GEOLOGICAL STRUCTURE AND EARTHQUAKE VULNERABILITY IN MARATHWADA REGION

Dissertation submitted in partial fulfillment of the requirement for the award of the degree of

MASTER OF PHILOSOPHY

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CERTIFICATE

I, **Manoranjan Mishra**, certify that the dissertation entitled "**GEOLOGICAL STRUCTURE AND EARTHQUAKE VULNERABILITY IN MARATHWADA REGION**" for the degree of **MASTER OF PHILOSOPHY** is my bonafide work and may be placed before the examiners for evaluation.

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Manoranjan Mishra

CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

CHAPTER 1

INTRODUCTION

The September 30, 1993 earthquake that has taken a toll of an estimated 11,000 human lives within a matter of minutes in early morning hours in Killari and nearby village, Latur district of Maharastra in Central India, will go down in history as the deadliest earthquake to strike a stable continental region (SCR). Also, it acquires the notoriety of being among the deadliest in world so far an earthquake in magnitude range from 5.5 to 6.5 (Johnston, 1994)

The stable continental crust regions are very quite parts of continents and far away from tectonic activity of plate boundaries. According to Johnston and Kanter (1) the bed shields – some of them more than 3 billion years old – that are ancient hearts of continents and platforms of sediment covered bedrocks which surround shields are qualified as stable crust. Johnston (2) has prepared a list of more than 800 stable continents regions with magnitude more than ,or equal to 4.5 or total moment released by these events is 10^{26} dyn cm/ year or less than 0.5% of global seismicity. The largest known earthquake belonging to this category occurred on 16 Dec 1811 and 23 Jan and 7 Feb 1812 in New Madrid (near Missouri in U.S.A). These earthquakes were magnitude of 8.2, 8.3 and 8.1 respectively. The next largest earthquake of magnitude 7.8 occurred in Kutch, India 1819.

The largest number of deaths so far reported for 1918 China (Naina) earthquake of magnitude 7.4, having claimed an estimated 10,000 human lives.

Noticeable events occurred in Tenant creek, Australia, on 22 Jan 1988. In unique sequence, three earthquake of magnitude 6.3, 6.4 and 6.7 occurred within a short period of 12 hours.

A moderate earthquake occurred in Latur and Osmanabad district of Maharastra state, India in the early hours of 30 Sep. 1993 (Radhakrishna: 1993; Gupta 1993, Ramakrishnan et al, 1994). This earthquake was felt widely in Central and South India, up to a distance of about 800 km. It caused anonymously heavy damage of life and property. Over 10,000 lives were believed to have been lost and many more injured. All villages in a heavily populated area of about 6-km radius (meizoseismal area) were razed to ground. The earthquake completely damaged about 200,000 houses in 67 villages in the district of Osmanabad and Latur alone. The earthquake also caused damage to some distant place in Bijapur, Bidar and Gulbarga districts of Karnataka and south Solapur in Maharastra state. Occurrence of earthquake just before 4.00am (local time) when most of the population were asleep after celebrating the festival of "Ganesh" immersion, extending up to early morning hours also increased the death toll.

Geologically, the area belongs to Deccan trap (plateau basalt of Paleocene age) series of lava flow covering an area of about 600,000 sq km in western and Central India (Wadia, 1964). Since the Decan trap lavas have blanketed pre-existing topography over a considerable area the stratigraphy of the underlying formation has been matter of wide speculation. If the continuation of older formation exposed on fringe of Decan trap is assumed, then it offers a wide choice, since the traps have contacts with the Precambrian Dharwar formation, granites and gneisses Proterozoic kaladgi and Bhima sediments of Gondwana (permo-carboniferous to Jussaric) sedimentary formation. The entire area is marked by gravity flow which suggests a mass deficiency in crust in the region. The earthquake occurred on the eastern margin of Decan trap formation and there is no clearcut information about thickness of basalt. In Killari area, few bore wells drilled for ground water to a depth about 200m did not touch the basement.

The following focal parameters of main shock determined by different agencies are presented.

Table No.1

EPICENTER OF LATUR EARTHQUAKE GIVEN BY DIFFERENT STATIONS

	Lat N	Long E	Depth	Orgin time			
USGS	18.055	76.424	6km	03h	55m	48.505	IST
NGRI	18.020	76.570	6km	03h	55m	49.895	IST
IMD	18.070	76.620	15km	03h	55m	47.505	IST

On the suggestion of H.K. Gupta Director NGRI, an informal committee consisting of P.L. Narual of GSI, B.K. Rastogi of NGRI, V.P. Kanable of IMD and G.D. Gupta of DST was constituted to arrive at a consensus. The committee approved the following parameters

MAGNITUDE = 6.3 on Ritcher scale

Intensity = IX on MSK scale

EPICENTER = LAT- $18^0.070$ N

LOG = $76^0.620$ E

DEPTH = 12 ± 3 km

ORGIN TIME = 03H55m 47.50s

Significant Earthquakes in Maharashtra

The following list briefly outlines the known earthquakes in this region which either had observed intensities of V or higher (historical events) or had known magnitudes of 5.0 or more (instrumental events). General locations are provided for historical events for which "generalized" epicentral co-ordinates are available. Some events which were significant for other reasons are also included. Events of intensity III or greater, in or in the immediate vicinity of Mumbai are also listed. This list will be updated whenever newer information is available. Aftershocks of the 1967 Koyna and 1993 Khilari earthquake will not be listed unless there exists additional data for them. It is to be noted that Magnitude and Intensity are not the same. All events are within the state or union territory covered on this page unless stated otherwise.

Acronyms Used: D=Depth, OT=Origin Time, Mw=Moment Magnitude, Ms-Surface Wave magnitude, Mb=Body Wave magnitude, ML=Local Magnitude, M?=Magnitude Type unknown

1524 A.D. – Off the coast of Dabghol, Maharashtra.

A large tsunami caused considerable alarm to the Portuguese fleet who were assembled off the coast of Dabhol Maharashtra.

Felt for close to 18 seconds in western Maharashta and in Goa and Karnataka.

1594 A.D. – Matheran area, Maharashtra

19.100 N, 73.200 E.

Maximum observed intensity IV. This region lies to the east of Mumbai and to the south-east of Kalyan. It is the earliest reported earthquake from this region.

26 May 1618 – Mumbai area, Maharashtra.

18.900 N, 72.900 E.

Maximum observed intensity IX. This is the most damaging earthquake known to date in or near the Mumbai area. 2,000 fatalities are blamed on this event. The exact location and magnitude of this earthquake are still nuclear.

1678 A.D. – Matheran area, Maharashtra.

19.100 N, 73.200 E. Maximum observed intensity VI. This region lies to the east of Mumbai and to the south-east of Kalyan.

09 December 1751 – Vangani – Matheran area, Maharashtra.

19.100 N, 73.200 E. Maximum observed intensity VI. This region lies to the east of Mumbai and to the south-east of Kalyan.

05 January 1752 – Badlapur-Neral area, Maharashtra.

19.100 N, 73.300 E. Maximum observed intensity V. This region lies to the east of Mumbai and to the south-east of Kalyan.

05 February 1752 – Lohagarh-Lonavala area, Maharashtra.

18.700 N, 73.400 E.

Maximum observed intensity V. This region lies to the west of Pune.

31 October 1757 – Valha – Jejuri area, Maharashtra.

18.200 N, 74.200 E Maximum observed intensity V. This region lies to the south-east of Pune.

1760 – Pune area, Maharashtra.

18.500 N, 73.900 E. Maximum observed intensity IV.

August 1764 – Mahabaleshwar-Panchgani area, Maharashtra.

17.900 N, 73.700 E

Maximum observed intensity VII. Felt in western Maharashtra, at Nashik, Phaltan, Wai, Karad and Hukeri. This regioin lies to the south-west of Pune.

29 May 1792 – Amli – Revadanda area, Maharashtra.

18.500 N. 73.000 E.

Maximum observed intensity V. This region lies to the south of Alibag and north of Murud.

23 February 1812 – Pune area, Maharashtra.

18.500 N, 73.900 E. Maximum observed intensity IV.

20 March 1826 – Talgaon – Kudal area, Maharashtra.

16.100 N, 73.700 E.

Maximum observed intensity IV. This region lies to the east of Malvan. This earthquake is also known as the Moze Morwade earthquake.

04 December 1832 – Ajgaon – Terekhol area, Maharashtra.

15.8000 N, 73.700 E.

Maximum observed intensity VI. This earthquake is the largest event known near the state of Goa. No moderate or major earthquakes have been recorded in Goa.

26 December 1849 – Bombay Harbour, Maharashtra. 18.900 N, 72.900 E.

Maximum observed intensity IV. This region to the east of Colaba, Mumbai.

November 1854 – Bombay Harbour, Maharashtra.

18.900 N, 72.900 E.

Maximum observed intensity IV. This region to the east of Colaba, Mumbai

18 December 1856 – Parsipada – Kasa Khurd area, Maharashtra.

20.000 N, 73.000 E.

Maximum observed intensity VII. This region lies to the east of Tarapur and to the west of Nashik.

18 November 1863 – Nagalwadi-Julwania area, Madhya Pradesh.

21.800 N, 75.300 E

Maximum observed intensity VI. This region lies along the border of Maharashtra in the Khandwa area of Madhya Pradesh.

04 July 1869 – Lasalgaon – Vinchur area, Maharashtra.

20.200 N, 74.200 E.

Maximum observed intensity V. This region lies to the north-east of Nashik.

12 July 1869 – Dhule area, Maharashtra.

20.900 N, 74.800 E.

Maximum observed intensity V.

22 November 1872 – Mahadeopur – Sironcha area, Andhra Pradesh.

18.860 N, 80.100 E.

Maximum observed intensity VI. This area straddles the state border between Andhra Pradesh and Maharashtra.

20 July 1935 – Parsipada-Kasa Khurd area, Mahrashtra, Ms 5.0.

20.000 N, 73.000 E.

This region lies to the east of Tarapur and to the west of Nashik

16 September 1935 – Vashi area, Maharashtra, M? 3.0.

19.100 N, 73.000 E

Maximum observed intensity III.

14 March 1938 – Bhusawal-Sawda area, Maharashtra, Mw 6.3.

21.130 N, 75.830 E, D=040.0 kms, OT=00:48:38 UTC.

Maximum observed intensity VII. This earthquake was felt over a wide region, including at Agra in the north and Mumbai in the west. Deep-seated event with a focal depth of 40 kilometers.

27 November 1945 – Off the Makran coast, Pakistan, Mw 8.0 (14)

24.5000 N, 63.000 E. D=025.0 kms, Ot=21:56 UTC (14)

At least 2000 people killed in southern Pakistan and neighbouring Iran. Tsunamis with heights of 12 meters struck the Makran coast. Damage also occurred at Ormara. 15 people were killed by the tsunami in Mumbai.

08 April 1951 – Off the Konkan Coast, M 6.0 (918.500 N, 70.800 Em,)

OT=20:53:08 UTC Centred in the Arabian Sea. 218 kilometers east-south-east of Mumbai. this was the largest earthquake in this part of the Arabian Sea in recent history. It was felt at Mumbai, Pune and Surat.

25 August 1957 – Lalburra – Tikari area. Madhya Pradesh, Ms 5.5.

22.000 N. 80.000 E. OT=21:04:50 UTC

-04 June 1965 – Koyna area. Maharashtra. M 5.4.

17.000 N. 73.400 E. OT=03:37:12 UTC

-No Comment –

25 April 1967 – Mahad – Goregaon area, Maharashtra, M? 5.9.

18.260 N, 73.300 E. D=051.0 kms. OT=03:53:19 UTC.

This event was located on the Konkan coast. to the south-west of Pune.

13 September 1967 – Koyna area, Maharashtra, M? 6.0.

17.600 N, 74.000 E, D=004.0 kms, OT=06:23:32 UTC.

Felt strongly in western Maharashtra. Some damage reported in the Koyna region.

13 September 1967 – Koyna area, Maharashtra, Ms 5.5.

17.400 N, 73.700 E, D=004.0 kms, OT=06:48:25 UTC.

Felt strongly in western Maharashtra. Some damage reported in the Koyna region.

10 December 1967 – Koyna area, Maharashtra, Mw 6.6.

17.450 N, 73.850 E, D=027.0 kms, OT=06:48:25 UTC.

200 people were killed and many villages in the Koynanagar area were severely affected. The Koyna Dam suffered some structural damage and leaks were observed in the face of the dam. Tremors were felt strongly in many towns and cities in western Maharashtra, including, Mumbai and Pune. Also felt in Goa and other parts of western and southern India.

26 September 1970 – Wai area, Maharashtra, M? 5.5.

18.000 N, 74.000 E, OT=16:36:44 UTC

It is located roughly 60 kilometers to the south of Pune. Though listed in the earthquake catalog this event is not listed in existing IRIS database, raising doubts over the authenticity of its occurrence.

17 February 1974 – Arabian sea, M 5.0

17.500 N, 73.100 E.

This event was located off the Konkan coast, to the west of Guhagar near Ratnagiri.

02 September 1980 – Koyna area, Maharashtra, Mw 5.0.

17.270 N, 73.760 E, D=033.0 kms, OT = 10:45:30 UTC

Second largest event in a series of small to moderate earthquakes from this date to the end of September 1980.

20 September 1980 – Koyna area, Maharashtra, Ms 5.2.

17.260 N, 73.640 E. D=019.0 kms. OT=10:45:30 UTC.

Second largest event in a series of small to moderate earthquakes from this date to the end of September 1980.

14 September 1983 – Bhatsa area, Maharashtram, Mb 4.30

19.640 N, 73.540 E. D=033.0 kms, OT=21:53:41 UTC.

This earthquake is believed to have been induced by the Bhatsa Dam.

14 November 1984 – Koyna area, Maharashtra, Mb 4.5.

17.280 N, 73.960 E, D=0150.0 kms, OT=11:58:20 UTC.

Felt strongly in western Maharashtra and as far as Belgaum, Karnataka. 2 injuries were reported.

12 August 1991 – Arabian sea, Ms 4.1.

18.387 E, 71.15E, D=033.0 kms. OT=16:41:06 UTC.

18 October 1992 – Nilanga – Killari area, Maharashtra, Mb 4.3.

18.100 E, 76.730 E, D=025.0 kms, OT=17:33:02 UTC.

Felt strongly in Latur district and many people rushed outdoors in panic. Many buildings were damaged by the tremor, which was the largest event in a swarm that was felt in the area from August to October 1992.

24 August 1993 – Arabian Sea, Mb 4.9.

20.700 E, 71.440 E, D=029.0 kms, OT=17:47:30.

This event was located in the Gulf of Khambat, to the west of Surat, Gujarat. This earthquake was felt widely in south-eastern Gujarat and parts of coastal Maharashtra. In Gujarat, people rushed out into the open at Ankleshwar, Bardoli, Bharuch and Bulsar. It was felt strongly (MM V) at Rajula. It was also felt (MM IV) at Amreli, Bhavnagar and Surat. In Maharashtra, it was felth (MM III) in Mumbai. Reports of tremors were received from Bandra, Chembur, Juju, Kandivili and Prabhadevi. The shock was perceived over an area with a radius of 250 kilometers.

28 August 1993 – Koyna area, Maharashtra, Mb 4.8.

17.240 N, 73.730 E, D=005.0 kms, OT=04:26:24 UTC.

Felt in western Maharashtra, including at Mumbai and Pune. 10 school students were injured in a stampede that broke out in their school in Ichalkaranji. Slight damage was reported for this temor.

30 September 1993 – Killari area, Maharashtra. Mw 6.2.

18.090 N, 76.470 E, OT=22:25:50 UTC.

Among the deadliest intraplate earthequakes on record. Close to 8,000 people were killed and thousands injured in the pre-dawn earthquake. Many villages in the epicentral area, around Killari were razed to the ground. 55 people were killed in the neighbouring state of Karnataka, in Gulbarga district. Strong tremors were experienced at Hyderabad, Pune and Mumbai and across much of Maharashtra, Karnataka, Andhra Pradesh and Goa. Tremors were felt as far as Chennai.

08 December 1993 – Chandoli area, Maharashtra, Mw 5.1.

17.000 N, 73.650 E, D=032.0 kms, OT=01:42:17 UTC.

1 elderly woman died of a heart attack and 6 injured in this early morning quake. It was felt very strongly all over western Maharashtra and Goa for close to 20 seconds. Moderate damage was reported in several villages in the epicentral area.

01 February 1994 – Koyna area, Maharashtra, Mb 5.0

17.228 N, 73.523 E, OT=09:30:55 UTC.

1 person hospitalised for shock in the Pimpri – Chinchwad area.

14 December 1995 – Killari area, Maharashtra, ML 4.6.

18.131N, 76.543 E, D=010.0 kms, OT=04:09:32 UTC

Felt in widely in the Marathwada area of Maharashtra. 10-12 wall collapses were reported from the Umarga area of Dharashiv (Osmanabad) district. Many houses in Ausa, Ganjankhed, Haregaon, Mangrul, Nandurga, Nimbala, Nilanga, Renapur, Sirsi Police Lines and Talni developed cracks.

31 May 1998 – Koparpada – Naude area, Maharashtra, ML 3.6 19.040 N, 73.110 E, OT=13:29 UTC.

This earthquake was the first instrumented event in this general area. Tremors were felt in Thane (MM IV-V) and at Dombivili, Kalyan, Kulgaon and Mumbra, Mild tremors (MM III-IV) were experienced in Mumbai at Borivali, Chembur, Dahisar, Juhu, Malad, Mira Road, Santa Cruz and Wadala as well as in south Mumbai.

12 March 2000-Koyna are, Maharashtra, Mw 5.0.

17.099 N, 73.673 E, D=033.0 kms, OT=18:03:56.27 UTC.

Felt widely in western Maharashtra and Goa for close to 30 seconds. Structural damage was reported in the epicentral region.

19 June 2000 – Killari area, Maharashtra, ML 4.6.

18.008 N, 76.532 E, OT=08:22 UTC.

Felt in Marathwada, Maharashtra. Also felt at Solapur in Maharashtra and Gulbarga in Karnataka.

05 September 2000- Koyna area, Maharashtra, Mw 5.3.

17.290 N, 73.760 E, D=010.0 kms, OT=00:32:45 UTC.

Largest earthquakes (based on seismic moment release) since December 1967. Felt strongly in many parts of western Maharashtra as well as in Goa and Karnataka. More than 400 buildings were damaged in this quake in Satara, Sangli and Kolhapur Districts. A temple at Jejuri in Pune district was also damaged. No injuries or fatalities were reported.

27 March 2003 – Koyna area, Maharashtra, ML 4.0

17.320 N, 76.740 E, OT=06:18:22 UTC.

Felt in many parts of western Maharashtra, as far as Mahabaleshwar and Khed in to the north. Slight damage (MM VI) was reported from Patan. The quake was felt strongly (MM V) in the Koyna and Chandoli areas. 1 fatality occurred when a wall collapsed at Sayyedwadi during an M3.2 foreshock.

This earthquake was centred in the Arabian Sea, roughly 138 kilometers south-southwest of Colaba, Mumbai.

LITERATURE REVIEW

The Latur earthquake of 30^{th} Sep. 1993 devastated an area about 110sq km in Marathawada region covering Latur and Osmanabad districts of Maharastra, will go in the annals of history as one of the deadliest earthquake in the stable continental regions of the world. The study of earthquake i.e. seismology is a multidisciplinary subject. There are numerous works carried out regarding earthquakes in general and Latur earthquakes in particular by Geologists, Geophysics etc. The literature consulated are as follows

[Gupta and Gupta][1] in his book "Earthquake studies in peninsular shield since 1993"have extensively looked into the mechanics and other phenomenon. The Indian shield experienced several earthquakes in last three to four decades, exemplified by ongoing seismicity around Kajna registered since 1997, the 1993 Latur earthquake, the 1997 Jabalpur and 2001 Bhuj earthquakes of moderate to high magnitude. In response to these events several parallel stream of investigations have been initiated that are relevant to promoting an understanding of crystal processes that lead to seismogenic deformation on the one hand and earthquake engineering, on the other. The main impetus to the research has emerged after 1993 Latur earthquake. The Department of Science and Technology stand foremost among several institutions in organizing these researches and has affected an inter-institutional inter action and brought together several individual researches in the field of seismology. As deformation is only rarely expressed in surface rupture (faults), understanding the kinematics of the deformation has been largely based on instrumental data. The Latur earthquake, however is a rare example where the co-seismic surface ruptures are present and have facilitated investigations through four bore holes drilled in

[1] Gupta, H.K. and Gupta, G.D. (eds) (2003) "Earthquake studies in peninsular shield since 1993" Memoir-5cs Geological society of India, Bangalore.

the rupture zone. The results throw light on deformation of 335m thick sequence of volcanic flows of Decan traps, underlain by some sediments lying on Archaean crystalline basement row dated 0.2574 million years. Thrust faulting is traced to a depth of 222m and large cumulative displacement of 3 to 6 cm along the fault are encountered against a sub-metre scale co-resmie displacement inferred due to the 1993 event. This leads to possibilities of paleoseismic event in the region and seismic ancestry that has potential for estimating recurrence period of earthquake on Latur fault. The thermal regime measure in the bore holes confirms a cold crust that has no memories of the 65 million year old Deccan volcanism. The stress field are 30% higher than comparable intra-continental regions and possibly the region up to Hyderabad may be sharing such a stress field. These may have implication in understanding the incessant but low seismicity of Hyderabad region.

Results of electromagnetic expression-cuts reveal an intra crustal layers of conductivity at depth of 10-15km below Latur and adjoining regions. This confirm earlier finding and underlines the role of fluids in effecting pore pressure that have potential to generate fault failure and seismogensis and to influence the overall theological response of the shield in the regions.

GPS and geodetic studies have been initiated both in Bhuj and in the Deccan volcanic provinces, including central India the site of 1999 Jabalpur earthquake, and the tract along east coast. Some interesting, through tentative, results of crustal displacements, velocity and strain rates are inferred which need further confirmation. More extensive and repetitive measurements over larger areas that ensure high resolution seem necessary.

The concluding parts of the volume present three papers that provide detailed account of recently upgrade and newly established seismic monitoring centres in the country through both World Bank assisted project and national efforts. An important part of setup are the modern computing and data center facilities that have been created. These facilities, no doubt, have already registered a phenomenal impact on quality and dimensions of seismological researches in India. The extensive facilities built call for interaction and collaborative efforts on a mass scale.

Karato [2] in his book "The Dynamic Structure of Deep earth: An interdisciplinary approach"addressed this mechanism of deepseated earthquakes. The theory of plate tectonics revolutionized our perception of solid earth from static to dynamic. It also explains most earth process such as mountain building, earthquakes and volcanic activity and went further to explain more enigmatic process such as deep earthquakes. Today we know that earth's interior is active as exterior. The book under review is an effort in that direction and it is an authoritative summary of current research in this field with author's critical evaluation of some of the theories. He has diligently translated the dynamic of the some of the complex processes that go within the earth, into a well-researched and easy to understand account. This book takes us on a journey, starting from the atomic level behaviour of earth's-materials.and effortlessly guiding through its transformation under extreme conditions of temperature and pressure, finally leading to a global scale assessment.

The first chapter of this book, the structure of earth and its constituents, review various models that explain the radial structure, chemical compostion and phase

[2] Karato, Shun-ichiro (eds) (2003) "The Dynamic structure of the Deep Earth: An interdisciplinary approach" Princeton University Press.

transformation starting with early theories on chemical and geo physics model, This chapter brings up many later ideas such as layered structures of the earth and phase transitions. At an early part of the book the author introduces many concepts that are derived from observations of seismic waves. This chapter deals with geochemical, geophysical, and seismological models etc. Result from high temperature, mineral physics experiment, observation of seismic waves are integrated to obtain an image of earth interior.

The second chapter of this book reviews various model on the origin of structure in upper mantle and demonstrate the role of water in its mechanical stratification. A review of current ideas and new experimental results in this chapter exposes reader to the plastic deformation providing newer insight to the process within asthenosphere. In this new lithosphere-athenosphere model various geophysical anomalies (low seismic velocity, high electrical conductivity) are caused by large amount of water dissolved in mantle minerals.

In the third chapter on seismic tomography and mantle convections, the author summarizes the recent results of other high-resolution seismological experiments. This chapter examines result of such high resolution experiment that have provided the most efficient tools to understand the structure of the earth. The way of anisotropy is handled in this chapter is an illustration how the author develop the idea from atomic level taking its grains and finally to global scale. Results from high pressure mineral and rock physics and seismology merge here to give us clear view of dynamics of some of earth processes.

[Gupta] [3] gives some introductory information about the stable continental region earthquakes their rarity and make specific remarks about past earthquakes globally. and a few which occurred in India. The stable continental region earthquakes account only about 0.5% of the annual seismic energy releases amounting to 10^{26} dyn-cm. With seismie moment of $1.8x10^{26}$ the Latur earthquake accounts for about 100SCR earthquake exceeding magnitude 6 as listed by Johnston (1993). Johnston (1994b) has further classified SCR earthquakes into two categories.

1. Those associated with past failed rifts
2. ' Those associated with cratons.

In second category, earthquakes exceeding magnitude occurrence every 17 years. So Latur earthquake is truly a very rare event.

[Mohan and Rao][4] on field based study of Latur earthquake present a detailed study of the meizoseismal area and isoseismal map prepared at different scale. In this paper as well as another related paper (Gupta et al 1993) the factors responsible for severe damage to houses are found to be a very shallow focal depth earthquakes, a poor construction and early morning hours of earthquake occurrence when most of people are asleep. The earthquake completely damaged some 19,000 houses and partially damaged some 200.000 houses in 67 villages in district of Osmanabad, Latur. They pointed out that earthquake intensity outside meizoseismal area drops very rapidly. It was felt upto a distance about of 800 km in the south. They attribute the large felt area to good transmission of seismic warco energy in the Deccan shield region as was also reported for

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[3] Gupta, H.K (1994) – "The Deadly Latur earthquake" edited book" Latur Earthquake" memoir 35, GSI, Banglore pp1.7.

[4] Mohan, I and Rao, M.N. (1994) – """A Field study of Latur earthquake of 30[th] Sep. 1993" edited book "Latur earthquake" GSI Banglore

earlier earthquake occurring in the Decan shield region, for example the Koyna earthquake of Dec. 10.1967 and the Bhadrachalan earthquake of April, 3, 1969.

Banmbach, Grosser, Schimdt, Paulat, Rietbrock Solmon and Sarkar [5] deal in detail with fore-shockand after shocks of Latur earthquakes. The closet seismic stations to the epicentral region is NGRI, Hyderabad at a distance about 220 km only earthquake of m>2 from Latur region could be detected. There was no fore-shock, large enough to be detected at Hyderabad before the Latur earthquake. However, during October-November 1992 several event m>2 from Latur region occurred, which are well recorded at Hyderabad. In seismology paralance, these are called pre-shocks. Some scientist had opined that these pre-shocks should have given indication of the impending earthquake. An important result of the study of fores-hocks and after shocks is finding a p-value, the characteristic features of decay of seismic activity in an earthquake sequence. For Latur region it is found to be o.s for 1992 sequence and o.q for after shock sequence in 1993 sequence indicate that the stress regime did not change in Latur, and therefore, 1992 sequence could not be considered to be a precursor to 1993 sequence. It may be pointed out that Tennant Creek earthquake sequence of 19.88 was also preceded by pre-shock sequence and after-shocks of Tennant Creek earthquakes was useful to infer the relation between the pre-shocks and the main shocks (Chay and Bowan ,1990)

In the absence of any near source, complete recordings of the Latur earthquake, the spatial distribution of after- shocks located using digital data has been assumed to be the rupture area. The information has been used to estimate certain critical parameters of the Latur earthquake as well as characteristic of the media. The stress drop is estimated to be 0.7 mega pascal and maximum displacement is estimated to be 1.7 metres. It is found from the acceleration and displacement spectrum that the signals get amplified in 20-30 Hz frequency range. A very high heterogeneity for the region is inferred from long signal duration and high frequency content of the after-shock records.

[Chetty and Rao][6] have given report on surface deformation and lineament pattern associated with Latur earthquake. Before occurrence of Latur, only nine other cases were known where stable continental region earthquakes had caused surface faulting (Adams et al. 1991). From the study of lineaments from satellite imagery, geomorphological considerations and field investigation, Chetty and Rao inferred that Latur earthquake is divided into a member of block. The blocks have differential vertical movements. They also found that the block around Makni, Lanjan, Killari, Narangwadi, defined by major lineaments on all sides, shows an elongation in Northwest-Southeast direction. This block has an area of about 20x30 km^2. They observed that all heavily damaged villages are located within this block.

[Sunder, Roy, Rao and Rao][7] reported of elevated surface temperature for a number of places after occurrence of the Latur earthquake. To authenticate them, temperature was measured at a depth of 1 meter and several sites of reported smoke emanation and surface heating. Sunder et al. report that there was no case of continued ground heating after any of these event. Temperature were also measured in 24 bore holes ranging from 20-180 meters depth in meizoseismal area of Latur earthquake.

