GIS INTEGRATION FOR MICROZONATION HAZARD MAPPING -A CASE STUDY OF BANGALORE CITY, INDIA

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Abstract

GIS will provide an effective solution for integrating different layers of information thus providing a useful input for city planning and in particular input to earthquake resistant design of structures in an area. Seismic hazard and microzonation of cities enable to characterize the potential seismic areas that need to be taken into account when designing new structures or retrofitting the existing ones In this paper, the details of seismic hazard analysis and preparation of microzonation maps for Bangalore using Geographical Information System (GIS) have been discussed and presented. Seismic hazard is the study of expected earthquake ground motions at any point on the earth. Microzonation is the process of sub division of region in to number of zones based on the earthquake effects in the local scale. Seismic microzonation is the process of estimating response of soil layers under earthquake excitation and thus the variation of ground motion characteristic on the ground surface. For the seismic microzonation, geotechnical site characterization needs to be assessed at local scale (micro level) along with geology, seismological details, which are further used to assess of the site response and liquefaction susceptibility of the sites. GIS is used as a tool to represent the all possible earthquake hazard parameters in the form of geographical maps, which is most useful for government agencies, non-governmental organizations, business communities and public for planning infrastructures developments, emergency preparedness and management. The microzonation, thus, achieved is envisaged as a tool for GIS landuse planning, hazard management, structural engineering, and insurance purposes.

Keywords: GIS, Seismic Microzonation, Peak ground acceleration, Seismic hazard, Site response, Hazard index.

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Introduction

Seismic hazard and microzonation of cities enable to characterize the potential seismic areas that need to be taken into account when designing new structures or retrofitting the existing ones. Study of seismic hazard and preparation of geotechnical microzonation maps will provide an effective solution for city planning and input to earthquake resistant design of structures in an area. Seismic hazard is the study of expected earthquake ground motions at any point on the earth. Microzonation is the process of sub division of region in to number of zones based on the earthquake effects in the local scale. Seismic microzonation is the process of estimating response of soil layers under earthquake excitation and thus the variation of ground motion characteristic on the ground surface. Geotechnical site characterization and assessment of site response during earthquakes is one of the crucial phases of seismic microzonation with respect to ground shaking intensity, attenuation, amplification rating and liquefaction susceptibility. Microzonation mapping of seismic hazards can be expressed in relative or absolute terms, on an urban block-by-block scale, based on local soil conditions (such as soil types) that affect ground shaking levels or vulnerability to soil liquefaction. Such maps would provide general guidelines for integrated planning of cities and in positioning the types of new structures that are most suited to an area, along with information on the relative damage potential of the existing structures in a region. In this study an attempt has been made to map the evaluated hazard parameters using GIS. Application of GIS for mapping of natural hazard is amply demonstrated by many researchers all over the world. Nath (2004) used GIS has integration tool to map seismic ground motion hazard for Sikkim Himalaya in India. In study GIS is used to compile available geotechnical and shallow geophysical data of Bangalore Mahanagar Palike (BMP) to characterize site. The data are analysis and coupled with earthquake hazard and assess the seismic hazard parameters. Finally GIS is used as master tool to represent seismic hazard parameters in the form of maps. These maps will be more useful for filed Engineers, Planners, Emergency service providers, Government officials, Decision makers and others in Natural disaster management officials.

GIS as a Tool

Geographical Information System (GIS) provides a perfect environment for accomplishing comprehensive regional seismic damage assessment, GIS has the capability to store, manipulate, analyze and display the large amount of required spatial and tabular data. One of the most important features of a geographic information system is the manipulation and analysis of both spatial (graphic) and Non-spatiaol (non-graphic) data. The procedures for data analysis typically found in most GIS programs as follows:

- Map overlay procedures, including arithmetic, weighted average, comparison, and correlation functions.
- Spatial connectivity procedures, including proximity functions, optimum route selection and network analysis.
- Spatial neighborhood statistics, such as slope, aspect ratio, profile and clustering.
- Measurements of line and arc lengths, of point-to-point distances, of polygon perimeters, areas and volumes.
- Statistical analysis, including histograms or frequency counts, regressions, correlations and cross-tabulation.
- Report generation, including maps, charts, graphs, tables and other user-defined information.

