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Seismic Risk Assessment of Nagpur City using the Geographic Information System

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Abstract

Earthquakes are the major threat to mankind accounting for almost half of the fatalitiesbrought about byall of the natural hazardsand desert their traces in societies for years. It is well known that seismic risk cannot be eliminated but minimized. Risk studies lay downthe roadmap to prepare and minimize the aftermath of any disastrous event. Geographic Information System (GIS)has been proved as an effectual tool for seismic risk assessment study. This study presents the seismic risk assessment of Nagpur city usingthe GIS framework. Albeit per Indian Standard (IS) 1893-2016 [1] seismic zonation of Nagpur city comes under zone II (relatively low seismic hazard zone), the seismic risk being a combination of hazard, elements at risk and, vulnerability cannot be denied. Similar to other Indian cities the city of Nagpur had a heterogeneous development pattern. Even though Nagpur city is municipalized in well distributed wards,many intra wards distributions show housing clusters of different socioeconomic status. Therefore, using the satellite imagery different socioeconomic housing clusters were identified and mapped in the ArcGIS platform. Six socioeconomic clusters were identified using satellite imagery for Nagpur. From the field survey of randomly selected typical clusters, 14 prevailing Model Building Types (MBTs)were identified. Census data were used to find the population density and its distribution throughout the city. Seismic hazard has been estimated from IS 1893-2016 [1] as well as using the probabilistic hazard map of NDMA [2]. Selected MBTs were assessed for their seismic vulnerability, seismic risk in terms of casualties and damage is calculated. Finally, thematic maps showing damages arrived from the various approach are shown and discussed.

Keywords:Damage, Fatalities, GIS,Model Building Type, Nagpur, Probabilistic,Seismic Risk,Vulnerability.

1. Introduction

Among all other natural hazards earthquake has always been a major threat to humanity. Several devastating earthquakesviz. Kangra 1905, Bihar/Nepal 1934, Koynanagar 1967, Kinnaur 1975, Bihar/ Nepal 1998, Uttarkashi 1991, Jabalpur 1997, Bhuj 2001, Kashmir 2005, Sikkim 2011, 2015, India/Nepal 2015 jolted Indian subcontinent. It seems that the frequency of these events upsurged in recent past years. Epicenters and magnitude of seismic activities oftenleft scientists and researcherssurprised,ruling out the possibility of a successful prediction and forecast of such eventsin the foreseeable future.As perThe Center for Research on the Epidemiology of Disasters (CRED)a disaster is, “a situation or event which overwhelms local capacity, necessitating a request at national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering”.

Between the year 1900 to 2015 total fatality due to earthquakes in Asia is estimated to be 18,23,324 persons with a total economic loss of 5222.7 million US dollar (US$).Out of total fatalities around 78,209 casualties were from the Indian subcontinent alone, leaving billion injured, houseless, exiled, crowning earthquakes as the deadliest natural disaster[3]. In the year 2018 alone, there were 315 natural disasters recorded causing 11,804 fatalities, affecting over 68 million lives, and resulting in (US$) 131.7 billion of economic loss. Fig. 1 shows the percentage share of various natural hazards in total fatalities.

The most distinctive feature which weigh the responsibility of minimizing earthquake damage to civil engineer is the way it affect the built environment and how its inadequacy to tackle this huge energy often leads to exacerbated disasters. Where under other hazards such as floods, cyclones, extreme heat, storm people find building and infrastructure as their savior on the contrary in seismic scenarios these developments often frighten the people. It is not an earthquake but buildings are the real culprit for putting people lives at risk and killing

For new building design, presentearthquake resistant design philosophy of IS code ensures life-safety by inducing sufficient stiffness, strength, and ductility to the structures to prevent collapse undersevere earthquakes, and to minimize the damage and loss of functionality under frequent but moderate intensity earthquakes. Under severe earthquake considered by Indian code the earthquake forcewhich is expected to acts on a structure isfour to five times higher

