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Landslide Susceptibility Assessment in the Guwahati City, Assam using Analytic Hierarchy Process (AHP) and Geographic Information System (GIS)

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***Abstract*-Landslide is one of the major geoenvironmental hazards causing damage to life and property every year in and around the Guwahati city. Apart from natural causes, the anthropogenic factors are contributing to the enhanced frequency and intensity of most of the recent landslides. However, a reliable inventory of present and past landslides and hazard zonation map for the city is still lacking. Landslide susceptibility zoning can help in mitigating this natural disaster and contribute towards sustainable development planning. The present study is carried out to prepare a landslide susceptibility map of the Guwahati city using Analytic Hierarchy Process (AHP) and Geographic Information System (GIS). Five probable causal factors that triggered the past landslides are used for pair-wise comparison and construction of matrices as required in the AHP. Landslide susceptibility index (LSI) was used in GIS environment to prepare a landslide susceptibility map of Guwahati city. The statistics shows that 11.1% of the study area falls in high susceptibility zone, 5.89% area falls in moderate susceptibility zone and 83.01% area falls in low to very low susceptibility zone. The past landslide locations are overlaid on the output map which shows that ~71% of the past landslides are from the high susceptibility zone and ~26% are from the moderate susceptibility zone**.

***Keywords*— Landslide, Landslide susceptibility index (LSI), AHP, GIS, Consistency Ratio (C.R.)**

I. INTRODUCTION

Landslide causes approximately 1000 deaths per year with damage of properties of about 4 billion US dollars around the world. Approximately, 0.49 million sq. km or 15% of the total area of India are vulnerable to landslide hazard. Out of this, 0.098 million km^2 is located in the north eastern region and rest 80% is spread over Himalayas, Nilgiris, Ranchi plateau, and Eastern & Western Ghats (GSI, 2006). Guwahati, the capital city of Assam and gateway to the seven north eastern states of India, has witnessed many landslides causing death and destruction particularly during last few decades. However, in spite of the fact that among all natural hazards landslide has caused maximum loss of life in Guwahati during last two decades, comprehensive study taking into account all aspects of landslide hazard is not yet available in public domain which is a hindering factor for policymakers and urban planners to initiate any mitigation and management plan. This calls for taking a holistic approach for systematic landslide inventory, analysis of causal factors and large scale landslide hazard zonation using suiTable tools and methods followed by developing a viable mitigation and management plan.

Landslide susceptibility zoning can help greatly in future risk mitigation and proper sustainable development planning in areas like Guwahati in which most of the past landslides were known to occur as a result of anthropogenic activities. In view of number of controlling variables that cause landslides including the landuse, it is often difficult to obtain a straight forward relationship and degree of mutual control of these variables. Under this circumstance, it is perceived that Multi Criteria Evaluation (MCE) involving the Analytic Hierarchy Process (AHP) developed by Saaty (2000) with its well known applicability in multi criteria decision making and the analytical capability of Geographic Information System (GIS) can be a strong tool for landslide susceptibility mapping. This technique is already in use for landslide susceptibility mapping and the results are found to be encouraging (Intarawichian et.al, 2010, Bachri et.al. ,2010)

II. STUDY AREA

The area under jurisdiction of the Guwahati Metropolitan Development Authority (GMDA) covering about 273 sq. km on both bank of the Brahmaputra river

(26º4'45"-26º13'33"N:91º34'14"-91º52'6"E) is considered for the present study (Figure 1). Most of the areas are under the administrative jurisdiction of Guwahati (Metro) district while the north Guwahati areas are under Guwahati (Rural) district.