Figure 1 shows the typical nitration GIS flow chart. Depending on the level of sophistication of a GIS, numerous application-specific analysis functions may exist. These include procedures such as geotechnical data, air pollution dispersion, ground water flow, a highway traffic routing. Most of the systems include some sort of built-in programming capability usually in the form of a software-specific macro language. This allows the user to develop a set of functions or analysis procedures that can be stored in a user-defined library. Often, the GIS macro language is very simplified and doesn't have to handle very high-level computational features such as recursion, numerous simulations, subscripted variables, and subroutines. For this reason, most GIS programs have the ability to communicate with external analysis and modeling programs. A system can typically output data in various formats to be used in various external programs such as spreadsheets, word processing, graphics, and other user-specified executable programs. The results of an external analysis can be used by GIS as both graphic and non-graphic data for further manipulation and analysis, or for final report and map generation. With these wide areas of application, GIS play a unique roll for hazard preparedness and management. In this study GIS is used as tool for mapping seismic hazard of Bangalore city.

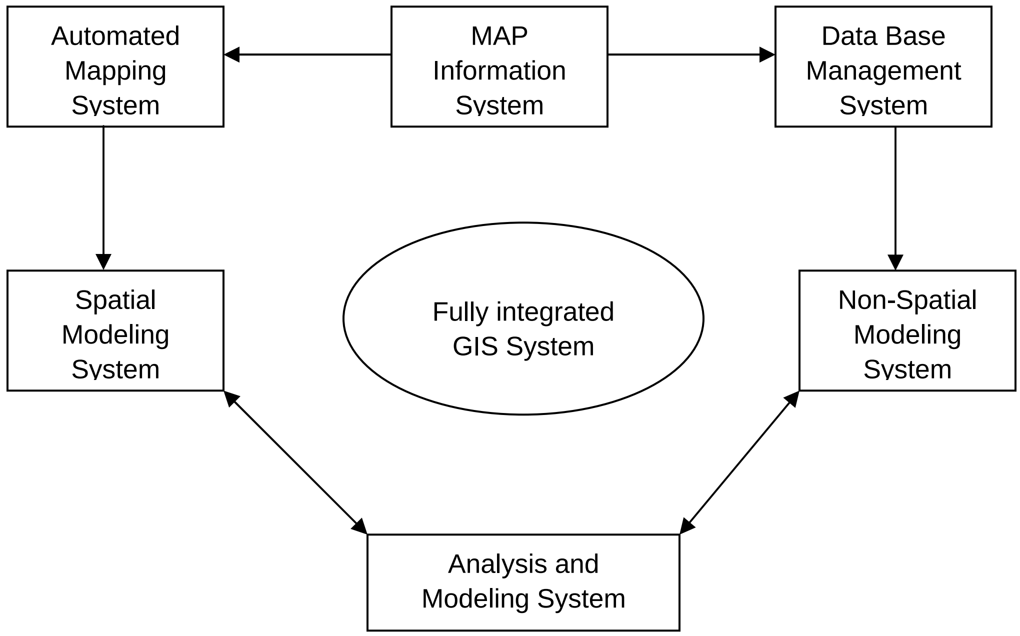

Figure 1: The information systems composing a fully integrated GIS (after Frost et al., 1992)

Bangalore

Bangalore is the capital of the state of Karnataka, occupies the heart of the Mysore Plateau with an average elevation of 920 m. It is located at 12.97° N 77.56° E. Synonymous with the IT revolution in India. It has a population of approximately of 6.8 million in the year of 2006. Bangalore is India's third-largest city. Bangalore has earned the name of capital city of "Silicon Valley of India", " Pub Capital of India", and "City of Gardens" among others, with its beautiful parks, avenues, multiplexes and historical monuments, Bangalore now to emerge as India's nano-technology hub. Bangalore is undoubtedly bubbling with life and energy with a salubrious climate. The city has several institutions of higher learning and research. The high-tech industries viz, aerospace, electronics, computer science, information technology etc., have made Bangalore their home due to easy access to vast pool of scientists and engineers.

