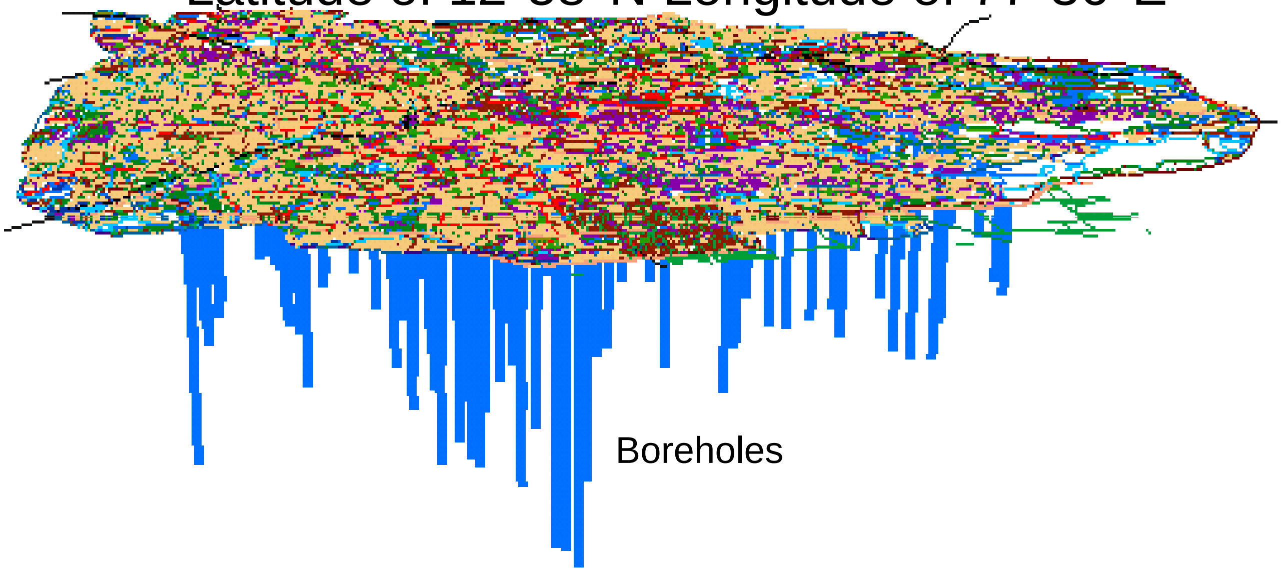
Seismic Microzonation of Bangalore Urban Centre : Integration Of Different Parameters to Develop Hazard Index Map Using GIS

Bangalore city 220 Km^2

Latitude of 12^{0}58''N Longitude of 77^{0}36''E



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Estimation of EQ hazard in an urban area is presented with an emphasis on local site effects

Outline

- **Introduction**
- **Microzonation of Earthquake I**
- **Microzonation of Bangalore**
- **Seismic Microzonation Maps**– Development of Hazard Index Map - Integrating geological & seismological layers using GIS - maps prepared
- **Summary**

Multidisciplinary approach – Engineering Seismology, soil dynamics, geotechnical and structural engineering

ESTIMATING RISK OF EARTHQUAKE DISASTER

- ***Seismic Risk***
  - ***Intensity at the epicenter (hazard),***
  - ***Objects and structures (exposure),***
  - ***Damageability (vulnerability),***
  - ***how far from the source and type of topography, soil deposits, water table (local site effects) – evaluation of local hazard***
- ***Reduction of vulnerability of our buildings and other structures, those existing and those being built or to be built, is the key to earthquake protection.***
- **It is here, the engineers have their most critical role to play.**

Microzonation is an important component of earthquake disaster risk management framework

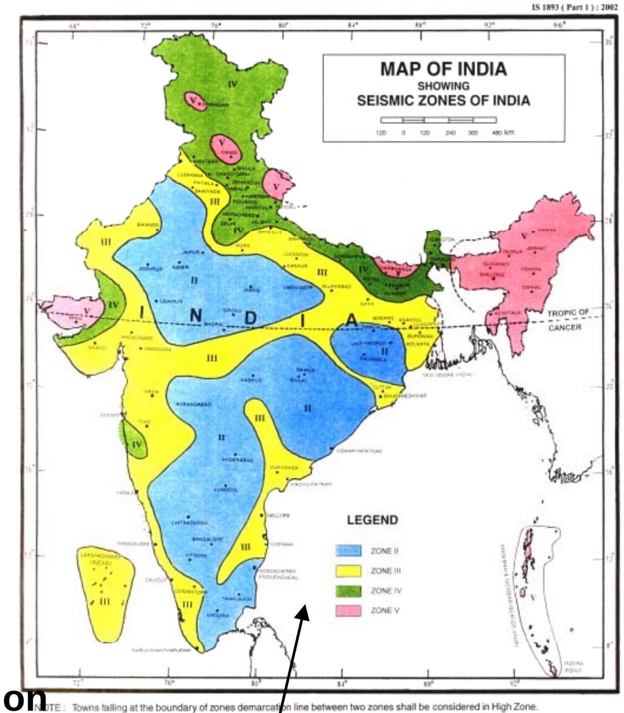
India's urban and semi-urban centers hazard assessment -considering local site effects is Important

It is here in evaluating Hazard, the Geotechnical engineers have their most critical role to play in assessing the local site effects.

Microzonation is defined as the zonation with respect to ground motion characteristics taking into account source and site conditions (ISSMGE/TC4, 1999).

Mitigation Strategies to reduce EQ Damages

- To Reduce Earthquake Disasters
  1. Understand the origins and forces caused by earthquakes- Assessment of seismic hazard
     - ❑ **Microzonation of a region.**
  2. Understand the behavior of structures under seismic action
  3. Know how to design buildings to prevent non-structural damage.
  4. Put that knowledge into practice- retrofit and rehabilitation of existing structures
     - ❑ **Development of appropriate code of practice**
     - ❑ **Development of quality control to insure correct application**
     - ❑ **Legislation**



- Buildings codes base seismic design forces on intensity of shaking during an earthquake. Design parameters are: Acceleration, velocity or spectral acceleration with a specified probability of exceedance. Mapping of these parameters on a national scale is called as MACROZONATION

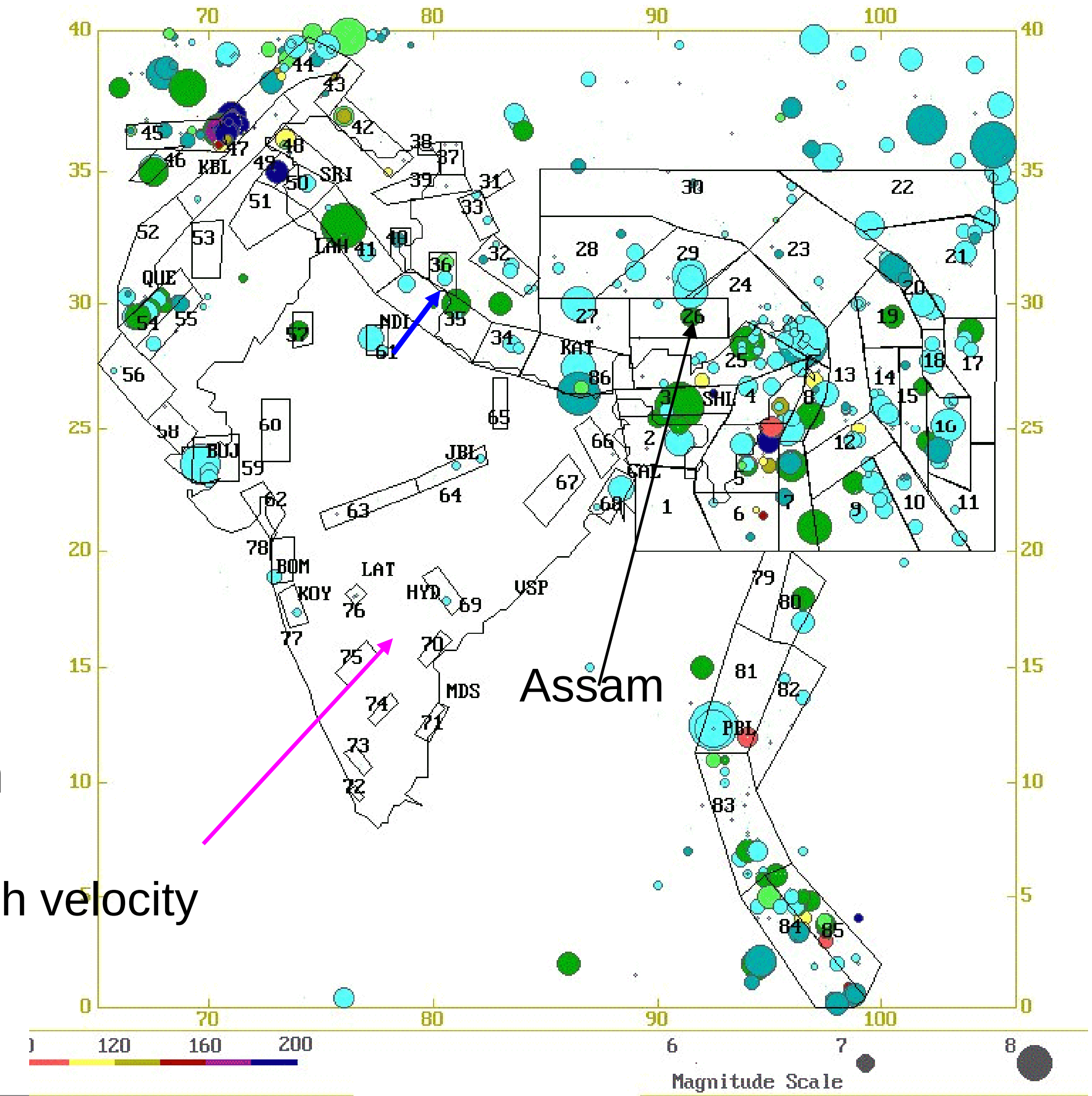
-Macrozonation are at small scales

Scale is in important issue: 1: 25000 or less for microzonation

Earthquakes in India

- Collision of India with Asia
  - region of greatest continental tectonic deformation in the world
- 15% of great earthquakes (M 8.0) in the 20th Century
- Assam EQ =8.5 – 7th largest
- Major earthquakes are at plate boundaries, intraplate, and along known faults

Global Seismic Hazard Assessment Program (GSHAP)



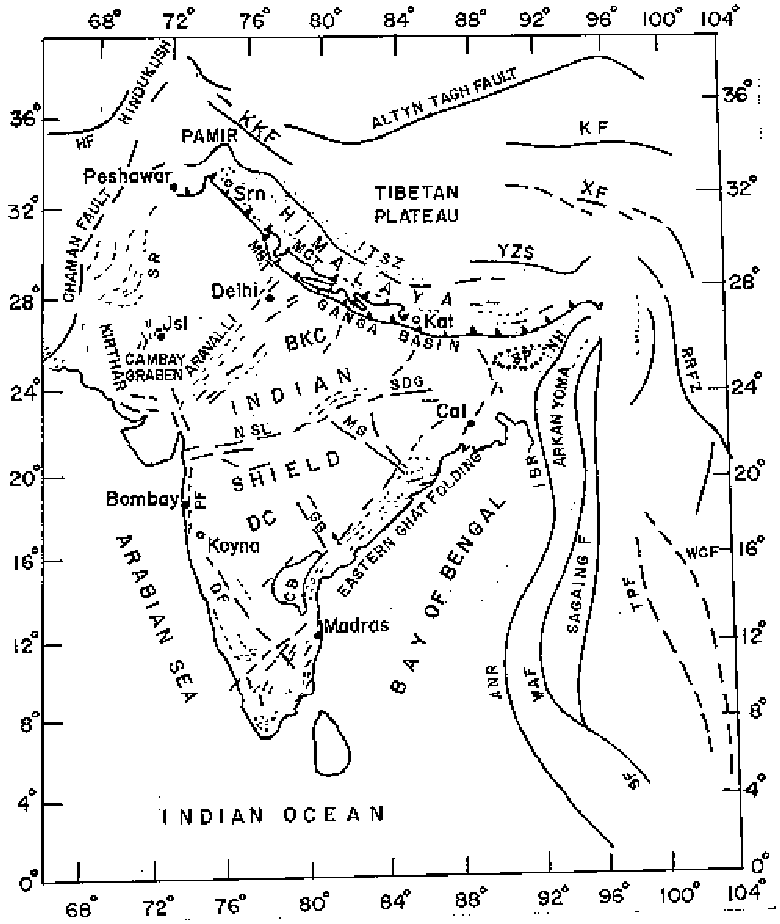
Seismic sources

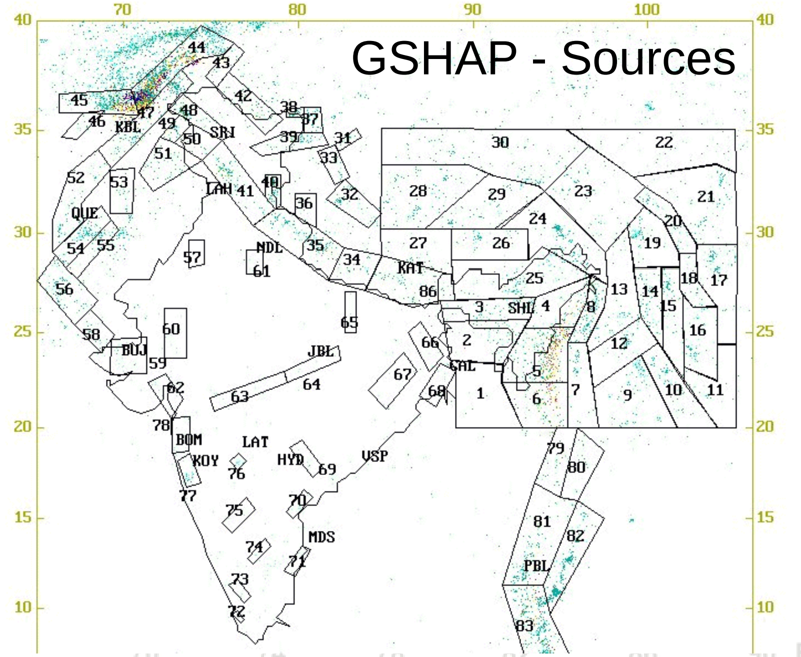
List of Major Earthquakes in India in the last 100 years

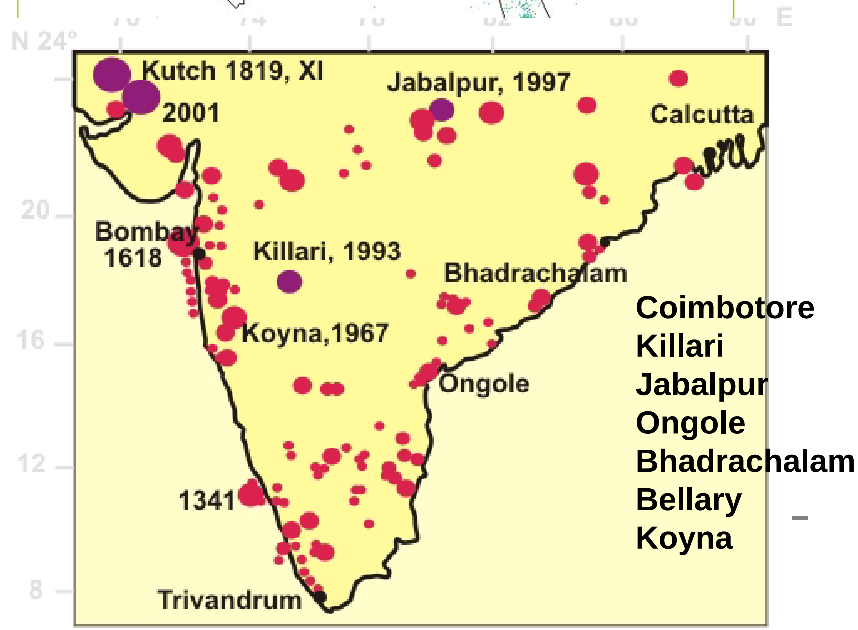
Date	Event	Time	Magnitude	Max. Intensity	Deaths
12 June 1897	Assam	16:25	8.7	XII	1500
8 Feb. 1900	Coimbatore	03:11	6.0	X	Nil
4 Apr. 1905	Kangra, Himachal Pradesh	06:20	8.6	X	19,000
15 Jan. 1934	Bihar-Nepal	14:13	8.4	X	11,000
31 May 1935	Quetta	03:03	7.6	X	30,000
15 Aug. 1950	Assam	19:31	8.5	X	1,530
21 Jul. 1956	Anjar ←	21:02	7.0	IX	115
10 Dec. 1967	Koyna	04:30	6.5	VIII	200
23 Mar. 1970	Bharuch ←	20:56	5.4	VII	30
21 Aug. 1988	Bihar-Nepal	04:39	6.6	IX	1,004
20 Oct. 1991	Uttarkashi, Uttranchal	02:53	6.6	IX	768
30 Sep. 1993	Killari (Latur)	03:53	6.4	IX	7,928
22 May 1997	Jabalpur, Madhya Pradesh	04:22	6.0	VIII	38
29 Mar. 1999	Chamoli, Uttranchal	12:35	6.8	VIII	63
26 Jan. 2001	Bhuj, Gujarat ←	08:46	7.7	X	13,805
08 Oct 2005	India-Pakistan	09.20	7.4	X	20,600

EQ's happened both at plate boundaries, intra plate and known faults (even in the shield region)

Peninsular India







Shield regions also generate earthquakes, much less frequently and of smaller magnitude, the activity occurring on paleorifts and other pre-existing structures.

Historic seismicity in peninsular India →

Major Hazards of Earthquakes

- Ground Shaking
- Liquefaction
- Landslides
- Tsunamis

Damages due to Earthquakes

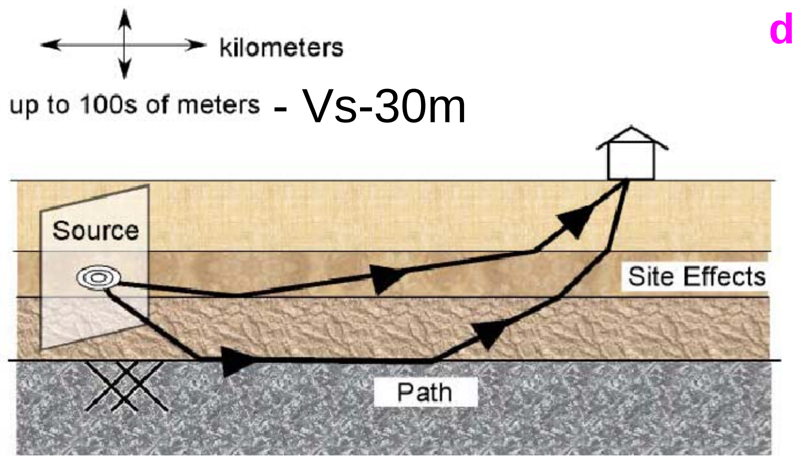
- Structural damage due to Inertia force during intense ground shaking
  - Frequency matching leading to resonance
- Indirect damage due to liquefaction or lateral spreading of the ground

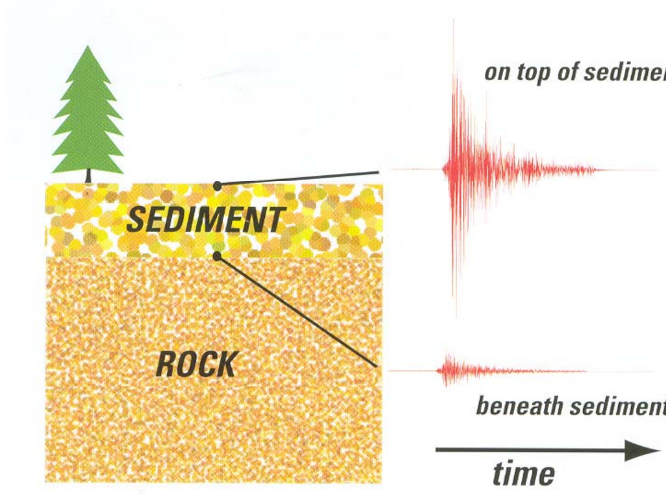
Reduced by following EQ Resistant Design

Even in developed world, geotechnics associated damage and mitigation measures have not yet been implemented to an extent to reduce the damage

Local Site Effects

Modification of the incoming wave field characteristics (amplitude, frequency, duration) due to soil characteristics and topography.





✓Seismic action at bed rock level

- ✓depends on the magnitude, source properties and properties of the path medium.
- ✓ Convolution of the input motion at the bed rock with the response of the upper soil layers will give surface result (Site conditions)
  - ✓ 1D representation with horizontal layers characterized by thickness and Vs-30m (geotechnical properties)
  - ✓ Field experiments – Ambient noise survey with reference sites

- 2D and 3D geometry, with linear and non-linear constitutive relations, topographical implications, etc influence the results

✓ Wave amplification in sediment layer

✓ Wave amplification due to Local topography

Damages due to local site effects and liquefaction in earthquakes

1985

Earthquake Damage in Mexico City, Mexico, September 19, 1985 - resonance

Million Dollar Bridge after 1964 Alaska earthquake

1964

Showa Bridge after 1964 Niigata earthquake

1995

Building in Kobe after 1995 earthquake

1999

Bridge in Taiwan after 1999 Chi-Chi earthquake

2001

Kandla port building after 2001 Bhuj earthquake

The effect of the subsoils on the earthshaking and building damage is emphasized.