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[5] Baumbach, M, Grosser, H., Schimdt, H.G., Paulat, A Rietbrock, A, Solomon, P. and Sarkar, D. - "Study of Foreshock and After shock of the intraplate Latur earthquake of Sep. 30 1993" Memoir 35, GSI, Banglore p-33-65

[6] Chetty, T.R.K, and Rao, M.N (1995) – "Latur earthquake of Sept. 30 1993, surface deformation and lineament pattern" G.S.I Banglore memoir – 37, p-65-75

[7] Sundar, A., Roy, S., Rao, G.V., Rao, R.V.M (1996) – "Ground-Temperature measurement at some sites of smoke emanation and bore hole – Temperature" GSI. Bangalore. Memoir-38,p75-83

Reddy. Rao, Rao, Gopalan[8] has reported a unique discovery of highly elevated soil-gas helium over surface ruptures associated with earthquake. The whole area has been divided into background zone where helium concentration is of order of 0.2 ppm or less, an intermeidate zone where the concentration is 0.2 to 1.0 ppm and a peak zone where the values are more than 1 ppm. As a matter of fact, there are several sites where helium survey over earthquake generated surface rupture has been conducted and a map prepared. Temporal variations are being studied by repeated observation at a limited set of stations. Efforts are also being made to investigate 3He/4He ratio to have some idea of the depth of source of helium.

Sarma, Virupakashi, Harinasayana, Murthy, Prabhakar, Rao, Verraswamy, Rato, Sarma, Gupta[9] have studied the physical process associated with an earthquake. The knowledge of sub-surface lithology and structure, very large variations in seismic velocities and densities in almost all horizontal layers of various lava flows of Decan Trap basalt formation, in epicentral region of Latur earthquake makes. Probing subsurface lithology and structure difficult by convectional use seismic method. Magnetotollurics provide an answer to the reports, the results of 16 wide band range (10^3 H_7-$10^{-3}H_7$) magnetotellusic soinding conducted in the region. The trap thickness in the region is inferred to be around 300-400 metre. They found an anomalously shallow upper crystal conducted in hypocentral zone embedded in an otherwise high restrictive zone embedded in an otherwise high upper crust at depth 6-10 km.

[8] Reddy, G.K., Rao, G.V., Rao, R.V.M and Gopralan, K. (1997) – "Surface rupture of Latur earthquake The soil-gas Helium signatur" GSI Banglore memoir-38 p83-101

[9] Sarma, S.V.S., Viruprakshi, G., Harinarayan, T., Murthy, Dab Prabhakar, S., Rao, E., Versaswamy, L., Rao, M, Sarma, and Gupta, K.R.B-(1997)- "A wide Bank Magnetotelluric study of the Latur. Earthquake reion, GSI, Banglore memoir 38 101-119

[Mishra, Gupta, Vyaghreswara][10] reported the gravity investigation conducted in epicentral region. A Bougner gravity low of about 5 mgal is observed in the epicentral region. They have also speculated on space and time variation of gravity field in earthquake region.

[Singh, Subhrahmangyam, Hodlur, Anjaneyulu][11] present their findings of investigating the reported variations in ground water levels in the earthquake affected zone. They infer, from a comparison of present day water table depths with the past depths available from the central ground water board, that the depth of water table has not changed significantly. They also observed that subnormal rainfall during the past two years might have caused the decline in water table.

[Rastogi][12] introduced the phenomena of reservoir induced seismically (RIS). In 1960, number of damaging earthquakes occurred in the vicinity of reservoir followed by long after shock sequence. However, past 30 years, things have changed drastically. In 70's, through detailed study of RIS sequences, criteria were generated to discriminate induced earthquakes for the normal (non induced) occurring in the vicinity of reservoirs, and through lab experiments, field observation, model, theoretical studies acceptable explanation of RIS were put forward (Gupta, 1992).

Now whenever an earthquake occurs in the vicinity of even a small reservoir, a section of earth scientist immediately classify it as induced by reservoir. This was also the case with Latur earthquake which occurred in the vicinity of Makai Dam. In an interesting study

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[10] Mishra, D.C., Gupta, S.B., Vyaghreswara M.B. -(1998)-"Space time distribution of Gravity field in earthquake affected areas of Maharastra"

[11] Singh, V.S., Subrahmanyam, K., Hodlus, G.K, Anjaneyulu, G.R. – (1998) "Report of Hydrological Reconnissance same earthquake affected village of Latur" G.S.I, Banglore memoir – 39 page 113-127

Rastogi arugues and gives convincing evidences, based on the characteristics of reservoir induced earthquake that Latur earthquake was not an induced one.

[Rastogi, and Rao][13] provide a report on smoke and gas emanation and subterranena sounds of micro earthquakes reported in press and by people following Latur earthquake. Smoke/gas emanation and subterranean sound of micro-earthquakes were observed from area of 200x300 sp.km centered around Latur

CRITICAL EVALUATION

The after shock data are to further analyzed. It has been noticed that signal duration of Latur after- shock is much longer than that of other strong after-shocks of earthquakes of comparable magnitude.

The longer code length, in case of Latur after-shocks could possibly be due to low attenuation and higher heterogeneity in the crust and uppermost mantle. The presence of scattered responsible for the longer code has been observed. An effort is also being made to improve the understanding of structure of uppermost strata in Latur region. Efforts are further being made to study geomorphometric and geological structure responsible for vulnerability of the area.

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[12] Rastogi, B.K – (2000)"Latur earthquake not triggered" G.S.I Banglore memoir-40 page – 127-131
[13] Rastogi, B.K, and Rao, M.N. – (2003)- "After effect of Latur earthquake smoke/ gas emanations and subterranean sound./ micro earthquakes" GSI Banglore memoir-42 p-131-139

SELECTION OF STUDY AREA: LATUR DISTRICT OF MAHARASTRA

In the early morning hours of September 30, 1991, in Marathwada region,an earthquake of magnitude of 6.6 struck an area vicinity of Latur which is approximately 500 km east of Mumbai (Bombay) an.. The epicenter was approximately 40 km south of Latur close to Killari village.Mass destruction was reported along with human loss. Hence it is necessary to study geomorphometric and geological parameters which lead to vulnerability of the area. The present district of Latur was actually carved out of Osmanabad in August 1981. The district is bounded by Nanded in the East. Osmanabad on Southwest, Beed on northwest, Parbani and Karnataka in the North and it shares a boundary with Andhra Pradesh on the southeast. For this purpose case study is limited to Latur district only.

RESEARCH QUESTIONS

What is the potential role of geological and geomorphological parameters in assessing vulnerability due earthquake in Latur district of Maharastra?

OBJECTIVES

1. To study the geological structure of Latur district such as
   - (i) Active faults
   - (ii) Historic and pre-historic earthquakes
   - (iii) Slip rates and nature of recurrence
   - (iv) Subsurface lithology, site of amplification and lateral spreading
2. To study the after shock situation and fault solution of the area.

3. To evaluate the geo-morphometric analysis of the area.

DATABASE

Data has been collected only from the secondary source:

- ✓ Toposheet having scale 1:250,000
- ✓ Geological map of Latur
- ✓ Digital Satellite imagery
- ✓ Document of Maharastra emergence earthquake rehabilitation program
- ✓ Research papers from journals

METHODOLOGY

Following geo-morphometeric parameters and formulae used for calculation

Morphometric Parameters	Symbol Used	Units
1. Number of stream order	Nu	Enumerative
2. Total number of streams within basic	$(En)u=N_1+N_2+N_3$	Enumerative
3. Bitureation Ratio	$Rb = \frac{Nu}{Nu+1}$	-
4. Total length of stream order u	Lu	Kms
5. Mean length of stream order u	$\bar{Lu} = \frac{Lu}{Nu}$	Kms
6. Total stream length within basin order	$(ELu)n=L_1+L_2+L_3$	Kms
7. Area of basin	Au	Sq.kms
8. Length of basin	Lb	Kms
9. Width of basin	Br	Kms

10.Basin perimeter		Cm
11. Basin circularity	Rc-Au/area of circle having same p	-
12. Drainage density	Du=(L)u/Au	Kms . per km^2
13. Basin elongation	Re =diameter of circle having same P/Lb	Kms . per km^2
14. Constant of Channel maintenance	C=1/du	Kms . per km^-
15. Stream frequency	Fu=Nu/Au	Number/Km^2
16. Texture ratio	Tu=Nu/Pu	Number/Km^2
17. Height of basin mouth	z	Meters
18. Height of height point of watershed	Z	Meters
19. Total basin relief	H=Z-2	-
20. Relief ratio	Rh=H/Lb	-
21. Ruggness number	Rn=DxH/5^{280}	-
22. Average slope	Tano= No. of contourxinterval grid/3361	Degree

GEOLOGICAL PARAMETERS

Recognition of fault

- ✓ There are several criteria for recognition of fault. Even when a fault line is mapped the dip of fault plane may not be measured. The dip can be measure in certain circumstance e.g. when the fault surface is exposed in scraps or road cuts or fault surface is located at different levels by drilling mining operation.
- ✓ Abrupt termination of beds along a line or sharply defined discontinuity can often inferred from study of Arial photographs. This is the most rapid method of locating large scale fautls.

- ✓ Faults can be identified in geologic map by repetition and omission of beds. Repetition may also result of folding however in this case the repetition is symmetrical. The repetition of bed also caused by faulting. The repetition of bed caused by faulting is characteristically asymmetrical..
- ✓ Fault can be located by occurrence of fault breecias along a continuous or discontinuous line. Fault breccia are crushed rocks with angular fragments within a finely pulverished matrix. The matrix often is silicified. Fault plane are associated with a pulverized clay like material like gouge.
- ✓ Slicken side or polished striated surface sub parallel to the fault plane are characteristic features. Rake of slicken side are used to know the direction of the movement of the faulted blocks

  Rake 0^o – movement is strike slip in nature.

  Rake 90^o – dip slip fault

  Rake in between 0^o - 90^o- oblique fault

USING GEOLOGICAL DATA FOR EARTHQUAKE STUDIES

Latur region is marked at present as low-level seismicity, but may still hold the potential for destructive earthquake.

Basic geological data required

1. Location of active fault
2. Nature of past activity, including historic and prehistoric earthquakes.
3. Slip rates and nature of reoccurence

4. Sub-surface lithology, vulnerability for liquifaction, site amplification, lateral spreading.

I. ASSESSING THE HISTORY OF FAULTS

Assessing the short-term activity of fault may be easier as the geodetic, historical and recent seismological data could provide some clues. But such a time window may not cover the recurrence period of most known faults, which are commonly in range of hundred years, even for active fault. Global examples indicate that geological method are most effective in extracting information on past earthquakes, which may have occurred several hundred or thousands of years ago. A systematic study of the fault scrap generates a broad spectrum of geological data on fault chronology, slip rate, recurrence interval, elapsed time, shaking intensity and fault geometry that are useful for understanding the source properties and also as inputs for vulnerability characterization.

II. RECURRENCE OF EARTHQUAKE IN TIME

The occurrences of various population of earthquakes has traditionally been understood to follow Gutenberg-Ritcher (G.R) relationship

$\log N = a - bM$

where N is number of earthquakes in a unit area per unit time. M is magnitude, and 'a' and 'b' are constants, representing the overall level of seismicity and ratio of small to large earthquakes. G.R relationship is useful to obtain estimates of average recurrence rate for earthquakes of specific magnitude in the region. Geological studies of active faults, however imply that the above relation under-estimates the potential for large earthquakes on some specific fault structures.

III. GEOLOGICAL INPUTS TO ESTIMATE EARTHQUAKE SIZE

One important function of paleoseismic studies is to calibrate paleomagnitudes using fault rupture length and maximum displacement. This is usually estimated either from the surface rupture length (L) or maximum displacement measured at the fault scrap. The measured value can be compared with that of the recent earthquakes of known magnitude.

IV. CHARACTERIZING SITE – CONDITIONS – GEOLOGICAL INPUTS

Large earthquake often produce near and far field shaking effects, due to liquefaction of soils amplification of seismic energy in valley fills and near surface soil layers. Amplification layer in source zone of the 1993 Killari earthquake was an important factor that led to severity of damage.

ORGANIZATION OF STUDY:

This present work has been organised in separate parts and chapters,based on the information and relevance of topic.

CHAPTER 1 -	- Introduction
	- Literature survey
	- Research question
	- Objectives
	- Database
	- Methodology
CHAPTER 2	- Geo-environmental information
CHAPTER 3	- Geological structure and after shock
	- Fault solution
CHAPTER 4	- Geo-morphometric analysis
	- Damage and causalities
CHAPTER 5	- Summary and conclusion

CHAPTER – II

GEO-ENVIRONMENTAL INFORMATION

Latur district was a part of undivided Osmanabad district until 1983 ,due to unavailability of separate data it is introduced through undivided Osmanabad (Latur)

HISTORICAL ORIGIN

In year 1853 the district was temporarily ceded by the Nizam to the British Government. It was reverted to Hyderabad in 1860. Its headquarter formally used to be at Naldurg and the district known as Naldurg till 1904. The district of Naldurg was abolished and new district of Osmanabad was formed with headquarters at Wasi .Later Washi emerged as Kalam and Naldurg as Tuljapur. Headquarter of Ausla tahsil were shifted to Latur and the tahshil was named as Latur tashils. Among Marathawada Osmanabad had biggest area under the Nizam's own estate called "Sarf-e-khas". Latur was formed out of undivided Osmanabad in 1983.

GEOGRAPHICAL LOCATION

The district of undivided Osmanabad is the southermost district in Aurangabad division of Maharastra state situated between 17^{0}.35' and 18^{0}.40' north latitude and 75^{0}.16' and 76^{0}.40' east longitude. The district has an area of 14.2717 sq.kms (55103 sq.miles) and population of 1.477656 according to 2001 census.

Location Map of Latur

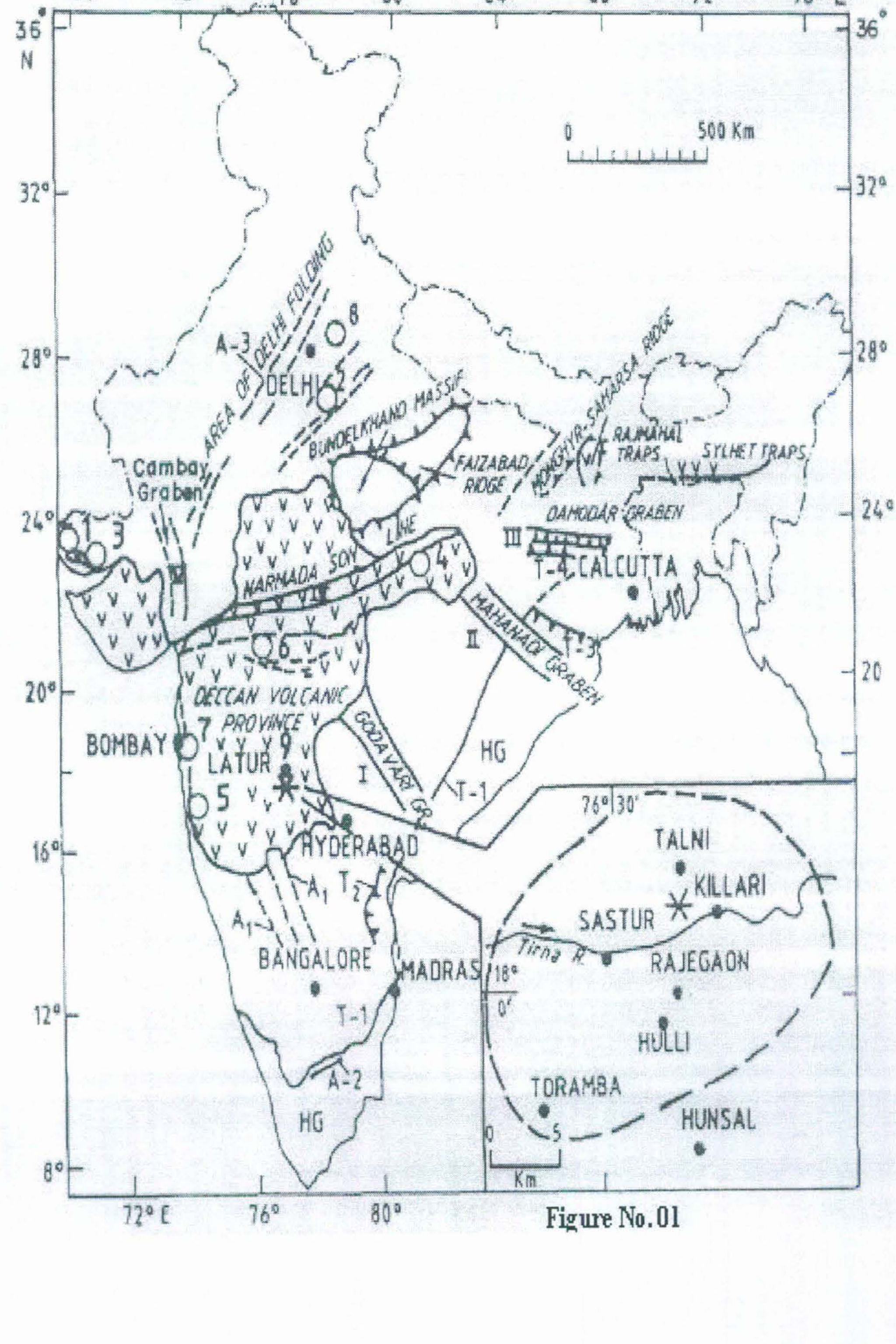
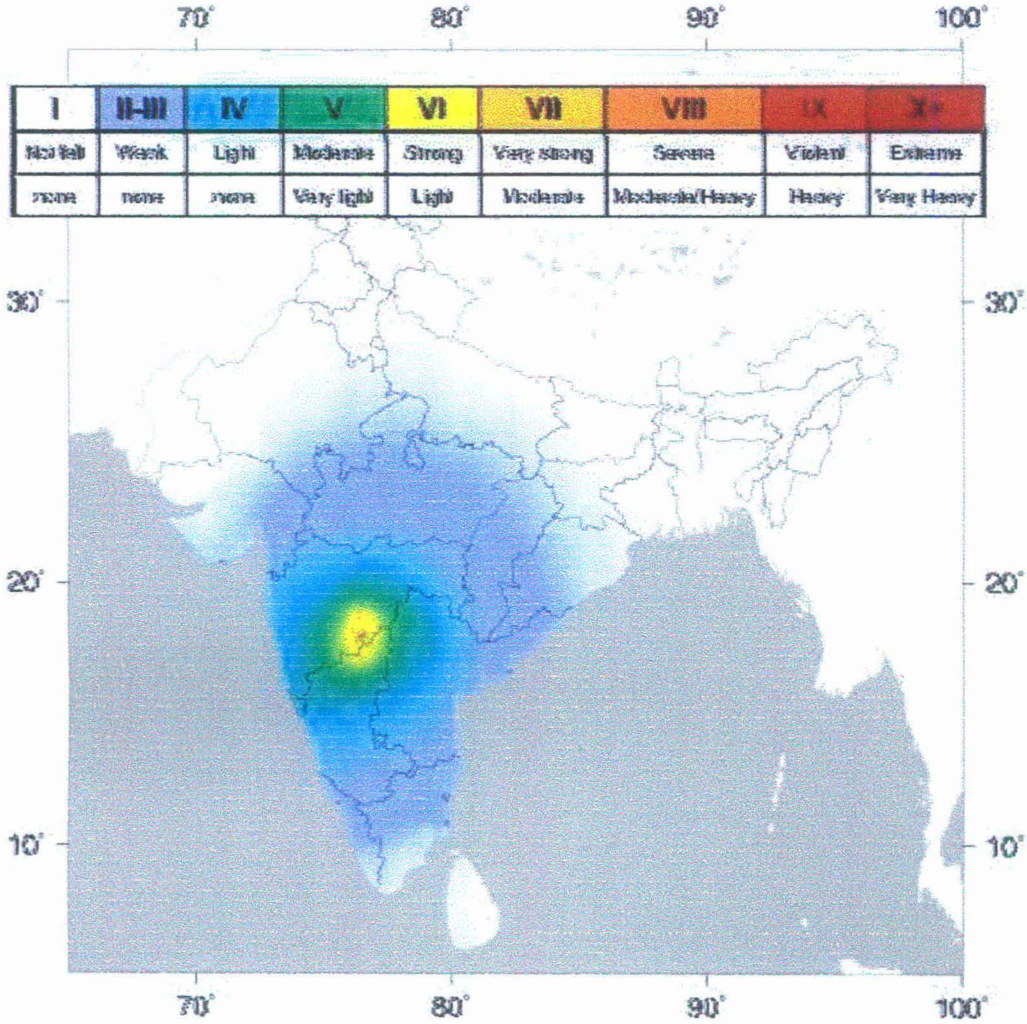


Figure No.01

30th September 1993, M_w6.2 Killari Earthquake **Figure No. 02**

Marathwada (Maharashra), India

Origin Time: 22:26:48 UTC   Epicentre: 18.006°N, 76.461°E I_{MAX}:



BOUNDARIES

It is bounded on the south-west by the Sholapur district, on the north-west by Ahmadnagar district, on the north by Bhir and Parbhani district on northeast by Nanded district and on the south-east and south by Bidar and Gulbarga district of the Mysore state.

GENERAL PHYSICAL FEATURES

A greater portion of the district lies on the triangular Balghat plateau, generally over 610 meters above sea level, sloping toward the south and east forming the water divide between Godavari and Bhima valleys. The northern bounding scrap of Balaghat plateau, running generally eastwards across the middle of the Bhir district enters Osmabad district near Deagon. In subdued form, it runs first southwards and then eastward gaining in attitude. It again runs southwards to east Chakur and then southeastwards to east of chakur and then southeast ward after passing by Vdgir district continues south-easterly course and passes out of district. The southern bounding scrap of this plateau backed by a chain of hill enters the district just west of Malewadi and Pakhrud villages and runs in general south easterly direction, though in some sections it has easterly and southerly trends.

The next divide is on the Balaghat plateau just behind its northern scrap. It enters the district near Langarwadi and runs south-eastwards passing through Vdgir. Two significant heights on this are Fanewal and Wadwal, both about 733 meters. This divide is generally in the northwest but decreases in height to the south-east where it is just above 625 meters. There is a low spur branching near Chakur first running north-eastward upto a point about two kilometer south of Sirur-Tajband. The main divide between the Manjra and the Bhima drainage system enters the district just in the north. The height point in the district is a little over 792 meters is situated on this divide, just north-west of Kanheri about 6 km southwest of Wasi.

RIVERS

MANAR – The Manar, the northernmost river of district rising on the north-eastern slopes of Balaghat plateau near Dharniapuri in Bhir district flows in a north-easterly course of 40 km within district.

TIRU – The Tiru river rises on the eastern edge of the plateau near Chakur and has a course of about 56 km within the district, flowing generally eastward to join Lendi at Kharka in Nanded district.

LENDI – The Lendi river rises similarly on the edge of plateau near Udgir further east and has only a small course within the district. It is joined by the Tisu at Kharka in Nanded district.

MANJRA – The Manjra river emerges above Gaurwadi near the northern edge of the Balaghat plateau in Bhir district and flows in south easterly direction toward Osmanabad district.

GHARNI – The Gharni is the only river of some size flowing as a left tributary of the Manjsa draining in the Balaghat plateau. The Gharna river is about 40 km long, rises three km north of Wadval-Rajura and flows southwards passing by Wadval-Rjura. Gharni, Nelegaon, all situated on western banks to join the Manjsa river near Jawalga.

DEVAN – Among the smaller left bank tributaries of the Manjra is Devan nadi with a course of about 20 km within district.

TAWARJA – The chief right bank tributaries of Manjra are the Tawarja and the Terna. The Tawarja river is about 50km long near rises near murhd railway station and it has a generally easterly course till it join the Manjra near Seoni village.

TIRNA – The Tirna river is about 150 km in length from source to its confluence with the Manhra.It has the longest course of all the rivers lying entirely within the district. The Tirna project consists of an eastern dam on the river Tirna above the village of Thailo, south of Dhoki, with only one canal on the right bank. On account of the low relief , the dam has to be very long and low in height, giving rise to a storage covering a wide area but of shallow depth.

PHYSIOGRAPHIC UNIT

Area has been divided into four physiographic units:

1. The Balghat plateau made of residual interfluves and the valleys of stream dissecting the plateau.
2. The northern-eastern region comprising the northern part of Ahmadpur and Udgir tahsils in Uaman, the Teru and Lendi drainage area.
3. The western buldge comprising Parenda Tahsil and western pat of Bhum tahsil
4. The south –west region comprising the southern and western parts of Tuljapur Tahsil in Bhima drainage area.

CLIMATE

As there is no meteorological station in Latur district the data is given for the undivided Osamanabad (Latur district)

Climate of the district is on the whole is dry except for during monsoon season. The year may be divided into four season for the study area.

i. The cold season from December to about middle February

ii. Summer season upto and of May

iii. Monsoon season from June to September

iv. Post monsoon or retreating monsoon season in October and November.

RAINFALL

Records of rainfall in the district are available for about 87 years for undivided Osmanabad alone, and for five other stations nearby for about a decade. The details of the rainfall at these station and district as a whole are given in Table I and 2 . The average annual rainfall in the district is 882.1mm (34.73"). The rainfall in these districts in general increases from the south-west toward north-east. About 84% of annual rainfall in the district is received during the south-west monsoon season, the rainiest month being July. The variation in annual rainfall from year to year is large in district. During 60 years period from 1901 to 1960 the highest annual rainfall amounting to 168% of normal occurred in 1916. The lowest rainfall amounting to 59% of normal occurred in 1918. In the same 60 years period from 1901-1960 the rainfall in the district was less than 80% of normal in 21 years.

Table no.2 reveals that the annual rainfall in the district was between 600 and 1,000 mm in 48 years out of total 60 years.

On average there are about 51 rainy days (i.e. days with rainfall of 2.5mm – 10% - or more) in a year in the district.

The heaviest rainfall in 24 hours recorded at station in the district was 247.1 mm (9.73") on Sep. 7, 1985 at Osmanabad.

Table No. 2.1

NORMAL AND EXTREMES OF RAINFALL IN UNDIVIDED DISTRICT OSMANABAD IN MM.

Station (1)	No. of yrs. of date (2)	Jan (3)	Feb (4)	March (5)	April (6)	May (7)	June (8)	July (9)	Aug. (10)	Sept. (11)
1. Osmanabad	60(a	4.6	0.3	7.6	17.3	26.4	153.7	174.7	155.2	208.8
	(b	0.3	0.3	0.7	1.7	2.1	8.7	11.9	10.6	10.6
2. Parenda	11(a	0.3	4.8	2.5	9.9	25.1	101.1	143.3	116.1	210.6
	(b	0.0	0.3	0.2	1.3	2.5	6.4	8.9	8.3	9.9
3. Udgir	11(a	1.3	5.6	7.9	13.5	35.8	184.4	301.0	226.6	218.9
	(b	0.2	0.4	0.7	1.5	2.5	9.6	12.5	11.8	9.7
4. Kalam	11(a	0.0	1.8	3.8	5.8	31.0	134.6	190.3	145.8	174.2
	(b	0.0	0.1	0.3	0.6	1.9	8.4	11.3	8.9	10.2
5.Ahmadpur	11(a	0.0	2.3	4.3	13.5	19.8	145.0	262.1	181.9	177.0
	(b	0.0	0.2	2.5	1.4	1.5	7.5	12.8	10.4	10.2
6. Tuljpur	11(a	0.3	2.8	8.9	19.6	40.4	138.4	268.5	196.9	212.3
	(b	0.0	0.3	0.9	1.4	2.3	7.8	12.7	12.5	11.3
7. Osmanabad (District)	(a	1.1	3.4	5.8	13.3	29.7	142.9	223.3	170.4	200.3
	(b	0.1	0.3	0.9	1.3	2.1	8.1	11.7	10.4	10.3

Taken from meteorological Department of the Government of India Pune.

