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Natural Hazards and Earth System Sciences
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Discussions

Interactive comment on "Seismic vulnerability and risk assessment of Kolkata City, India" *by* S. K. Nath et al.

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Point by point response to the observations & comments of # Reviewer 2 on the Manuscript titled "Seismic Vulnerability & Risk Assessment of Kolkata City, India" (ms# nhess-2013-467) We greatly appreciate the critical review of the manuscript by the anonymous referee#2. Our response to the observations and comments are given below.

Overall Observations of Reviewer # 2 : "The paper presents a case study of multi-criteria seismic risk assessment for the city of Kolkata (India), with a population of 14 millions (2011 Census). Supplementary to the earthquake engineering work, the study makes an intensive use of Satellite data and GIS technology for many of the necessary

parameters. A seismic risk study for such a huge city is a remarkable task and the work described in the paper is expected to involve a large number of persons over several years. Such studies are of importance, not only for the scientific community but also for local authorities.

However the paper seems to have some weak points: Specific Comments & Response to each: Comment 1: There is no description of the regional seismicity (the city is large, but to what seismic sources it is exposed? what magnitudes can these sources produce? what earthquakes and what damage was experienced by the city? (only a reference to an event in 1934 exists, and it is poor);

Response: Initially we submitted a manuscript titled "Earthquake Scenario in West Bengal with emphasis on Seismic Hazard, Vulnerability & Risk Microzonation of Kolkata City, West Bengal, India". The manuscript went through the usual review process with two anonymous referees critically examining the initial submission. Based on the volume of the work the suggestions of the reviewers and the handling Editor had been towards breaking the manuscript into multiple submissions as companion papers for further consideration of publication in the same volume of the journal. Consequently we came up with two distinctive manuscripts: one as the revised version submitted titled "Earthquake Scenario in West Bengal with emphasis on Seismic Hazard Microzonation of the City of Kolkata, India" (ms# nhess-2012-455) of the initial submission and a new companion paper titled "Seismic Vulnerability & Risk Assessment of Kolkata City, India" (ms# nhess-2013-467) which is the present manuscript under consideration. The theme of the revised version of ms# nhess-2012-455 being on the seismic microzonation, regional seismicity and seismic hazard aspects, the same has been dealt in greater details there (revised ms# nhess-2012-455) which is still under review. However as per the suggestions of Referee #2, just to bring in the issue of seismicity to the center stage of the discussion we have added the following discussion in the marginally revised version of the manuscript (ms# nhess-2013-467) in section 2. "Kolkata is situated in the Bengal Basin, a huge pericratonic Tertiary basin with enormous thickness of fluvio-marine sediments (Dasgupta et al., 2000). The Bengal basin can be divided into three structural units; the westernmost shelf or platform, the central hinge or shelf/slope break and deep basinal part in the east and southeast that presently open in the Bay of Bengal. Kolkata is located over the western part of the hinge zone across which sediment thickness and facies significantly varies from shelf area in the west to the deep basinal part in the east. The most prominent tectonic feature in the Bengal basin is the NE-SW trending Eocene Hinge Zone (EHZ), also known as Calcutta-Mymensing Hinge Zone. The EHZ is 25 km wide extending to a depth of about 4.5 km below Kolkata. The Hinge zone and the deep basin are overlain by thick alluvium to a maximum depth of about 7.5 km. The tectonic grains of Main Boundary Thrust (MBT), Main Central Thrust (MCT), Main Frontal Thrust (MFT), Dhubri Fault, Dauki Fault, Oldham Fault, Garhmoyna–Khandaghosh Fault, Jangipur-Gaibandha Fault, Pingla Fault, Debagram-Bogra Fault, Rajmahal Fault, Malda-Kishanganj Fault, Sainthia-Bahmani Fault, Purulia Shear Zone, Tista Lineament, and Purulia lineament largely influence the seismicity of the region. Besides its nearby sources Kolkata is affected by the far away sources like Bihar-Nepal seismic zone, Assam Seismic Gap, Shillong Plateau, Andaman-Nicobar seismic province, and the N-E Himalayan extent. The City has been rocked time and again by both near and far field earthquakes of moderate to large magnitudes. Among the far source earthquakes that was felt in Kolkata include the events of 1897 Shillong Earthquake of Mw 8.1, 1918 Srimangal earthquake of Mw 7.6, 1930 Dhubri earthquake of Mw 7.1, 1934 Bihar-Nepal earthquake of Mw 8.1, 1950 Assam Earthquake of Mw 8.7 and 2011 Sikkim Earthquake of Mw 6.9. The Bihar-Nepal earthquake of Mw 8.1 induced MMI intensity of the order of VI-VII in Kolkata and caused considerable damage to life and property (GSI, 1939). The two near source earthquakes reported in Kolkata are the 1906 Kolkata Earthquake with intensity V-VI (Middlemiss, 1908) and the 1964 Sagar Island earthquake of Mw 5.4 with damage intensity of VI- VII surrounding the City (Nath et al., 2010). However, the maximum intensity reported in Kolkata is MMI VII generated from both the near source earthquake of 1964 and the distant earthquakes of 1897 & 1934 making the City highly vulnerable to seismic threat (Dasgupta et al.,

2000)." [Incorporated in Section 2 of the revised manuscript already under discussion]

Comment 2:Building typology is evaluated using satellite images and visual interpretation techniques; the construction material identified through these techniques has in many cases a limited correlation with the structural material and with the structural type, this brings a not at all negligible uncertainty of the final results (and the matter of uncertainty is not clearly addressed in the paper);

