Spatial Variability of Resonance Frequency and Ground Amplification in Kochi City South- Central Kerala (SCK) Region –Paradigm to Seismic Microzonation

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Abstract

Digital maps of the Kerala state and the Kochi city were prepared using MapInfo GIS software package considering all the available primary and secondary data. Ambient noise records (988) closely spaced sites in and around the city were collected, processed and estimated site response parameters. It is observed that the estimated resonance frequency varies significantly within short distances. Low resonance frequency values (≤ 1.0 Hz) coupled with higher levels of site amplification were observed in coastal and backwater areas covered with younger alluvial deposits and high resonance frequency values (> 5 Hz) with charnockites and laterites in the hinterlands. Database of the estimated site specific response parameters were compiled and studied their spatial variability. The digital layers of the estimated site response parameters were prepared, geocoded, contoured, prepared isolines, in relation to various surface features are presented in map. Further, study area has been divided into different regions based on classification of the site response parameters. Spatial variability of resonance frequency and site amplification were studied along eight profiles taken on the contour maps of these two site response parameters. Finally a composite seismic microzonation map for the Kochi city based on spatial variability of resonance frequency and site amplification was prepared. Three Seismic Microzones I, II and III were identified. Microzones I and III occupy the easternmost and westernmost parts of the city respectively whereas Microzone II is sandwiched between them and these zones are associated with distinct site response characteristics. The results revealed that the buildings and structures in Microzone III have highest probability to achieve resonance as compared to Microzones II and I when the natural frequency of ground motion matches with that of the structures. It is estimated that longer duration ground shaking will occur in Microzone III and adjoining areas of Microzone II. The Microzone I and the adjoining portions of the Microzone II are relatively safer as compared to the remaining portions of Microzones III and II..

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Keywords: resonance frequency 1, ground amplification 2, hinterlands 3, isolines 4, seismic microzonation

1. Introduction

Destructive effects of earthquakes is becoming alarming day by day because of growth in population, the rapid rate of industrialization, the large scale engineering activities and their impact on the environment. There is a need for increased efforts to minimize resulting seismic hazards. **T**he effects of ground motion (vibrations) on various structures as well as on human beings have become a great concern for the society. Most of the damage as observed in destructive earthquakes around the world is mainly associated with seismic wave amplification which is caused by the characteristics of sites. Site effects associated with local geological conditions constitute an important part of any seismic hazard assessment. In the last three decades, it have been seen that such damages occur quite far away from the epicenter and are generally attributed to the sediment- induced amplification of seismic waves when they pass through such formations [1]; [2]; [3]; [4]; [5]; [6]; [7]. Manipulating site specific response data (site amplification and resonance frequency) and their association with the existing secondary data (surface and subsurface features) in GIS environment would be more meaningful which eventually help in delineating individual potential sites that is vulnerable to the increased ground shaking of an earthquake. Many large earthquakes are known to have tremendous site effects even in the near-field [8]; [9]; [10]; [11]; [12]; [13]; [14]. It has been established that seismic energy gets trapped at sites having soft soil or topographical undulations resulting in enhanced ground vibrations that may increase damage to the manmade structures. Based on theoretical analysis and observational data, [15] has observed that each site has a specific resonance frequency at which ground motion gets amplified. In such condition, manmade structures having resonance frequency matching with that of the site have the maximum likelihood of getting damaged. Such resonances and amplifications of ground motion is not observed on relatively flat surface where hard rock is exposed. Evaluation of site-specific risk is essential, particularly, while installing critical structures like nuclear power plants, subways, bridges, elevated highways, sky trains and dam sites for which seismic microzonation maps serve as ready reckoner for site selection for such important constructions. Seismic microzonation can be considered as the preliminary phase of earthquake risk mitigation studies. In view of this, site specific response characteristics [16] of a particular site play vital role in the construction of seismically safe structures.