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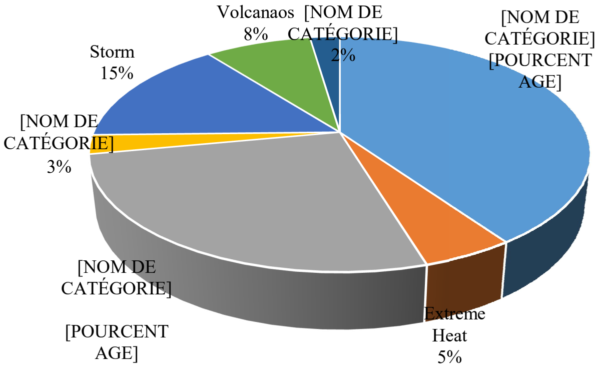

Fig. 1. Fatalities (%) breakup for the year 2018 [3]

than the prescribed reduced design earthquake force (reduced by response reduction factor)depending upon the ductility.Moreover, it should be noted that various uncertainities are associated with seismic hazard which may be beyond the consideration of seismic hazard prescribed in IS 1893-2016 [1].

In case of pre existing buildings a relatively poor performance during past earthquakes has been observed. This may be due to various reasons viz. either those buildings were not designed for earthquake or might be designed for lower earthquake force, poor construction and detailing practice, degradation due to various environmental factors etc. However, in Indian condition its is more often observed that the old structures suffer damages, not because of time-dependent degradation and dilapidatedconditions but design inadequacies. Furthermore, many newly built structures perform even worseowning to their non-compliance to the existing code and rather, poor construction practices. It is important to recognize that the earthquake exposition of many locations is changing. Subsequently, the risks in some regions have increased significantly. Thus, the evolution of earthquake engineering practices essentially necessitates the vulnerability assessment of the existing infrastructure.

As evident the casualties and overall direct and indirect losses caused by the earthquakes and associated environmental disasters can never be eliminated but minimized by long term prevention policy which shall includes; a) evaluation of seismic hazard and corresponding risk, b)mandatory compliance of building codes, and c) thoughtful land use planning considering the seismic hazard and their mitigation measures beforehand.Seismic risk assessment studies broadly involves the following parameters as shown in Equation-1. Fig. 2 illustrate the key stages of any Earthquake Loss Estimation (ELE) methodology.

$$\text{Seismic Loss (SL)} = H \times E \times V \times D \quad (1)$$

Where, 'H'representsseismic hazard, 'E'represents exposure, 'V' represents seismic vulnerability, and 'D' represents the damage to loss conversion.

Either empirical or analytical approach is commonly used for vulnerability assessment. Both approaches has some shortcomings and cannot accommodate all the requirements alone,necessitating combination of both the approach in one methodology often known as hybrid

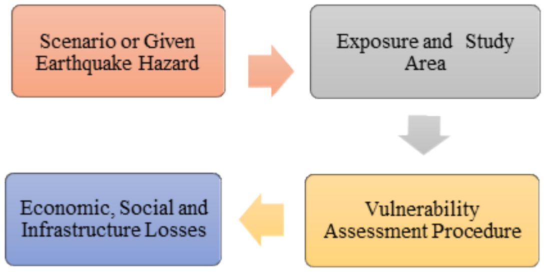

Fig. 2. Essential Plug-ins of an ELE Methodology

approach. Whitman et al. [4] described a methodology for compiling and presenting statistics concerning damage to different types of buildings subjected to altered earthquake intensities. Damage to the building is influenced by many factors, the same building responds differently to the different ground shakings. The degree of damage must be expressed in probabilistic terms, which can be well summarized in the form of Damage Probability Matrix (DPM). DPMs can be developed either empirically based on the experiences from past earthquakes or by performing a theoretical analysis i.e. analytical approach. Applied Technology Council [5] consists of DPM data formed based on the judgment of credible earthquake engineering professionals. The experts provided the low, best and high estimates of the damage factors considering all the 36 Model Building Types (MBTs) subjected to earthquake intensity from VI to XII on a Modified Mercalli Intensities (MMI) scale. Sinha et al. [6] invented a seismic risk assessment method "RISK.iitb". Combined with GIS kernel it offers illustrative graphical inputs and outputs. The seismic risk for Mumbai city is assessed, considering two source models i.e. Point and line, for a deterministic seismic hazard. Using empirical relationship thePeak Ground Acceleration (PGA) is converted into equivalent MMI. The DPMs based on the Indian buildings' data are used for damage and loss estimation.