Response: We have incorporated accuracy assessment of the building typology theme derived from satellite imagery as well as Visual Rapid Screening as follows. "The most common way to represent the confidence level in the assessment of remote sensing data is in the form of computing an error matrix (Congalton, 1991). We derive error matrices for both the structural and socio-economic vulnerability exposures for comparisons. It is based on the widely used accuracy assessment technique of statistical correlations between two map data –one categorized from the Rapid Visual Screening (RVS) which we term as 'reference' and the other derived exclusively from remote sensing data which is termed as 'classified' (Story and Congalton, 1986; Jensen, 1996). The correlation indicators used in the present analysis include "overall accuracy" i.e. the percentage of matched data between the 'reference' and the 'classified' maps, "user's accuracy" i.e. the percentage of matched data in the 'classified' map, "producer's accuracy" i.e. the percentage of matched data in the 'reference' map, and the kappa value defining a measure of the differences between the 'reference' and the chance agreement between both the maps. The kappa value is computed using equation (1). The kappa statistics >0.80 suggests 'strong' agreement, a value within a range of 0.60-0.80 suggests 'good' agreement and the chance of agreement is remote while kappa is close to 0 indicating 'poor' agreement (Landis and Koch, 1977). The 'Margfit' procedure has also been used on each error matrix through the application of a FORTRAN code "Margfit" available in Congalton et al (1991). The underlying methodology utilizes an iterative proportional fitting to conform to the sum of each row and column in the error matrix to a predetermined value. A normalized accuracy is calculated by summing the values on the major diagonal and dividing it by the sum of the total values in the normalized error matrix (Congalton and Green, 1999). As a result, both the producer's and user's accuracies have been incorporated in the normalized cell value which is based on a balanced effect of these two accuracy measures (Congalton and Green, 1999). In the present study, the structural and socio-economic vulnerability exposures (e.g. building typology, building height and landuse/landcover) derived from satellite imagery in case of building typology & landuse/landcover and that generated from Google Earth 3D aspect for building height are used as 'classified' data and the one derived through Rapid Visual Screening from 1200 survey locations being considered as 'reference' data have been used for the accuracy assessment of all the themes. For Rapid Visual Screening a hand held GPS (Global Positioning System) is used for coordinate generation at each of the 1200 locations and the survey is conducted on the vulnerability types as has been depicted in Fig. 3 for sample RVS for building heights at four locations in the City. The error matrices generated for landuse/landcover, building typology and building height are given in Tables 2, 3 & 5 respectively, wherein the kappa statistics exhibit a good agreement between the field-based 'reference' and the remotely 'classified' data for all the vulnerability exposures considered in the present analysis. [Incorporated in Section 3 of the revised manuscript already under discussion]

Comment 3: The building typology identified in this way has little correlation with the exercise of computing damage probabilities (at the end of the paper) for 4 model type buildings, and with the description of the 5 building categories from BIS (2002); Response: In the present study, the building materials have been categorized into 5 classes (A: A1- mud and unbrick wall, A2- stone wall; B- burnt bricks building/buildings of the large block and prefabricated type/building in natural hewn stone; C: C1-i concrete building and C1-ii newly built-up concrete building) as per BMPTC (1997) . The Rapid Visual Screening (RVS) survey has been conducted for collecting building data. A total of about 1200 nos. of sample buildings over the study region were surveyed and the building data have been electronically warehoused for further analysis. The

probability of damage in each seismic risk zone is calculated in relationship with the given ground motion parameters to evaluate the building performance for a particular seismic event. Based on RVS technique, we have selected four model building types viz. RM2L, RM2M, URML and URMM based on the capacity curves provided in NIBS (2002). In the present context, 'RM2L', 'RM2M' types represent 'C' type structure while URML and URMM represent 'B' type structure. We calculated the demand spectrum curve of spectral acceleration, the peak building response and the cumulative damage probabilities of all the four-model type buildings. The demand spectrum curve of spectral acceleration is a function of spectral displacement, spectral response at the period 0.3 and 1.0 sec that has been used for the characterization of the ground motion demand. The spectral displacement is computed using equation (9). The capacity curve represents the characteristics of a structure, which is a plot of lateral resistance of a building as a function of the characteristic lateral displacement. The capacity curve is characterized by three control points: design capacity, yield capacity, and ultimate capacity. The peak building response is estimated from the interaction of the building capacity curve and the demand curve at the specified building location. The peak building response at the point of interaction of the capacity curve and the demand curve is used with fragility curve to estimate the damage state probability. Table 10 enlists the calculated peak building response values for all four-model building types.

Comment 4: Even the authors mention HAZUS methodology, in their paper the classification of structural system, heights, and seismic design criteria does not follow the HAZUS approach;

Response: It is indeed true that for the best possible assessment of the vulnerability and risk of an earthquake prone district, it is necessary to have the maximum possible information such as the one proposed by HAZUS (Sarris et al., 2010) risk assessment model that require detailed inputs on structural configuration in terms of design, shape, height & number of stories, building proximity, lateral strength, stiffness, ductility, foundation, material and its construction practice etc. The focus definitely is on building-specific study from building inventory of group of buildings with similar characteristic and classification. In the present investigation we proposed an alternative approach based on Satellite Imagery, Google Earth and Rapid Visual Screening for a broader estimation of socio-economic and structural vulnerability of the City of Kolkata and its seismic risk thereof.

Comment 5: The vulnerability curves that seem to be used in the computations are given for structural typologies different then those identified from satellite images; Response: The Vulnerability Curves for the observed damage (GSI, 1939) due to 1934 Bihar-Nepal earthquake of Mw8.1 for RCC, Steel, Masonry and Non-engineered structures in Kolkata and adjoining regions have been constructed following Sinha and Adarsh (1999) as presented in Fig.7. However, as per BMTPC regulations the RCC and Steel type structures represent 'C' typology, the Masonry structures represent the 'B' typology while the Non-engineered structures represent 'A' typology respectively.

Comment 6: Building age is also identified using satellite data from different periods, so the results may also incorporate significant uncertainties; moreover, the classification in classes is not made in relation with the evolution of the seismic design regulations, so such age classes have a limited relevance for seismic vulnerability and risk;

Response: In context to the above comment the following justification have been incorporated in the revised manuscript "Remote sensing imagery is ideally used to monitor and detect urban land cover changes that occur frequently in urban and peri-urban areas as a consequence of incessant urbanization (Zha et al., 2003). Land covers in urban areas tend to change more drastically over a short period of time than elsewhere because of rapid economic development. In the present study, the built–up areas were obtained from the LANDSAT TM, ETM and MSS classified images of eight different periods (1975, 1980, 1985, 1990, 1995, 2000, 2005 and 2010) to monitor the dynamic changes of urban sprawl (Small, 2002; Zhang et al., 2002). For the purpose, we have used Normalized Difference Built-up Index (NDBI) for classification of built-up areas (Zha et al., 2003). Change detection analyses describe the differences between

the images of the same scene at different periods. The building age/urban growth of Kolkata have been estimated using change detection technique in ERDAS IMAGINE 9.0 software as depicted in Fig.8. For the map validation purposes we have selected a sample block in the Newtown financial and infrastructural hub of Kolkata where Landsat TM and Google Earth imageries of 2005 & 2010 have been considered as 'classified' & 'reference' data sets respectively for urban growth assessment and its allied error statistics. Figure 9 depicts the urban expansion during the period 2005-2010 based on both Landsat TM and Google Earth Imageries. The associated error matrix is given in Table 4. It is seen that the optimal lifetime of structures in Kolkata is between 40-50yrs. The urban expansion has been divided into seven clusters such as, younger than 10 yrs, 10-20 yrs, 20-30 yrs, 30-35 yrs, 35-40 yrs, 40-50 yrs and older than 50 yrs as depicted in Fig. 8. The older buildings (>50yr) have been adopted from "Atlas of the City of Calcutta & its Environs" (Kundu and Aag, 1996). However, older buildings are likely to be vulnerable to severe damage or total collapse under strong seismic excitations. There are many aged ill-conditioned, closely spaced structures in Kolkata which also seem to be highly vulnerable to seismic threat. We, therefore, incorporated building age/ growth in AHP protocol for the structural risk assessment of Kolkata". [Incorporated in Section 3.4 of the revised manuscript already under discussion]