There were over 150 lakes, though most of them are dried up due to erosion and encroachments leaving only 64 at present in an area of 220 sq km. These tanks were once distributed throughout the city for better water supply but presently in a dried up condition and encroached. The tank beds have the silty clay and silty sand with filled soil above, over which buildings/structures have been built. Because of density of population, mushrooming of buildings of all kinds from mud buildings to RCC framed structures and steel construction and, improper and low quality construction practice, Bangalore is vulnerable even against average earthquakes (Sitharam et al. 2006; Sitharam and Anbazhagan 2007). It is mandatory to estimate effects of earthquake in Bangalore. In this paper presets the estimation of earthquake hazard and mapping using GIS tool.

GIS has been used in engineering sciences for data collection, interactions, organization and distribution of geological data and maps. The project in engineering sciences will have many types of data sources in which GIS is an invaluable tool for integration of many different types. Visualization is another GIS activity which is very useful in this project. This includes creating maps on screen, producing hard copy maps and delivering maps. The Bangalore map forms the base layer for development of GIS model. The map entities were developed in view of two aspects, firstly for locating the bore logs points to the utmost accuracy on a scale of 1:20000 and secondly for identification of bore logs/data points by end user. The base map was developed with several layers of information. Some of the important layers considered are the boundaries (Outer and Administrative), Contours, Highways, Major roads, Minor roads, Streets, Rail roads, Water bodies, Drains, Landmarks and Bore locations. Digitized map was developed mainly using hard copy of Bangalore guide map, published by Survey of India in 1983 and several other sources from standard publishers were used for reference. Digitization of the map layers was done in AutoCAD and then imported to Arc GIS 1. Few combinations of layers that can be viewed in the form of map with various ground truths such as elevations of locations, drainage pattern and tank locations, typical map is shown in Figures 2. Figure 2 depicts the borehole locations with respect to water features like lakes, tanks, and natural drains, which could be helpful in prediction of soil behavior and also information can be derived for ground water management and planning. In this study also developed the 3-D model of boreholes is described. The boreholes are represented as 3 dimensional objects projecting below the map layer in 0.5m intervals. Also image files of bore logs and properties table has been attached to location in plan. These 3-D boreholes are generated with several layers with a bore location in each layer overlapping one below the other and each layer representing 0.5 m interval of the subsurface. 3-D borehole consists of several donut elements in different layers placed coinciding one below the other. This view gives a visual idea of the depth to which geotechnical data is available in each borehole. Several other important layers are available in the map, which would be of interest to many engineering groups.