2. GIS Integrated Seismic Risk Assessment

Towards the end of the 60s,Roger Tomlinson known as 'Father of GIS',developed the first GIS for the Canada Land Inventory, and with endowing of Environmental Systems Research Institute Inc. (ESRI) in 1969,the GIS emerged [7]. GIS application with high-resolution satellite imagery enhancesthe proficiency of data collection techniques and progressively being used in spatial decision support systems. Enabling speedy collection, handling, and examining the data of damage data over a large geographical extent particularly in the post damage scenario collection. For the same purpose, conventional methods require months, by then already a lot of ground changes may have taken place resulting in an inconsistent damage and loss assessment. Once the digital database consisting of information on buildings, infrastructure, and other utilities is prepared in the GIS platform it servesas an input for planning appropriate disaster mitigation and preparedness strategies.The use of GIS integrated with RADIUS reduced the efforts for making and planning efficient decisions and finding the risk-prone regions Alam et al. [8]. The methodology serves as a vital

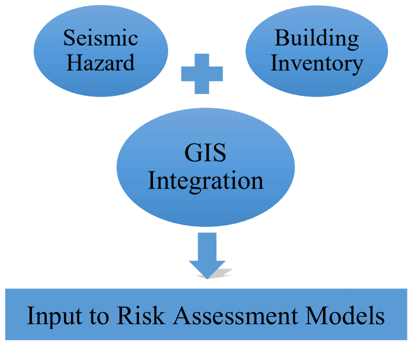

Fig. 3 Role of GIS in Preparation of Input to Seismic Risk Studies

Table-1 Population Growth Trend [12]

Census year	Population (millions)	Decadal change (millions)	Growth rate (%)
1971	0.86	--	--
1981	1.21	0.35	40
1991	1.62	0.40	33
2001	2.05	0.43	26
2011	2.41	0.35	18
***2021**	**2.96**	**0.55**	**23**

means for a quick assessment of probable damage following any disastrous earthquake event, as GISanalyses the spatial location and organizes layers of data into visualization using maps and 3D scenes. This distinctive ability enables GIS to conceal deeper understandings of data, such as patterns, relationship, and situations which assist one in taking better decisions.

Inthe mid 90s with a substantial advancement in GIS technology, researcher and software developers started integrating its application in their methodologies. HAZUS is one of the most popular methodologies in the field of risk assessment, HAZUS with ArcGIS provides a common platform for estimating the losses from three different hazard models viz. earthquake, flood, and hurricane [9]. The credibility of the GIS technology in seismic risk assessment has already been setup by many studies and programs (Alam et al. [8]; King et al. [10]; Maithani and Sokhi [11]; Sinha et al. [6]). Fig. 3 illustrates the role of GIS in ELE.

In recent years, GIS proved a great help in risk estimation and is being put to use in assessing risk to property and life arising from hazards such as earthquakes, hurricanes, cyclones, and floods. Management, analysis, and graphical illustration of the risk and hazard data can be done within a GIS framework, furthermore, as these data consists of associated location information, their spatial interrelationships can be determined and used in computer-basedriskassessment tools.