2. Study Area and Geology

Kochi, the main commercial and industrial city of Kerala state, which has witnessed tremendous growth almost in all the fields during the past 50 years, is selected for site response study and preparation for seismic microzonation map using site response data derived through ambient noise measurements. The study area is bounded by longitude 76^0 11'- 76^0 26' E and latitude 09^0 49'- 10^0 05' N and covers an area of 630 km^2 including 120 km^2 water-bodies (Fig. 1). The city falls mainly into two physiographic zones, coastal plain and midland. The coastal plain, a low lying area (elevation <10 m) is characterized by backwaters, marshy lands, sandy flats and alluvial plains. The midland region has a rolling topography with low hills and narrow valleys. The hills are generally covered with laterite or laterite soils and the valleys are alluviated. There are about 13 small islands along the backwaters, which are formed by alluvial deposits [17]. The city and its surroundings are situated mostly on loose sediments of alluvium, clay, loamy sands, silt, laterites etc. and have vast area of intermittent water bodies (Fig. 1). Most of the waterlogged low-lying areas have been reclaimed for various developmental activities such as residential, commercial and industrial settlements. Geologically, two distinct litho-units are discernible in and around Kochi city [18]. The eastern part is occupied by hard rocks representing Precambrian metamorphosed rocks while the coastal tract in the west is covered by soft rock or the unconsolidated coastal alluvium. The structural features in the city are masked by extensive water bodies and thick vegetation. The seismicity in and around its close vicinity has been extremely poor since historical past in which only two earthquakes with maximum magnitude 5 have occurred in 1953 and 1986 [19]; [20]; [21] as shown in Fig. 1.

3. Preparation of digital map themes in GIS environment

In order to prepare GIS maps of Kerala state and Kochi city, Survey of India (SOI) toposheets, Resource Atlas of Kerala by CESS (1984; 1:1000,000) and GSI map (1:500,000) were consulted. Initially, a base map of the region was prepared using relevant information from these maps as primary data and the available existing secondary data (surface and subsurface features). This map was digitized in MapInfo GIS software. The digital map of Kerala state was prepared considering distribution of various geological formations (such as sediments, laterites, Precambrian crystalline & associated intrusive etc), lineaments/ faults, earthquakes etc. as map themes. The map themes used for the preparation of digital map for the Kochi city were: Landuse, Drainage (waterbodies, lakes, rivers, streams and canals); Transport network; general and detailed geology, Geomorphology/ relief features, Lineament/ faults, Soil conditions/ types etc.

4. Methodplogy

There are several methods used for estimation of site responses [22]; [23]; [24]. The ambient noise (microtremor) measurement is widely used for site response studies [25]; [26], [27], [16]. Ambient noise, a low-level vibrations caused by natural (wind, ocean tides etc.) and the cultural sources [17], is the property of each and every site differently on the surface of the earth and mostly dependent on the characteristics of the materials lying between ground surface and basement rocks. Ambient noise implies that large - scale sedimentary structures are alive, even the low-levels of background noise in the crust are enough to excite the response of valleys and basins. The interest in ambient noise arises because seismic stations situated on soil sites record higher amplitudes of ground vibration than stations on bedrock sites. This shows that earthquake related ground motion is very much dependent on local surficial conditions especially the character of top soils about 100 m thick above the basement and soft soil beneath any site. The H/V technique developed by [25] was used for estimating site response parameters. Seismic microzonation, that identifies individual critical areas based on their potential for hazardous earthquake effects, is especially applicable in urban areas where risk due to ground motion is highest.

5. Field instruments used for ambient noise measurement

The following field equipments were used for the acquisition of ambient noise data in the field:

- CityShark II 3-C Seismic Recorder with accessories for recording ambient noise;
- Lennartz LE-3Dlite triaxial active geophone with 1 Hz natural frequency;
- Handheld Garmin GPSMAP 76S for site location;
- Laptop for retrieval of ambient noise data from compact flash, data processing and management in the Field.
- External USB HDD for microtremor data storage in the field.

CityShark II, a three component seismic recorder (N-S, E-W and Z) with an internal quartz clock accuracy of ± 1.5 ppm and a three component active geophone were used for ambient noise data acquisition in Kochi city area. The CityShark recorder and seismometer are two independent units and both are connected by a cable at sites for recording ambient noise.