III. GENERAL GEOLOGY AND GEOMORPHOLOGY

The Guwahati city is characterized by a unique geological and geomorphological setting of verdant hills and intermontanne valleys. Geologically it is part of the Meghalaya Precambrian province comprising granite gneiss, migmatite, amphibolite, quartzite, grey porphyritic granite, fine grained granite with thin veneer of alluvial patches and colluvial valley fills. Dominant rock types are found to be the granitic gneisses, quartzites and granites as recorded in the field. Inclusions of schists and amphibolites are found inside granite gneiss; occur as thin bands, lenses and lenticular patches parallel to the foliation of the country rock. The limited outcrops of pink granite are flanking the grey orphyritic granite at low elevation. Previous workers (Maswood and Goswami, 1974; Maswood, 1981, 1982) reported granitic gneisses, quartzites and porphyritic granites with subordinate amphibnolites, aplites, biotite schist, sillimanite-biotite schist, amphibolites and pegmatites etc. besides metamorphic country rocks comprising hornblende-biotite schist, hornblende-pyroxene granulite, biotite-sillimanite schist and biotite schist in and around Guwahati. In topographic lows the basement is overlain by a cover of Quaternary alluvium of variable thickness composed of unconsolidated sand, silt and clay. Along many tracts occupied by the palaeochannels, the typical Brahmaputra sand with abundant biotite and mostly silty are encountered.

Low lying Precambrian residual hills, and inselbergs are doting in and around the city interspersed with elongated low lying valley fills and marshes. Broadly three geomorphic units, viz., the denudo-structural hills (residual hills), the alluvial plains and the marshy lands including static water bodies can be identified from satellite images. About 60% of the total study area is less than 60 m amsl whereas the elevation of the rest 40% area ranges between 60-410 m amsl.

IV. DATABASE AND METHODOLOGY

Survey of India topographic maps and Satellite data as given in Table 1 and Digital Elevation Model (DEM) together with field inputs were used as primary data source for this study. All locational data were based on documentation using a handheld GPS (Garmin eTrex Vista H). The thematic layers were generated using remote sensor data, SRTM DEM and field surveys. The different procedures involved in AHP for assigning relative weights to all the factors that are responsible towards landslide susceptibility of the study area are mentioned below.

Figure 1: Location Map of the Study Area

As per requirement of the AHP, the five thematic layers/factors known as criteria in AHP are arranged in hierarchical order of priorities in rows and columns for generation of pair-wise comparison matrix. Similarly, the classes of each factor are also arranged in similar manner followed by their comparison using the 9 point scale developed by Saaty(2000) for pair-wise comparison (Table II).

TABLE 1: DETAILS OF DATA BASE

Data Type	Index/Path and Row	Scale/ Resolution	Date	Source
Topomap	78N/(11,12, 15, 16)	1:50000	1967	SoI
Landsat ETM	137-42	30m	Feb, 2002	Open source
IRS LISS III	110-052	23.5m	Dec,1998	NRSC, Govt. of India
IRS LISS III	110-052	23.5m	Nov, 2005	
IRS LISS III	110-052	23.5m	Feb, 2010	
SRTM DEM		1arc sec	Open source	

Each matrix is given as an input in the Matlab software to derive the largest positive eigenvalue. This largest positive eigenvalue is used to calculate the Consistency Index (C.I.) using the following equation.

$$\text{Consistency Index (C.I.)} = \frac{\lambda_{\max} - n}{n-1}$$

where $\lambda_{\max}$ is the largest positive eigen value of the matrix and n is order of matrix.Finally, the Consistency ratio (C.R.) is calculated using the following formula:

$$\text{Consistency Ratio (C.R.)} = \frac{CI}{RI}$$

where R.I. is called Random Index and depends on the order of the matrix (n). The standard value of R.I. is represented in Table III. If the threshold of Consistency ratio (C.R.) is achieved (C.R.<0.1), the weights of each row of the matrices are calculated.

TABLE II: SCALE FOR PAIR-WISE COMPARISONS (SAATY, 2000)

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another, its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between adjacent scale values	When compromise is needed
Reciprocals	Opposites	Used for inverse comparison

Calculation of weights also involves several steps. Geometric mean is calculated for each row of the matrix. For calculation of weight for each row, the geometric mean of each row is divided by the total of geometric mean in a column of a matrix. The weight thus calculated is normalized so that their sum is 1.