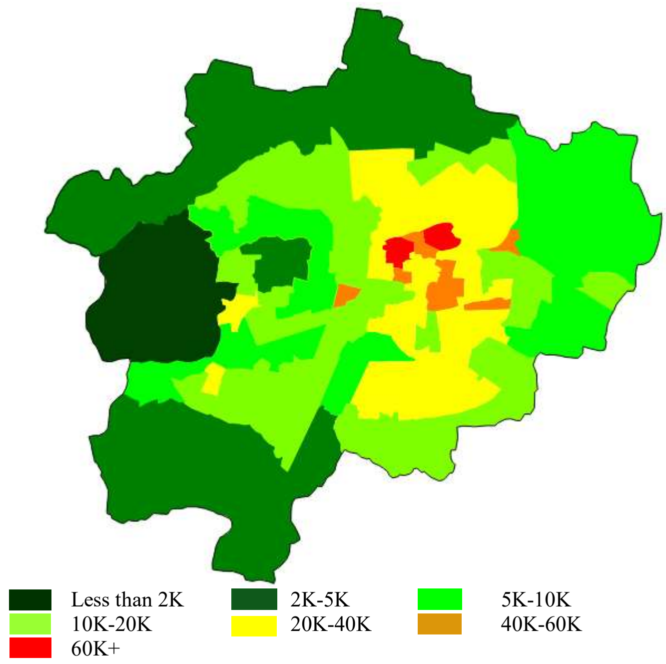

Fig. 4. Population Density Distribution of NMC

Table -2. Wards Classified Based on Population Density

People/Km^2	Ward number
0-2K	46
2K-5K	1, 2, 13, 14, 48, 115, 116, 121
5K-10K	4, 27, 28, 30, 43, 44, 45, 49, 86, 87, 89, 97, 107, 114
10K-20K	3, 8, 11, 12, 15, 16, 17, 18, 29, 41, 42, 47, 50, 58, 59, 78, 79, 81, 82, 83, 88, 93, 96, 108, 109, 110, 111, 113, 117, 119, 120, 122, 129, 130, 131, 135, 136
20K-40K	5, 6, 7, 9, 10, 19, 20, 21, 22, 23, 24, 25, 26, 31, 33, 34, 37, 38, 39, 40, 51, 57, 60, 61, 62, 63, 65, 68, 70, 71, 77, 80, 84, 85, 90, 91, 92, 94, 98, 99, 100, 101, 102, 103, 104, 105, 112, 118, 123, 124, 125, 126, 127, 128, 132, 133, 134
40K-60K	32, 54, 64, 69, 72, 73, 74, 75, 76, 95, 106
60K+	35, 36, 52, 53, 55, 56, 66, 67

Nagpur Study Area and Exposure

Nagpuris the third largest city and the winter capital of the Indian state of Maharashtra. Located in the eastern part of Maharashtra, extending over 20°34'52" N to 21° 43' 23" N latitude and 78° 15' 06" E to 79° 39' 40" E longitude, situated almost at the geographic center of the country at an altitude of 310 meters above sea level. Providing habitation to 2.4 million people, it stands tall as the 13th largest city in India, with an average density of 11,304 persons/km^2. Nagpur MunicipalCorporation (NMC) has an area of 225.08 square km. The population density of Nagpur city area under NMCwas 11,056 persons/km^2 in 2011. An oxford economics report states, "Nagpur is projected to be the fifth-fastest-growing city in the world from 2019-2035

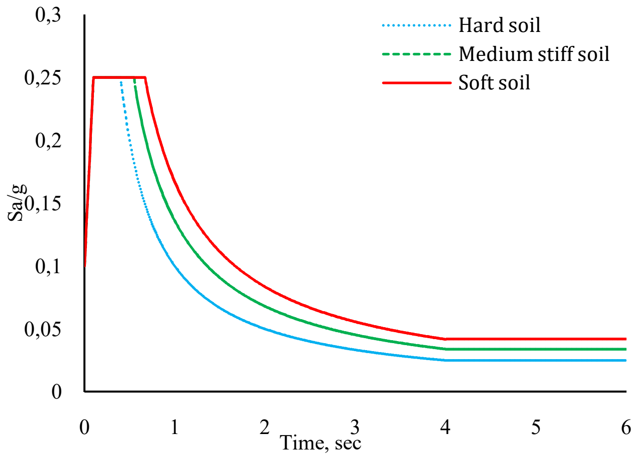

Fig. 5 Acceleration Coefficient (Sa/g) Corresponding to 5% Damping.

with an average growth of 8.41%." To cater to these needs and public expectations, infrastructural development is on the rise like never before.

Table-1 shows the Population growth trend for the last four decades. Using the incremental increase method the projected population for the year 2021 is forecasted.

Ward number 35, 36, 52, 53, 55, 56, 66 and 67 which are adjacent to each other and situated around the central part of the city has the highest population density. Settlements in these areas are the oldest and highly concentrated having the narrow roads. Olden houses and chawl like settlements can be commonly observed in these areas whereas commercial and market activities along roadside. Table-2 provides the ward classificationbased on the population density and Fig. 4 map their distribution throughout the city.