6. Data Processing and Estimation of Site Response Parameters

A database was generated by listing a total of 988 ambient noise record observed at different sites in varying geological formations and morphological features. Data processing and estimation of site response parameters were carried out using J-SESAME software (version 1.08) developed under European Project SESAME 2000-2004 ([28], [29]) for processing of ambient noise data. The entire exercise on processing and analyzing the ambient noise data and estimating the site specific response parameters, in the present case, showed that the use of CityShark for microzoning an area saves a considerable amount of time and provides quick and reliable estimates of site specific response parameters and characteristic site periods. The cutoff frequency used in the present work is 25 Hz. The time window length selected for processing the noise data of N-S, E-W and vertical (V) components is 20 sec. A minimum of 10 windows was taken for obtaining reliable results on site parameters (but less than 10 windows at a few important locations were also taken for comparing the results). Traces of ground motion at each site were generated for further processing to compute H/V. H/V is computed by merging the horizontal components (NS and EW) with a geometric mean option. The horizontal component of the spectra was estimated by taking the square root of the product of N-S and E-W components (H= sqrt (H ew*H_ns)).

The first resonance frequency (Fo) corresponding to maximum site amplification is estimated from the plot of H/V and frequency. Since horizontal-to-vertical (H/V) spectral ratio of ambient noise at a site roughly equals the S-wave transfer function between the ground surface and the bedrock on assuming that the shear wave dominates the ambient noise [25]. This means that the H/V peak period and the peak value itself corresponds to the natural site period and amplification factor, respectively. Thus, the method is so simple that it does not require any boreholes. Using the resonance frequency thus estimated for Kochi city, the characteristic site periods (in sec) at all the observation sites have been estimated which is found to have the range 6.3< Ts ≤1.2 sec. The computed data on resonance frequencies (Fo), site amplifications (H/V) and characteristics site periods (Ts) were incorporated in the original database generated earlier for the field records. This database is used for extracting statistical information on site response parameters, which eventually is considered for the preparation of seismic microzonation map for Kochi city.

