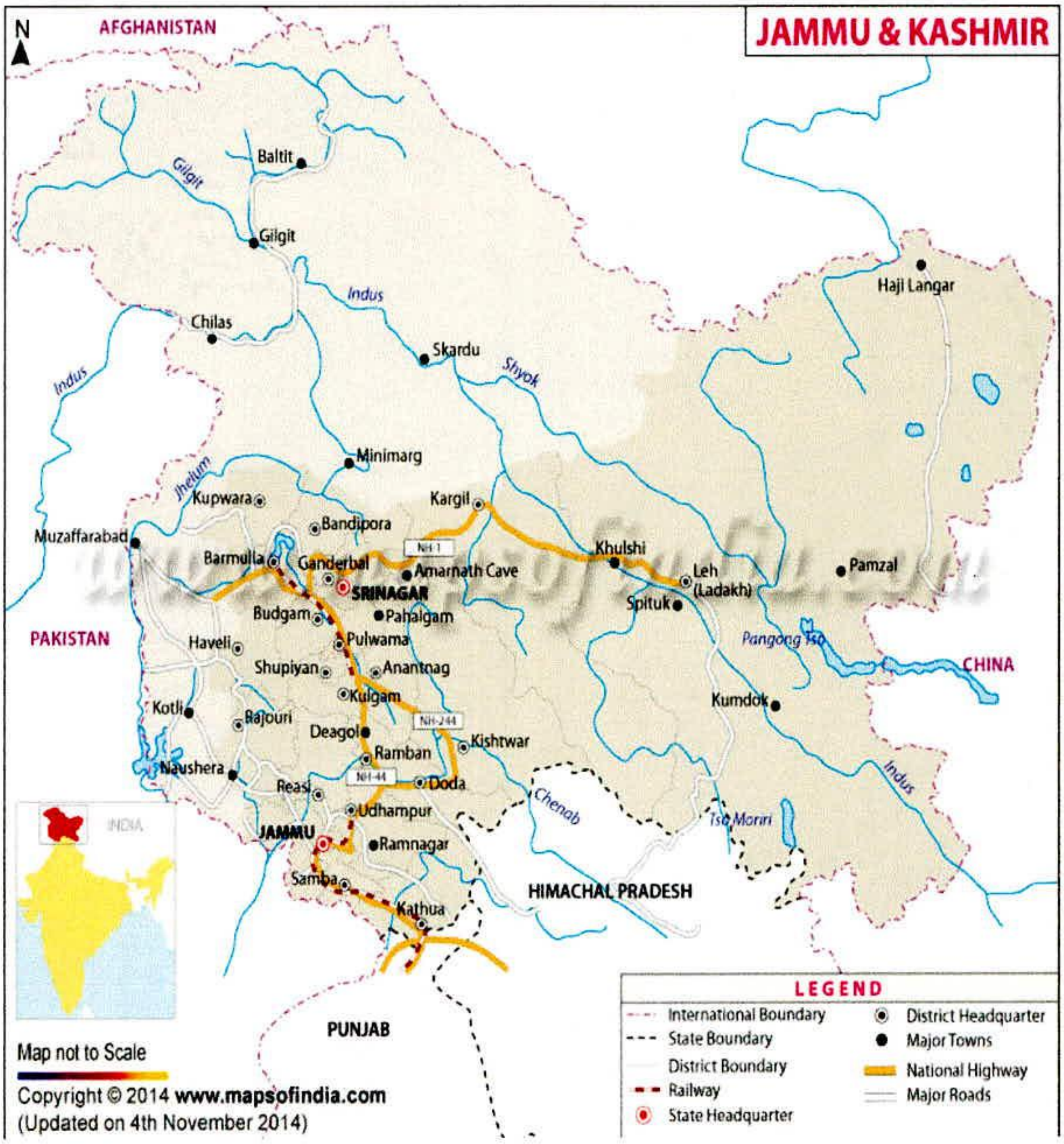


Figure 4: Map shows district headquarters, Major towns, State and international boundaries of Jammu and Kashmir (source: Maps of India), and outline of Jammu & Kashmir.

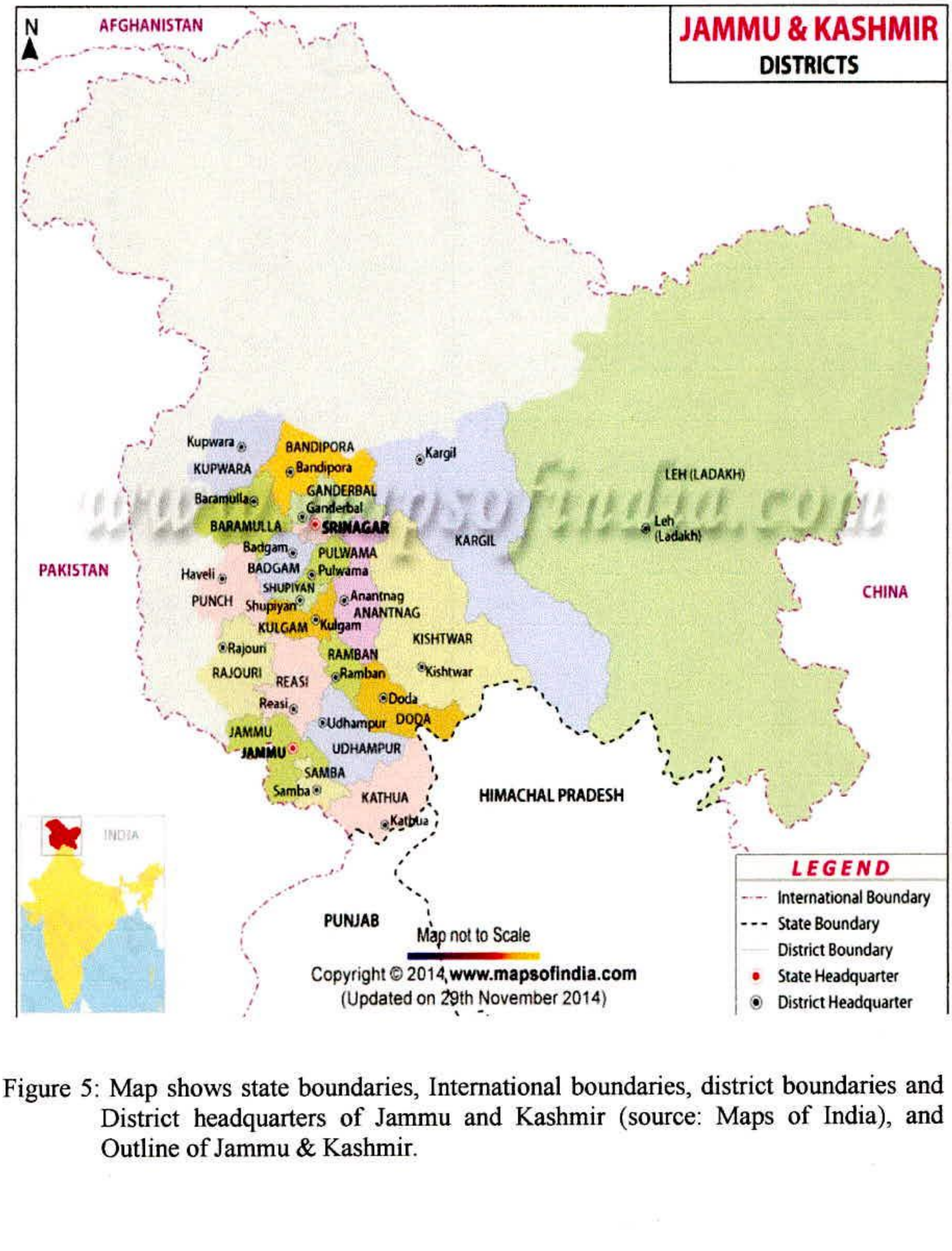


Figure 5: Map shows state boundaries, International boundaries, district boundaries and District headquarters of Jammu and Kashmir (source: Maps of India), and Outline of Jammu & Kashmir.

Chapter 2

DATA USED

2.1 ALL SEISMOGENIC SOURCE ZONES (SSZ)

The north western Himalayan region is divided into nine seismogenic source zones, from SSZ1 to SSZ9 (Mridula et al. 2014a). In SSZ 1, 181 earthquakes occurred in the time span 1827-2011. The maximum observed magnitude ($M_{max, obs}$) was 8.0, which was the great Kangra earthquake and it occurred in Kangra District of Himachal Pradesh. Nearest prominent tectonic feature to this earthquake was Main Boundary Thrust (MBT). Maximum calculated magnitude ($M_{max, cal}$) for this SSZ was 8.71 ± 0.87. It means that in SSZ 1, the maximum magnitude can vary between 7.84 and 9.58. The Kangra SSZ is the most vulnerable SSZ in terms of return period and magnitude (Rashmi et al. 2014).

2.2 STATES AND DISTRICTS IN KANGRA SEISMIC SOURCE ZONE (KSSZ)

Total area covered by the Kangra Seismic Source Zone (KSSZ) is 24,013 sq km. The area covered by the Kangra SSZ includes some parts of Jammu & Kashmir and Himachal Pradesh. For Himachal Pradesh, the districts which are covered in the Kangra SSZ are Chamba, Kangra, Hamirpur, Bilaspur and some parts of Mandi, Kullu and Lahul and Spiti. For Jammu & Kashmir the following districts are in Kangra SSZ: Kathua, Udhampur, Doda, Kishtwar, Anantnag and Pulwama.

2.3 SEISMIC HAZARD PARAMETERS

As per Mridula et al. (2014b) seismic hazard parameters for Kangra SSZ are M_c, a, b value, λ_m, and $M_{max, cal}$ where M_c is the magnitude of completeness, defined as the lowest magnitude at which all events in a space–time domain are detected. λ_m is the annual rate of exceedance of an earthquake of magnitude greater than or equal to magnitude M. The regression parameter '*a*' signifies seismic activity. '*b*' value reflects the relative likelihood of occurrence of large and small magnitude earthquakes. A low '*b*' value indicates frequent occurrence of high magnitude earthquakes whereas a high '*b*' value indicates frequent occurrence of low magnitude earthquakes. $M_{max, cal}$ is the maximum calculated magnitude.

2.4 SEISMICITY DATA

The 181 earthquakes considered for the study purpose have their magnitude $\geq$3. They have their epicenter in the Kangra Seismogenic Source Zone. The seismicity data taken for the study are taken from 1827 - 2011. The epicenters of the earthquakes lies between the latitude 31°-35°N and longitude 75°-78°E. List is given in Table 2.1. Seismicity of area in and around Kangra seismic source zone is shown in figure 7.

2.5 TECTONICS

The prominent tectonic features in the study area are: MBT, MCT, Sundarnagar Fault, Kishtwar Fault, Jwalamukhi Thrust, Vaikrita Thrust, Drang Thrust, Mastgarh Anticline and many unnamed lineaments. Tectonics in and around Kangra seismic source zone is shown in figure 8.

2.6 ISRO

The Indian Space Research Organization (ISRO) is the primary space agency of India. ISRO is among the largest government space agencies in the world. Its primary objective is to advance space technology and use its applications for national benefit. The ISRO Toposheet used for this study purpose is given in figure 9.

ISRO launched Cartosat- 1 with the primary objective of providing high resolution satellite data of 2m in track stereo. DEM generated by Cartosat-1 facilitates large scale mapping and terrain modeling. Cartosat-1 satellite consists of two panchromatic cameras with 2.5 m spatial resolution. Two images are acquired simultaneously at a time, one forward looking (Fore) at +26 degrees and another rear looking (Aft) -5 degrees for near instantaneous stereo data. The time difference between the acquisitions of the same scene by two cameras is about 52 seconds. The spacecraft body is steerable to compensate the earth rotation effect and to force both fore and aft cameras to look at the same ground strip when operated in stereo mode. The stereo pairs have a swath of 26 km and a fixed B/H ratio of 0.62.

A digital elevation model (DEM) is a digital model or 3D representation of a terrain's surface. A DEM can be represented as a raster (a grid of squares, also known as a height map when representing elevation) or as a vector-based triangular irregular network (TIN). DEMs are commonly built using data collected using remote sensing techniques, but they may also be built from land surveying. DEMs are used often in geographic information systems, and are the most common basis for digitally-produced relief maps.

The methodology adopted to produce the CartoDEM involved stereo-strip triangulation of 500 km strip stereo pairs using high precise ground control points, interactive cloud masking, and automatic dense conjugate pair generation using matching approach. Seamless homogeneous DEM is produced by TIN modeling of irregular DEM, interpolation for regular DEM generation and automatic strip to strip mosaicing. These automatically generated DEM tiles are further evaluated for quality and tile editing to remove anomalies. The primary output unit is a tile of 7.5' X 7.5' extents with DEM spacing of 1/3 arc-sec, and co-registered ortho-image of resolution 1/12 arc-sec. However data sets are available at 1 and 3 arc-sec .i.e. 30 m and 90 m spacing at equator which are generated by sub sampling the original 1/3 arc-sec data. The CartoDEM is a surface model of elevation and covers land surfaces of India. It is comprised of tiles that contain at least 0.01% of Indian landmass are included. As per the design of CartoDEM, the DEM accuracy is 8m at LE90 and 15m at CE90 for ortho data.

Common uses of DEMs include the following:

1. Contour generation
2. Drainage network analysis
3. Quantitative analysis of run-off and soil erosion
4. Volume-area calculations
5. Design of hydraulic structures
6. Design of new road, rail and pipeline alignments
7. Watershed planning
8. Urban utility planning
9. Extracting terrain parameters for geomorphology

10. Modeling water flow for hydrology or mass movement (for example avalanches and landslides)
11. Creation of relief maps
12. Rectification of aerial photography or satellite imagery
13. Terrain analysis in geomorphology and physical geography
14. Geographic Information Systems (GIS)
15. Engineering and infrastructure design
16. Global positioning systems (GPS)

In this work DEMs are used to assess topographical aspects of seismic hazards.

LIMITATIONS OF DEM:

1. Large amount of data redundancy in areas of uniform terrain.
2. Inability to adapt to areas of differing relief complexity without changing grid size.
3. Can have problems deriving holes or islands
4. Can introduce a triangular discretisation hindering some forms of spatial analysis.

2.7 ISRO TOPOSHEETS

The following ISRO Topo sheets, given in figure no. 10, are covered in the area of Seismogenic Source Zone 1: 43O, 43P, 52C, 53D, 52H, 53A. The contour interval is 50 m. Toposheet showing the study area, ISRO Toposheet, state boundaries, seismogenic source zones in figure 9.

2.8 MHD CATALOGUE

The Merged, Homogenized, Declustered Catalogue (MHD) catalogue consists of events upto year 2012 (Mridula et. al., 2014a). Western Himalaya region in the vicinity of Main Boundary Thrust (MBT) and Main Central Thrust (MCT) within latitudes 29.0° to 36.0°N and longitudes 73.0° to 80.0°E. A total of 117 tectonic features which include various thrusts, faults, lineaments, anticlines and suture zones were identified. Nine Seismogenic Source Zones (SSZ1 to SSZ9), were identified on the basis of seismicity and the tectonics. Seismic hazard parameters were computed for each source zone. The Kangra SSZ was the most vulnerable SSZ in terms of return period and magnitude.