Table No. 2.1

tion	No. of Yrs of data	Oct (12)	Nov (13)	Dec (14)	Annual (15)	Heigh annual rainfall (16)	Lowest annual rainfall ast. Of normal yr (17)	Amount (mm) (18)	Heaviest rainfall in 24 hours date (19)
Osmanabad	60(a	56.6	24.1	7.4	839.7	168 (1916)	54	247.1	1895
	(b	3.8	1.3	0.5	52.5		(1918)		Sept 7
Parenda	11(a	83.1	22.6	3.8	728.2	131 (1956)	60 (1952)	151.9	1950
	(b	4.7	0.7	0.2	43.4				Sept 7
Udgir	11(a	75.2	8.4	0.5	1079.1	138 (1955)	68 (1960)	157.7	1954
	(b	4.0	0.9	0.1	53.9				Sept 27
Kalam	11(a	67.1	20.3	1.3	776.0	147 (1956)	60 (1952)	103.4	1959
	(b	3.6	1.2	0.2	46.7				Sept 27
Ahmadpur	11(a	53.6	13.7	0.0	873.2	155 (1955)	75	158.2	1954
	(b	3.6	0.5	0.0	50.6		(1959)		Sept 27
Tuljapur	11(a	99.1	10.4	3.8	1001.4	140 (1956)	61	143.5	1958
	(b	5.3	0.6	0.2	55.3		(1960)		July 1
Osmanabad	(a	72.5	16.6	2.8	882.1	168 (1916)	59 (1918)		
District)	(b	4.2	0.9	0.2	50.5				

(a) Normal rainfall in mm (b) Average number of rainy days (days with rain 2.5mm or more). Based on available data upto to 1960 + years given in brackets

Table-2.2

FREQUENCY OF ANNUAL RAINFALL IN OSMANANAD

Range in mm (1)	No. of Yrs. (2)	Range in mm (3)	No. of yrs. (4)
401-500	1	901-1000	13
501-600	5	1001-1100	5
601-700	15	1101-1200	4
701-800	10	1201-1300	1
801-900	5	1301-1400	0
		1401-1500	1

TEMPERATURE

There being no meteorological station in the district the description which follows is mainly based on records of observatories in the neighbouring district where climate conditions are similar. The cold weather commences toward end of November when temperature began to decrease rapidly. December is generally the coldest month with the mean daily maximum temperature at about 29.5^0C (85.1^0F) and mean daily minimum at about 15^0C (39.2 or 41.0^0F). The period from about middle of February to the beginning of South-West monsoon is one of the continuous rise of temperature. May is generally the hottest month with mean daily maximum temperature at about 40^0 C (77.0^0 F). The summer is intense and maximum temperature sometime goes upto 45^0 C (113.0^0 F). Afternoon thundershowers which occur on somedays being welcome relief though only temporarily. With onset of south – west monsoon in the district early in June there is appreciable drop in temperature.

VEGETATIONS

The district has negligible forest resource mainly concentrated in Taljapur tehsil which is divided into three beats, placed under the charge of the round-officers. The forest in district covers an area of only 15.411 square kms. (5.95 sqm). The forests are thorny scrub type, common species found being Khair (*Acalia catechu*) Hivar (*Acacia Leulophela*), Hankel (*hymno-sopria emarginata*), Aroni Apta (*Baunhina racemosa*). Babhub (*Acacia arabica*). The forest have extensive grassy areas in underrating places. The important species of grass found are Kusah, Sheda and Marvel. A major portion of the forest produce is consumed locally.

GEOLOGY

Geologically the entire area is occupied by the basaltic lava flow known as the 'Decan Trap' with flat top and step like deposition. These Deccan traps are considered to have resulted from fisiuse type of lava eruptions. They are presumed to have formed during the cretaceous-Eocene period.

The basaltic flow thickness of the individual flow ranges from 15 to 20 m in the Beed district with pinching out toward Gulberga to 4 to 15 m in the Decan Trap peripheral region. Each individual flow is seperated by intertrappean beds varying from 0.5m to 1m, of red clay type locally known as Red Bole. These red bole beds are prominently seen in Latur, and down south towards the Gulberga area. The bore hole data in Killari area show following sequence.

Table 2.3

GEOLOGICAL COVERING IN DECCAN PLATEAU

Upper flow	Minimum thickness	Maximum thickness
Intertrappean	0.4m	15m
Zeolitic Basalt	0.5m	1m
Intertrappean	15m	20m
Basalt	0.5m	1m
Intertrappean	-	1m
Hard massive basalt	-	40m

Data collected from Sh.S.R.Hedge, senior Geologist. The traps are generally of variable thickness ranging from 15m to 60m based on field characteristics (Zutshi 1991). At places the upper basaltic flow is topped by the development of laterite in patches. The hill top is the north of the affected area at Lanjan and Nilanga is about .643 m above mean sea level and the plain lies at average altitude of 491-552m above mean sea level. The average relief of the area vary from 132m to 119m. The lava flow can be differentiated into anygdaloid, vesicular and massive basalts. The vesicles in the lava flow are filled with secondary minerals like zeolite, calcite, agate, jasper etc. Most of these flow are doleritie in nature. These horizontal lava flow are cut by doleritic or basalt dykes and sills. The peripheral zone of Deccan lava show pysoclastic nature.

The low lying areas in the region are mostly filled with Pleistocene order alluvium, laterite, and black cotton soil which is very fertile. Such places have water wells and tanks. The southern Deccan Trap periphery consists of upper Precambrian, lower Paleozoic Vindhyan and Kusnool system, resting over the Precambrian unclassified granites of the basement crust.

Kaila et al (1979), Kaila and Bhatia (1981) and Kaila (1989) on the basis of DSS profiling have concluded that below Deccan Trap the Dharwar and Kaladgi –Bhima formation are missing. The granite and gneisses with humps and depression, showing old topographic variations are prominent, directed by deep-seated faults. These granites and gneisses belong to the Hyderabad craton which has undergone several crystal faulting before the outpouring of the Deccan lava. Basement ridges mentioned by Rao (1993) may represent old rifts and garbens filled with late Paleozoic and covered with Deccan lava.

TECTONICS OF THE AREA

Mahadevan (1989) while delineating the major lineaments of the peninsular shield. mentioned the rift structures which led to the formation of linear volcano – rudimentary basins in the Archean craton around 3000Ma ago, exemplified by younger green stone belts in south Karnataka. The old linear rift must have been reoccupied by lava flowing during the formation of Deccan Trap sometime in Cretaceous-Eocene time as tissues eruption (west ,1962). Small vent type of structure with lava flows are reported at various places whereas large volcanic expansion type structure are present in the northern part of the Decan Trap. K-Ar dating gave estimate of 60-45 Ma age of these flows (Raja. Rao. 1982)

The peninsular shield is transected by many deep long and straight fault trending prominently in NE-SW, N-S, NW-SE and E-W directions. The faults originated during Precambrian time. These are the result of two stage evolution i.e. the tensional tectonic stage when the rital valley (3200Ma) was formed and the transform tectonic stage around

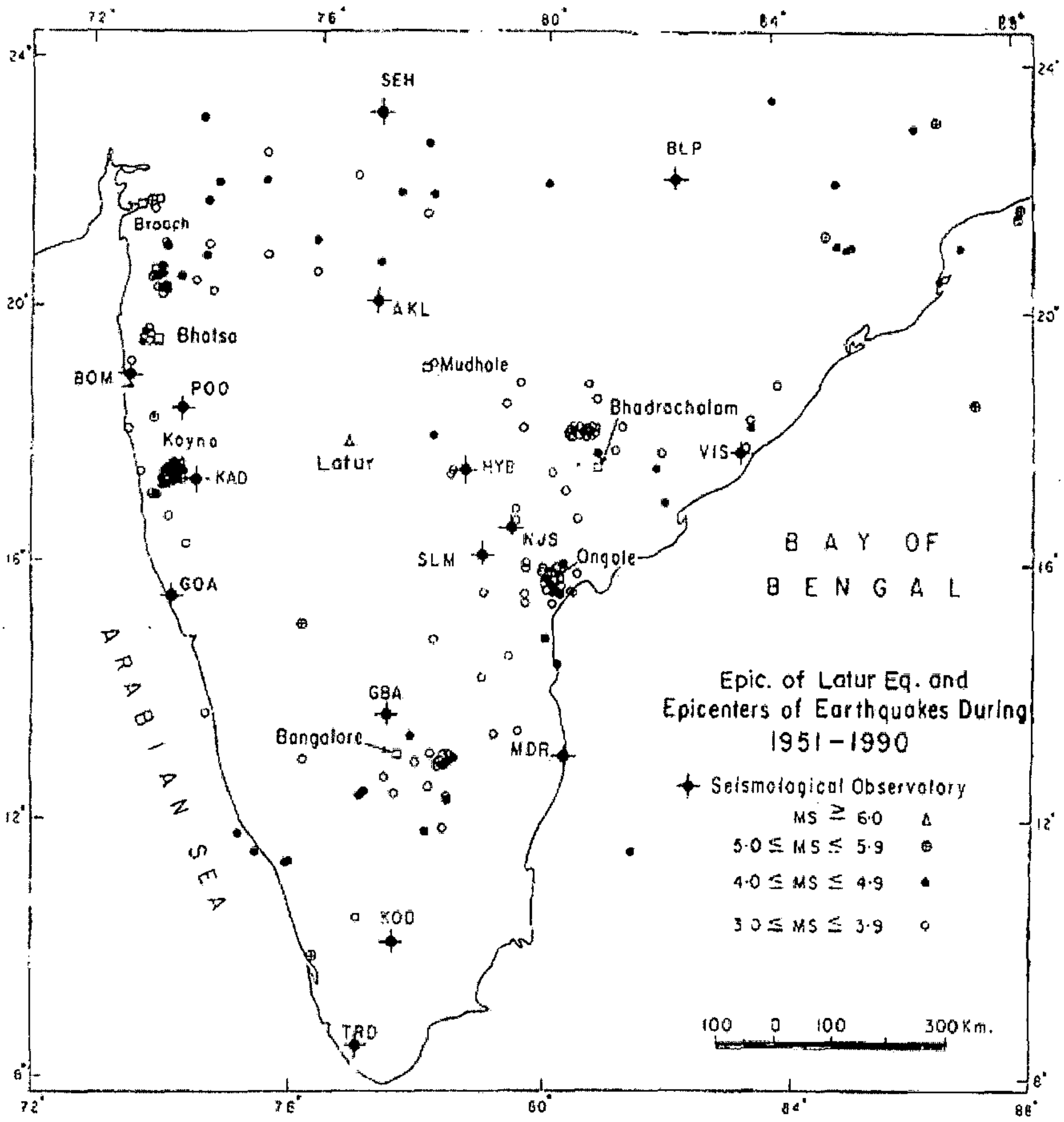

SEH
BLP
Broach
AKL
Bhatsa
BOM
POO
Mudhole
Bhadrachalam
Koyna
Latur
KAD
HYB
VIS
KJS
SLM
Ongole
GOA
BAY OF BENGAL
ARABIAN SEA
GBA
Bangalore
MDR
KOD
TRD
Epic. of Latur Eq. and Epicenters of Earthquakes During 1951 – 1990
Seismological Observatory
MS ≥ 6.0
5.0 ≤ MS ≤ 5.9
4.0 ≤ MS ≤ 4.9
3.0 ≤ MS ≤ 3.9
100 0 100 300 Km.

Figure No. 03

ISOSEISMALS FOR THE LATUR EARTHQUAKE BY
HLK GUPTA 1998

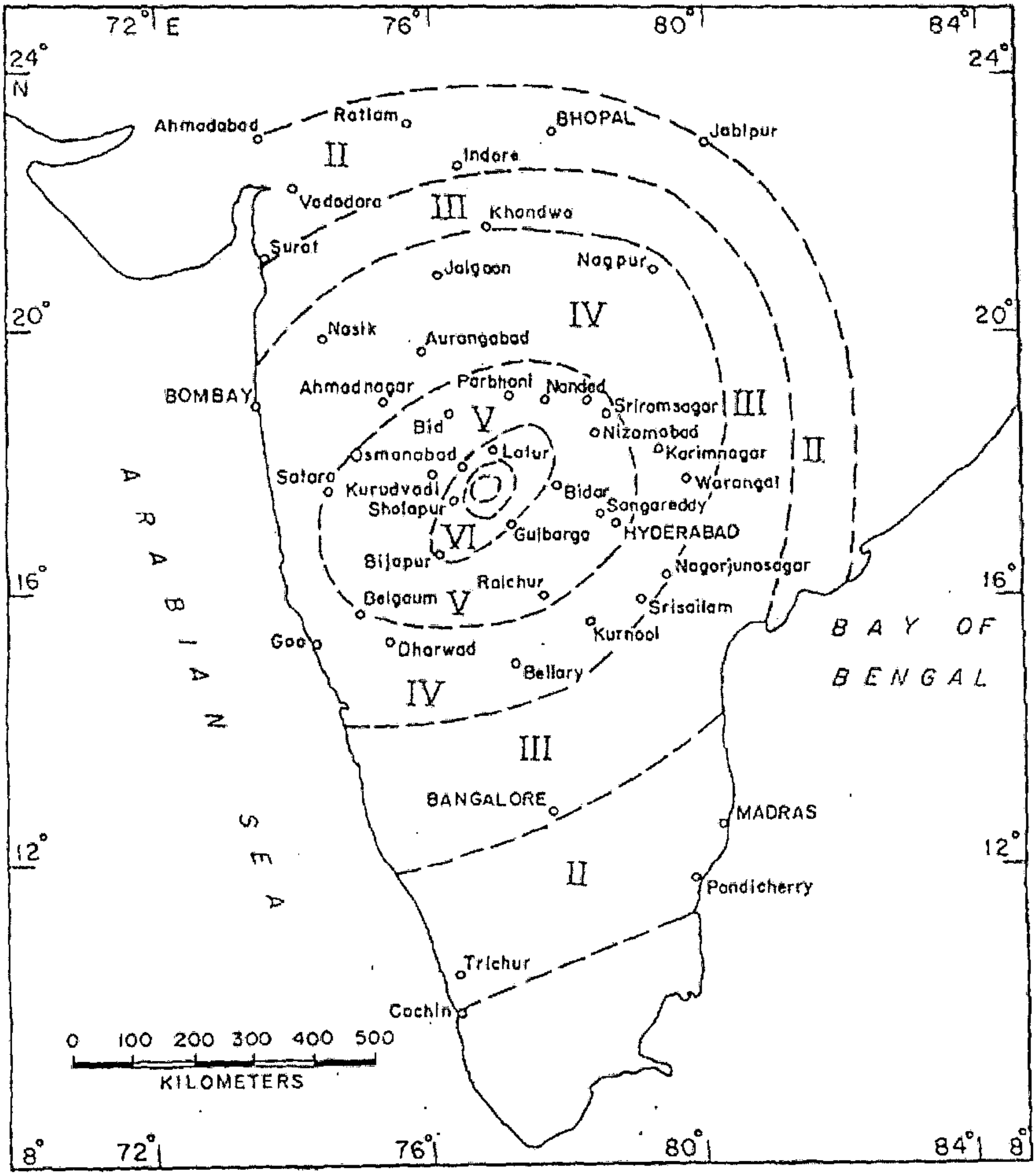
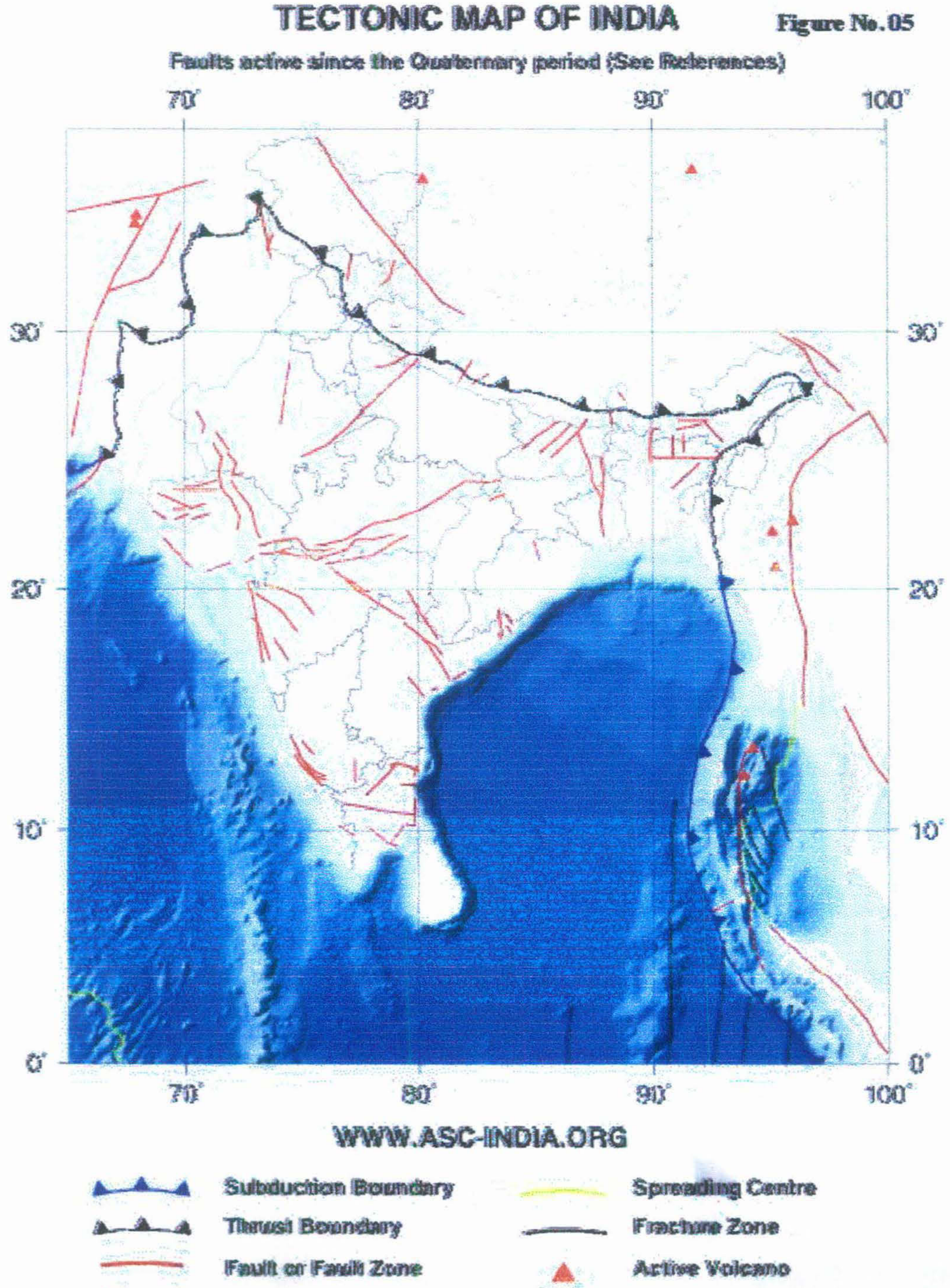


Figure No. 04



TECTONIC MAP OF INDIA
Figure No.05
Faults active since the Quaternary period (See References)
70°
80°
90°
100°
30°
20°
10°
0°
WWW.ASC-INDIA.ORG
Subduction Boundary
Thrust Boundary
Fault or Fault Zone
Spreading Centre
Fracture Zone
Active Volcano

2600Ma. When the graben spilt up longitudinally by dextral strike. Slip fault (Kumar 1975a). Major tectonic features of the peninsular area are a failed rift associated with 1819 great inter-continental earthquake of in the kutch area.

The west coast shows activity along three major tectonic lineaments NNW-SSE. Coastal down faulting; formation of the compressional ridges with NW-SE strike of folded and faulted sediments south of Sri Lanka (Kumar, 1975b) and a deep basement fault between Ratnagiri on the west coast to Vedaranayam on the east coast and further southeast, passing in the northeast of Sri Lanka. The panvel flexure is a mono climate features formed due to compressive forces parallel to west coast of India in Kurduwadi – Pune area. There are many such features which are parallel to the Kuruwadi site.

A number of processes may be responsible for tectonic stresses caused in the peninsular area. The discontinuities in the main fault lineaments and the segment behavior along with a shift of or stepping of, energy to the next segment, cause acumulation of elastic strain energy in the end zones of fault segments and this stepping creates a zone of micro-earthquakes along with step resulting in aftershock clustering between the fault segments. The rupture shows no evidence on the surface inspite of micro-earthquake aftershock cluster that may be associated with it. It is possible that fault segment are offset and separated by right-lateral strike-ship trending Nu5m forming a tectonic system that is cinematically consistent with a NE-SW compression.

GEO-HYDROLOGY OF THE AREA

Groundwater occurs in weathered, vesicular fracture and jointed basalt. Spatial variation of water table was seen to range between 3m to 14m below ground level (bge).

Groundwater is extracted from shallow aquifer zone through large diameters. Depth to water level in those basewells range from 30m to 35m bge.

SHALLOWDEPTHS

Comparison of present water table with past data of central groundwater board (Singh', 1988) show that the depth of water table has not changed significantly. Sub-normal rainfall during the last two year had caused decline of water table. But a good rainfall in the year (1993)has resulted in the reconpment of the aquiters. There is thus no discernible effect of earthquake on the shallow aquifer zone.

A short duration pumping test was conducted on a digwell at Karla village (some northeast of Killari village) where the GDSA had also conducted a pumping test in 1990. The aquifer parameters obtained from this test were T = 47.5sqm/day

S=0.025 which are in same range obtained by GSDA

DEEP AQUIFER

In two village (Talni and Kantha) borewells are reported to have failed after the earthquake. An abnormal phenomenon was observed in two borewells at Talvi and Chincholi Jagan where foam was gushing out. No other borewell in the vincity exhibited this phenomenon.

GROUND CRACKS AFTER MAIN SHOCK

Table 2.4

DETAILED OF GROUND CRACKS REPORTED AFTER A MONTH OF MAINSHOCK.

S.No	Locality	Strike	Extension	Other Observation
1.	Samadasga near Ausa	-	350m long 5.8cm wide crack	Soundaranjan et al (1993)
2.	Rajegaon	$N10^0E$	L : 300-400m W: 1-10cm	Confined to a foot path, located on the northern bank of the Tirana river liquefaction after the main earthquake is also reported .
3.	Sankral Village (Ansa Taulka)	$N10^0E$	L: 40-50cm W: 1-10cm	Some dirty smell reported while the crack got widened gradually. These are seen in agricultural field NE. of the village
4.	Sastur Village	$N80^0E$	L: 80-100cm W: 0-5cm	Confined to an elevated foot path an open well nearly got water column of 3-5m subsequent to earthquake. Some interesting results were obtained by AMD by measuring random gas in the area.
5.	Chandesur 7km south of Latur	$N5^0E$	L: 100-120cm W: 10-15cm D: 50cm	Occurs between Chandesur and Khatwa village in the agriculture cultural land.
6.	Bendkal (Lohara)	N-S curved	L: 80-100cm W: 0-10cm	Occurs in the village by a side of a domestic well. These extend into the adjacent well smoke emanation along with warming up of the ground also reported along this week.

CHAPTER III

GEOLOGICAL STRUCTURE AND SEISMIC ACTIVITY

INTRODUCTION

The Latur earthquake forms a unique example amongst the ten world- wide known historical 'stable continental Region' (SCR) earthquakes, which produced surface faulting (Adams et al., 1990). Geologically, the area Consists of extensive Deccan basalts (65 Ma) spreading over an area of about 512,000sq.Km. Earthquakes are concentrated at the southeastern fringe of the Deccan trap region, beneath which 2.6 Ga old Precambrian rocks are believed to exit.

SURFACE DEFORMATION

A surface deformation zone produced by the Latur earthquake occurs across the cultivated areas between Killari and Talni villages. The mapped Killari- Talni surface deformation zone (KDZ) extends over a strike length of about 3 Kilometres in NW-SE direction with a width of about 300m (Gupta et al., 1993). Deformation is mostly characterized by surface rupturing and is associated with geomorphological changes in the form of relative subsidence and/or uplift and local upheavals of ground . There are no rock outcrops, and soil thickness varies from a few centimeters to nearly 2m over shallow bed rock .

The KDZ shows discontinuous and arcuate lines of displacement with the southern block generally going down. The strike of escarpment varies sharply. In the southeast, a maximum throw of 0.7m is recorded with excellent exposure of free face in a small segment of KDZ. A narrow elevated linear ridge of about 40 m long and 2-8 m wide bounded on either side by subsidence is conspicuous in the southeastern part close to Killari

A few isolated vertical (1.5 m deep) open fracture of different orientation are also recorded in KDZ where the overburden topsoil is relatively more compact. Many of the ground cracks lie in continuity along the line of escarpment. Often, they show sigmoidal, arcuate and en-echelon patterns of typical tensional origin. Intense rupturing in the lining of walls as well as wall collapses occurred only in open wells. Some gases have reportedly emanated from a borewell in the close vicinity of KDZ.

Large-scale ruptures in the form of longitudinal cracks occurred along the bunds of a canal with differential subsidence near Talni.

A small scale NNE-SSW elongated depression has also been formed close to the agricultural field. An overall southerly subsidence, associated with southerly dipping fault planes, is observed.

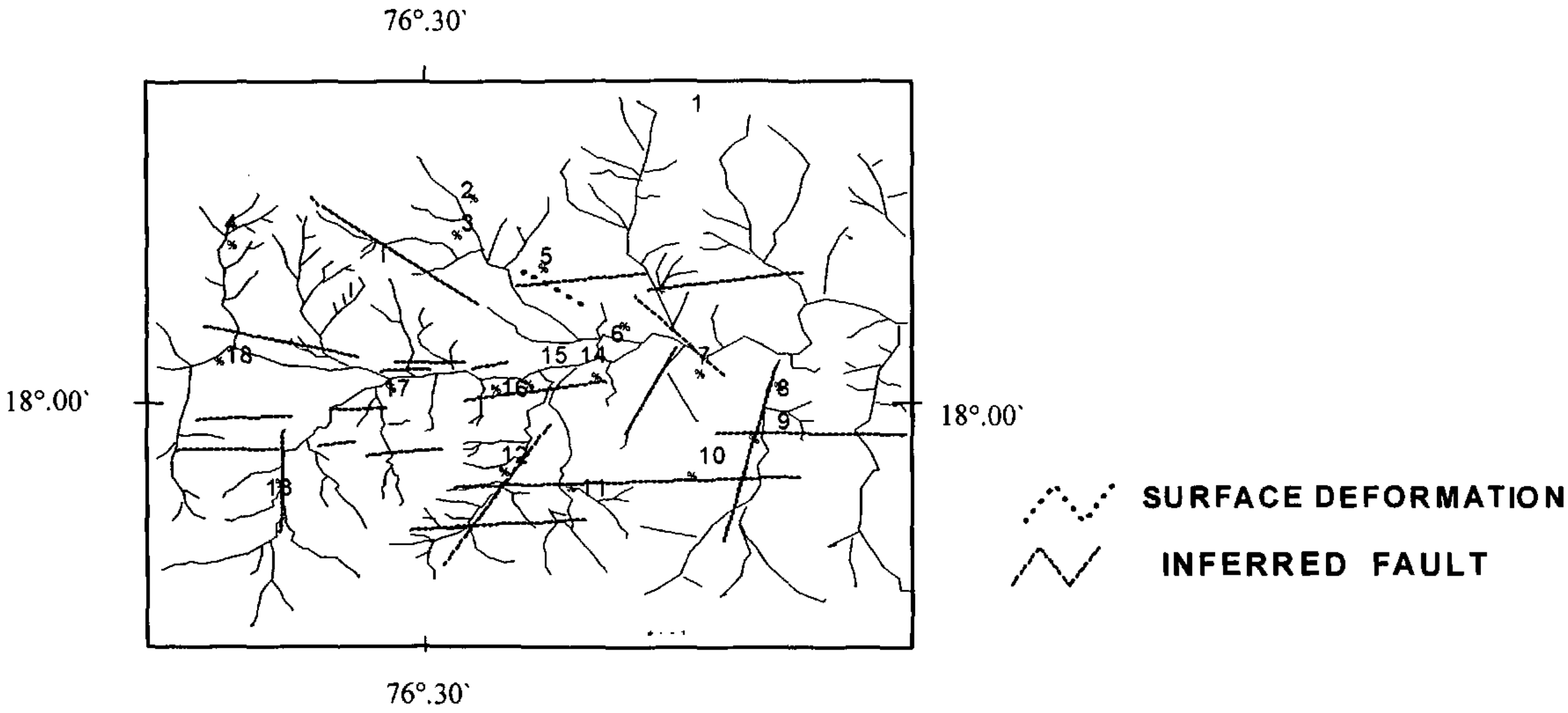
GEOMORPHOLOGICAL CHARACTERISTICS

Topographically, the area shows undulating terrain with the river course of Tirna flowing over 580 m level while its watershed boundaries lie along 640 m level. Higher elevation (670 m) is represented by a few elongated ridges, capped by laterite. The heavily damaged villages lie mostly on 580-600 m surface levels. The source of Tirna river which is ~ 50 km away, NW of Makni, lies at 620 m level.