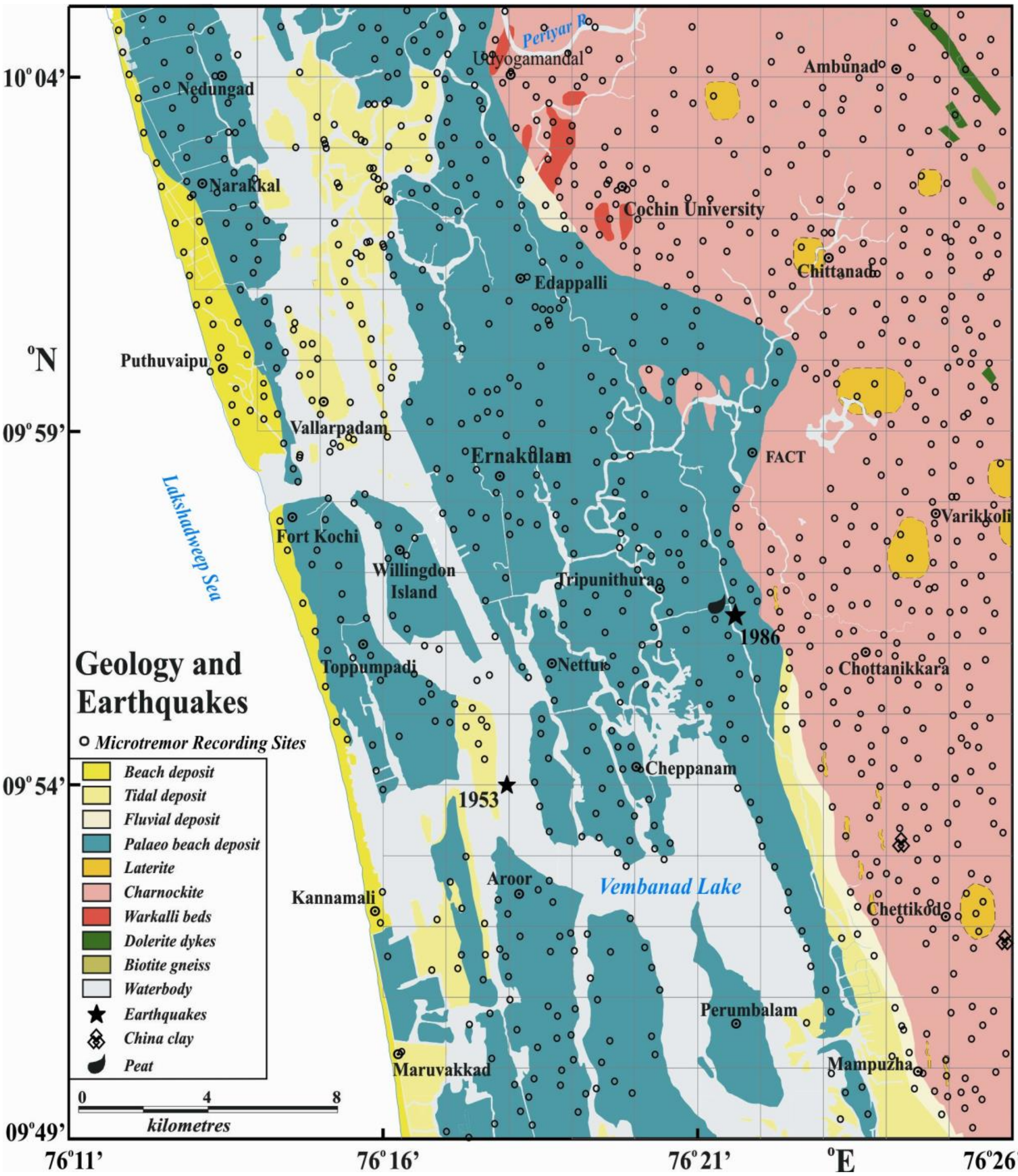

Fig. 1: Spatial distribution of ambient noise recorded sites over the geological features of Kochi city

Total all the 988 records were processed, and estimated level of ground amplification and resonance frequency at each site and compiled a database using date, place names, latitude, longitude, morphology and soils, H/V and resonance frequency. The ambient noise recorded sites were classified according to their fundamental frequency Fo [30] as:

(1) **Low frequency sites** (Fo ≤ 1 Hz)

(2) **Medium frequency sites** (1 Hz < Fo ≤ 5 Hz)

(3) **High frequency sites** (Fo > 5 Hz)

7. Variation of Site Response Parameters along Profiles in Kochi City

In order to extract values of resonance frequency and the peak site amplification at closely spaced intervals along profiles, DEM maps of these two parameters were used. Using the Vertical Mapper, eight cross-sections were taken on the DEMs of resonance frequency and the peak site amplification as shown in

