# GIS Based Seismic Risk Analysis
# of Ahmedabad City, India

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**Abstract.** Earthquakes have been one of the most dangerous and calamitous hazards faced by mankind. Lots of researches have been focused on how to forecast, prevent and mitigate the effects caused by Earthquake or seismic hazards. This paper has been one such effort that utilized various properties pertaining to geotechnical, seismic and topographical aspects of Ahmedabad city in India to evaluate the vulnerability and susceptibility of the region to earthquakes. Factors such as population, water table variation, shear wave velocity, peak ground acceleration at rock and surface level, spectral acceleration and predominant frequency were mapped layer-by-layer using ArcGIS. Analytical hierarchy approach for multi criteria decision system was used to determine the relative importance of each parameter, thus giving us risk index for different areas of Ahmedabad city to seismic hazards. From the study it is found that all though most of the factors are having their higher values in south zone and/or in west zone, higher risk is to be seen in these zones, but population map indicates that south zone has higher population therefor giving higher risk at this zone.

**Keywords:** Seismic hazards · Arc GIS · Analytical hierarchy approach
Risk index

## 1 Introduction

Gujarat is one of the most seismic prone intercontinental regions of the world. It has experienced two large earthquakes of magnitude Mw 7.8 and 7.7 in 1819 and 2001 respectively and seven earthquakes of magnitude Mw 6.0, during the past two centuries. The intense aftershock activity of 2001 Bhuj earthquake is continuing. Through March 2008, 14 aftershocks with Magnitude 5.0–5.8, about 200 aftershocks with magnitude 4.0–4.9, about 1600 aftershocks of with magnitude 3.0–3.9, and several thousand aftershocks with magnitude <3 have been recorded. Regional seismicity has also increased with Mw 5.0 earthquakes and associated foreshocks and aftershock sequences [5]. Many authors have carried out various seismic studies in Ahmedabad and surrounding regions [9–12]. Thaker and Rao [6] carried out seismic hazard analysis

in Ahmedabad region. Mehta et al. [7] reviewed seismic hazards studies in Indian subcontinents. Rao et al. [8] carried out deterministic seismic hazard analysis of Ahmedabad region.

Ahmedabad, According to the Bureau of Indian Standards falls under seismic zone 3, in a scale of 2 to 5 (in order of increasing vulnerability to earthquakes). The Deccan basement, generally found in adjacent Cambay basin at 4 to 5 km depth is missing at Ahmedabad and the hard rock basement of granite rock occur at depth of 7 to 8 km. The upper 200–300 m below Ahmedabad city is mostly alluvium, formed by the meandering Sabarmati River in the past. Ahmedabad lies in two marginal faults and also on the intersection of two minor lineaments [6].

In past years, study has been done for Ahmedabad city using different methods [4, 6, 8] and by considering different factors, but they had limitations in terms of data collected, methods of collection for that data, resolution of satellite images etc. Moreover, no study has been done by consideration of combination of factors included in this study. In this GIS based analysis of risk index, technical factors and one socio-economic factor are considered. If study is only concerned for technical factors then risk index cannot be calculated, without taking population into account as without any considerable population the most vulnerable place due to seismic activities cannot be said contains high risk. Factors those considered in this analysis are: population, peak ground acceleration, predominant frequency, spectral acceleration, shear wave velocity, compressible wave velocity, standard proctor test values and ground water table.

This study contains layer by layer data analysis of factors mentioned above on the base map of Ahmedabad city in ArcMap (Arc GIS). Here, topo sheets (from survey department of India) of Ahmedabad city are used as base map in Arc GIS and data are added on topo sheets in various layers. AHP (analytical hierarchy process) is used to merge all the layers according to their weightage, which is calculated by making matrix and by prioritizing each factors. From integrated map made as a result of AHP, risk index is calculated for different areas of Ahmedabad city ranging from 1–5 (1 as less severe to 5 as high severe zones).