Table 2.1: List of earthquakes in Kangra seismogenic source zone, arranged in decreasing order of magnitude. Number of events=181. (Source: personal Communication, Mridula Singh). Magnitude is in moment magnitude scale, M_w

S No	Year	Month	Day	hour	Minute	Longitude	Latitude	Depth km	Magnitude (M_w)
1	1905	04	04	00	50.00	76.25	32.30	0.00	8.00
2	1906	02	28	00	0.00	77.00	32.00	0.00	7.00
3	1945	06	22	18	0.00	75.90	32.60	0.00	6.50
4	1947	07	10	10	19.00	75.90	32.60	0.00	6.20
5	1986	04	26	07	35.00	76.40	32.15	33.00	5.80
6	1975	12	05	07	37.00	76.13	33.10	23.80	5.60
7	1973	10	24	05	23.00	75.92	33.15	36.90	5.60
8	1990	12	25	03	56.00	75.76	33.31	51.10	5.60
9	1962	09	15	12	35.00	76.20	31.90	0.00	5.50
10	1827	09	1	00	0.00	76.00	32.50	0.00	5.50

11	1950	08	12	03	59.00	75.90	32.60	0.00	5.50
12	1980	08	23	09	36.00	75.75	32.96	3.20	5.50
13	1962	06	17	04	39.00	75.83	33.74	88.00	5.50
14	1973	01	16	09	31.00	75.83	33.29	39.20	5.30
15	2001	09	28	04	37.00	75.83	33.30	27.10	5.30
16	1978	06	14	04	12.00	76.61	32.24	6.70	5.20
17	2009	05	19	07	29.00	75.79	33.23	19.20	5.20
18	1993	09	15	03	8.00	75.74	33.33	43.70	5.20
19	1968	11	05	02	2.00	76.48	32.28	33.00	5.10
20	1985	12	29	09	31.00	76.10	32.68	0.00	5.10
21	1980	05	01	05	43.00	75.97	33.03	18.10	5.10
22	2005	05	26	12	41.00	76.27	33.13	47.60	5.10
23	1977	06	22	03	53.00	76.04	33.18	47.00	5.10
24	1977	12	21	02	8.00	76.17	33.45	28.80	5.10
25	2004	11	11	02	13.00	76.61	32.37	15.00	5.00
26	1973	12	16	09	16.00	76.19	32.37	18.00	5.00
27	1982	05	07	07	44.00	76.01	32.62	39.70	5.00
28	1988	11	25	12	7.00	75.81	32.89	79.90	5.00
29	1982	09	08	05	53.00	75.50	32.93	33.00	5.00
30	1975	10	30	02	36.00	75.96	32.97	45.30	5.00
31	1974	11	16	04	18.00	76.23	33.01	35.80	5.00
32	1979	12	22	10	28.00	75.90	33.11	17.60	5.00
33	1984	05	23	03	14.00	75.93	33.17	13.80	5.00
34	1973	07	13	10	3.00	75.67	33.17	47.60	5.00
35	1967	07	02	08	32.00	75.71	33.21	42.00	5.00
36	1990	11	12	03	45.00	75.82	33.25	66.70	5.00
37	1978	02	23	02	1.00	76.06	33.43	14.80	5.00
38	1978	09	28	05	32.00	76.05	33.49	40.30	5.00
39	1987	10	06	04	33.00	76.40	32.07	51.10	4.90
40	1970	03	05	06	34.00	76.61	32.32	33.00	4.90
41	1995	03	24	11	52.00	76.17	32.67	29.20	4.90
42	1970	01	17	06	33.00	76.64	32.70	22.00	4.90
43	1981	07	12	08	45.00	76.09	32.73	35.90	4.90
44	2005	07	04	07	44.00	76.32	32.78	10.00	4.90
45	1975	10	30	02	20.00	75.71	32.89	75.00	4.90
46	2002	01	27	10	33.00	75.99	33.10	30.80	4.90
47	1966	03	16	12	8.00	75.91	33.23	33.00	4.90
48	1989	05	10	08	19.00	75.65	33.33	36.60	4.90
49	1979	06	02	01	5.00	76.01	33.75	33.00	4.90
50	1986	04	22	09	29.00	76.95	31.85	32.20	4.80
51	1975	09	16	04	20.00	76.25	32.34	58.80	4.80
52	1991	06	23	02	45.00	76.76	32.38	22.90	4.80
53	2005	02	28	06	1.00	76.53	32.45	4.80	4.80
54	2001	10	14	09	14.00	76.16	32.52	21.40	4.80
55	1983	05	30	08	39.00	75.49	32.71	41.40	4.80
56	1986	07	30	04	3.00	75.85	33.05	61.20	4.80
57	1997	07	29	06	0.00	76.86	31.56	49.20	4.70
58	1998	10	17	09	24.00	76.53	32.42	11.10	4.70
59	2009	07	17	11	7.00	76.72	32.51	42.00	4.70
60	1994	05	13	09	19.00	75.95	32.55	33.00	4.70
61	1982	09	04	12	33.00	76.14	32.59	33.00	4.70

62	2005	04	14	07	11.00	76.40	32.62	25.70	4.70
63	1989	11	04	01	22.00	76.04	32.63	71.70	4.70
64	1976	04	10	07	9.00	76.39	32.65	62.00	4.70
65	2006	05	09	01	30.00	76.63	32.72	35.90	4.70
66	1992	02	13	10	43.00	76.61	32.76	17.60	4.70
67	1977	01	21	02	57.00	75.98	32.76	51.00	4.70
68	2003	05	11	04	34.00	76.02	33.02	22.70	4.70
69	2008	05	10	06	35.00	76.19	33.03	40.30	4.70
70	1979	06	11	11	25.00	76.25	33.13	40.90	4.70
71	1981	12	14	06	25.00	75.72	33.19	21.40	4.70
72	2001	02	04	10	14.00	75.83	33.29	19.20	4.70
73	1981	09	27	11	10.00	75.64	33.30	33.00	4.70
74	1981	11	09	07	31.00	75.85	33.33	33.00	4.70
75	2003	03	02	03	23.00	75.75	33.33	23.70	4.70
76	1983	10	12	02	44.00	75.72	33.76	33.00	4.70
77	1972	10	26	02	5.00	76.35	32.05	82.30	4.60
78	1987	12	26	01	3.00	76.94	32.15	33.00	4.60
79	1992	01	26	11	48.00	76.44	32.31	41.40	4.60
80	1984	11	12	10	30.00	76.85	32.39	33.00	4.60
81	1992	09	06	02	10.00	76.53	32.70	38.30	4.60
82	1996	05	23	11	51.00	76.49	32.78	48.40	4.60
83	1996	09	14	12	22.00	76.40	32.82	45.00	4.60
84	1989	06	04	11	56.00	76.13	32.90	63.50	4.60
85	1987	05	20	12	32.00	76.27	32.92	33.00	4.60
86	2011	10	22	21	7.00	75.81	32.94	10.00	4.60
87	1999	11	29	02	31.00	75.65	33.00	33.00	4.60
88	1976	05	22	06	32.00	75.83	33.05	71.20	4.60
89	1973	04	10	12	10.00	75.75	33.17	60.90	4.60
90	1980	02	05	08	17.00	75.81	33.25	33.00	4.60
91	2000	09	26	07	39.00	75.70	33.41	9.00	4.60
92	2000	12	26	05	37.00	76.67	32.37	5.60	4.50
93	1970	01	02	08	1.00	76.00	32.50	96.00	4.50
94	1996	07	14	12	40.00	76.49	32.55	39.20	4.50
95	2008	06	15	11	2.00	76.40	32.96	39.30	4.50
96	2007	10	14	05	47.00	75.77	33.26	7.90	4.50
97	2009	01	31	03	7.00	76.49	32.51	11.50	4.40
98	2007	10	04	05	14.00	76.16	32.53	12.60	4.40
99	1990	09	05	09	15.00	76.16	32.66	33.00	4.40
100	2001	04	25	06	28.00	76.66	32.80	15.00	4.40
101	2002	03	18	04	29.00	76.26	32.81	10.50	4.40
102	1996	05	09	08	25.00	76.34	32.82	56.00	4.40
103	1978	05	17	08	39.00	75.73	32.89	96.00	4.40
104	2000	01	16	12	0.00	75.82	33.27	38.50	4.40
105	1993	07	12	01	27.00	75.90	33.33	33.00	4.40
106	2001	01	08	09	1.00	75.96	33.43	37.60	4.40
107	1997	08	13	11	10.00	76.69	31.41	62.90	4.30
108	1998	11	06	02	29.00	76.01	32.30	34.10	4.30
109	2003	11	24	10	47.00	76.49	32.38	23.90	4.30
110	2003	12	21	02	14.00	76.61	32.40	33.00	4.30
111	2004	02	22	08	23.00	76.22	32.56	15.00	4.30
112	1976	04	16	08	15.00	76.21	32.68	92.00	4.30
113	1998	03	20	01	3.00	76.38	32.70	19.30	4.30
114	2007	06	17	11	55.00	76.57	32.71	4.60	4.30

115	1997	01	19	02	38.00	76.23	32.73	58.70	4.30
116	1994	07	02	08	34.00	76.35	32.79	33.00	4.30
117	2009	06	04	01	50.00	76.05	32.83	17.10	4.30
118	1996	05	16	05	18.00	76.15	32.87	65.30	4.30
119	2010	03	25	02	33.00	76.19	32.91	10.00	4.30
120	1999	09	18	04	30.00	76.18	32.94	48.40	4.30
121	1998	07	06	10	24.00	75.76	32.94	58.50	4.30
122	1993	01	24	04	47.00	76.08	32.98	33.00	4.30
123	1996	01	17	12	22.00	76.12	33.02	49.60	4.30
124	2010	01	11	06	11.00	76.06	33.11	9.60	4.30
125	2001	01	25	12	39.00	76.07	33.22	17.50	4.30
126	2010	06	04	11	58.00	76.27	33.25	30.10	4.30
127	2006	12	26	04	25.00	75.81	33.25	40.60	4.30
128	2002	07	02	05	36.00	75.73	33.27	1.40	4.30
129	2001	03	24	02	39.00	75.67	33.38	33.00	4.30
130	2008	07	05	10	28.00	75.94	33.42	51.30	4.30
131	2005	10	05	08	29.00	75.73	33.64	10.00	4.30
132	2006	04	21	11	20.00	76.71	32.36	9.40	4.20
133	2007	06	14	07	52.00	76.69	32.41	4.20	4.20
134	1998	03	19	11	34.00	76.26	32.51	63.80	4.20
135	2008	09	14	10	11.00	76.34	32.56	12.80	4.20
136	2005	06	18	04	1.00	76.26	32.84	33.00	4.20
137	2003	04	27	07	17.00	76.69	32.85	12.70	4.20
138	2010	04	10	12	26.00	76.59	32.86	15.00	4.20
139	2000	11	16	01	43.00	76.29	32.91	55.60	4.20
140	2004	12	30	05	5.00	76.35	32.94	38.40	4.20
141	2001	01	30	02	50.00	76.49	32.96	10.00	4.20
142	2004	03	30	08	53.00	76.28	33.05	14.20	4.20
143	1989	06	11	11	5.00	76.47	33.08	33.00	4.20
144	1998	07	01	10	50.00	75.90	33.08	22.80	4.20
145	2003	12	12	05	33.00	76.00	33.11	33.00	4.20
146	1999	07	12	09	45.00	75.82	33.16	66.00	4.20
147	2002	05	10	06	0.00	75.90	33.18	17.60	4.20
148	2005	10	11	10	53.00	75.83	33.35	21.20	4.20
149	2002	12	17	10	28.00	75.76	33.45	33.00	4.20
150	2003	02	03	11	2.00	77.00	31.95	12.80	4.10
151	2005	02	28	04	4.00	76.27	32.49	37.60	4.10
152	2004	07	22	03	31.00	76.80	32.56	18.90	4.10
153	2008	05	29	10	30.00	76.06	32.65	23.40	4.10
154	2010	06	21	08	42.00	76.05	32.72	8.30	4.10
155	1997	11	09	01	57.00	76.34	32.73	33.00	4.10
156	2008	05	20	11	42.00	75.90	32.76	22.10	4.10
157	2003	09	15	12	28.00	76.03	32.80	32.10	4.10
158	2008	03	11	04	44.00	76.04	32.98	43.80	4.10
159	2006	06	11	12	59.00	75.72	33.01	10.00	4.10
160	2008	01	03	02	10.00	75.93	33.18	35.00	4.10
161	2006	04	04	11	40.00	75.86	33.18	43.30	4.10
162	2007	06	14	12	27.00	75.76	33.21	18.00	4.10
163	2010	01	19	08	45.00	76.85	32.40	1.00	4.00
164	2006	03	29	10	56.00	75.53	32.71	17.80	4.00
165	2008	03	24	09	48.00	76.33	32.88	9.40	4.00
166	1998	01	29	10	58.00	76.11	32.88	67.00	4.00

167	1996	05	15	03	2.00	75.81	33.15	57.90	4.00
168	1998	08	17	05	55.00	75.71	33.15	33.00	4.00
169	1998	05	18	12	29.00	75.84	33.16	64.90	4.00
170	2007	11	02	09	25.00	76.36	33.27	35.00	4.00
171	1996	09	23	11	13.00	75.64	33.40	33.00	4.00
172	2000	02	22	05	53.00	75.78	33.43	14.50	4.00
173	1996	12	23	09	52.00	76.89	32.39	33.00	3.90
174	2006	09	13	04	23.00	76.74	32.77	10.00	3.90
175	2008	05	02	08	20.00	76.20	32.84	32.90	3.90
176	2009	09	25	10	40.00	75.87	32.96	24.60	3.90
177	2008	04	05	07	28.00	75.93	33.01	26.60	3.90
178	1996	12	16	05	59.00	75.99	33.14	45.70	3.90
179	1997	04	12	05	35.00	75.74	33.45	33.00	3.90
180	2008	05	23	09	17.00	75.86	33.49	15.00	3.90
181	2002	11	30	10	54.00	76.87	32.40	15.00	3.80

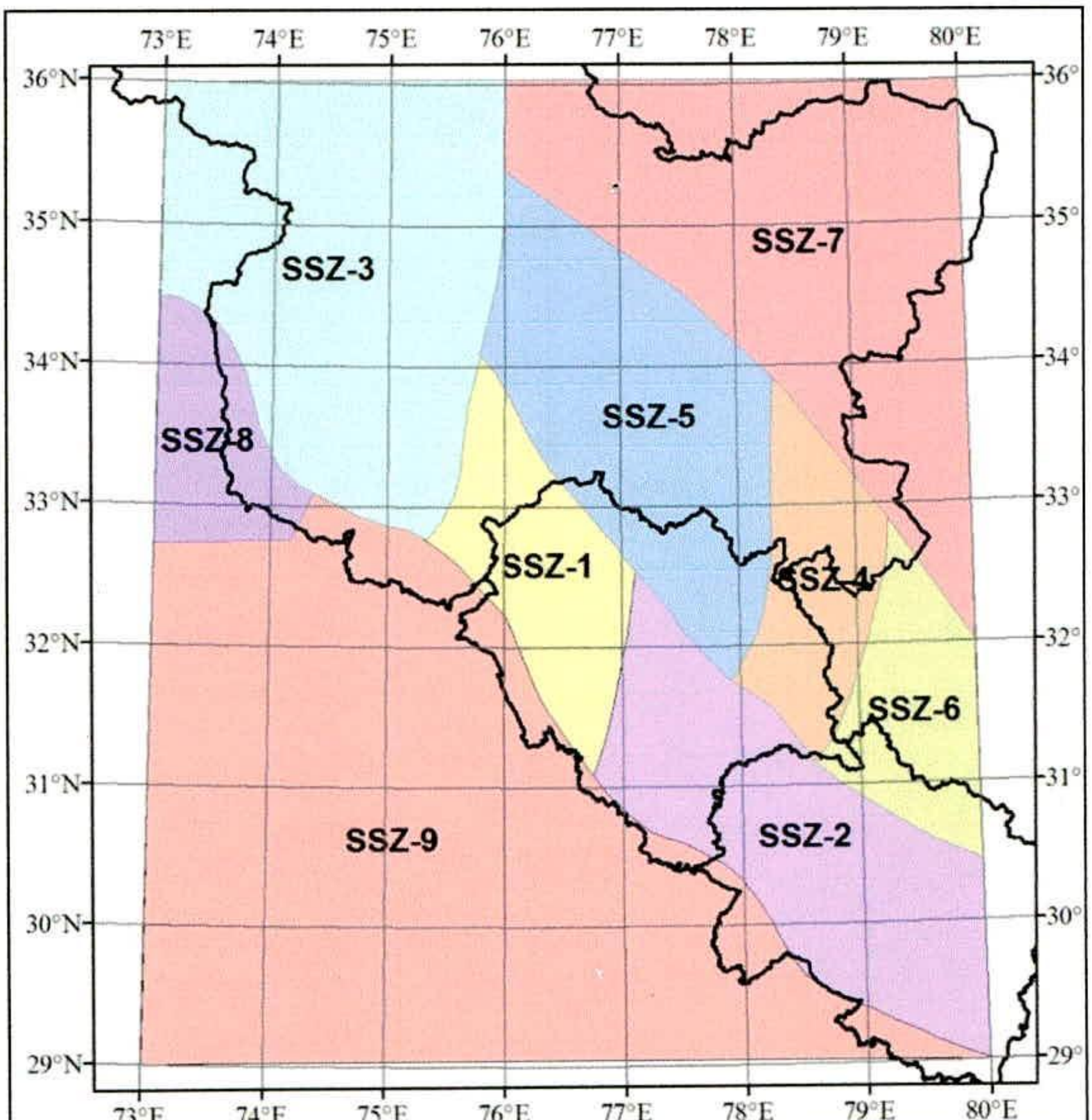
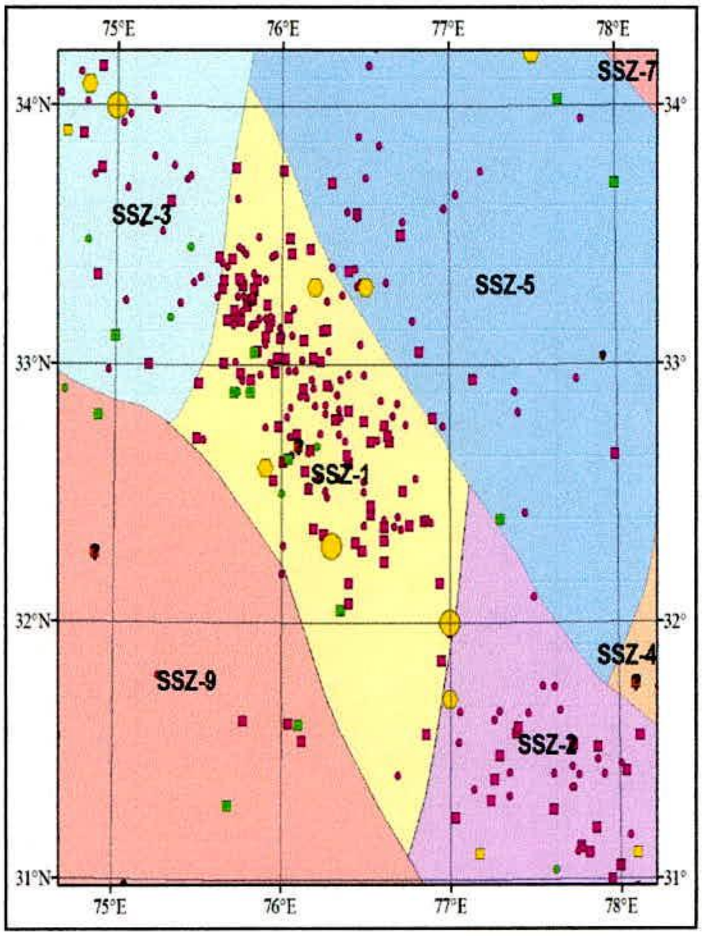
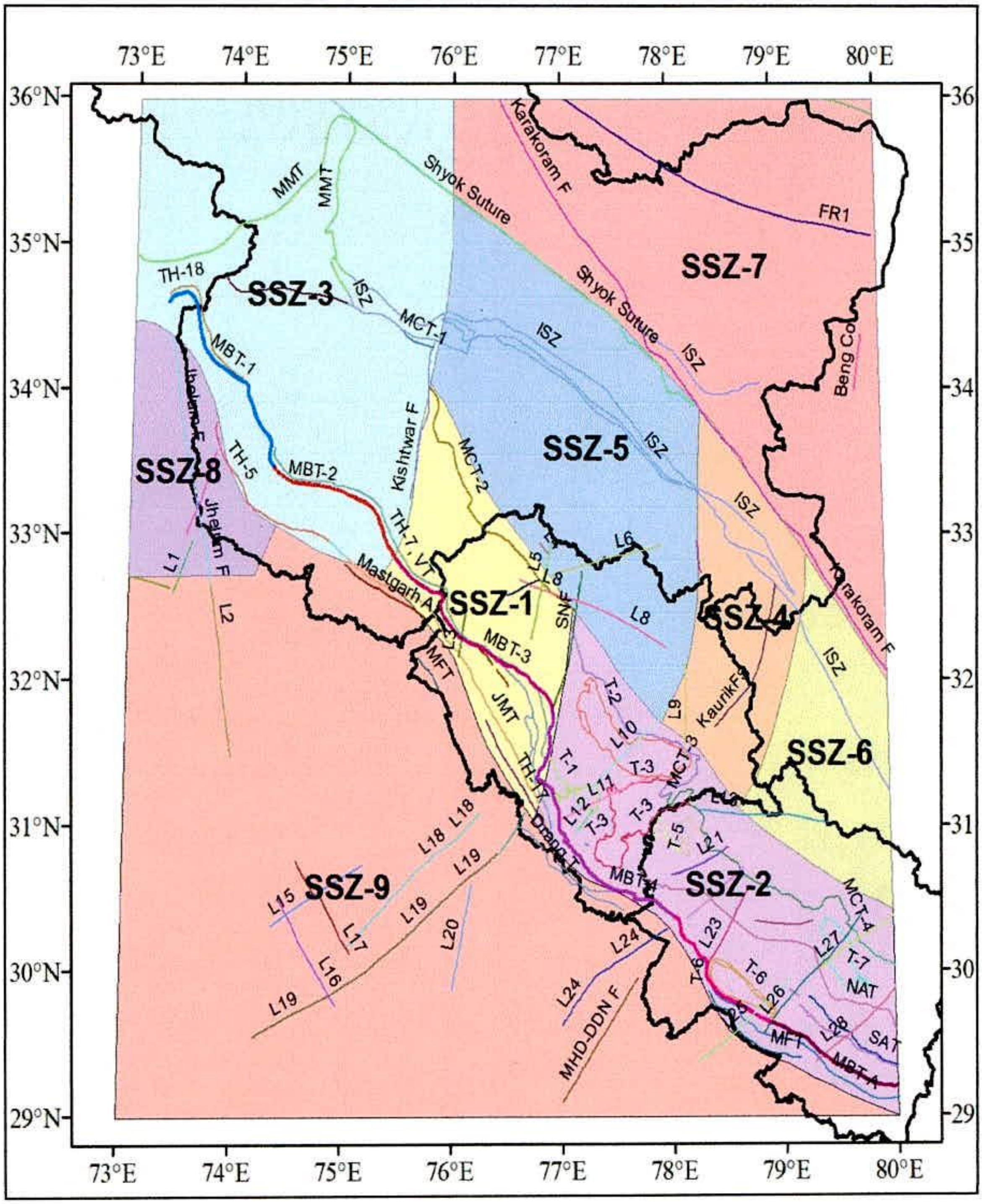