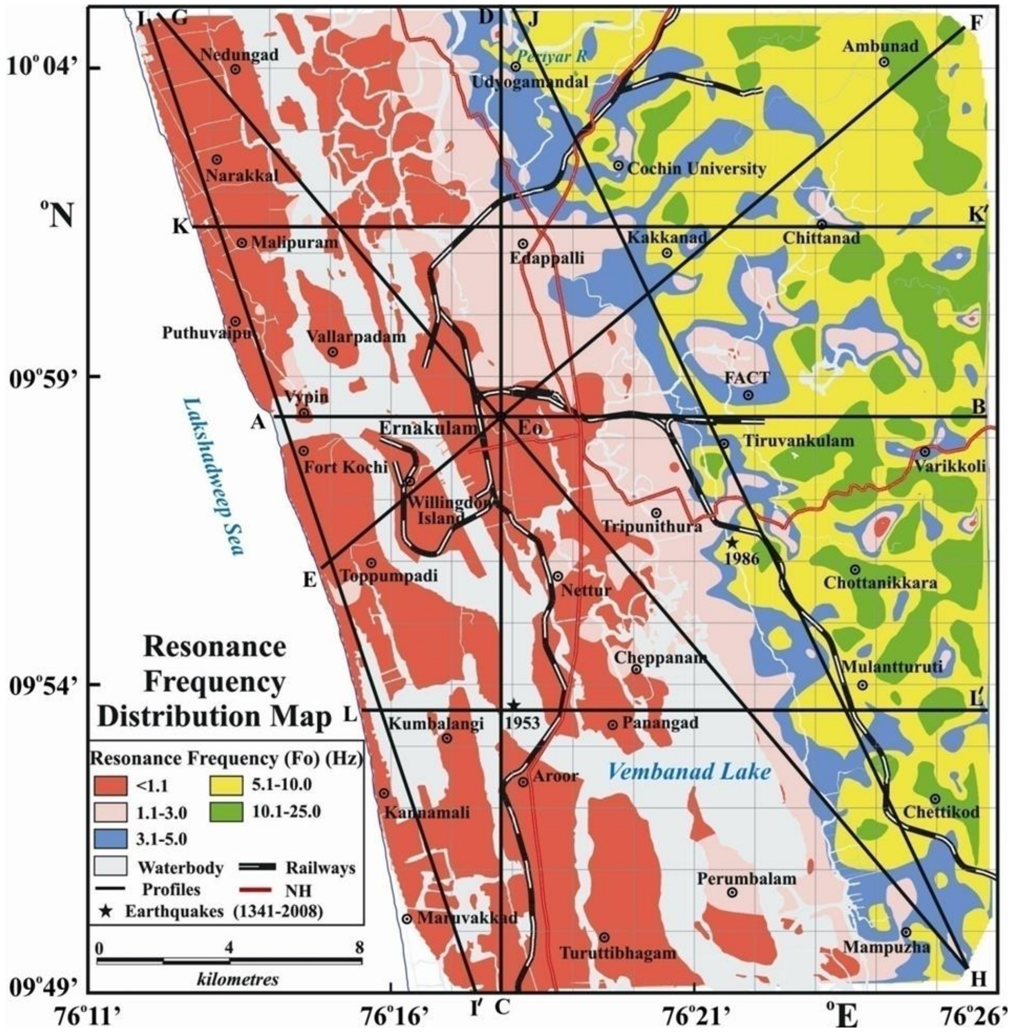

Fig. 2 (a): Region map of resonance frequency for Kochi city with eight profiles along which variation patterns of computed resonance frequency are studied. Cross-sections along these profiles were initially observed on the DEMs of resonance frequency along which its values are extracted at closely spaced intervals of distance in order to understand its variation (refer Table 1 for details on length and orientations of the profiles, important places through which profiles pass, minimum and maximum values of resonance frequency).

Fig. 2 (a, b). The values of resonance frequency and the peak site amplification were extracted at closely spaced intervals with distance along these profiles. The orientation of the profiles are shown in Fig. 2 (a, b) and other details pertaining to each profiles such as directions, lengths, minimum and maximum values of resonance frequency and site amplifications are furnished in Table 1.