Comment 7:The site-structure quasi-resonance is investigated based on a rough structural type classification (different from the other classifications within the paper) and fundamental period of vibration evaluation, and on the site predominant frequency identified through H/V technique (data coming from an impressive 1200 site measurements campaign); the ambient vibration-based site predominant frequency does not match the site predominant frequency during earthquakes so frequently, and almost never in case of strong earthquakes; since no data about the potential earthquakes and ground motions in the region is presented, it is hard to evaluate the appropriateness of the approach given in the paper;

Response: The response of a building to seismic shaking at its base depends on the design quality of construction. The most important factor is the height of the building. The type of shaking and the frequency of shaking depend on the structure as well as the site of its construction. The fundamental frequency of structures may range from about 2 Hz for a low structure up to about 4 stories, and between 0.5-1 Hz for a tall building from 10-20 stories; thus the tall buildings tend to amplify the longer period motions compared to small buildings (Kramer, 1996). Each structure has a resonance frequency that is the characteristic of the building. Therefore, in developing the design strategy for a building, it is desirable to estimate the fundamental periods both of the building and the site on which it is to be constructed so that a comparison can be made to understand the possibility of quasi-resonance. In the present study, Google Earth and about 1200 ground truth GCP have been used for visual identification of building height using 3D aspect and its validation. In Fig. 10 the building height map of Kolkata is presented. The accuracy statistics between the RVS derived 'reference' and the Google Earth derived 'classified' maps have been presented in Table 5. The building heights have been categorized into 5 classes; houses-1floor, buildings-2 to 4 floors, tall buildings- 5 to 8 floors, multistoried buildings- 9 to 10 floors and skyscrapers >10 floors. Therefore, the approximate fundamental natural period of vibration (Ta), in seconds, has been estimated by the empirical expression (BIS, 2002) as given in equation (2). The site fundamental period has been estimated from microtemor H/V spectral ratio (Nakamura, 1989) based on equation (3). The H/V response curves obtained from the microtremor survey reflects the geology and soil properties of the test site. Lermo and Chavez-Garcia (1993) examined the relevance of HVSR for weak and strong motion earthquake records and found good agreement in the soil resonance frequencies. Using 1D models of shear wave velocity, they validated the applicability of HVSR. In the present study, ambient noise data acquired using SYSCOM MR2000 at 1200 locations in the City have been processed using View2002 and GEOPSY software (www.geopsy.org). The Predominant Frequency distribution map shown in Fig. 11 is prepared on GIS platform exhibiting a variation between 0.6 Hz to 3.1 Hz. The proximity of Predominant Frequency of the soil column and the natural frequency of

life line facilities indicates higher vulnerability of the built-up environment owing to resonance effects (Nath and Thingbaijam, 2009). Normally, the natural period of vibration of any structure should not coincide with the predominant period of earthquake excitations, otherwise resonance may occur and even the strongest structure may collapse (BIS, 2002). Figure 12 represents the difference between the structure's natural period of vibration and the predominant period of the respective site indicating damage possibilities of existing structures/logistics due to the impact of an earthquake- the larger the difference the lesser is the possibility of destruction.

Comment 8:The seismic hazard microzonation is in fact a ground multi-hazard and ground properties microzonation through a hazard index; authors don't give any details regarding the different hazards and ground properties, and they are only referring to another paper submitted to NHESS and present some small figures, more details are however welcomed; Response: The detailed description about the Seismic Hazard Microzonation themes have been discussed in the manuscript (nhess-2012-455) titled "Earthquake Scenario in West Bengal with emphasis on Seismic Hazard Microzonation of the City of Kolkata, India". However, a brief description about the same is incorporated in this revised manuscript which reads like: "The major Geomorphological units present in Kolkata are Deltaic plain, interdistributory marsh, paleo-channels, younger levee adjacent to river Hoogly and older levee on both sides of the Adi Ganga (Roy et al., 2012) as depicted in Fig. 13(a). Based on the proportions of sand, silt and clay-sized particles obtained from 350 boreholes in Kolkata, the bottom sediments have been classified according to Shepard's diagram (O'Malley, 2007) that exhibit highly liquefiable sediments viz sand, sand-silt clay, sandy clay, silty sand and silty clay upto about $\sim$5 m as shown in Fig.13(b). Ground water table depth is among the major contributors affecting the stability of the soil column. The water table depths obtained from 350 boreholes calibrated with post monsoon piezometer survey are used to generate a water table depth variation map of the City as shown in Fig.13(c) depicting water table fluctuation between 0.1 - 7.7 m. Site Classification of Kolkata performed using in-depth Geophysical and Geotechnical investigations from 350 borehole data based on

NEHRP, USGS and FEMA nomenclature places the City in D1 (Vs30: 180-240 m/s), D2 (Vs30: 240-300 m/s), D3 (Vs30: 300-360 m/s) and E (Vs30 <180 m/s) classes as shown in Fig.13(d). The Probabilistic Seismic Hazard Assessment at surface consistent level performed by propagating the bedrock ground motion with 10% probability of exceedance in 50 years through 1D sediment column using an equivalent linear analysis of an otherwise nonlinear system predicts a Peak Ground Acceleration variation from 0.176g to 0.253g in the City as depicted in Fig.13(e). There had been evidences of wide spread liquefaction in Kolkata triggered by the 1934 Bihar-Nepal Earthquake of Mw 8.1.Therefore, soil liquefaction in terms of Factor of Safety against liquefaction is considered as one of the major contributors of seismic hazard potential in Kolkata and is, therefore, used in the present microzonation protocol. The standard methodology given by Youd et al (2001), Idriss & Boulanger (2006) and Iwasaki et al (1982) based on SPT-N value is used for liquefaction susceptibility computation considering surface PGA distribution with 10% probability of exceedance in 50 years. LPI values have been categorized according to Iwasaki et al (1982) as: Non-liquefiable (LPI = 0), Low (0 < LPI < 5), High (5 < LPI < 15) and Severe (LPI > 15) as shown in Fig.13(f). The details of each theme have been given in Nath et al (2013)."