Fig.7 Shows the drainage pattern around Tirna river course. A number of subsurface (subterranean) faults have been inferred, based on anomalous and/or sudden changes in the drainage pattern like sharp bending, straight course convergence, of divergence, offset

Figure No. 07

INFERRED SUBSURFACE FAULT ARROUND TIRNA RIVER



SCALE-----1:250000

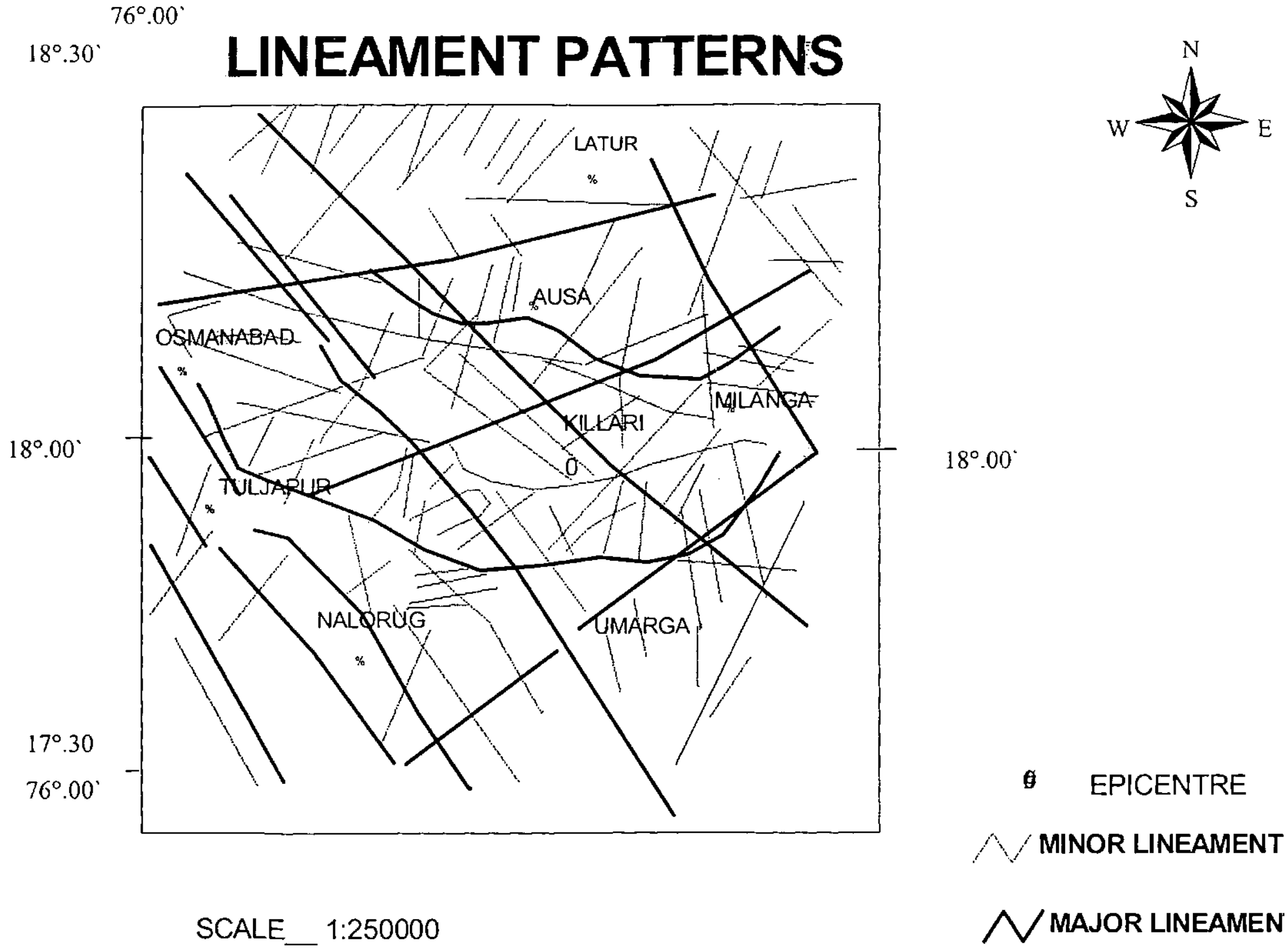
Source: Survey General of India. Toposheet No. 56B/11 drainage, deflected drainage etc.where sub-surface faults trend predominantly in east-west direction. Faults are also inferred in other directions which include NNE-WSW, NW-SE and N-S. these are mostly concentrated on either side of Tirna river course.

The villages most affected by the earthquake are confined to watershed boundaries of the Tirna river course between 76^0 20`E and $76^{0}$`40E longitude. Based on the elevation changes, several subsurface fault could be inferred along the profile which possibly are still active. By and large, it could be seen that the block containing Tirna valley bounded by E-W faults with inward dips has gone down, relative to the adjacent block. However, within this block, the picture is not yet clear about the relative displacement. A series of sub – parallel and sub-surface faults are inferred. All the subsurface faults inferred from the geomorphological parameters and drainage patterns fit into a three dimensional block structure in the area involving vertical movement Furthermore there seems to be a correlation between the present movement and topography where areas undergoing depression are already low-lying and those undergoing uplift are already elevated, suggesting that the current movement are part of a long tern process. The overall scenario is that the affected area confined to the area of depression showing down-faulted nature of the block.

LINEAMENT PATTERNS

The Lineament pattern interpreted from satellite images, on a 1:250,000 scale (fig. 8) shows the presence of two major sets of lineaments; one trending NW-SE and the other along ENE-WSW. The latter is relatively younger, displacing the former in a sinistral fashion. These displacements have been confirmed from the ground truth of offset

Figure No. 08



Source: N.R.S.A.

drainage. One of the displacements coincides with a major lineament trending ENE-WSW, which passes through Lamzan, shifting the course of Tirna river. This Lineament is a fault extending up to Tuljapur in the west, with a clear cut offset of about 1 Km, and could represent an active lineament. The other significant lineament along NW-SE coincides with the Tirna river Course. It is also interesting to note the occurrence of an archeological site on this lineament in the upper Tirna river course. This river takes a turn to the south from its earlier easterly course. Marshy lands, sag ponds and unusually large scale alluvial deposits present at this place indicate a large scale subsidence/uplift. This is quite evident from a well-exposed vertical of about 10 m tick alluvium. (Gupta,H.K,1994)

There are other lineaments tending in different directions; but many of them are sub parallel to the major trends. The density of lineament seem to be higher, close to the Tirna river course. Some of the lineament terminate abruptly against the river course suggesting river course itself is tectonically active. The epicenter of the earthquake lies at 2 km northwest of Killari village, coinciding with the intersection of many Small Scale lineaments trending NW-SW, NE-SW and EW.

Ground verification of lineaments is handicapped because of lack of outcrops and visible displacement. However in general, the lineaments are characterized by (i) straight segments of drainage pattern, (ii) increased depth of soil horizon and weathered basalt. (iii) presence of high yielding well and dense vegetation, (iv) intense fracturing in rocks at shallow depth, (v) low-lying topography associated with steep valleys, (vi) the presence of fluvial deposits, often associated with sandy beds and (vii) discontinuous pattern of lineament etc. These suggest that many of the lineament represent fractures and fault zones in the area.

FORESHOCK AND AFTER SHOCK

MAIN SHOCK

The Latur earthquake occurred on September 29,1993 at 22.25 UTC. Its epicenter was situated in a stable continental region with low seismicity. The event had a magnitude of 6.3 (mb) and belongs to the class of the rarely occurring strong stable continental region earthquakes. The source mechanism was of thrust type with the compression axis in the northeast-southwest direction. From September 29,1993 to January 20, 1994 the permanent seismic station at Hyderabad recorded 42 earthquakes of magnitude 2.0 and above, those lay close to that of Latur earthquake. The strongest after-shock had magnitude of 4.4 and occurred 45 min after the main event. Difference of 2 between the strongest aftershock seems to be typical for the intraplate earthquakes.

Table :3.1

EPICENTER, DEPTH OF LATUR EARTHQUAKE BY DIFFERENT STATION

Origin Time (UTC)	Lat ^{0}N	Long ^{0}E	Depth(km.)	Magnitude (mb)	Source
22:25:48.6	18.07	76.45	6.8	6.3	USGS
22:25:48.6	18.02	76.56	15.0	6.1	GEOSCOPE
22:25:48.6	18.01	76.56	6.0	6+	NGRI
22:25:52.0	18.11	76.55	15.0	-	HRV

Table:3.2

STRIKE, DIP AND RAKE ANGLE

Agency moment, NM	Strike1	Dip1	Rake1	Stricke2	Dip2	Rake2
USGS $1.7X10^{18}$	123	41^0	92^0	299^0	49^0	88^0
Harvard Univ. (HRV).	134	437^0	112^0	284^0	47^0	68^0

FORESHOCK

There were no foreshocks recorded for the earthquake of September 29,1993. However, some activity was observed during 1992.Altogether, 26 tremors were recorded by the HYB seismological station from 18^{th} October 1992 to 15^{th} November 1992 from region. Figure: 9,10 histograms of the shocks recorded during this period and Table 3.3 the tremors recorded by HYB seismological observatory. The largest magnitude was 4.0 on 18^{th} October, 92. The detectability was Ms>2.0 Minor damages to the houses were reported from the villages of Killari and nearby places whereas subterranean sounds were reported for shocks with magnitude less than 2.0 (Ms) which could not be recorded.

TIME DISTRIBUTION OF AFTER SHOCK

The number of events with M>2 decreased significantly after October 18. It appears that there were 2 periods of slightly increased activity, the first on around November 12 and the second around December 20,1993.

Table: 3.3

AFTERSHOCK DATA FROM NOV. 12 TO DEC. 20 1992

Date	Arrival time (GMT)	Magnitude
18.10.92	11 02 19.0	2.0
	17 33 36.8	4.0
	18 00 32.6	3.0
	18 26 48.6	2.3
	21 23 33.5	3.0
	23 04 56.5	2.3
	23.27 15.7	2.2
19.10.92	23 28 32.6	2.0
	01 13 35.5	2.0
	07 28 53.0	2.3
	13 58 12.0	2.0
20.10.92	00 16 48.0	2.0
	04 31 42.5	2.3
21.10.92	07 26 21.5	2.0
	12 38 43.3	3.4

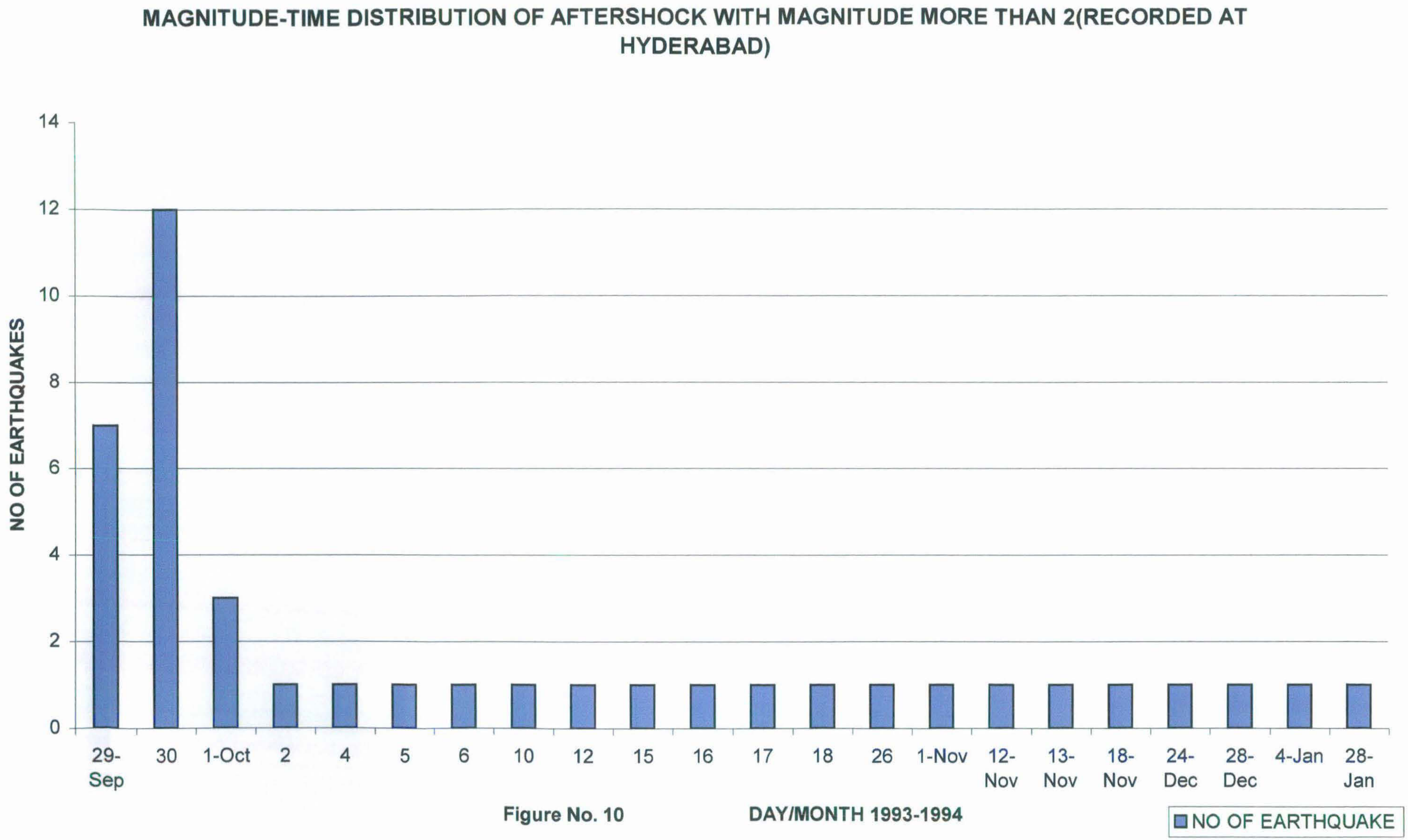
23.10.92	15 16 41.5	2.2
24.10.92	01 42 37.0	2.0
27.10.92	06 42 50.0	2.0
28.10.92	09 51 24.0	2.9
	22 48 41.0	2.0
01.11.92	23 53 36.7	3.3
02.11.92	00 07 35.0	3.8
	01 25 37.2	2.8
04.11.92	08 10 05.0	2.0
09.11.92	11 21 58.7	2.0
15.11.92	07 37 36.0	2.6

Table:3.4

AFTERSHOCK DATA 29.9.93 TO 20.01.94

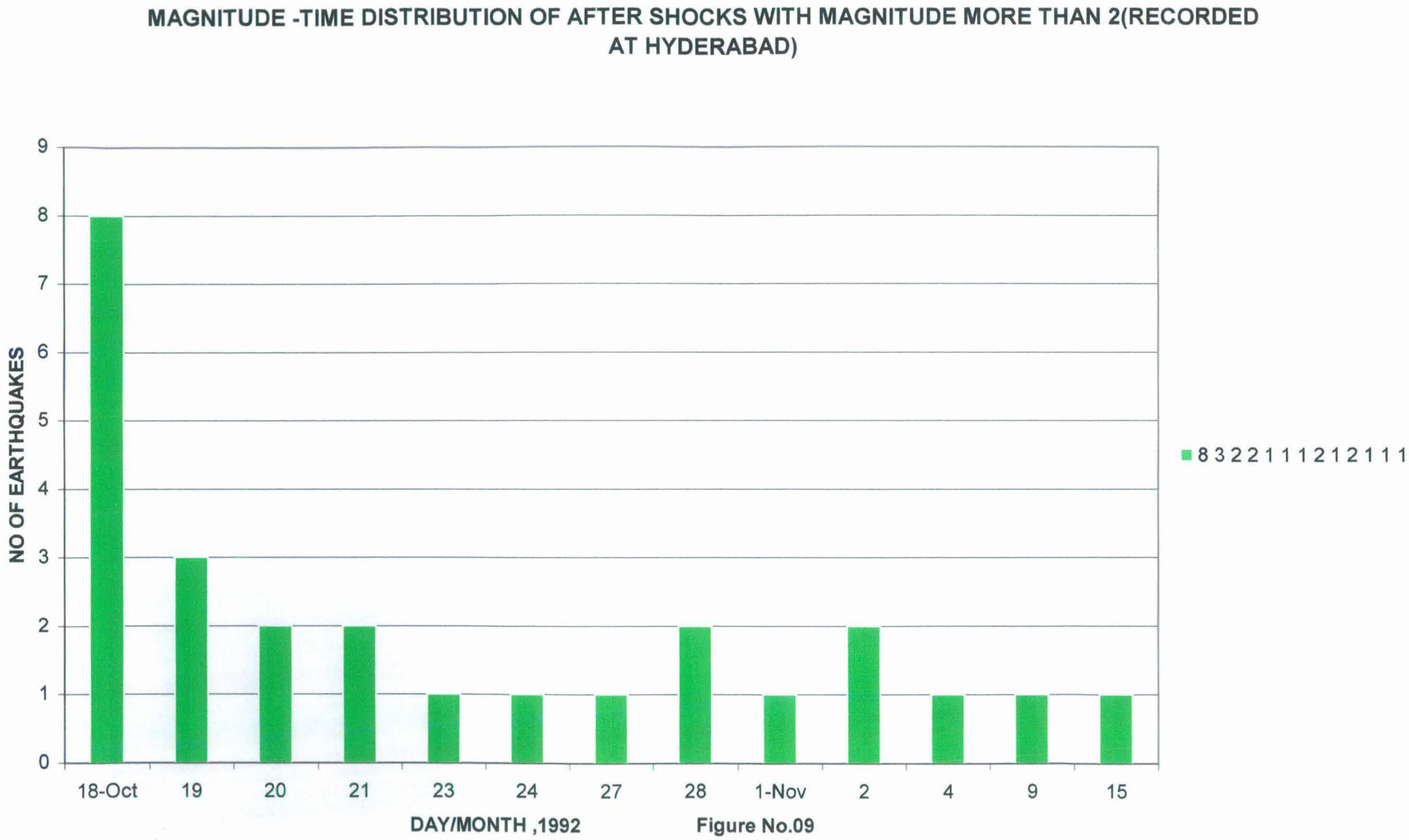
Date	Arrival time(GMT)	Magnitude
29.9.93	22 26 23.7	6.3
	22 44 23.7	2.0
	22 49 38.0	2.0
	22 55 50.5	2.0
	23 11 33.6	4.4
	23 24 48.5	2.0
	23 47 39.5	2.0
30.9.93	00 07 17.5	2.0
	00 53 48.5	4.3
	01 03 53.0	2.7
	02 17 31.5	4.3
	03 32 19.5	3.1
	04 12 39.0	2.0
	05 15 51.5	2.0
	06 17 56.0	1`2.0
30.9.93	08 53 22.5	2.3
	09 15 49.0	2.0
	10 20 24.5	2.7
	22 59 48.0	2.3
01.10.93	07 56 44.0	2.0

	17 01 50.5	4.1
	19 31 54.5	2.1
02.10.93	23 16 02.3	3.5
04.10.93	21 10 07.0	3.3
05.10.93	19 10 49.6	3.7
06.10.93	19 10 33.5	2.0
08.1093	20 45 41.6	4.3
10.10.93	17 56 36.5	2.0
12.10.93	15 32 43.0	2.2
15.10.93	03 24 52.0	2.0
16.10.93	08 58 49.0	2.3
17.10.93	00 08 01.5	2.6
18.10.93	18 10 17.5	2.3
28.10.93	09 21 54.0	2.1
01.11.93	06 29 21.5	2.0
12.11.93	13 28 04.5	3.9
13.11.93	04 21 38.5	2.4
18.11.93	14 02 02.0	3.5
24.11.93	14 46 35.2	3.3
20.12.93	02 43 41.0	2.4
06.01.94	07 12 16.5	2.7
20.01.94	10 56 23.0	2.3



MAGNITUDE-TIME DISTRIBUTION OF AFTERSHOCK WITH MAGNITUDE MORE THAN 2(RECORDED AT HYDERABAD)
NO OF EARTHQUAKES
14
12
10
8
6
4
2
0
29-Sep
30
1-Oct
2
4
5
6
10
12
15
16
17
18
26
1-Nov
12-Nov
13-Nov
18-Nov
24-Dec
28-Dec
4-Jan
28-Jan
DAY/MONTH 1993-1994
NO OF EARTHQUAKE

Figure No. 10



MAGNITUDE -TIME DISTRIBUTION OF AFTER SHOCKS WITH MAGNITUDE MORE THAN 2(RECORDED AT HYDERABAD)
NO OF EARTHQUAKES
0
1
2
3
4
5
6
7
8
9
8 3 2 2 1 1 1 2 1 2 1 1 1
18-Oct
19
20
21
23
24
27
28
1-Nov
2
4
9
15
DAY/MONTH ,1992

Figure No.09

LOCATION OF THE AFTERSHOCK

The epicenter of the Latur earthquake was within the area covered by the late Cretaceous basalt flows (Deccan Traps) which is underlain by granite. There were no studies to estimate the velocity structure beneath the area close to the epicenter, but for the deep seismic sounding profiles by NGRI, in Koyna region at a distance of more than 200 km towards the west of the epicentral region. The massive Deccan basalt which cover approximately an area of 5,00,000 sq.km. thinout towards the east. It was estimated that the thickness of the basalt in the epicentral region may be around 300km, As the thickness of the basaltic layer is estimated to be only little effect on the location of the epicentres. Ramakrishna Rao (1989) analyzed travel times of seismic waves, crossing the aftershock area in the northwest-southeast direction. About 700 tremors were recorded from 8th October 1993 January 1994. Out of these, only 187 tremors could be located using the entire data set. The epicentral parameters of the located events are listed in Table.3.1 The number of recorded aftershocks is significantly smaller as compared to the aftershock frequency of intraplate events with comparable main shock magnitudes. locational accuracy changes with time because of the changing network configuration and the number and types of stations available.

The aftershock area has a diameter of only about 15 km and most of the epicenters were located in the center of this area with a decrease being observed towards the fringe. A majority of located events cluster southwest of a line striking NW-SE and passing through the point of maximum surface displacement (Seeber 1993, and personal observation) and close to the point of confluence of the tributaries of the Tirna river. The distribution of aftershock suggests that the fault plane of the Latur event strides NW-SE. This is in agreement with the best double couple fault solution derived from centroid moment tensor solutions as published by USGS .

CHAPTER IV

DRAINGE MORPHOMETRY, DAMAGE AND CASUALTIES

DRAINAGE MORPHOMETRY

Measurement of shape or geometry of any natural form – be it plant, animal or relief features, is termed as morphometry. (Strahler, A.N. , 1969). But in geomorphology morphometry may be defined as the measurement and mathematical analysis of the configuration of earth surface and shape and dimension of land.

It has two distinct branches viz (i) relief morphometry and (ii) fluvial morphometry

Relief morphometry include analysis of terrain characterizes through hypsometric curves, clinographic curves percentage hypsometric curves etc. Area – height curves, altimetric frequency histograms and curves, super imposed, projected and composite profiles which assists in landform characteristics of land from characteristics of drainage basin or of any geomorphic unit

Fluvial morphometry includes the consideration of linear, areal and relief aspects of fluvially originated drainage basin. The linear aspect deals with the hierarchical orders of streams, number, lengths of stream segments and various relationships among them and related morphometric components.Areal aspect includes the analysis of basin parameters. Basin shape (both geometrical and topographical), basin area and related morphometric, beside hypsometric clinographics and altimetric analyses, the study of absolute and average slope and dissection index

INTRODUCTION

Various morphometric parameters of twenty three micro drainage basin has been worked out, which is bounded between

Latitude – 17°.30' ,18°.30'.and

Longitude– 76°. 00' , 77°. 00'

Lithology and structures have greatly influenced the different morphometric parameters. The drainage pattern of area is rectangular.

PHYSIOGRAPHY

Topographically, the area shows gently undulating terrain with the river course of Tirna flowing over 580m level while its watershed boundaries lie along 640m level. The higher elevation (670m) is represented by few elongated ridges, capped by laterites. The heavily damaged village lie mostly at 580-600m. surface levels. The source of Tirna river which is ~ 50cm NW of maleailies at 620m level.

Table: 4.1

GROUPING OF BASIN

Group	Basin No.	Type
A	1, 2, 3, 4, 7, 10,12, 13, 16, 17, 18	Left bank
B	5, 6, 8, 9, 11, 14, 15, 19, 20	Right bank

TOTAL NUMBER OF STREAMS WITHIN BASIN

The purpose of stream ordering is to provide estimate of stream flows and erosional capacity. Data available for correlation is used for present study .Tirna river basin group into very low – (8-10), (11-12), moderate – (13-17), high (18-28), very high (26-34). The maximum mean value of parameter is shown by basins group B with value 15-92 with variation of – 0.02. The lowest mean value shown by basin group A with value 15-98 having variation to .02.

TOTAL STREAM LENGTH WITHIN BASIN

Mean length of channel segment of successive higher order of a drainage network forum geometric series. This law of stream length hold true for drainage basin of all sizes, irrespective of physiographic and climatic environment.

Table:4.2

CALCULATION OF MORPHOMETRIC PARAMETERS

BASIN NO	N1	N2	N3	EN	BIFVRCATION RATIO N1/N2 + 1	N2/N3 + 1	TOTAL L1	TENGTH L2	OF STREANS L3	EL ORDER	MEAN IST ORDER	LENGTH OF SIREAN ORDER IIND	IIIRD
1	8	2	1	11	2.66	1	2	0.75	0.75	3.5	0.25	0.375	0.75
2	7	2	1	10	2.33	1	0.3	0.8	0.75	3.25	0.28	0.25	0.75
3	8	2	1	11	2.66	1	2.5	0.75	0.5	3.75	0.31	0.37	0.5
4	10	3	1	14	2.5	1.5	2.75	1.5	0.5	4.75	0.275	0.50	0.5
5	14	2	1	17	4.46	1	4.75	1.75	0.5	7	0.33	0.57	0.5
6	7	2	1	10	2.33	1	2.25	0.5	0.75	3.5	0.32	0.25	0.75
7	9	2	1	12	3	1	2.25	0.75	0.75	3.75	0.25	0.37	0.75
8	13	3	1	17	3.25	1	5	1	1	7	0.38	0.33	1
9	6	2	1	9	2	1.5	1.75	1	0.5	2.25	0.29	0.5	0.5
10	8	2	1	11	2.66	1	2.75	0.5	0.5	3.75	0.34	0.24	0.5
11	12.	2	1	15	4	1	3	0.75	0.75	4.5	0.25	0.37	0.75
12	20	4	1	25	4	1	6	1.5	1.5	9	0.3	0.37	1.5
13	9	2	1	12	3	2	2	0.5	0.75	3.25	0.22	0.25	0.25

14	18	4	1	23	3.6	1	4.5	1	1.5	7	0.25	0.25	1.5
15	7	2	1	10	2.33	2	1.5	0.5	0.75	2.75	0.21	0.25	0.75
16	29	4	1	34	5.8	1	8.5	1.25	1.5	11.25	0.35	0.31	1.5
17	10	3	1	14	2.5	2	2.55	0.5	2	5	0.25	0.16	2
18	5	2	1	8	1.66	1.5	1.5	0.5	0.37	2.37	0.30	0.25	0.37
19	9	2	1	12	3	1	2	0.75	0.5	3.25	0.22	0.37	0.5
20	20	3	1	24	5	1.5	5.75	1.75	0.75	8.25	0.257	0.58	0.75

BASIN NO	BASIN AREA	LENGTH OF BASIN	WIDTH OF BASIN	BASIN PERIMETER	DRAINAGE DENSITY DENIEY	CHANNEL MAIN NACE C=1/DU.
1	0.97	3.3	3.8	3.5	6.60	0.15
2	0.49	2	3.5	2.5	10.15	0.09
3	0.71	3.9	4.4	3	7.35	0.13
4	0.97	4.3	2.2	3.5	8.33	0.12
5	2.19	6.8	2.9	5.25	6.54	0.15
6	0.60	2.1	3.7	2.75	10	0.1
7	0.71	2.4	2.6	3	9.14	0.10
8	0.71	4	4.2	3	7.36	0.13
9	0.84	4.1	2.8	3.25	6.5	0.15
10	0.45	2.1	3.4	2.5	11	0.09

11	1.27	4.4	2.8	4	6.33	0.15
12	1.99	7.4	4.4	5	7.5	0.13
13	0.40	1.8	2.4	2.25	12.5	0.08
14	1.27	5	3.3	4	9.58	0.10
15	0.49	2.4	2.3	2.5	10.5	0.09
16	3.36	3.8	6.8	6.5	7.16	0.13
17	0.84	5.1	1.8	3.25	12.8	0.07
18	0.49	3.5	1.7	2.5	9.11	0.10
19	0.60	2	4	2.75	7.73	0.12
20	2.19	4.7	3.6	5.25	8.87	0.11

BASIN	STREAM I ORDER	FREQUENCY II ORDER	FU =NU/AU III ORDER	Dn – TEXTURE I ORDER II ORDER		RA 710= Nu / Pu III ORDER	HEIGHT OF MANTIN	Hight Z	TOTAL RELIEF RATIV Z	RLIEF Ratio	Ridges number
1	15	3.77	1.88	2.28	0.57	0.25	450	620	170	51.5	0.21
2	21.28	6.25	3.125	2.8	0.8	0.4	460	701	241	120.5	0.46
3	15.6	3.92	1.96	2.66	0.66	0.33	450	711	261	66.92	0.36
4	17.54	5.26	1.754	2.85	0.85	0.28	4.70	702	232	53.9	0.36
5	13.08	1.86	0.93	2.66	0.38	0.19	450	682	232	33.6	0.287

6	20	5.71	2.85	2.54	0.72	0.36	470	680	210	100	0.39
7	21.95	4.87	2.43	3	0.66	0.33	470	665	205	85.4	0.35
8	13.6	3.15	1.05	4.33	1	0.33	643	700	143	35.75	0.19
9	10.52	3.50	1.75	1.84	0.67	0.30	634	610	46	11.2	0.05
10	23.52	5.88	2.94	3.2	0.8	0.4	649	698	49	23.3	0.10
11	16.90	2.8	1.40	3	0.5	0.25	617	686	69	15.68	0.08
12	16.66	3.38	0.83	4	0.8	0.2	616	672	56	7.56	0.07
13	32.14	7.14	3.57	4	0.8	0.24	616	661	45	25	0.106
14	24.65	5.47	1.36	4.5	1	0.25	619	643	24	4.8	0.04
15	26.92	7.79	3.84	2.8	0.8	0.4	610	629	19	3.75	0.03
16	18.47	2.54	0.63	4.46	0.61	0.15	625	615	29	7.63	0.03
17	25.64	7.69	2.56	3.07	0.92	0.30	615	612	57	11.17	0.13
18	19.23	7.69	3.54	2	0.8	0.4	615	663	48	13.17	0.08
19	21.42	4.76	2.38	3.27	0.72	0.36	607	620	13	6.5	0.01
20	21.50	3.22	1.07	3.80	0.57	0.19	583	610	17	3.61	0.027

Table 4.3

MORPHOMETRIC AVERAGE AND VARIATIONS

	Nu		Lu		Au		Lb		Du		
Group	M	+A	M	+A	M	+A	M	+A	M	+m	
Left band	15.18	+0.02	4.87	0.83	1.03	0.04	3.6	0.15	9.24	-0.48	
Right bank	15.22	-0.20	6.72	1.02	1.12	-0.05	3.94	-0.18	8.15	+0.60	

Very low (2.37 – 2.75 kms), low (2.75 – 3.75) moderate (3.75 – 5), high (5 – 9 kms), very high (9 – 11.25 kms).The maximum mean value is shown by the basins in group B with a value 6.72, having variation of -1.02.The lowest mean value shown for basin group A with a value of 4.87 having variation of 0.83.