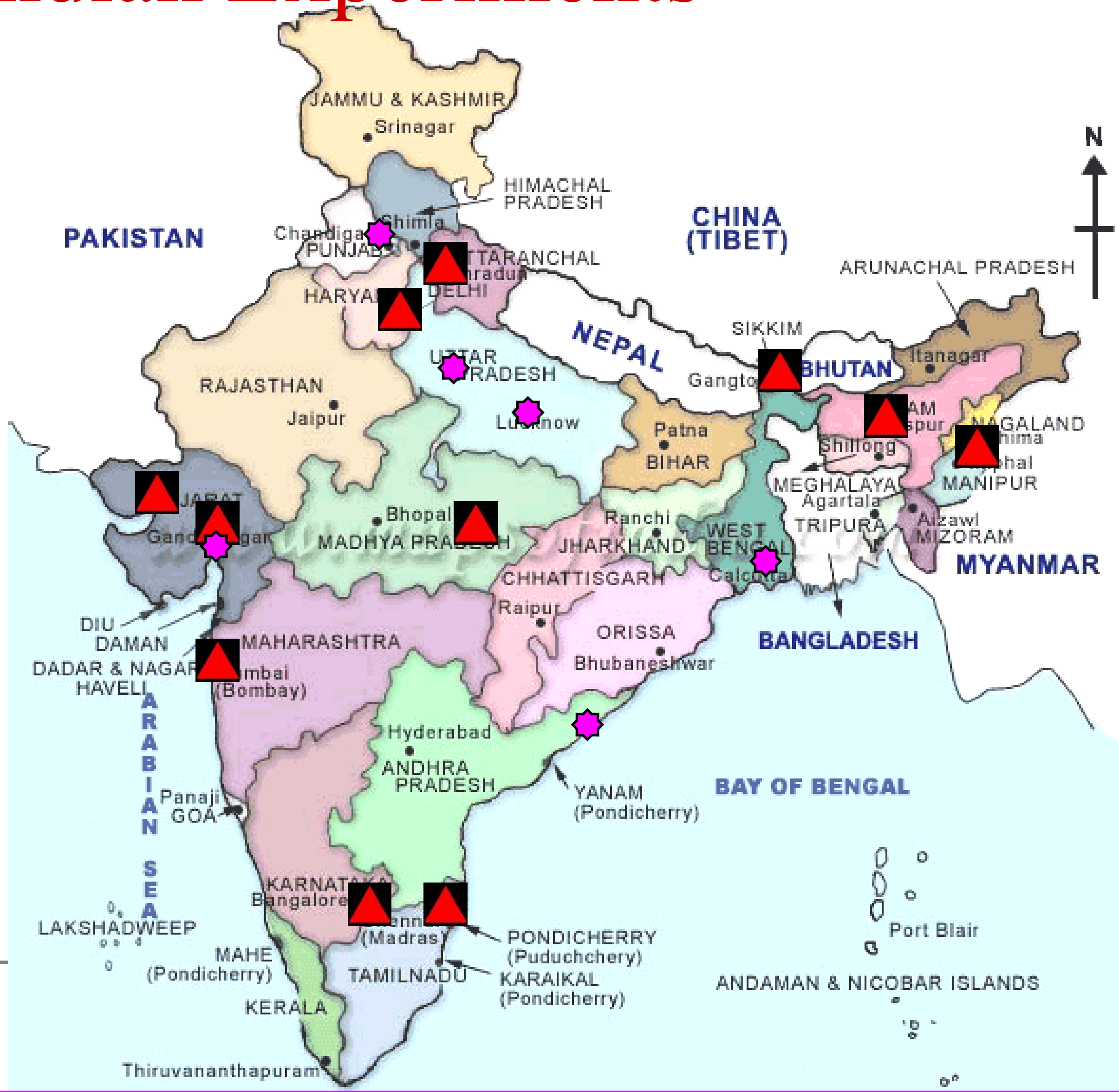
Microzonation Levels with Scale

- First grade (Level I) map - with scale of 1:1,000,000 – 1:50,000 Ground motion was assessed based on the Historical earthquakes and existing information of geological and geomorphological maps.
- Second grade (Level II) map - with scale of 1:100,000-1:10,000 Ground motion is assessed based on the microtremor and simplified geotechnical studies
- Third grade (Level III) map-with scale of 1:25,000-1:5,000 ground motion has been assessed based on the complete geotechnical investigations and ground response analysis

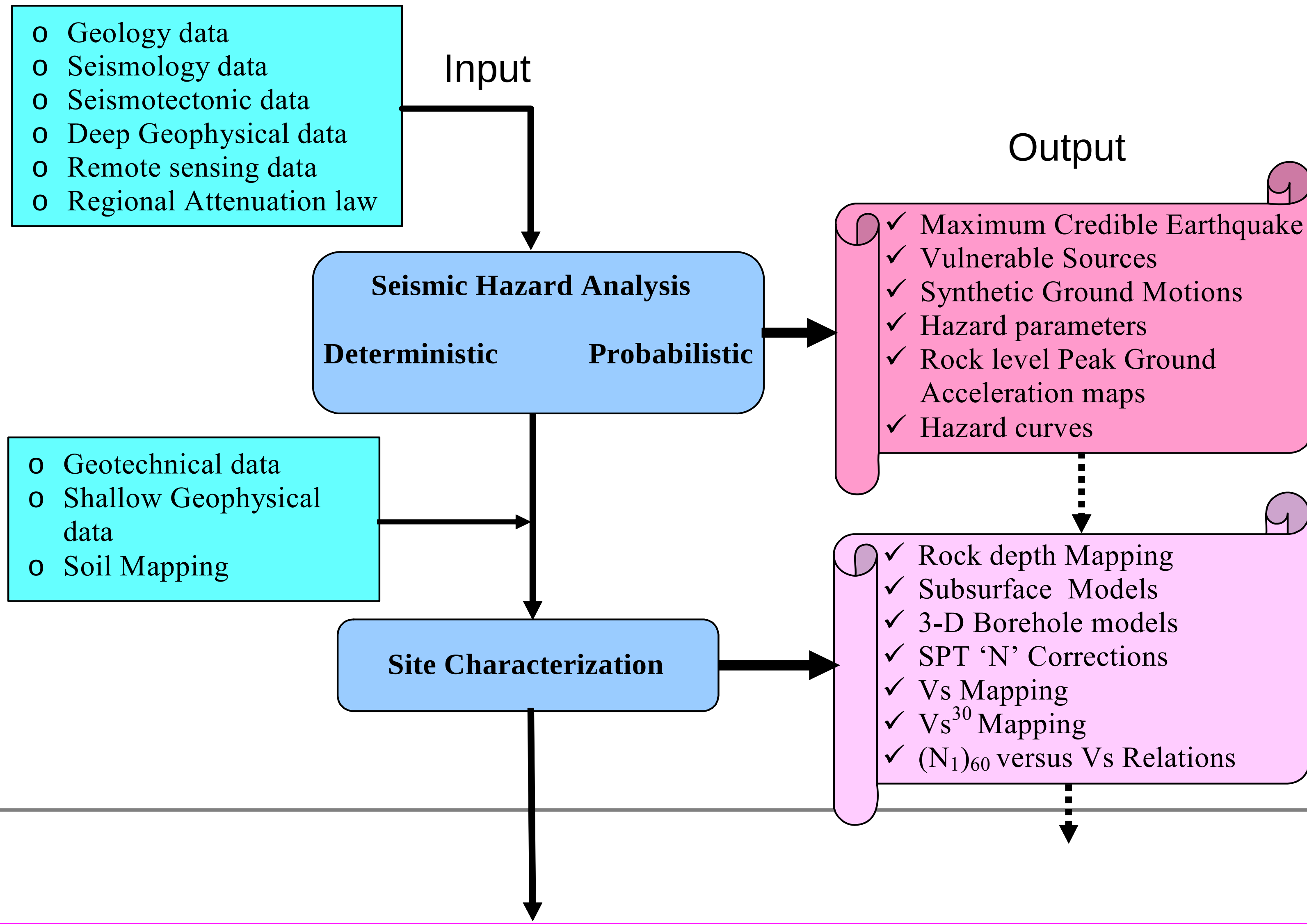
Microzonation of earthquake hazard

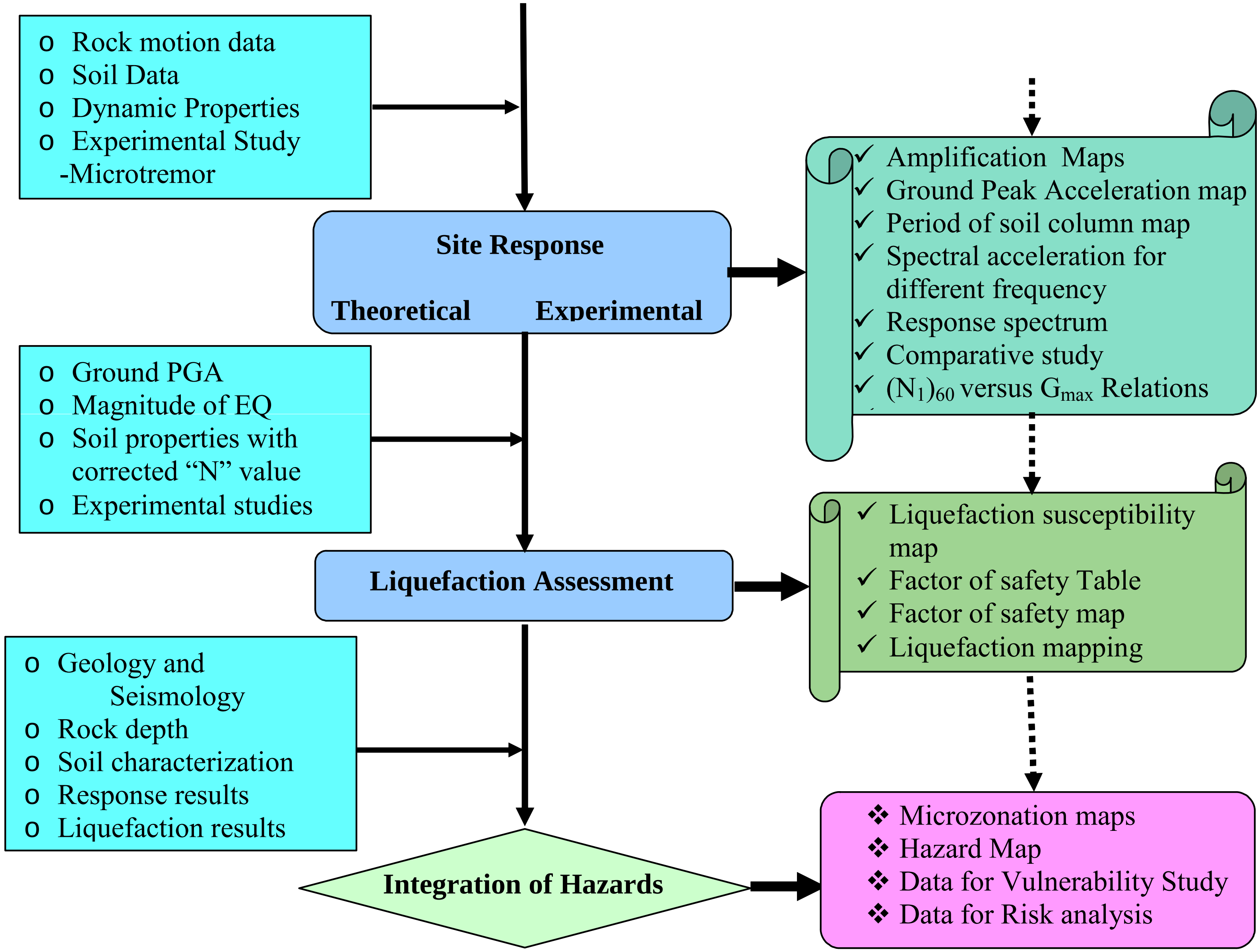
Indian Experiments

City / Areas
Jabalpur, MP
Sikkim
Mumbai
Delhi
North East India
Gauwhati
Ahmedabad
Dehradun
Bhuj
Chennai
Bangalore
Gandhidham
Vishakpatnam
Kolkata
Chandigarh



Steps for Seismic Hazard Analysis and Microzonation of Bangalore




o Rock motion data
o Soil Data
o Dynamic Properties
o Experimental Study -Microtremor
Site Response
Theoretical
Experimental
✓ Amplification Maps
✓ Ground Peak Acceleration map
✓ Period of soil column map
✓ Spectral acceleration for different frequency
✓ Response spectrum
✓ Comparative study
✓ $(N_1)_{60}$ versus G_{max} Relations
o Ground PGA
o Magnitude of EQ
o Soil properties with corrected "N" value
o Experimental studies
Liquefaction Assessment
✓ Liquefaction susceptibility map
✓ Factor of safety Table
✓ Factor of safety map
✓ Liquefaction mapping
o Geology and Seismology
o Rock depth
o Soil characterization
o Response results
o Liquefaction results
Integration of Hazards
❖ Microzonation maps
❖ Hazard Map
❖ Data for Vulnerability Study
❖ Data for Risk analysis

USE OF MICROZONATION MAPS

- Detailed evaluation of potential EQ hazards, urban development plans, comprehensive planning and zoning, siting of public facilities and utilities, redevelopment and retrofit plans, emergency management
- Seismic microzonation maps do not provide detailed hazard parameters at the level of the specific building site. However, they do provide guidance to the municipal planning department where site specific investigations are required

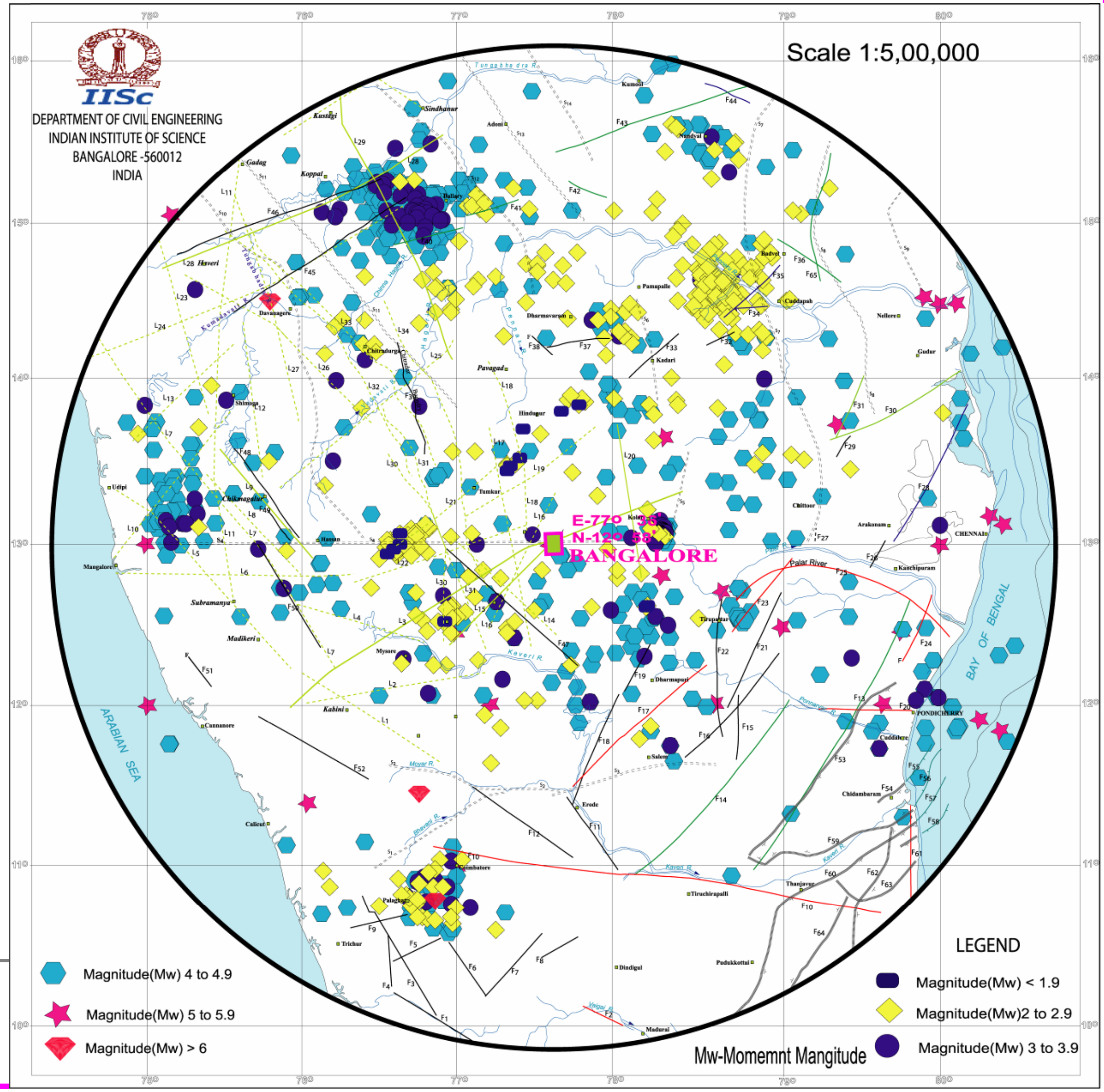
Seismicity of Study area   seismotectonic map

Events:

- 1421 Earthquake Events
- Ms, Mb, Intensity ➔ Mw

  3< = 394 events
  3 to 3.9 =790 events
  4 to 4.9 = 212 events
  5 to 5.9 = 22 events
  >6 = 3 events

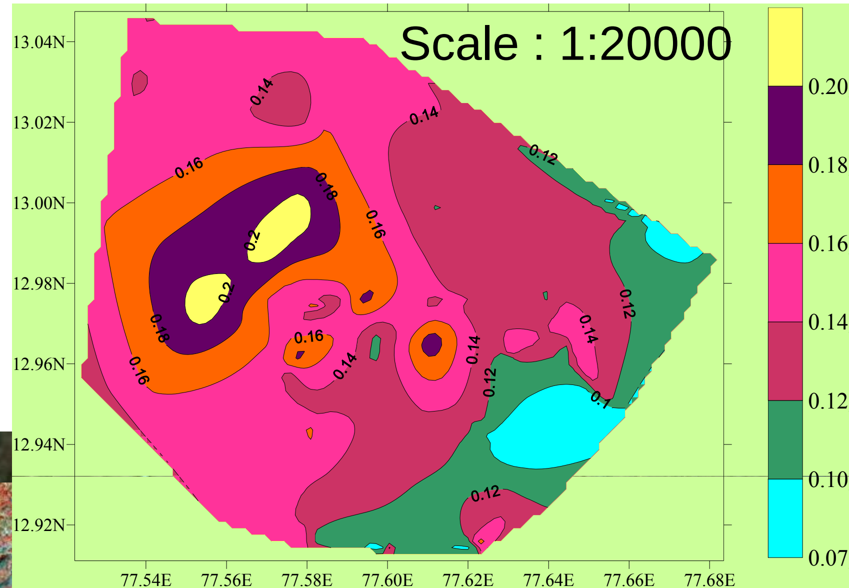
- Maximum earthquake magnitude is 6.2.
- Period (1807-2006)

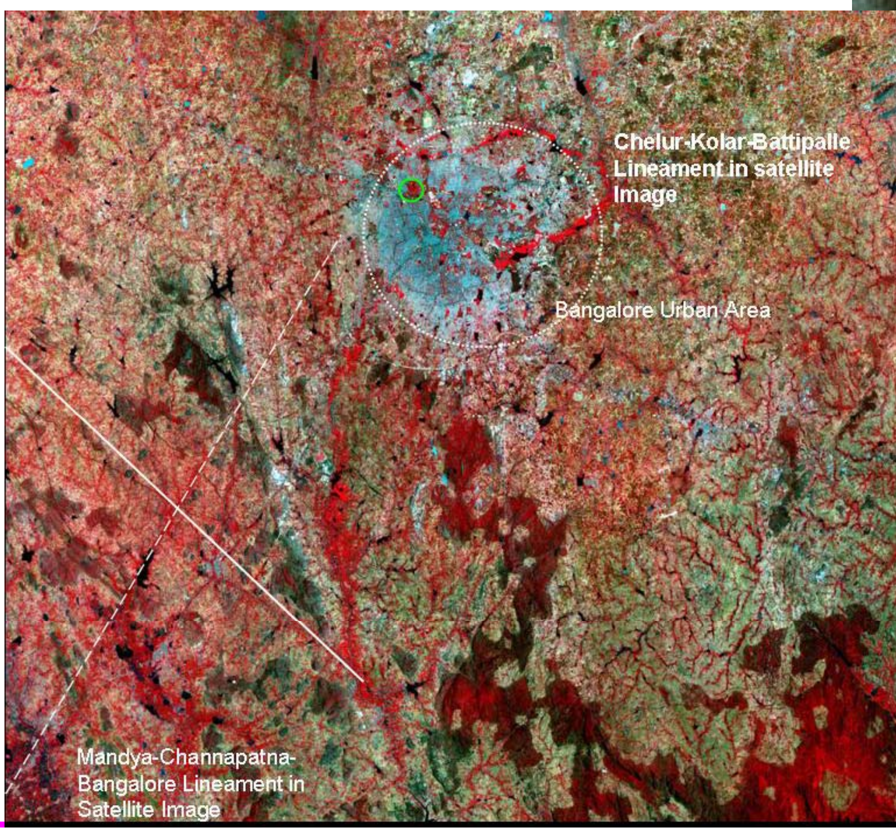


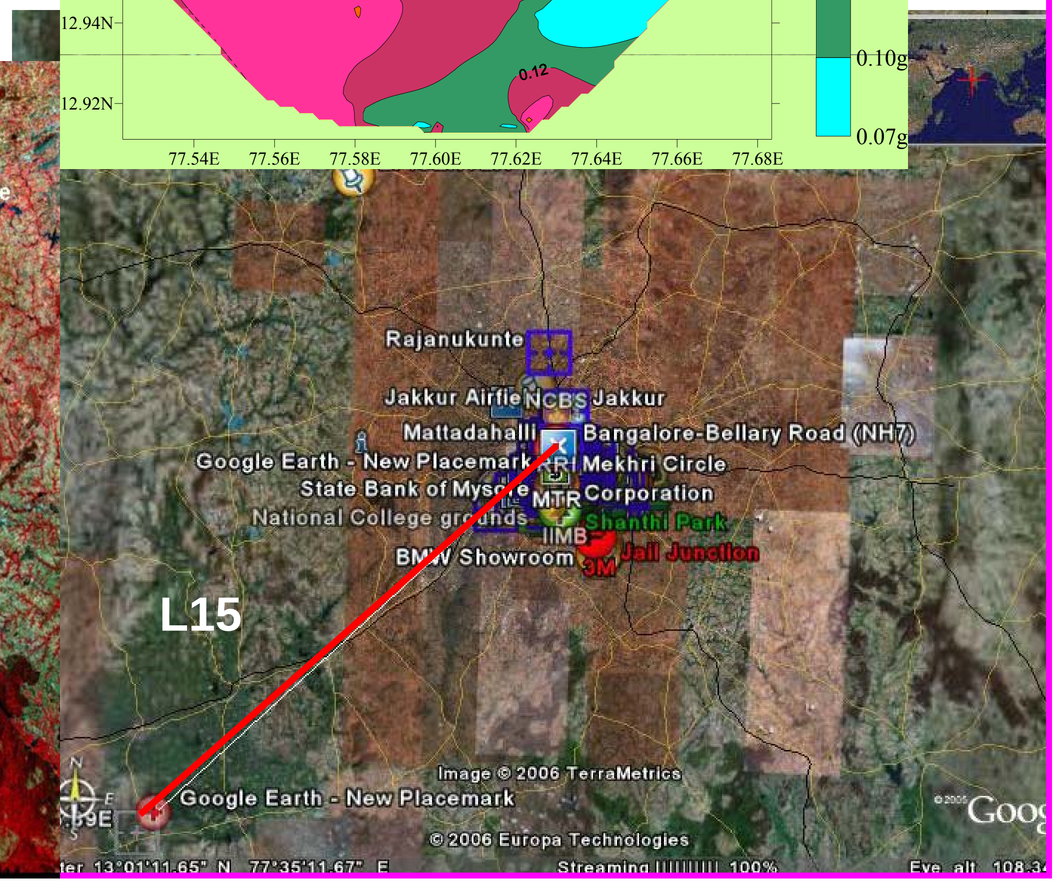
Natural Hazard and Earth Science System-EGU - 2006

Peak Ground Acceleration at Rock Level

- L15 Passes Through Bangalore
- Synthetic Ground motion generated at each borehole location