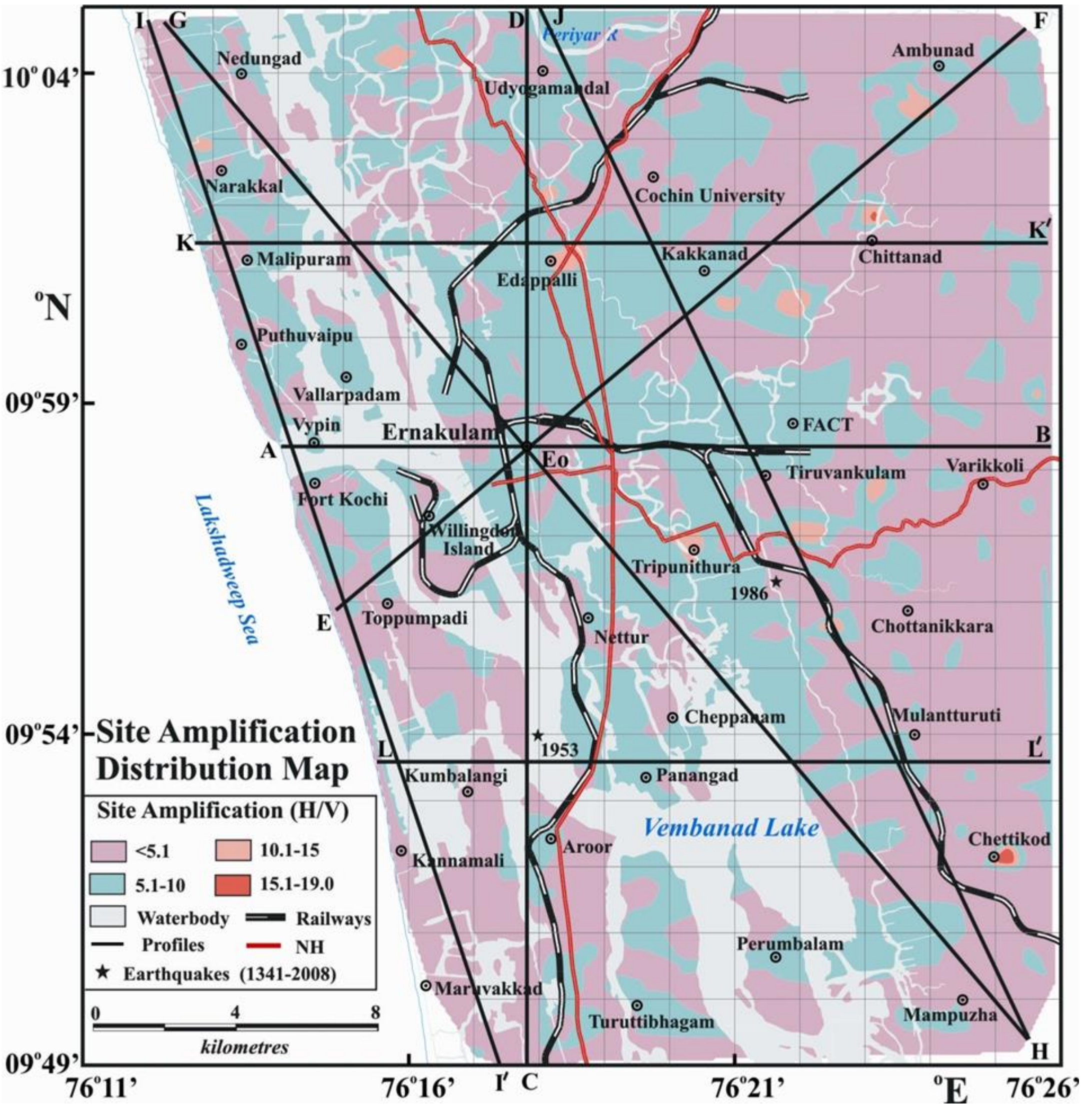

Fig. 2 (b): Region map of site amplification (H/V) for Kochi city with eight profiles along which variation patterns of computed H/V are studied. Cross-sections along these profiles were observed initially on the DEMs of H/V along which its values are extracted at closely spaced intervals of distance in order to understand its variation (refer Table 1 for details on length and orientations of the profiles, important places through which profiles pass, minimum and maximum values of site amplification).

Table 1 - Details of profiles taken as cross section on the DEMs of resonance frequency and site amplification (H/V) in Kochi city (Fig. 2 a,b).

Profile Nos.	Profile Names	Profile length (km)	Profile Orientations	Important Locations along the Profiles	Range of Site Response Parameters			
					Fo (Hz)		H/V	
					Min	*Max*	*Min*	*Max*
1	A-Eo-B	21.34	W-E	Vypin-Ernakulam-Varikkoli	0.6	11.9	1.7	8.7
2	C-Eo-D	29.26	S-N	Turuttibhagam-Erna-kulam-Udyogamandal	0.5	7.2	3.0	8.6
3	E-Eo-F	24.86	SW-NE	Toppumpadi-Ernakulam-Ambunad	0.5	15.8	2.0	11.0
4	G-Eo-H	36.85	NW-SE	Nedungad-Ernakulam-Mampuzha	0.5	9.9	2.3	8.2
5	I-I'	30.36	NW-SE	Nedungad-Fort Kochi-Maruvakkad	0.5	1.3	2.2	9.6
6	J-H	31.46	NW-SE	Udyogamandal-Tiruvan-kulam-Mampuzha	2.4	12.6	2.0	11.6
7	K-K'	24.0	W-E	Malipuram-Kakkanad-Chittanad	0.5	12.3	1.1	11.0
8	L-L'	18.7	W-E	Kumalangi-Panangad-Mulantturuti	0.5	17.7	2.2	8.1