Figure 6: Map shows SSZ 1 surrounded by SSZ 3, SSZ 5, SSZ 4, SSZ 2, SSZ 7 and SSZ 9, (after Mridula et. al., 2014a). Outline of Indian states: Himachal Pradesh, Jammu & Kashmir and Uttarakhand.



Symbol	Year	Depth (km)	Magnitude
	1552-1963	33 km	3.5 - 4.5
			4.6 - 5.9
			6.0 - 6.9
			>7.0
	1964-2012	0-70	3.5 - 4.5
			4.6 - 5.9
			6.0 – 6.9
			>7.0
	1964-2012	71-300	3.5 - 4.5
			4.6 - 5.9
			6.0 – 6.9
	1964-2012	unspecified	3.5 - 4.5
			4.6 - 5.9
			6.0 – 6.9

Figure 7: Map shows SSZ 1 surrounded by SSZ 3, SSZ 5, SSZ 4, SSZ 2, SSZ 7 and SSZ 9. Seismicity of area in and around seismogenic source zone 1 (Mridula et. al., 2014a)



SSZ-1
SSZ-2
SSZ-3
SSZ-4
SSZ-5
SSZ-6
SSZ-7
SSZ-8
SSZ-9
Shyok Suture
Karakoram F
FR1
MMT
ISZ
MCT-1
MBT-1
MBT-2
MBT-3
TH-18
TH-5
Kishtwar F
MCT-2
MCT-3
MCT-4
Mastgarh A
MFT
JMT
SNF
MHD-DDN F
NAT
SAT
MBT-A
Beng Co
KaurikF

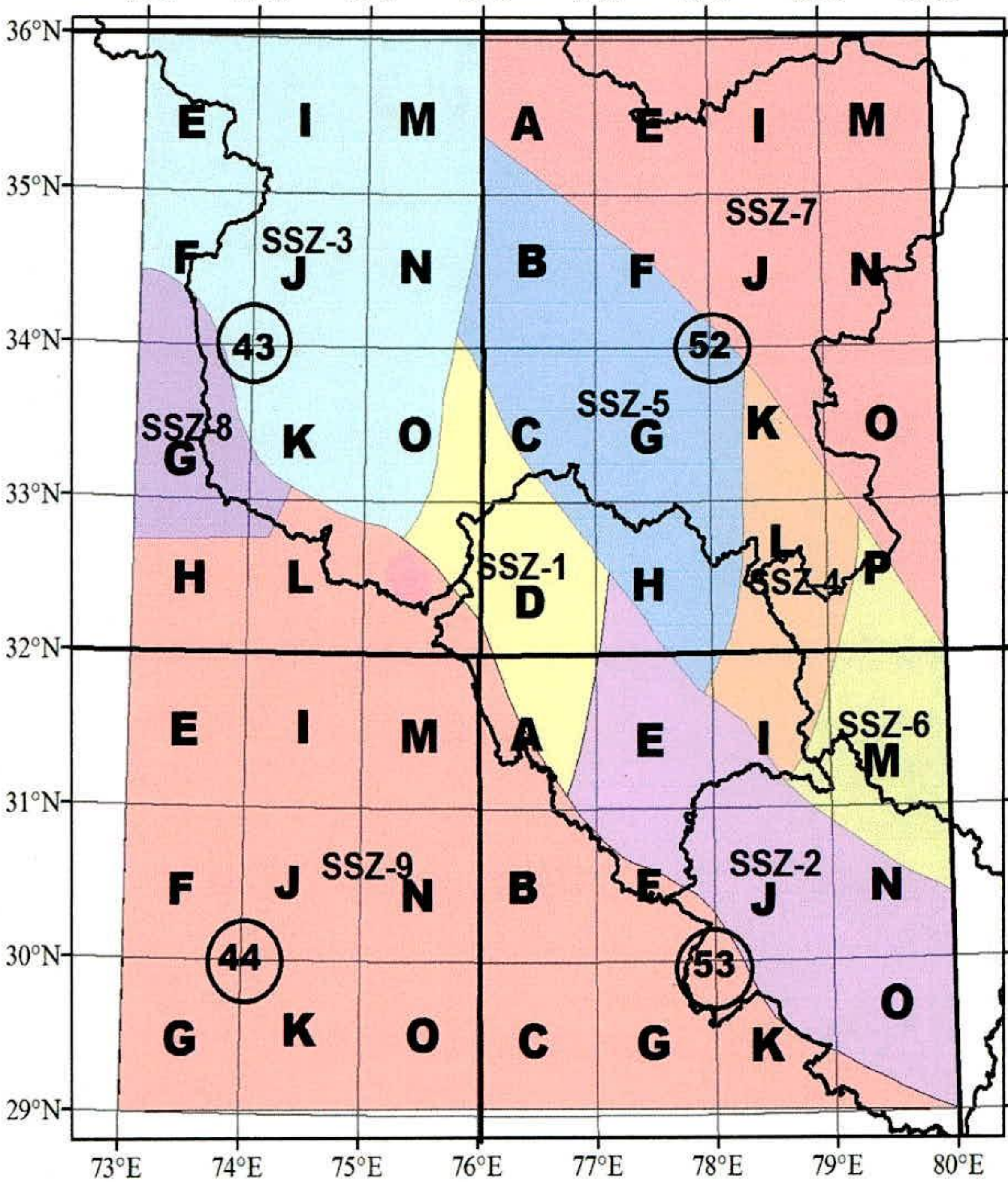


Figure 9: Map shows SSZ 1 surrounded by SSZ 3, SSZ 5, SSZ 4, SSZ 2, SSZ 7 and SSZ 9, Outline of Indian states: Himachal Pradesh, Jammu & Kashmir and Uttarakhand and ISRO Toposheets in and around Kangra Seismogenic Source Zone (SSZ 1).

Chapter 3

METHODOLOGY

3.1 Method

To estimate topographical aspects of seismic hazard the following methodology was adopted:

- An area around each epicenter is considered.
- A buffer zone of 25 km is created around it.
- Within that buffer maximum and minimum elevation is estimated, by using ArcGIS.
- A straight line is drawn between the maximum and minimum elevation.
- The distance between the maximum and minimum elevation is estimated to find out the gradient.
- Along the straight line checks are made for any humps that are more than 50 meters. Any hump less than 50 m is ignored and that more than 50 m is considered for further study.
- For some earthquakes, there are several maxima and minima elevation within the buffer zone. For each maxima and minima separate straight lines are drawn and then checked for any humps along each line.
- Districts and Talukas near the maximum and minimum elevation and along the straight line between the maximum and minimum elevation is noted.
- Any river or drainage system near the maximum and minimum elevation is noted.

This exercise was carried out for several large earthquakes in the Kangra Seismogenic Source Zone. An example is shown for the great Kangra earthquake of 1905.

3.2 THE 1905 KANGRA EARTHQUAKE

The 1905 Kangra earthquake occurred in the Kangra Valley and the Kangra region of Himachal Pradesh in India on 4 April 1905. The time of occurrence was 00:50min as per UTC. The earthquake measured 7.8 on the surface wave magnitude scale. The epicenter of the earthquake was at 76.25°E 32.30°N. The estimated life loss was more than 20,000 and economic loss was calculated to be 2.90 million rupees. Damage and casualties also occurred in adjoining parts of Punjab including in the cities of Amritsar, Lahore, Jalandhar, Ludhiana and Sialkot, (Source: A note on the Kangra Ms = 7.8 earthquake of 4 April 1905, Nicholas Ambraseys and Roger Bilham).

ISRO Topo sheet 52D, relevant to the epicenter of the Kangra EQ of 1905 was considered and the Digital Elevation Model was downloaded, at contour interval = 50 m. Distance between the maximum and minimum elevation was noted as 42.12 km. in addition the following observations are noted: The district at the maximum elevation is Chamba and that at the minimum elevation is Kangra (as per Survey of India map). Taluka along the line joining the maximum and minimum elevation are Brahmaur, Dharamshala, Shahpur, Jawali (maximum to minimum).

It was observed that there were no humps along the straight line joining the maximum and minimum elevation. No major rivers could be identified in the buffer zone, as observed in ISRO map and SESIAT5. The estimated maximum elevation was 4850m which is located at Brahmaur Taluka in Chamba district and the minimum elevation estimated was 350m located at Jawali Taluka in Kangra district.

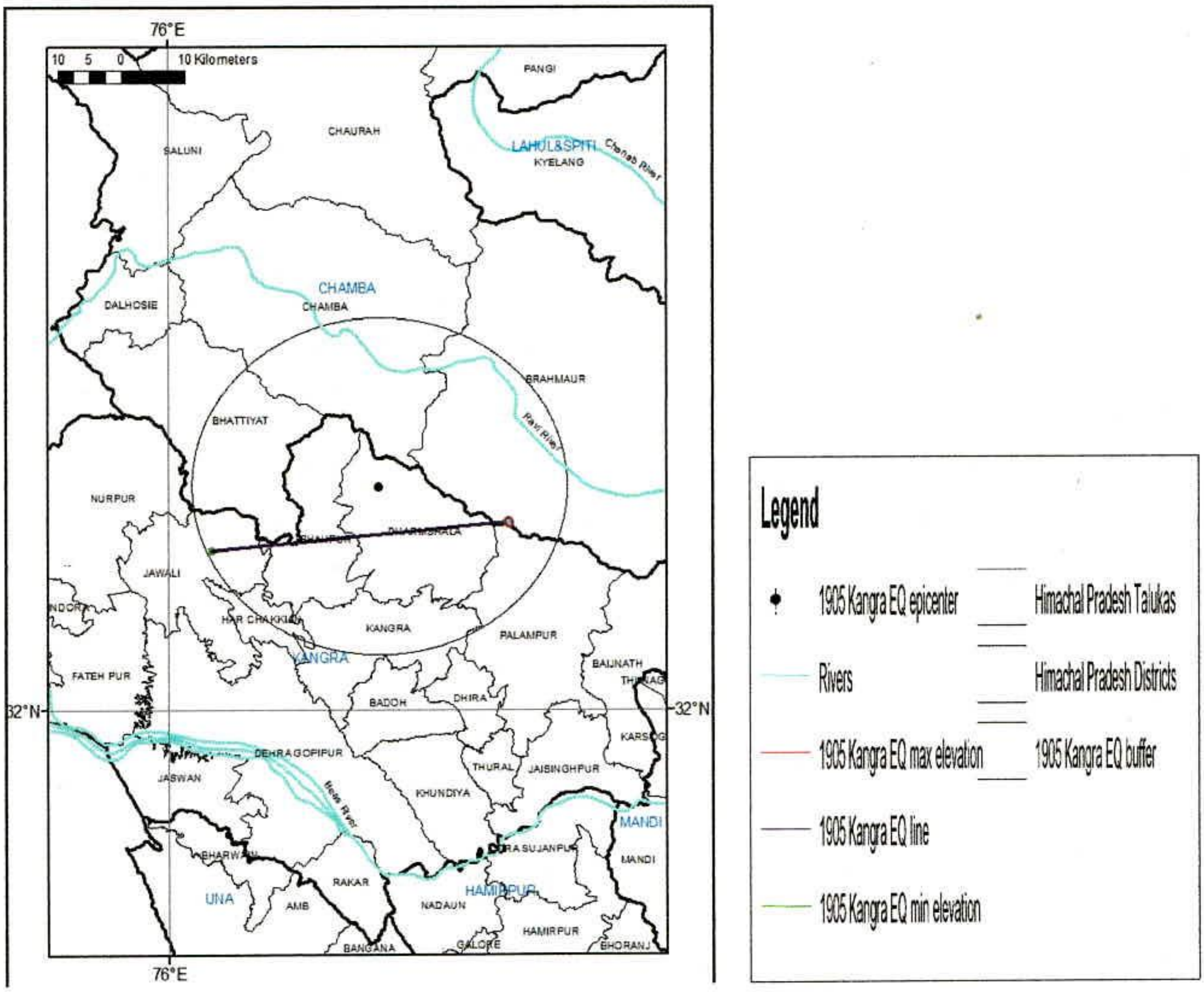


Figure 10: Map shows 1905 Kangra buffer zone, Maximum and minimum elevation within the buffer zone and State boundaries, districts and Talukas of Himachal Pradesh. DEM taken from ISRO Toposheets, district and place names taken from SoI map.

ANALYSIS

4.1 EARTHQUAKES IN KANGRA SSZ:

For the study purpose for Kangra Seismogenic Source Zone, total 181 earthquakes (≥3 magnitude) within the period of 1827-2011 are taken into consideration. All earthquakes in the study area are studied and observed in details. Details of four earthquakes: namely the 1905 Kangra earthquake, 1906 earthquake, 1945 earthquake and 1947 earthquake, which have magnitude greater than 6 is shown here as an example. The Kangra earthquake is discussed in Chapter 3.

4.2 FOR 1906 EARTHQUAKE

The earthquake occurred on 28th February 1906. The magnitude of the earthquake was 7.0, measured on the surface wave magnitude scale. The epicenter was at 77.0°E 32.0°N. The topographical data relevant to the epicenter of the 1906 Himachal Pradesh earthquake are given here: ISRO Topo sheet 52D, Digital Elevation Model, was downloaded, for contour interval of 50 m, (Link: http://bhuvan.nrsc.gov.in/bhuvan_links.php). A 25 km buffer zone around the epicenter of the earthquake is considered. The maximum and minimum elevation is estimated by using ArcGIS. The estimated maximum and minimum elevation are: Maximum elevation = 4950m, Minimum elevation =650 m. The maximum and minimum elevation within the buffer zone is shown in the figure 11.