[Incorporated in Section 4 of the revised manuscript already under discussion]

Comment 9: Through the paper, the comparison of different data with the historical observed data from past earthquakes is quite weak;

Response: It is indeed a very good observation of the reviewer but in Kolkata, there is no detailed historical report available regarding the earthquake devastation/damage except for the 1934 Bihar-Nepal Earthquake of Mw 8.1 in GSI memoirs (GSI, 1939). However the City has been rocked time and again by both near and far field earthquakes of moderate to large magnitude. Among the far source earthquakes that was felt in Kolkata include the events of 1897 Shillong Earthquake of Mw 8.1, 1918 Srimangal earthquake of Mw 7.6, 1930 Dhubri earthquake of Mw 7.1, 1934 Bihar-Nepal earthquake of Mw8.1, 1950 Assam Earthquake of Mw 8.7 and 2011 Sikkim Earthquake

of Mw 6.9. The Bihar-Nepal earthquake of Mw 8.1 developed MMI intensity of the order of VI-VII in Kolkata and caused considerable damage to life and property (GSI, 1939). The two near source earthquakes reported in Kolkata include the 1906 Kolkata Earthquake with intensity V-VI (Middlemiss, 1908) and the 1964 Sagar Island earthquake of Mw 5.4 with damage intensity of VI- VII surrounding the Kolkata city (Nath et al., 2010). However, the maximum intensity reported in Kolkata is MMI VII generated from both the near source earthquake of 1964 and distant earthquakes of 1897 & 1934 making the province seismically vulnerable (Dasgupta et al., 2000)." Comment 10: The references are rather limited;

Response: A few more important references that have been incorporated and cited in the revised manuscript are listed below.

Comment 11: Due to the large size of the city the figures are sometimes quite hard to read.

Response: All the figures are accordingly modified and high resolution diagrams are incorporated in the revised manuscript.

Extra references: BIS.: IS 1893–2002 (Part 1): Indian Standard Criteria for Earthquake Resistant Design of Structures, Part 1 – General Provisions and Buildings, Bureau of Indian Standards, New Delhi, 2002. BMTPC.: Vulnerability Atlas of India: Earthquake, Windstorm and Flood Hazard Maps and Damaged Risk to Housing, Ministry of Housing & Urban poverty Alleviation, Government of India, First Revision, 1997. Congalton, G. R.: Review of Assessing the Accuracy of Classifications of Remotely Sensed Data, Remote Sens. Environ., 37,35-46, 1991. Congalton, R., and Mead, R.: A quantitative method to test for consistency and correctness of photo interpretation, Photogrammetric Engineering and Remote Sensing, 49, 69-74, 1983. Congalton, R. G., and Green, K.: Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. CRC Press, Inc, Boca Raton, Florida, 137, 1999. Dasgupta, S., Sural, B., Harendranath, L., Mazumadar, K., Sanyal, S., Roy, A., Das, L.K., Misra, P. S. and Gupta, H.: Seismotectonic Atlas of India and its Environs, Geological Survey of India, Calcutta, India, 2000. GSI.: The Bihar-Nepal Earthquake of 1934, Geol. Surv. India, Mem.,73, 1939. Idriss, I. M. and Boulanger, R. W.: Semi-empirical procedures for evaluating liquefaction potential during earthquakes, Soil. Dyn. Earthq. Eng., 26(2–4), 115–130, 2006. Iwasaki T, Tokida K, Tatsuoka F, Watanabe S, Yasuda S, and Sato, H.: Microzonation for soil liquefaction potential using simplified methods, In: Proceedings of 3rd international conference on microzonation, Seattle, 3, 1319–1330, 1982. Jensen, J. R.: Introductory digital image processing: A remote sensing perspective (Second edition), Prentice Hall, Inc., Upper Saddle River, New Jersey, USA, 1996. Kramer, S. L.: Geotechnical Earthquake Engineering, Prentice Hall, Upper Saddle River, NJ, 653 pp, 1996. Kundu A. K. and Aag, P,: Atlas of the City of Calcutta & its Evnirons, National Atlas and Thematic Mapping Organization, Ministry of Science and Technology, Government of India, 1996. Landis, J. R., and Koch, G. G.: The measurement of observer agreement for categorical data. Biometrics 33, 159ïĂ■174, 1977. Lermo J. and Chilvez-Garcfa, F. J.: Site effect evaluation using spectral ratios with only one station, Bulletin of the seismological society of America, 83, 1574-1594, 1993. Middlemiss,C.S.: Two Calcutta Earthquakes of 1906. Records Geol. Surv. ind., 36(3), 214-232, 1908. Nakamura, Y.: A Method for Dynamic Characteristics Estimations of Subsurface using Microtremors on the ground Surface, QR RTRI, 30, 25ïĂ■33, 1989. Nath, S. K. and Thingbaijam, K. K. S.: Seismic hazard assessment-a holistic microzonation approach, Nat. Hazards Earth Syst. Sci., 9, 1445-1459, 2009. Nath, S. K., Thingbaijam, K. K. S., Vyas, J. C., Sengupta, P., and Dev, SMSP.: Macroseismic-driven site effects in the southern territory of West Bengal, India, Seismol. Res. Lett., 81, 480–487, 2010. Nath, S. K., Adhikari, M. D., Maiti, S. K., Devaraj, N., Srivastava, N. and Mohapatra, L. D.: Earthquake Scenario in West Bengal with emphasis on Seismic Hazard Microzonation of the city of Kolkata, India, Nat. Haz. Eart. Sys.Sci., 2013 (revised manuscript under review). NIBS.: HAZUS99- earthquake loss estimation methodology, technical manual In, FEMA (Editor), Technical Manual. Federal Emergency Managemen Agency (FEMA), National Institute of Building Sciences (NIBS), Washington. DC., 2002, pp. 325. O'Malley, J.: U.S. Geological Survey