Sparsely populated areas are located along theexterior boundaries of the city as can be seen from Fig. 4 i.e. ward number 1, 2, 4, 13, 14, 28, 30, 43, 44, 46, 48, 49, 86, 87, 97, 114, 115, 116, and 121. These are the grey areas in the city where most of the development activities escalated recently, particularly in the southern part of the city i.e. ward number 114, 115, 116, and 121 profited by presence of an airport in their vicinity are witnessing tremendous real estate development and are expected to attract lots of projects and people, unlike the ward number 1, 2, 4, 13, and 14 i.e. northern part of the city, development is confined tonew housing settlements.

Majority of the western part of the city i.e. ward number 44, 46, 48, and 49 was developed during the British province homemany of the government institutes and organizations spreading over a large land area contributing to relativelymeagerpopulation density.

3. Seismic Hazard Definition for Nagpur

Evaluation of possible hazards is the first step in risk assessment. There are two possible ways either to follow a deterministic approach i.e. Deterministic Seismic Hazard Analysis (DSHA) or to use probabilistic framework i.e. Probabilistic Seismic Hazard Assessment (PSHA).Halder et al.[13] presented a comparison of risk assessment for an intensity-based approach versus response spectrum derived seismic hazard. Damage and loss estimates were found to be highly sensitive to the seismic hazard considered.

DSHA involves consideration of all the possible seismic events, defined by location and magnitude, capable of significantly affecting the site of interest. The resulting ground motions at the site, from which the controlling event is determined using the region-specific attenuation relationship. It is also possible to have more than one governing event which needs to be considered in the design and assessment of seismic hazard at a site.Using the IS-1893 2016 [1] formulation and relevant parameters, the response spectra for Nagpur city shown in Fig. 5 is developed.

Whereas in PSHA all the possible earthquakes capable of affecting a site, and frequency of occurrence of earthquakes of different magnitude are known through a recurrence relationship Kramer [14].Several attempts havebeen made by the researchers in order to develop the Probabilistic Seismic Hazard map of India and on a micro-level to develop the map for a specific city or region.NDMA [2] consist of a countrywide detailed studyfor the development of PSHA risk map, following which the PSHA map has been reproduced around the Nagpur city, see Fig. 6 and 7.

Using the PGA values for short and at 1 second period, acceleration obtained from Fig. 6 and 7, response spectra based on probabilistic seismic hazard is developed following the ASCE 7-10 [15] procedure. In the absence of soil site classification for the Nagpur city, spectra for all three soil site conditions are developed in Fig. 8.

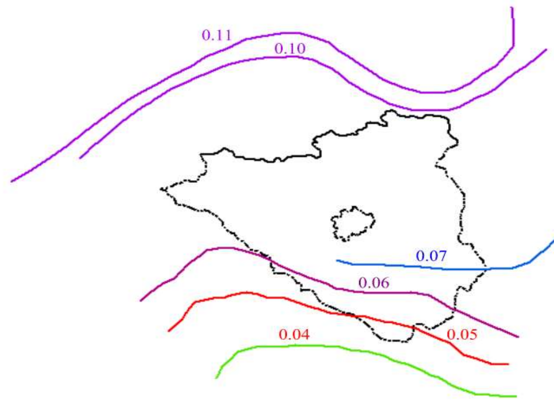

Fig. 6 Short Period Spectral Acceleration at T = 0.2 second with Return Period of 2500 years on A-type Sites (5% damping) [2]

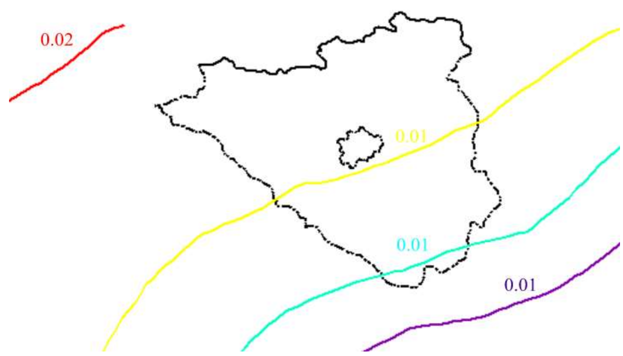

Fig. 7 Long Period Spectral Acceleration at T = 1 second with Return Period of 2500 years on A-type Sites (5% damping) [2]