TABLE III: RANDOM INDEX (R.I.) UP TO 15TH ORDER OF MATRIX

Order of matrix	Random Index (R.I.)
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

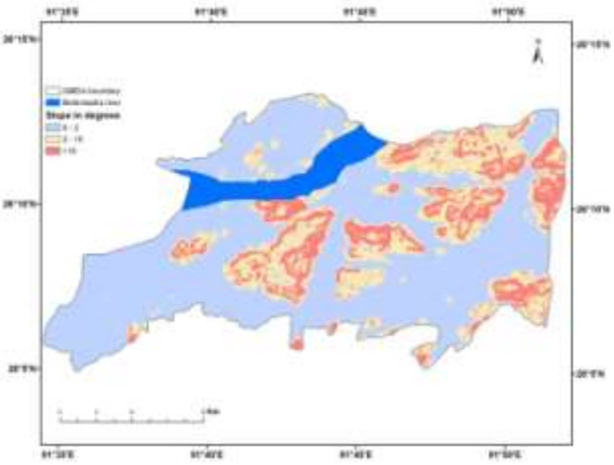

Figure 2 Slope map of the study area

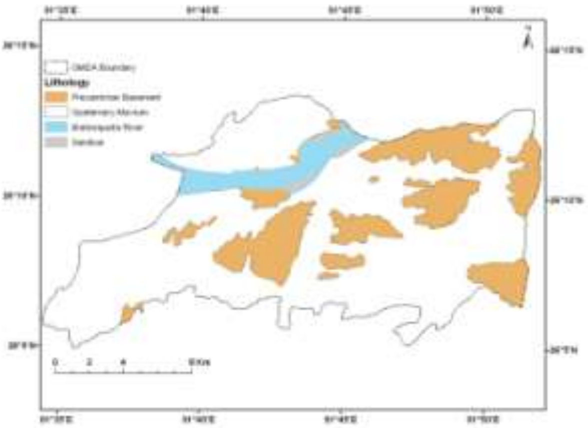

Figure 3: Geology map of the study area

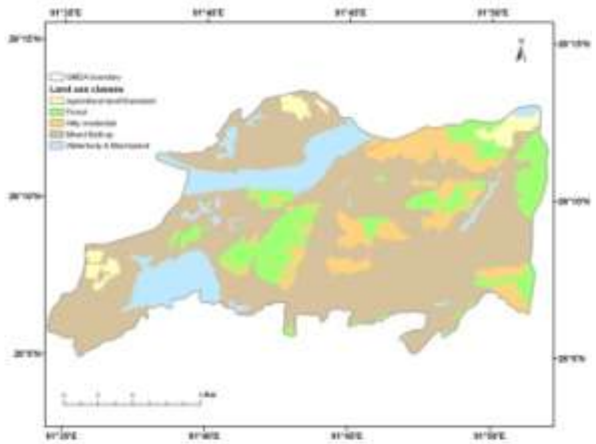

Figure 4: Land use map of the study area

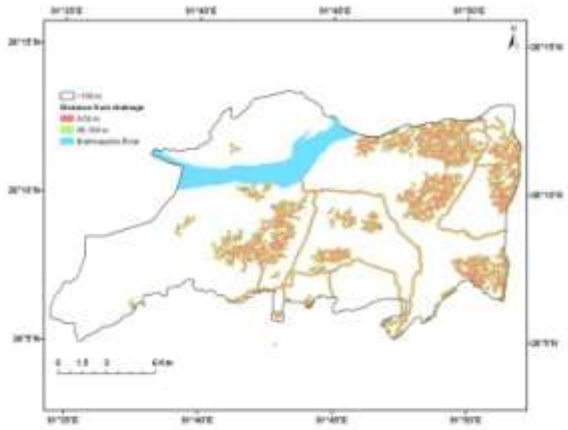

Figure 5: Distance to drainage map of the study area

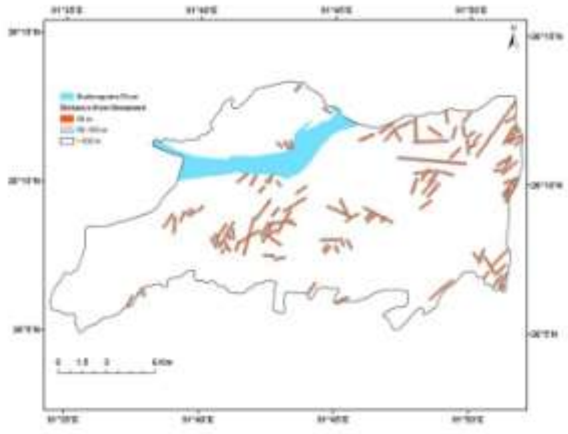

Figure 6: Distance to lineament map of the study area

V. RESULTS AND DISCUSSION

Table IV gives the comparison matrix of factors responsible for landslide hazard while Table V-IX give comparison matrix for different classes of the thematic factors viz., landuse, slope drainage, geology and lineament while the Figures 2-6 present the thematic maps generated for this study. All the weights of classes of each of the 5(five) factors derived using AHP were assigned in the attribute Table to create weighted raster maps of the thematic layers. The weighted raster maps were loaded in the ArcGIS 9.3 software and the Landslide Susceptibility Index is applied in the raster calculator tool of Spatial Analyst Extension to produce the landslide susceptibility map of the study area.