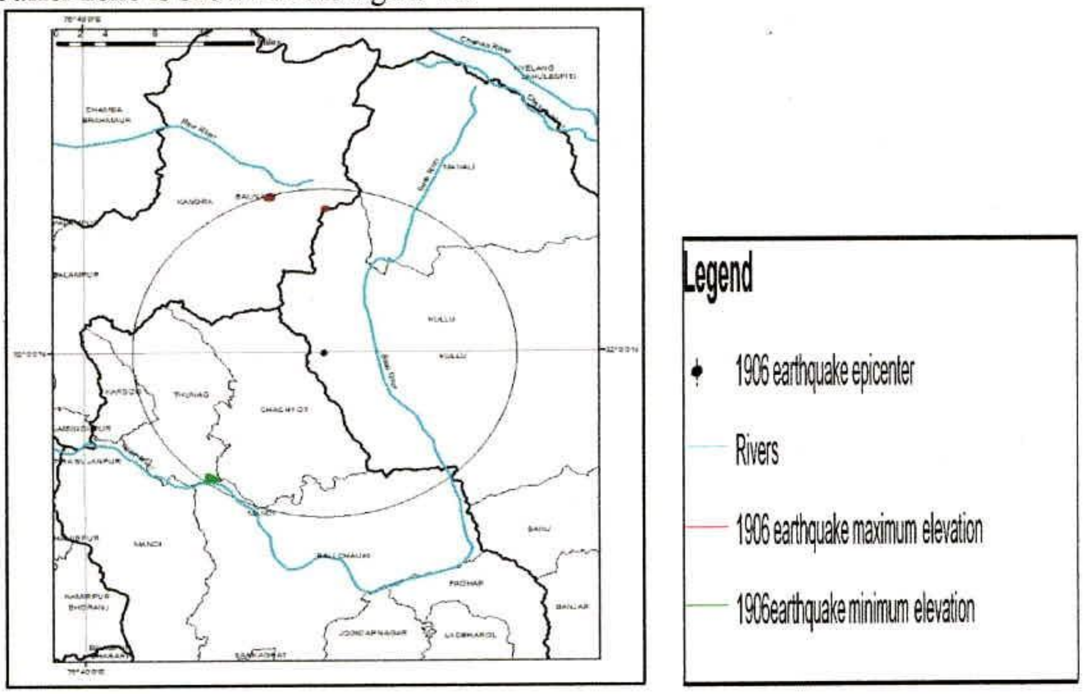


Figure 11: Map showing 1906 earthquake buffer around the epicenter, maximum and minimum elevation within the buffer zone, State boundaries, districts and Talukas of Himachal Pradesh.

By drawing a straight line between the maximum and minimum elevation, any humps between these two points is checked and those humps which are greater than 50m are noted for further discussion. Since there are three minimum elevations and two maximum elevations, straight lines are drawn from the respective minimum elevation to the maximum elevation and then the following observations shown in figure 12 are noted:

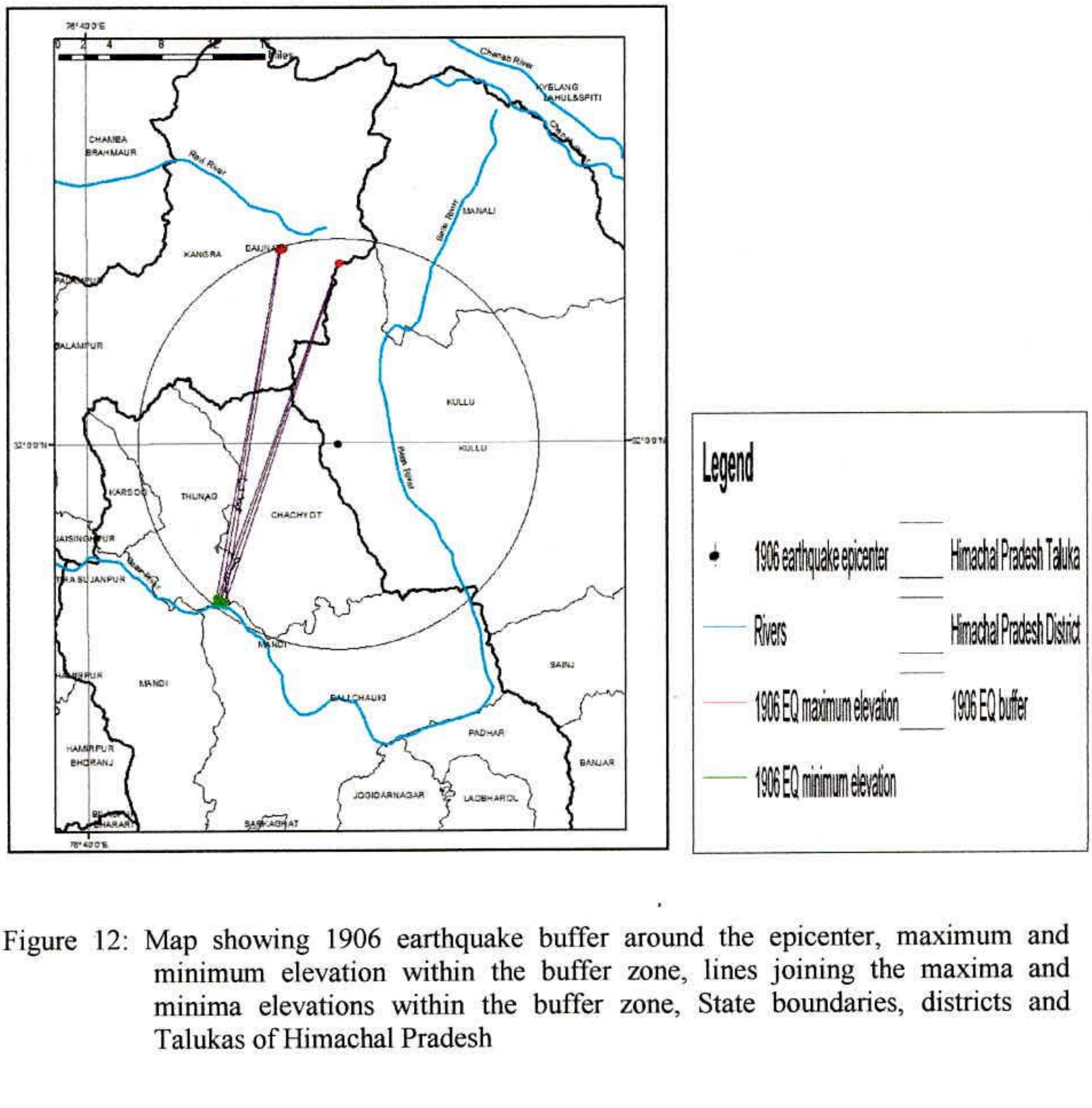


Figure 12: Map showing 1906 earthquake buffer around the epicenter, maximum and minimum elevation within the buffer zone, lines joining the maxima and minima elevations within the buffer zone, State boundaries, districts and Talukas of Himachal Pradesh

For Line 1, following are noted (refer figure 13): The length of the straight line is estimated to be 43.90 km. The districts at the maximum elevation are estimated to be in Kangra and that at the minimum elevation is Mandi (as per Survey of India map). Taluka on this line is Baijnath, Chachyot, Thunag and Bali Chauki (from maximum to minimum). In between the minimum and maximum points, the elevation increases to 2150 m and then it decrease to 1750m. Again there is linear increment to 3850 m and decreases to 3150 m after which it increases to the maximum elevation of 4950 m, as per ISRO map. The river observed at maximum elevation is Ravi and that at minimum elevation is Beas (as identified on ISRO map and SESIAT5). The estimated maximum elevation is 4950 m located at Baijnath Taluka in Kangra district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 650 m located at Thunag and Bali Chauki Taluka in Mandi district (as identified on ISRO and SESIAT5).

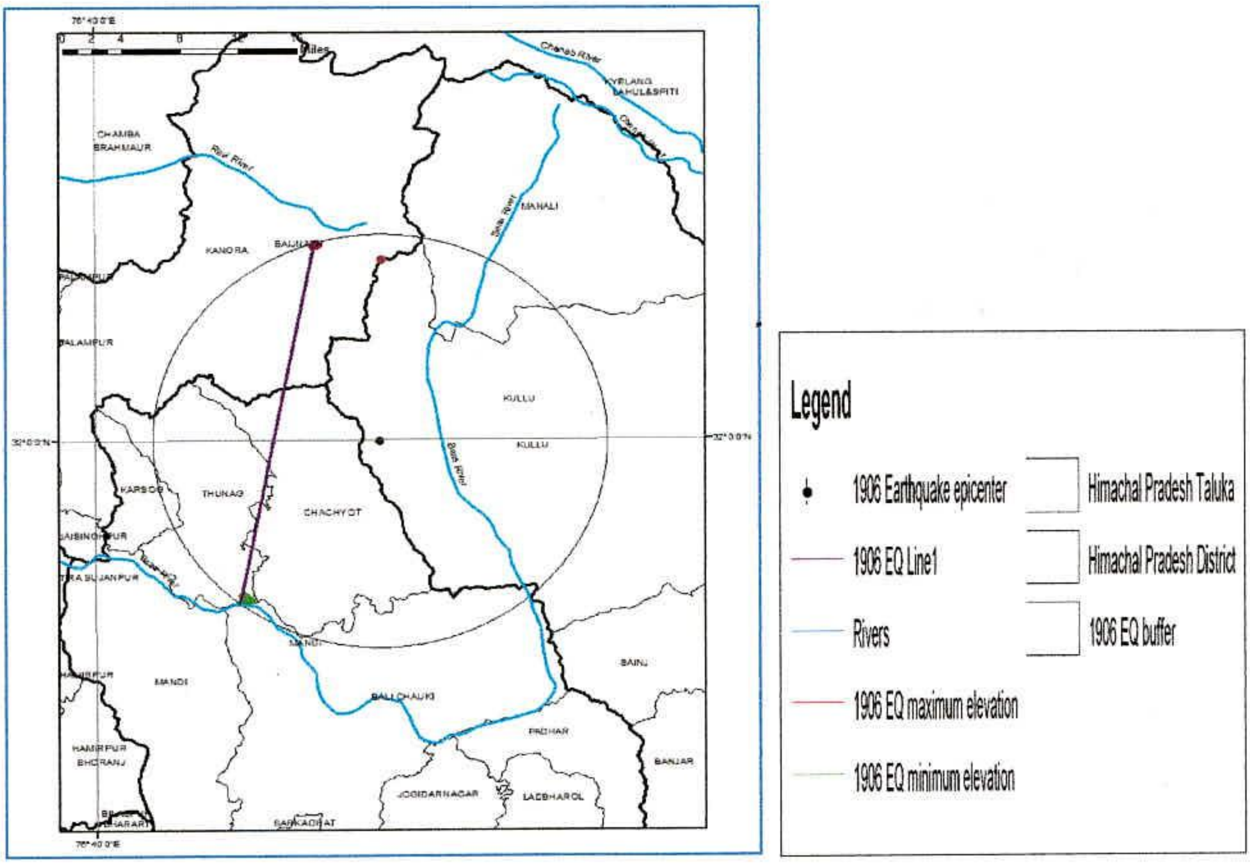


Figure 13: Map showing 1906 earthquake buffer around the epicenter, maximum and minimum elevation within the buffer zone, line1 joining the first maximum and minimum elevation, state boundaries, districts and Talukas of Himachal Pradesh.

The following are noted Line 2(refer figure 14): The length of the straight line is estimated to be 43.03 km. The districts at the maximum elevation are estimated to be in Kangra and that at the minimum elevation is Mandi (as per Survey of India map). Taluka on this line is Baijnath, Chachyot, Thunag and Bali Chauki (from maximum to minimum). In between the minimum and maximum points, the elevation increases to 2150 m and then it decrease to 1750m. Again there is linear increment to 3850 m and decreases to 3150 m after which it increases to the maximum elevation of 4950 m, as per ISRO map. The river observed at maximum elevation is Ravi and that at minimum elevation is Beas (as identified on ISRO map and SESIAT5). The estimated maximum elevation is 4950 m located at Baijnath Taluka in Kangra district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 650 m located at Thunag and Bali Chauki Taluka in Mandi district Mandi (as identified on ISRO and SESIAT5)

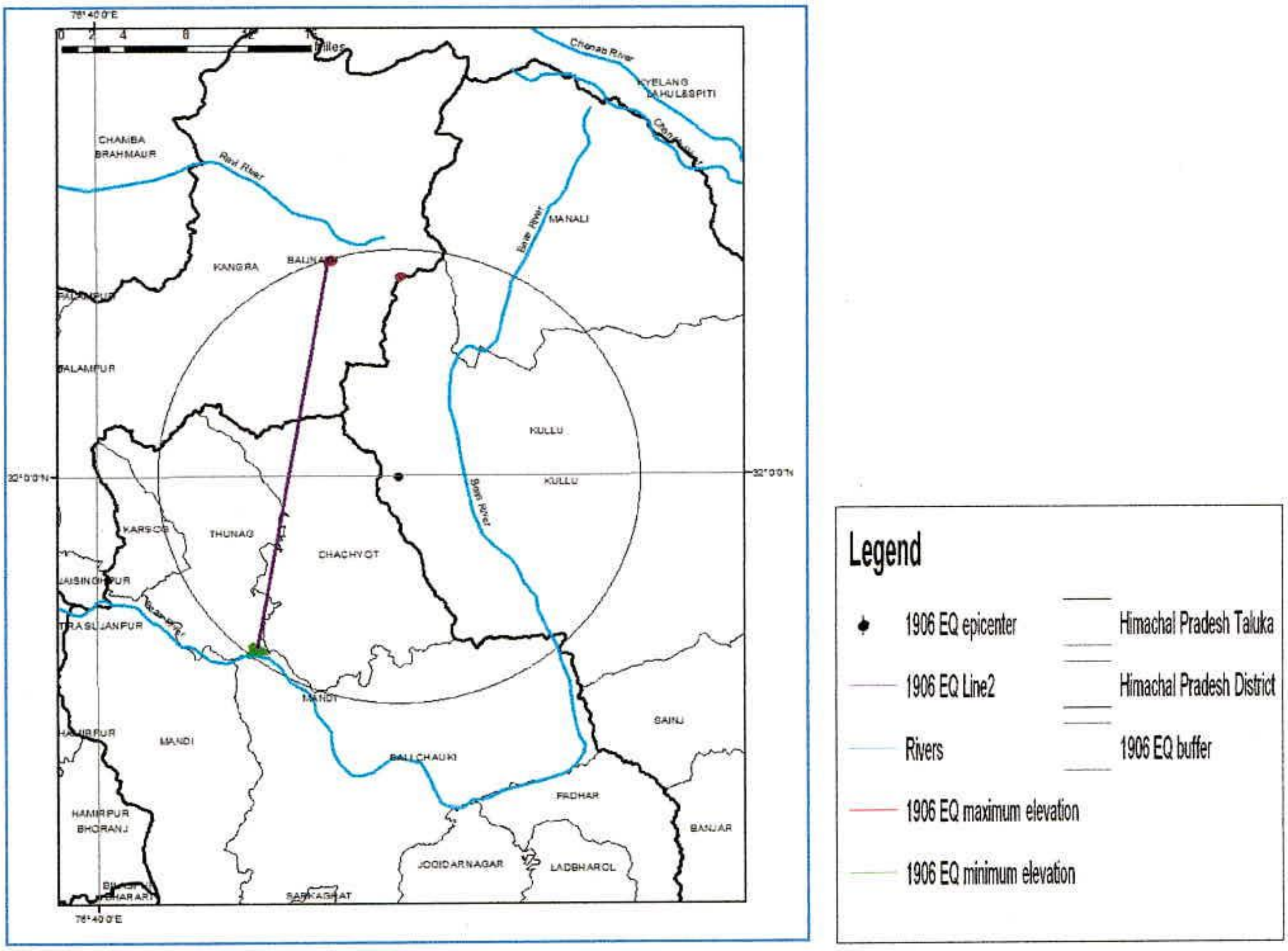


Figure 14: Map showing 1906 earthquake buffer around the epicenter, maximum and minimum elevation within the buffer zone, line2 joining the maximum and minimum elevation, state boundaries, districts and Talukas of Himachal Pradesh.

The following are noted for Line 3 (refer figure 15): The length of the straight line is estimated to be 43.45 km. The districts at the maximum elevation are Kangra and that at the minimum elevation is Mandi (as per Survey of India map). Taluka on this line is Baijnath, Chachyot, Thunag and Bali Chauki (from maximum to minimum). In between the minimum and maximum points, the elevation increases to 2150m and then there is a decreases to 1750m. Again there is linear increment to 3850 m and decreases to 3150m after which it increases to the maximum elevation of 4950m, as per ISRO map. The river observed at maximum elevation is Ravi and that at minimum elevation is Beas (as identified on ISRO map and SESIAT5). The estimated maximum elevation is 4950 m located at Baijnath Taluka in Kangra district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 650m located at Thunag and Bali Chauki Taluka in Mandi district Mandi (as identified on ISRO and SESIAT5).