AREA OF BASIN

The maximum mean value for this parameter is shown by basin group B having a value 1.12 having a variation of – 0.05. The lowest mean value of this parameter is shown by basin group with a variation of 0.04.

Very low (0.26 – 0.32) Sq Km.

Low (0.32 – 0.42)

Moderate (0.42 – 0.73)

High (0.73 – 1.2)

Very high (1.2 – 1.57)

DRAINAGE DENSITY

Drainage density is defined as the length of stream segment within a basin to the basin area. It is a dimension inverse of length. It is generally affected by geology, climate, permeability of soil or rock etc. (Massimo, 1968).

The maximum mean value is shown by basins in group A having value of 9.24 with a variation of– 0.48. The mean value is shown by basin group B having a value of +8.15 and variation of +0.60.

Drainage density has been grouped into very low (6.33 – 6.66), low (6.6 – 7.73) moderate (7.33 – 9.58), high (9.58 – 11) and very high (11 – 12.8)

CHANNEL MAINTENANCE

It is defined as inverse of drainage density channel maintenance has been grouped into very low (6.33 – 6.6), low (6.6 – 7.73) moderate (7.73 – 9.58), high (9.58 – 11), very high (11 –12.8).

STREAM FREQUENCY

Stream frequency refers to the number of stream segments per unit area. Like drainage density stream frequency also depend upon the physical character sties of catchments and climate conditions.

Stream frequency of 1^{st} order has been grouped into –

Very low (10.52 – 13.6), low (13.6 – 17.54) moderate (17.54 – 20), high (20 – 25.64), very high (25.64 – 32.14).

Stream frequency of 2^{nd} order has been grouped such as very low (1.86-2.81), low(2.81-3.92) moderate (3.92-5.26), high (5.26-6.25) and very high (6.25-7.79).

stream frequency of III rd order has also been categorized into Very low (0.63-0.93), low (0.93-1.4), moderate high (1.4-1.96), high (1.96-3.12), very high (3.12-3.84),

DRAINAGE TEXTURE

Drainage texture is an indicator of spacing of stream in a unit area. It refers to relative segments of given length per unit area and represents various regional scale of texture of drainage fineness. The varying grade of texture of drainage texture. does not not refer to steepness of slope, amount of relief or stage in geomorphic cycle. Like earlier morphometric components, drainage Texture ratio of 1^{st} order grasped into very low (1.84-2.28), (low 2.28-2.85), moderate (2.85-3.27), high (3.27-4), very high(4-4.5),

Texture ratio of II nd order has also been grouped into

Very low (0-0.1), low (60.1-0.5), very low (0.5-0.72),high (0.72-0.85), moderate (0.5-0.72), very high (0.85-1),

Texture ratio of III rd order is as follows

Very low (0.15), low (0.15-0.2), moderate (0.2-0.28), high (0.28-0.33), and very high (0.33-0.4).

BIFURCATION RATIO

The number of streams of various order in drainage basins are counted and totaled. Number decreases in a regular way with increasing order of streams forming geometric series. The other aspect of bifurcation ratio shows the ratio between the numbers of segment of any given order to the number of segments of the next highest order.

Bifurcation ratio No 2 has been grouped into. Low (1), moderate (1-1.5), high (1.5-2), Bifurcation ratio No 1 has been also categorized into Very low (1.66-2), low (2-2.66), moderate (2.66-3.25), high (3.25-4.46), very high (4.46-5.6),

RELIEF RATIO

It is defined as ratio between total relief basin and length of the basin it is grouped into Very low (3.61-7.63), low (7.63-15.68), moderate (15.68-35.75), high (35.75-66.92), very high (66.92-120.5).

RUGGEDNESS INDEX

Ruggedness index is the measure of surface unevenness under a given lithological basement complex. It is a derivative of longstanding interaction between the available sharpness of local relief and the amplitude of available drainage density. Physical Environmental parameters such as slope, precipitation, weathering, soil texture, natural vegetation etc are partially responsible for evolving ruggedness of a surface (patnaik, 1993). Chorley (1972) derived the method of ruggedness index for measuring the extent of dissection by taking into account both relief and drainage. Based on the ruggedness value,the study area has been grouped into :

Basin No 2 – 0.46

Basin No 5 – 0.39

Basin No 3,4 - 0.36

Basin No 20 - 0.1

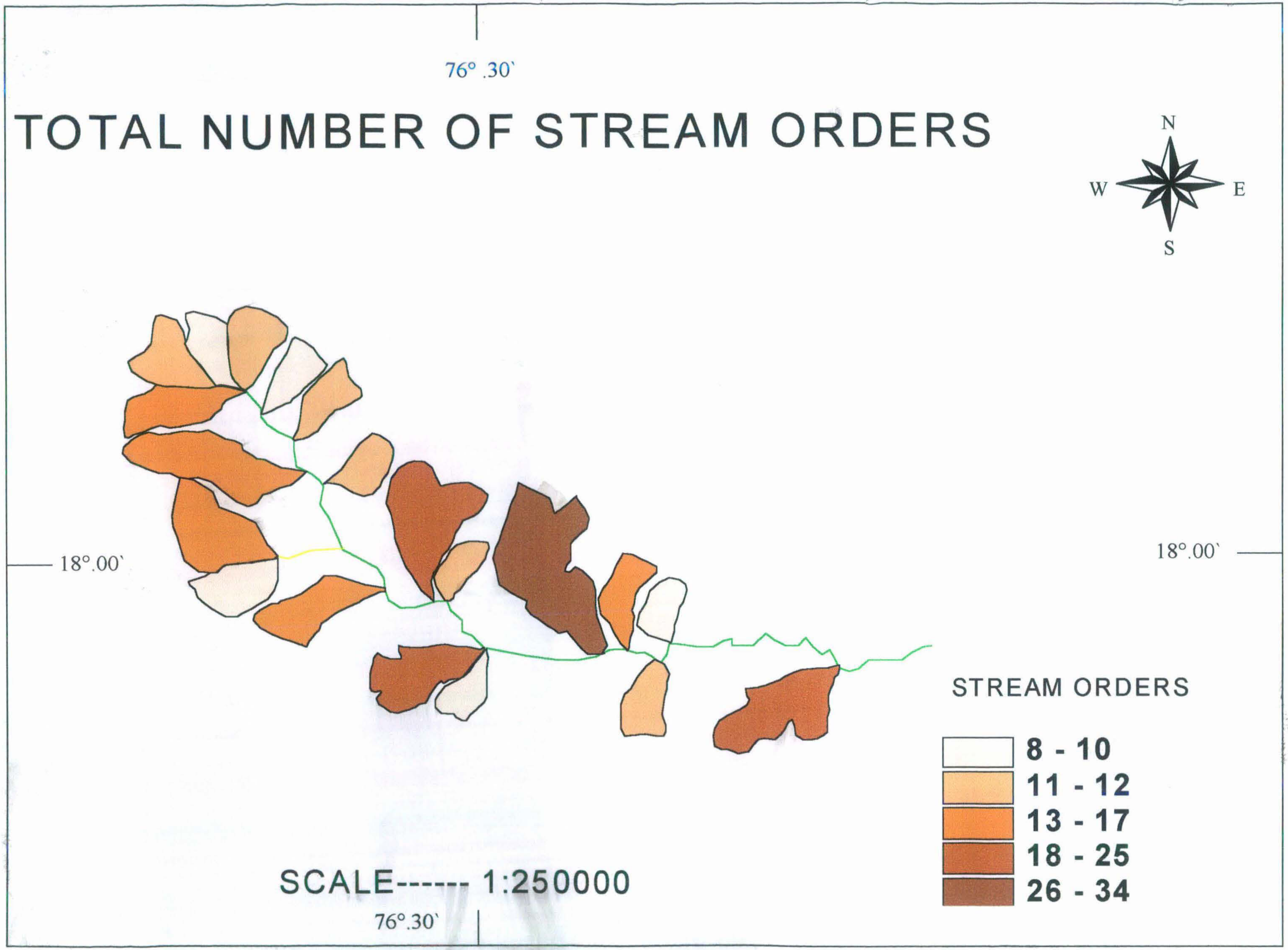
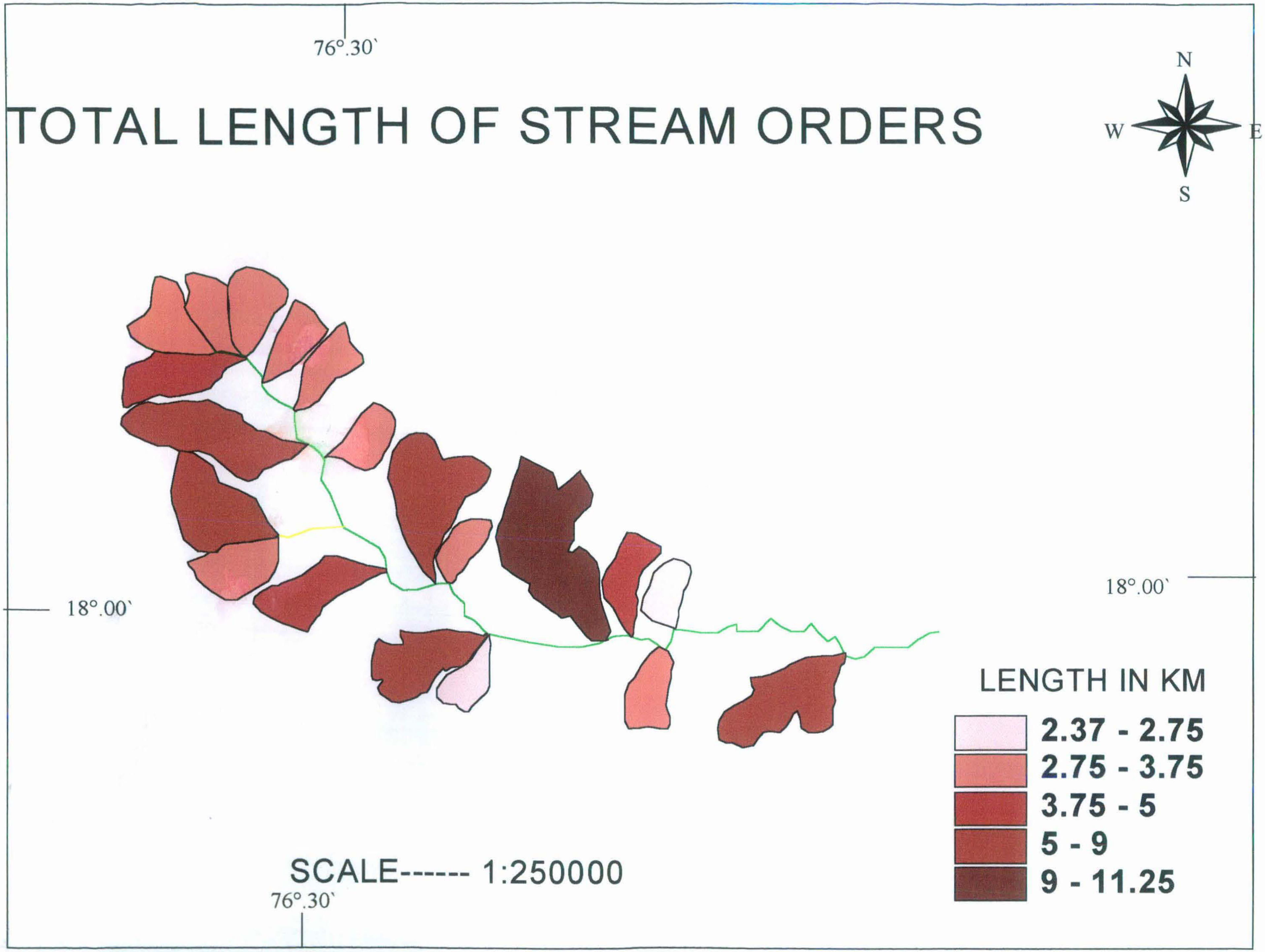

76° .30`
TOTAL NUMBER OF STREAM ORDERS
N
W
E
S
18°.00`
18°.00`
STREAM ORDERS
8 - 10
11 - 12
13 - 17
18 - 25
26 - 34
SCALE------ 1:250000
76°.30`

Figure No. 11



76°.30`
TOTAL LENGTH OF STREAM ORDERS
N
W
E
S
18°.00`
18°.00`
LENGTH IN KM
2.37 - 2.75
2.75 - 3.75
3.75 - 5
5 - 9
9 - 11.25
SCALE------ 1:250000
76°.30`

Figure No. 12

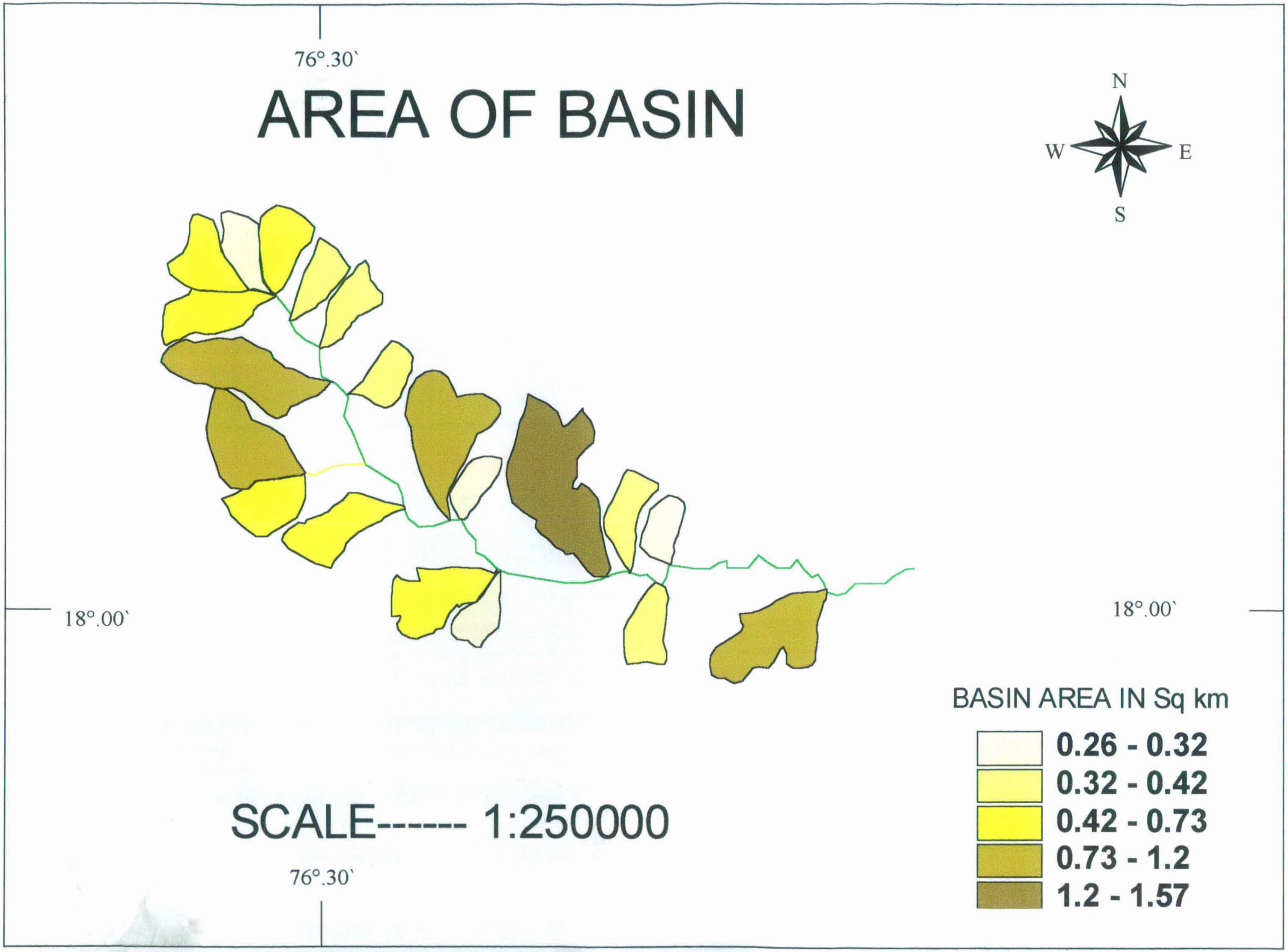

76°.30`
AREA OF BASIN
N
W
E
S
18°.00`
18°.00`
BASIN AREA IN Sq km
0.26 - 0.32
0.32 - 0.42
0.42 - 0.73
0.73 - 1.2
1.2 - 1.57
SCALE------ 1:250000
76°.30`

Figure No. 13

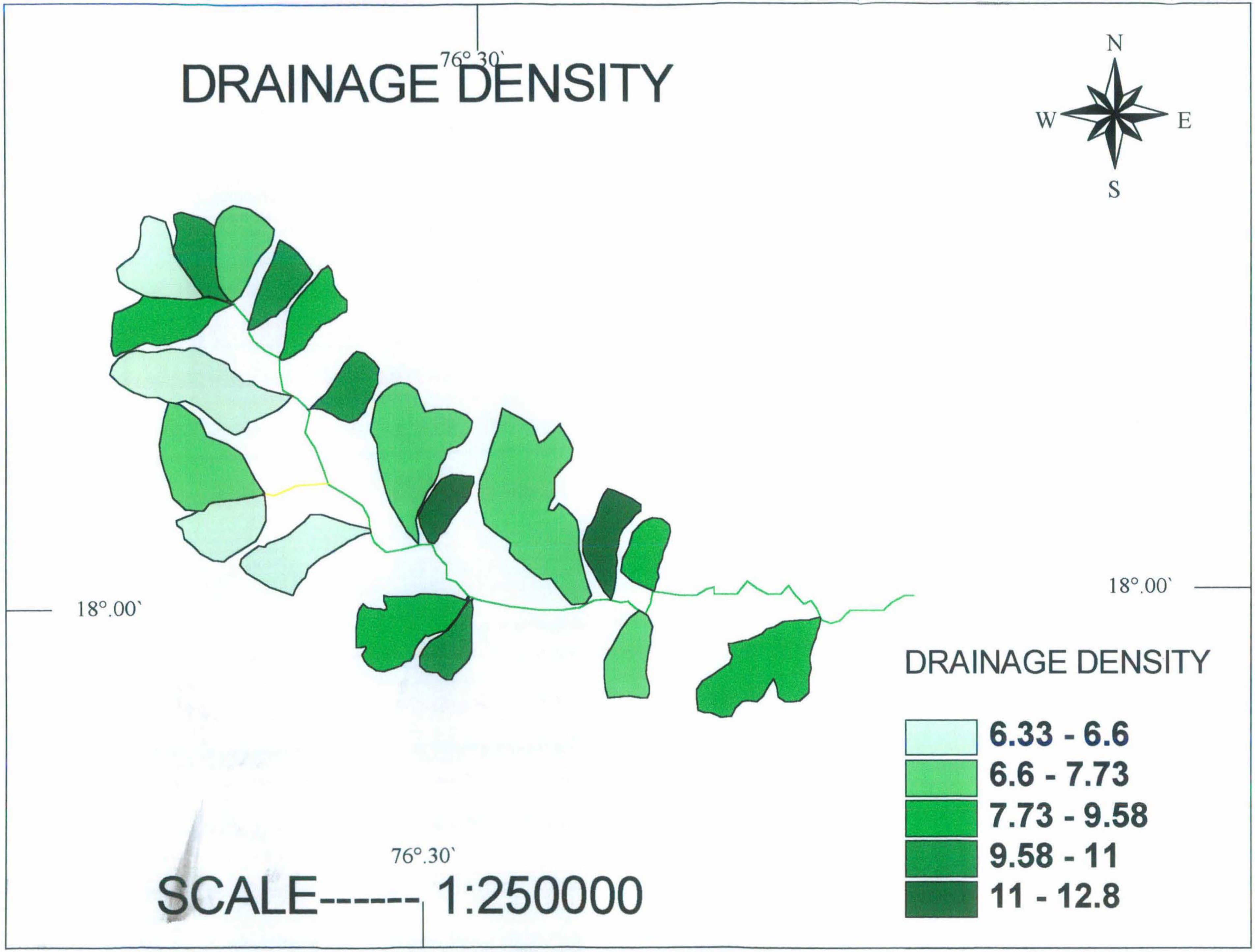
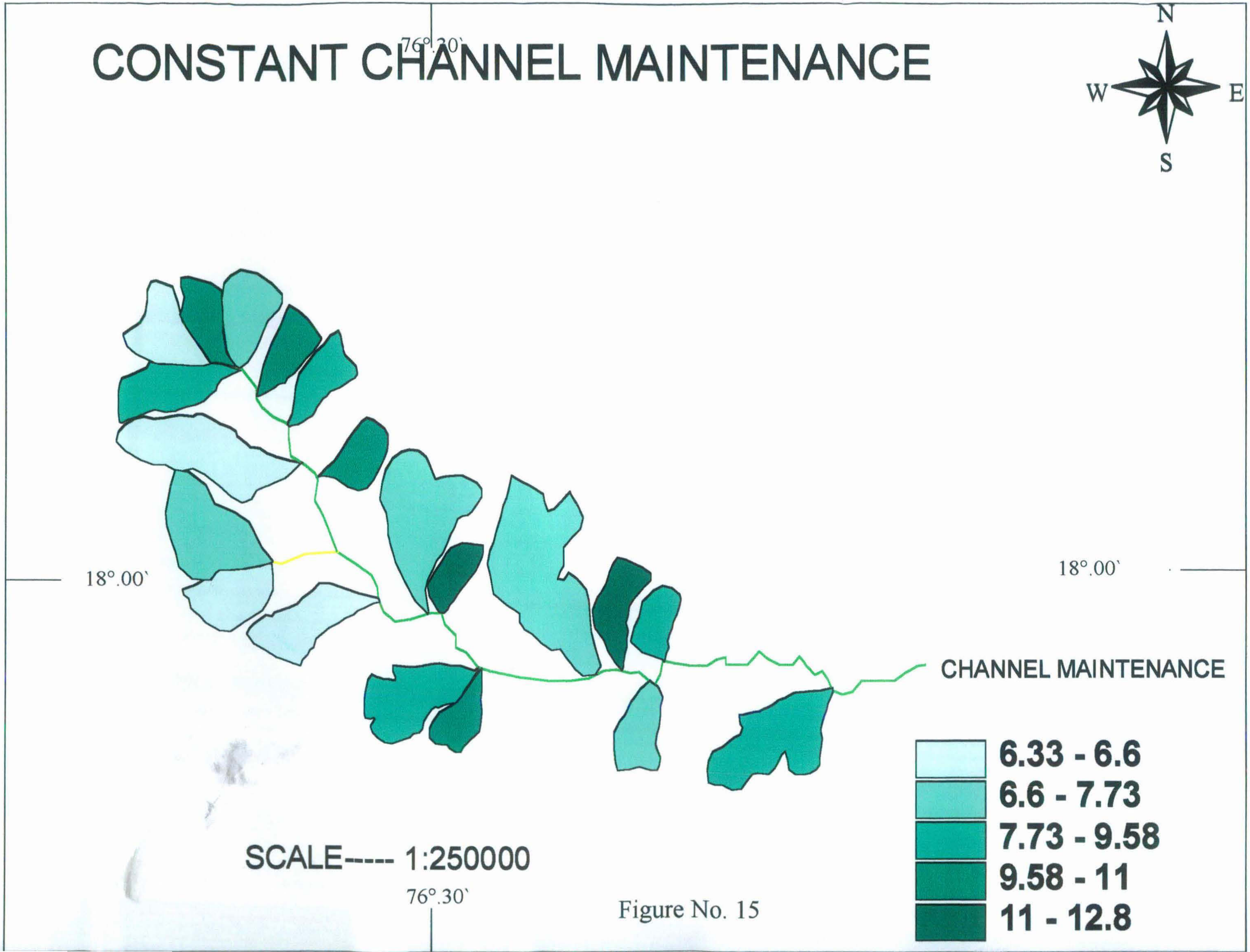

DRAINAGE DENSITY
76° 30`
N
W
E
S
18°.00`
18°.00`
DRAINAGE DENSITY
6.33 - 6.6
6.6 - 7.73
7.73 - 9.58
9.58 - 11
11 - 12.8
76°.30`
SCALE------ 1:250000

Figure No. 14



CONSTANT CHANNEL MAINTENANCE
76°.30`
N
W
E
S
18°.00`
18°.00`
CHANNEL MAINTENANCE
6.33 - 6.6
6.6 - 7.73
7.73 - 9.58
9.58 - 11
11 - 12.8
SCALE----- 1:250000
76°.30`

Figure No. 15

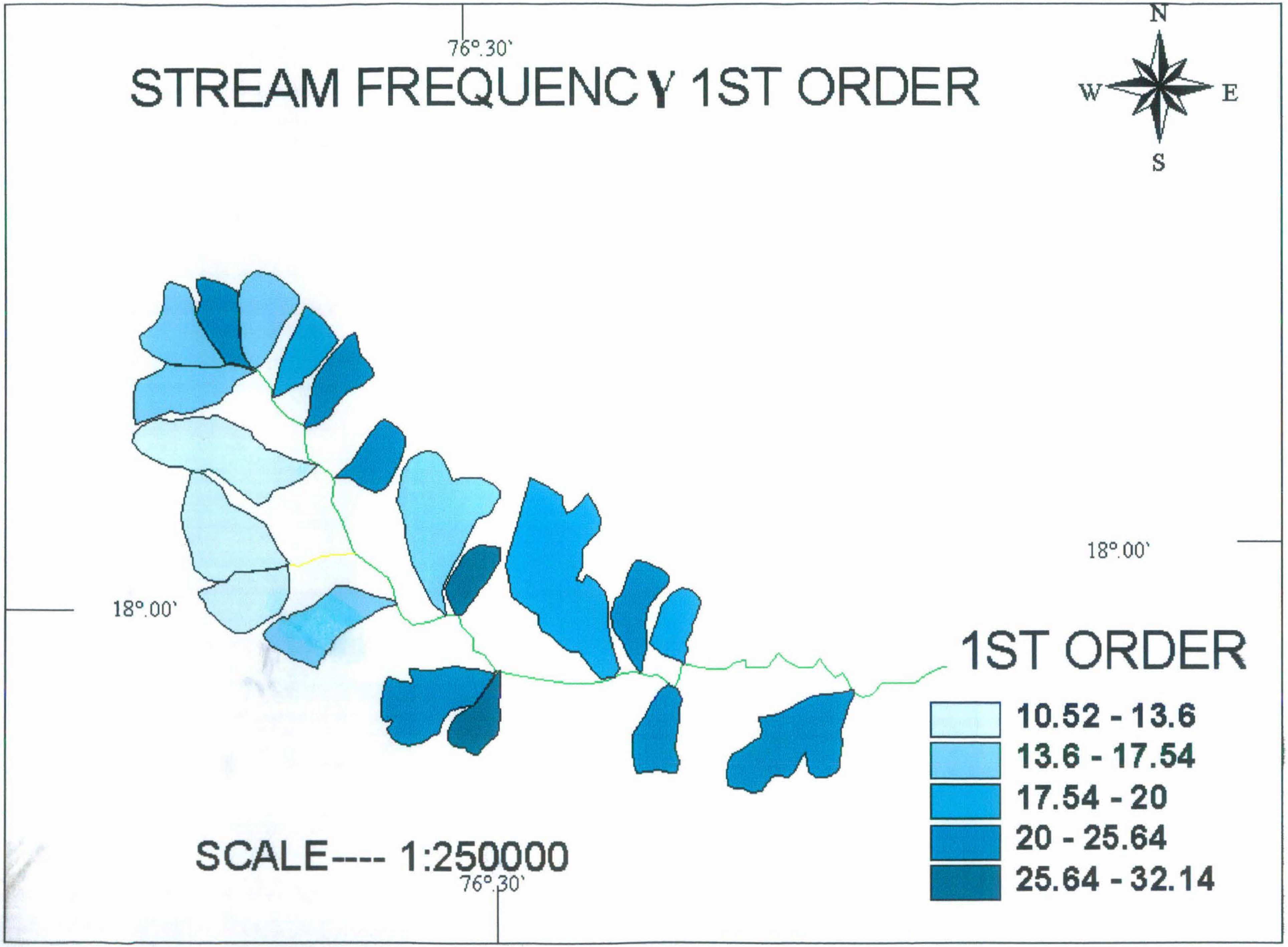

STREAM FREQUENCY 1ST ORDER
76°.30'
N
W
E
S
18°.00'
18°.00'
1ST ORDER
10.52 - 13.6
13.6 - 17.54
17.54 - 20
20 - 25.64
25.64 - 32.14
SCALE---- 1:250000
76°.30'