The distribution pattern of resonance frequency and the site amplification along the above mentioned eight profiles reveal that soft soils with thick sedimentary columns (tidal, fluvial and palaeo beach deposits) in and around the coastal belt and backwater zones are associated with lower bound of resonance frequency and are likely to amplify ground motion greatly that may result in relatively more damage. On the other hand, higher bound of resonance frequency in the eastern portion of the city having charnockite and laterite formations are observed which may not amplify ground motion much. In such areas, damage will be limited. But strong amplification may occur in scattered sites having undulations in the surface topography and basement, and adjacent valleys filled with soft soils.

8. Characteristics of Seismic Microzones

The study region covers an area of about 520 km^2 (28 km x 29 km) excluding water bodies. For better visual effects, 3-D views of the resonance frequency and the site amplification (H/V) are compared with their surface distribution patterns. The characteristics of three zones; Seismic Microzones I, II and III are identified from the microzonation maps (Fig 3). Microzones I, has been delineated as an area occupied by the highest bound of estimated resonance frequency (> 5 Hz) coupled with the lowest bound of characteristic site periods ($\leq$ 1.2 sec) and is defined as regions that produce generally lower bound of site amplification but likely to generate, under certain geologic setup, a comparatively higher amplification of ground motion also at limited sites. This Microzone is considered to be a stable zone. Microzones II, this Microzone has been defined as an area occupied by the medium level of estimated resonance frequency (1.1- 5.0 Hz) coupled with medium level of characteristic site periods (1.2 -6.3 sec). Such zones generally produce moderate (most of the area) to high to very high level of ground motion amplification (certain limited zone with favourable geologic setup). This Microzone is observed to be moderately unstable. Microzone III has been defined as an area associated with the lowest bound of estimated resonance frequency (≤ 1.0 Hz) coupled with longest characteristic site period > 6.3 sec. Such zones generally produce high to very high amplification of ground motion in the delineated zone. This Microzone is observed to be highly vulnerable to ground shaking and hence it is unstable.