ArcMap Sediment Classification Tool: Installation and User Guide, USGS, Open-File Report 2007-1186, 2007. Roy, P. K., Banerjee, G., Mazumdar, A., Kar, A., Majumder, A., and Roy, M. B.: A Study to ascertain the Optimum Yield from Groundwater Source in the Eastern Part of Kolkata Municipal Corporation Area in West Bengal, India European Journal of Sustainable Development, 1(2), 97-112, 2012. Sarris, A., Loupasakis, C., Soupios, P., Trigkas, V., and Vallianatos, F.: Earthquake vulnerability and seismic risk assessment of urban areas in high seismic regions: application to Chania City, Crete Island, Greece , Nat. Hazards, 54, 395–412, 2010. Sinha, R. and Adarsh, N.: A Postulated Earthquake Damage Scenario for Mumbai. ISET Journal of Earthquake Technology, 36 (2-4), 169–183, 1999. Small, C.: Multi-temporal analysis of urban reflectance, Remote Sensing of Environ., 81, 427– 442, 2002. Story, M., and Congalton, G. R.: Accuracy Assessment: A User's Perspective, Photogrammetric Engineering and Remote Sensing, 52, 397-399, 1986. Youd, T. L., Idriss, I. M., Andrus, R. D., Arango, I., Castro, G., Christian, J. T., Dobry, R., Finn, W. D. L., Harder Jr, L. F., Hynes, M. E., Ishihara, K., Koester, J. P., Liao, S. S. C., Marcuson-III, W. F., Martin, G. R., Mitchell, J. K., Moriwaki,Y., Power, M. S., Robertson, P. K., Seed, R. B. and Stokoe-II, K. H.: Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, ASCE, J. Geotech. Geoenviron. Engg., 127, 817ïĂ■833, 2001. Zha, Y., Gao, J. and Ni, S.: Use of normalized difference built-up index in automatically mapping urban areas from TM imagery, Int. J. Remote Sensing, 24(3), 583-594, 2003. Zhang, Q., Wang, J., Peng, X., Gong, P. and Shi, P.: Urban built-up land change detection with road density and spectral information from multi-temporal Landsat TM data, Int. J. Remote Sensing, 23(15), 3057-3078, 2002.

Figures caption: Fig. 3. Rapid Visual Screening (RVS) survey (at about 1200 sites) for Field and Google Earth comparisons of existing building height in urban Kolkata for potential Seismic Vulnerability Assessment. Fig. 7. Vulnerability Curves for observed damage inflicted by the 1934 Bihar-Nepal Earthquake of Mw 8.1 (GSI, 1939) on various Building Typology in Kolkata and adjoining regions based on Sinha and Adarsh, (1999). Fig. 9. Urban expansion during the period 2005-2010 based on both Landsat TM and Google Earth Imageries. Fig. 10. Building Height distribution map of Kolkata using Google Earth. Fig. 11. Spatial distribution of Predominant Frequency in Kolkata as obtained from Ambient Noise Survey at 1200 locations and processing those by Nakamura Ratio. Fig. 12. The difference between the natural period of vibration of structures and the predominant period of respective sites indicating damage possibilities of existing structures/logistics. Fig. 13. Seismic Hazard Microzonation protocol for Kolkata showing the weights assigned to each theme labeled according to hazard contribution, (a) Geomorphology (b) Sediment Class, (c) Ground Water Table, (d) NEHRP Site Class (e) Spatial distribution of PGA in Kolkata with 10% probability of exceedance in 50 years at Surface, (f) Liquefaction Potential Index (LPI) Distribution in Kolkata, and (g) Seismic Hazard Microzonation Map of Kolkata.

Please note that these comments were earlier made available to us alongwith the editorial decision about the acceptance of the original manuscript for discussion with an instruction for uploading the original manuscript as it is. We however revised the manuscript to its present form before uploading it for typesetting for discussion wherein all the above responses were incorporated with due inclusion of revised texts, new tables (Tables 2,3,4,5) and figures (Figs 3,9 and modified all figures especially Figs 7,10,11,12,13) in the revised version which is actually under discussion now. It is, therefore suggested that the Referee#2 may please read the discussion paper for an understanding of the changes made in consideration of his comments and suggestions clarified above.

Please also note the supplement to this comment:
http://www.nat-hazards-earth-syst-sci-discuss.net/2/C916/2014/nhessd-2-C916-2014-supplement.pdf

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., 2, 3015, 2014.

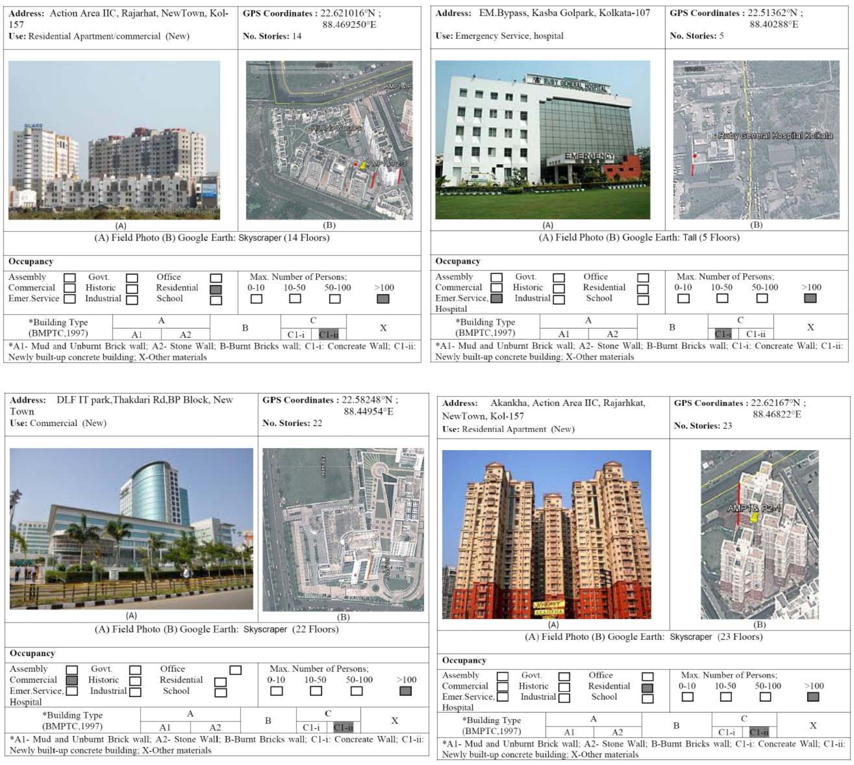

Fig. 1. Fig. 3. Rapid Visual Screening (RVS) survey (at about 1200 sites) for Field and Google Earth comparisons of existing building height in urban Kolkata for potential Seismic Vulnerability Assessment.