Figure No.16

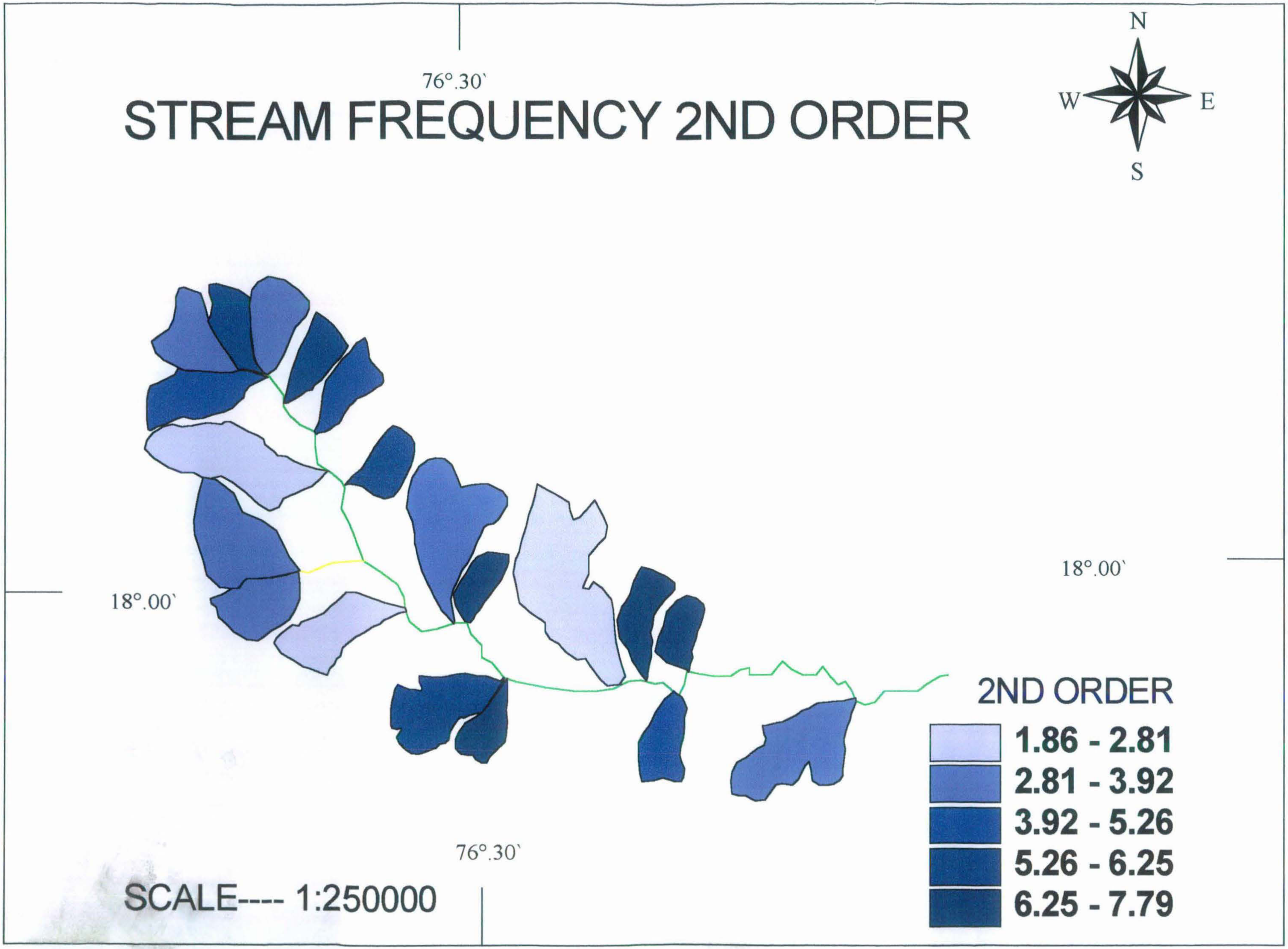

76°.30`
STREAM FREQUENCY 2ND ORDER
N
W
E
S
18°.00`
18°.00`
2ND ORDER
1.86 - 2.81
2.81 - 3.92
3.92 - 5.26
5.26 - 6.25
6.25 - 7.79
76°.30`
SCALE---- 1:250000

Figure No. 17

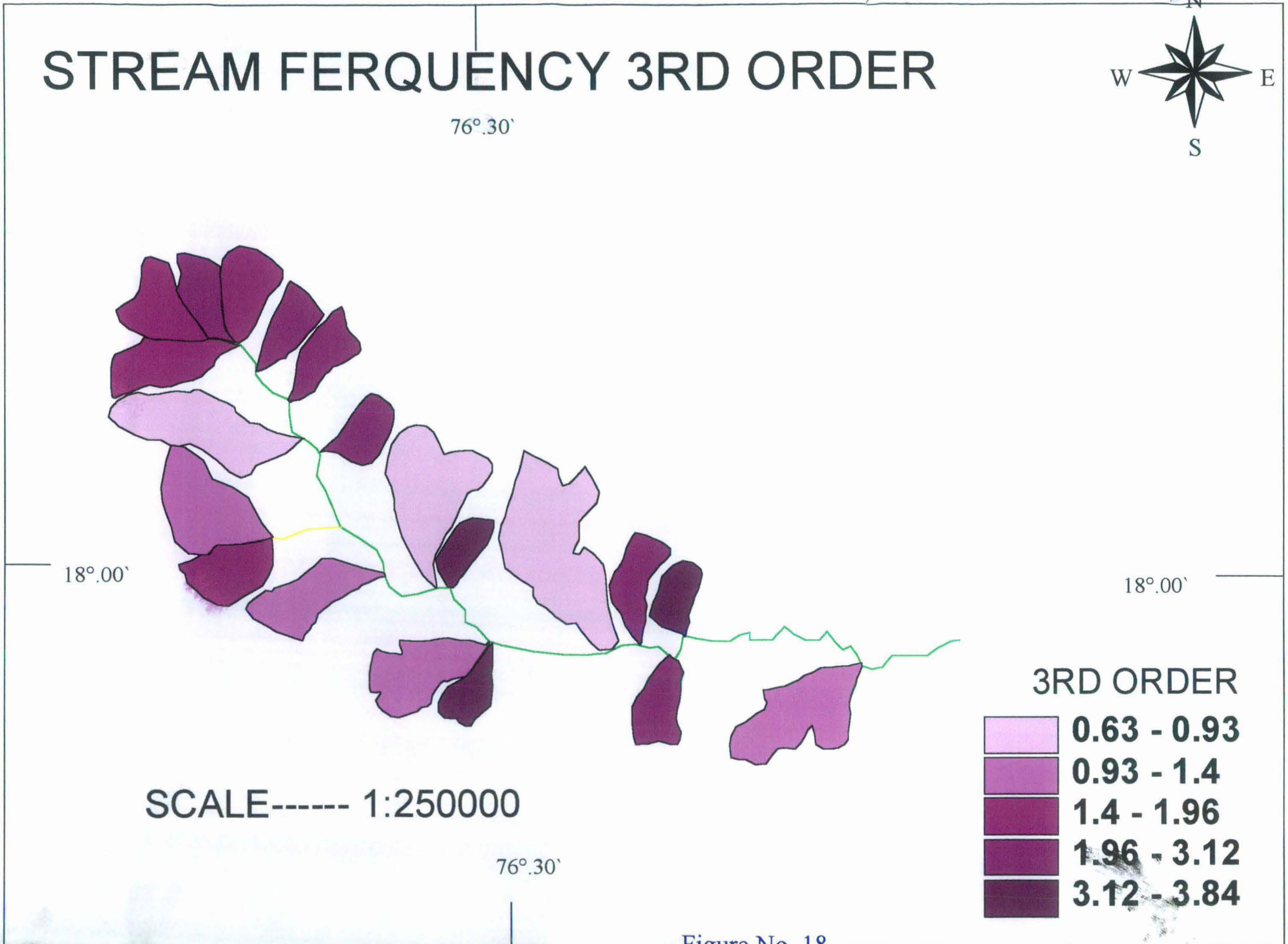
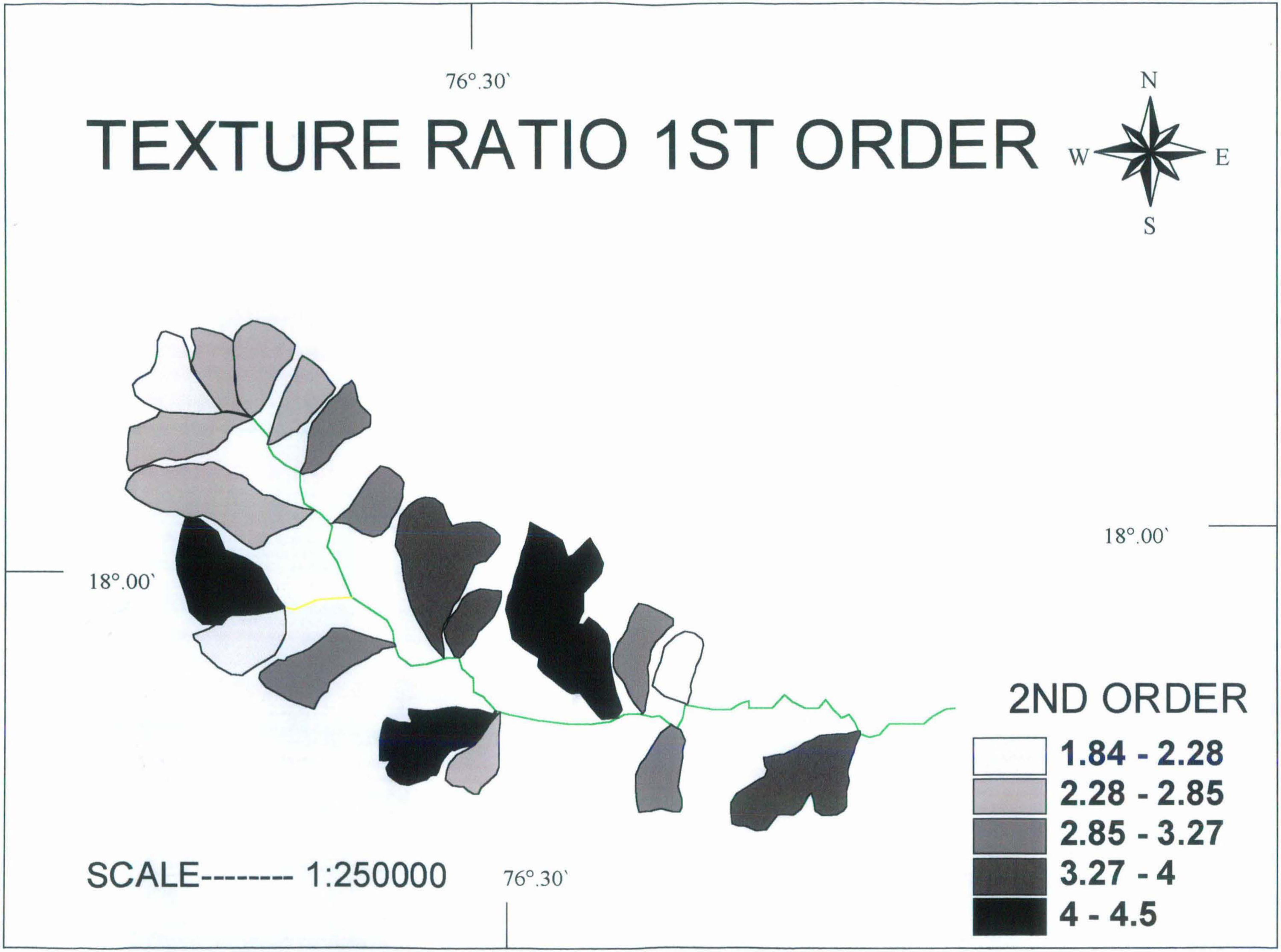

STREAM FERQUENCY 3RD ORDER
N
W
E
S
76°.30`
18°.00`
18°.00`
SCALE------ 1:250000
76°.30`
3RD ORDER
0.63 - 0.93
0.93 - 1.4
1.4 - 1.96
1.96 - 3.12
3.12 - 3.84

Figure No. 18



76°.30`
TEXTURE RATIO 1ST ORDER
N
W
E
S
18°.00`
18°.00`
2ND ORDER
1.84 - 2.28
2.28 - 2.85
2.85 - 3.27
3.27 - 4
4 - 4.5
SCALE-------- 1:250000
76°.30`

Figure No. 19

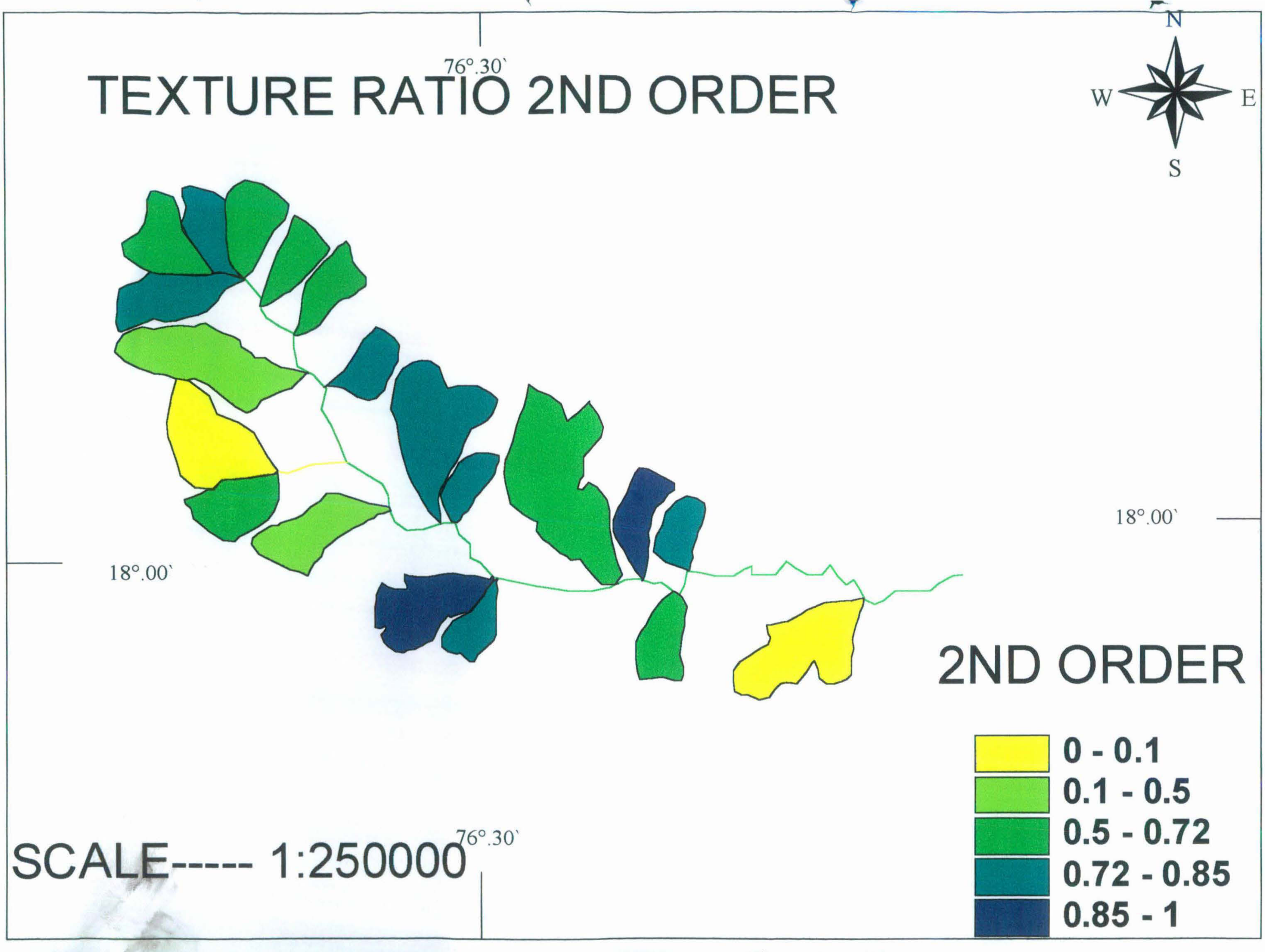

TEXTURE RATIO 2ND ORDER
76°.30`
N
W
E
S
18°.00`
18°.00`
2ND ORDER
0 - 0.1
0.1 - 0.5
0.5 - 0.72
0.72 - 0.85
0.85 - 1
SCALE----- 1:250000
76°.30`

Figure No. 20

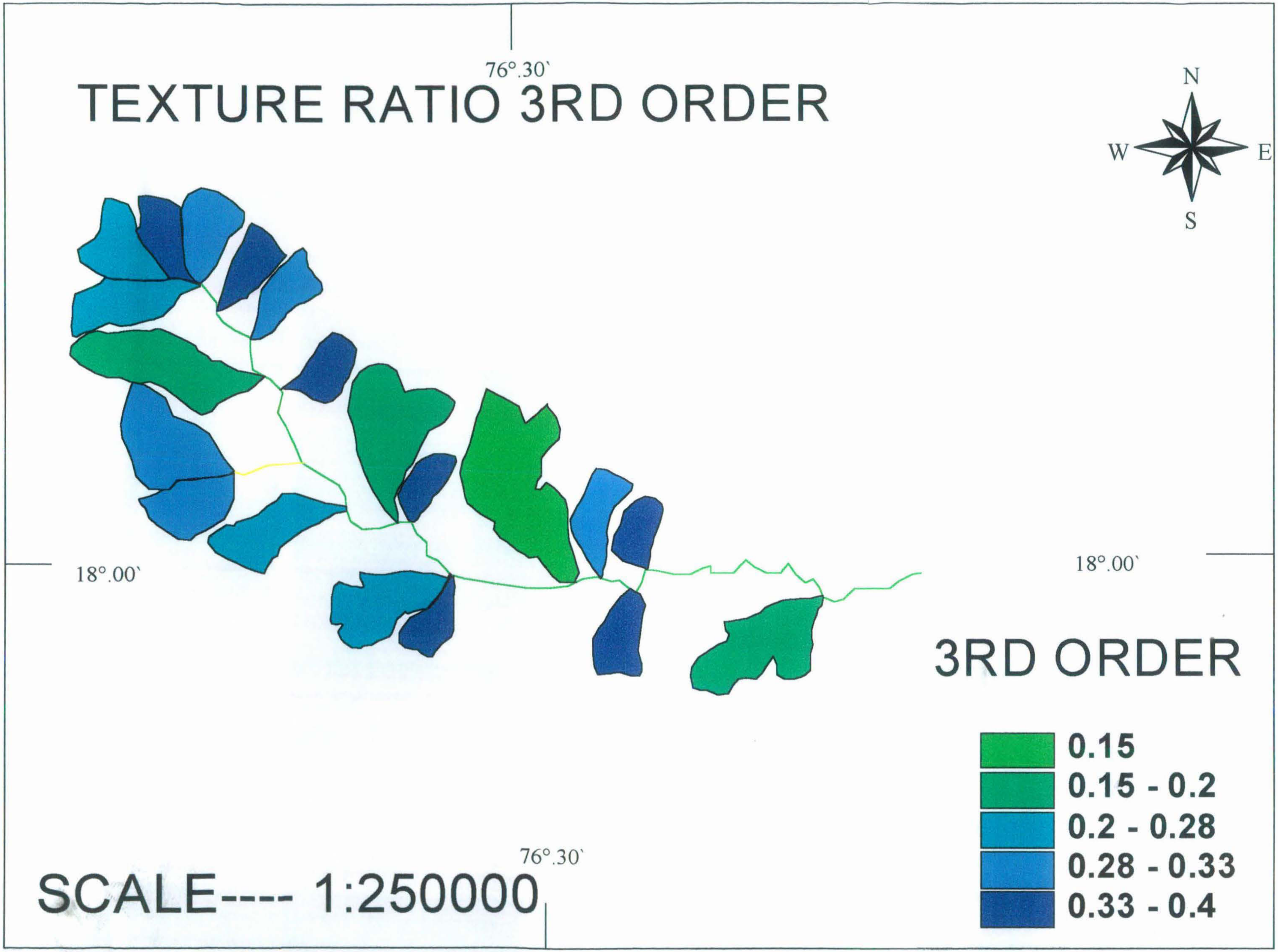
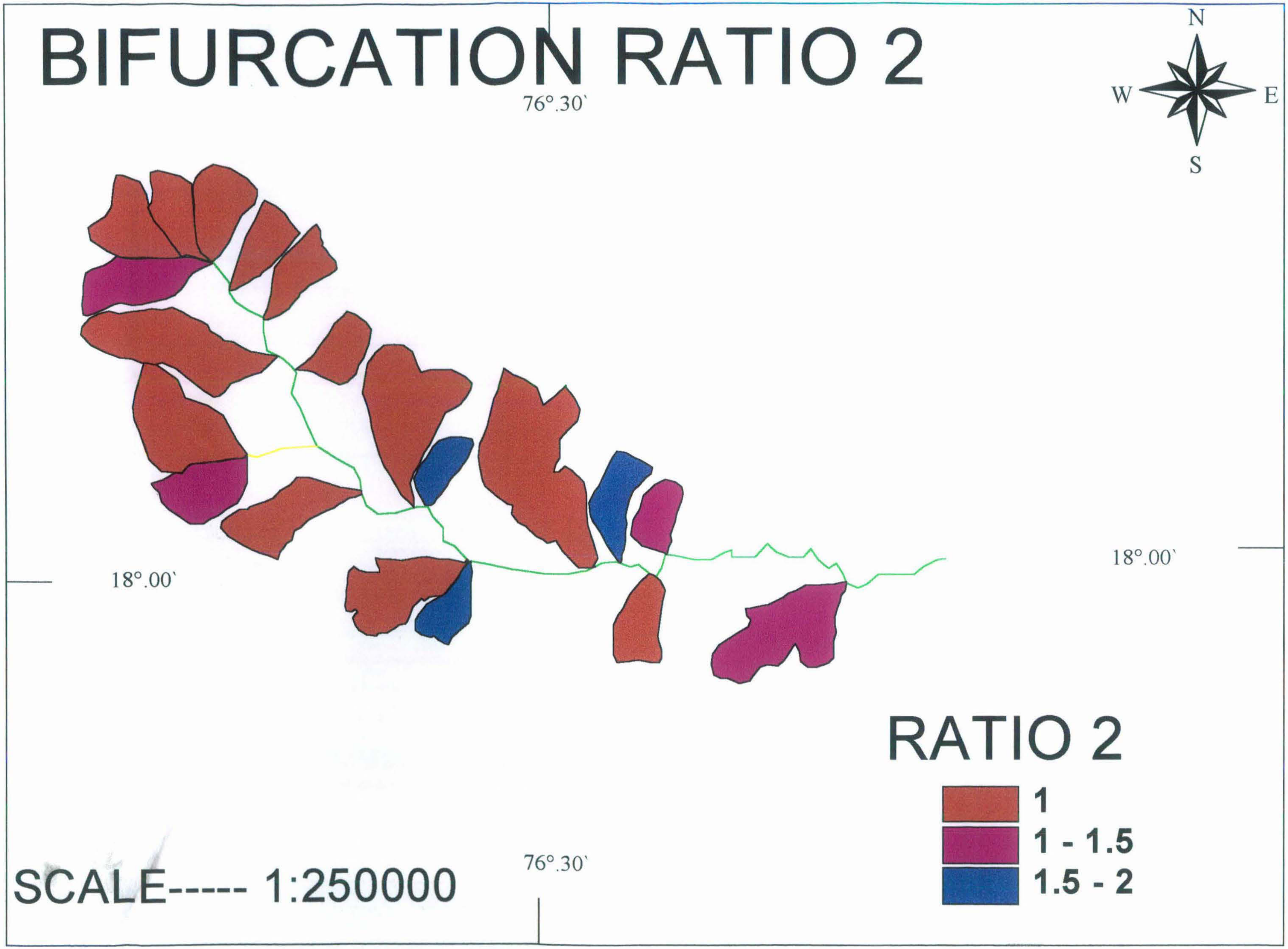
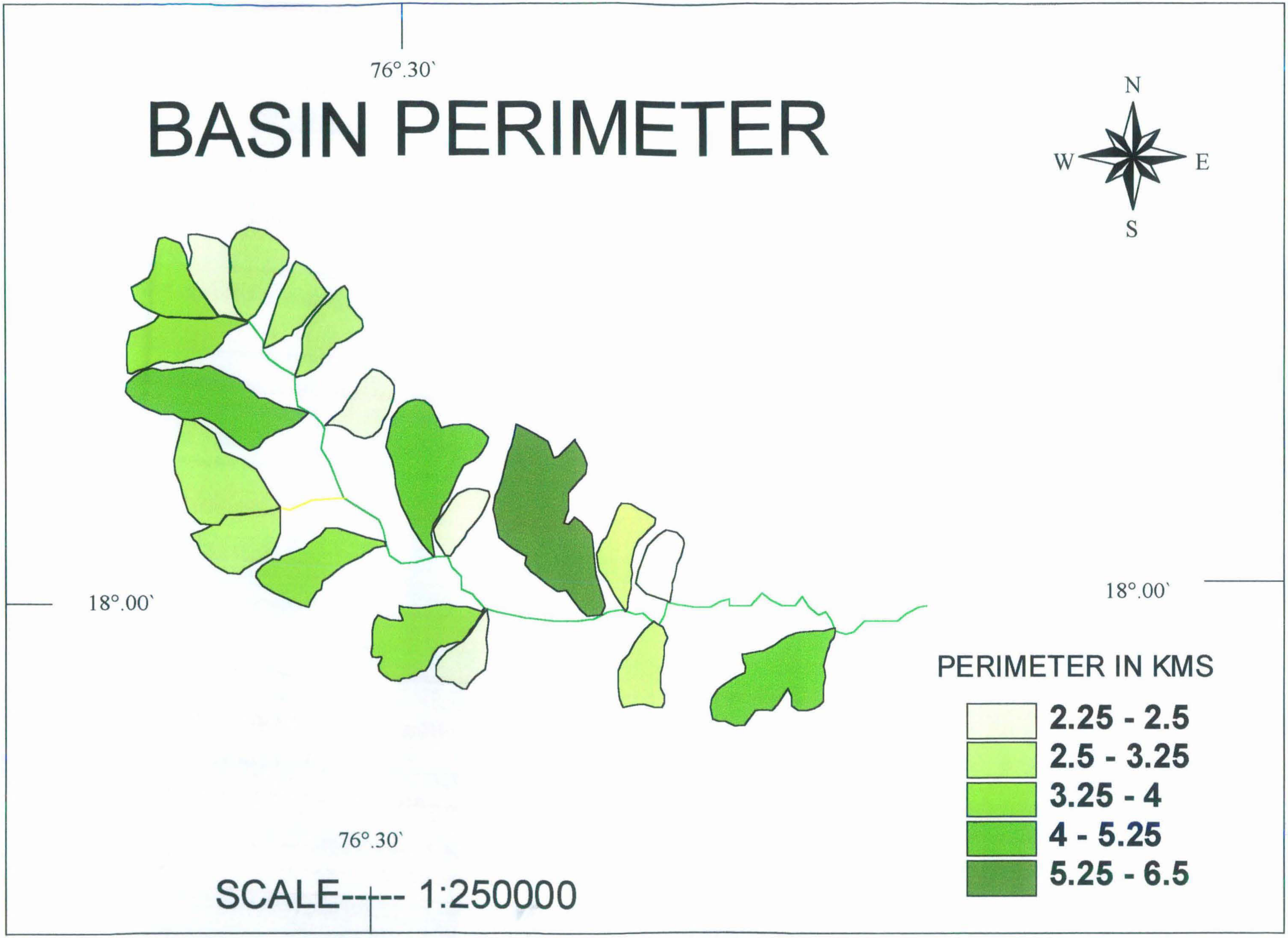

76°.30`
TEXTURE RATIO 3RD ORDER
N
W
E
S
18°.00`
18°.00`
3RD ORDER
0.15
0.15 - 0.2
0.2 - 0.28
0.28 - 0.33
0.33 - 0.4
76°.30`
SCALE---- 1:250000

Figure No. 21



BIFURCATION RATIO 2
N
W
E
S
76°.30`
18°.00`
18°.00`
76°.30`
RATIO 2
1
1 - 1.5
1.5 - 2
SCALE----- 1:250000

Figure No. 22



76°.30`
BASIN PERIMETER
N
W
E
S
18°.00`
18°.00`
PERIMETER IN KMS
2.25 - 2.5
2.5 - 3.25
3.25 - 4
4 - 5.25
5.25 - 6.5
76°.30`
SCALE---- 1:250000

Figure No.23

DAMAGE AND CASUALATIES

MEIZOSEISMAL AREA: EARTHQUAKE DAMAGE

The villages of Killari, Talni, Mangrul, Sastur, Holli, Rajegaon, Rebe Chincholi, Petsangvi and Yekondi located in an area of about 6 km radius were completely razed to the ground. These villages are located on either side of the west to east flowing Tirna river. Most of the structures were single storied and constructed with locally available undressed stones (boulders of Deccan basalts) piled one above the other and bonded with mud (grey coloured). The walls constructed in the region are unusually thick with width varying from 0.5m to 2m **(Figure 24).** Abnormally thick walls are built due to the easy availability of local construction material. These also provide a better thermal insulation against severe heat during summer months when the temperature shoots well above 40°C and a give better protection against burglaries. The houses have wooden plank roofs. The use of heavy boulders, some times weighing above 50kg, and poorly bonded with mud has been mainly responsible for the damage. The construction practice actually amounts to stacking of stones with mud into three layers to be termed as inner wall, middle wall and outer wall. Thick roofs laid with soil of 30 cm to 50cm thickness unduly load the structures. Static strength of such a structure is good. However the dynamic properties are extremely poor as earth tremors of magnitude ~ 4.0 during 1992 had severely damaged many buildings. The collapsed of thick walls and roofs resulted in the debris accumulating shoulder high in the rooms, burying many people. The lanes and streets had also turned into heaps of stones making relief operation difficult.