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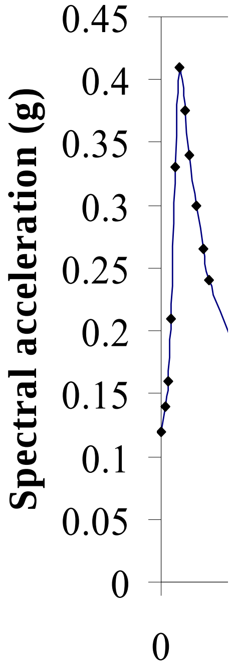
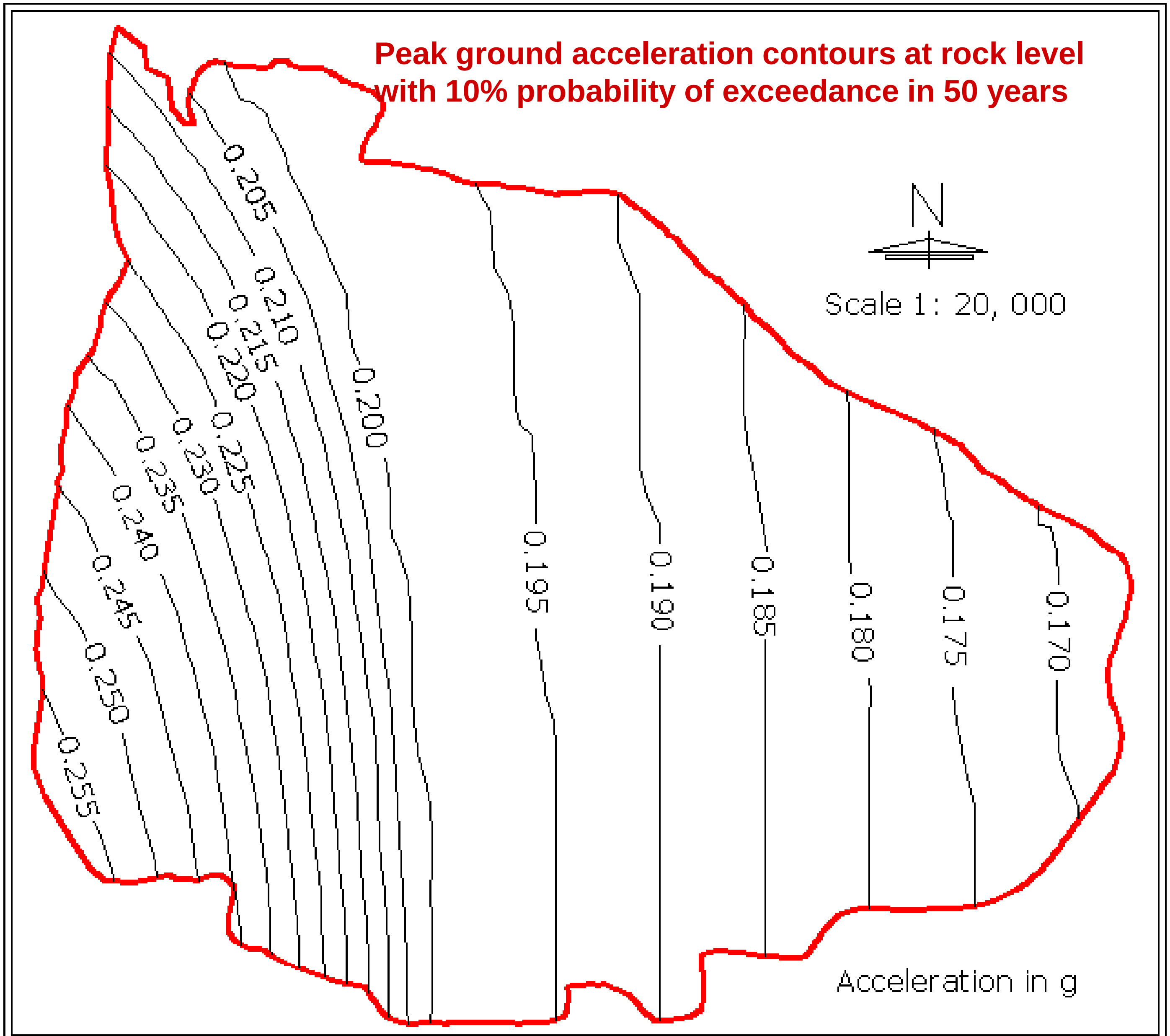




d Bangalore

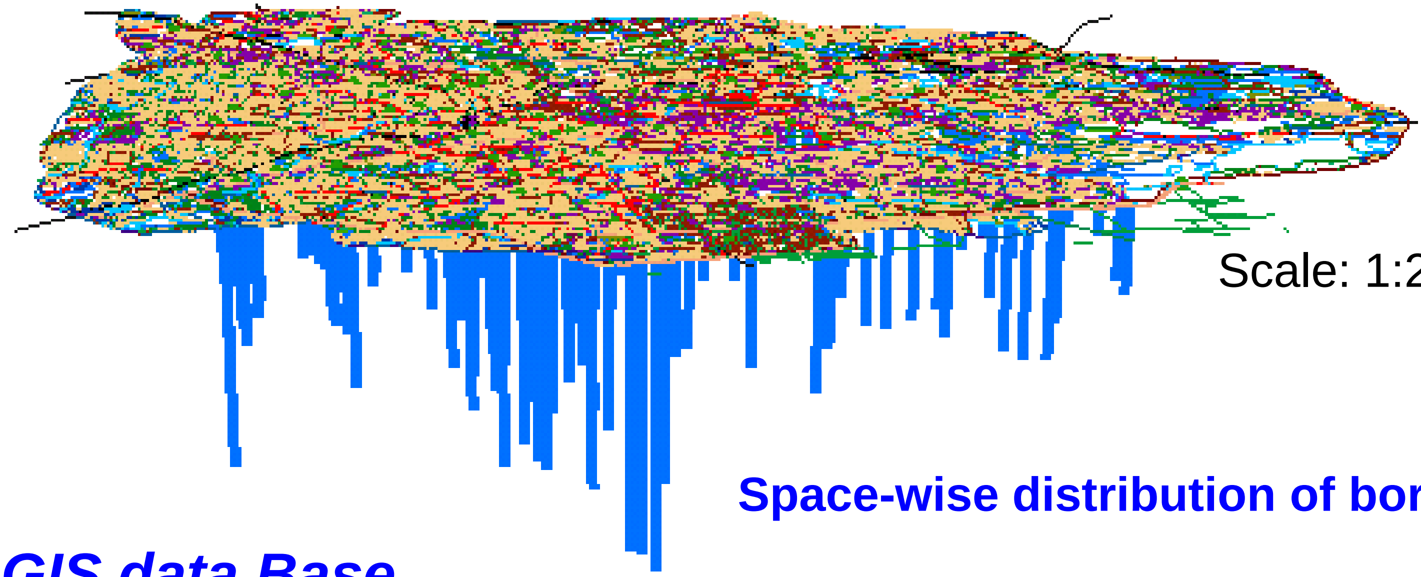
(years)
angalore
66
672
6666
4444

od (years)
Bangalore
1000
84034
465116

Data from Raghu Kanth and Iyengar (2006)

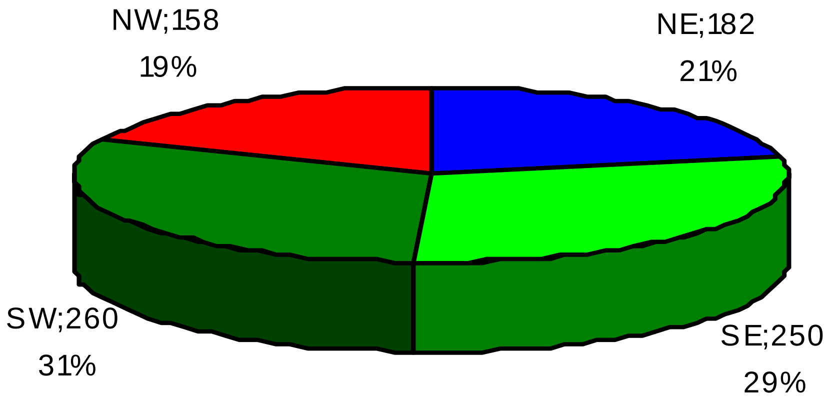
These Sa/g values are much higher than codal values

SITE CHARACTERIZATION -
3D Sub Surface Model of Bangalore- using borehole data



Scale: 1:20000

Space-wise distribution of boreholes



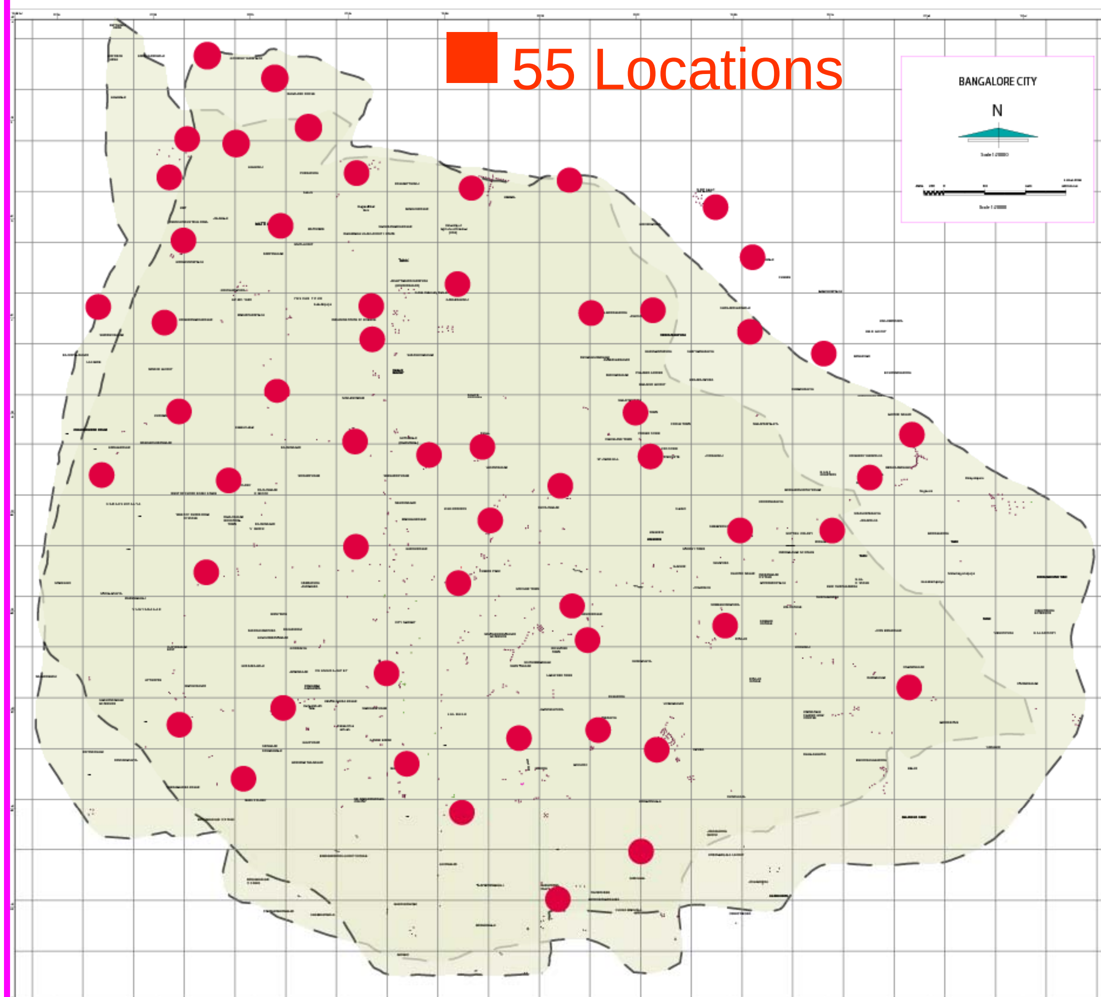
GIS data Base

- 900 Boreholes- bore log with SPT "N" value
- Depth up to 40m
- Properties and Water Table Information

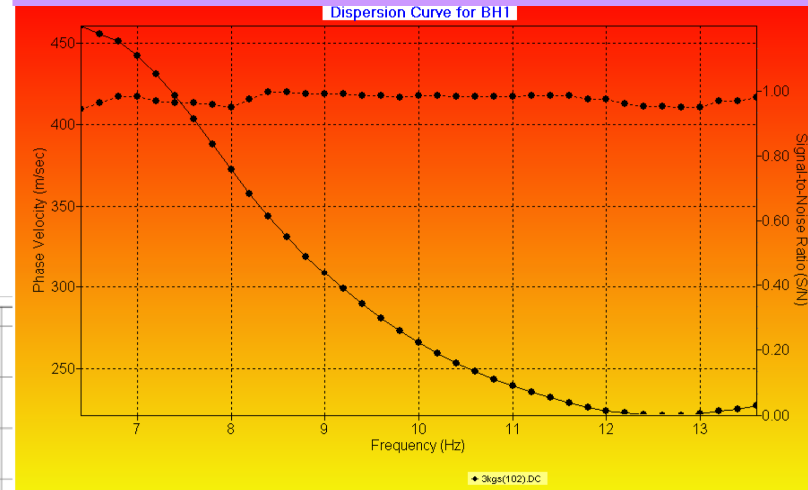
Multichannel Analysis of Surface Wave (MASW) –Geophysical Testing

➔Vs Profiling 1D-55

➔Vs Profiling 2D -22

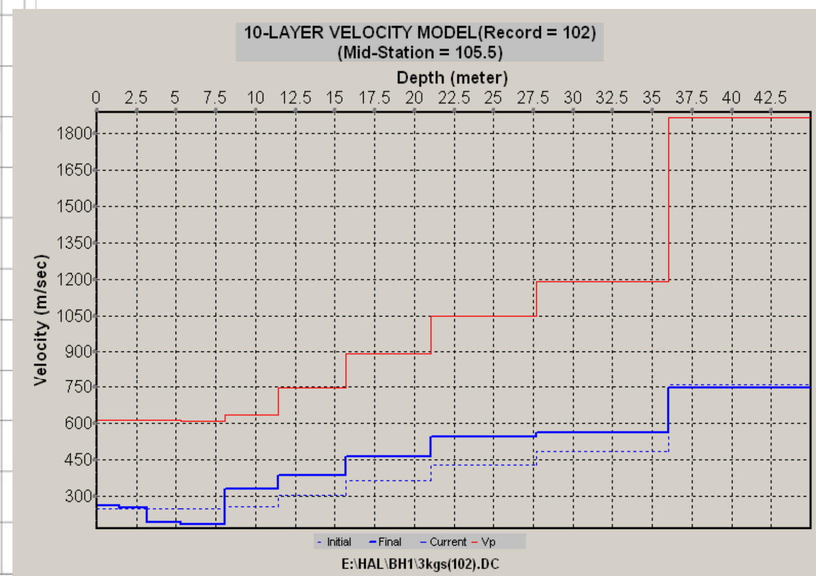


Dispersion Curve

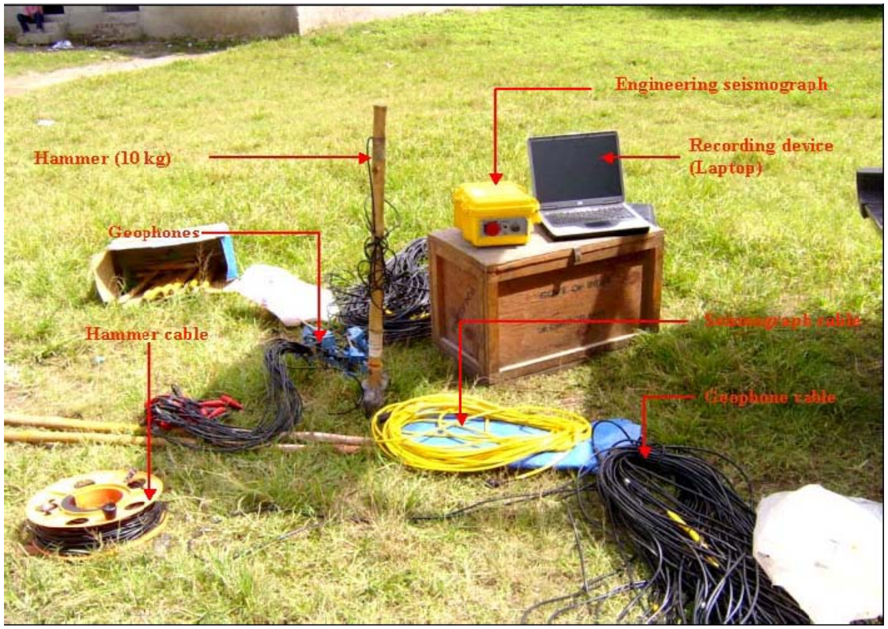


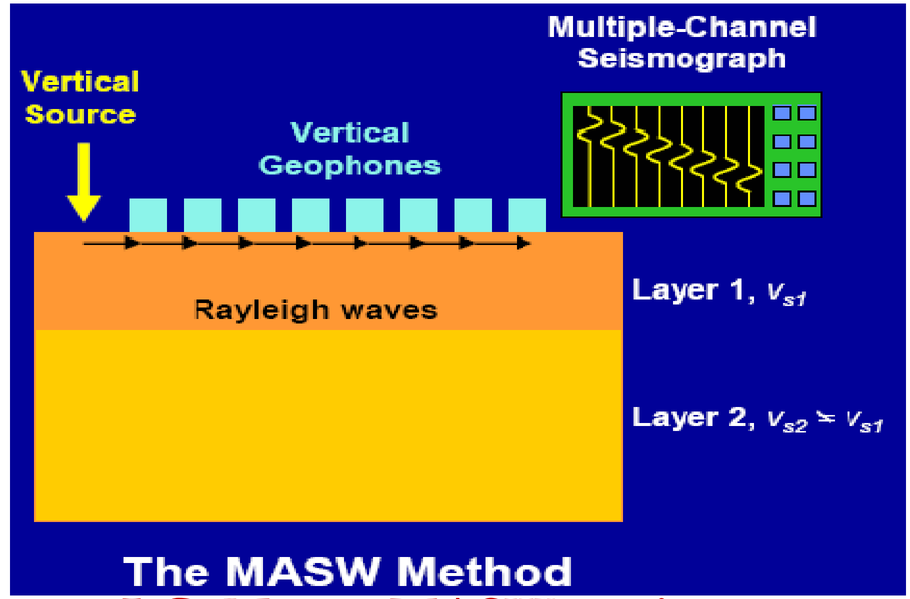
Shear Wave Velocity Profiling

- Surfseis (Kansas Geological Survey)

