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Soil Amplification Factor Zonation of Kathmandu Valley

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Abstract

Nepal resides on the ridge of Eurasian and Indian tectonic plates because of which frequent occurrence of earthquakes are inevitable. Moreover, Kathmandu valley is a basin created from ancient lake deposits made up of silt, clay, sand, and gravel in irregular layers ranging in age measuring several hundred meters in depth. Significant differences in a structural damage in the basin have been observed compared with the surrounding exposed rock or even within the basin itself from place to place during earthquakes providing insights that the geology of a particular region and subsoil properties significantly affect the characteristics of ground motion. As the valley accommodates several low-rises to medium-rise buildings, historically important places, and monuments, there are possibilities during an earthquake that the amplified frequencies may cause a resonance with structures in a broad frequency range, leading to the possible collapse of structures. So it is necessary to determine the amplification factor, especially in soft soils. In this study, 1D ground response analysis through an equivalent linear analysis approach has been performed for various sites using Kobe earthquake ground motion record with DEEPSOIL Software. Results of this study indicate that the amplification factor is higher towards northern deposits than southern. Thus, site soil conditions must be considered during the construction of earthquake-resistant structures or as for preparedness to reduce the extent of possible damages tremors could create.

Keywords

Kathmandu valley, Earthquake, Local Geology, Amplification factor

1. Introduction

Nepal is situated in one of the most severe earthquake-prone areas of the world. The seismic activity in Nepal is due to the tectonic movement of the Indian plate against the Eurasian plate.The movement of the plate is believed to be the cause of the formation of the Himalayan range. Kathmandu valley is one of the large intermountain basins developed in the Lesser Himalaya of central Nepal. Kathmandu valley has experienced several media to large-scale earthquakes in the past. A major earthquake hit Nepal in April 2015 with an epicenter at the Gorkha district of Nepal. Despite Kathmandu valley being quite far from the center of the earthquake, it still suffered major damage due to the geological features of the region. The soils of the valley are mainly the product of weathering rocks within its watershed boundary filled with 500-600m of Fluvio-Lacustrine Soil [1] lying above the metasedimentary formation of Lesser Himalaya[2] comprising of clayey, silty, sandy and gravely sediments which is mostly unconsolidated.

Local geology strongly influences the amplitude, duration, and frequency of a ground motion. The extent of influence is determined by geometry, sub-surface soil properties, site topography, and input motion characteristics [3]. The soil parameter and geologic conditions that have a significant effect on the amplification of ground motion at a site include depth of soil layers above bedrock, soil's nonlinear stress-strain behavior, and variation in its type and properties with depth, lateral heterogeneity, and surface topography[4]. The phenomenon of soil amplification occurs when the seismic excitation of bedrock is modified during the transmission of shear waves through the overlying soil to the foundation

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(surface). Therefore, soft soil deposits of Kathmandu valley were thought to have played a major role in such damage. The amplitudes of seismic waves increase as they pass soft soil layers near the earth's surface which is referred to as site amplification.

Seismologists and engineers have worked towards the development of quantitative methods for predicting the ground response by one-dimensional, two-dimensional, and three-dimensional ground response analysis methods. Ground response analysis enables geotechnical engineers to assess soil deposit's natural frequencies, determine ground motion amplification and evaluate acceleration response. Furthermore, these parameters can be taken into consideration while designing earthquake-resistant design structures.

Kathmandu valley resides in a high earthquake-prone area. Major Earthquakes recorded here have uneven damages patterns for the same seismic input and resonate with structures in a broad frequency range of waves due to complex and varying geology of different areas of the valley which makes the need for detailed study of local geology. But no enough study covers the entire Kathmandu valley regarding the response of local geology. So in this study, modeling of soil layers of varying depth from different places of the valley have been carried out to compare seismic surface response at various places of the Kathmandu valley for the same seismic input that is Kobe motion (1995) with peak ground acceleration of 0.8g to demonstrate amplification of soil layers and map them accordingly.The simulation was performed using the DEEPSOIL computer program which is capable of performing one-dimensional analysis. Field borehole data of various sites of Kathmandu valley are considered for analysis.

