Lecture 18: Introduction to GIS, Integration of hazard parameters on GIS platform; Final zonation map preparation with case study of Bangalore

Topics

- Geographical Information System (GIS)
- Analytic Hierarchy Process (AHP)
- Earthquake hazard parameters
- Themes and its weights for GIS integration
- Hazard Index
- Deterministic seismic microzonation map
- Probabilistic seismic microzonation map

Keywords: *Hazard integrations, Geographic Information System, Earthquake Hazard Parameters, Microzonation maps*

Topic 1

Geographical Information System (GIS)

- Geographic information systems (GIS) or geospatial information systems is a set of tools that captures, stores, analyzes, manages, and presents data that are linked to location(s).

- In the simplest terms, GIS is the merging of cartography, statistical analysis, and database technology. GIS may be used in geography, cartography, remote sensing, land surveying, public utility management, natural resource management, precision agriculture, photogrammetry, urban planning, emergency management, navigation, aerial video, and localized search engines.

- 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.

- 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 GIS is the manipulation and analysis of both spatial (graphic) and non-spatial (non-graphic) data. The procedures for data analysis typically found in most GIS programs are as follows:

1. Map overlay procedures, including arithmetic, weighted average, comparison, and correlation functions.
2. Spatial connectivity procedures, including proximity functions, optimum route selection and network analysis.
3. 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.
4. Statistical analysis, including histograms or frequency counts, regressions, correlations and cross-tabulation.
5. Report generation, including maps, charts, graphs, tables and other user-defined information.

- Figure 18.1 below 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.

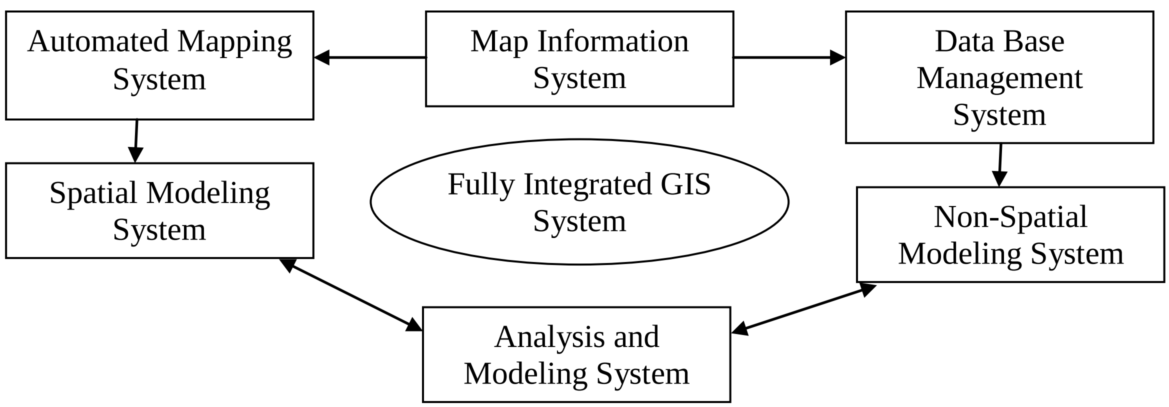

Fig 18.1: The information systems composing a fully integrated GIS (after Frost et al., 1992)

- 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 role for hazard preparedness and management.

Topic 2

Analytic Hierarchy Process (AHP)

- Saaty's Analytical Hierarchy process constructs a matrix of pair-wise comparisons (ratios) between the factors of earthquake hazard parameters (EHP). The constructed matrix shows the relative importance of the EHP based on their weights.

- If 9 earthquake hazard parameters are scaled as 1 to 9, 1 meaning that the two factors are equally important, and 9 indicating that one factor is more important than the other. Reciprocals of 1 to 9 (i.e., 1/1 to 1/9) show that one is less important than others.

- The allocation of weights for the identical EHP depends on the relative importance of factors and participatory group of decision makers. Then the individual normalized weights of each EHP are derived from the matrix developed by pair-wise comparisons between the factors of EHP.

- This operation is performed by calculating the principal Eigen vector of the matrix. The results are in the range of 0 to 1 and their sum adds up to '1' in each column. The weights for each attribute can be 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 sums of rating or scores for each region of cells or polygon of the mapped layers. Since EHP vary significantly and depends on several factors, they need to be classified into various ranges or types, which are known as the features of a layer.