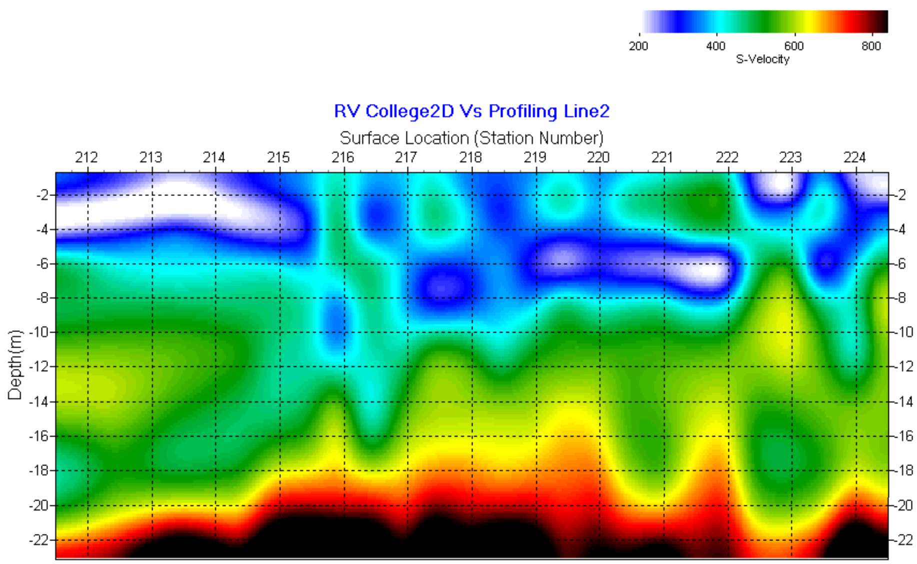


MASW Instrument





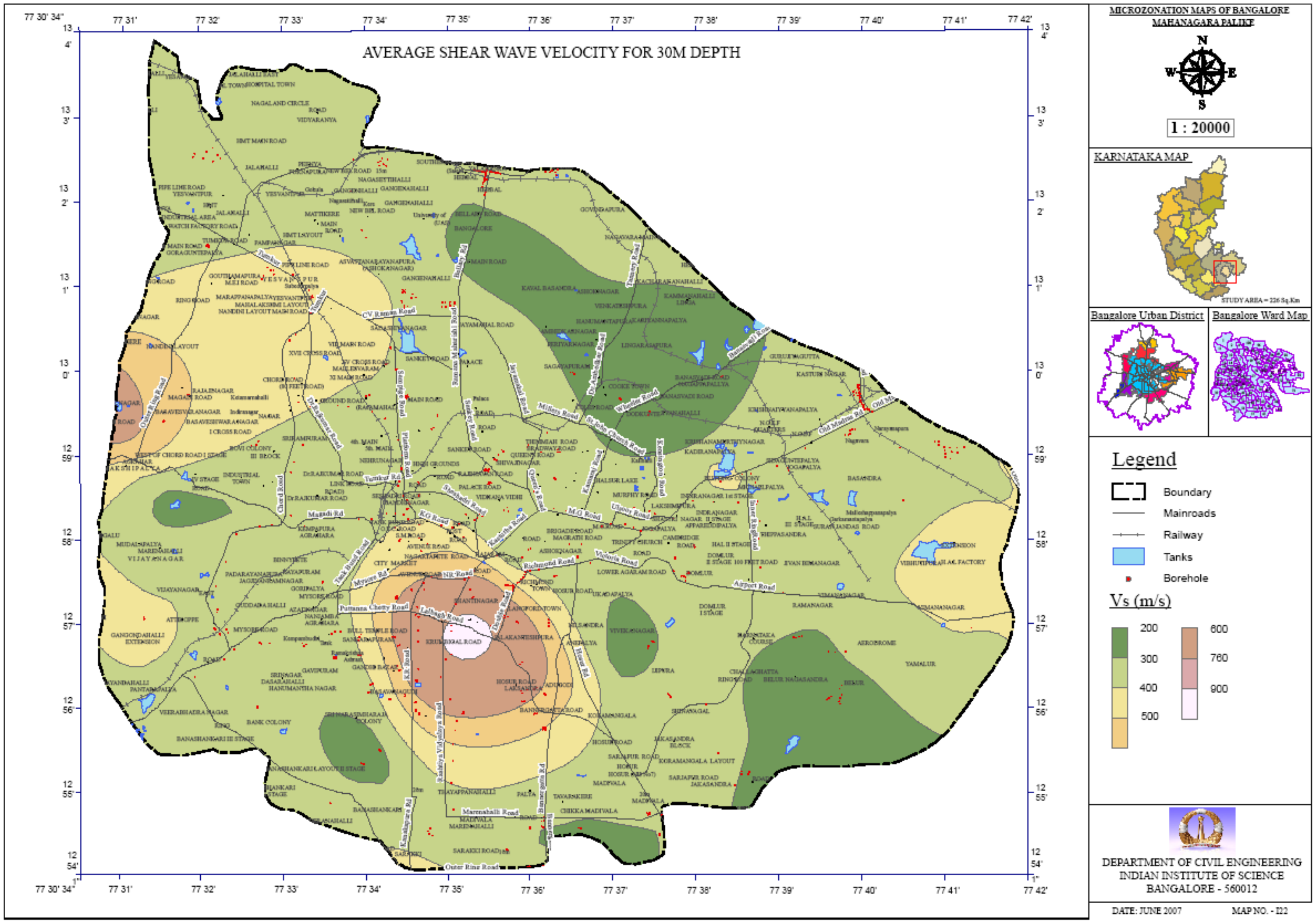
J.C. Nagar MASW testing



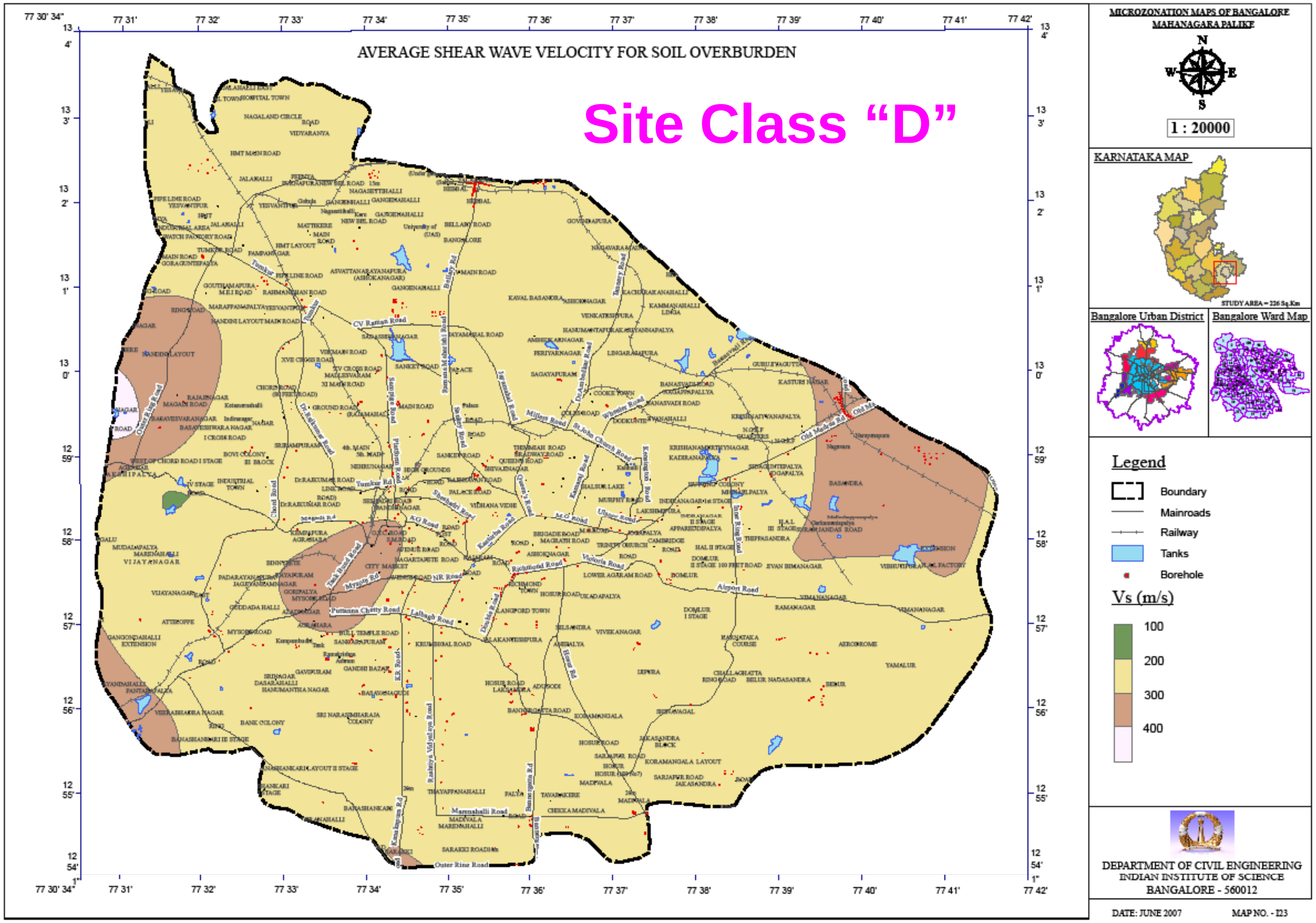
Subsurface Velocity in 2D

Vs average for 30m Depth

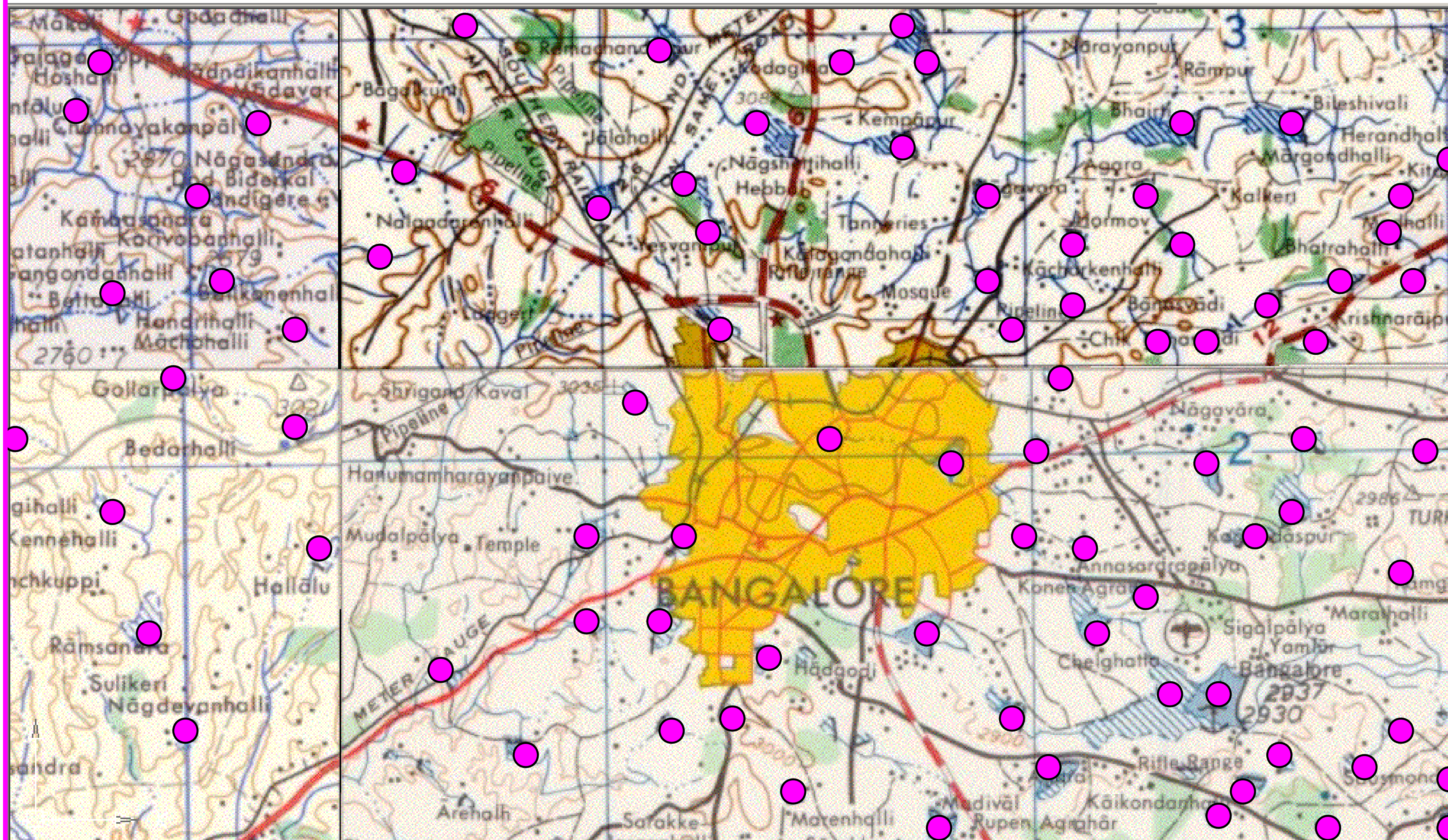
Site Class "C and D"



Average shear wave velocity for soil Overburden



Old tanks in Bangalore – Topo Sheet of 1960



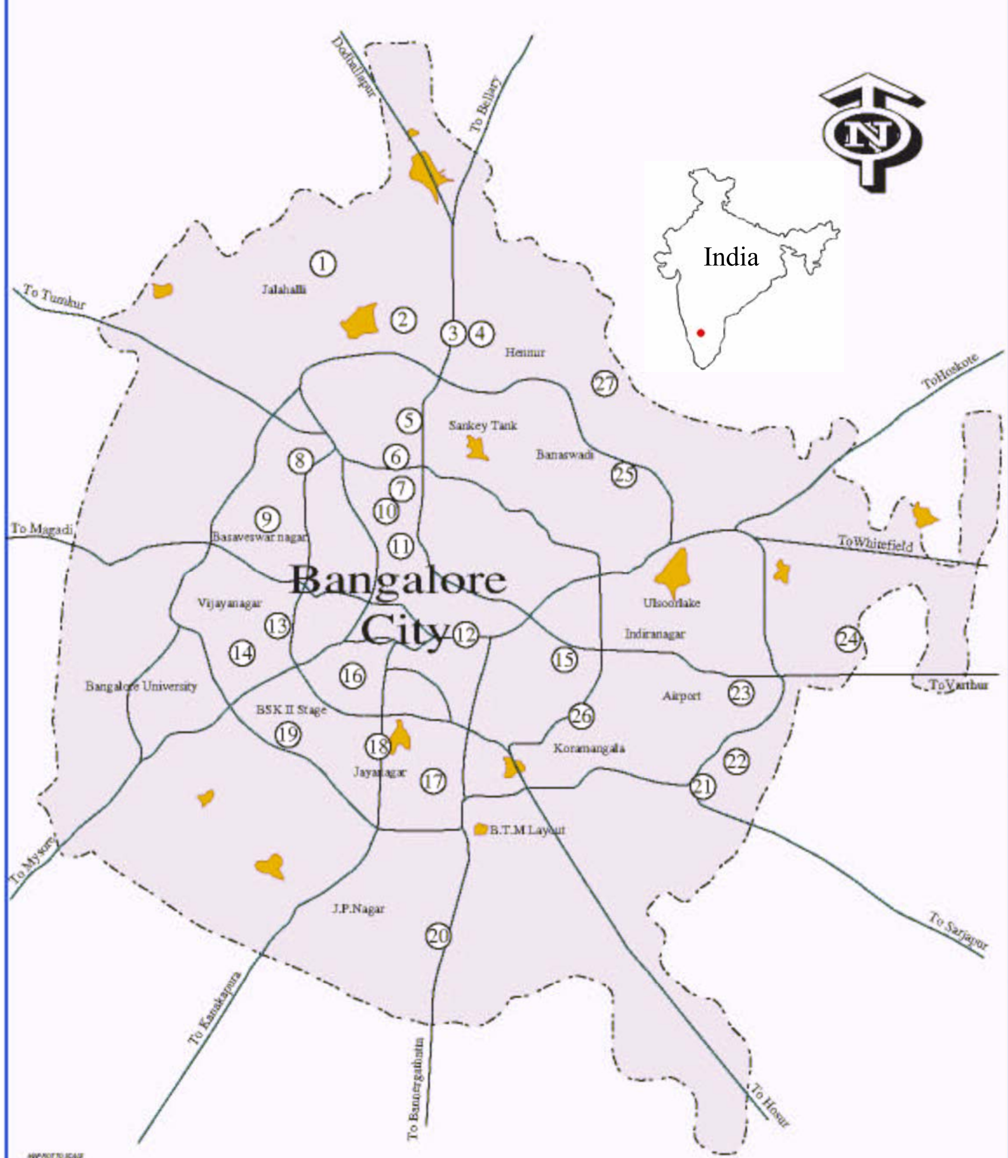
within Corporation boundary

Tanks / lakes in Bangalore and present status

1	Vidyaranyapura Lake	Vidyaranyapura(Jalahalli East)
2	Gokula Tank	Mattikere
3	Geddalahalli Lake	RMV 2nd Stage, 1st Block
4	Nagashettihalli Lake	RMV 2nd Stage, 2nd Block
5	Tumkur Lake	Mysore Lamps
6	Ramshetty Palya kere	Milk Colony (Playground)
7	Oddarapalaya Lake	Rajajinagar (Industrial Area)
8	Ketamaranahalli Lake	Rajajinagar (Mahalakshmipuram)
9	Kurubarahalli Lake	Basaveshwaranagar (Chord Road)
10	Agasana Lake	Gayathri Devi Park
11	Jakkarayana kere	Krishna Floor Mills
12	Dharmambudhi Lake	Kempegowda Bus Terminal
13	Vijayanagar Chord Rd Lake	Vijayanagar
14	Marenahallli Lake	Marenahalli
15	Sampangi Lake	Kanteerva Stadium
16	Kalasipalya Lake	Kalasipalya
17	Siddapura Lake	Siddapura/Jayanagar 1 stBlock
18	Tyagarajanagar Lake	Tyagarajanagar
19	Kadirenahalli Lake	Banashankari 2nd Stage
20	Sarakki AgraharaLake	JP Nagar 4th Phase
21	Koramangala Lake	National Dairy Research Institute
22	Chinnagara Lake	Ellpura
23	Domlur Lake	Domlur Second Stage
24	Kodihalli Lake	New Thippasandra /Government Buildings
25	Banaswadi Lake	Subbayapalya Extension
26	Shule Tank	Ashok Nagar, Football Stadium
27	Hennur Lake	Nagavara (HBR Layout)

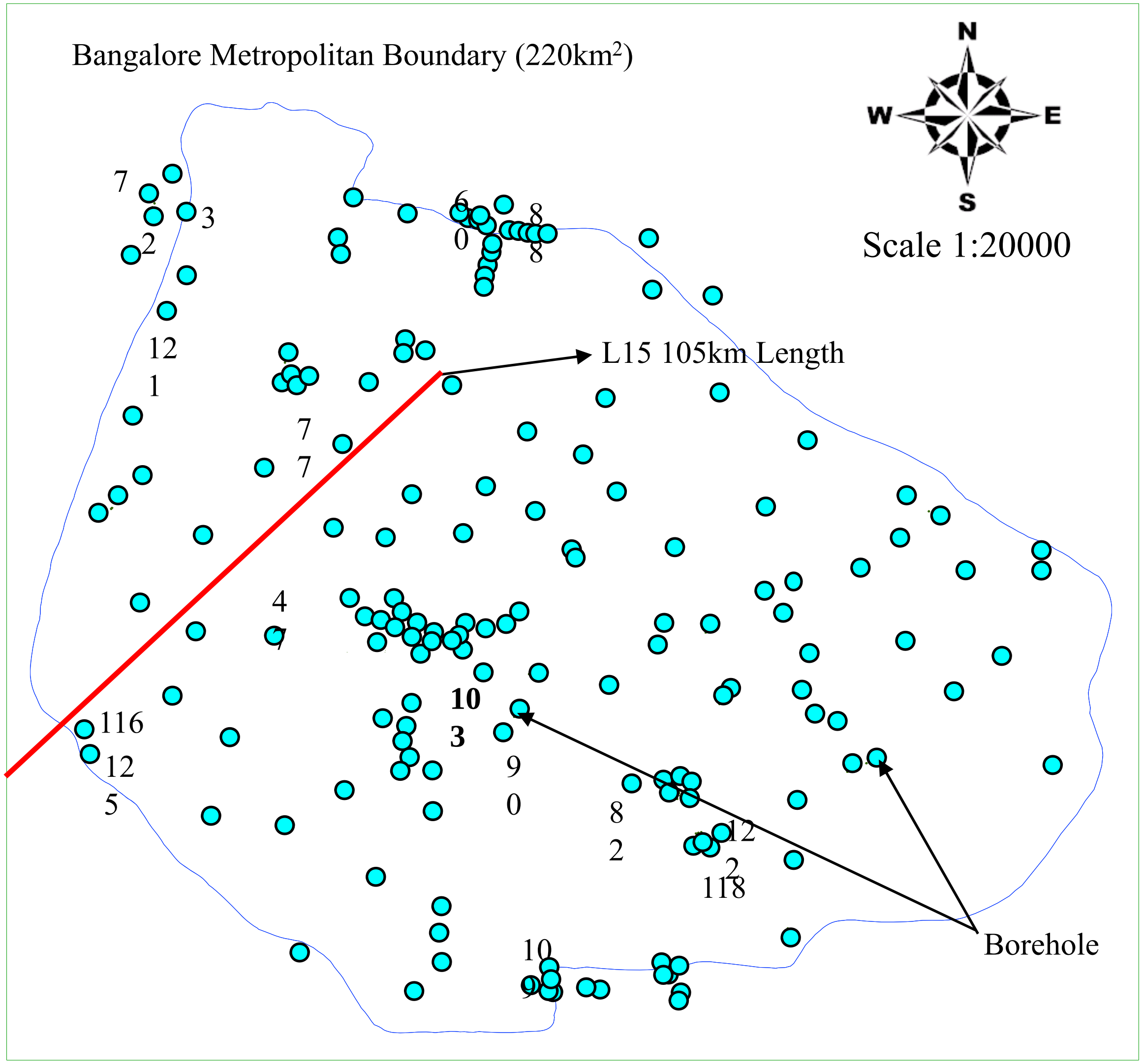
About 150 lakes now reduced to 64

Location of the Dried and Filled up water bodies in Bangalore City



Geotechnical Data for Ground Response Analysis

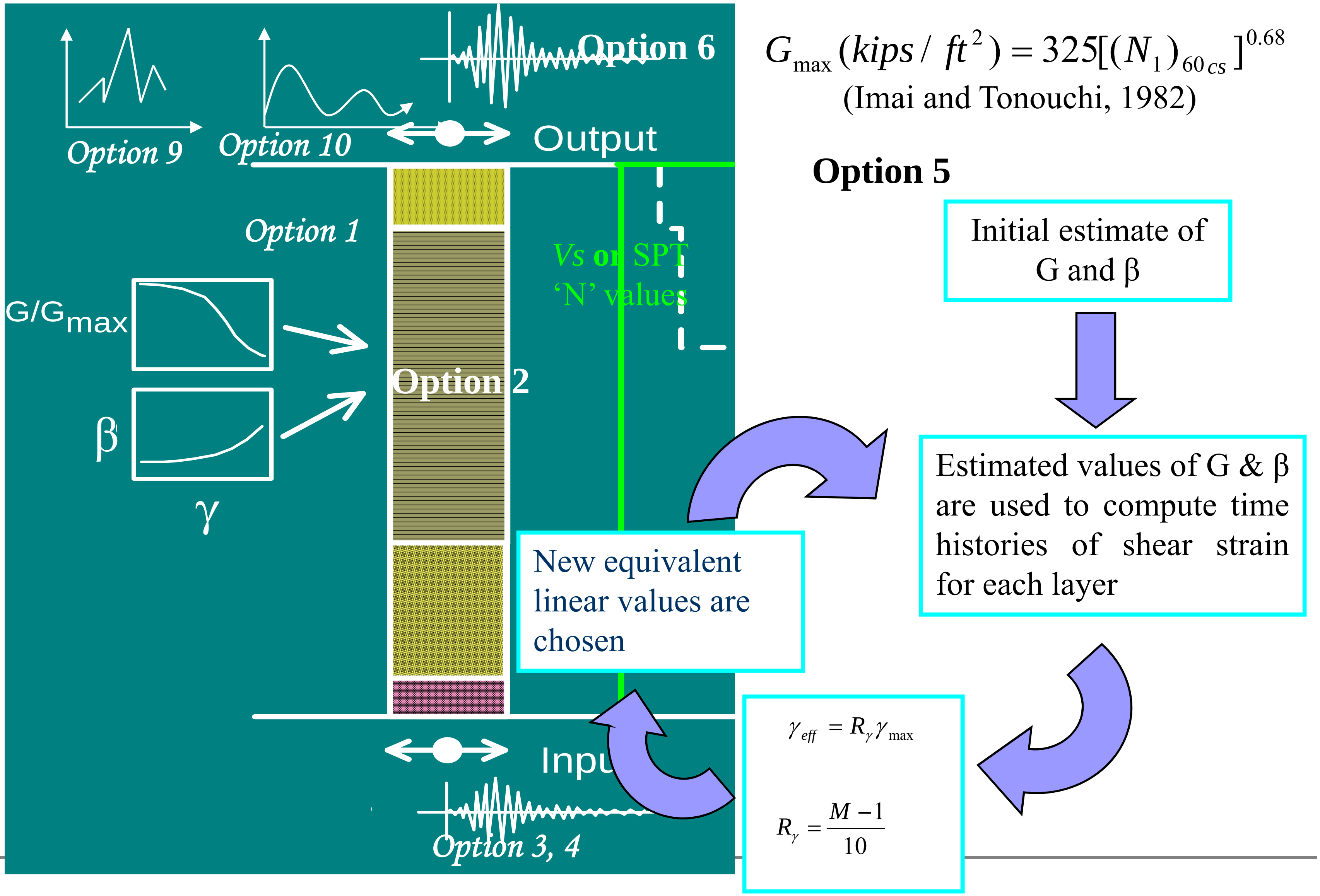
- From data base 160 borelogs selected
- SHAKE2000
  - SITE CHARACTER-IZATION +
  - INPUT BEDROCK MOTION
  - GROUND RESPONSE ANALYSIS
  - RESPONSE PARAMETERS



✓Equivalent Linear Approach

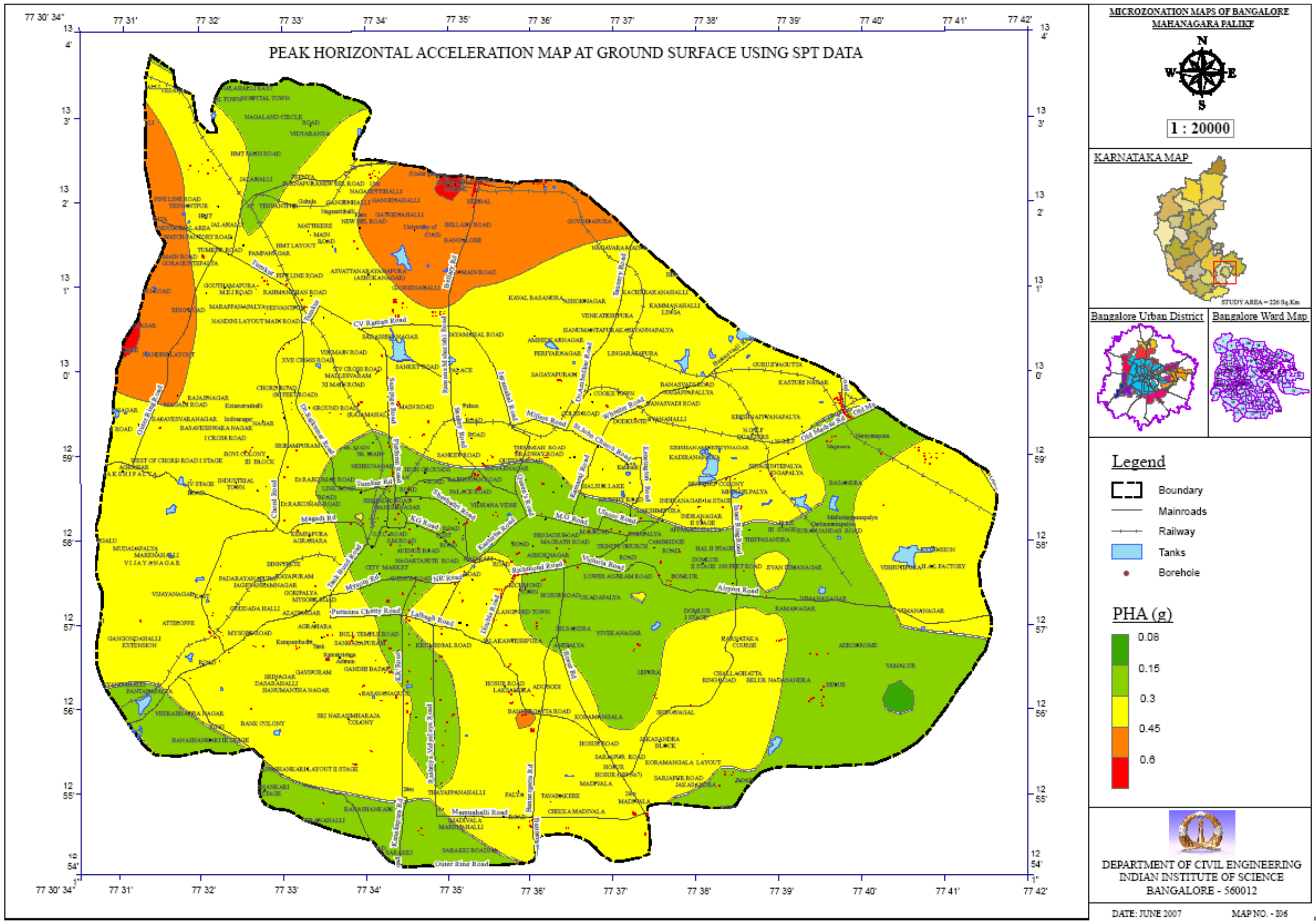
$$G_{max}(kips/ft^2) = 325[(N_1)_{60cs}]^{0.68}$$