2. Geological Formation of Kathmandu Valley

Kathmandu Valley is an intermontane basin lying in Kathmandu Nappe [5] formed by thrusting of MCT and is surrounded by higher Himalayan and Tethyan Himalayan rocks. The basement rock of the nappe comprises of Bhimphedi group overlaid by the Phulchoki group [6] and is composed of two series of geological successions. Precambrian to Devonian rock forms the basement and hills surrounding the valley overlaid by Quaternary sediments and recent alluvium [7]. The thickness of the sediment deposits (Lacustrine and Fluvial origin) are up to 550-650 m in the central part of the basin.The deposited sediments are usually a mix of gravel, sand, silt, and clay [8, 1]. This mixture is predominantly on the sandy side. The southern part of the valley are the sediments of alluvial fan facies consisting of basal boulder bed and are more cohesionless consisting of boulders and gravels along with silty and clayey matrix compared to the northern part as the river deposits are carried from the northernmost part with steep slopes and dispersed in flood basins in the southernmost parts with gentler slopes. The central parts of the valley comprise of open lacustrine facies possessing a sequence of dark grey to black highly plastic clay and silts, and the young northern parts have marginal fluvio-deltaic facies consisting of poorly graded coarse sands, gravel, and silts infilled with clays in some places [9].

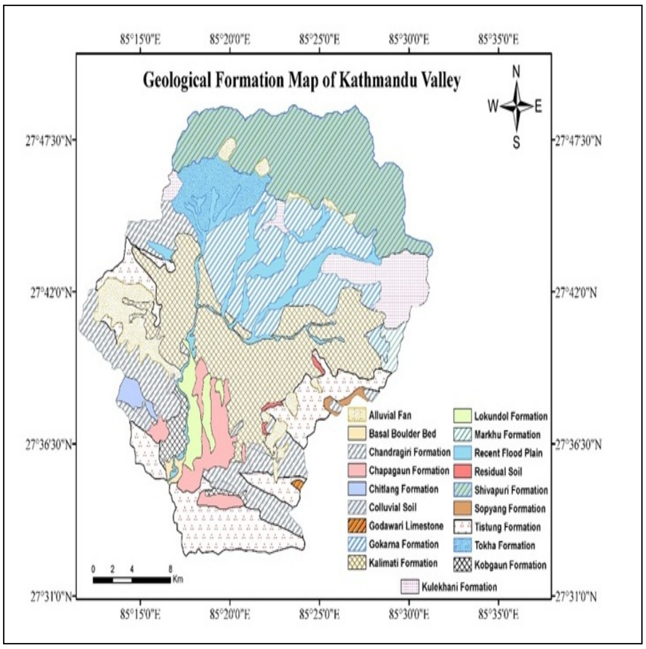

Figure 1: Geological Formation Map of Kathmandu Valley *(Source:Gov.of Nepal, Department of Geology and Mines)*

3. Methodology

Borehole data from 76 different locations drilled at 10-30m with an SPT value less than 50 in each layer were assessed for this study. Shear wave velocity has been considered for defining the stiffness of the soil. For evaluating shear-wave velocity (Vs) profiles, the SPT-N values are used through available correlations. Empirical correlation between uncorrected standard penetration resistance (N) and shear wave velocity

(VS) for Kathmandu Valley, Nepal is given by the following equations [10].

For all soils:

$$V_s = 115.8N^(0.251)(R^2 = 0.623) \quad (1)$$

For silt:

$$V_s = 102.4N^(0.247)(R^2 = 0.355) \quad (2)$$

For Sand:

$$V_s = 78.7N(0.352)(R^2 = 0.441) \quad (3)$$

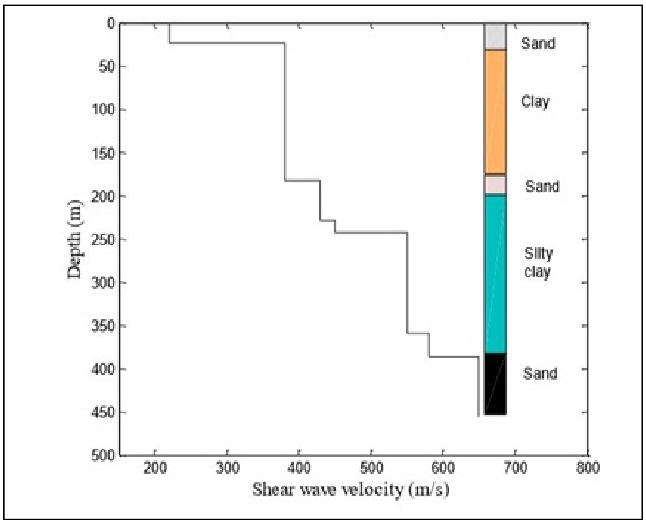

Figure 2: Representative vertical shear wave velocity variations in a borehole [10]

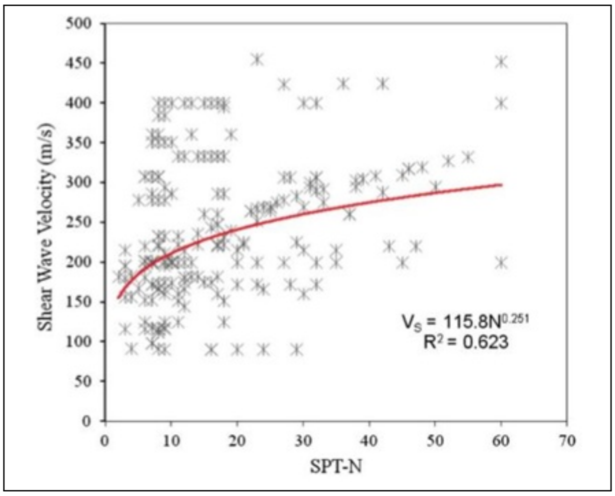

Figure 3: V_S-N correlation for all soils of Kathmandu Valley [10]

Rigid bedrock has been used in the analysis and the rigidity for bedrock has been obtained by considering a very high shear wave velocity. Input motion considered for the present analysis was 1995's Kobe Earthquake of magnitude Mw=6.9 observed as 0.834 PGA and Tm= 0.641s from the database available in DEEPSOIL V7 [11].

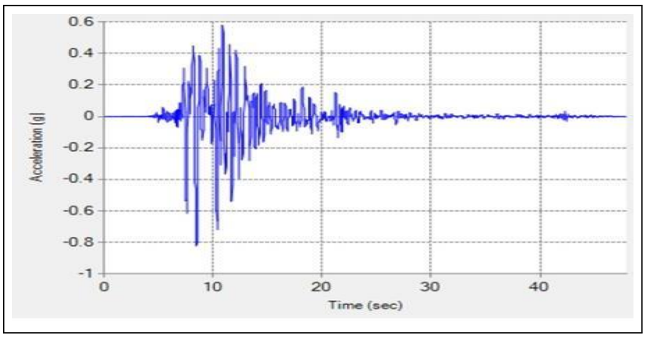

Figure 4: Acceleration time history of the recorded Kobe earthquake motion (PGA=0.80g)

3.1 1D ground response analysis

1D ground response analysis are performed assuming horizontal soil layers, boundaries of infinite lateral extension, and vertically propagating shear waves in order to model the propagation of seismic waves through the soil profile.There are different approaches to performing 1D ground response analysis.1.Linear approach 2.Equivalent linear approximation approach 3.Non-Linear approach. The linear method of analysis assumes that shear modulus (G) and damping ratio (ξ) be independent of strain and constant for each layer, so analysis does not satisfy the nonlinear behavior of soil deposits. Hence, the extension of the above linear method is the equivalent linear method of analysis in which the nonlinear hysteretic stress-strain behavior of cyclically loaded soils is approximated by equivalent soil properties.On the other hand,nonlinear method uses direct numerical integration in the time domain to analyse the actual nonlinear response of the soil deposit In this study,1D ground response have been performed using equivalent linear analysis methods using DEEPSOIL V7.

Following assumptions have been implied in this analysis:

1. The soil sample extends infinitely in the horizontal direction.
2. Each layer in the system is completely defined by its value of shear modulus, critical damping ratio, density, and thickness.
3. The response in the system is caused by the upward propagation of shear waves from the underlying rock formation.