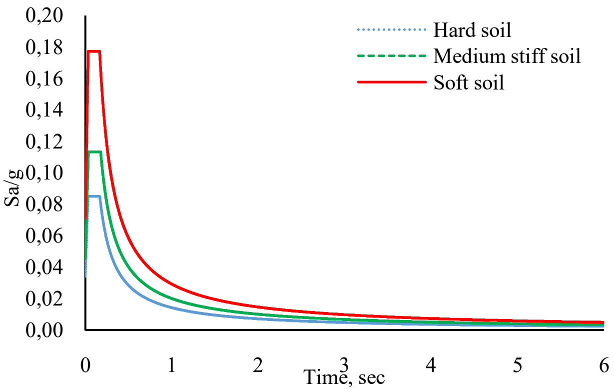

Fig. 8 Response Spectra for Nagpur City Based on Probabilistic Approach

4. Socioeconomic Cluster and Settlement Pattern

Nagpur is an old city and as any of the Indian cities, the city has a complex heterogeneous pattern. The number of wards in a city is decided and marked based on the population of the city. The number of wards and their delineation changes often as the city expands and the population increases,the ward delineation remains independent of the socioeconomic stature and built facilities. As evident there exist a lot of diversity within the same ward boundaries in terms of living standards, education, culture, etc.

Kotharkar et al. [16] selected sixty clusters within the Nagpur's municipal limits and categorized them under following nine typologies i.e. Urban villages (UV), Squatter settlements (SQ), Old areas (OLD), Employers' colonies (EC), Fringe areas (FR), Middle-income group (MIG), Lower income group (LIG), Higher income group (HIG), Gated Communities (GC).

Slum Clusters: Slum as quoted by Cist and Halbert "Area of poor and dilapidated houses and poor people". These definitions do not fit well today in most of the Indian cities' context. Typical slums are witnessing a shift in housing patterns. From field surveys, these clusters were found to have almost 37 percent of single-storey pucca houses i.e. RC slab with masonry wall yet dominated by 59 percent temporary houses i.e. house with a temporaryroof. As can be inferred from the representative pictures of slum clusters, see Fig. 9, a variety of low-cost roofing materials, clay tiles, and corrugated galvanized iron sheets are commonly used with un-plastered/ un-painted brick masonry walls with mud or burnt clay bricks flooring, without any provision of earthquake-resistant construction practices. Most of the population reliesupon uncertain means of livelihood, such as, construction laborers, rickshaw pullers, daily wagers and low paid unorganized industry workers, etc. These are highly populated settlements extending in relatively small areas, giving rise to a higher population density.

Low Income Housing Clusters: These are the settlements occupied by low paid government and private sector workers, generally having a regular source of income. The Majority of dwellings are single and double storied, together contributing around 80% of constructed houses followed by the 13 percent temporary dwellings. Masonry construction practice was commonly observed, built by local mason without use of any heavy machinery. Average quality of materials are used in walls and roofs. Population density in these clusters is very high. Dwelling units are generally built continuously without any gap. Fig. 10 provide an overview of the clusters from the pictures taken from various typical clusters sharing same characteristics.

Earth-explorer imagery for Typical Slum Cluster

Fig. 9 Representative Images from Typical Slum Clusters

Earth-explorer imagery for Typical Low Income Cluster

Fig. 10 Representative Images from Typical Low-Income Clusters

Earth-explorer Imagery forTypical Lower Middle-Income Clusters

Fig. 11 Representative Images from Typical Lower Middle-Income Clusters

Middle-Income Clusters: Inhabited by the small businessmen, shopkeepers, government servants, middle-level workers in commercial and industrial establishments. Nowadays, these localities are usually better planned with wider roads and approaches situated along the outer circle. However, old localities are haphazardly settled and crowded with very narrow lanes as exist in the central part of the city. Houses havesimple to highly complex floor plans and elevations. Relatively good quality burnt clay bricks in cement mortar are commonly used as walling material plastered and painted on both sides. Reinforced concrete is common in columns, beam, and floor/roof slabs. Owning to the differences between old andnewly settled clusters, two sub-clusters as lower middle-income class Fig. 11 and upper middle-income class Fig. 12 respectively were studied separately.

High-Income Clusters: Occupied by the economically affluent class such as big businessmen, industry owners, upper-level executives and government officials, ministers,and established professionals. Houses in these clusters are well planning in terms of space utilization and aesthetics, have lavish interior and exterior architectural features see Fig. 13. Buildings have complex floor plans and elevations. Houses are built keeping some setback distances, leaving indoor green spaces. Having good open roads on two to three sides of housing units and plenty of free open space, population density is generally low in these clusters.