(Imai and Tonouchi, 1982)



✓Peak Ground Acceleration and Amplification Ratio

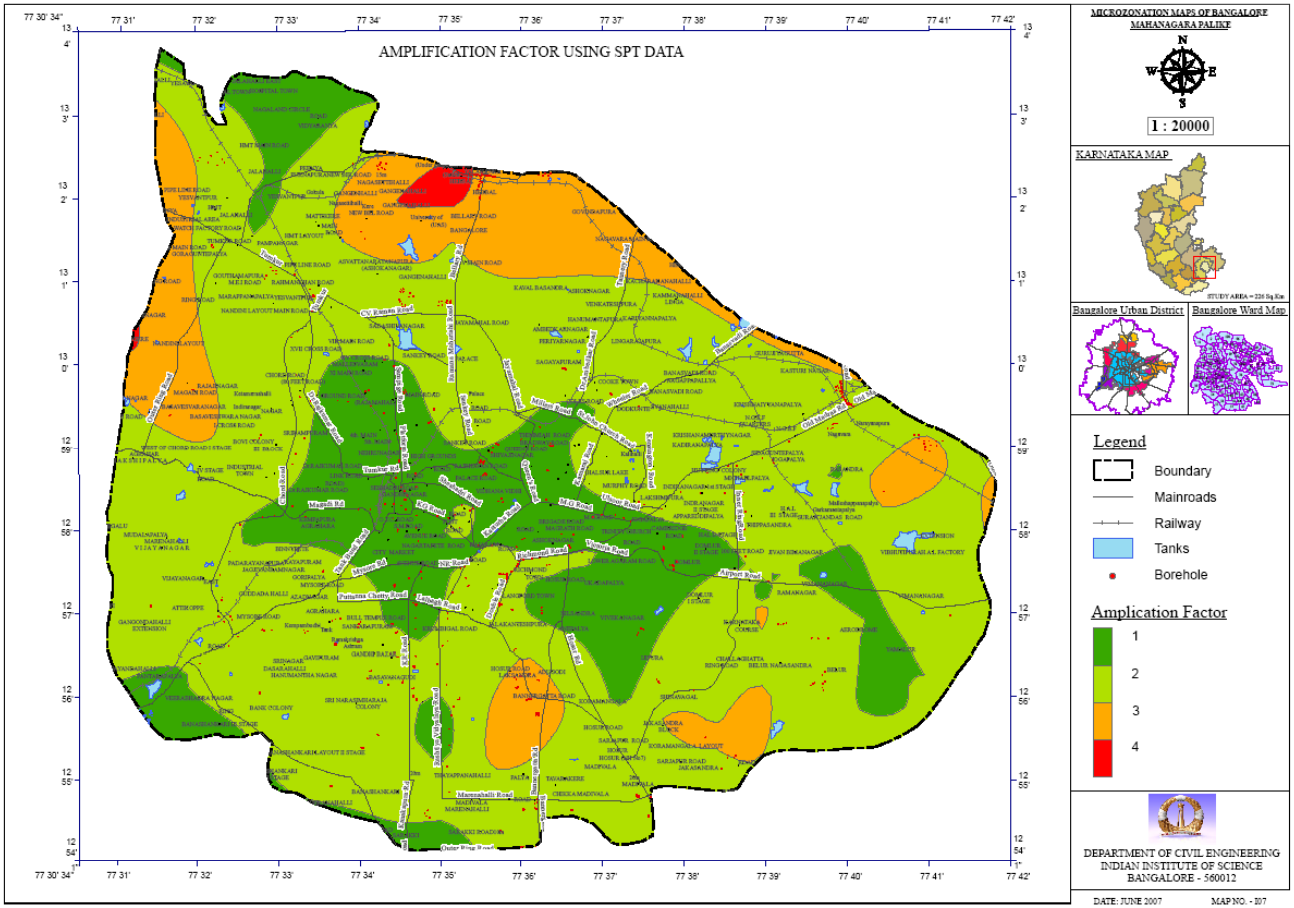
Peak Horizontal Acceleration map at Ground Surface



✓Peak Ground Acceleration and Amplification Ratio

Amplification Factor Zones

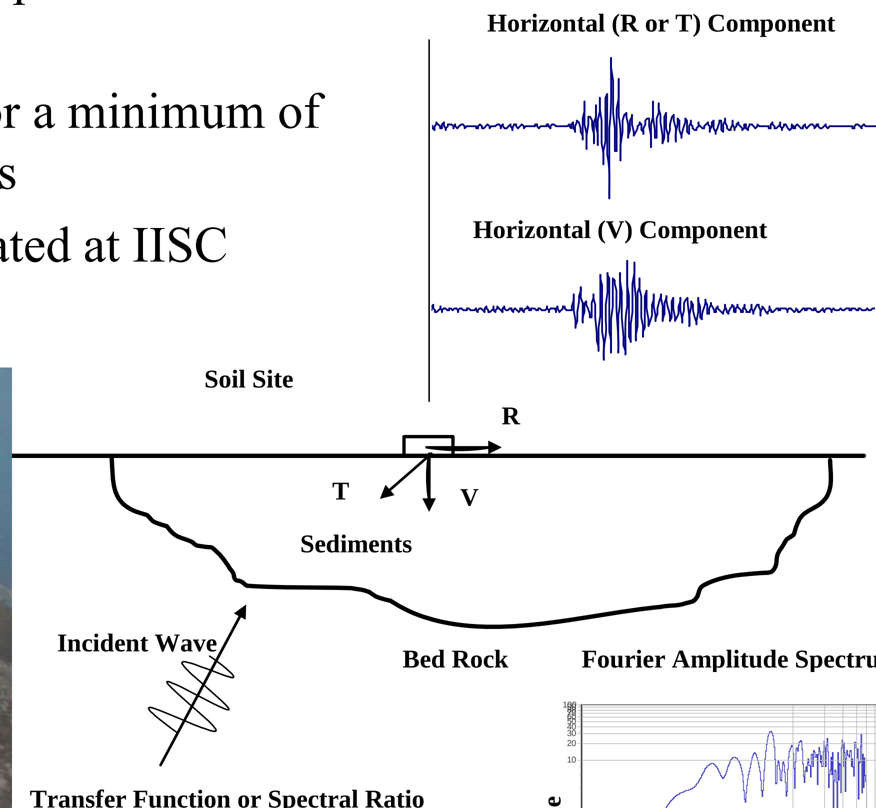
Zone	Amplification Factor
1 (I)	1.00-1.99
2 (II)	2.00-2.99
3 (III)	3.00-3.99
4 (IV)	> 4.00



✓Instrument and Methodology

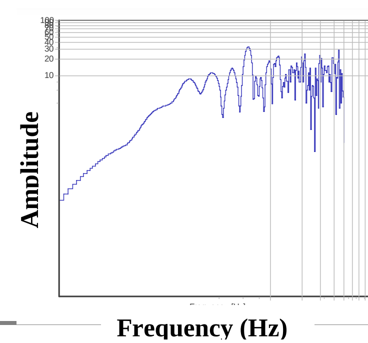
Predominant frequency is obtained by evaluating the horizontal to vertical spectral ratio (Nakamura, 1989)

- L4-3D short period sensors equipped with digital acquisition systems
- The duration of recording was for a minimum of 3 hours and a maximum of 26 hrs
- One permanent station was operated at IISC rock outcrop



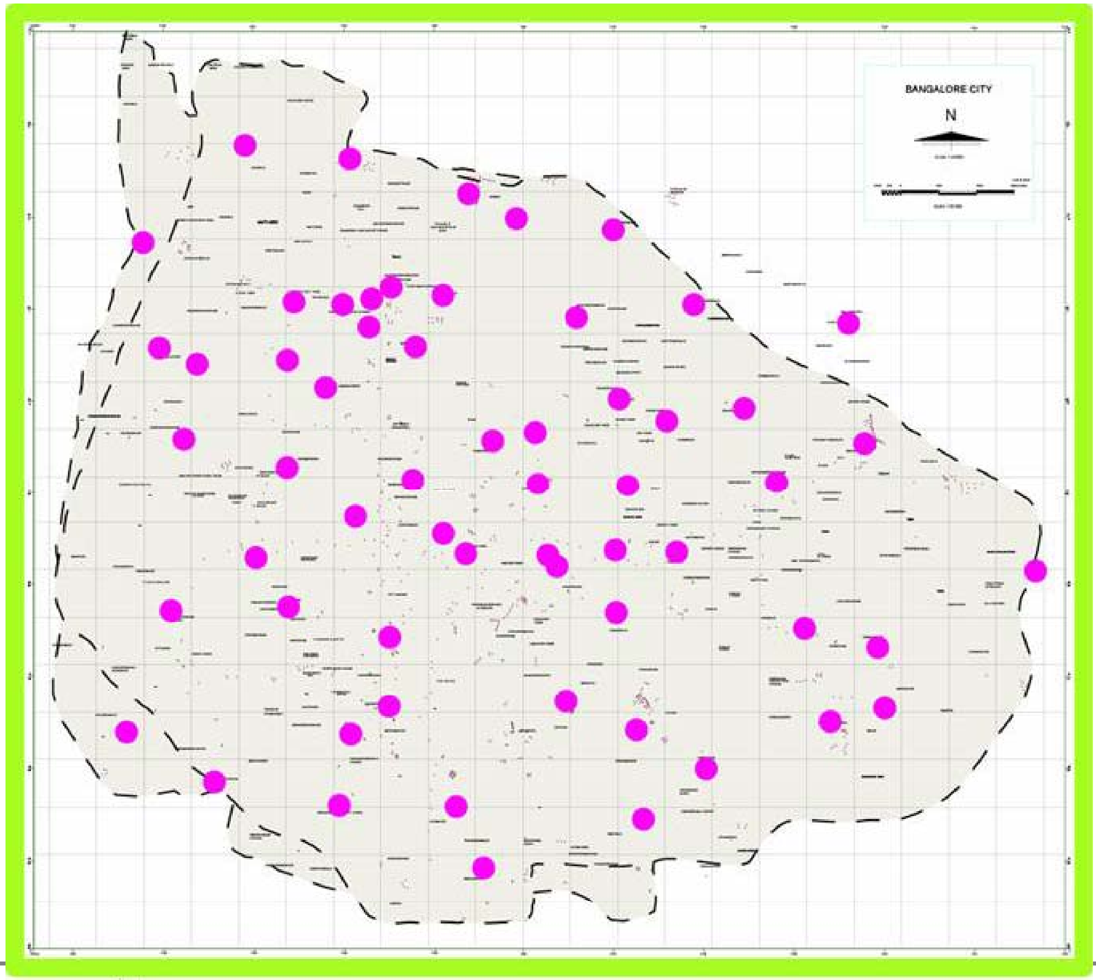
$$S(f) = \frac{A(f)horizontal}{A(f)Vertical}$$

Fourier Amplitude Spectrum

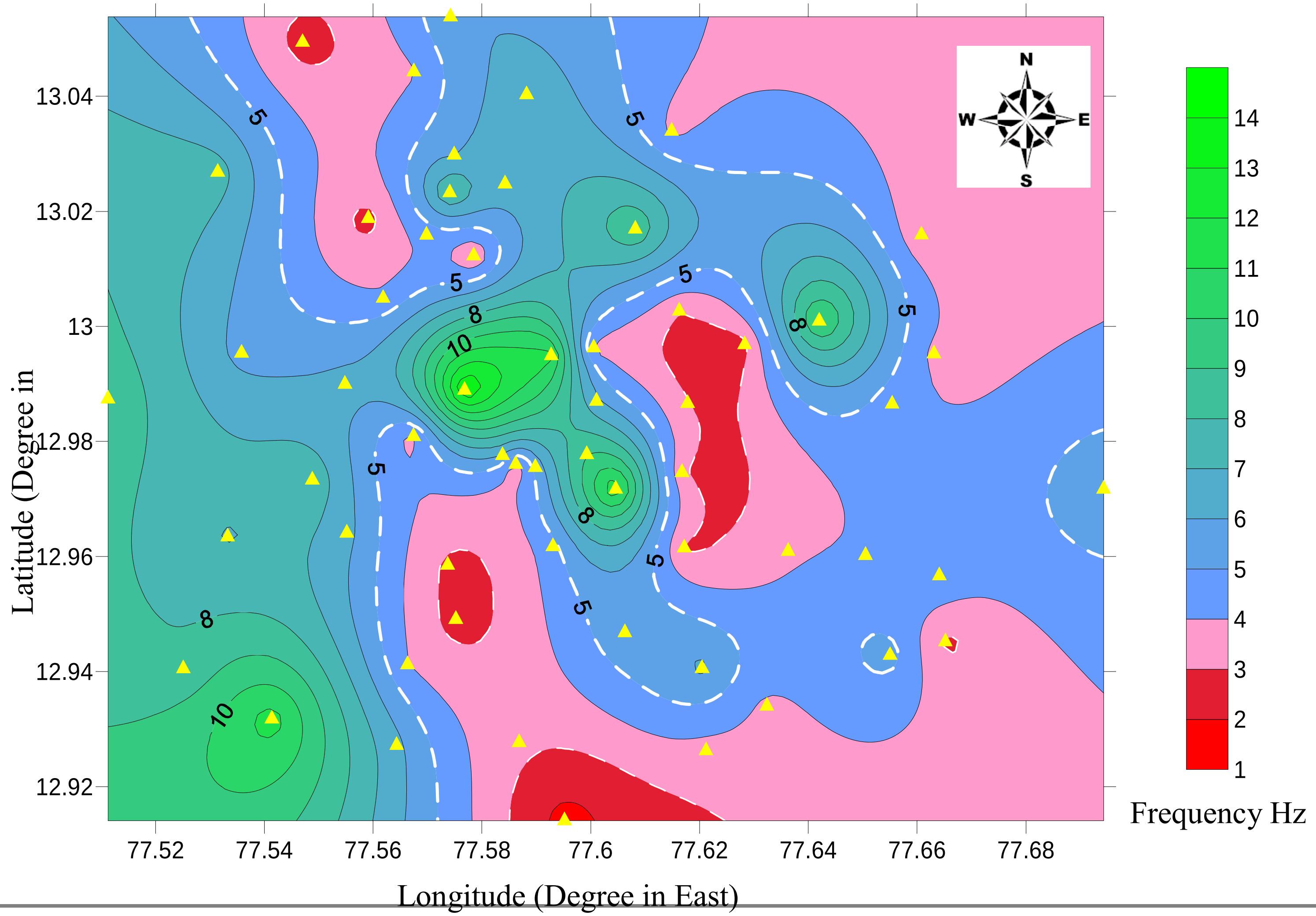


✓Testing location

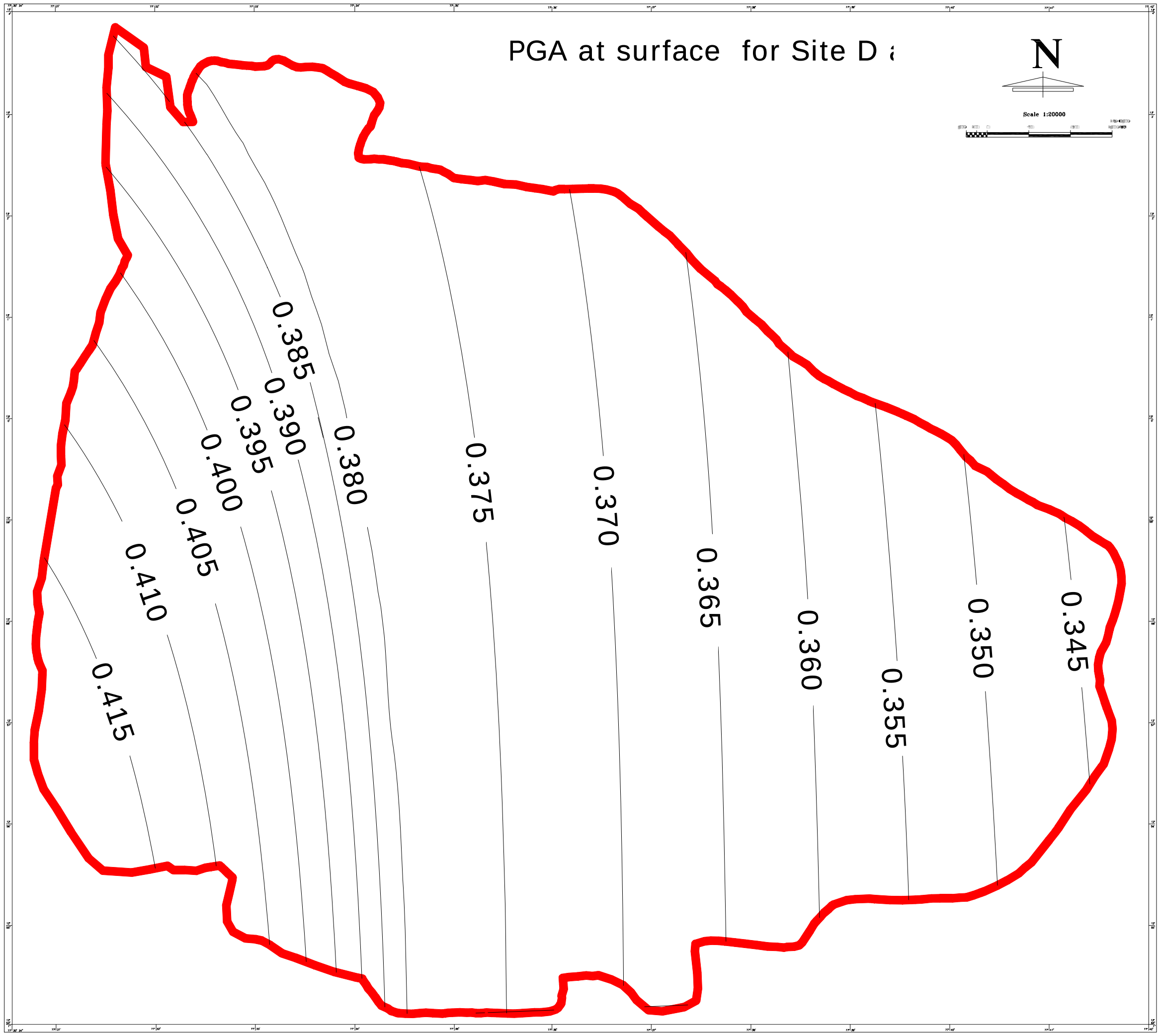
- 54 location testing was done
- The spectra and the H/V ratios have been computed using the JSESAME program
- Places are selected mostly like schools collages and Govt buildings