4. The shear waves are given as acceleration values of equally spaced time intervals. Cyclic repetition of the acceleration time history is implied in the solution.
5. The strain dependence of modulus and damping is accounted for by an equivalent linear procedure based on an average effective strain level computed for each layer.
6. Calculation of all response spectra is done at the top of the selected base layer.
For uniform damped soil on a rigid rock the basic wave equation is, [3]

$$\rho \frac{\partial^2 u}{\partial t^2} = G\frac{\partial^2 u}{\partial z^2} + \eta \frac{\partial^3 u}{\partial z^2 \partial t} \tag{4}$$

Solution to the above wave equation is,

$$u(z,t) = Ae^{i(\omega t + k*z)} + Be^{i(\omega t - k*z)} \tag{5}$$

where, $u(z,t)$ refers to the horizontal displacement at a depth z at time $'t'$; 'A' and 'B' are amplitudes of waves traveling in the $-z$ (upward) and $+z$ (downward) directions, respectively ; 'ρ' is the density; 'G' is the Shear modulus and 'η' is the viscosity which equals $(2G/x)f'$.'k' is the wave number which equals = ω/Vs, where 'ω' is wave frequency, Vs = shear wave velocity. k* refers to the complex wave number and is given by$k* = k(1.0 - \zeta)$. where ζ = Damping ratio
The transfer function by, [3]

$$F_2\omega = \frac{1}{cos[\frac{\omega H}{V-s}(1+i\zeta)]} \tag{6}$$

and the amplification function is given as,[3]

$$|F_2(\omega)| = \frac{1}{\sqrt{cos^2(\frac{\omega H}{Vs}) + [\zeta(\frac{\omega H}{V_s})]^2}} \tag{7}$$

Discrete data or extended hyperbolic models are used to define damping ratio curves and shear modulus properties for equivalent linear analysis.So, carrying out analysis through discrete points method G/G_{max} and damping ratio ζ function are the defined function of strain. Set of material curves have been defined for modulus reduction and damping ratio curve for different soils in DEEPSOIL Software. For clayey soils, plasticity index and effective vertical stress shall be defined, and for sandy soils, effective vertical stress for estimation of modulus reducing and damping curves.

For a particular site at a given time history at the bedrock motion, shear wave velocity profile with depth and modulus reduction, and damping curves are the parameters required to find out ground motion amplification through ground response analysis.

4. Results

The ground response analysis was carried out using Kobe motion from the available database of DEEPSOIL V7 at the bed rock level.Soil properties and SPT N-values were taken according to the bore hole data and shear wave velocity was computed using emprical equations from 1,2, and 3.Damping ratio was considered 5% for the reponse spectrum.The acceleration,velocity,displacement and arias intensity time history plots at ground level for Gangabu site is given in Figure 5. Strain vs. time and shear stress ratio vs time at ground level for gongabu site are given by Figure 6. Fourier amplification ratio vs. frequency at ground level for Gongabu site is given by Fig.7 and spectrum for 5% damping at ground level for Gongabu site is given by Figure 8.

Amplification of peak ground acceleration at surface layer with respect to maximum horizontal acceleration at bedrock obtained by DEEPSOIL at various places in kathmandu valley is tabulated in Table 1.Amplification factor zonation map of the Kathmandu valley is presented in Figure 9.