## 2 Factors Considered

### 2.1 PGA (Peak Ground Acceleration)

PGA is equal to the amplitude of the largest absolute acceleration recorded on an accelerogram at a site during a particular earthquake. In an earthquake, damage to buildings and infrastructure is related more closely to ground motion, rather than the magnitude of the earthquake itself. For moderate earthquakes, PGA is a reasonably good determinant of damage.

Here, PGA values are taken as average of values from different ground motion data carried out in the region in the separate analysis, further, standard deviation of the data set is added to the average value to keep it on higher side. PGA at rock level and surface level both for the Ahmedabad city are plotted through ArcGIS. Maps of PGA at surface level for depth 0 m, 1 m, 2 m, 3 m and 4 m are plotted. The map of PGA at surface level reveals higher values at south zone and north zone of the city 1 m (refer

Fig. 1), 2 m and 3 m depth where, central zone, west zone and east zone have the average lower values for PGA in comparison. PGA value for 4 m depth has average values concentrated over city area, lower values around the surroundings of the city and higher value of 0.915 g (g = gravitational acceleration) at the central zone near Shahpur. PGA value at surface level ranges from 0.062 g to 0.915 g for the city. PGA value at rock level has very slight change over the whole area of the city ranges from 0.056 g to 0.067 g (Fig. 1).
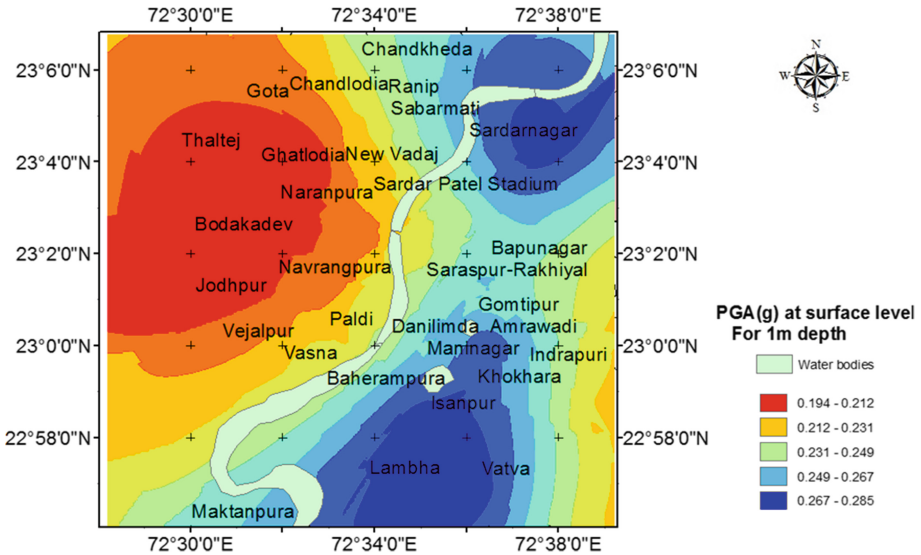


**Fig. 1.** PGA at surface level.

## 2.2   Predominant Frequency (PF)

Predominant frequency is the second prioritized factor obtained by carrying out ground response analysis. Map of predominant frequency show higher values at west zone and on some areas of north zone and central zone of the city. Predominant frequency value has normal average distribution over other areas ranges from 2.021 Hz to 4.355 Hz.

## 2.3   Population

Population is socio-economic factor and its importance is very much high. For example, if earthquake occurs in a region where there is less population than the damage will be less than highly populated regions.

Population is the major factor affecting to seismic risk of the city. The area and word wise population data have been collected from Ahmedabad Municipal Corporation and population density model for Ahmedabad city was prepared. This map reveals that the most of the population is accumulated over south zone, central zone and some areas of north zone and east zone. West side of the city has comparatively lower population density.

## 2.4 Spectral Acceleration (SA)

The spectral Acceleration is equally important parameters obtained from ground response modeling. The Maps for different spectral acceleration for different time (0.1 s, 0.2 s, 0.3 s, 0.5 s and 1 s) are plotted which conclude that spectral acceleration has the lowest value of 0.060 g for 1 s time and the highest value of 0.733 g for 0.2 s and 0.5 s. From maps of spectral acceleration, it can be said that south zone and north zone have average higher values of spectral acceleration.