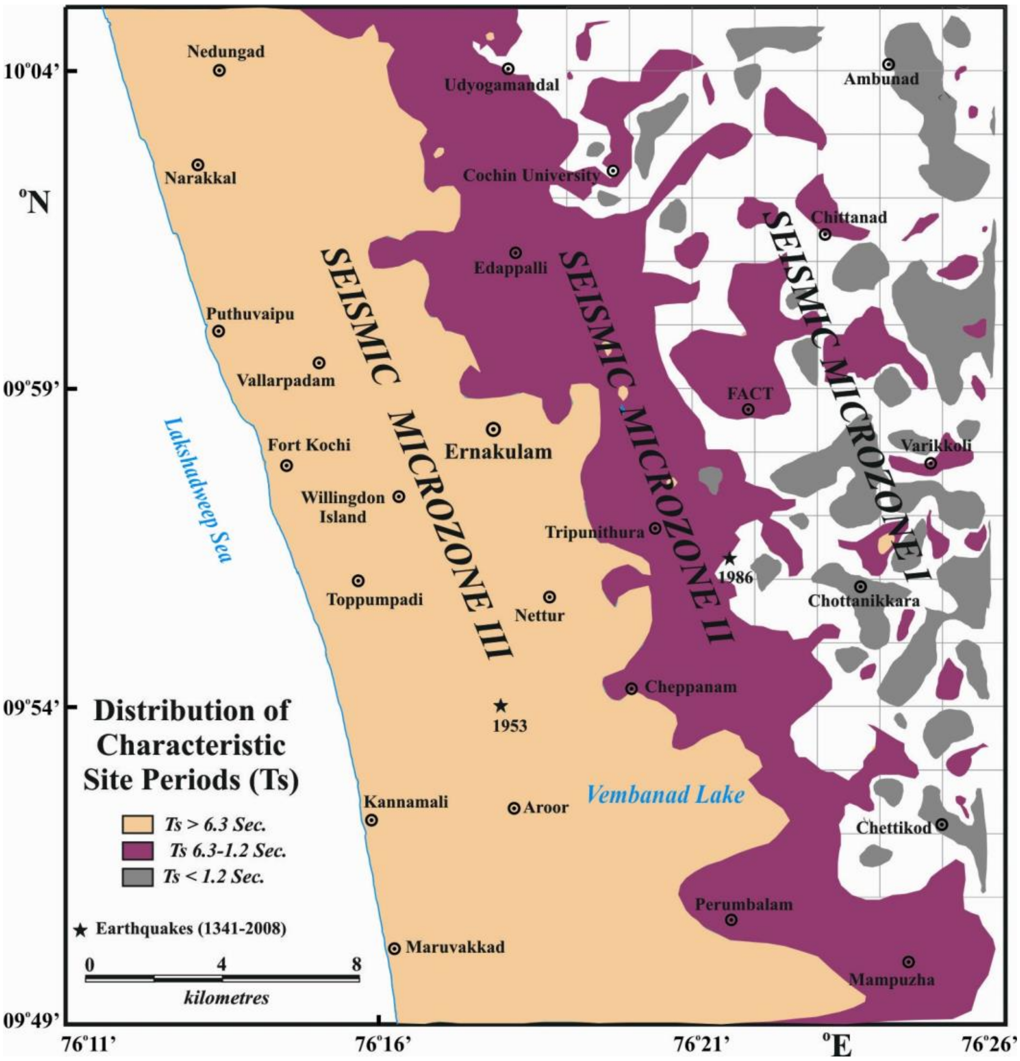

Fig. 3: Distribution map of estimated Characteristic Site Period in the identified seismic microzones in Kochi city (please refer text for details).

9. Discussion and Conclusions

The findings of the present work have been quite encouraging on the assessment of site specific ground motion vibrations that can be expected in coming years in different parts of the Kochi city due to an earthquake. The site specific response parameters estimated by analyzing ambient noise records was found to vary significantly within short distances in the city. The estimated resonance frequency helped to prepare the seismic microzonation map for the city on classifying the area into three distinct zones which differ appreciably in their site response characteristics and associated characteristics site periods. The resonance frequency is spatially distributed in three NW-SE trending segments parallel to the coast and the lower bound of resonance frequency values (≤ 1.0 Hz) coupled with generally higher level of site amplification were observed in coastal and backwater areas covered with younger alluvial deposits, and high resonance frequency values (> 5 Hz) to charnockite and laterites in the hinterlands.

Similar results were also obtained on the estimated resonance frequency and the site amplification along profiles parallel to and perpendicular to the west coast. A sudden increase in resonance frequency and reduction in the site amplification was observed at the boundary of younger alluvium deposits and the charnockite-laterite formations along the profiles. On the other hand, no significant variation in site response characteristics was noticed along the profiles parallel to coastline (NW-SE) having more or less similar geological setup. The estimated higher bound of characteristic site periods more than 6.3 sec was found in coastal belt and its vicinity having soft soil deposits and lower bounds less than 1.2 sec in hinterlands with charnockite and laterites. The present study indicates that, the use of CityShark for microzoning an area saves a considerable amount of time and provides quick and reliable estimates of site specific response parameters and characteristic site periods. It is inferred that the resonance frequency estimated through closely spaced interval of observed ambient noise records can find application in identifying boundaries of different geological formations. The methodology developed and as adopted in the present work may be extended to other urban centres in the state which may provide base data to generate a comprehensive model for the long-term seismic hazards assessment and prediction.

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