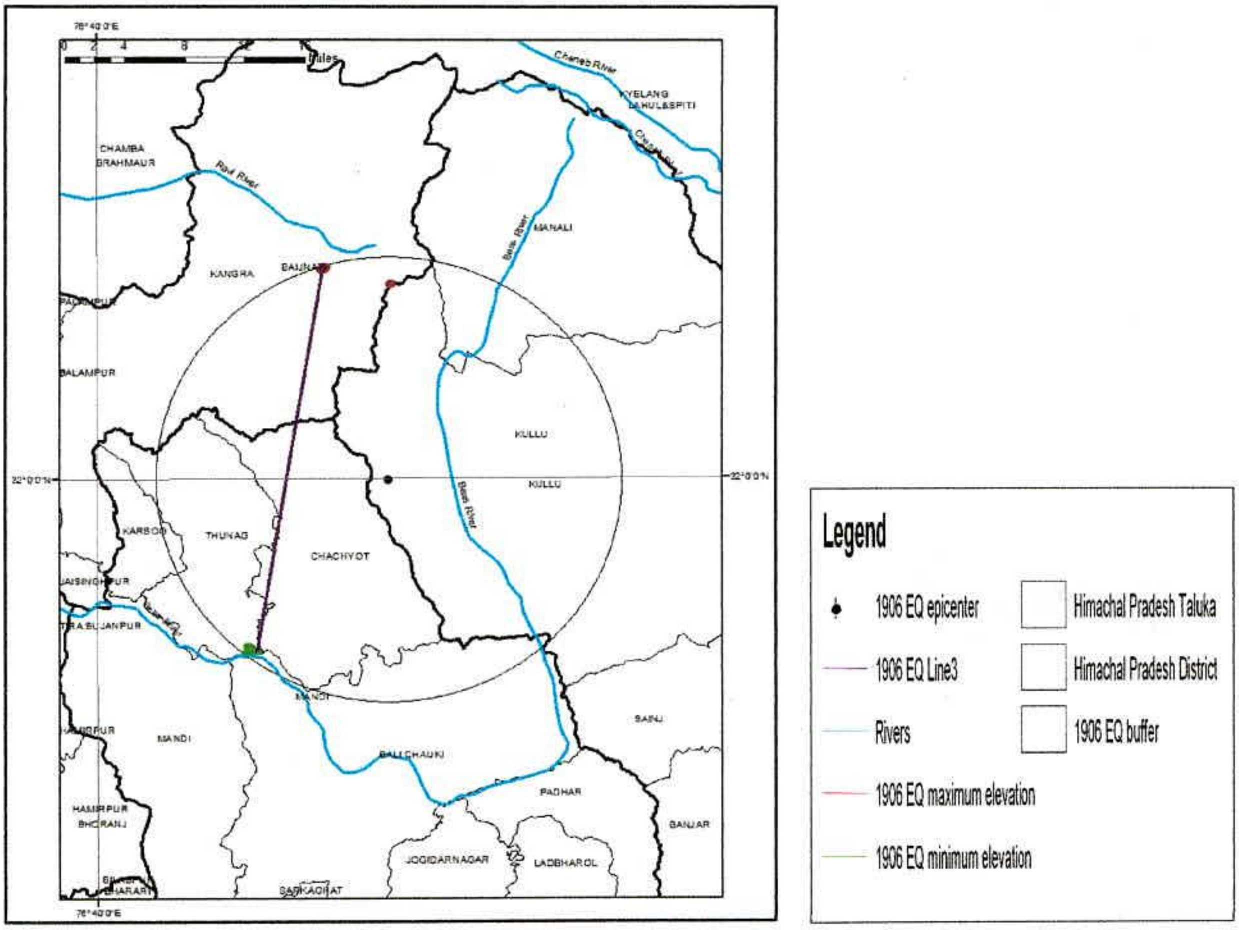


Figure 15: Map showing 1906 earthquake buffer around the epicenter, maximum and minimum elevation within the buffer zone, line3 joining the maximum and minimum elevation, state boundaries, districts and Talukas of Himachal Pradesh.

The following are noted for Line 4 (refer figure 16): The length of the straight line is estimated to be 44.60 km. The districts at the maximum elevation are Kangra and that at the minimum elevation is Mandi (as per Survey of India map). Taluka on this line is Baijnath, Kullu, Chachyot, Thunag and Bali Chauki (from maximum to minimum). In between the minimum and maximum points, the elevation increases from 650m to2050m and then it decreases to 1650m. Again there is an increment to 4050m and decreases to 3850m after which it increases to the maximum elevation of 4950m as observed by ISRO map. The river observed at maximum elevation is Ravi and that at minimum elevation is Beas (as identified on ISRO map and SESIAT5). The estimated maximum elevation is 4950 m located at Baijnath Taluka in Kangra district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 650m located at Thunag and Bali Chauki Taluka in Mandi district Mandi (as identified on ISRO and SESIAT5).

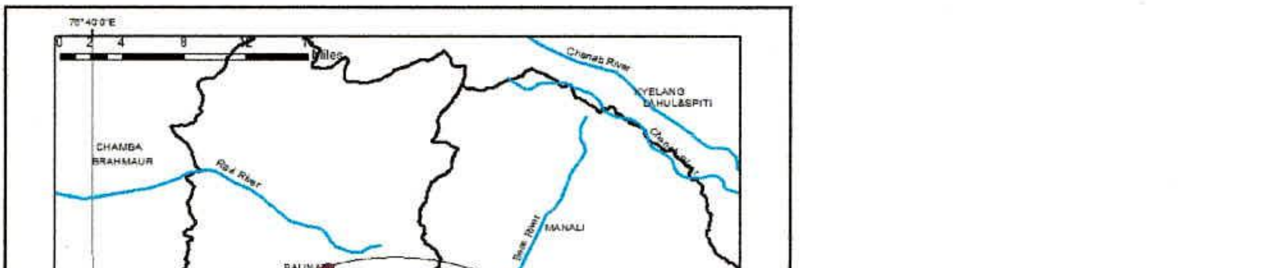


Figure 16: Map showing 1906 earthquake buffer around the epicenter, maximum and minimum elevation within the buffer zone, line4 joining the maximum and minimum elevation, state boundaries, districts and Talukas of Himachal Pradesh.

The following are noted for Line 5 (refer figure 17): The length of the straight line is estimated to be 43.68 km. The districts at the maximum elevation are Kangra and that at the minimum elevation is Mandi (as per Survey of India map). Taluka on this line is Baijnath, Kullu, Chachyot, Thunag and Bali Chauki (from maximum to minimum). In between the minimum and maximum points, the elevation increases from 650m to 2050m and then it decreases to 1650m. Again there is an increment to 4050m and decreases to 3850m after which it increases to the maximum elevation of 4950m as observed by ISRO map. The river observed at maximum elevation is Ravi and that at minimum elevation is Beas (as identified on ISRO map and SESIAT5). The estimated maximum elevation is 4950 m located at Baijnath Taluka in Kangra district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 650m located at Thunag and Bali Chauki Taluka in Mandi district Mandi (as identified on ISRO and SESIAT5).

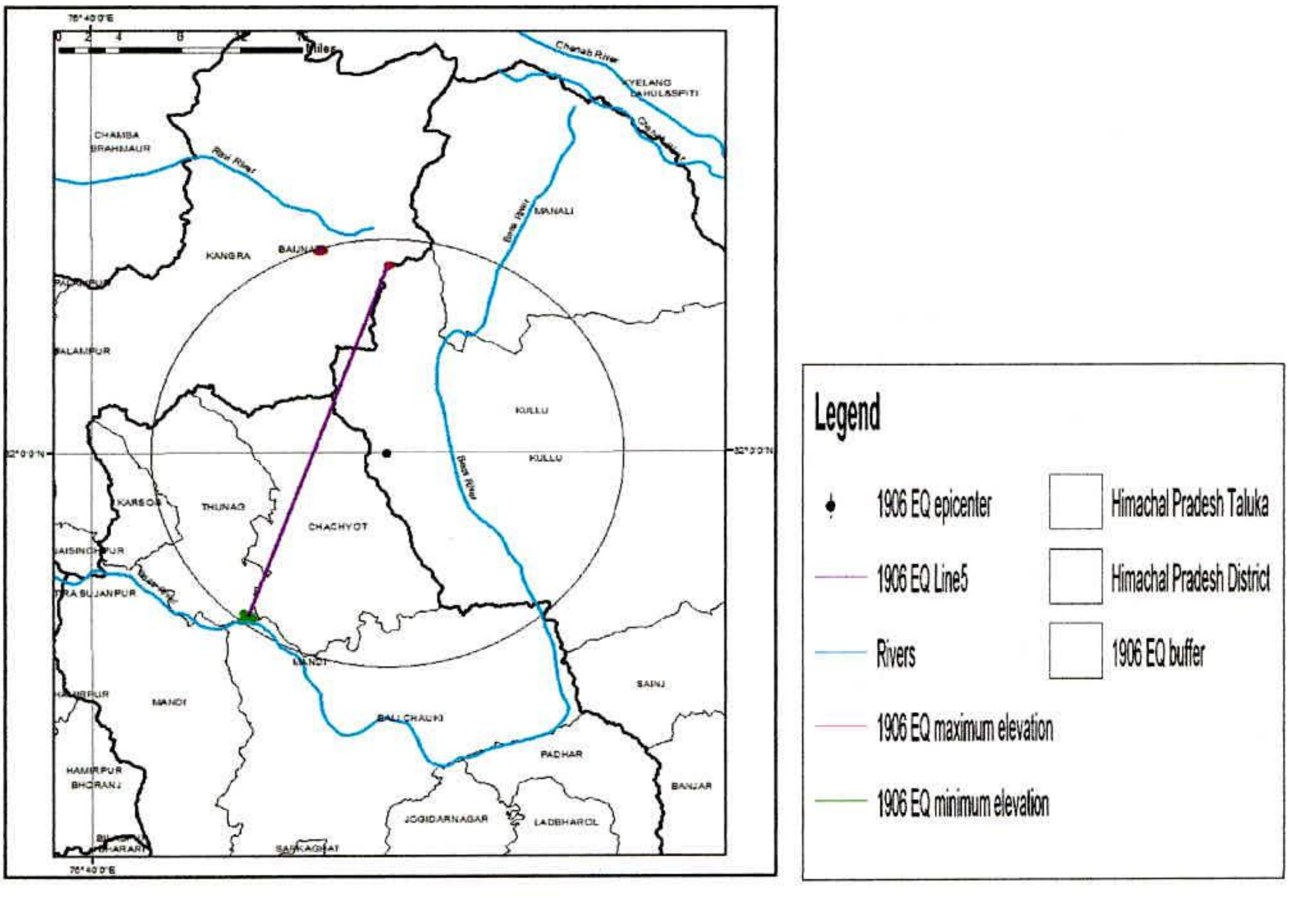


Figure 17: Map showing 1906 earthquake buffer around the epicenter, maximum and minimum elevation within the buffer zone, line5 joining the maximum and minimum elevation, state boundaries, districts and Talukas of Himachal Pradesh.

The following are noted for Line 6 (refer figure 18): The length of the straight line is estimated to be 43.75km. The districts at the maximum elevation are estimated to be in Kangra and that at the minimum elevation is Mandi (as per Survey of India map). Taluka on this line is Baijnath, Kullu, Chachyot, Thunag and Bali Chauki (from maximum to minimum). In between the minimum and maximum points, the elevation increases from 650m to 2050m and then it decreases to 1650m. Again there is an increment to 4050m and decreases to 3850m after which it increases to the maximum elevation of 4950m as observed by ISRO map. The river observed at maximum elevation is Ravi and that at minimum elevation is Beas (as identified on ISRO map and SESIAT5). The estimated maximum elevation is 4950 m located at Baijnath Taluka in Kangra district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 650m located at Thunag and Bali Chauki Taluka in Mandi district Mandi (as identified on ISRO and SESIAT5).

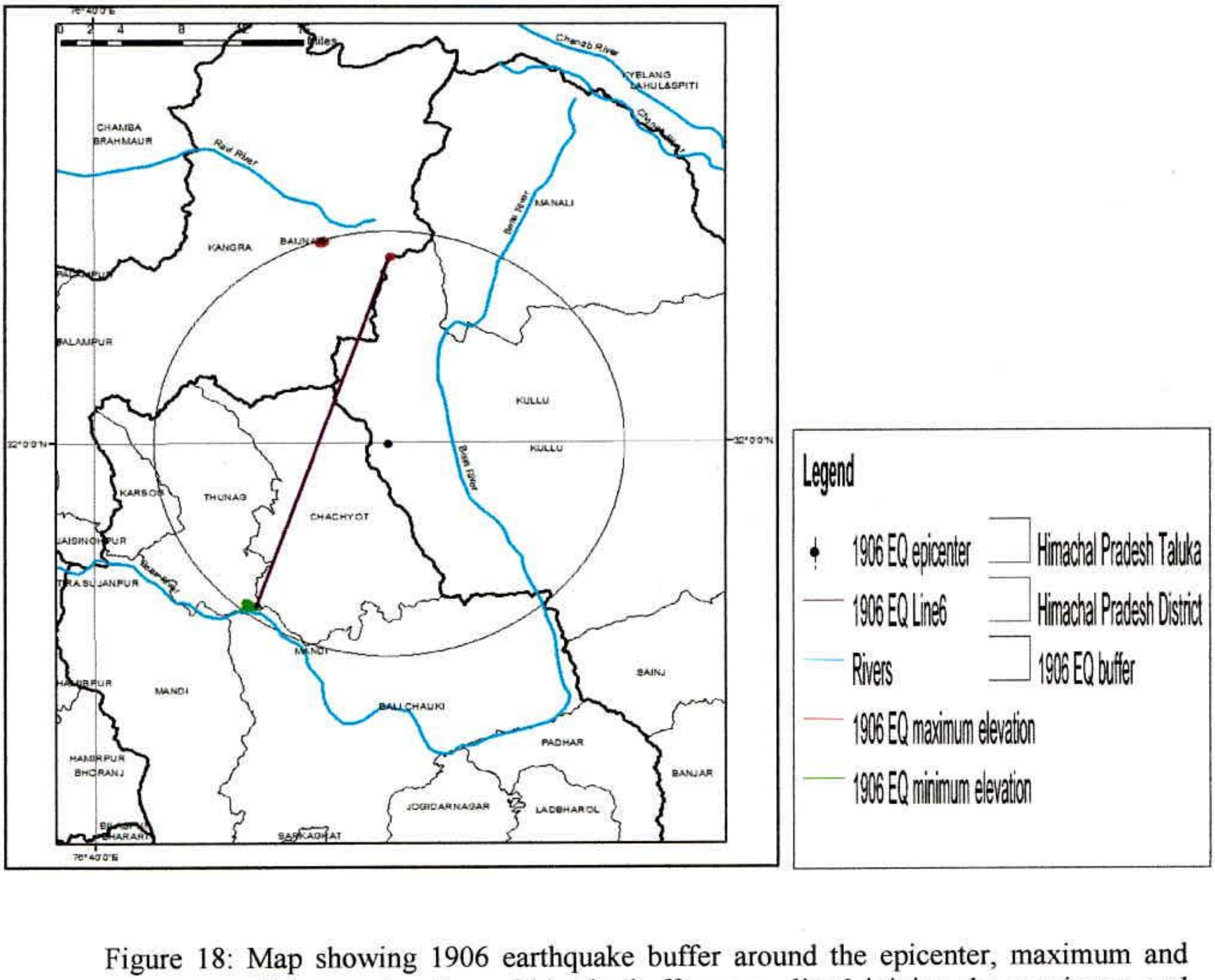


Figure 18: Map showing 1906 earthquake buffer around the epicenter, maximum and minimum elevation within the buffer zone, line6 joining the maximum and minimum elevation, state boundaries, districts and Talukas of Himachal Pradesh

4.3 1945 AND 1947 EARTHQUAKES

Since the epicenter of the 1945 earthquake and 1947 earthquake are the same, analysis for both is carried out with only one buffer zone around the epicenter. The 1945 earthquake occurred on 22 June 1945 – Near Padua Kathwa District, J&K (H.P, J&K Border region). The magnitude of the earthquake was 6.0 measured on surface wave magnitude scale. The time of occurrence was 18:00:51 UTC. The epicenter was at 32.60°N, 75.90°E. The 1947 earthquake occurred on 10th July 1947. The epicenter was at 32.60°N, 75.90°E near Padua, Kathwa District, J&K (H.P, J&K Border region). The magnitude was 6.0 measured on surface wave magnitude scale and time was 10:19:20 UTC. Data relevant to the epicenter of the 1945 and 1947 earthquakes are as follows: ISRO Toposheet 52D, Digital Elevation Model was downloaded, Link: http://bhuvan.nrsc.gov.in/bhuvan_links.php. The maximum and minimum elevation estimated by using ArcGIS is 3350m and 750m. Since there are nine minimum elevations, separate lines are drawn from the respective minimum elevation to the maximum elevation and then the following observations are noted as shown in figure 19, figure 20 and figure 21.

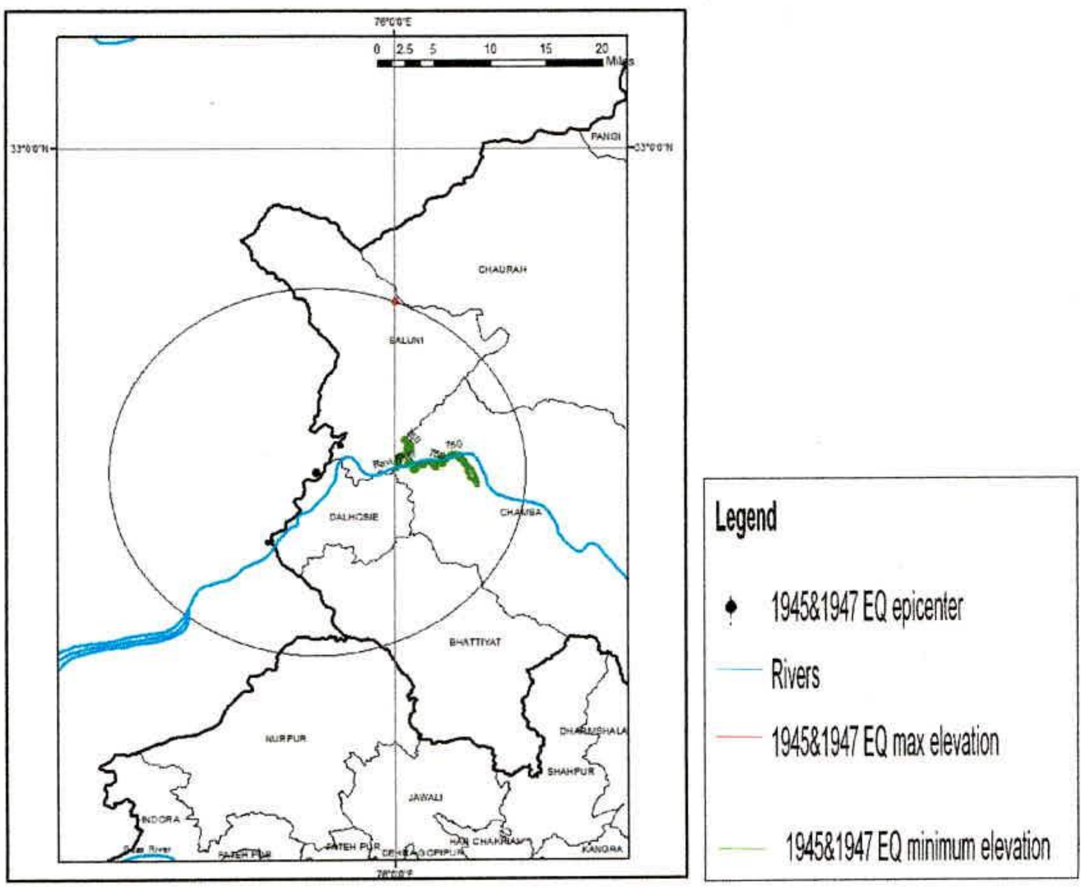


Figure 19: Map showing 1945 and 1947 earthquake buffer around the epicenter, maximum and minimum elevation within the buffer zone, state boundaries, districts, Talukas and rivers in the buffer zone.