- Hence each EHP features are rated or scored within EHP and then this rate is normalized to ensure that no layer exerts an influence beyond its determined weight. Therefore, a raw rating for each feature of EHP is allocated initially on a standard scale such as 1 to 10 and then normalized using the relation,

$$Xi = \frac{Ri - Rmin}{Rmax - Rmin} \qquad (18.1)$$

Where, R_i is the rating assigned for features with single EHP, R_{min} and R_{max} is minimum and maximum rate of particular EHP.

Topic 3

Earthquake hazard parameters

- Earthquake hazard analysis requires and assessment of earthquake hazard parameters and the future of earthquake potential in a region. Earthquake hazard parameters such as,

    1. maximum regional magnitude M_{max}
    2. activity rate λ, and
    3. the b parameter in the Gutenberg-Richter distribution

- **Maximum regional magnitude M_{max}** - The maximum magnitude is an important variable in the seismic hazard estimation as it reflects maximum potential of strain released in larger earthquakes.

- The instrumental and historical records of earthquakes are often too short to reflect the full potential of faults or thrusts. The maximum regional magnitude, Mmax, is defined as the upper limit of magnitude for a given region or it is magnitude of largest possible earthquake.

- In other words it is a sharp cut-off magnitude at a maximum magnitude Mmax, so that, by definition, no earthquakes are to be expected with magnitude exceeding Mmax.

- **Activity rate λ** - The rate of seismicity varies with time. Though aftershock sequences can strongly influence the rate, they are not the only reason for the variation.

- Defining a seismicity rate requires several things. First off, region must be defined for which one want to find a rate. That area can be any size. Boundaries can be assigned even in depth, so that one is actually counting the rate of earthquakes within a particular volume. Whatever one chooses, the boundaries should be definite, and fixed.

- Naturally, to count earthquakes, you need a way to record and locate earthquakes, or access to a reliable source of data (already recorded for you). There are many seismic databases around the world that offer information to the public.

- **The b parameter in the Gutenberg-Richter distribution** - It has been observed from the earlier analysis that the data set is not complete for the interval 1807 to 1967. Generally "b" value is computed from the analysis of whole set of data without testing the completeness of the data which gives error in the estimation of "b" value.

- Following the method proposed by Stepp (1972), it was found that data set is complete since 1967. Hence, computation of “b” value is carried out using the data set from 1967 to 2010.

- **Geomorphological Attributes** - The geomorphological attributes are the geology and geomorphology (GG), rock depth/ soil thickness (RD/ST), soil type and strength (represented in terms of average shear wave velocity) (SS), drainage pattern (DP) and elevation level (EL).

- **Seismological Attributes -** The seismological thematic maps have been generated based on detailed studies of seismic hazard analysis, site response studies and liquefaction analysis. From these studies different earthquake hazard parameters are mapped. But for final Index map preparation and GIS integration only selected maps are considered as themes which are:

    1. PGA at rock level at 10 % probability in 50 years exceedance based on PSHA.
    2. Amplification factor based on ground response analysis using SHAKE2000.
    3. Predominant frequency based on site response and experimental studies.
    4. Factor of safety against Liquefaction potential.

Topic 4

Themes and its weights for GIS integration

Table 18.1: 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 borehole	7
SS	Equivalent Shear wave velocity for Soil	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

- Table 18.1 gives weights of each theme used for hazard index mapping

- In this method, a matrix of pair-wise comparisons (ratio) between the factors is built, which is used to derive the individual normalized weights of each factor. The pair-wise comparison is performed by calculating the principal Eigen vector of the matrix and the elements of the matrix are in the range of 0 to 1 summing to '1' in each column.

- The weights for each theme can be 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. Table 18.2 gives the pair-wise comparison matrix of themes and the calculated of normalized weights.

- Within individual theme a grouping has been made according to their values. Then rank is assigned based on the values. Usually these ranks varies from 1 to 10, highest rank is assigned for values more hazard in nature.