## 2.5 Compressive Wave (P-Wave) Velocity (Vp) and Shear Wave (S-Wave) Velocity (Vs)

P-waves and S-waves (transverse waves) are the two main types of elastic body waves, called seismic waves in seismology. Here average velocity of the wave, over the particular depth is been taken. Average P-wave and S-wave velocity is determined by following formula.

$$Vavg(h) = \frac{h}{\sum ha/Vi}$$

Where, h is the particular depth.

Maps for depth of 10 m, 20 m and 30 m are plotted in ArcGIS by taking average P-wave velocity for particular depth. Distribution for the values of average velocities was discrete for all the depth, all over the city. P-wave velocities are ranging from 0.447 km/s to 0.743 km/s for different depth where S-wave velocities are ranging from 0.284 km/s to 0.530 km/s.

## 2.6 Ground Water Table (GWT)

The water table fluctuates both with the seasons and from year to year because it is affected by climatic variations and by the amount of precipitation used by vegetation.

For larger earthquakes, the presence of ground water tends to decrease the horizontal acceleration response on the surface of basin, while the opposite trend is observed for horizontal displacement response. For earthquake of smaller intensity, the seismic response of a basin is almost not affected by the presence of ground water. Thus, the presence of ground water will have larger effects on the seismic response of a basin for larger earthquakes than for small earthquakes [2].

Maps of depth for water table are plotted as before monsoon season and after monsoon season to compare the ground water depth change during the monsoon season. Average 3 m high is noted as change after monsoon over the city. Highest water table is seen at areas Gomptipur, Behrampur, Paldi and Vatva.

## 2.7 Standard Penetration Test (N-Value)

Extensive geotechnical data collected from various private and government organization and synthesized. The SPT N values for the city is taken from the and plotted for

different depth (2 m, 4 m, 6 m, 8 m, 10 m and 12 m), which indicate that south zone and north-west zone have higher N values in general where other zones have average lower N values in comparison.

## 3   Multi Criteria Analysis (MCA)

MCA describes any structured approach used to determine overall preferences among alternative options, where the options accomplish several objectives. In MCA, desirable objectives are specified and corresponding attributes or indicators are identified.

In this study, **AHP** (analytical hierarchy process) is used to integrate all the maps created by Arc GIS. AHP was introduced by Saaty (1980) as a management tool for decision making in multi attribute environments. The fundamental approach of AHP is to break down a "big" problem into several "small" problems; while the solution of these small problems is relatively simple, it is conducted with a view to the overall solution of the big problem [1]. AHP involves building a hierarchy of decision elements (factors) and then making comparisons between possible pairs in a matrix to give a weight for each element and also a consistency ratio. It is based on three principles: decomposition, comparative judgment and synthesis of priorities [3]. It is a multiple criteria decision-making technique that allows subjective as well as objective factors to be considered in the decision-making process. AHP aims at quantifying relative weights for a given set of criteria on a ratio scale. Two features of AHP differentiate it from other decision-making approaches. One, it provides a comprehensive structure to combine the intuitive rational and irrational values during the decision-making process. The other is its ability to judge the consistency in the decision-making process.

Parameters are prioritized according to their importance and influence to the seismic activities and hazard. PGA was given the highest priority (9) and GWT was given the least priority (3). SPT-N value, Vs and Vp were given the same priority (5) (see Table 1).