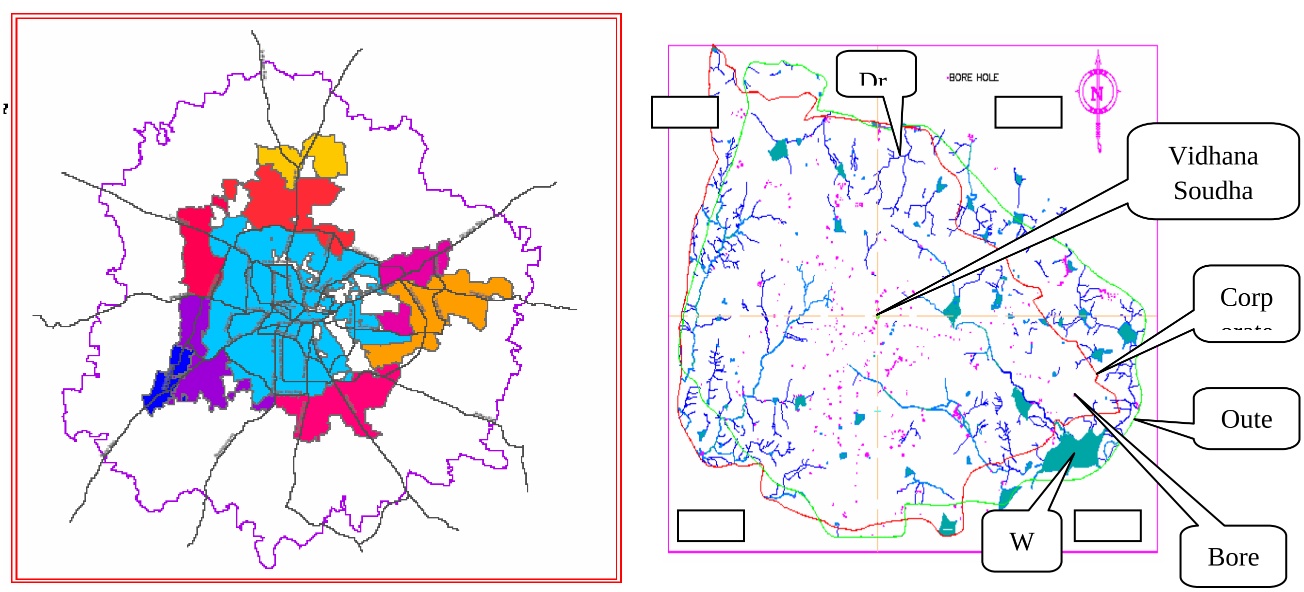

Figure 1: GIS model of borehole locations with respect to water features

Site Characterization

Site characterization has also been carried out using measured shear wave velocity with the help of shear wave velocity survey using MASW. MASW (Multichannel Analysis of Surface Wave) is a geophysical method, which generates a shear-wave velocity (*Vs*) profile (i.e., *Vs* versus depth) by analyzing Raleigh-type surface waves on a multichannel record (Park et al., 1999; Xia et al., 1999; Xu et al., 2006). It is a seismic method that can be used for geotechnical characterization of near surface materials (Park et al, 1999; Xia et al, 1999; Miller et al, 1999a; Park et al, 2005a; Kanli et al, 2006). MASW system consisting of 24 channels Geode seismograph with 24 geophones of 4.5 Hz capacity were used in this investigation. The shear wave velocity of Bangalore subsurface soil has been measured and correlation has been developed for shear wave velocity (Vs) with the standard penetration tests (SPT) corrected 'N' values. About 58 one-dimensional (1-D) MASW surveys and 20 two-dimensional (2-D) MASW surveys has been carried out with in 220 sq.km Bangalore urban area. Dispersion curves and shear velocity 1-D and 2-D have been evaluated using SurfSeis software. Using 1-dimensional shear wave velocity, the average shear wave velocity of Bangalore soil has been evaluated for depths of 5m, 10m, 15m, 20m, 25m and 30m (Vs^{30}) depths. GIS is used has master tool to preset average shear wave velocity estimated in 2-D map. A typical map is shown in Figure 2 for avenger shear wave velocity at 5m. The sub soil classification has been carried out for local site effect evaluation based on average shear wave velocity of 30m depth (Vs^{30}) of sites using NEHRP (National Earthquake Hazard Research Programme) and IBC (International Building Code) classification. Bangalore falls into site class D type of soil. Mapping clearly indicates that the depth of soil obtained from MASW is closely matching with the soil layers in the bore logs. The measured shear wave velocity at 38 locations close to SPT boreholes, which are used to generate the correlation between the shear wave velocity and corrected 'N' values using a power fit. Also, developed relationship between shear wave velocity and corrected 'N' values corresponds well with the published relationships of Japan Road Association (JRA, 1980).