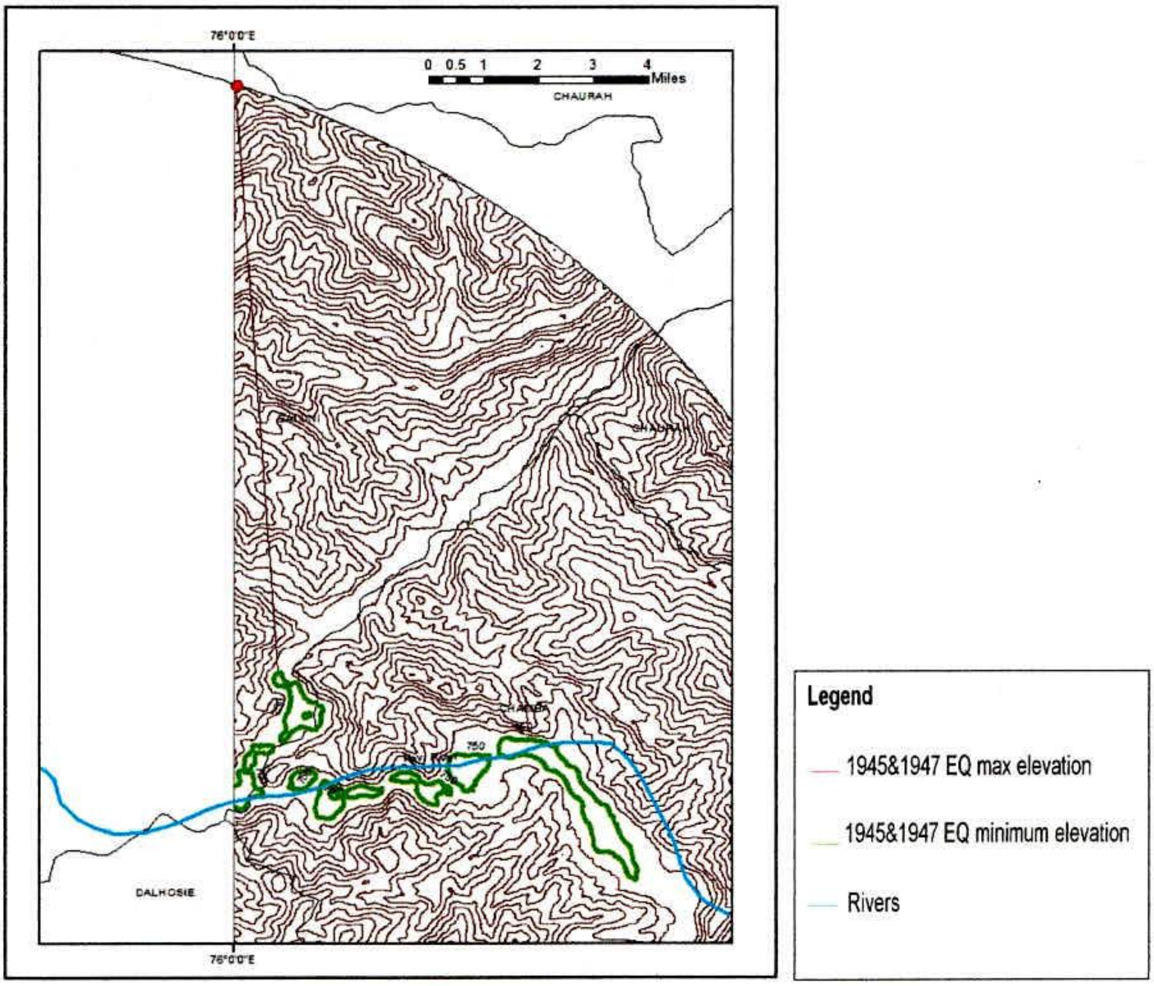


Figure 20: Map showing 1945 and 1947 earthquake maximum and minimum elevation within the buffer zone

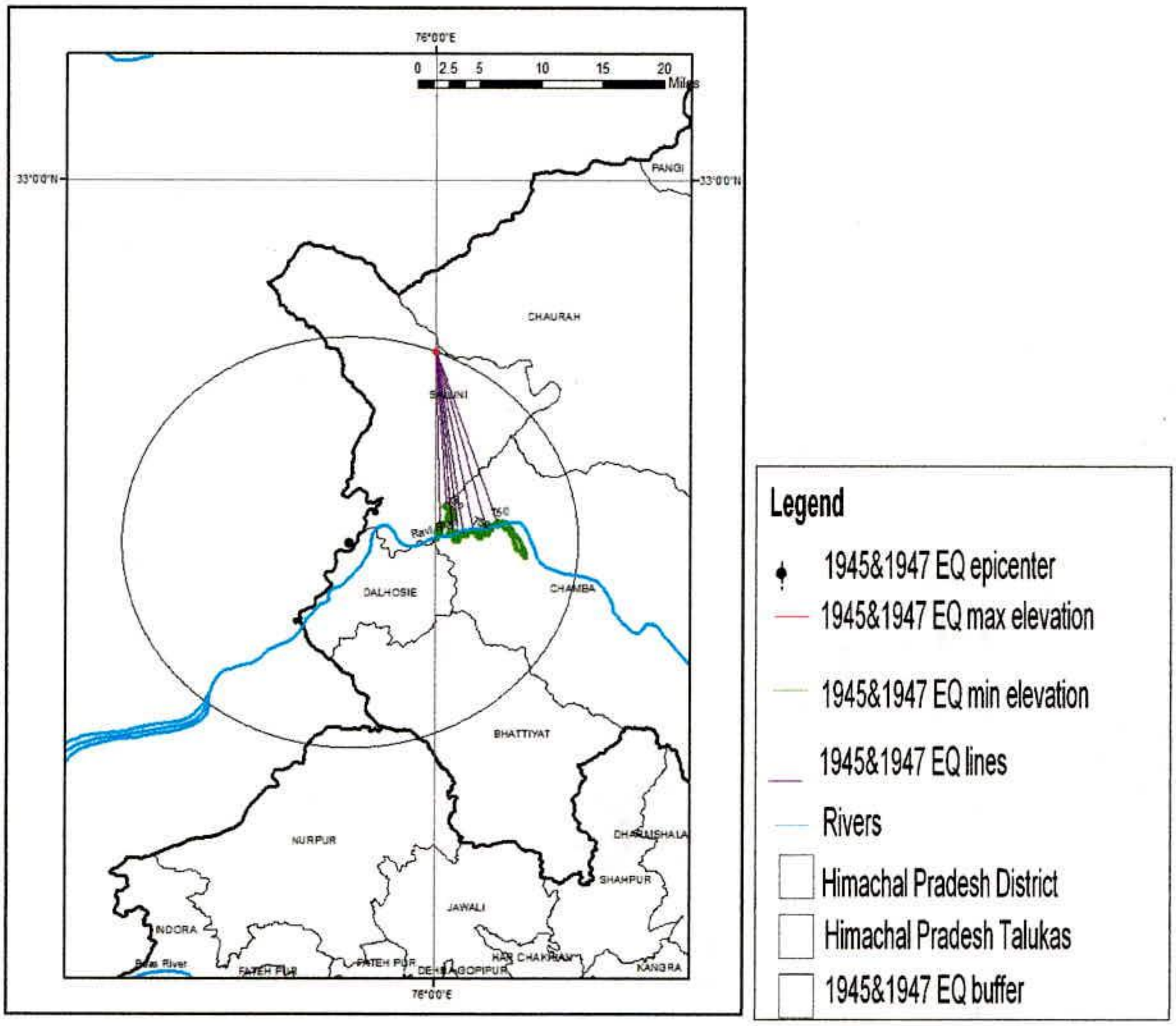


Figure 21: Map showing 1945 and 1947 earthquakes buffer around the epicenter, maximum and minimum elevation within the buffer zone, straight lines drawn between each maximum and minimum elevation, state boundaries, districts, Talukas and rivers within the buffer zone.

The following observations are noted for Line 1 (refer figure 22): The length of the straight line 20.757 km. The district at the maximum and minimum elevation is Chamba (as per Survey of India map). Taluka on this line is Saluni both at maximum and minimum elevation. Along the line joining the minimum and maximum elevation, the elevation increases to 2100m and then decreases to 1500m after which it increases to the maximum elevation of 3350m, as observed by ISRO map and SEISAT5. The estimated maximum elevation is 3350m located at Saluni Taluka in Chamba district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 750m Saluni Taluka in Chamba district (as identified on ISRO and SESIAT5). The river observed at both maximum and minimum elevation is Ravi as identified on ISRO map and SESIAT5.

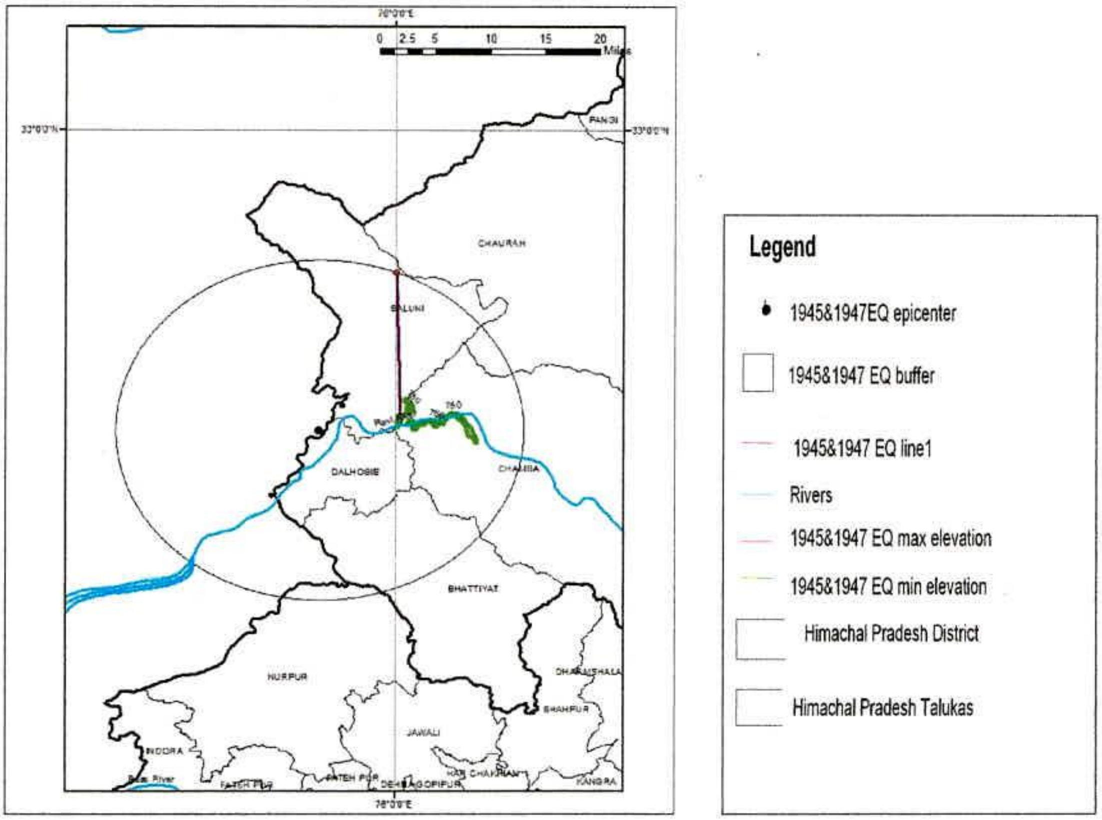


Figure 22: Map showing 1945 and 1947 earthquakes buffer around the epicenter, maximum and minimum elevation within the buffer zone, straight line1 drawn between each maximum and minimum elevation, state boundaries, districts, Talukas and rivers within the buffer zone.

The following observations are noted for Line 2 (refer figure 23): The length of the straight line is estimated to be 18.510 km. The district at the maximum and minimum elevation is Chamba (as per Survey of India map). Taluka on this line is Saluni both at maximum and minimum elevation. Along the minimum and maximum, the elevation increases to 1100m and then it decreases to 850m, again increases to 2100m and decrease to 1450m, increases to 1900m and then decreases to 1800m and after which it increases to the maximum elevation of 3350m, as observed by ISRO map and SEISAT5. The estimated maximum elevation is 3350m located at Saluni Taluka in Chamba district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 750m Saluni Taluka in Chamba district (as identified on ISRO and SESIAT5). The river observed at both maximum and minimum elevation is Ravi as identified on ISRO map and SESIAT5.

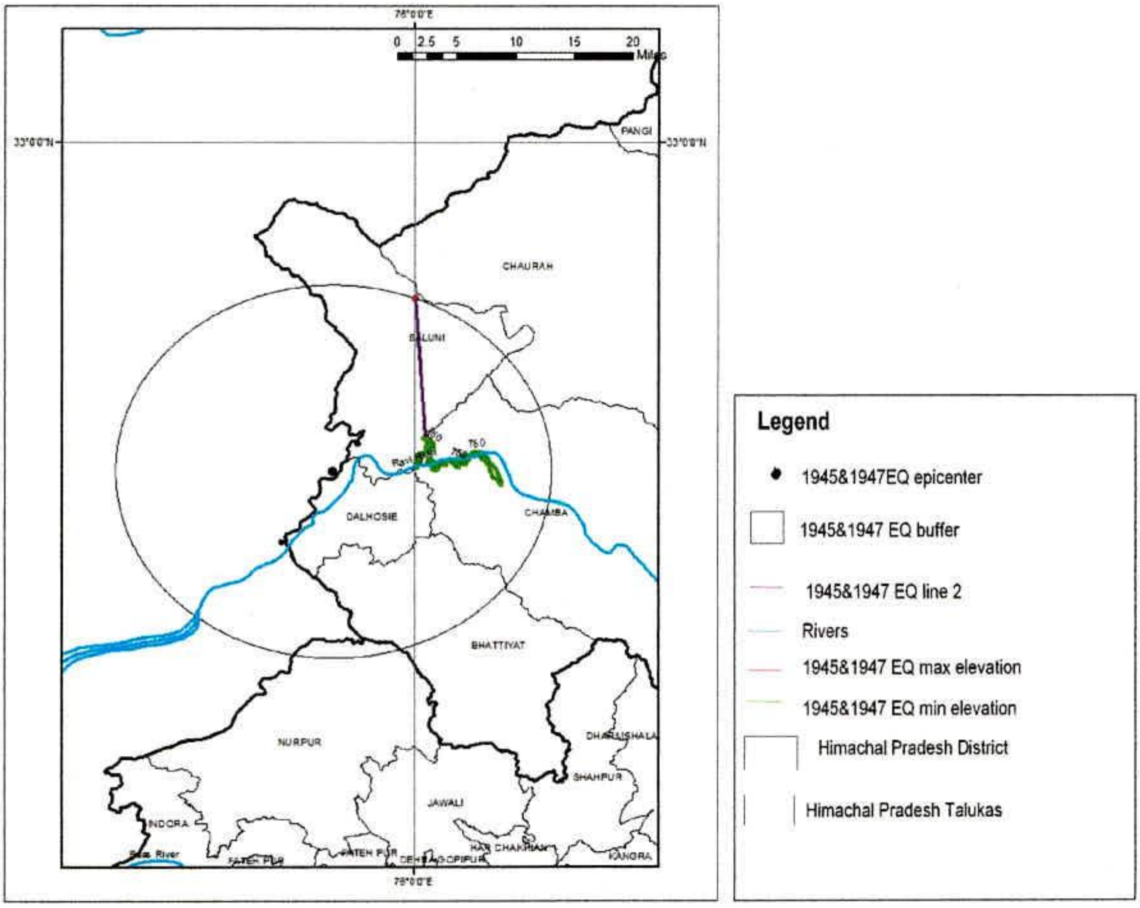


Figure 23: Map showing 1945 and 1947 earthquakes buffer around the epicenter, maximum and minimum elevation within the buffer zone, straight line2 drawn between each maximum and minimum elevation, state boundaries, districts, Talukas and rivers within the buffer zone.

The following observations are noted for Line 3(refer figure 24): The length of the straight line is estimated to be 21.64 km. The district at the maximum and minimum elevation is Chamba (as per Survey of India map). Taluka on this line is Saluni both at maximum and minimum elevation. Along the minimum and maximum, the elevation increases from 750m to 950m and then it decreases to 750m, again increases to 1600m and decrease to 1450m, increases to 2100m and then decreases to 1450m and after which it increases to the maximum elevation of 3350m, as observed by ISRO map and SEISAT5. The estimated maximum elevation is 3350m located at Saluni Taluka in Chamba district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 750m Saluni Taluka in Chamba district (as identified on ISRO and SESIAT5). The river observed at both maximum and minimum elevation is Ravi as identified on ISRO map and SESIAT5.