**Table 1.**  Priority of the parameters.

| PGA (ground) | 9 |
|---|---|
| PF | 8 |
| Population | 7 |
| SA | 6 |
| Vs | 5 |
| Vp | 5 |
| SPT-N | 5 |
| PGA (rock) | 4 |
| GWT | 3 |

If **pairwise comparison matrix** (see Table 2) A is n × n matrix, where n is the number of factors considered. Each component $a_{jk}$ of the matrix represent the importance of the $j^{th}$ criterion relative to the $k^{th}$ criterion. If $a_{jk} > 1$, then the $j^{th}$ criterion is

**Table 2.** Pairwise comparison matrix.

| | PGA at ground | PF | Population | SA | Vs | Vp | SPT-N | PGA at rock | GWT |
|---|---|---|---|---|---|---|---|---|---|
| PGA (ground) | 1.00 | 1.12 | 1.28 | 1.50 | 1.80 | 1.80 | 1.80 | 2.25 | 3.00 |
| PF | 0.88 | 1.00 | 1.14 | 1.33 | 1.60 | 1.60 | 1.60 | 2.00 | 2.67 |
| Population | 0.78 | 0.87 | 1.00 | 1.67 | 1.40 | 1.40 | 1.40 | 1.75 | 2.33 |
| SA | 0.67 | 0.75 | 0.86 | 1.00 | 1.20 | 1.20 | 1.20 | 1.50 | 2.00 |
| Vs | 0.56 | 0.62 | 0.71 | 0.83 | 1.00 | 1.00 | 1.00 | 1.25 | 1.67 |
| Vp | 0.56 | 0.62 | 0.71 | 0.83 | 1.00 | 1.00 | 1.00 | 1.25 | 1.67 |
| SPT-N | 0.56 | 0.62 | 0.71 | 0.83 | 1.00 | 1.00 | 1.00 | 1.25 | 1.67 |
| PGA (rock) | 0.44 | 0.50 | 0.57 | 0.67 | 0.80 | 0.80 | 0.80 | 1.00 | 1.33 |
| GWT | 0.33 | 0.37 | 0.43 | 0.50 | 0.60 | 0.60 | 0.60 | 0.75 | 1.00 |
| Sum | 5.78 | 6.5 | 7.43 | 8.67 | 10.4 | 10.4 | 10.4 | 13.00 | 17.33 |

more important than the $k^{th}$ criterion, while if $a_{jk} < 1$, then the $j^{th}$ criterion is less important than the $k^{th}$ criterion. If two criteria have the same importance, then the entry $a_{jk}$ is 1.

**Normalized value** (see Table 3) is determined by dividing each cell with the sum of the relative column. If sum of the column 1 is $\sum A$, then normalized value for cell 1 is $a_{11}/\sum A$ ($a_{11}$ is the value of pairwise comparison in cell 1).

**Table 3.** Normalized value and weights of each parameter.

| | Normalized value | C | Weights |
|---|---|---|---|
| PGA (ground) | 0.17 | 1.558 | 0.173 |
| PF | 0.15 | 1.285 | 0.154 |
| Population | 0.13 | 1.212 | 0.135 |
| SA | 0.11 | 1.038 | 0.115 |
| Vs | 0.10 | 0.865 | 0.096 |
| Vp | 0.10 | 0.865 | 0.096 |
| SPT-N | 0.10 | 0.865 | 0.096 |
| PGA (rock) | 0.08 | 0.692 | 0.077 |
| GWT | 0.06 | 0.519 | 0.058 |

**Weights** (see Table 3) for each parameter are calculated by dividing sum of the row by the number of parameters considered in comparison. If the sum of one row is C, then weight of that factor should be C/9.

Then **weighted sum values** (see Table 4) for implementation in ArcGIS are calculated according to priorities of data. Sum of these values should be equal to the weight of that factor.