Table 18.2: Pair-wise comparison matrix of Themes and their normalized weights

Theme	PGA	AF	ST	Vs	FS	PF	EL	DR	GG	Weights
PGA	1	9/8	9/7	9/6	9/5	9/4	9/3	9/2	9/1	0.200
AF	8/9	1	8/7	8/6	8/5	8/4	8/3	8/2	8/1	0.178
ST	7/9	7/8	1	7/6	7/5	7/4	7/3	7/2	7/1	0.156
Vs	6/9	6/8	6/7	1	6/5	6/4	63	6/2	6/1	0.133
FS	5/9	5/8	5/7	5/6	1	5/4	5/3	5/2	5/1	0.111
PF	4/9	4/8	4/7	4/6	4/5	1	4/3	4/2	4/1	0.089
EL	3/9	3/8	3/7	3/6	3/5	3/4	1	3/2	3/1	0.067
DR	2/9	2/8	2/7	2/6	2/5	2/4	2/3	1	2/1	0.044
GG	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	0.022

- These ranks are normalized in range 0-1. The assigned ranks with normalized values are given in Table 18.3.

Table 18.3: Normalized ranks of the themes

Themes	Values	Weight	Ranks	Normalized Ranks
SOT (m)	≤5.0	0.2857	1	0
	5-≤10		2	0.25
	10-≤15		3	0.5
	15-≤20		4	0.75
	>20		5	1
EVS(m/s)	≤100	0.2381	4	1
	100-≤200		3	0.66
	200-≤300		2	0.33
	≤>300		1	0
FSL	<1	0.1905	3	1
	1-≤2		2	0.5
	>2		1	0
DPGA (g)	≤0.12	0.1429	1	0
	0.12-≤0.13		2	0.25
	0.13-≤0.14		3	0.5
	0.14-≤0.15		4	0.75
	>0.15		5	1
SRAF	1-≤2	0.0952	1	0
	2-≤3		2	0.66
	3-≤4		3	0.33
	>4		4	1
SPF (Hz)	≤3.5	0.0476	5	1
	3.5-≤5.0		4	0.75
	5-≤7.5		3	0.5
	7.5-≤9.5		2	0.25
	9.5-≤11		1	1
PPGA (g)	≤0.20	0.1429	1	0
	0.20-≤0.22		2	0.66
	0.22-≤0.24		3	0.33
	0.24-≤0.26		4	1

Topic 5

Hazard Index

- Based on above attributes, two types of hazard index map are generated.

    1. One is deterministic seismic microzonation map (DSM), which is basically deterministic hazard index map using PGA from deterministic approach and other themes.
    2. Another map is the probabilistic seismic microzonation map (PSM). Probabilistic hazard index are calculated similar to DSM but PGA is obtained from probabilistic seismic hazard analysis.

- Hazard index is the integrated factor, depends on weights and ranks of the seismological and geomorphological themes. Theme weight can be assigned based on their contribution to the seismic hazard.

- Rank can be assigned with in theme based on their values closer to hazards. Usually higher rank will be assigned to values, which is more hazardous in nature, for example larger PGA will have the higher rank.

- The contributing themes and their weights are listed below in the above Table. Once the identical weights are assigned then normalized weights can be calculated based on the pair-wise comparison matrix.

- Some of the attributes (like PGA and Vs) has two values for the same theme, hence both are given same weights with different percentage. The normalized weights are calculated using Saaty's Analytical Hierarchy Process (Nath, 2004).

Topic 6

Deterministic seismic microzonation map

- Deterministic seismic microzonation map is hazard index map for worst scenario earthquake. Important factor of PGA (weight is 9) is estimated from synthetic ground motions, which are generated based on MCE of 5.1 in moment magnitude.

- Hazard index values are estimated based on normalized weights and ranks through the integration of all themes using the following equation:

$$DSM = \left(\begin{array}{l} DPGA_W DPGA_r + AF_W AF_r + ST_W ST_r + SS_W SS_r + \\ FS_W FS_r + PF_W PF_r + EL_W EL_r + DR_w DR_r + GG_w GG_r \end{array} \right) / \sum w \quad (18.2)$$

- Using estimated values deterministic seismic microzonation map has been generated.

- Figure 18.2 shows the deterministic seismic microzonation map for Bangalore. Integrated GIS map shows that hazard index values vary from 0.10 to 0.66.

- These values are grouped into six groups, <0.1, 0.10-0.15, 0.15-0.30, 0.3-0.45, 0.45-0.6 and 0.6 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.