Contour map of dominant frequency

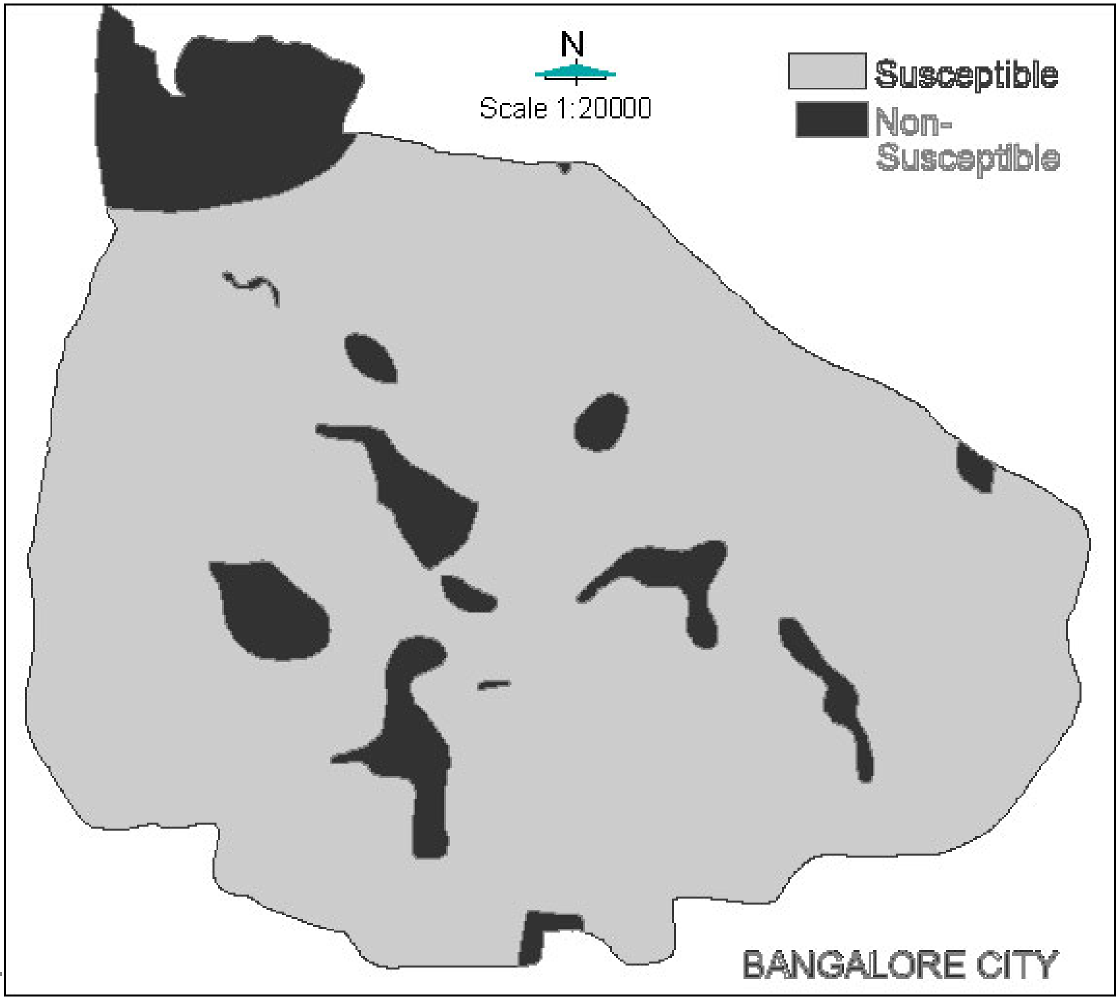


Surface level PGA for site class D using PSHA

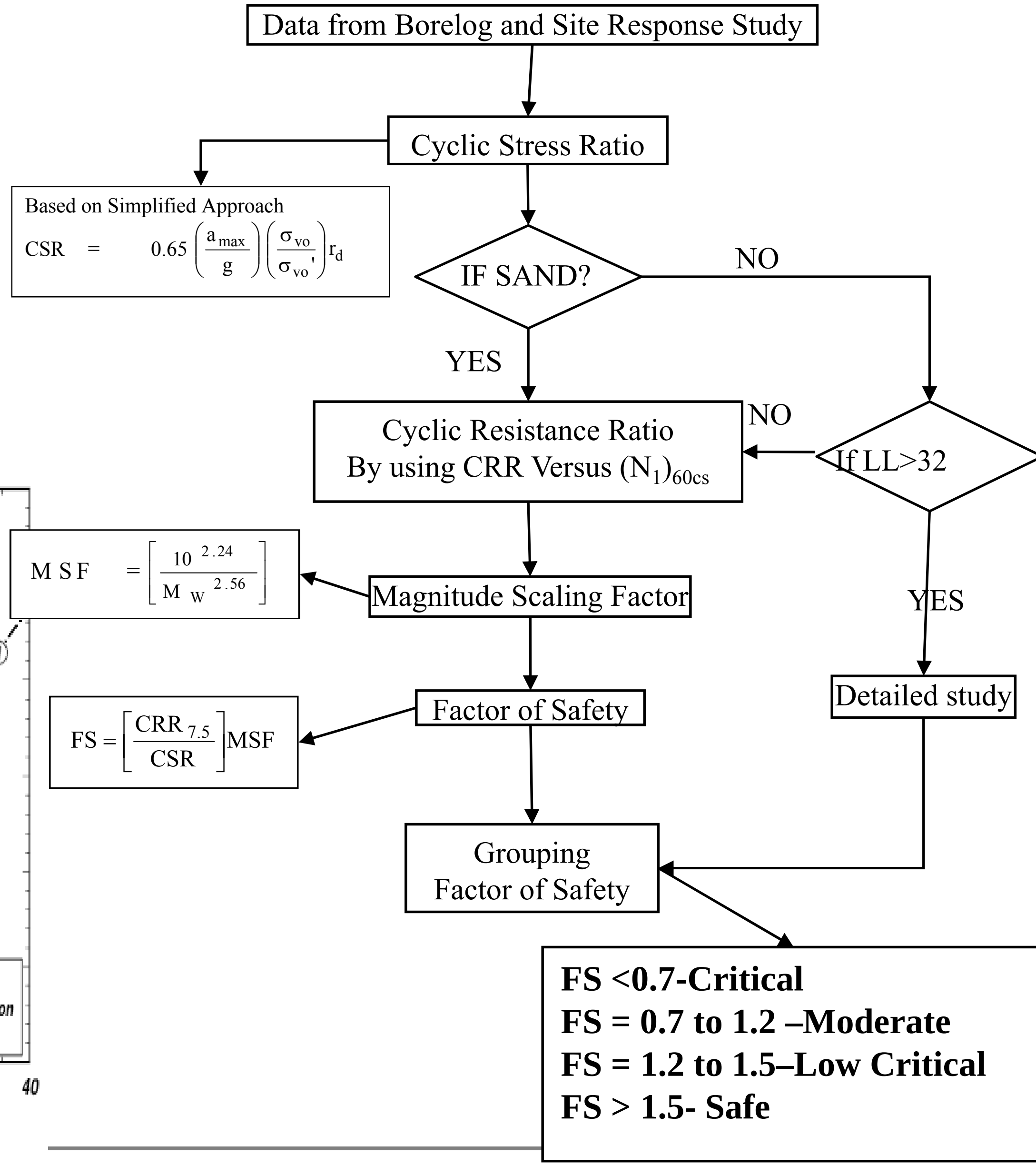


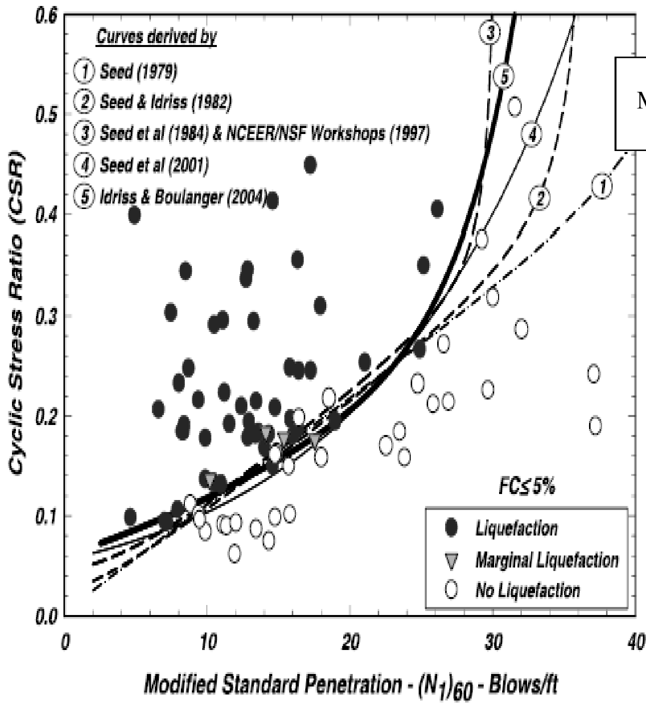
✓Liquefaction Susceptibility Map

- Susceptible areas have been identified by considering the approach of Pearce and John (2005)
  - Presence of sand layers at depths less than 20m,
  - Encountered water table depth less than 10m, and
  - SPT field "N" blow count less than 20
- From SPT data susceptibility has been assessed



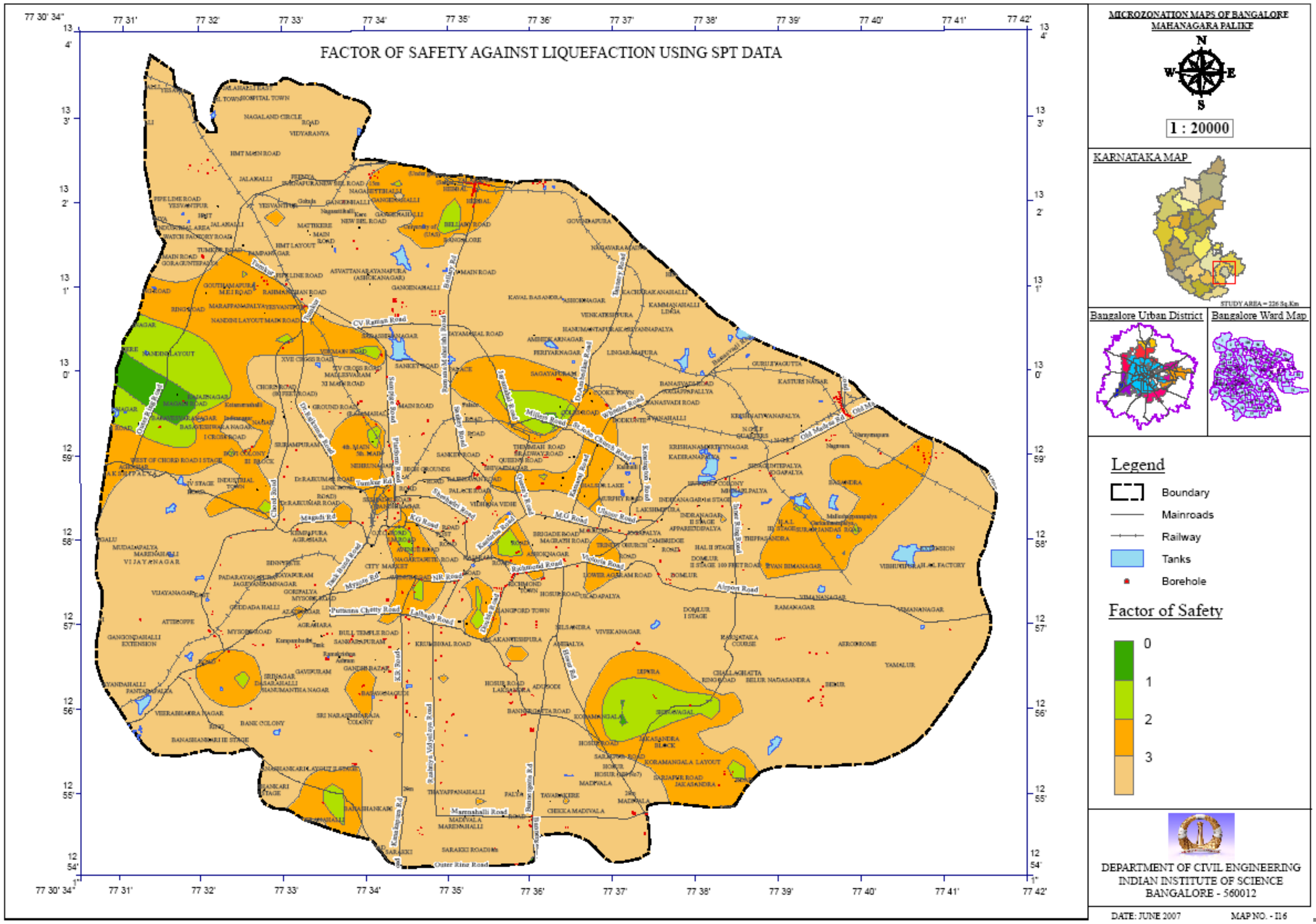
Flow chart for Liquefaction Hazard Assessment





Simplified Procedure (Seed and Idriss, 1971) and subsequent revisions (Seed et al., 1983, 1985; Youd et al., 2001; Cetin et al., 2004)

Factor of safety against Liquefaction



Integration of hazard maps on GIS Platform

- Saaty's Analytical Hierarchy process constructs a matrix of pair-wise comparisons (ratios) between the factors of earthquake hazard parameters (EHP)
- Total 9 parameters are selected in this study
- Geomorphological Attributes -4 (also SPT and MASW)
- Seismological Attributes -5
- Weights and ranks are assigned based on the importance of factors towards hazard
- ArcGIS-9.2 has been used

The advantage of GIS is the capacity for spatial analysis, and the advantage of AHP is the capacity of multi-index integrated evaluation

Analytical Hierarchy Process

- Devised by Thomas Saaty
- Each stakeholder compares each pair of factors
- Assigns comparative weights
- forming a complete matrix
- Weights must sum to one

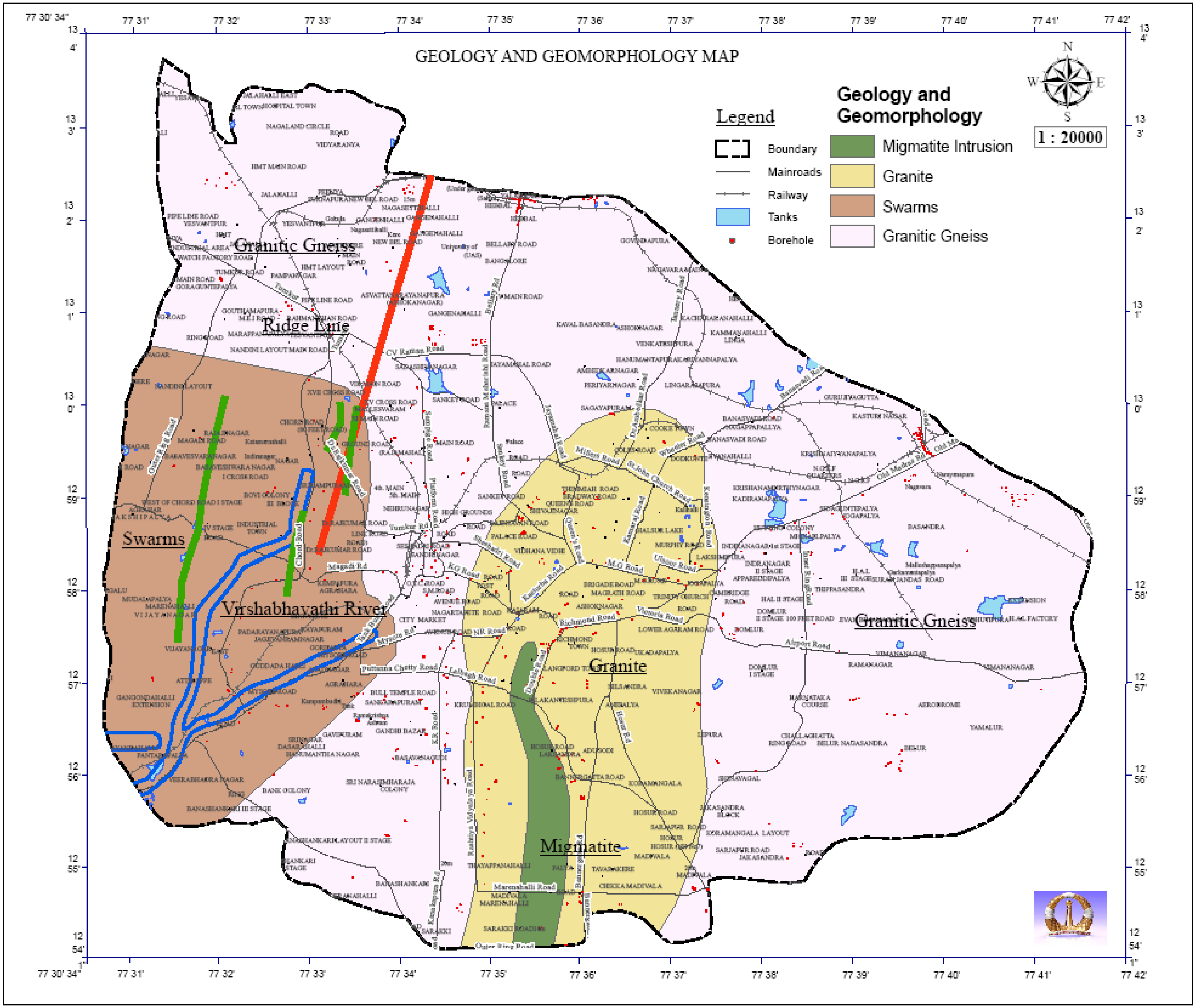
Although the AHP method has its unique advantages in multi-index integrated evaluation, it has some deficiencies- it can not effectively reflect the spatial distribution pattern of the evaluation results. However, GIS technology has strong spatial analysis capabilities, which can counter the AHP's deficiencies.

Our method combines GIS with AHP is into the evaluation of seismic Hazards.

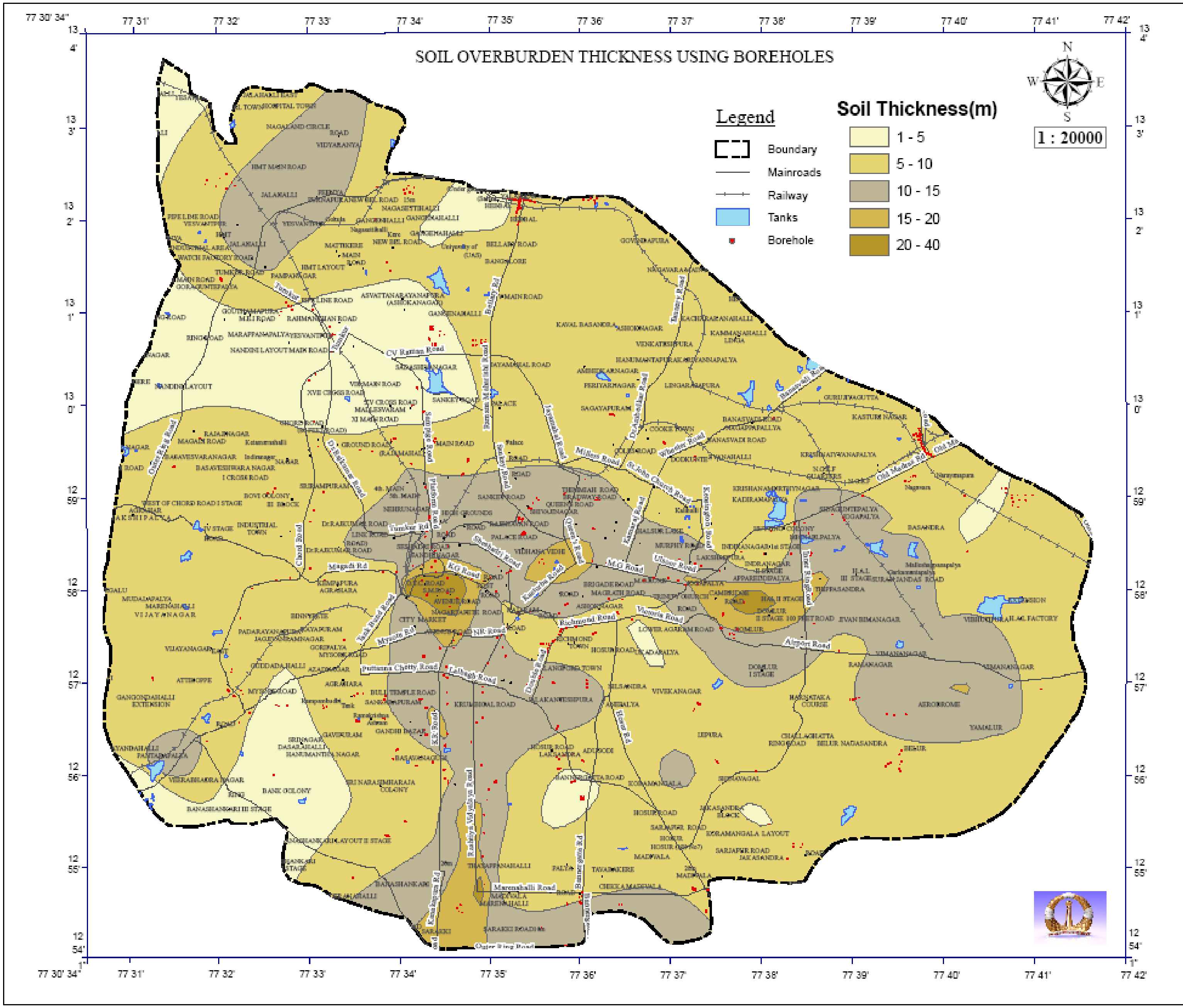
The study, through GIS, divides the area into regular grids and then plots the divided map of seismic hazards into a format that allows the classification of hazard index indicating high to low hazard

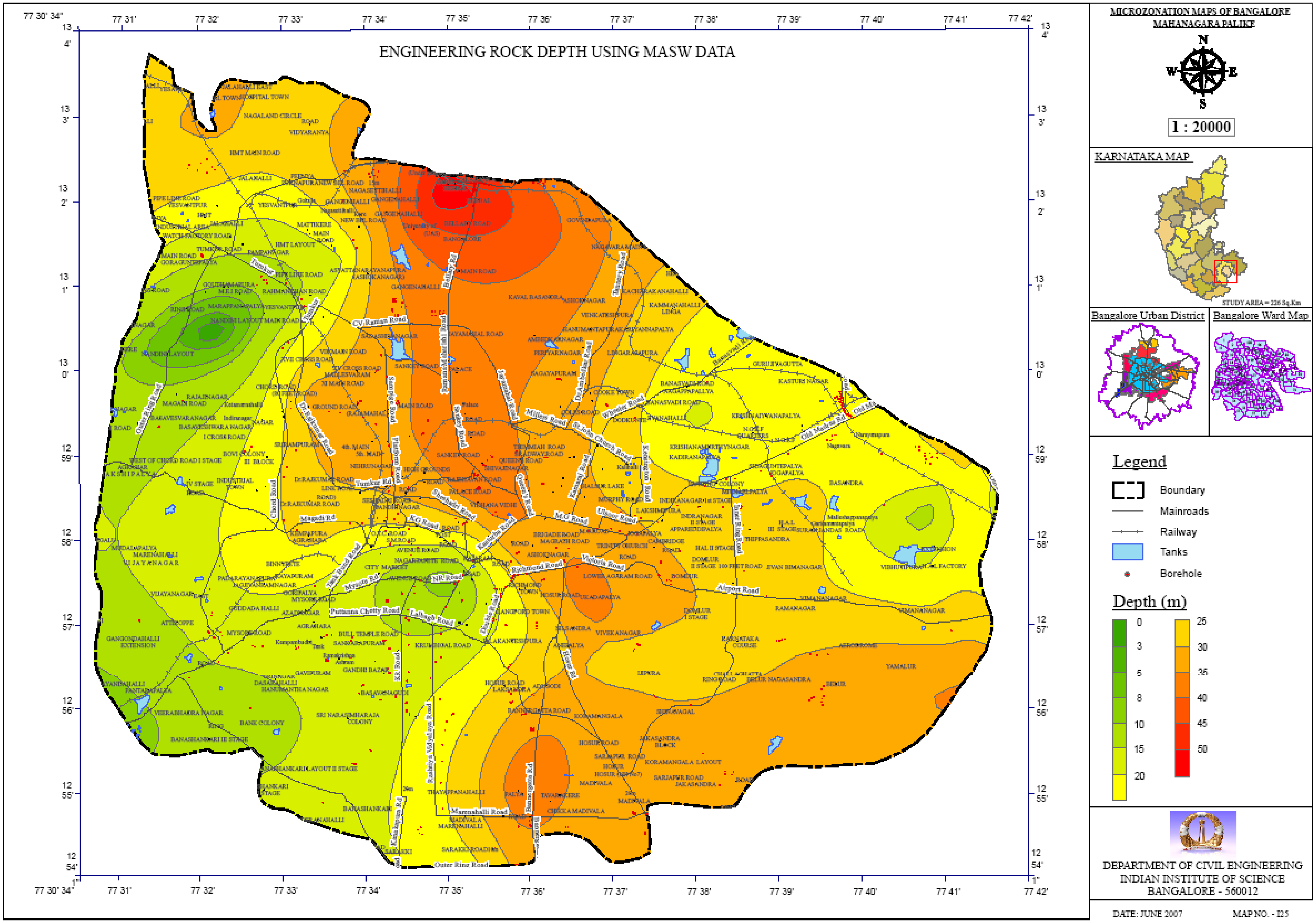
Themes and its weights for GIS integration