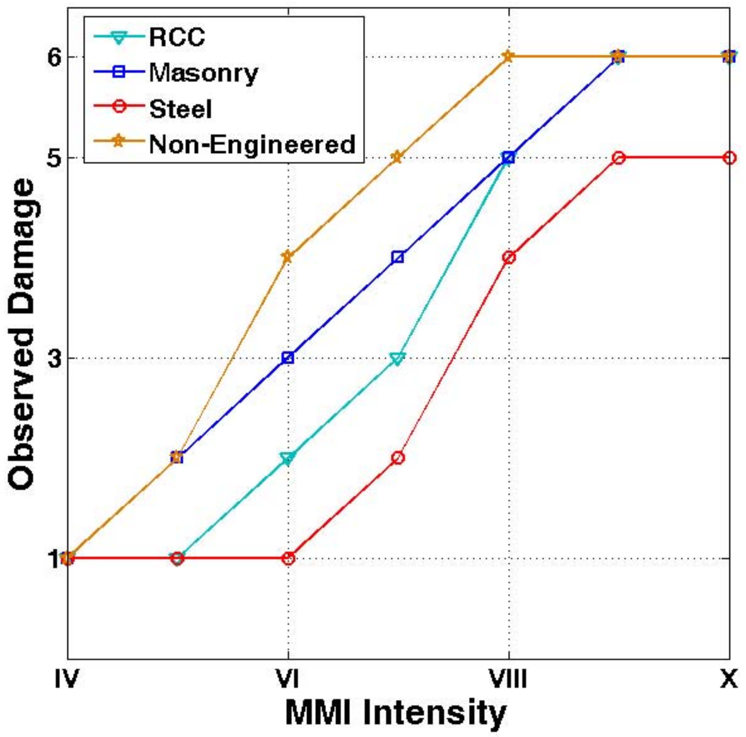

Fig. 2. Fig. 7. Vulnerability Curves for observed damage inflicted by the 1934 Bihar-Nepal Earthquake of Mw 8.1 (GSI, 1939) on various Building Typology in Kolkata and adjoining regions based on Sinha and Ad

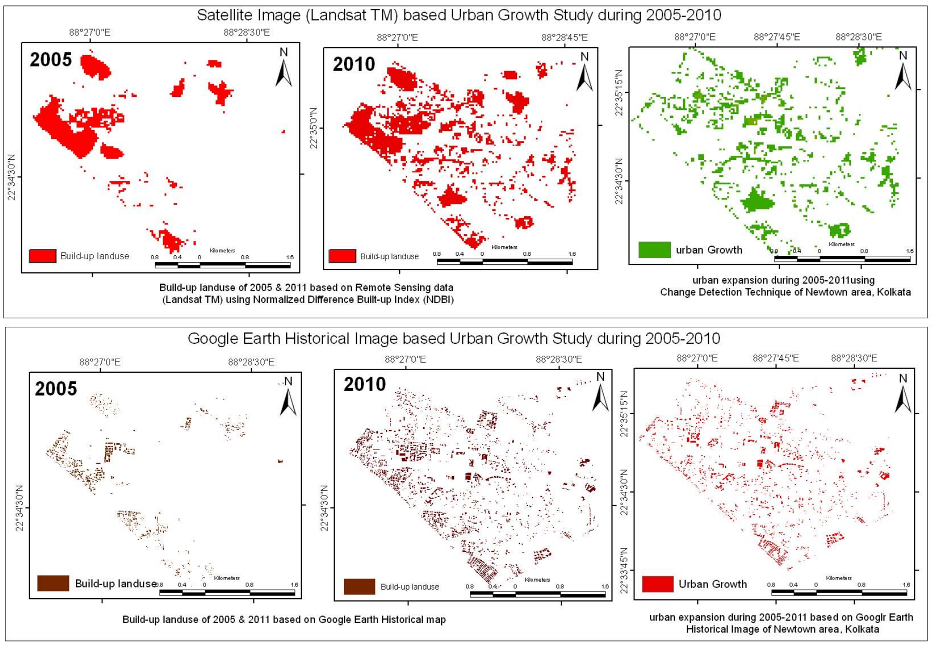

Fig. 3. Fig. 9. Urban expansion during the period 2005-2010 based on both Landsat TM and Google Earth Imageries.

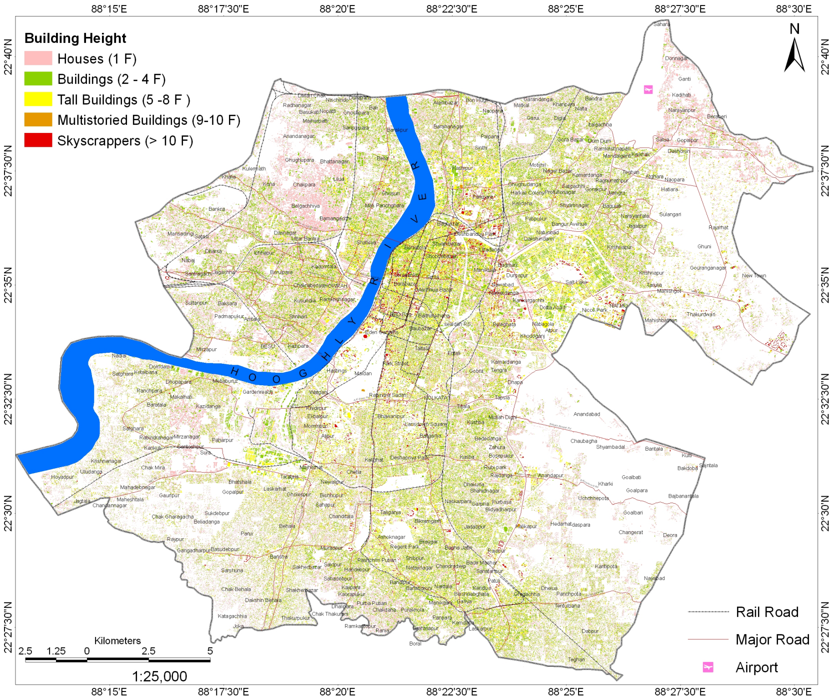

Fig. 4. Fig. 10. Building Height distribution map of Kolkata using Google Earth.