Earthquake Effects

Earthquake damage is commonly controlled by three interacting factors- source and path characteristics, local geological and geotechnical conditions and type of structures. Obviously, all of this would require analysis and presentation of a large amount of geological, seismological and geotechnical data. History of earthquakes, faults/sources in the region, attenuation relationships, site characteristics and ground amplification, liquefaction susceptibility are few of the important inputs required. Microzonation has generally been recognized as the most accepted tool in seismic hazard assessment and risk evaluation and it is defined as the zonation with respect to ground motion characteristics taking into account source and site conditions (TC4- ISSMGE, 1999). Making improvements on the conventional macrozonation maps and regional hazard maps, microzonation of a region generates detailed maps that predict the hazard at much lager scales. Damage patterns of many recent earthquakes around the world, including the 1999 Chamoli and 2001 Bhuj earthquakes in India, have demonstrated that the soil conditions at a site can have a major effect on the level of ground shaking. For example, in the Chamoli earthquake, epicenter located at more than 250 km away from Delhi caused moderate damage to some of the buildings built on filled up soil or on soft alluvium. The Bhuj earthquake caused severe damage not only in the epicentral region, but even in Ahmedabad, about 250 km away, which attributed to increased ground shaking of the soft alluvium.

Hazard at Rock Level

Deterministic Seismic Hazard Analysis (DSHA) for Bangalore has been carried out by considering the past earthquakes, assumed subsurface fault rupture lengths and point source synthetic ground motion model. The seismic sources for region have been collected by considering seismotectonic atlas map of India and lineaments identified from satellite remote sensing images. Analysis of lineaments and faults help in understanding the regional seismotectonic activity of the area. Maximum Credible Earthquake (MCE) has been determined by considering the regional seismotectonic activity in about 350 km radius around Bangalore. Earthquake data are collected from IMD, USGS, NGRI, CESS, ASC and other public domain sites. Source magnitude for each source is chosen from the maximum reported past earthquake close to that source and shortest distance from each source to Bangalore is arrived from the newly prepared seismotectonic map of the area. Using these details, and, attenuation relation developed for southern India by Iyengar and Raghukanth (2004), the peak ground acceleration (PGA) has been estimated. A parametric study has been carried out to find fault subsurface rupture length using past earthquake data and Wells and Coppersmith (1994) relation between the subsurface lengths versus earthquake magnitudes. About more than 60% of earthquake magnitude matches for the subsurface length corresponding to 3.8% of the total length of fault. Assuming 3.8 % of the total length of fault as the subsurface rupture length expected maximum magnitude for each source has been evaluated and PGA is estimated for these magnitudes. Further seismological model developed by Boore (1983, 2003) SMSIM program has been used to generate synthetic ground motions from vulnerable sources identified in above two methods. From the above three approaches maximum PGA of 0.15g was estimated for Bangalore. This value was obtained for a maximum credible earthquake (MCE) having a moment magnitude of 5.1 from a source of Mandya-Channapatna-Bangalore lineament. Considering this lineament and MCE and 850 borehole locations, PGA values are estimated, which are used to prepare rock level PGA with help of GIS tool. Seismic hazard parameter 'b' has been evaluated considering the available earthquake data using (1) Gutenberg–Richter (G-R) relationship and (2) Kijko and Sellevoll (1989, 1992) method utilizing extreme and complete catalogs. The 'b' parameter was estimated to be 0.87 from G - R relation and 0.87± 0.03 from Kijko and Sellevoll method. Further, probabilistic seismic hazard analysis for Bangalore region has been carried out considering six seismogenic sources identified in DSHA. From the analysis, mean annual rate of exceedance and cumulative probability hazard curve for Peak Ground Acceleration (PGA) and Spectral Acceleration (SA) have been generated. The quantified hazard values in terms of the rock level peak ground acceleration (PGA) are mapped on a grid size of 0.5 km to 0.5 km.