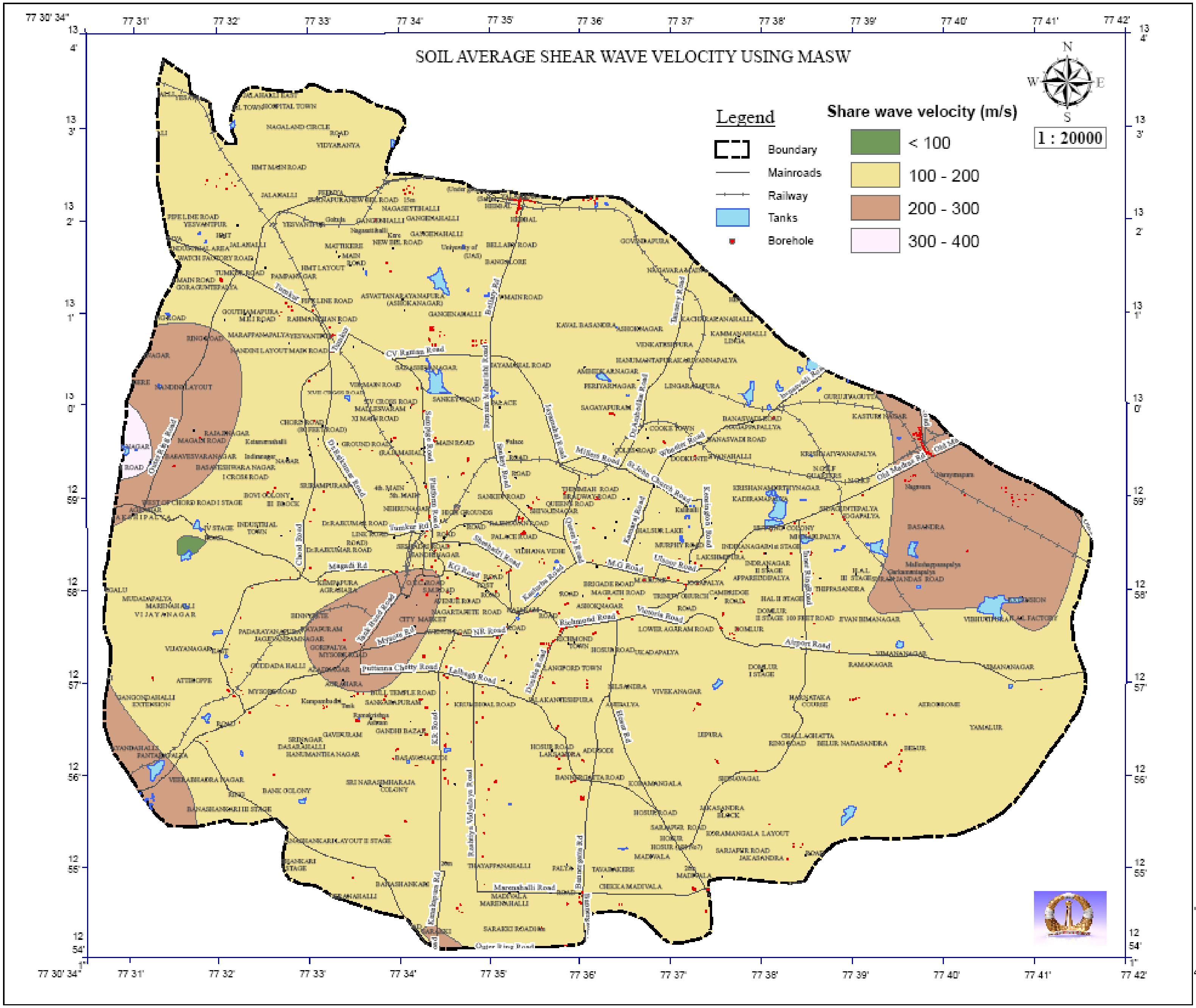
Index	Themes	Weights
PGA	Rock level PGA using DSHA-DPGA	9
	Rock level PGA using PSHA-PPGA	9
AF	Amplification factor	8
ST	Soil Thickness using MASW	7
	Soil Thickness using borehole	7
SS	Equivalent Shear wave velocity for Soil	6
	Equivalent Shear wave velocity for 30 depth	6
FS	Factor of safety against liquefaction	5
PF	Predominant period / frequency	4
EL	Elevation levels	3
DR	Drainage pattern	2
GG	Geology and geomorphology	1

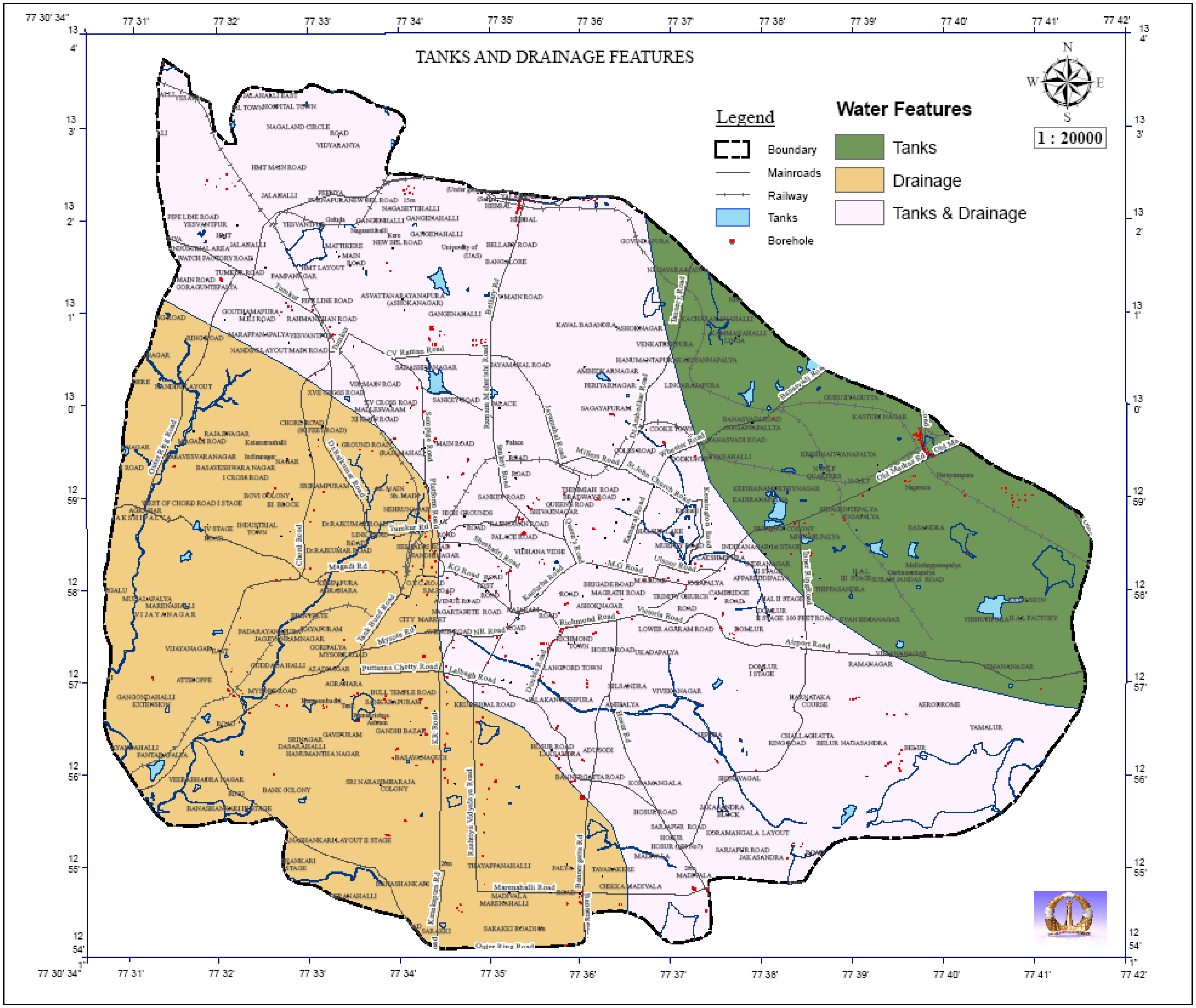


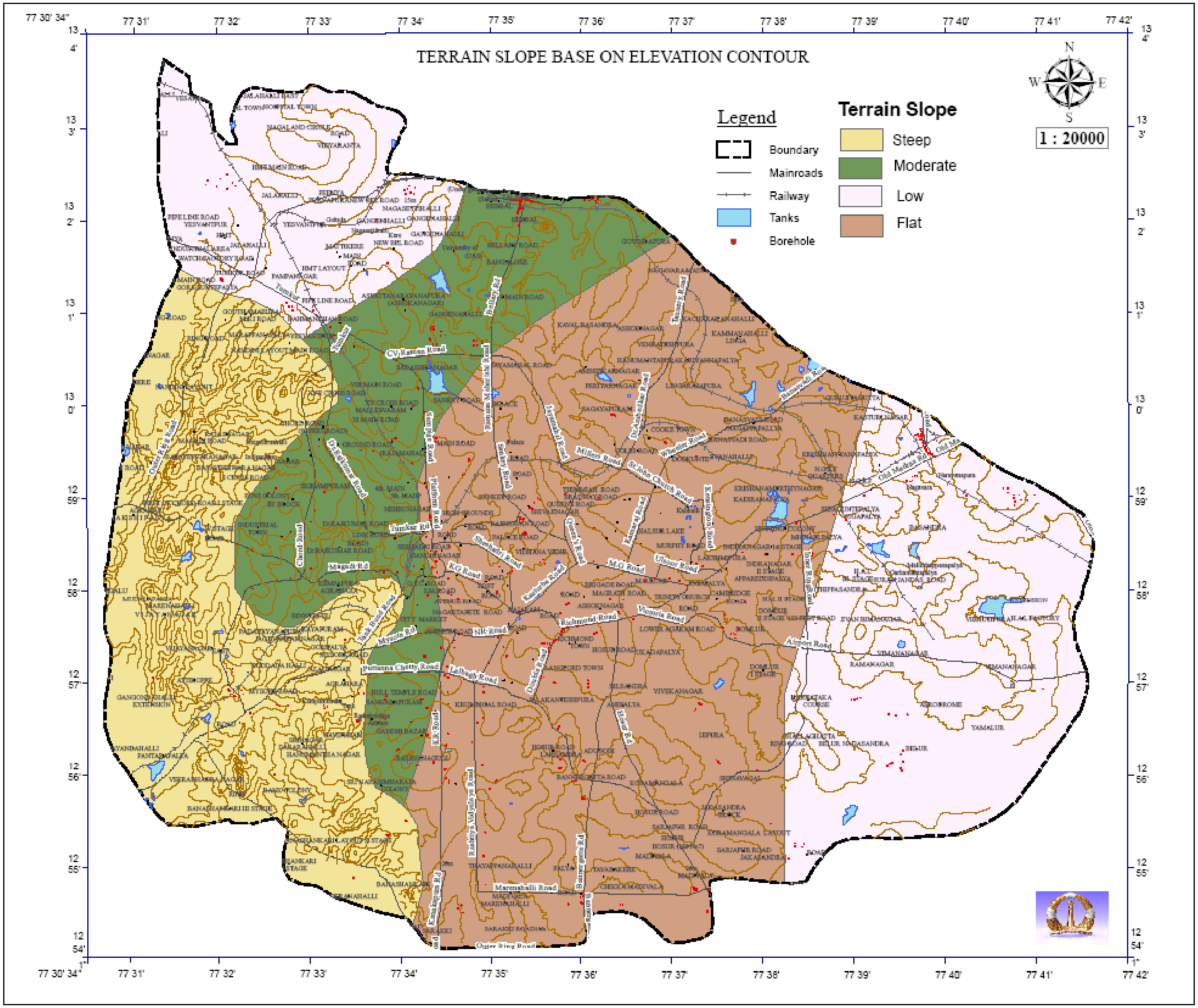
GEOLOGY AND GEOMORPHOLOGY MAP
Legend
Boundary
Mainroads
Railway
Tanks
Borehole
Geology and Geomorphology
Migmatite Intrusion
Granite
Swarms
Granitic Gneiss
1 : 20000
N
S
E
W
Granitic Gneiss
Ridge Line
Swarms
Vrshabhavathi River
Granite
Migmatite
Granitic Gneiss

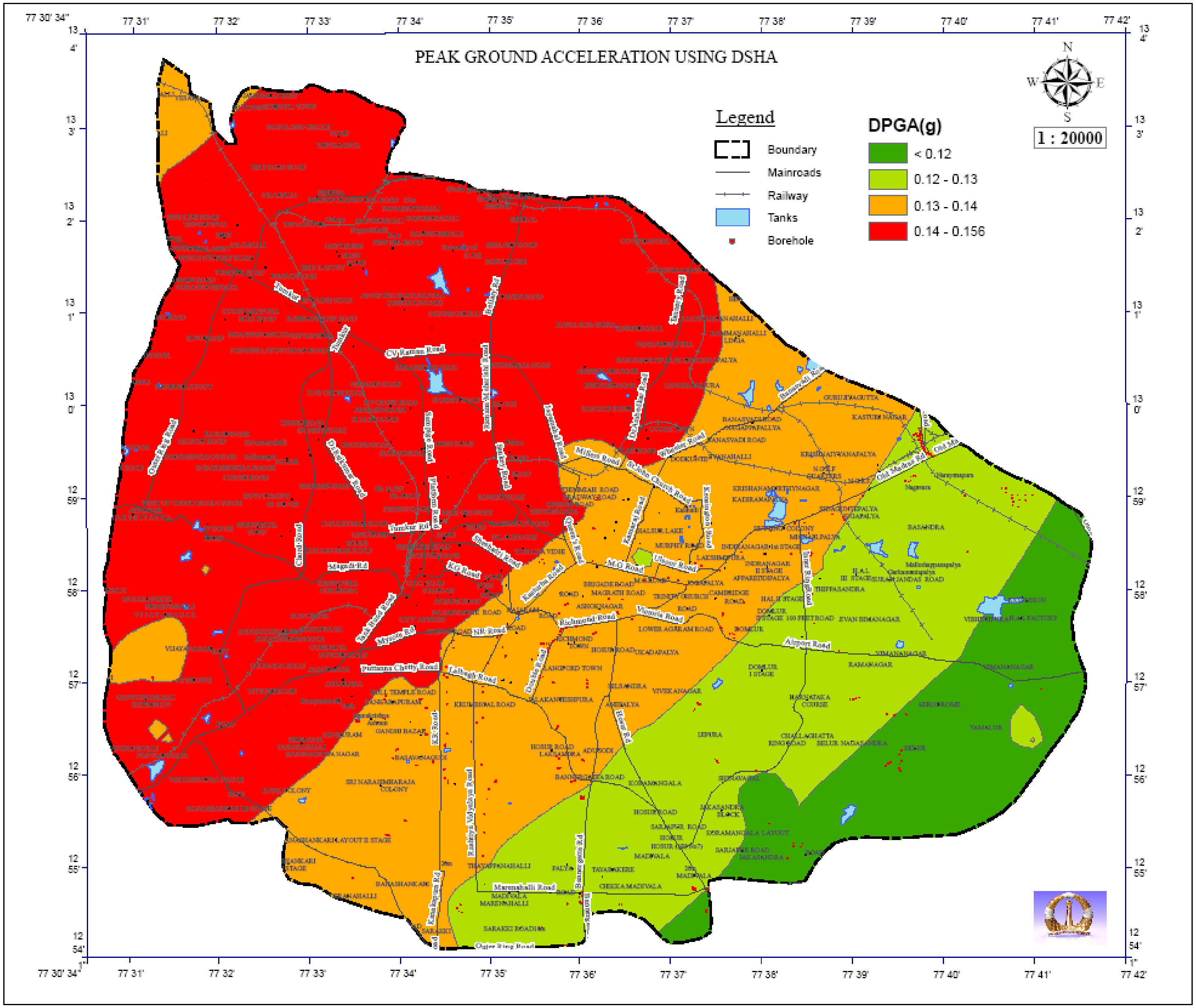

SOIL OVERBURDEN THICKNESS USING BOREHOLES
Legend
Boundary
Mainroads
Railway
Tanks
Borehole
Soil Thickness(m)
1 - 5
5 - 10
10 - 15
15 - 20
20 - 40
1 : 20000
N
S
E
W

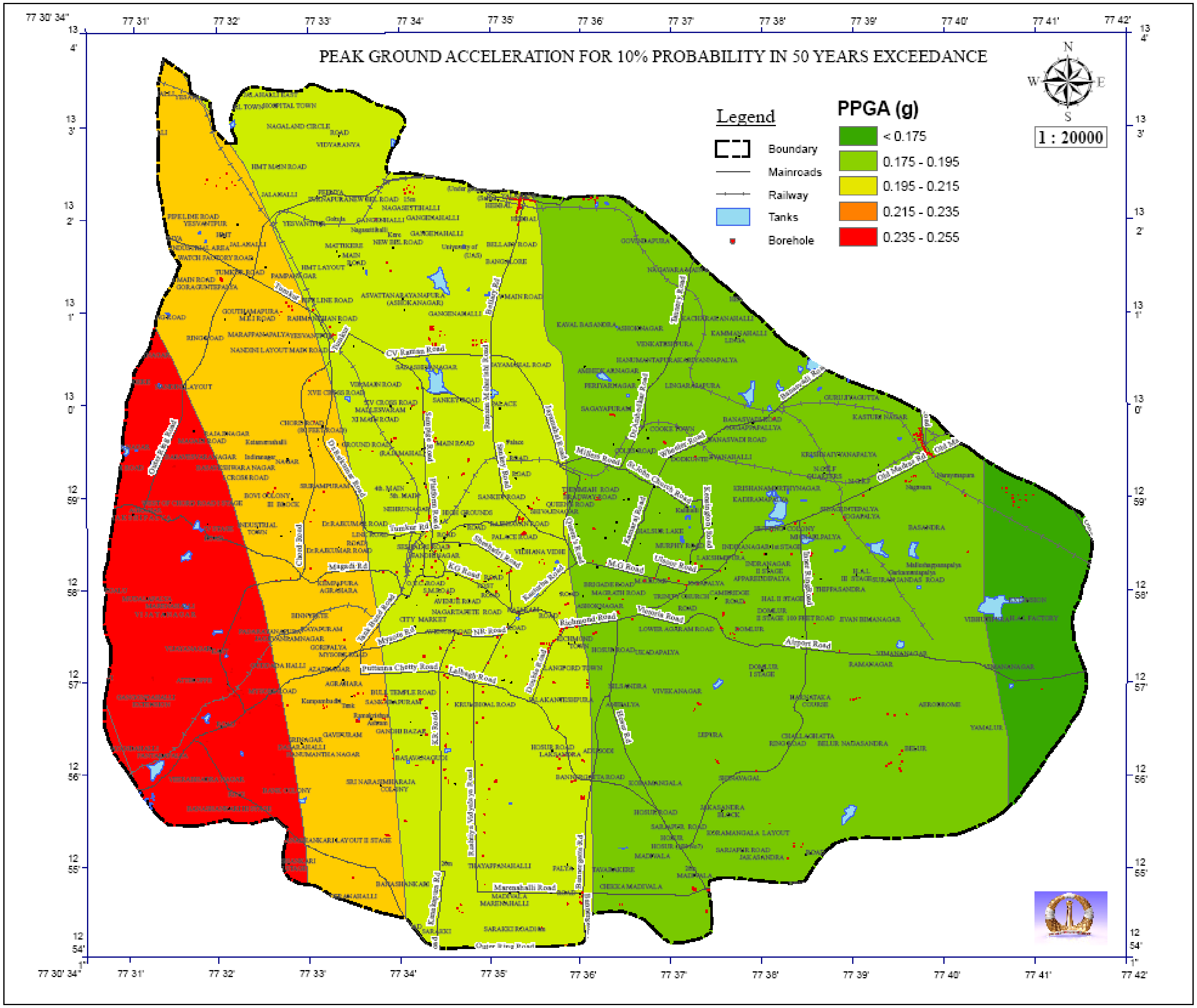

ENGINEERING ROCK DEPTH USING MASW DATA
MICROZONATION MAPS OF BANGALORE MAHANAGARA PALIKE
N
S
E
W
1 : 20000
KARNATAKA MAP
Bangalore Urban District
Bangalore Ward Map
Legend
Boundary
Mainroads
Railway
Tanks
Borehole
Depth (m)
0
3
5
8
10
15
20
25
30
35
40
45
50
DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF SCIENCE
BANGALORE - 560012
DATE: JUNE 2007
MAP NO. - 125

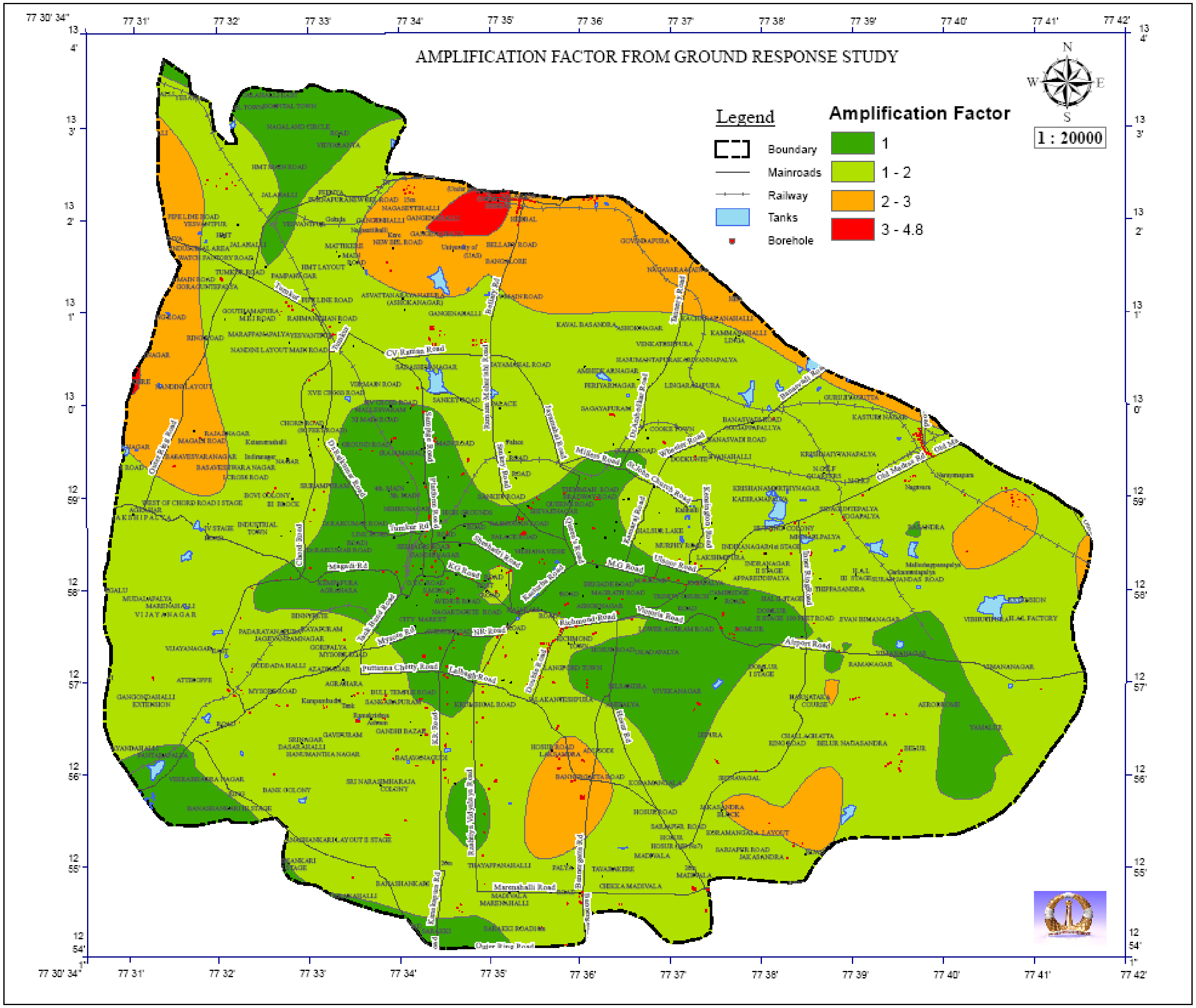

SOIL AVERAGE SHEAR WAVE VELOCITY USING MASW
Legend
Boundary
Mainroads
Railway
Tanks
Borehole
Share wave velocity (m/s)
< 100
100 - 200
200 - 300
300 - 400
1 : 20000
N
S
E
W