$$\text{Landslide Susceptibility Index (LSI)} = \sum_{i=1}^{n}(W_i \times R_i)$$

Where W_i = Factor weight
And R_i = Class weight/rating for factor i

The weighted map thus obtained is reclassified again into 4(four) susceptibility classes. The area covered by the Brahmaputra River is excluded in the preparation of final landslide susceptibility map (Figure 7). The locations of past landslides are overlaid on the landslide susceptibility zone map to see the efficacy of the analysis. It is found that ~71% of past landslides recorded under this study occurred in the high susceptibility zone, ~26% occurred in moderate susceptibility zone and only one landslide incidence recorded from the very low susceptibility zone. This landslide is a rock fall due to expansion of National Highway 37 and as such, is an aberration with respect to the susceptibility considering the physical site factors.

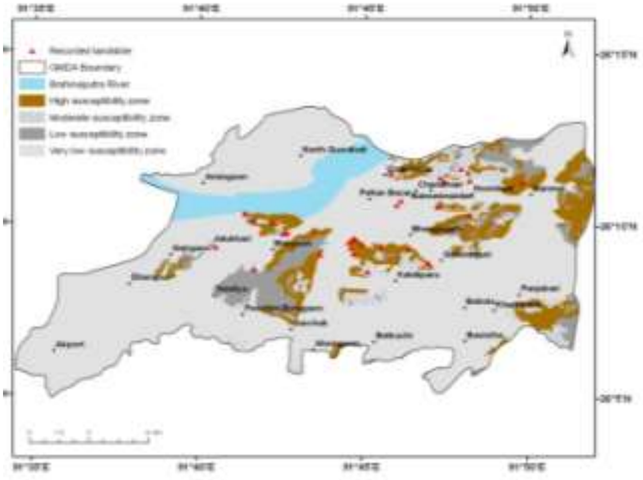

Figure 7 Landslide susceptibility map of Guwahati city

TABLE IV: COMPARISON MATRIX OF FACTORS RESPONSIBLE FOR LANDSLIDE HAZARD

Factors	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Slope	1	3	5	6	7	3.080	0.587
Land use	1/3	1	5	5	7	1.291	0.246
Geology	1/5	1/5	1	3	5	0.493	0.094
Distance from drainage	1/6	1/5	1/3	1	2	0.223	0.043
Distance from lineament	1/7	1/7	1/5	1/2	1	0.160	0.030