Site Response Using Soil Profiles

Bangalore city, a fast growing urban center, with low to moderate earthquake history and highly altered soil structure (due to large reclamation of land) is been the focus of this work. In the present study, an attempt has been made to assess the site response using geotechnical, geophysical data and field studies. The subsurface profiles of the study area within 220sq.km area was represented by 170 geotechnical bore logs and 58 shear wave velocity profiles obtained by MASW survey. The data from these geotechnical and geophysical technique have been used to study the site response. These soil properties and synthetic ground motions for each borehole locations are further used to study the local site effects by conducting one-dimensional ground response analysis using the program SHAKE2000. The response and amplification spectrum have been evaluated for each layer of borehole location. The natural period of the soil column, peak spectral acceleration and frequency at peak spectral acceleration of each borehole has been evaluated and presented as maps. The microzonation maps prepared indicates a medium variation in amplification potential. With the amplification factors varying from 1 to 4.7 and period of soil column from 0.08 to 4.5 seconds, the region is moderately amplifying. A peculiar feature of the study region is that it has reclaimed land from silted lakes/tanks leading to significant variations in ground response. The response spectrum for 5% damping at the ground surface obtained for 160 borehole locations and 58 MASW survey locations clearly indicate that the range of spectral acceleration (SA) at different frequencies varied from 0.01 to 2.17g. The site response studies also carried out experimentally based on recording the ambient noise for a selected period of duration. The noise was recorded at 54 different locations in 220sq.km area of Bangalore city using L4-3D short period sensors (CMG3T) equipped with digital data acquisition system. The predominant frequencies obtained from experimental result range between 1.2 Hz - 11 Hz which matches well with the 1-dimensional ground response analysis presented earlier.

Liquefaction Hazard

To study the liquefaction hazard in Bangalore, the liquefaction hazard assessment has been carried out using standard penetration test (SPT) data and soil properties. Factor of Safety against liquefaction of soil layer has been evaluated based on the simplified procedure of Seed and Idriss (1971) and subsequent revisions of Seed et al (1983, 1985), Youd et al (2001) and Cetin et al (2004). Cyclic Stress Ratio (CSR) resulting from earthquake loading is calculated by considering moment magnitude of 5.1 and amplified peak ground acceleration. Cyclic Resistant Ratio (CRR) is arrived using the corrected SPT 'N' values and soil properties. Cyclic resistance ratio (CRR) is arrived based on corrected 'N' value from a plot of CRR versus corrected 'N' value from a large amount of laboratory and field data. Factor of safety against liquefaction is calculated using stress ratios and accounting necessary magnitude scaling factor for maximum credible earthquake. A simple spread sheet was developed to carryout the calculation for each bore log. The factor of safety against liquefaction is grouped together for the purpose of classification of Bangalore (220 sq. km) area for a liquefaction hazards. Using 2-D base map of Bangalore city, the liquefaction hazard map was prepared using AutoDesk and ESRI packages. The results are grouped as four groups for mapping and presented in the form of 2-dimensional maps. About 90% of the area in Bangalore have heigher factor of safety and are non-liquefiable. This study shows that Bangalore is safe against liquefaction except at few locations where the overburden is sandy silt with presence of shallow water table.

Integration of Maps

All above seismic hazard parameters are coupled and assign weight factor in between 3-1to each theme depending on their contribution towards seismic hazard, the higher weight in this case being attached to site response for making it local-specific. The weight of a theme is determined Saaty's Analytical Hierarchy Process (Nath, 2007) is followed. In this method, a matrix of pairwise comparisons (ratio) between the factors is built, which is used to derive the individual normalized weights of each factor. The pairwise comparison is performed by calculating the principal eigenvector of the matrix and the elements of the matrix are in the range of 0 to 1 summing to '1' in each column (Nath 2007.) The weight for each theme is calculated by averaging the values in each row of the matrix. These weights will also sum to '1' and can be used in deriving the weighted sum of rating or scores of each region of cells or polygon of the mapped layers. Since the values within each thematic map/layer vary significantly, those are classified into various ranges or types known as the features of a layer. These features are then assigned ratings or scores within each layer, normalized to 0–1. The layer-wise normalized feature scores for all the themes are given in Table III. All the thematic maps are registered with one another through ground control points and integrated step-by-step using the aggregation method in GIS. The seismological and geological themes when integrated together through similar expression give final microzonation map of Bangalore.

Remarks

In this study the seismic hazard parameters of rock level PGA using DSHA and PSHA, site characterization parameters, site response parameters and liquefaction parameters are estimated and mapped using GIS as master tool. These parameters can be integrated using GIS integration tool, the final seismic hazard and microzonation map will be prepared for Bangalore. GIS is the master tool for all kind of hazard management.