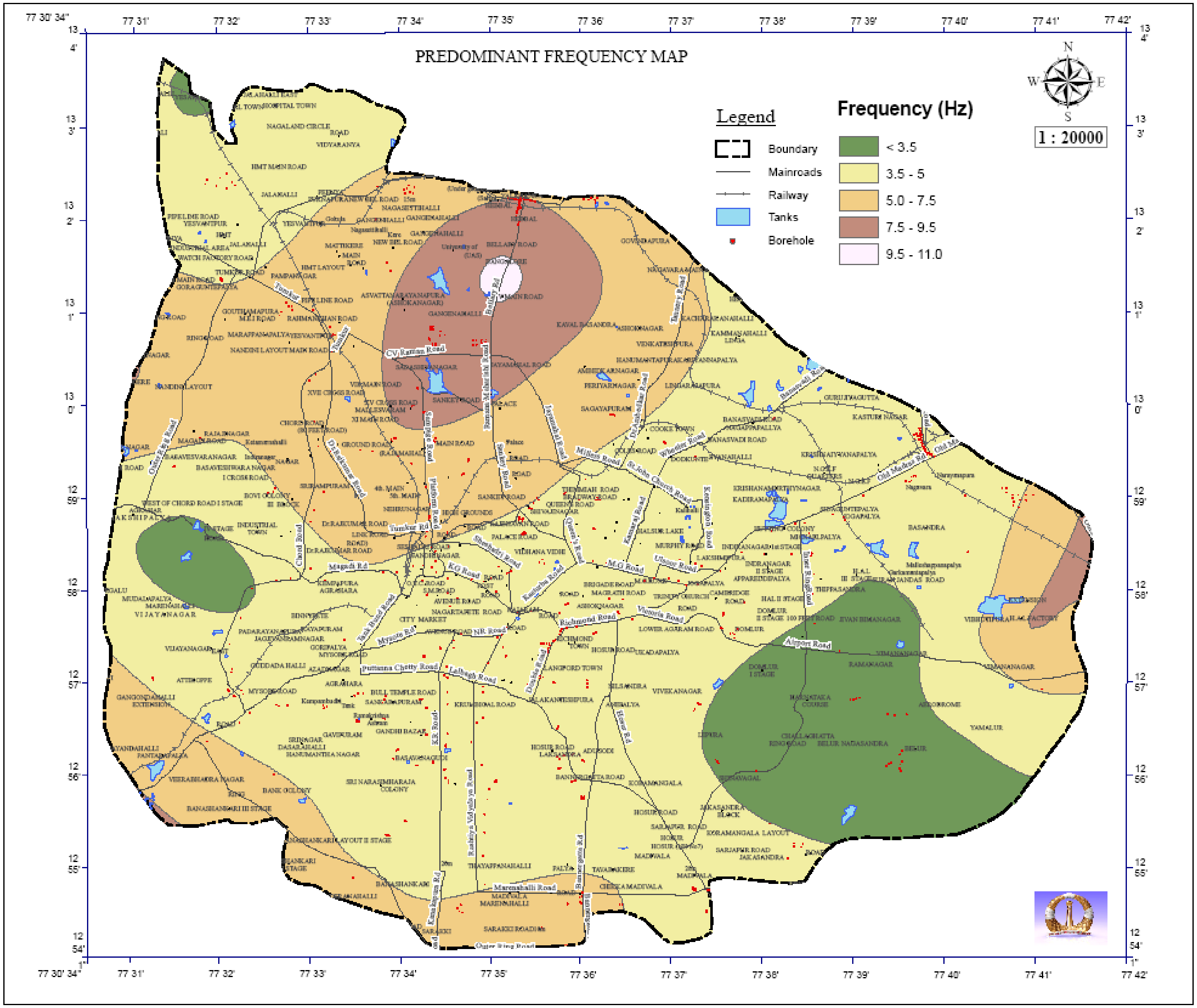

TANKS AND DRAINAGE FEATURES
Legend
Boundary
Mainroads
Railway
Tanks
Borehole
Water Features
Tanks
Drainage
Tanks & Drainage
1 : 20000
N
S
E
W

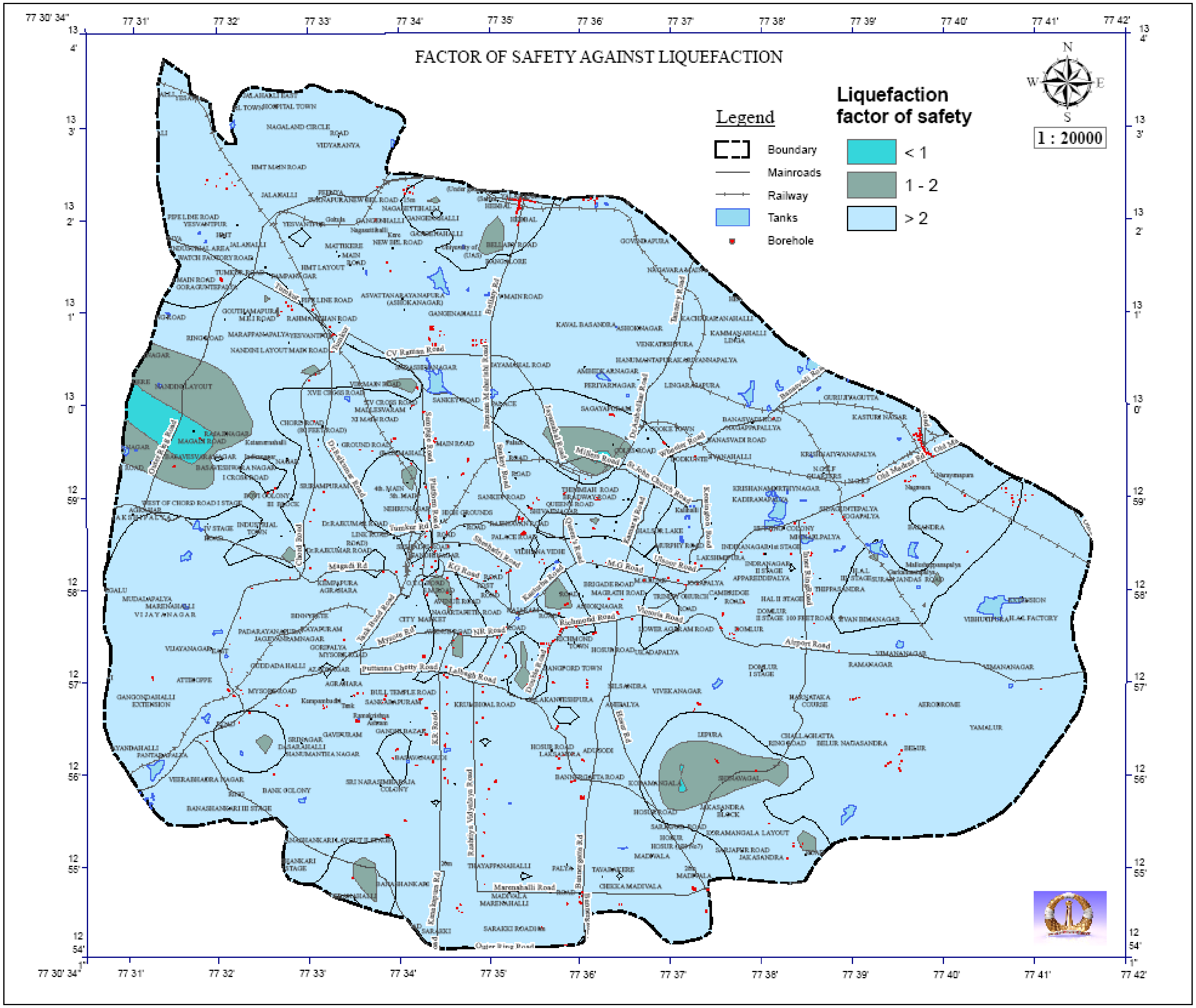

TERRAIN SLOPE BASE ON ELEVATION CONTOUR
Legend
Boundary
Mainroads
Railway
Tanks
Borehole
Terrain Slope
Steep
Moderate
Low
Flat
1 : 20000
N
S
E
W


PEAK GROUND ACCELERATION USING DSHA
Legend
Boundary
Mainroads
Railway
Tanks
Borehole
DPGA(g)
< 0.12
0.12 - 0.13
0.13 - 0.14
0.14 - 0.156
N
S
E
W
1 : 20000


PEAK GROUND ACCELERATION FOR 10% PROBABILITY IN 50 YEARS EXCEEDANCE
Legend
Boundary
Mainroads
Railway
Tanks
Borehole
PPGA (g)
< 0.175
0.175 - 0.195
0.195 - 0.215
0.215 - 0.235
0.235 - 0.255
1 : 20000
N
S
E
W


AMPLIFICATION FACTOR FROM GROUND RESPONSE STUDY
Legend
Boundary
Mainroads
Railway
Tanks
Borehole
Amplification Factor
1
1 - 2
2 - 3
3 - 4.8
1 : 20000
N
S
E
W


PREDOMINANT FREQUENCY MAP
Legend
Boundary
Mainroads
Railway
Tanks
Borehole
Frequency (Hz)
< 3.5
3.5 - 5
5.0 - 7.5
7.5 - 9.5
9.5 - 11.0
N
S
W
E
1 : 20000


FACTOR OF SAFETY AGAINST LIQUEFACTION
Legend
Boundary
Mainroads
Railway
Tanks
Borehole
Liquefaction factor of safety
< 1
1 - 2
> 2
1 : 20000

Normalized ranks of the themes

Themes	Values	Weight	Ranks	Normalized Ranks
PGA (g)	<0.12	0.200	1	0
	0.12 to0.13		2	0.33
	0.13 to 0.14		3	0.66
	0.14 to 0.15		4	1
AF	1-2	0.178	1	0
	2-3		2	0.33
	3-4		3	0.66
	>4		4	1
ST (m)	1-5	0.156	1	0
	5-10		2	0.25
	10-15		3	0.5
	15-20		4	0.75
	20-25		5	1
Vs (m/s)	<100	0.1333	4	1
	100 -200		3	0.66
	200 -300		2	0.33
	300 -400		1	0
FS	<1	0.111	3	1
	1-2		2	0.5
	>2		1	0
PF (Hz)	<03.5	0.0889	1	0
	3.5 -5		2	0.25
	5-7.5		3	0.5
	7.5 -9		4	0.75
	9-11		5	1

Deterministic seismic microzonation map

$$DSM-HI=\begin{pmatrix}\mathrm{DPGA}_W\,\mathrm{DPGA}_r+AF_W\,AF_r+ST_W\,ST_r+SS_W\,SS_r+\\ FS_W\,FS_r+PF_W\,PF_r+EL_W\,EL_r+DR_w DR_r+GG_w GG_r\end{pmatrix}/\sum W$$

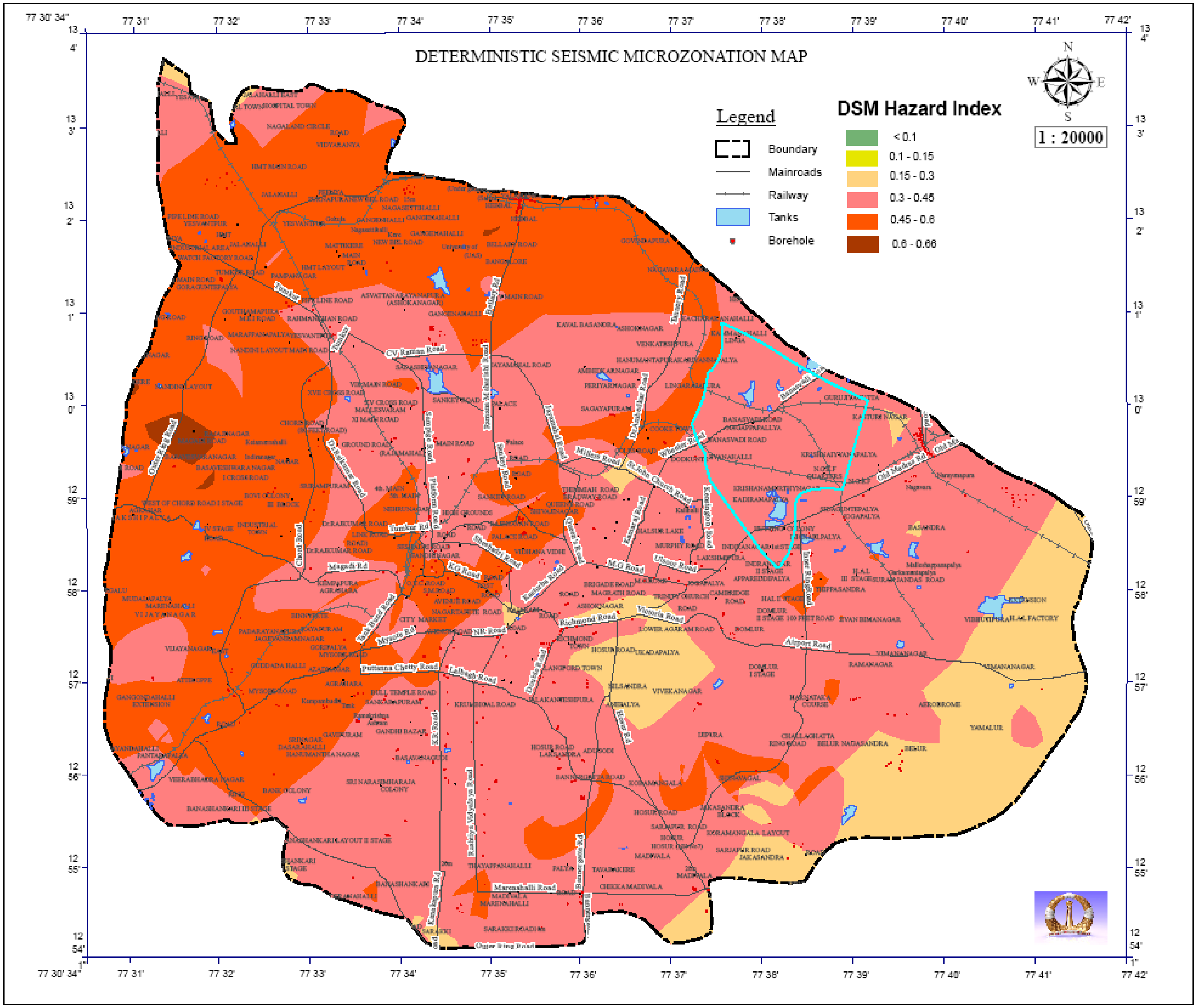
Integrated GIS map shows that

hazard index values vary from 0.10 to 0.66

❖The maximum hazard is attached to the seismic hazard index greater than 0.6 at western part of Bangalore.

❖Eastern part of city attached to a minimum hazard when compare to other areas.

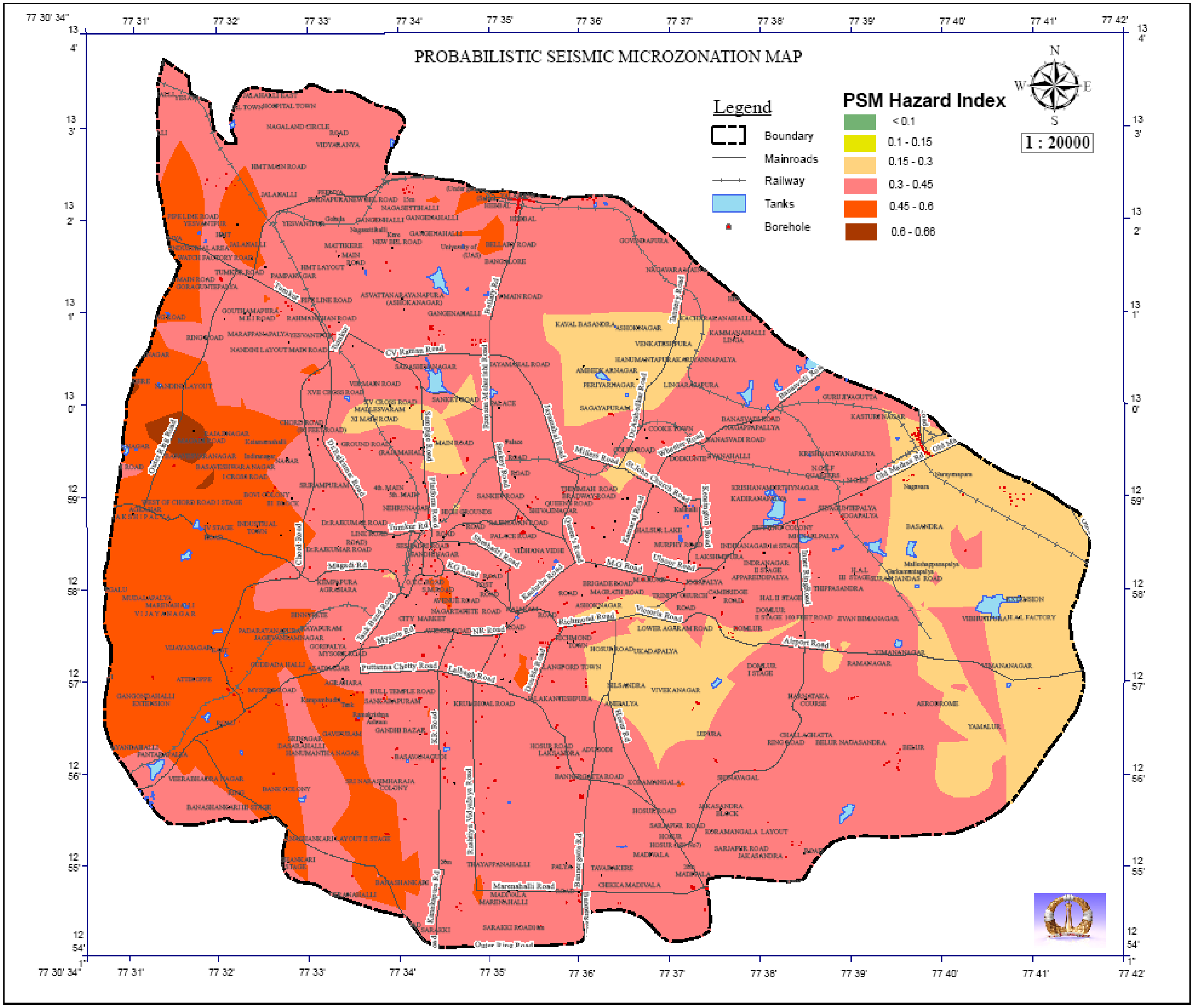
❖Western and southern part has mixed hazard and northern part has moderate hazard.


DETERMINISTIC SEISMIC MICROZONATION MAP
Legend
Boundary
Mainroads
Railway
Tanks
Borehole
DSM Hazard Index
< 0.1
0.1 - 0.15
0.15 - 0.3
0.3 - 0.45
0.45 - 0.6
0.6 - 0.66
N
S
E
W
1 : 20000

Probabilistic seismic microzonation map

$$PSM-HI=\begin{pmatrix} \mathrm{PPGA}_W \mathrm{PPGA}_r + AF_W AF_r + ST_W ST_r + SS_W SS_r + \\ FS_W FS_r + PF_W PF_r + EL_W EL_r + DR_w DR_r + GG_w GG_r \end{pmatrix} / \sum W$$

- Probabilistic hazard index values vary from 0.10 to 0.6
- These values are lesser than that of deterministic hazard index.
- The maximum hazard is attached to the seismic hazard index greater than 0.6 at south western part of Bangalore.
- Lower part (south) of Bangalore is identified as moderate to maximum hazard when compare to the northern part.

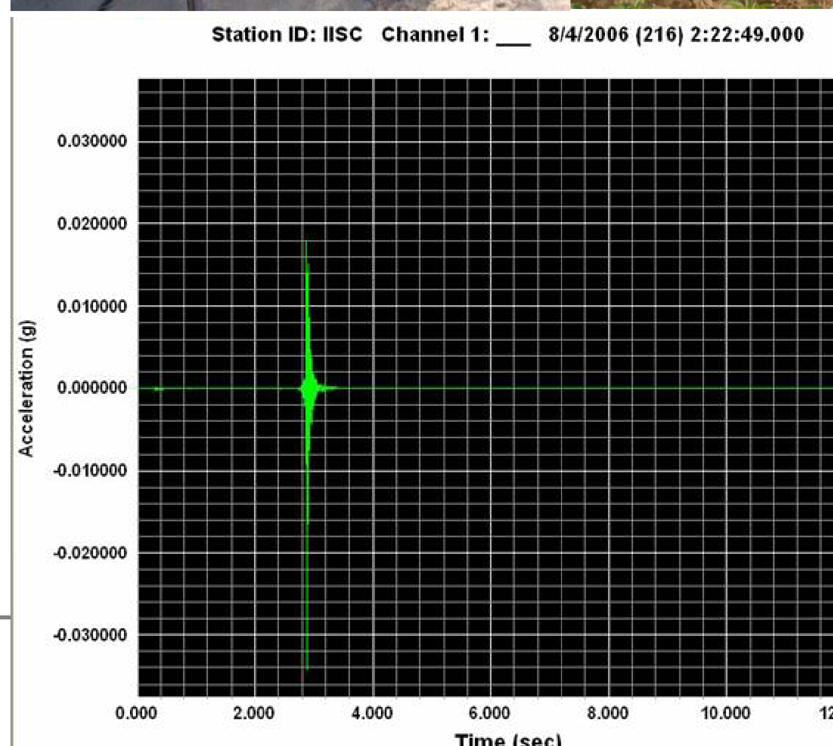

PROBABILISTIC SEISMIC MICROZONATION MAP
Legend
Boundary
Mainroads
Railway
Tanks
Borehole
PSM Hazard Index
< 0.1
0.1 - 0.15
0.15 - 0.3
0.3 - 0.45
0.45 - 0.6
0.6 - 0.66
N
S
W
E
1 : 20000

Conclusions

- Area with Maximum hazard covered by DSM-HI is larger when compared to PSM-HI
- Maximum hazard at western part of city in DSM may be attributed to the location of seismic source (Mandya-Channapatna- Bangalore lineament) and larger PGA in that area.
- PSM shows that the maximum hazard is at south western part, because the maximum number of seismogenenic sources is located in that direction.

Installations of Strong Motion Accelerographs and BBS

- 8 SMA procured from M/s Kinemetrics, USA installed in Bangalore (1 in Mysore)
- 6 surface and 2 borehole sensors.
- Many mild earthquakes recorded.
- EQ of 3.4 in the border of Andhra, Tamil Nadu and Karnataka recorded.
- BROAD BAND SEISMOGRAPH STS 2 – M/s Kinemetrics is installed



SUMMARY

- Seismic hazard is evaluated for Bangalore with local site effects - maps have been prepared in GIS 1:20000 scale
- Microzonation study employed the following aspects:
  - Maximum credible earthquake considering both DSHA and PSHA –0.15g
  - Use of Attenuation relation developed for PI
  - Site characterization by geotechnical and geophysical methods
  - Site specific ground motion studies based on both analytical (1D equivalent linear analysis) and ambient noise survey – Moderate amplification
  - Liquefaction Analysis – No liquefaction threat
- Considering a Grid 1kmx1km– PSHA is carried out including site response
- Hazard maps have been prepared.