1.Slope, 2. Land use, 3. Geology, 4. Distance from drainage, 5. Distance from lineament, 6. Geometric mean, 7. Weight

Consistency Index (C.I.) = 0.0931
Consistency Ratio(C.R.) = 0.0831

TABLE V: COMPARISON MATRIX FOR DIFFERENT CLASSES OF LAND USE

Land use class	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Hilly residential	1	3	9	9	9	4.656	0.521
Forest	1/3	1	9	9	9	3.000	0.336
Mixed Built-up	1/9	1/9	1	2	2	0.548	0.061
Agricultural land/Grassland	1/9	1/9	1/2	1	2	0.415	0.046
Waterbody & Marshyland	1/9	1/9	1/2	1/2	1	0.315	0.035

1. Hilly residential, 2. Forest, 3. Mixed Built-up, 4. Agricultural land/Grassland, 5. Waterbody /Marshyland, 6. Geometric mean, 7. Weight

Consistency Index (C.I.) = 0.07165
Consistency Ratio (C.R.) = 0.063973

TABLE VI: COMPARISON MATRIX FOR DIFFERENT CLASSES OF SLOPE

Degrees	**>10º**	**2º-10º**	**<2º**	**Geometric mean**	**Weight**
>10º	1	3	9	3.000	0.655
2º-10º	1/3	1	7	1.326	0.290
<2º	1/9	1/7	1	0.251	0.055

Consistency Index (C.I.) = 0.04015,
Consistency Ratio (C.R.) = 0.069224

TABLE VII: COMPARISON MATRIX FOR DIFFERENT CLASSES OF GEOLOGY

Geology	**Gneissic rocks**	**Alluvium**	**Geometric mean**	**Weights**
Precambrian	1	9	3.000	0.9
Alluvium	1/9	1	0.333	0.1

Consistency Index (C.I.) = 0
Consistency Ratio (C.R.) = 0

TABLE VIII: COMPARISON MATRIX FOR DISTANCE FROM DRAINAGE

Distance from drainage (m)	**0-50**	**50-100**	**>100**	**Geometric mean**	**Weight**
0-50	1	3	7	0.682	2.759
50-100	1/3	1	2	0.216	0.874
>100	1/7	½	1	0.103	0.415

Consistency Index (C.I.) = 0.001, Consistency Ratio (C.R.) = 0.002

TABLE IX: COMPARISON MATRIX FOR DISTANCE FROM LINEAMENT

Distance from lineament (m)	**0-50**	**50-100**	**>100**	**Geometric mean**	**Weights**
0-50	1.0	5.0	7.0	3.271	0.740
50-100	0.2	1.0	2.0	0.737	0.167
>100	0.14286	0.5	1.0	0.415	0.094

Consistency Index (C.I.) = 0.0071
Consistency Ratio (C.R.) = 0.0122

TABLE X: STATISTICS OF LANDSLIDE SUSCEPTIBILITY ZONES

Sl. No.	**Susceptibility class**	**Area (Sq. km)**	**% of area**	**No. of Landslides**
1	Very low	196.66	76.06	1
2	Low	17.98	6.95	0
3	Moderate	15.24	5.89	8
4	High	28.69	11.10	22

VI. CONCLUSION

The present study is an attempt to see the efficacy of Analytic Hierarchy Process (AHP) and Geographic Information System (GIS) for landslide susceptibility mapping of the Guwahati city. Five probable causal factors that triggered the past recorded landslides are used for pair-wise comparison and construction of matrices as required in the AHP. The Landslide susceptibility index (LSI) was used in GIS environment to generate the final hazard zonation map. The statistics shows that ~11% of the study area are in high susceptibility zone while ~6% and 83.% areas are in moderate and low to very low susceptibility zones respectively. Overlay of past landslide positons on the susceptibility map show good corroboration of the final output thus confirming efficacy of the method.

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