Topic 7

Probabilistic seismic microzonation map

- Similar to DSM hazard index calculation, probabilistic hazard index has been estimated, but PGA values are taken from the probabilistic seismic hazard analysis.

- PGA at 10% probability of exceedance in 50 years has been estimated considering six seismogenic sources and regional recurrence relation.

- Based on probabilistic hazard index values probabilistic seismic microzonation map (PSM) has been generated.

- Probabilistic hazard index values are estimated based on normalized weights and ranks through the integration of all themes using the following equation:

$$PSM = \left(\begin{array}{l} PPGA_w PPGA_\gamma + AF_w AF_\gamma + ST_w ST_\gamma + SS_w SS_\gamma + \\ FS_w FS_\gamma + PF_w PF_\gamma + EL_w EL_\gamma + DR_w DR_\gamma + GG_w GG_\gamma \end{array} \right) \Big/ \sum W \qquad (18.3)$$

- Figure 18.3 below shows the probabilistic seismic microzonation map based on calculated hazard index.

- Probabilistic hazard index values vary from 0.10 to 0.66 and has been grouped to six such as <0.1, 0.10-0.15, 0.15-0.30, 0.3-0.45, 0.45-0.6 and 0.6 to 0.66.

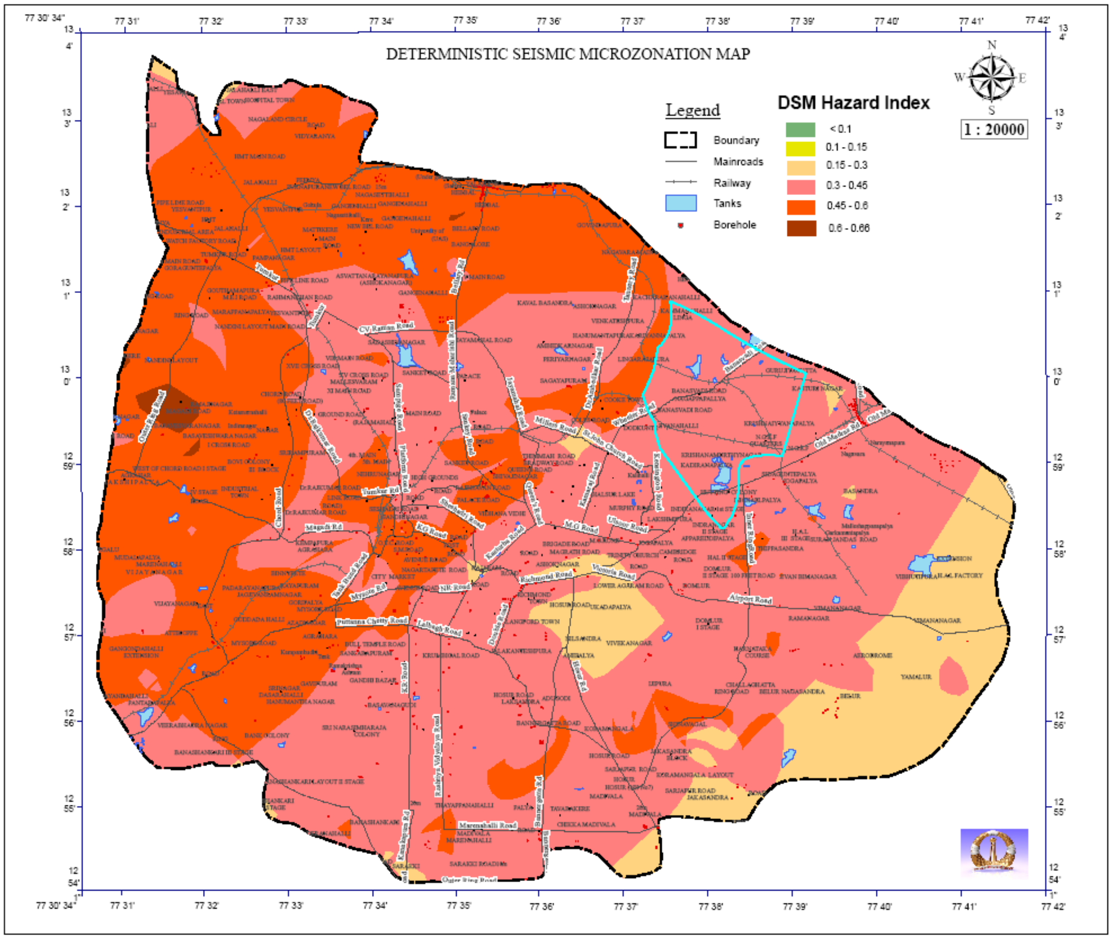

Fig 18.2: Deterministic seismic microzonation map of Bangalore

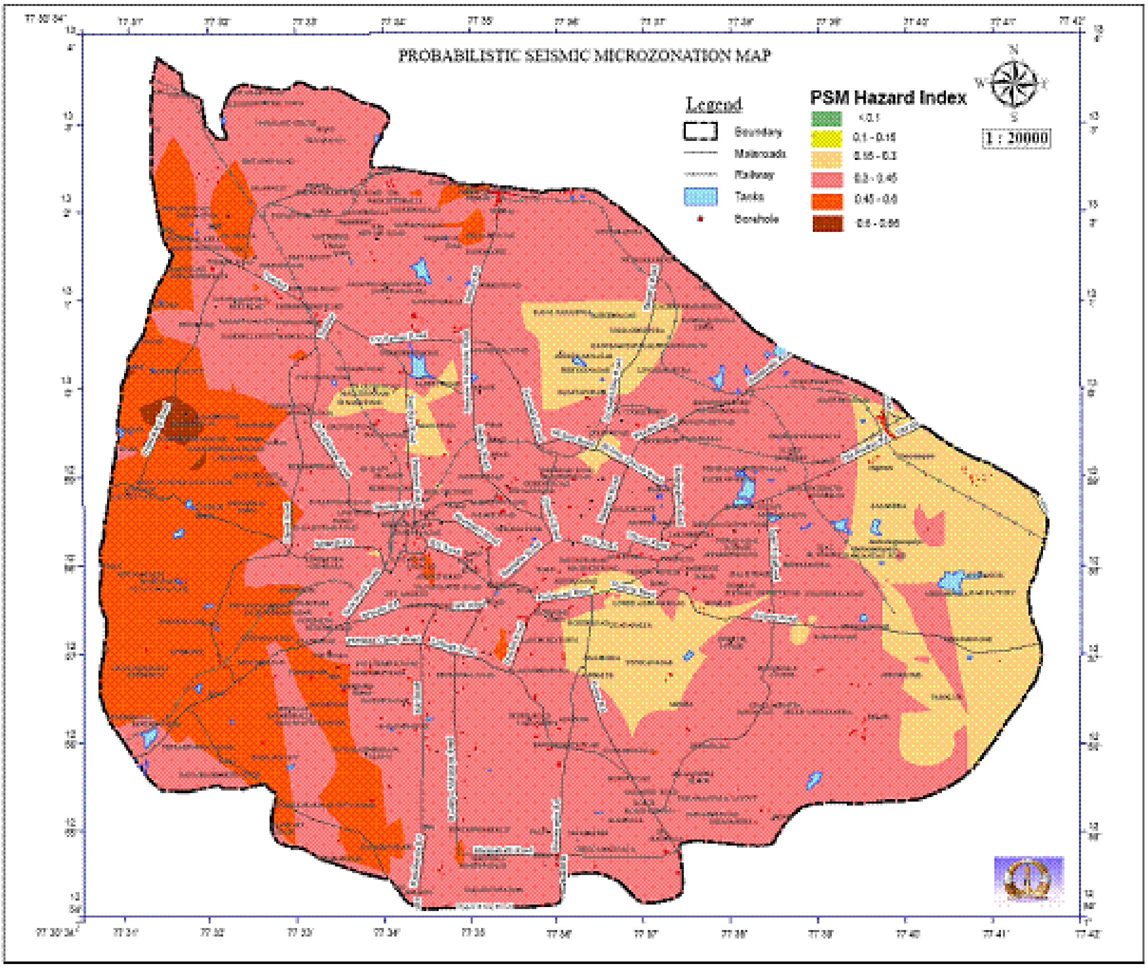

Fig 18.3: Probabilistic seismic microzonation map of Bangalore

- These values are lesser that 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 compared to the northern part.

End of Lecture 18 Introduction to GIS, Integration of hazard parameters on GIS platform; Final zonation map preparation for hazard and risk