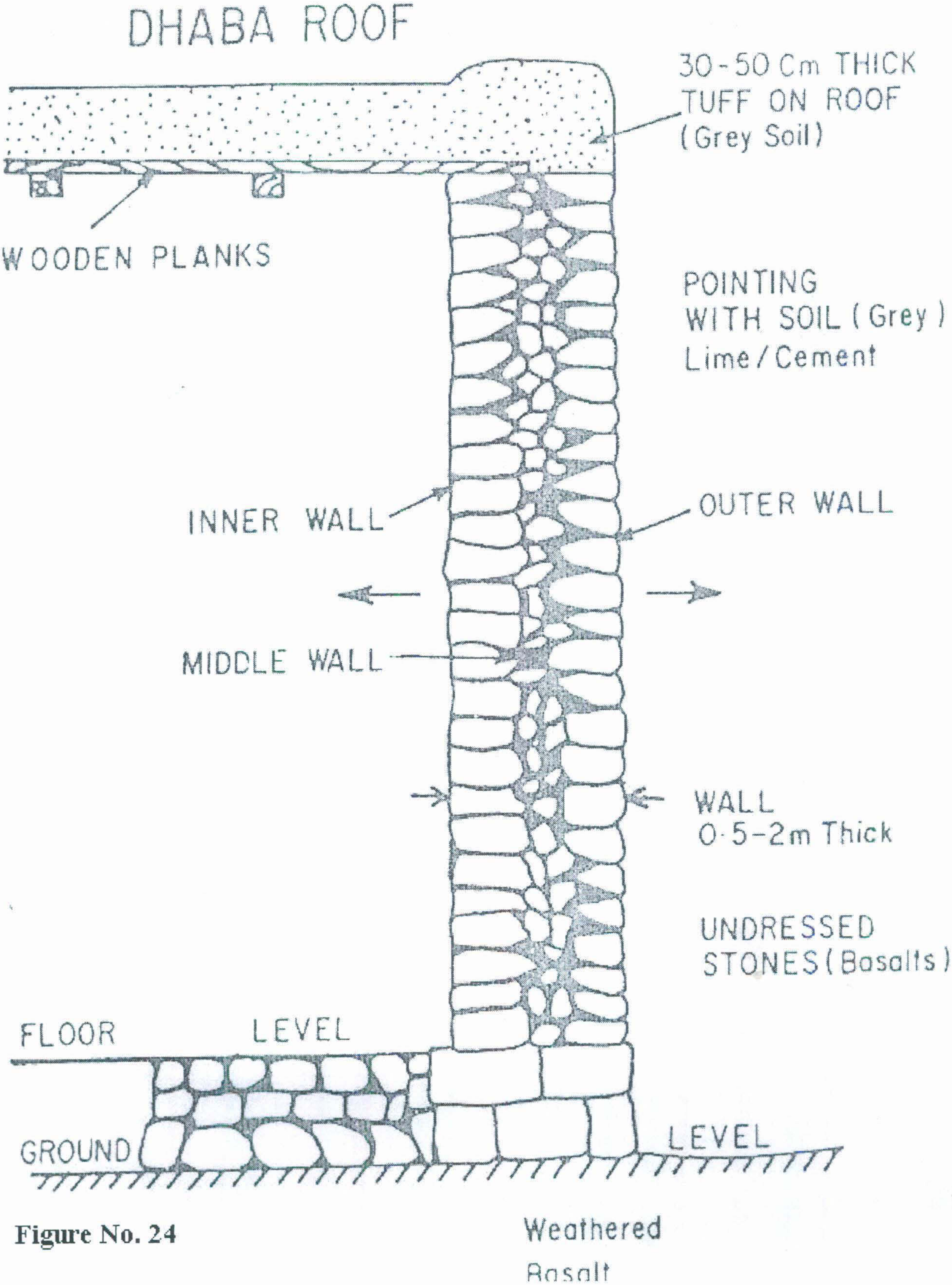

DHABA ROOF
30-50 Cm THICK
TUFF ON ROOF
(Grey Soil)
WOODEN PLANKS
POINTING
WITH SOIL (Grey)
Lime/Cement
INNER WALL
OUTER WALL
MIDDLE WALL
WALL
0·5–2m Thick
UNDRESSED
STONES (Basalts)
FLOOR LEVEL
GROUND LEVEL
Weathered
Basalt

Figure No. 24

The engineered structures **(Plate No. 1 & 2)** though not many in number, withstood the earthquake resistance due to hitherto accepted aseismic character of the region, have escaped with minor damage of gaping cracks seldom there has been any structures. All the water tanks (**Plate No.** 7) in the villages mentioned above are intact and have escaped with minor cracks.

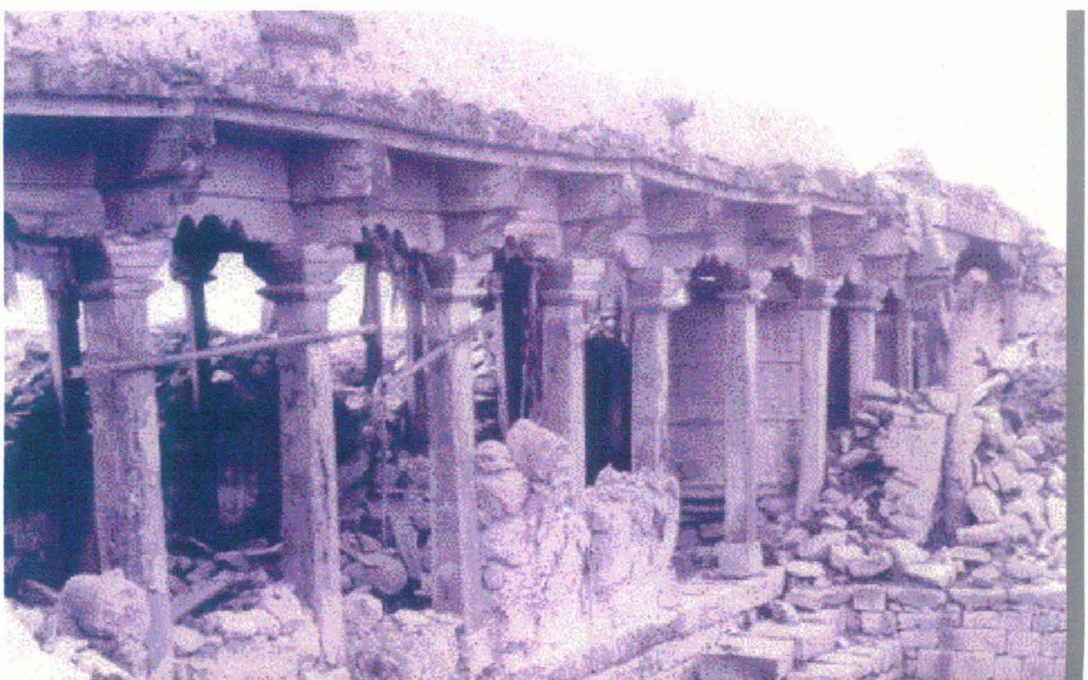
RESPONSE OF BUILDING

Engineered structures were relatively scarce in the affected area. A maximum intensity level of MM VII- IX could be determined by the performance of the few-constructed brick-and-mortar structures.The collapse of traditional stone-and-mud building in the mesoseismal area was nearly total. The wood-plank roofs of these single-story dwelling typically are topped with a 30-60 cm thick layer of clay to provide protection from rain and heat. All such construction behaved very poorly due to the heavy mass at the roof and the poor strength of the supporting rubble masonry walls; such houses were the main cause for the high number of casualties.

A number of dwellings in the affected villages had timber columns connected together with transverse and longitudinal beams. The roof planks in these houses were supported by the timber beams and columns rather than the rubble masonry walls. The poorest people in the villages lived in thatch-type houses consisting of wooden vertical posts and rafters connected with coir rope ties. Thatched roofs and panels or a series of small stocks or slit bamboo woven together form the walls. Mud – plaster provided a wall finish in some of these houses. These houses performed extremely well with only minor cracks in the mud- plastered walls.

Indian Army searching the rubble, Khilari. TRF

Plate - 1



A brick masonry school building in Rajegaon collapsed. The roof of precast panels lacked adequate connections

Plate - 2

Some house were made of load-bearing walls of burnt-clay bricks in cement mortar supporting either a reinforced concrete slab or a corrugated sheet roof. These suffered varying degrees of damage, but none collapsed. In a residential colony at Killari, a house supporting a light roof of corrugated asbestos sheets sustained only hairline cracks in the walls. Surprisingly, a few brick masonry houses in the area were found to have concrete lintel bands. The Indian building code only recommend lintel bands for seismic zones IV and V. Such houses performed very well with no damage.

A one-room 8x8 m school building in the village of Rajegaon had exterior load-bearing walls of brick masonry with cement mortar. The roof consisted of lightweight precast planks 4 m long and 12cm thick spanning from a light steel truss at the center of the building to the masonry walls. The planks were held together at the line of the truss by steel strips tacked with an epoxy material.

The roof panels collapsed, demonstrating, yet again the seismic vulnerability of precast panels without adequate connections.Some of the factors that contribute to the poor performance of the traditional structure are unavoidable, given the materials available within the economic constraints. Some patterns of failure, however, point to improvements that probably could be made within these limitation. For example stone walls tended to separate along axial planes, with the two faces collapsing in opposite direction. Large stones for cross-wall ties are difficult to procure from the native weathered basalt, but suitable material should be sought from out source. The heavy roofs used for thermal insulation contributed heavily to destruction and casualties. Vertical wooden posts that supported some roofs saved many lives Because timber is a scarce resource, some effective alternative should be developed. The villages had a elevated water tanks consisting of a reinforced concrete container supported on concrete moment-resisting frame about 10 m high, a standard design of the public health engineering department. Tank capacities ranged from 40 kl to 200 kl. Most of these tanks survived the earthquake with little or no damage. The one tank that suffered a complete collapse came straight down, burying the remains of six supporting columns directly under the bottom dome of the tank. Evidence of a circumferential displacement of about 0.5 suggest torsional vibration were the primary cause of this damage.

Several structures in the Lower Tirna river irrigation system were damaged. Cement slabs lining the main canal were often horizontally cracked and buckled towards the axis of the canal .The embankment of the lower Tirna dam suffered longitudinal fissuring along the crest, but spillways and gates were apparently undamaged. Several bridges sustained minor damage. The bearing on one of the piers of a six-span overpass were damaged when the pier moved away from the abutment by about 4 to 5 cm.

The only exception was a water tank at Rene Chincholi, which was slightly tilted due to failure of foundation. However, a water tank at Kawtha village (**Plate No.** 7) collapsed completely, whereas the damage suffered by the village otherwise was much less. On scrutiny it was observed that this failure was due to column collapse caused by the defective design i. e. improper reinforcement of columns. There were no damages to bridges, roads and culverts anywhere in the region due to the earthquake. No trees fell or branches were damaged by this earthquake. Electric and telephone poles were at normal sight in nearby regions. The sugar factory located 2 km east of Killari village , however, remained intact and there has been no damage at all. This factory has 10m tall cement mortar stone walls and a steel chimney of 10-m height. Absence of damage in this factory is attributed to the good construction, using cement ,mortar, foundation on hard rock and steep drop in the intensity immediately east of Killari. The steep fall in earthquake intensity was clearly inferred from other structures (**Plate No. 3**) in Killari Tanda located towards northeast of Killari village. Also, the villages east of Killari had suffered much less damage indicating a steep drop in intensity.

Towards west, near Makni village, there were clear indications of steep drop in intensity. There had been less damage to the houses constructed in a better way i.e. using dressed stones, as compared to the use of undressed boulders in villages near Killari. There was practically no damage to the Makni irrigation dam project building. The only significant feature observed after the earthquake was about a 30 m long longitudinal crack down to a depth of about 1 m in the earth portion of the dam on its right flank. This has been caused by the shaking in the 1.75 m thick 'murrum' cover provided over the black cotton soil earthen dam to protect it against the fissures which develop in black cotton soil on drying. Another feature observed is about 5-8 cm wide gap caused due to separation and settlement of the earthen part of the dam with respect to the concrete structure. This had been caused by the differential shaking of the two portions of the dam. Evidence of some separation was observed, even before the earthquake due to settlement on the earthen portion of the dam. The dam was about four years old and such settlement of unconsolidated material by shaking or by other natural processes is expected. There has been no damage to the dam and its appurtenances.

DAMAGE IN KILLARI VILLAGE

Killari villages is the biggest village in the area with a population of over 20,000. It is situated on the northern bank of the west to east flowing Tirna river. The portion of the village situated near the river bank had suffered excessive damage probably due to higher thickness of loose alluvium layer. The Killari village had been completely razed to the ground and the construction material used in the abnormally thick walls and roofs had almost raised the level of the village site to mare than 1.5 m .One three storied newly constructed building, however, had escaped unscathed by the earthquake as it was a well designed R.C.C. construction. The general view of Killari village where practically all the building had collapsed except for the above where practically all the building survived total collapse. All building using stone and mud masonry had been totally destroyed. Some had cracks and there were also cases of movement or rotation of structures. No of such features either follow the weaknesses in structural designs, joint planes and/or loading of the structures. The unaffected water tank of about 10m height and other structures suggest the ground shaking to be predominantly vertical in nature (from the study of the unaffected structures in Killari)which could be related to L-waves.

DAMAGE TO SASTUR VILLAGE

Sastur village located south of Tirna river was also one of the villages heavily damaged. Destruction to houses is almost total except for a few cement–brick–concrete structures. Out of two historical monuments located in Sastur one collapsed The damaged upper portion of the monument, locally know as "Fumbaj" , collapsed in such a manner that the debris fell equally on the four sides of the square structure. This indicates that the acceleration was predominantly vertical. Another interesting observation is of 'maruti temple' where the mud walls on all sides had crumbled but the heavily loaded structure remained intact on its wooden posts. Super structure of the temple suggests the near absence of horizontal acceleration at the time of earthquake..

While the Mezoseismal area (maximum damage) was confined to an area of 6 km radius near Killari with maximum intensity **VIII** and rapid fall of intensity with distance indicates shallow focus of the earthquake. Nevertheless, the shock felt area had been extremely large. This may be attributed to efficient transmission of seismic waves in the Precambrian shield. Similar observations were made for other earthquakes in the peninsular shield region. The Koyna earthquake of 10th December 1967 was also felt over a very large area.

The village of Talni, 2 km north of Killari village is another village north of Tirna river which had suffered heavy damage and destruction. North of Talni steep drop in intensity had been observed.

Between Talni and Killari villages surface deformation has been observed over an area of 250 m x 10m and which was uplifted by 50 cm. A detailed study of this zone has been presented in a paper by Chetty and Rao ,1996. Village of Petsangvi had also suffered extensive damage. All the buildings had collapsed.

EARTHQUAKE ACTIVITY IN 1992 NEAR KILLARI

A number of mild tremors occurred in October-November 1992 and were felt in Killari and nearby village. About 125 tremors were reported to have been felt locally by the public. The magnitude of the largest tremor on 18th October 1992 was ~ 4.0 on Richter scale and caused damage to about 100 house in Killari village. Many houses with mud –

stone construction had developed cracks. Details of earthquake activity in 1992 has been reported by Baumbach et al. (1994)

HISTRICAL RECORD OF SEISMICITY

The peninsular shield region of India was considered to be aseismic. However, the earthquake in Koyna (1967), Bhadrachalam (1969) and Bharuch (1970) have raised some doubts about the aseismic nature of the shield. During the last three decades a low magnitude seismic activity has been found to be prevalent in the peninsular shield (Indra Mohan et al. 1980). This may partly be attributed to the installation of seismic stations at Hyderabad and Gauribidanur and increased awareness. An earthquake of magnitude 6.3 on 10th December 1967 had been the most damaging earthquake prior to 1993 earthquake and was also felt widely in an area with a radius of about 700 km. had a local intensity of + VIII caused loss of life and property in addition to damage to dam structure, and raised doubts about the safety of precious power genetation project (Gupta et al., 1969). The increased level of seismicity in the Koyna region and in the adjoining Warna dam region continues till today. Four earthquake of magnitude between 5.0 and 5.5 have occurred in Koyna – Warna region between 28th August 1993 to 1st February 1994 with many more small magnitude shocks. The Koyna region has, on the other hand, reported so far over35,000 tremors with about 70 shocks having magnitude 4.0 and above.

A list of earthquakes which have occurred in the peninsular shield in general and Maharashtra region in particular was compiled by Kilkar (1968) and Gubin (1968). In the coastal strip of Konkan, on the west coast of India, extending from Bombay upto Goa

(15030'n, 740e), nine earthquakes have been reported for the period 1594 to 1832 A. D. In addition, six earthquakes have been reported as located along the continental divide, for the period 1752 to 1835 A. D. It is significant to note that from 1835 to 1951 A. D. period for which a comparatively better records are available, not a single event was reported. The absence of seismic activity during this period may perhaps, be responsible for the prevailing belief of the aseismic character of the region. Later, two minor shock were felt at the coastal town of Jaigarh (170 18' n, 730 13' e) in 1951 and one around Ratnagiri in September 1962.

SUBTERRANEAN SOUND AND SMOKE EMISSIONS

Several reports of subterranean sounds associated with feeble shaking have been reported in the past from the different parts of Decan trap region (Deshmukh 1968). An earthquake which occurred in October – November, 1956, in Halbarga village, Bidar District (18.0N, 77.20'E) in Karnataka state is close to the present site. Several tremors were felt along with rumbling sounds heard on many occasions in an area of about 1.6 km radius. The intensity of the shaking was worked out between III & IV on M.M. scale. In Homnabad in Karnataka state, located on Hyderabad–Bombay highway, there were several report of smoke or vapour emission associated with the heating of the ground surface after earth tremors in 1934 and 1935. Several reports of subterranean sound and smoke or vapour emissions along with heating of the ground were reported on a area scale during the three week period after the Killari earthquake in an area of about 200 km radius.

Table 4.4

SUMMARY OF OBSERVATIONS MADE AT THE SITES DURING 1983 AND EARLIER AS REPORTED BY ASOLKAR (1983).

Locations	Observations
BHIR DISTRICT	Fissure 30'-40' length and 2' deep
Kolewadi	A fissure along Nala bed
Kapildharwad	A water tank collapsed
Manjarsumba	Subterranean sound (s. s.).
Ammmbajogai	Mild tremors
Ghatnandur	S. S. A number of walls collapsed. Two children died and 36 sheep buried.
PARBHANI DISTRICT Dampuri	S. S. heard from 23.9.83. Increased in intensity and frequency. On 8.10.93 7, sounds were beard lide rumbling or blasting sound. Falling of utensils. Development of fissures and Landslide. Shattering of Roof tins. Reports of steam coming out of ground.
Wapti	Subterranean sound heard earlier in 1966, 1967, 1974 & 1975 also. Also reports in 1983 from villages of pagra and sina. Big

	sounds in June & September 1983. Normally after rains.
Kotha	Mild subterranean sounds in September 1983.
Kurunda	Subterranean sounds like blasting
OSMANABAD DISTRICT Bori	Subterranean sound for about 6 month in 1967. Mild tremors were felt. Two springs were created.
LATUR DISTRICT Yeldari	On 9.10.1983 at 17:15 hrs. thundering sound was heard.
Satala	A mild tremor in Subterranean Kaothala & Takil for about 2 months. 18 events between 6.10.83. cracks development in number of houses. Falling of objects.
Bolegaon	Rumbling sound in 1970 with severe intensity. Shattering of Tin roofs. No cracks observed. Intensity less in 1983. One loud sound on 13.9.83 at 10A.M.

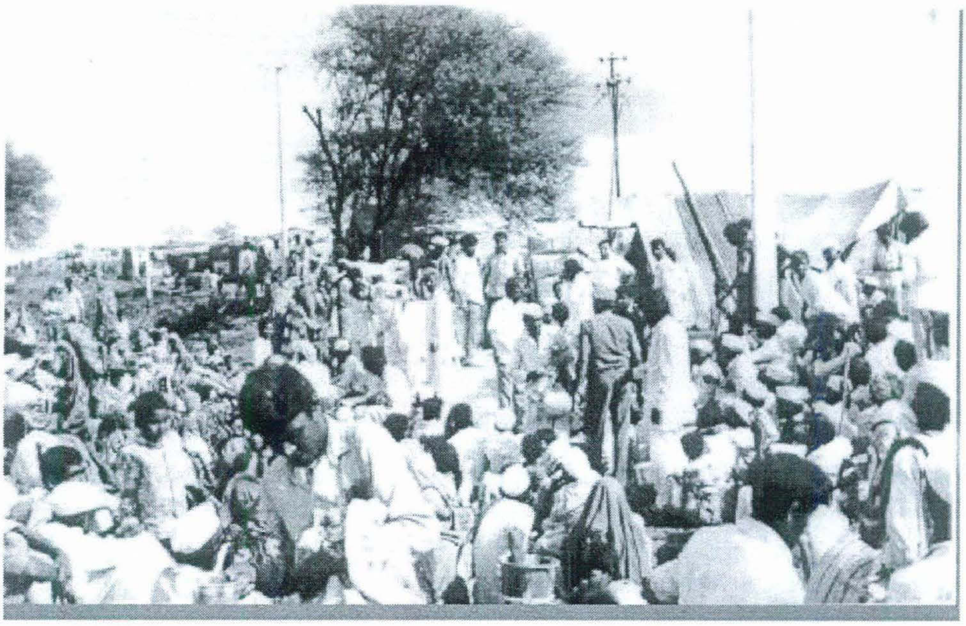
Khulgapur	Subterranean sound on 16.10.83. cracks in a few houses. 16 sounds between 16.10.83 – 15.11.83. Harwadi – north of Khulgapur experienced on 27.10.83.cracks developed in some houses. Some sliding.
Lohara	Subterranean sounds moderate to low intensity with occasional tremors during 1st week of September 83 to 2nd week of October 83. Similar sounds reported in 1953. No cracks observed. On 12 October, 1983. Four big sounds like blasting.
Yarul	Subteranean sounds. Subsidence in portion of village. Oozing of spring water for 3 days.

Left-lateral strike slip. Unknown location. GSI

Plate - 3

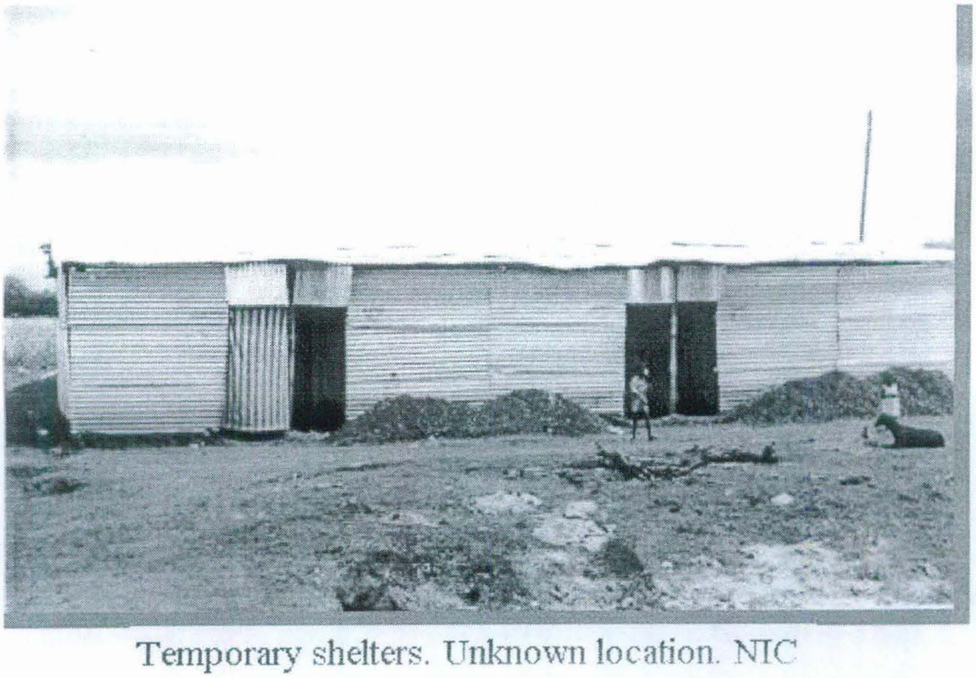
Mud masonry building, Sarni. GSI

Plate - 4



Distribution of relief. Unknown location. NIC

Photo No. 5

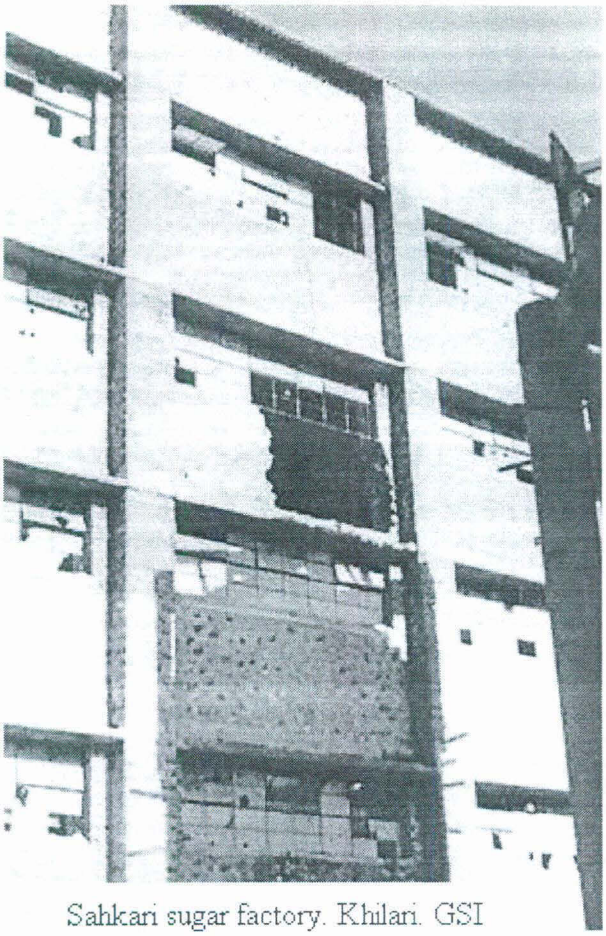


Temporary shelters. Unknown location. NIC

Photo No. 6

While most elevated water tanks performed well, this tank of Kautha collapsed straight down into its crumpled supports. Circumferential displacement of about 0.5m suggests that rotational vibration led to its collapse.