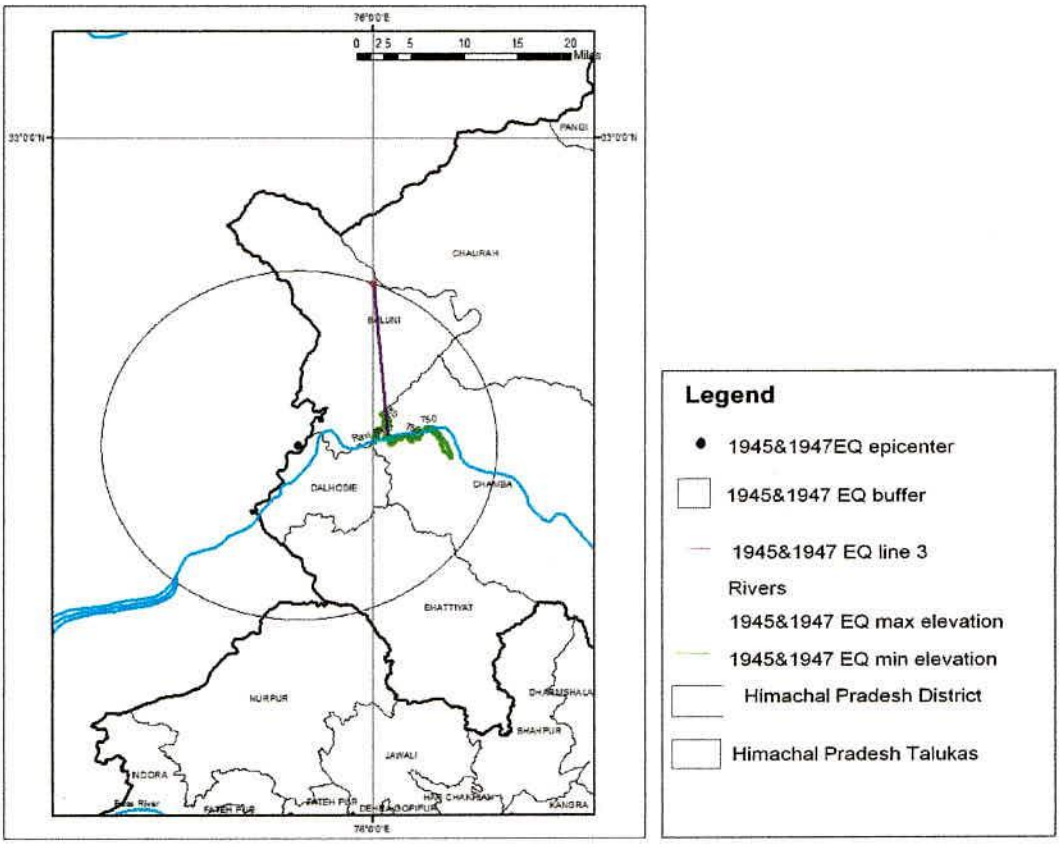


Figure 24: Map showing 1945 and 1947 earthquakes buffer around the epicenter, maximum and minimum elevation within the buffer zone, straight line3 drawn between each maximum and minimum elevation, state boundaries, districts, Talukas and rivers within the buffer zone.

The following observations are noted for Line 4 (refer figure 25): The length of the straight line is estimated to be 19.85 km. The district at the maximum and minimum elevation is Chamba (as per Survey of India map). Taluka on this line is Saluni both at maximum and minimum elevation. Along the line joining the maximum and minimum elevation, the elevation increases from 750m to 950m and then it decreases to 750m, again increases to 1600 m and decrease to 1450m, increases to 2100m and then decreases to 1450m and after which it increases to the maximum elevation of 3350m, as observed by ISRO map and SEISAT5. The estimated maximum elevation is 3350m located at Saluni Taluka in Chamba district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 750m Saluni Taluka in Chamba district (as identified on ISRO and SESIAT5). The river observed at both maximum and minimum elevation is Ravi as identified on ISRO map and SESIAT5.

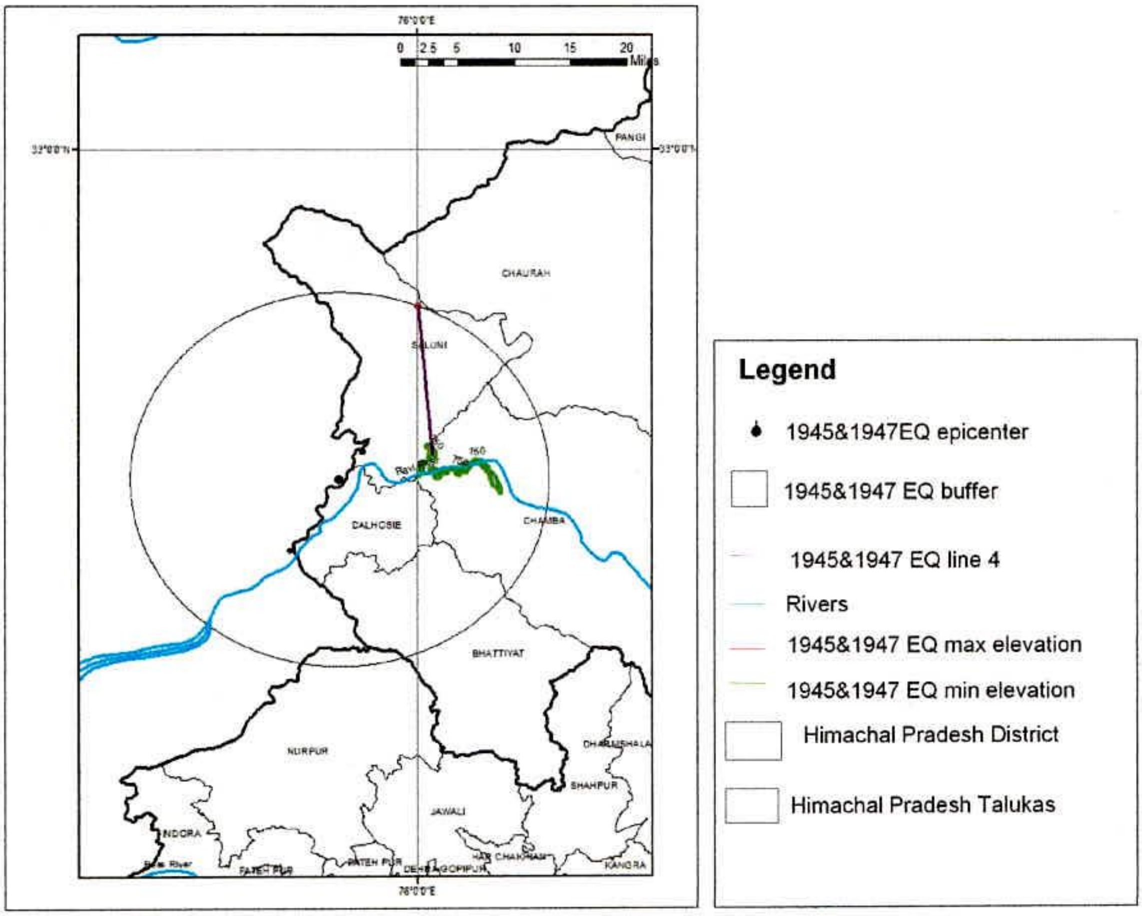


Figure 25: Map showing 1945 and 1947 earthquakes buffer around the epicenter, maximum and minimum elevation within the buffer zone, straight line4 drawn between each maximum and minimum elevation, state boundaries, districts, Talukas and rivers within the buffer zone.

The following observations are noted for Line 5 (refer figure 26): The length of the straight line is estimated to be 22.007 km. The district at the maximum and minimum elevation is Chamba (as per Survey of India map). Taluka on this line is Saluni both at maximum and minimum elevation. Along the line joining the maximum and minimum elevation, we observed that there is elevation increment from 750m to 950m and then it decreases to 750m, again it increases to 1600 m and then decrease to 1450m, then again it increases to 2100m and then decreases to 1450m and after which it increases to the maximum elevation of 3350m as observed in ISRO map and SEISAT5. The estimated maximum elevation is 3350m located at Saluni Taluka in Chamba district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 750m Saluni Taluka in Chamba district (as identified on ISRO and SESIAT5). The river observed at both maximum and minimum elevation is Ravi as identified on ISRO map and SESIAT5.

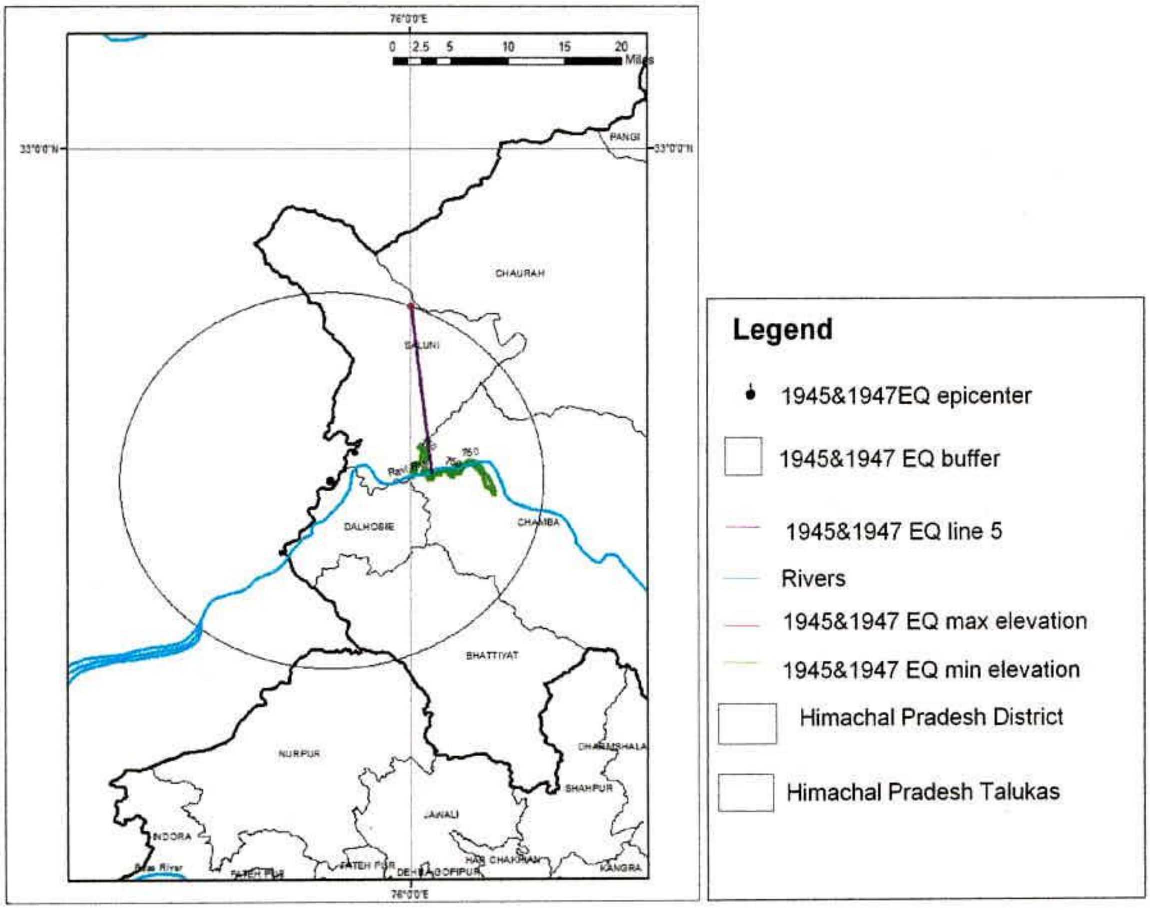


Figure 26: Map showing 1945 and 1947 earthquakes buffer around the epicenter, maximum and minimum elevation within the buffer zone, straight line5 drawn between each maximum and minimum elevation, state boundaries, districts, Talukas and rivers within the buffer zone.

The following observations are noted for Line 6 (refer figure 27): The length of the straight line is estimated to be 22.308 km. The district at the maximum and minimum elevation is Chamba (as per Survey of India map). Taluka on this line is Saluni both at maximum and minimum elevation. Along the straight line joining the maximum and minimum elevation points, the elevation increases from 750m to 900m and then it decreases to 750m, again increases to 1100 m and decrease to 800m, increases to 2150m and then decreases to 1450m and after which it increases to the maximum elevation of as observed in ISRO map and SEISAT5. The estimated maximum elevation is 3350m located at Saluni Taluka in Chamba district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 750m Saluni Taluka in Chamba district (as identified on ISRO and SESIAT5). The river observed at both maximum and minimum elevation is Ravi as identified on ISRO map and SESIAT5.

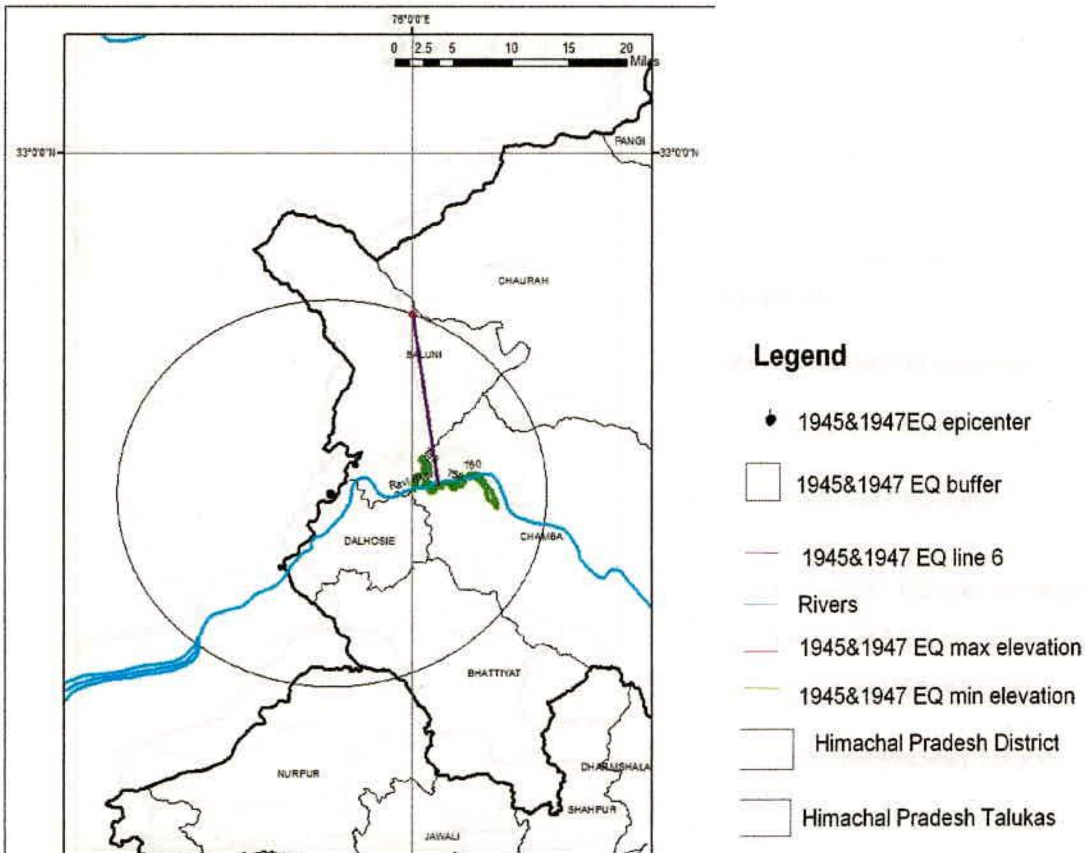


Figure 27: Map showing 1945 and 1947 earthquakes buffer around the epicenter, maximum and minimum elevation within the buffer zone, straight line6 drawn between each maximum and minimum elevation, state boundaries, districts, Talukas and rivers within the buffer zone

The following observations are noted for Line 7 (refer figure 28): The length of the straight line is estimated to be 22.006 km. The district at the maximum and minimum elevation is Chamba (as per Survey of India map). Taluka on this line is Saluni both at maximum and minimum elevation. In between the minimum and maximum points, the elevation increases from 750m to 1350m and then it decreases to 800m ,again increases to 1050 m and decrease to 950m , increases again to 1950m and then decreases to 1400m and after which it increases to the maximum elevation of as observed in ISRO map and SEISAT5. The estimated maximum elevation is 3350m located at Saluni Taluka in Chamba district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 750m Saluni Taluka in Chamba district (as identified on ISRO and SESIAT5). The river observed at both maximum and minimum elevation is Ravi as identified on ISRO map and SESIAT5.