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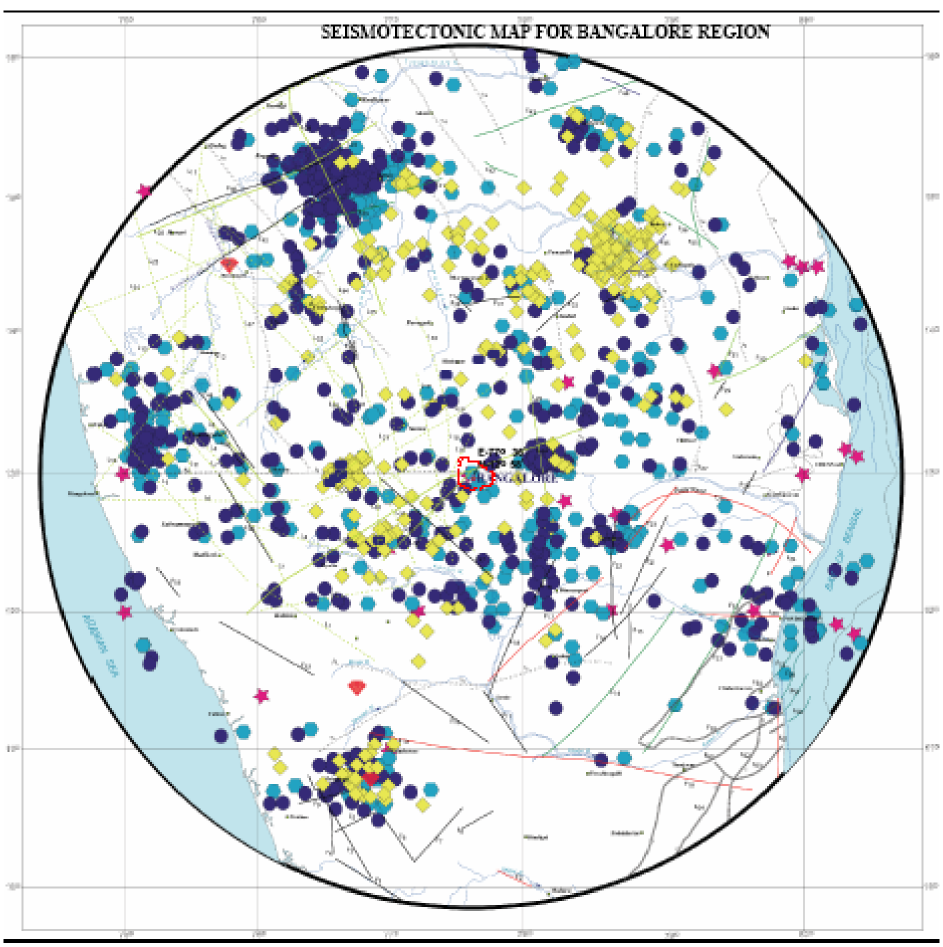
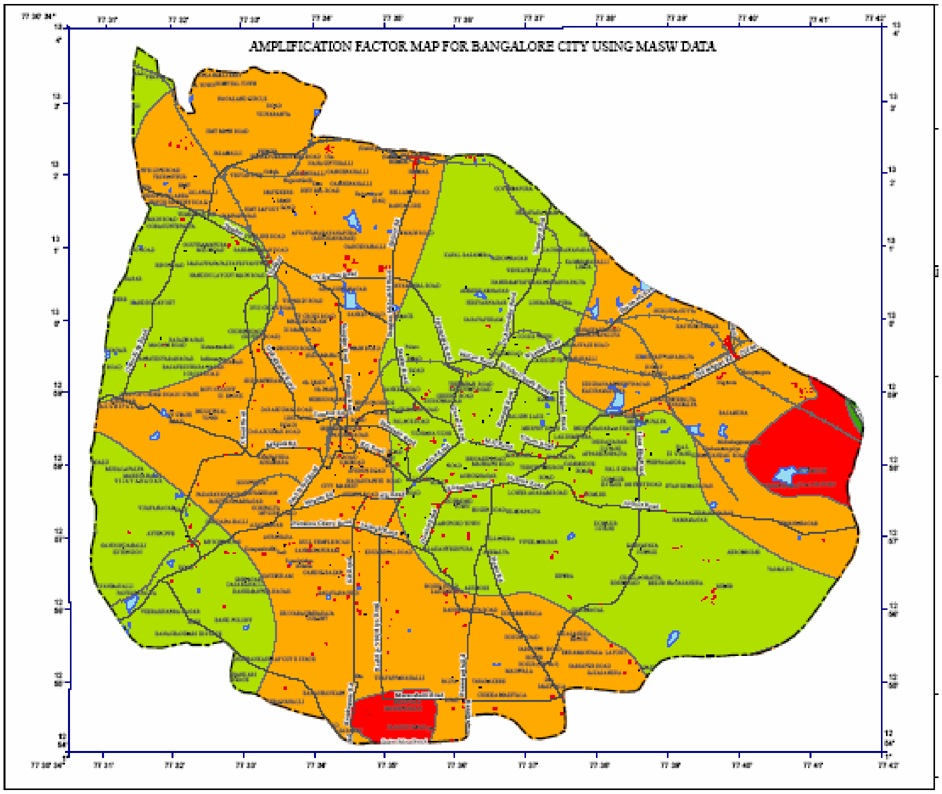