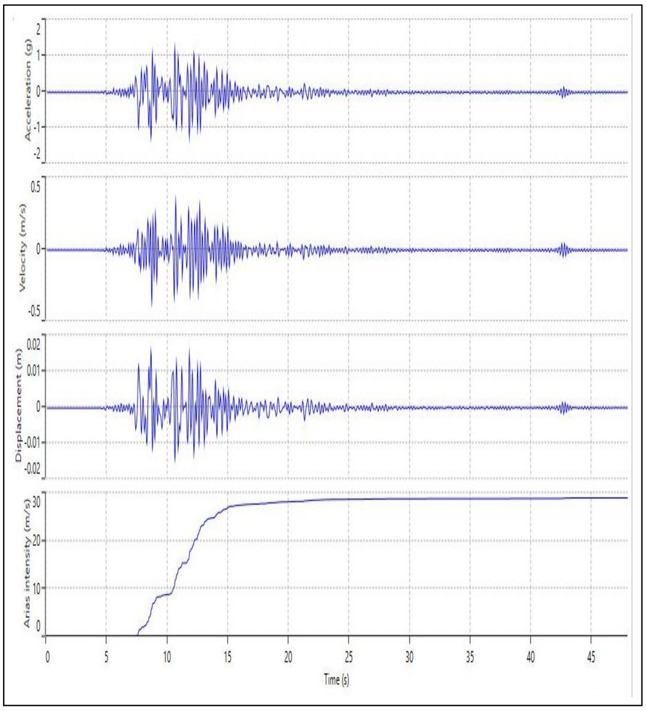

Figure 5: Time History Plots at ground level for Gongabu site

Table 1: Amplification factor in various locations in Kathmandu Valley

SN	Location	Amplification factor $\frac{PGA_{surface}}{PGA_{bedrock}}$	SN	Location	Amplification factor $\frac{PGA_{surface}}{PGA_{bedrock}}$	SN	Location	Amplification factor $\frac{PGA_{surface}}{PGA_{bedrock}}$
1	Anamnagar	1.1	27	Godawari	1.7	53	Ravibhawan II	1.6
2	Balkot	1.6	28	Gongabu	1.8	54	Sankhamul I	3.2
3	Balkumari	1.2	29	Gwarko	1.1	55	Sankhamul II	1.6
4	Bafal	1.1	30	Gyaneshwor	3.1	56	Sanepa Thulo Dhunga	2.5
5	Balaju	1.2	31	Hariharbhawan	4.1	57	Sanepa I	1.3
6	Baneshwor	2.2	32	Hattiban	1.8	58	Sanepa II	2.1
7	Battisputali	1.3	33	Hattigauda	1.7	59	Sinamangal I	1.9
8	Bauddha	1.3	34	Jhamsikhel	1.4	60	Sinamangal II	2.0
9	Bhaisepati	1.4	35	Kalanki	2.3	61	Sitapaila	1.1
10	Budhanilakantha	1.6	36	Kamaladi	1.8	62	Soalteemode I	1.1
11	Balaju	1.2	37	Khichhapokhari	1.4	63	Soalteemode II	1.4
12	Baneshwor	2.2	38	Khumaltar	1.5	64	Sukedhara	1.2
13	Battisputali	1.3	39	Kuleshwor	1.4	65	Swayambhu I	1.6
14	Bauddha	1.3	40	Kumaripati	1.3	66	Swayambhu II	1.9
15	Chabahil	1.1	41	Kupondole	2.5	67	Teku I	2.5
16	Champadevi	1.5	42	Lazimpat I	2.6	68	Teku II	1.5
17	Chobhar	1.4	43	Lazimpat II	2.1	69	Thamel	3.7
18	Civil Homes Sundhara	2.1	44	Maharajgunj	2.1	70	Thankot I	2.6
19	DFID	1.2	45	Nagarkot	2.8	71	Thankot II	2.5
20	Dhapasi	1.1	46	Nakhu	1.2	72	Thapathali I	2.3
21	Dhumbarahi	1.2	47	Naxal	1.2	73	Thapathali II	5.6
22	Dillibazar	2.6	48	New Road	4.2	74	Tokha	2.2
23	DurbarMarg	1.4	49	Pulchowk	1.9	75	Tripureshwor	4.3
24	Exhibition Road	1.2	50	Putalisadak	1.1	76	Kanti Hospital	1.8
25	Ghhatekulo	1.9	51	Ratobangla	1.1			
26	Gatthaghar	1.4	52	Ravibhawan I	1.4			