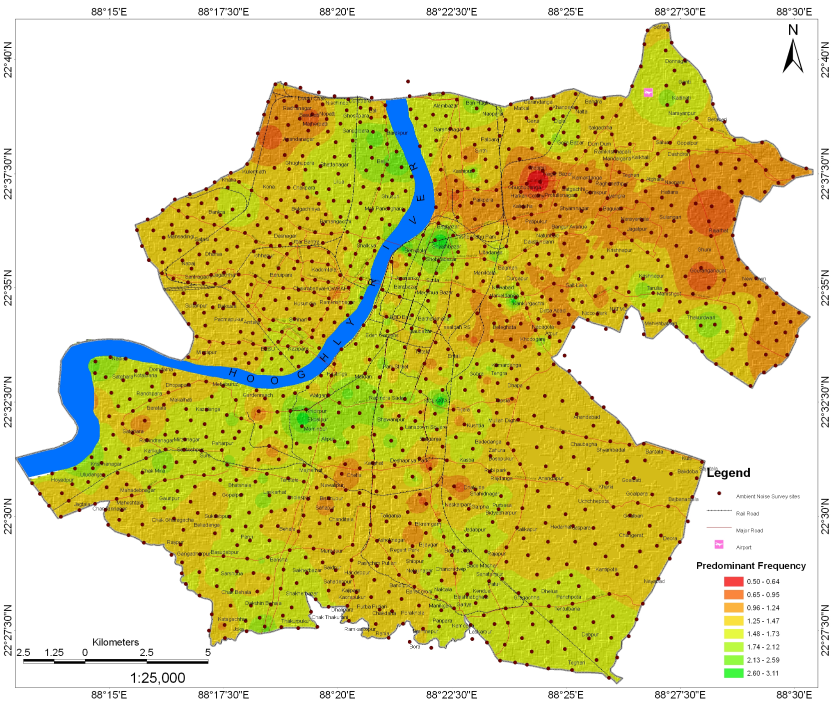

Fig. 5. Fig. 11. Spatial distribution of Predominant Frequency in Kolkata as obtained from Ambient Noise Survey at 1200 locations and processing those by Nakamura Ratio.

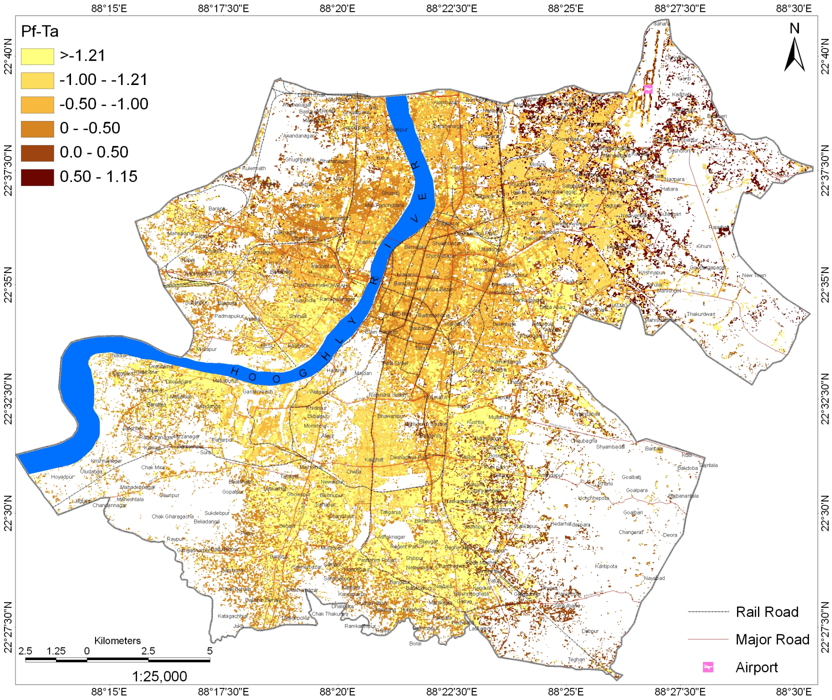

Fig. 6. Fig. 12. The difference between the natural period of vibration of structures and the predominant period of respective sites indicating damage possibilities of existing structures/logistics.

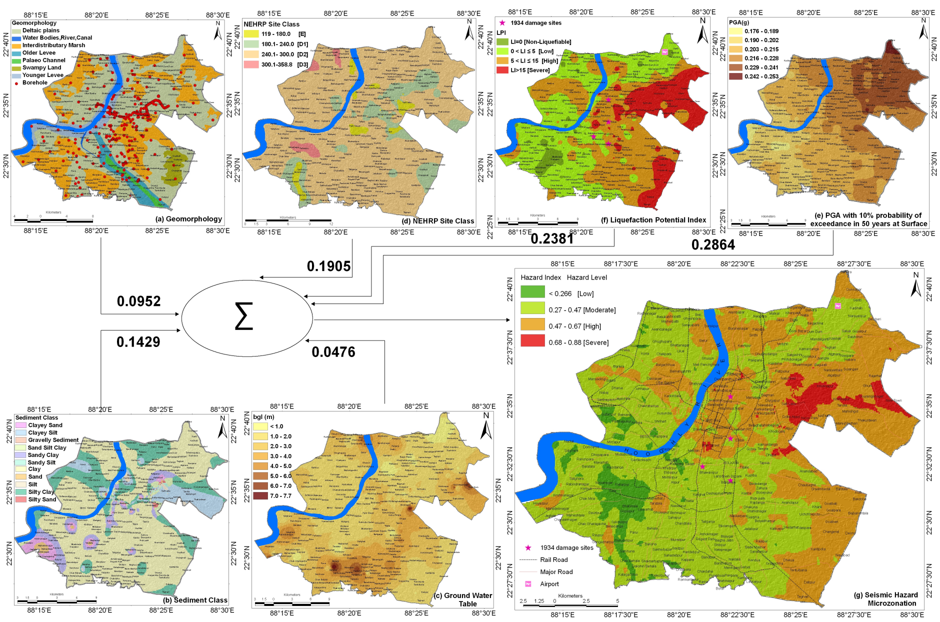

Fig. 7. Fig. 13. Seismic Hazard Microzonation protocol for Kolkata showing the weights assigned to each theme labeled according to hazard contribution, (a) Geomorphology (b) Sediment Class, (c) Ground Water T

The *kappa* value can be expressed as,

$$k = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r}(X_{i+}X_{+i})}{N^2 - \sum_{i=1}^{r}(X_{i+}X_{+i})} \tag{1}$$

Where, N is the total number of sites in the matrix, r is the number of rows in the matrix, X_{ii} is the number in row i and column i, X_{i+} is the total for row i, and X_{+i} is the total for column i (Jensen, 1996; Congalton and Mead, 1983).