**Table 4.** Weighted sum values of each parameter

| Factors | Weights | Value | Weighted sum value |
|---|---|---|---|
| PGA at surface level | 0.173 | 0 m | 0.0576 |
| | | 1 m | 0.0461 |
| | | 2 m | 0.0345 |
| | | 3 m | 0.023 |
| | | 4 m | 0.01153 |
| Predominant frequency | 0.154 | | 0.154 |
| Population | 0.135 | | 0.135 |
| Spectral acceleration | 0.115 | 0.1 s | 0.0461 |
| | | 0.2 s | 0.0307 |
| | | 0.3 s | 0.023 |
| | | 0.5 s | 0.0153 |
| | | 1 s | 0.0077 |
| S wave velocity (Vs) | 0.096 | 10 m | 0.048 |
| | | 20 m | 0.032 |
| | | 30 m | 0.016 |
| P wave velocity (Vp) | 0.096 | 10 m | 0.048 |
| | | 20 m | 0.032 |
| | | 30 m | 0.016 |
| SPT value | 0.096 | 2 m | 0.0271 |
| | | 4 m | 0.0226 |
| | | 6 m | 0.018 |
| | | 8 m | 0.0136 |
| | | 10 m | 0.0091 |
| | | 12 m | 0.0045 |
| PGA at rock level | 0.077 | | 0.077 |
| Ground water table | 0.058 | After monsoon | 0.0387 |
| | | Before monsoon | 0.0193 |

## 4   Result and Conclusion

Integration of maps (prepared from the data of different factors affecting) through AHP method gave the seismic risk index of the city. Integration of different factors are done layer by layer in ArcGIS using weighted sum tool. Risk index is divided in 1 to 5 as 1 is lowest risk and 5 is highest risk (see Fig. 2).

In general most of the GIS maps of factors such as PGA at surface level, SA, P wave and S wave velocities, ground water table and SPT-N are having their higher values in south zone and/or in west zone, higher risk is to be seen in these zones but population map indicates that south zone have higher population therefor giving higher risk at this zone. Almost all the factors has moderate values on both sides of the river, hence moderate risk is observed in these areas and due to less population in west zone it has lower risk index in the risk map.
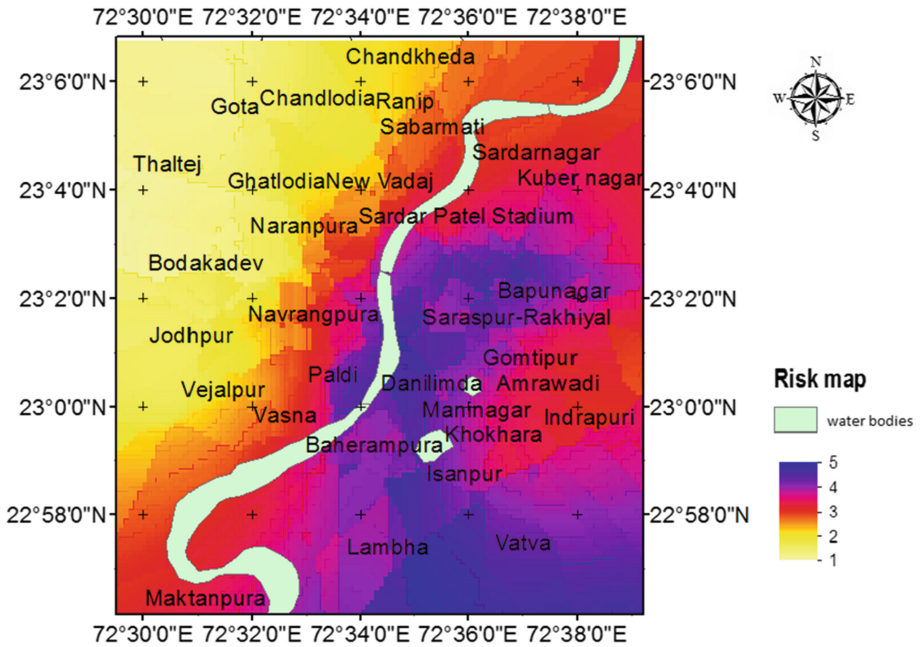
**Fig. 2.** Risk index map for Ahmedabad city.

This map can be used to estimate risk if any earthquake strikes in the region. Local Municipal Corporation can implement rules and regulations (for building heights, set-back distance, structural specifications) accordingly for construction of any residential or commercial buildings and bridges in high risk areas of the city. Prior to construction, structural designs can be improved accordingly to the risk factor accounted in the area.

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