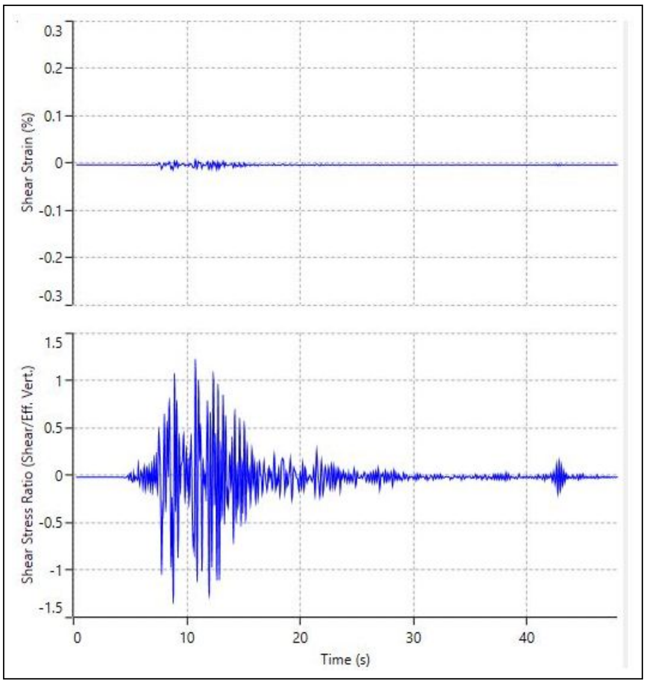

Figure 6: Strain vs. Time and Shear stress ratio vs. Time plots at ground level for Gongabu site

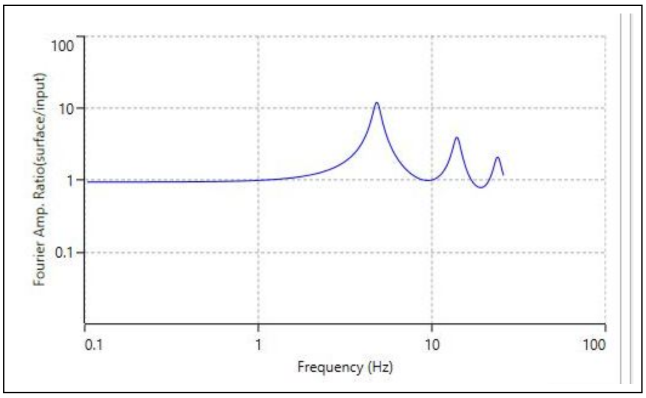

Figure 7: Fourier amplification ratio vs frequency plot at ground level for Gongabu site