The approximate fundamental natural period of vibration (T_a), in seconds, has been estimated by the empirical expression (BIS, 2002);

$$\begin{aligned} T_a &= 0.075h^{0.75} && \text{for RCC frame Building} \\ &= 0.085h^{0.75} && \text{for Steel frame Building} \\ &= \frac{0.09h}{\sqrt{d}} && \text{all other Buildings} \end{aligned} \tag{2}$$

Where, 'T_a' = Fundamental period of vibration in seconds 'h' = Height of the Building in meters. d= Base dimension of building at plinth level in 'meters', along the considered direction of the lateral force.

The site fundamental period has been estimated from microtemor H/V spectral ratio (Nakamura, 1989) based on the following equation:

$$H/V_{spectralratio} = \sqrt{\frac{\sum P_{NS}(\omega) + \sum P_{EW}(\omega)}{\sum P_V(\omega)}} \tag{3}$$

Where, $P_{NS}(\omega)$, $P_{EW}(\omega)$ and $P_V(\omega)$ are the power spectra of NS, EW and the vertical components respectively, summation is taken over the data blocks.

The spectral displacement is computed as;

SD =9.8*SA*T2 (9)

Where, 'SA'= Amplified Spectral Acceleration in 'g' (Nath et al., 2013), 'T' = Time Period (sec) and 'SD'= Spectral Displacement (inches).

Fig. 8. Equations

Table 2: Error matrix derived for Landuse/Landcover mapping in Kolkata.

		GPS based ground truth (reference data)										User's accuracy
Satellite Image (LISS-IV) based LULC (classified data)		RCIA	RPWC	PL	OS	VG	SL	DFL	AL	CL	Total	
	RCIA	452	0	0	5	0	0	0	10	0	467	96.78
	RPWC	0	43	0	0	0	15	0	0	0	58	74.13
	PL	0	0	37	0	11	0	0	2	5	55	67.27
	OS	12	0	0	32	0	3	11	3	1	62	51.61
	VG	0	0	17	0	89	2	5	7	3	123	72.35
	SL	0	7	0	0	3	98	11	5	3	127	77.16
	DFL	0	0	0	5	0	0	37	9	3	54	68.51
	AL	17	0	0	3	5	7	13	71	18	134	52.98
	CL	0	0	2	1	9	3	5	11	85	116	73.27
	Total	581	50	56	46	117	128	82	118	118		
Producer's Accuracy		93.97	86.00	66.1	78.0	76.0	76.6	45.1	65.7	72.0		
			Overall Accuracy							78.92		
			Normalized Accuracy							70.00		
			Kappa value							0.733		
			Kappa Variance							0.0002		

#Residential Commercial and Industrial area (RCIA),River/Pond/Waterbody/Canal (RPWC), Plantation (PL), Open Space (OS),Vegetation (VG), Swampy Land (SL), Dry Fellow Land (DFL), Arable Land (AL), Cultivated Land (CL).

Fig. 9. Table 2: Error matrix derived for Landuse/Landcover mapping in Kolkata.

Table 3: Error matrix derived for Building Typology in Kolkata.

Satellite Image based Building Typology (classified data)	Rapid Visual Screening based Building Typology (reference data)						User's accuracy
	A1	A2	B	C1-i	C1-ii	Total	
A1	105	29	19	11	7	171	61.4
A2	27	128	25	15	11	206	62.1
B	11	19	93	13	6	142	65.5
C1-i	12	17	26	243	37	335	72.5
C1-ii	5	9	13	42	271	340	79.7
Total	160	202	176	324	332		
Producer's Accuracy	65.6	63.3	52.8	75.0	81.6		
		Overall Accuracy					70.4
		Normalized Accuracy					68.1
		Kappa value					0.61
		Kappa Variance					0.00028

A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concreate Wall; C1-ii: Newly built-up concrete building.

Fig. 10. Table 3: Error matrix derived for Building Typology in Kolkata.

Table 5: Error matrix derived for Building Height in Kolkata.

Google Earth 3D Aspect based Building Height (classified data)	Rapid Visual Screening based Building Height (reference data)						User's accuracy
	Houses (1F)	Buildings (2 -4 F)	Tall (5-8F)	Multistoried (9-10F)	Skyscrapers (>10F)	Total	
Houses (1F)	247	49	0	0	0	296	83.4
Buildings (2 -4 F)	55	298	27	0	0	380	78.4
Tall Buildings (5-8F)	0	29	195	19	0	243	80.2
Multistoried Buildings (9-10F)	0	0	10	128	24	162	79.0
Skyscrapers (>10F)	0	0	0	18	97	115	84.3
Total	302	376	232	165	121		
Producer's Accuracy	81.8	79.3	84.1	77.6	80.2		
		Overall Accuracy					80.6
		Normalized Accuracy					80.5
		Kappa value					0.74
		Kappa Variance					0.00022

Fig. 11. Table 5: Error matrix derived for Building Height in Kolkata.

Table 10: Peak building response estimated for four significant model building types.

	Peak Building Response (Inches)			
Model Building	RM2L	RM2M	URML	URMM
Type	Reinforced Masonry Bearing Wall with Precast concrete diaphragms, Low rise (1-3 stories)	Reinforced Masonry Bearing Wall with Precast concrete diaphragms, Low rise (4-7 stories)	Unreinforced Masonry Bearing Wall, Low rise (1-2 stories)	Unreinforced Masonry Bearing Wall, Low rise (3+ stories)
S_D (inch)	0.71	0.727	0.639	0.735

Fig. 12. Table 10: Peak building response estimated for four significant model building types.

Table 4: Error matrix derived for Building Growth/Age during 2005-2010 in Newtown, Kolkata.

		Urban Expansion based on Google Earth Imageries (reference data)			**User's accuracy**
Urban Growth using Multi-temporal Landsat TM data (classified data)		High Expansion	Low Expansion	Total	
	High Expansion	678	69	747	90.7
	Low Expansion	93	281	374	75.1
	Total	771	350		
	Producer's Accuracy	87.9	80.3		
			Overall Accuracy		85.5
			Normalized Accuracy		84.4
			Kappa value		0.67
			Kappa Variance		0.00056

Fig. 13. Table 4: Error matrix derived for Building Growth/Age during 2005-2010 in Newtown, Kolkata.