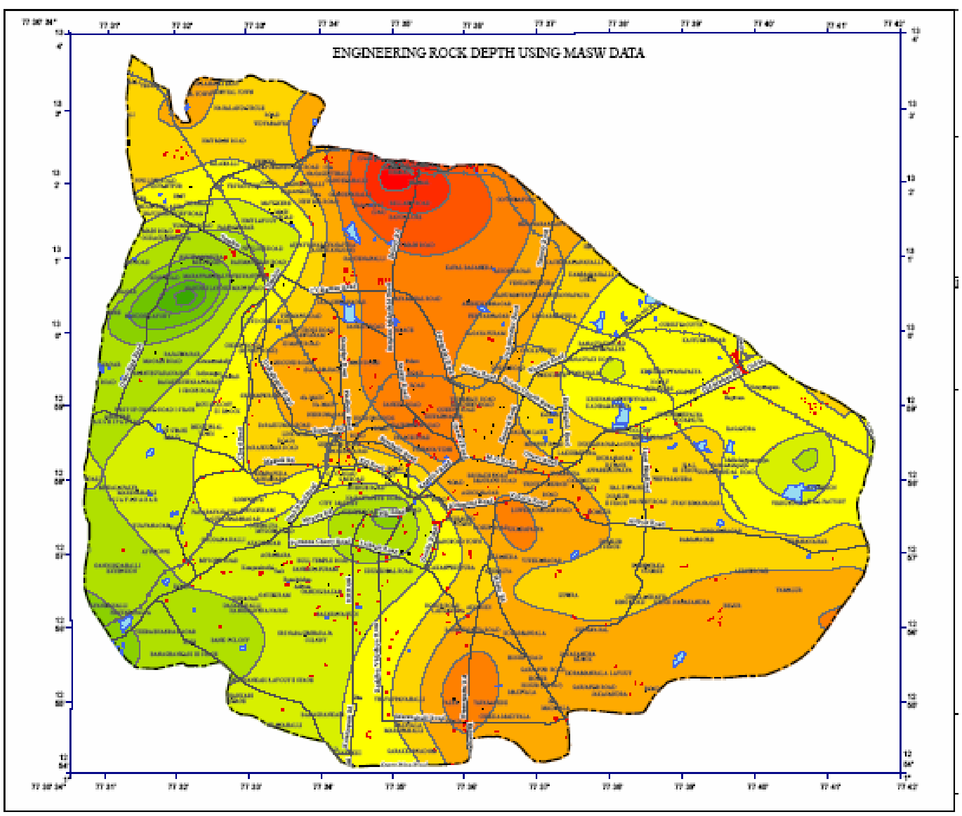
Sample Maps:




AMPLIFICATION FACTOR MAP FOR BANGALORE CITY USING MASW DATA


ENGINEERING ROCK DEPTH USING MASW DATA