Photo No. 7



Sahkari sugar factory. Khilari. GSI

CHAPTER-V

Summary and Conclusion

The tectonic fabric of the area defined by the lineaments present close similarities to the granite-gneiss terrain of Peninsular India. It suggests that the Precambrian tectonic framework has been impressed on to Deccan basaltic cover pointing to the reactivation of the basement (presumably Precambrian gneissic terrain). Similar inference was also drawn from the lineament patterns by Powar and Patil (1980). Following the analogy from the Precambrian terrain (Chetty, 1993), the NW-SE lineaments may represent shear zones along which strike-slip displacements have taken place while dip-slip displacements are common features along the ENE-WSW cross faults. These lineaments may thus represent shear zones, fault zones or fracture planes. The reactivation of the basement beneath Deccan traps suggests that geological deformation is a continuous process. This has been further supported by geomorphological characteristics and neotectonic faults inferred from this study. Based on geomorphological studies in Deccan trap region, Raju et al., (1971) concluded that differential movements of individual areas have taken place in post trappean period essentially controlled by tectonic features. In the light of the foregoing discussion and based on this studies it can be suggested that the area is geologically active and the processes have been continuous. Based on the study of active and neotectonic faults, it has been demonstrated elsewhere that intracontinental faulting deformation can be explained with a model of continuous deformation (Mercier et al., 1979.)

The mapped surface deformational features such as arcuate and discontinuous displacement scraps, extreme variations in strike along the length, differential subsidence and/or upliftment with throw predominantly to the south, vertical open fracture, suggest that the surface deformation accompanying the earthquake is likely to be related to differential movements of blocks. The NW-SE orientation of KDZ occurring close to a NW-SE-trending major lineament passing through Killari, and the presence of other sub-parallel lineaments on either side clearly show that this NW-SE major lineament has been quite active. Ground observations suggest that the drainage pattern is mostly lineament-controlled.

The lineaments inferred from the Satellite images and the faults inferred from geomorphological considerations suggest that the area is divided into a number of blocks which have got involved in vertical movements.

- As maximum inferred sub-surface faults are concentrated either side of Tirna river, it proves that river flown in a fault, not along the slope and hence the river is seismologically tectonically controlled.

Again the lineament pattern also suggest that

i. straight segments of drainage pattern

ii. increased depth of soil horizon and weathered basalt,

iii. presence of high yielding wells and dense vegetation.

iv. Intense fracturing in rocks at shallow depth.

v. Low-lying topography associated with steep valleys

vi. The presence of fluvial deposits are often associated with sandy beds

vii. Discontinuous pattern of lineament

These suggest that many lineaments represent fault and fracture zone hence it is seen that change in linear structure is maximum concentrated along watershed of the river

- From the 187 after- shock evidence proves that the after- shock data is clustered near the point of confluence of the two tributaries of the Tirna river south of Killari village, which proves the river is seismologically tectonic.
- Geological structure suggests that the river is rectangular drainage pattern suggest and sudden changes, sharp bending, straight courses, convergence or divergence off set drainage and deflected drainage which infer the trends of sub-surface fault.
- The earthquake caused anomalously high damage to life and property in about 6 km radius near Killari in the district of Osmanabad and Latur of Maharashtra.
- Almost all the existing structure were razed to the ground and/ or rendered unsafe for living. The damage can be ascribed as total in the meizoseismal area.
- The heavy toll to life and property is attributed to the nature of construction prevalent in the region by using heavy and undressed stones and mud mortar.
- The intensity outside the meizoseismal area dropped steeply to VII and VI at a distance of about 6 km and 11 km respectively. Small meizoseismal area suggests shallow depth of focus which is estimated as 12$\pm$ 3km.

- The earthquake was reported to have been felt in an extensively large area. The large area where felt can be attributed to the good transmission of seismic waves in the peninsular shield region.
- A recapitulation of seismicity of the region indicates absence of any activity during 1838 to 1951 A.D. This has probably led to the conclusion of assigning aseismic character to the region.
- The micro earthquake activity; subterranean sounds; smoke, steam and gas emanations, are prevalent in the whole region. Such activities were observed after heavy rains.
- The earthquake activity of 1992 near Killari village was not considered as precursor to any large earthquake in the region because of the prevailing belief of the aseismic character of the region.

The gruesome statistics are quite effective in delimiting the mesoseismal area. In an area of 10x10Km centered as Tirna river 20% of the people were killed. Outside the area relative casualties decreases rapidly. This mesoseismal area along probably corresponds spatially to the main shock rupture, the surface along the northern limit of the area.

No. of deaths in year 1993 all over the world from appendix show that highest no. of death which is around 9748 in India which proves that vulnerability is high.

Hence we should remain prepared for reducing the earthquake vulnerability as compared to world standard, keeping in mind the peculiar geological and geomorphological parameters.

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APPENDIX 1

Epicentral paramenters of the aftershock located using the mobile seismic network.

Gap- maximum azimuthal gap between two stations.
N - number of reading used in locating the earthquake.
DM- distance from the epicenter to the nearest station in KM.
RMS- root mean square error of time residuals.
ERH- horizontal location error in Km.
ERZ- vertical location error in Km.
Q- quality of the solution (A,B,C, or D).

Date	Origin	Lat n	Long E	Depth	No	Gap	Dmin	Rms	Erh	Erz	Qm
931010	117 47.77	18-0.00	76-34.29	2.89	6	231	6.1	6.1	0.2	0.2	C1
931010	1755 37.70	18-0.05	76-31.48	3.85	8	250	10.7	0.09	0.8	2.1	C1
931011	64 32.62	17-58.01	76-30.88	10.41	8	246	13.1	0.09	0.8	1.2	C1
931012	533 50.56	17-59.38	76-34.34	5.53	7	228	6.5	0.09	0.9	1.7	C1
931012	1415 51.49	18-4.18	76-33.96	9.28	10	201	8.3	0.08	0.6	0.6	C1
931012	1532 5.61	18-0.42	76-32.99	12.59	10	202	8.1	0.15	1	1.1	C1
931013	1618 28.17	17-59.84	76-32.70	8.14	8	204	8.8	0.12	1.2	1.8	C1
931014	1025 51.17	17-59.43	76-32.18	5.34	7	207	9.9	0.13	2.3	5.9	D1
931015	323 52.09	18-1.67	76-38.31	1.38	8	1.9	1.7	0.08	0.7	1.1	B1
931016	719 31.97	18-1.82	76-34.36	8.1	5	305	5.7	0.09	3.3	2.1	D1
931016	858 13.24	18-2.75	767-33.29	3.65	6	264	8	0.17	2.6	3.1	D1
931017	07 26.40	18-0.65	76-33.72	0.59	10	156	4.4	0.18	1.3	27.8	C1
931017	1030 370-.74	18-0.64	76-27.35	1.39	6	329	13	0.01	0.3	3.3	C1
931017	1045 5036	18-2.14	76-29.02	3.23	5	324	9.4	0.01	0.5	1.1	C1
931017	1137 36.28	18-2.04	76-38.01	1.68	6	286	1.8	0.02	0.3	0.3	C1

Date	Origin		Lat N	Long E	Depth	No	Gap	Dmin	Rms	Erh	Erz	Qm
931017	14 3	4.60	18- 1.05	76-30.63	4.48	6	307	7.4	0.01	0.2	0.3	C1
931017	14 5	13.55	18- 3.42	76-32.31	3.53	6	319	3.6	0.01	0 2	0.2	C1
931017	1752	17.70	18- 1 77	76-31 23	4.02	6	304	5.8	0.01	0 3	0.4	C1
931017	1755	49.44	18- 0.59	76-31.27	5.37	6	299	6.9	0.01	0 2	0.2	C1
931017	18 2	55.95	18- 1.09	76-35.58	2.68	6	147	3.4	0.02	0.1	0.3	B1
931017	1852	7.63	18- 2.90	76-31.34	3.87	5	315	5.2	0.02	0.5	0.8	C1
931017	2111	40.51	18- 1.37	76-31.09	5.21	5	303	6.4	0.2	0.2	0.3	C1
931017	2124	23.71	18- 3.20	76-29.47	4.44	5	327	8.5	0.01	0.4	0.8	C1
931017	2127	54 17	18- 2.20	76-031.43	5.02	9	260	5.3	0.07	0.7	1.0	C1
931017	2224	23.88	18- 1.94	76-30.96	3.43	6	308	6.2	0.00	0.1	0.1	C1
931017	23 9	47.92	18- 1.48	76-33.84	2.60	6	230	2.8	0.00	0.0	0.1	C1
931018	238	52.44	18- 0.53	76-33.30	3.59	6	255	4.8	0.01	0.1	0.2	C1
931018	1321	4.70	18- 2.58	76-32.25	3.04	9	269	3.7	0.10	0.1	1.5	C1
931018	1638	32.07	17-59.74	76-31.83	4.98	6	293	6.8	0.00	0.1	0.1	C1
931018	1657	50.63	18- 0.69	76-28.97	7.39	5	320	10.3	0.00	0.1	0.1	C1
931018	18 9	42.70	17-59.02	76-33.08	5.62	13	80	4.4	0.21	1.1	1.9	B1
931018	1822	18.43	18- 1.07	76-33.16	3.58	6	257	4.0	0.02	0.2	0.3	C1
931018	1835	57.42	18- 1.55	76-34.39	2.54	6	200	2.6	0.01	0.1	0.1	C1
931018	2032	10.27	18- 0.71	76-30.69	5.80	6	306	7.6	0.00	0.0	0.1	C1
931018	2110	2.56	18- 1.52	76-33.83	3.42	6	230	2.8	0.01	0.1	0.1	C1
931018	2225	39.58	18- 0.75	76-34.68	2.14	6	196	3.7	0.01	0.0	0.1	C1
931018	2238	29.63	18- 1.80	76-33.76	2.16	6	235	2.3	0.01	0.1	0.2	C1
931019	115	32.96	18- 2.84	76-32.08	3.49	6	308	3.9	0.01	0.1	0.2	C1
931019	339	56.71	18- 2.80	76-34.52	1.09	5	175	0.5	0.01	0.1	0.1	C1
931019	1038	39.45	18- 1.56	76-33.58	2.80	6	242	2.9	0.01	0.1	0.2	C1
931019	1511	8.12	18- 2.91	76-31.88	3.06	6	311	4.3	0.01	0.2	0.2	C1
931019	1611	19.93	18- 0.86	76-32.96	2.32	6	264	4.5	0.01	0.1	0.3	C1
931019	1717	42.16	18- 1.57	76-28.39	3.95	6	325	10.7	0.01	0.2	0.5	C1
931019	1840	13.48	18- 1.40	76-33.51	2.89	5	245	3.2	0.01	0.1	0.2	C1
931019	1929	7.66	18- 1.66	76-33.30	1.72	5	255	3.0	0.00	0.1	0.2	C1
931019	1957	32.36	18- 1.10	76-33.25	2.26	6	254	3.9	0.01	0.1	0.2	C1
931019	2054	27.76	18- 0.53	76-26.17	2.01	6	333	15.0	0.01	0.2	1.3	C1
931019	2110	18.72	18- 0.97	76-33.23	2.44	6	255	4.1	0.01	0.1	0.2	C1
931019	2121	29.48	18- 0.14	76-31.74	4.58	11	98	6.9	0.10	0.7	1.3	B1
931019	2121	29.46	18- 0.24	76-31.41	0.33	12	100	15.9	0.18	0.621	4.0	C1
931019	2337	16.46	18- 2.37	76-33.11	2.09	6	278	2.4	0.01	0.1	0.1	C1
931020	013	12.49	17-58.30	76-32.79	2.28	6	300	5.0	0.00	0.0	0.1	C1
931020	1 0	3.04	17-58.20	76-32.71	2.23	5	303	5.2	0.01	0.2	0.5	C1
931020	442	9.23	17-56.35	76-39.57	3.18	6	326	8.5	0.03	0.6	1.2	C1
931020	644	51.74	17-56.52	76-39.14	4.09	5	324	7.7	0.00	0.1	0.1	C1
931020	1034	2.41	18- 1.93	76-34.10	2.70	6	216	1.9	0.01	0.0	0.1	C1
931020	1258	20.52	18- 1.89	76-32.09	3.84	6	292	4.4	0.02	0.2	0.3	C1
931020	1437	1.18	18- 1.71	76-34.22	2.61	6	208	2.3	0.01	0.1	0.2	C1
931020	1534	46.44	18- 1.82	76-31.98	3.46	6	293	4.6	0.01	0.2	0.2	C1
931020	1919	44.05	18- 1.79	76-34.46	2.76	6	193	2.2	0.01	0.1	0.2	C1
931020	1926	59.24	18- 1.76	76-34.40	2.81	6	197	2.2	0.00	0.0	0.1	C1
931020	1955	35.60	18- 1.49	76-31.63	3.67	5	296	5.4	0.01	0.3	0.5	C1
931020	2030	25.51	17-59.62	76-34.47	2.02	6	234	2.3	0.00	0.1	0.1	C1
931020	2150	30.23	18- 1.82	76-31.27	4.12	5	304	5.7	0.00	0.1	0.1	C1
931020	22 8	31.08	18- 1.69	76-36.94	2.23	6	195	1.3	0.02	0.2	0 3	C1
931020	2220	50.20	17-59.57	76.34.44	2.64	8	175	2.3	0.10	0.7	1.2	B1
931020	2220	50.29	17-59.64	76.34.52	2.08	6	231	2.3	0.00	0.0	0.1	C1
931020	2241	58.30	17-59.77	76-32.23	5.81	9	189	6.1	0.08	0.7	1.0	C1
931020	2315	1.79	17-59.63	76-34.48	2.05	6	233	2.3	0.00	0.0	0.0	C1
931020	2338	53.70	18- 2.28	76-32.27	3.30	6	294	3.8	0.01	0.1	0.2	C1
931020	2346	37.70	17-59.66	76-31.79	5.81	6	295	6.8	0.00	0.0	0.1	C1
931021	0 3	49.64	17-59.60	76-34.40	1.97	5	237	2.4	0.00	0.0	0.0	C1
931021	0 7	24.49	18- 1.76	76-33.51	2.06	6	247	2.6	0.01	0.1	0.2	C1
931021	024	31.24	18- 1.55	76.33.69	0.39	5	237	2.8	0.02	0.4	9.5	D1
931021	025	8.24	18- 2.95	76-32.10	3.65	8	235	3.9	0.03	0.3	0.4	C1
931021	130	5.80	18- 2.25	76-29.25	4.25	8	250	9.0	0.02	0.2	0.4	C1
931021	222	12.57	18- 1.72	76-32.44	4.59	8	282	4.0	0.05	0.5	0.7	C1
931021	1041	8.63	18- 1.71	76-33.90	2.55	7	227	2.4	0.04	0.4	0.8	C1
931021	1445	45.22	18- 1.86	76-33.57	3.36	8	143	2.4	0.10	0.8	1.2	B1

Date	Origin	Lat N	Long E	Depth	No	Gap	Dmin	Rms	Erh	Erz	Qua
931118	1959 28.37	17-58.96	76-33.98	2.27	5	149	7.4	0.06	1.4	4.3	C1
931119	22 9 58.80	17-59.72	76-29.08	4.00	5	149	14.2	0.01	0.2	0.6	C1
931121	1645 18.83	18- 3.05	76-28.18	0.64	6	113	10.8	0.17	2.1	99.1	C1
931122	637 51.87	18- 3.05	76-32.10	5.00	6	195	3.9	0.23	6.5	5.1	D1
931122	723 28.74	18- 4.20	76-29.01	1.34	4	183	9.6	0.08			C1
931122	1131 52.88	17-56.23	76-34.40	2.25	5	147	12.4	0.38	2.1	11.0	D1
931124	447 52.71	18- 5.43	76-32.15	2.50	4	165	6.0	0.11			C1
931124	1446 1.71	18- 2.02	76-31.86	5.00	12	95	4.6	0.22	1.1	2.8	B1
931125	2114 47.69	18- 1.76	76-32.38	0.57	5	142	4.0	0.03	0.6	11.5	D1
931126	0 6 54.64	18- 0.99	76-31.56	3.20	6	143	6.0	0.05	0.4	1.2	B1
931126	19 9 30.74	18- 1.84	76-31.71	1.61	5	130	5.0	0.09	1.9	7.4	D1
931127	142 52.60	18- 0.29	76-34.40	5.00	8	181	4.9	0.51	4.8	7.8	D1
931128	212 38.22	18- 1.83	76.33.00	1.79	11	76	3.1	0.22	0.9	2.3	B1
931128	358 28.21	18- 1.90	76-31.89	1.08	11	102	4.7	0.22	0.8	5.6	C1
931128	614 46.98	17-59.73	76-31.28	5.00	12	146	2.4	0.20	0.8	2.0	C1
931128	20 6 28.98	18- 1.08	76-33.82	3.07	5	204	3.5	0.11	3.0	35.9	D1
931130	1851 39.16	18- 2.74	76-31.17	0.37	6	204	5.5	0.10	1.11	55.5	D1
931130	19 2 50.02	18- 0.32	76-29.18	1.66	10	93	5.5	0.19	1.4	6.8	C1
931130	2237 19.24	18- 1.64	76-31.41	2.52	8	95	5.1	0.18	2.0	2.8	B1
931201	7 5 53.53	18- 1.89	76-32.48	0.82	6	262	3.8	0.16	2.6	8.7	D1
931206	2057 23.80	17-53.62	76-35.47	5.00	3	187	7.3	0.01			C1
931207	1739 39.94	18- 5.20	76-30.64	3.41	16	100	8.3	0.31	0.7	3.6	C1
931215	023 59.33	18- 4.30	76-30.85	11.10	9	117	8.8	0.20	0.9	1.5	B1
931217	0 2 48.93	18- 5.11	76-28.52	20.21	7	140	18.6	0.28	1.7	3.8	C1
931217	1554 47.21	18- 0.11	76-31.55	5.00	3	99	6.8	0.12	1.4	2.4	B1
931219	849 44.44	18- 3.75	76-32.91	1.09	6	323	13.7	0.38	5.1	57.3	D1
931220	243 3.69	17-59.86	76-28.65	5.00	9	86	5.2	0.38	2.8	6.2	C1
931221	5 2 20.23	17-59.55	76-31.73	2.50	3	166	21.7	0.16			C1
931223	145 56.09	17-47.10	76-37.58	5.00	4	187	18.0	0.26			C1
931223	1424 55.79	17-58.27	76-29.80	4.14	7	107	8.6	0.16	1.7	2.4	B1
931225	2231 27.65	18- 2.44	76-30.03	3.88	6	237	11.2	0.09	1.4	3.1	C1
931229	319 54.61	17-59.05	76-32.77	6.19	9	139	4.3	0.15	1.1	1.3	C1
931231	1557 17.14	17-59.68	76-32.85	3.39	9	101	4.4	0.07	0.4	0.9	B1
940106	711 41.21	18- 1.89	76-32.58	2.50	8	95	5.1	0.62	3.1	17.0	C1
940107	2313 8.48	18- 3.95	76-31.23	5.00	6	182	20.4	0.04	1.5	2.8	C1
940109	758 4.98	17-59.20	76-26.74	11.72	12	142	5.3	0.52	2.4	5.5	D1
940110	2252 22.50	18- 1.01	76-28.31	2.50	8	185	8.2	0.24	1.6	9.2	D1
940111	2019 31.99	18- 0.41	76-31.28	5.00	10	119	3.2	0.49	2.5	6.5	C1
940115	016 48.48	18- 1.12	76-28.81	5.23	15	111	7.5	0.37	1.5	5.4	C1
940115	920 52.87	17-57.63	76-21.41	1.25	9	272	6.0	0.47	3.5	19.6	D1
940119	524 18.97	18- 0.77	76-29.51	5.00	3	141	6.1	0.01			C1
940120	1055 45.74	18- 0.00	76-27.49	13.38	10	135	6.5	0.54	2.3	6.6	C1

Date	Origin		Lat N	Long E	Depth	No	Gap	Dmin	Rms	Erh	Erz	Qm
931021	1628	28.95	18-1.81	76.32.60	3.11	6	259	3.7	0.01	0.1	0.1	C1
931021	1658	58.13	18-0.98	76-35.59	2.38	6	148	3.4	0.00	0.0	0.1	B1
931021	18 2	26.70	18-2.04	76-30.87	3.22	6	310	6.3	0.01	0.2	0.3	C1
931021	1856	43.54	18-0.28	76-32.62	4.29	6	275	5.7	0.01	0.2	0.2	C1
931021	2041	28.31	18-3.81	76-32.39	2.65	6	327	3.7	0.01	0.2	0.2	C1
931021	22 3	54.79	17-59.25	76-29.50	8.42	6	318	10.7	0.01	0.3	0.4	C1
931022	0 6	26.34	18-1.33	76-31.96	3.70	6	259	5.1	0.02	0.3	0.4	C1
931022	311	53.90	18-0.83	76-33.19	2.52	6	257	4.4	0.01	0.2	0.3	C1
931022	1717	12.64	18-1.04	76.34.40	2.67	5	146	3.5	0.14	2.7	4.4	D1
931024	612	40.12	18-0.31	76-34.40	1.79	6	145	4.9	0.10	1.2	4.3	C1
931024	1741	44.62	18-1.96	76-31.19	2.30	6	[illegible]	5.8	0.10	1.2	4.6	B1
931024	2314	50.52	18-1.92	76-33.40	1.28	6	[illegible]	2.5	0.03	0.5	1.5	B1
931025	2024	23.14	18-0.36	76-34.26	1.53	6	144	3.8	0.03	0.5	2.1	C1
931025	2142	37.42	18-3.05	76-34.40	5.00	4	[illegible]	[illegible]	0.66			C1
931026	822	45.57	17-59.59	76-33.15	23.25	19	151	3.8	0.24	0.9	1.8	C1
931026	17 8	12.77	18-1.53	76-33.34	0.72	16	116	3.1	0.16	0.5	4.4	B1
931026	1932	51.74	18-1.29	76.31.82	2.84	7	172	5.3	0.11	1.5	4.9	C1
931026	2047	42.47	18-3.05	76-30.41	2.08	5	195	6.9	0.05	1.2	4.6	C1
931027	1546	21.29	18-2.73	76-30.75	5.44	5	318	6.3	0.00	0.1	0.1	C1
931027	22 3	9.80	18-1.94	76-31.49	5.00	4	233	5.3	0.02			C1
931028	921	17.35	18-1.25	76-29.76	4.95	20	95	5.6	0.32	0.9	3.2	C1
931028	952	27.25	17-58.07	76-30.60	7.11	5	267	11.1	0.01	0.2	0.5	C1
931028	2227	36.69	17-59.18	76-30.62	6.60	6	192	9.5	0.03	0.4	0.6	C1
931029	1718	49.59	18-0.34	76-33.31	4.33	5	172	5.1	0.03	0.5	0.7	C1
931030	031	9.41	18-0.38	76-31.43	6.67	5	210	6.9	0.05	1.1	1.4	C1
931030	1039	38.48	17-59.68	76-31.59	3.18	5	199	7.7	0.02	0.2	0.6	C1
931030	1414	56.37	17-58.70	76-29.98	3.44	19	61	8.3	0.15	0.4	1.3	B1
931030	1935	31.60	17-58.72	76-32.10	8.91	10	150	8.7	0.11	0.8	1.1	B1
931031	1719	33.75	17-58.28	76-35.26	2.50	5	124	8.8	0.16	2.0	6.5	D1
931031	23 1	46.93	18-0.46	76-35.24	0.45	4	124	4.9	0.07			C1
931101	528	40.26	18-0.72	76-32.44	0.55	15	135	5.3	0.18	0.6	20.4	C1
931101	628	45.77	18-0.15	76-34.40	2.24	7	122	5.2	0.12	1.4	4.4	B1
931101	1614	47.82	18-1.12	76-33.67	1.43	8	282	3.5	0.17	1.6	2.7	C1
931102	155	13.99	17-57.56	76-33.02	6.55	4	241	10.2	0.00			C1
931103	733	33.95	18-0.46	76.34.08	0.68	4	154	4.6	0.05			C1
931103	733	33.95	18-0.11	76-33.30	1.66	4	170	5.5	0.13			C1
931103	19 9	39.93	17-59.66	76-34.40	4.94	4	190	11.6	0.08			C1
931105	0 2	58.65	18-1.27	76.34.23	3.53	4	153	3.1	0.09			C1
931105	1213	0.88	18-1.75	76-31.41	2.11	11	93	5.6	0.11	0.5	2.3	B1
931105	1254	9.53	18-3.14	76-33.10	4.18	3	289	2.1	0.01			C1
931105	2036	1.98	18-1.30	76-31.82	5.00	5	201	5.2	0.12	2.7	3.2	D1
931105	2312	17.55	17-56.84	76-34.40	4.77	4	189	11.3	0.14			C1
931106	2046	0.04	18-1.02	76-33.01	1.11	4	188	4.2	0.00			C1
931107	2344	34.82	18-1.51	76-33.96	0.86	4	158	3.8	0.06			C1
931107	2354	29.68	18-0.05	76-38.54	0.83	4	112	7.9	0.06			C1
931108	1948	51.08	17-58.93	76-31.77	6.16	5	139	8.7	0.01	0.1	0.2	C1
931109	1411	0.12	17-59.91	76-34.40	2.50	4	139	5.6	0.21			C1
931109	1527	13.34	18-2.73	76-31.78	10.30	5	270	4.5	0.02	0.5	0.5	C1
931109	17 5	41.61	18-5.64	76.30.16	3.59	9	134	8.8	0.23	0.4	1.9	B1
931110	1613	45.06	17-55.10	76.33.38	0.81	4	143	14.6	0.00			C1
931111	026	21.92	18-1.30	76-32.56	0.55	9	131	4.3	0.12	0.6	15.7	C1
931111	2342	14.89	18-0.47	76-30.70	5.00	6	252	26.8	0.15	3.0	13.2	D1
931112	646	37.16	18-1.11	76-35.27	5.00	12	87	3.8	0.23	0.9	1.8	B1
931112	916	20.54	18-1.35	76-27.66	3.63	21	89	2.3	0.18	0.4	0.9	B1
931112	1327	31.75	18-0.05	76-32.65	2.50	15	81	6.1	0.38	1.2	9.3	C1
931113	421	2.50	18-4.15	76.31.35	1.94	15	94	5.7	0.18	0.5	0.2	B1
931114	747	10.62	18-2.37	76-29.77	3.55	8	281	8.1	0.07	0.7	1.5	C1
931115	1055	19.04	18-3.05	76-31.23	7.00	11	173	5.4	0.31	1.5	2.4	C1
931116	12 0	59.01	18-0.94	76-31.47	3.65	14	108	6.2	0.23	1.1	2.5	B1
931116	20 1	47.93	18-2.76	76-31.98	3.72	7	104	4.1	0.05	0.4	0.6	B1
931116	2021	15.46	18-0.77	76.33.55	5.00	9	120	4.2	0.18	0.9	2.3	B1
931116	2032	44.98	18-3.61	76.32.35	1.37	8	103	3.6	0.11	0.4	2.3	B1
931118	814	1.32	18-0.54	76-30.85	8.54	13	90	7.5	0.17	0.8	1.0	B1
931118	14 1	27.38	18-0.55	76-30.16	8.79	9	110	8.5	0.16	1.0	1.7	B1

APPENDIX II

Date UTC	Region	Magnitude	Number Killed *
1993 01 08	Republic of South Africa	2.7	6
1993 01 13	Jamaica Region	5.5	1
1993 01 15	Kokkaido, Japan Region	7.6	2
1993 01 31	Yunnan, China	4.9	2
1993 03 12	Fiji Islands Region	6.4	5
1993 03 20	Xizang	6.2	2
1993 04 18	Central Peru	6.3	6
1993 05 14	Republic of South Africa	3.8	7
1993 07 10	Costa Rica	5.8	2
1993 07 12	Hokkaido, Japan Region	7.7	243
1993 07 22	Northern Colombia	6.1	2
1993 08 01	Sudan	5.5	2
1993 09 10	Near Coast of Chiapas, Mexico	7.2	1
1993 09 21	Oregon	6.0	2
1993 09 29	India	6.2	9748
1993 10 11	South of Honshu, Japan	6.9	1
1993 10 13	Eastern New Guinea Region, P.N.G.	6.9	60
1993 10 16	Eastern New Guinea Region	6.3	3
1993 11 22	Near Coast of Nicaragua	5.9	1
Total			