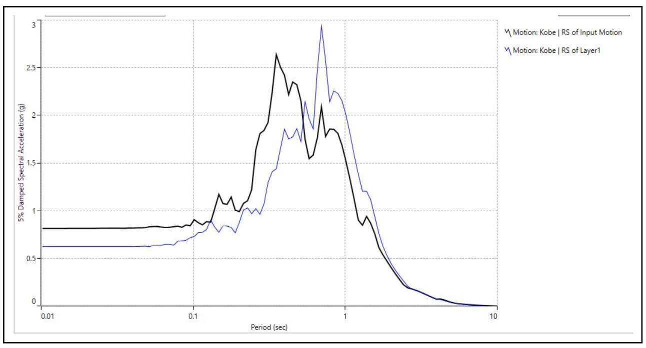

Figure 8: Response spectrum for 5% damping at ground level for Gongabu site

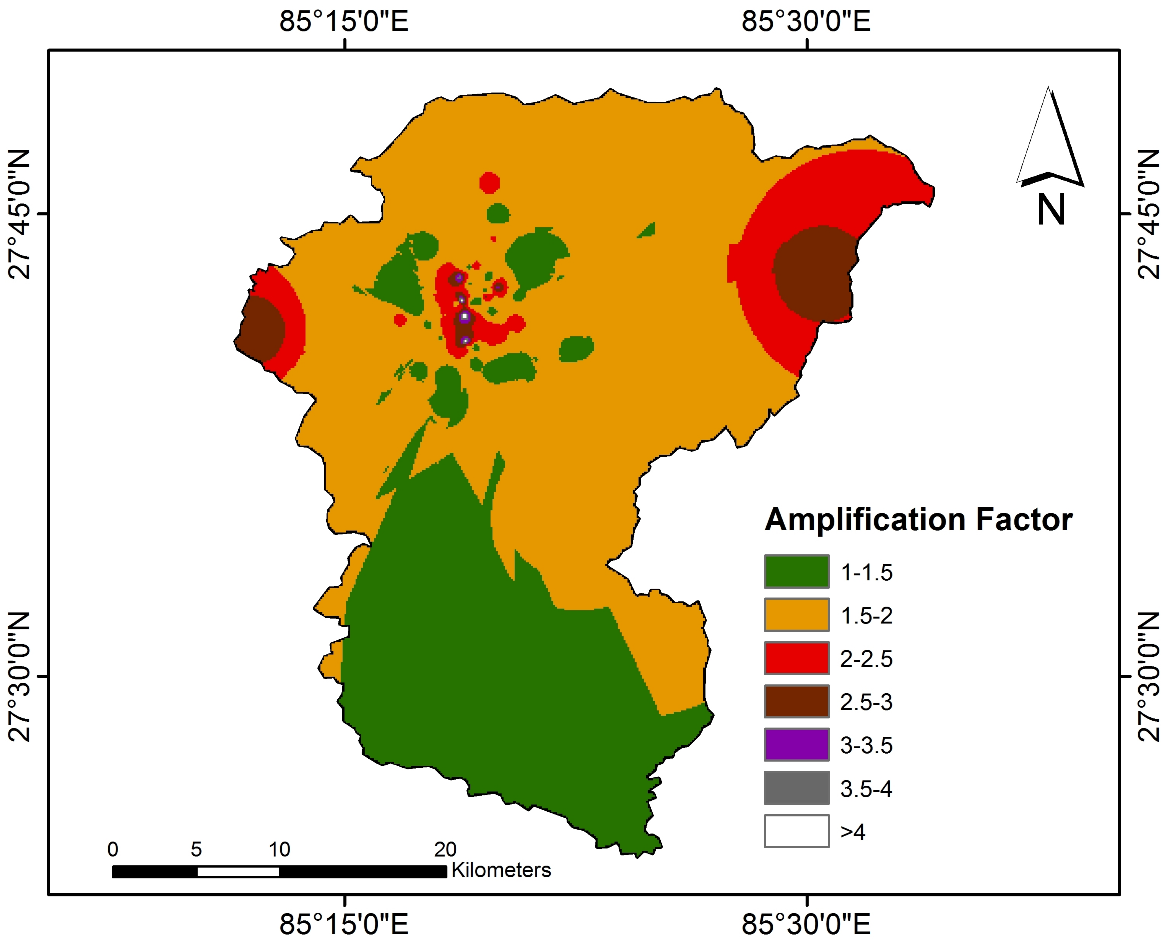

Figure 9: Soil Amplification factor zonation map of Kathmandu Valley

5. Conclusion

The study on the ground amplification factor of the soil deposits of the Kathmandu valley was performed using equivalent linear analysis technique on DEEPSOIL Software. During analysis, the Kobe earthquake motion was used as a ground motion to the soil profiles. With the results obtained, the following conclusions have been made:

- Local geology indeed influences the amplification of ground responses significantly.
- In most of the soil deposits around the Kathmandu valley, the amplification factor ranges from 1 to 3 times.
- Generally the amplification factor is higher towards the northern deposits than the southern deposits.
- The amplification factor is higher in the soil deposits where the depth of clay is more in comparison to other sand and gravel deposits.
- The amplification of a damped soil layer varies with the frequency content of the time history.
- The amplification of soil deposits increases with the decrease of shear wave velocity of bedrock.

6. Recommendation

This study has presented the amplification factor zoning map of the Kathmandu valley. During the progression of study, there are few areas that have surfaced for future studies. Following are the recommendations:

- This study was conducted with data collected from 76 borehole logs from various locations of the Kathmandu valley.It is recommended to carry out further study of this region using more borehole data from varied locations for more precised results.

- In this study, the analysis was carried out using DEEPSOIL. It is recommended to analyse seismic ground response using various other softwares like D-MOD,SHAKE for comparative study.
- This study was conducted using equivalent linear analysis which is the approximation to the actual non linear ground response.Thus,it is recommended to carry out non linear analysis in order to calculate actual non linear response of soil deposits.

Acknowledgment

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