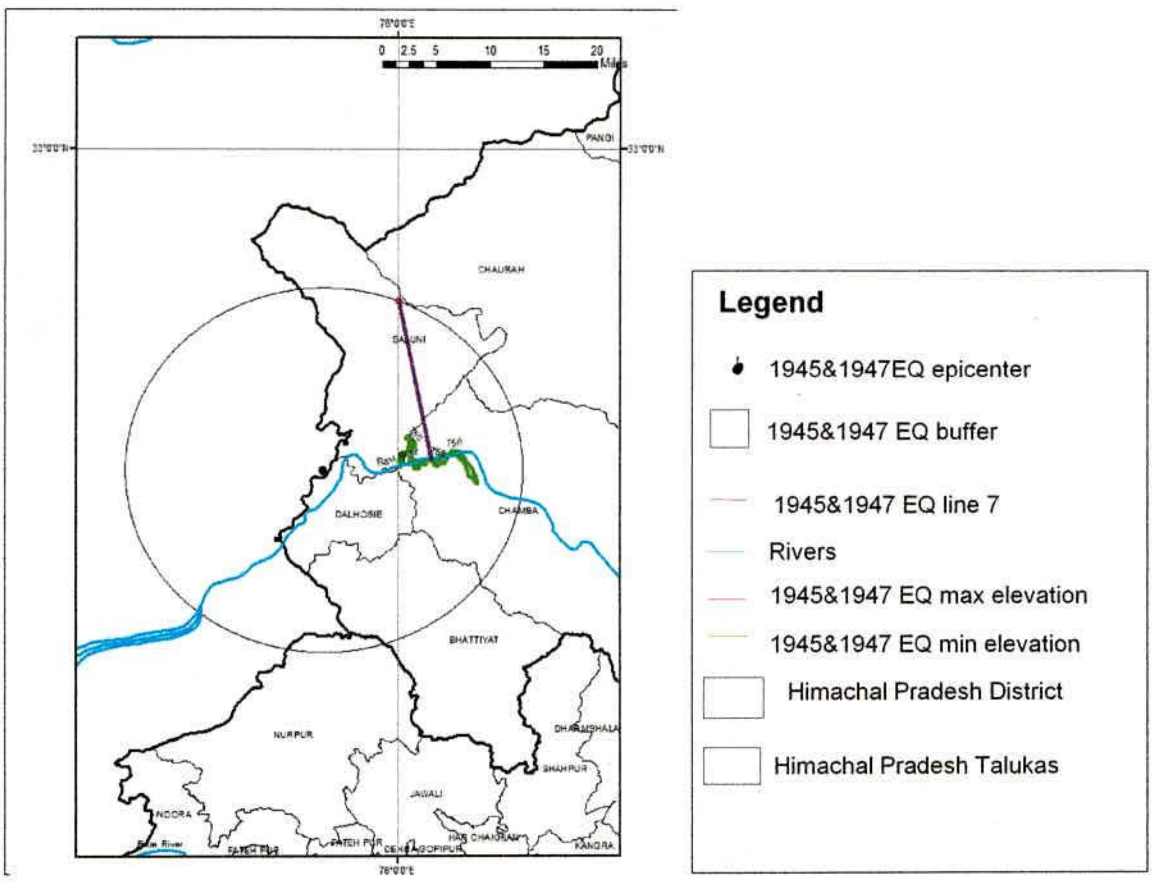


Figure 28: Map showing 1945 and 1947 earthquakes buffer around the epicenter, maximum and minimum elevation within the buffer zone, straight line 7 drawn between each maximum and minimum elevation, state boundaries, districts, Talukas and rivers within the buffer zone.

The following observations are noted for Line 8 (refer figure 29): The length of the straight line is estimated to be 21.748 km. The district at the maximum and minimum elevation is Chamba (as per Survey of India map). Taluka on this line is Saluni both at maximum and minimum elevation. Along the straight line joining the maximum and minimum elevation, the elevation increases from 750m to 1450m and then it decreases to 1100m, again increases to 1200 m and decrease to 800m, increases to 1350m and then decreases to 1200m, again increases to 1900m and decreases to 1350m, after which it increases to the maximum elevation of as observed in ISRO map and SEISAT5. The estimated maximum elevation is 3350m located at Saluni Taluka in Chamba district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 750m Saluni Taluka in Chamba district (as identified on ISRO and SESIAT5). The river observed at both maximum and minimum elevation is Ravi as identified on ISRO map and SESIAT5.

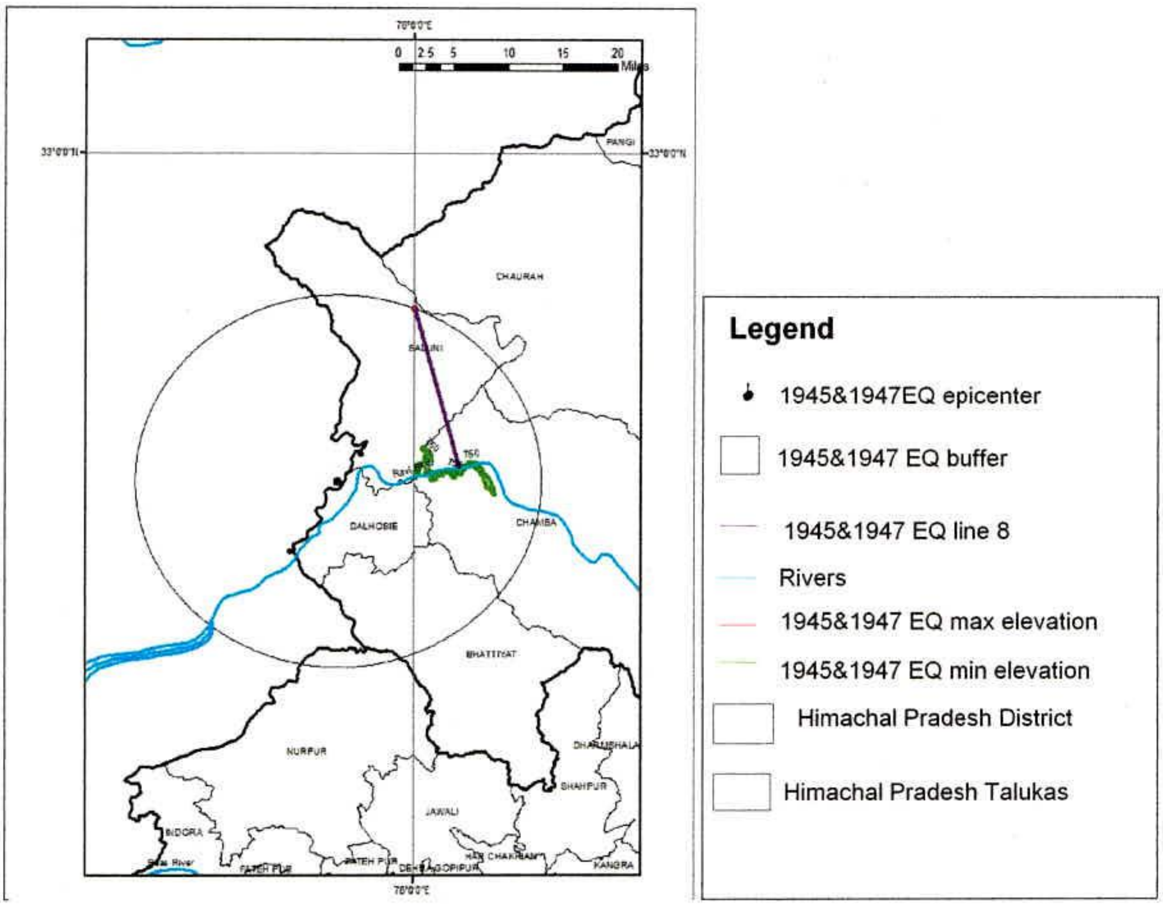


Figure 29: Map showing 1945 and 1947 earthquakes buffer around the epicenter, maximum and minimum elevation within the buffer zone, straight line 8 drawn between each maximum and minimum elevation, state boundaries, districts, Talukas and rivers within the buffer zone

The following observations are noted for Line 9 (refer figure 30): The length of the straight line is estimated to be 21.597 km. The district at the maximum and minimum elevation is Chamba (as per Survey of India map). Taluka on this line is Saluni both at maximum and minimum elevation. Along the straight line joining between the maximum and minimum elevation, the elevation increases from 750m to 1450m and then it decreases to 1100m, again increases to 1200m and decrease to 800m, increases to 1250m and then decreases to 1200m, again it increases to 1850m and decreases to 1350m, and after which it increases to the maximum elevation of as observed in ISRO map and SEISAT5. The estimated maximum elevation is 3350m located at Saluni Taluka in Chamba district as observed by the combination of ISRO and Survey of India maps. The minimum elevation estimated is 750m Saluni Taluka in Chamba district (as identified on ISRO and SESIAT5). The river observed at both maximum and minimum elevation is Ravi as identified on ISRO map and SESIAT5.

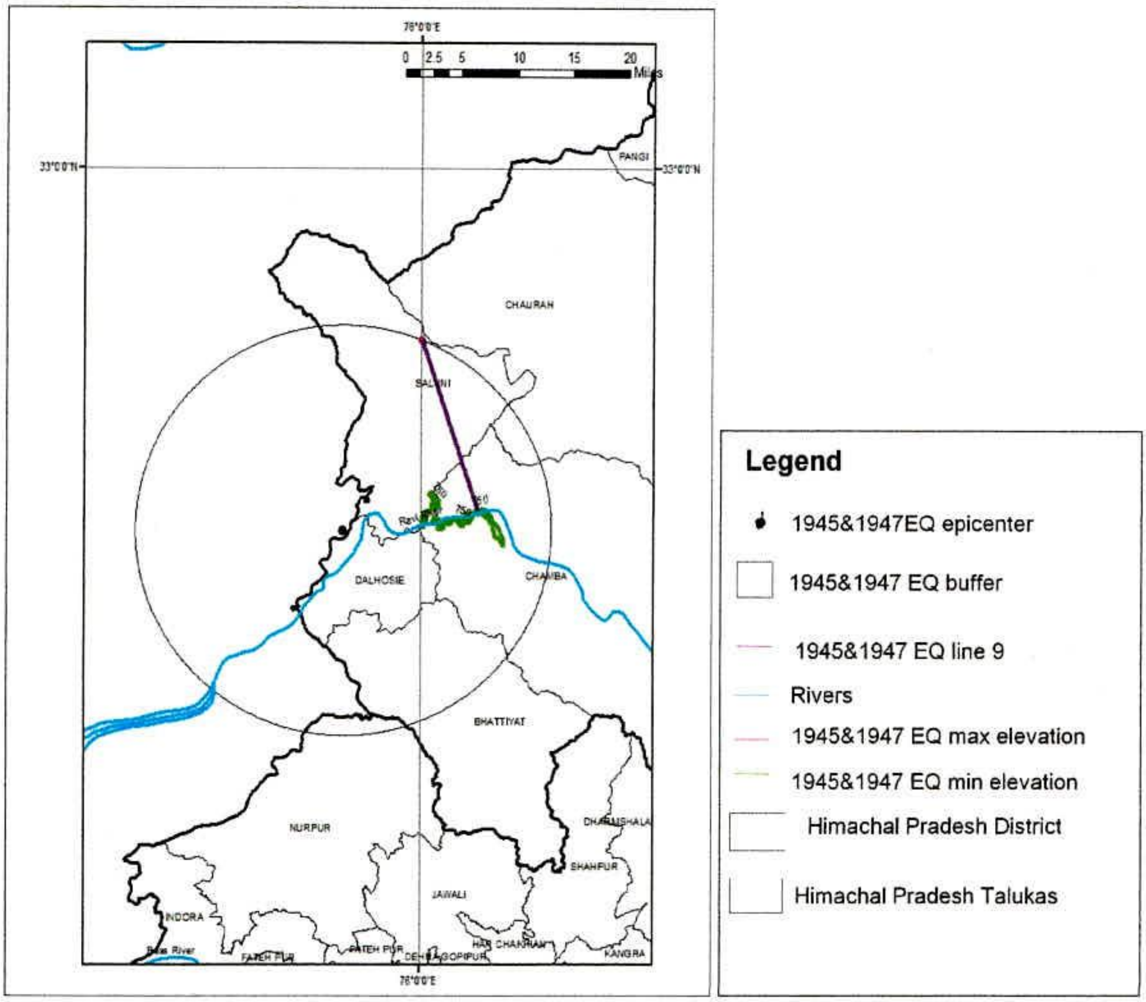


Figure 30: Map showing 1945 and 1947 earthquakes buffer around the epicenter, maximum and minimum elevation within the buffer zone, straight line 8 drawn between each maximum and minimum elevation, state boundaries, districts, Talukas and rivers within the buffer zone.

Table 2.2: Lists of earthquakes in seismogenic source zone 1 showing the maximum and minimum elevation along with their Toposheet number

S N	Year	Month	Day	hour	Minute	Longitude East	Latitude North	Depth km	Magnitude M_w	Max elev m	Min elev m	Toposheet no.
1	1905	04	04	00	50.00	76.25	32.30	0.00	8.00	4850	350	52D
2	1906	02	28	00	0.00	77.00	32.00	0.00	7.00	4950	650	52D
3	1945	06	22	18	0.00	75.90	32.60	0.00	6.50	3350	750	43P
4	1947	07	10	10	19.00	75.90	32.60	0.00	6.20	3350	750	43P

Chapter 5

RESULTS AND DISCUSSIONS

5.1 Results

Variation in elevation or slope may result in increase of seismic hazard like landslide in that region. Presence of major rivers and drainage system should be taken into account for assessment of seismic hazard like landslide and liquefaction. For the great 1905 Kangra earthquake, there is linear variation of elevation from minimum to maximum. No humps are observed between the two elevations. No rivers or drainage system are identified within the buffer zone by ISRO map and SEISAT5. For 1906 earthquake, three minimum and two maximum elevations are observed within the buffer zone. Separate straight lines are drawn between each minimum and maximum point. Several humps are observed along the line joining the maximum and minimum point. The maximum elevation difference is estimated to be 700 m located at Baijnath Taluka in Kangra district. The river Ravi and Beas are within the vicinity of the region. Similarly, for 1945 and 1947 earthquakes there are elevation differences along the line joining the maximum and minimum elevation. The maximum elevation difference estimated is 850 metres located in Saluni Taluka of Chamba district. The river Ravi in located near the minimum elevation point. No river or drainage system is identified near the maximum elevation point as per ISRO map and SESIAT5.

5.2 Discussions

Along the straight line drawn between the maximum and minimum elevation within the defined buffer zone we observed that humps are present for some earthquakes. Humps which are less than 50m are ignored and for those which are greater than 50 metres along the straight line are studied in detail. Seismic hazard may vary depending on the presence of humps or elevation difference and it cannot be ignored for the assessment of seismic hazard. Higher the elevation difference more will be the probability of occurrence of seismic hazard. Rugged topography may contribute to higher seismic hazard to the region. For example, the probability of occurrence of landslide is higher at mountain tops than that in the flat topography. In the flat topography the presence of a river or drainage system may even increases the seismic hazard.

For the great 1905 Kangra earthquake no humps were observed, major rivers or drainage system along the straight line between the maximum and minimum elevation point as observed in Survey of India maps. But it cannot be concluded that there will be no risk of seismic hazard within this buffer zone. A more detailed analysis with better availability of data would give better results. For 1906 earthquake there are two maximum elevation points and three minimum elevation points. Separate lines are drawn from each maximum elevation to minimum elevation point. There are variations in elevation along the lines joining the maximum and minimum elevation. Humps greater than 50m are observed in many regions. The maximum elevation difference is 700 metres which is located at Baijnath Taluka in Kangra district. River Ravi is located near the maximum elevation and at the minimum elevation the river Beas is located. The presence of these two rivers may increases the seismic hazard of the area. There might be more probability of landslides and liquefaction in the vicinity of the rivers and hence increasing the seismic hazard. Similarly, for 1945 and 1947 earthquakes there are elevation differences along the line joining the maximum and minimum elevation. The maximum elevation difference estimated between the maximum and minimum elevation is 850 metres located in Saluni Taluka of Chamba district. The river Ravi in located near the minimum elevation point. No river or drainage system is identified near the maximum elevation point as per ISRO map and SESIAT5.

Buffer zones with no humps or elevation difference along the straight line drawn between the maximum and minimum elevation will have lesser possibility of seismic hazard like landslide in comparison to the buffer zone having more humps. More the number of humps higher will be the probability of occurrences of landslide. Higher the elevation difference more will be the probability of slope failures. Presence of rivers or drainage systems near a higher slope will increase the seismic hazard to the topography.

5.3 Application Areas

Seismic hazard assessment can be used in such hilly areas for modifying building codes for standard buildings, designing larger buildings and civil infrastructure projects like dams or bridges, land use planning and also in determining insurance rates. Topographical aspects of seismic hazard assessment can be taken as a guideline to estimate the slope failure and hence to determine landslide hazard. Topographical analysis can help with the initial identification of active structures and, in some cases, provide constraints on the nature of deformation along them. A quantitative topographic assessment can be a quick and useful tool for identifying zones of active rock uplift and the seismic hazards associated with them. The use of topography in ground motion simulations to obtain more accurate predictions of earthquake ground motions up through the fundamental resonance frequency of the topographic feature.

Advantages

Landslides hazard assessment can be done based on the slope and elevation difference of the topography. Higher the elevation difference more will be the possibility of occurrence of landslide. In addition to other parameters of estimating landslide hazard, topography of the region can be one of the important parameters used to estimate the hazard. Rugged topography can be one of the major factors contributing to seismic hazard like landslide.

Limitations

DEM Toposheets of Jammu& Kashmir were not available. Hence detail study of elevation difference of districts and Talukas which are in the study area could not be carried out for Jammu & Kashmir region. Major drainage systems, if present cannot be identified in ISRO maps and SEISAT5. Population and built up environment of road and infrastructures are not taken into account in this study.

5.4 Conclusions

Seismic hazard like landslide is directly related to slope with steep topography. Landslide hazard assessment taking topographical aspects can be an important approach for seismic hazard assessment in the region with rough and steep topography exists. In the present study an estimate is made for the probability of landslides within the buffer zone around the epicenter of the earthquake. Slope variation between the maximum and minimum elevation point is also taken into account for the estimate of slope failure. Maximum variation in elevation in the study area is 850metres which is in the buffer zone of 1945 and 1947 earthquakes. It is located at Saluni Taluka of Chamba district in Himachal Pradesh. Since the slope is steeper at this location landslide hazard assessment should be estimated taking all the available parameters. In this study an estimate is made of slope angles, so that potential of landslides can be estimated, based on slopes and topography.

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