Earth-explorer Imagery for Typical Upper Middle-Income Clusters

Fig. 12 Representative Images from Typical UpperMiddle-Income Clusters

Earth-explorer Imagery for Typical Upper Class Clusters

Fig. 13 Representative Images from Typical Upper Income Clusters

Group Housing Settlements: Areas with group housing settlements usually consists of three to four stories buildings built in olden times and six or more storied buildings built in recent time see Fig. 14, these clusters were found to be spread over considerable extent within the city, necessitating to be defined in a separate class for a more refined risk study.

Earth-explorer Imagery for Typical Group Housing Clusters

Fig. 14 Representative Images from Typical Group Housing Clusters

Out of many parameters influencing and contributing to socioeconomic conditions, one useful way is to examinethe living conditions which are closely related to the type of houses and construction practices of a region. This can be easily accomplished from a distance by study and analysis of satellite images. For this purpose, using the satellite imagery the Nagpur city area was studied and analyzed in detail for the identification of various clusters within the city boundary, based on prevailing construction. Fig. 15 shows the extent of various socioeconomic clusters in the Nagpur city.

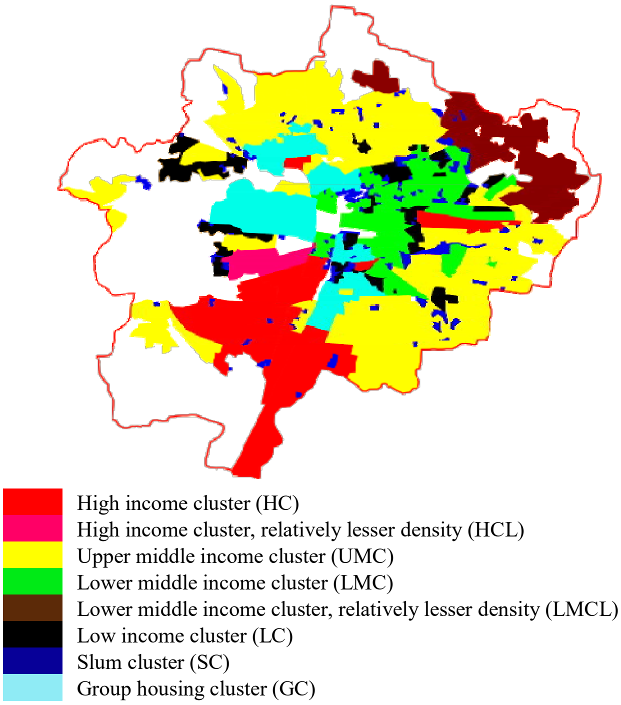

Fig. 15 Identified Socioeconomic Clusters in Nagpur City

6. Buildings Damage Estimation

Prasad et al. [17] presented a seismic risk estimation technique based on socio-economic status representing reasonably uniform seismic risk. Building inventory data is collected adopting the high-resolution satellite imagery supported with physical ground surveys. The dominating six types of socio-economic clusters present in the Nagpur city were identified,from thorough study of building characteristics in theidentified clusters, 14 representative buildings were chosen as MBTs. A detailed description of selected MBTs is given in Table 3.

Table- 3 Model Building Types (MBTs) Presents in Different Socioeconomic Clusters of Nagpur City

S.no.	Label	Description	Roof	Storey
		Temporary houses		
1	AM1	Rammed mud/sun-dried bricks/rubble stone in mud mortar	R2	1-2
		Masonry structures		
2	MC1	Burnt clay brick / rectangular stone/ concrete blocks in cement mortar	R2	1-2
3	MC2		R3	1-2
4	MC3L		R6	1-2
5	MC3M		R6	3+
6	ME1L	Burnt clay brick/concrete blocks in cement mortar provided with seismic bands and vertical r/f at corners and jambs	R6	1-2
7	ME1M		R6	3+
		RC Framed structures		
8	RC1L	RC frame with URM infills without any consideration for earthquake forces	R6	1-3
9	RC1M		R6	4-7
10	RC2L	RC frame with URM infills earthquake considered in design but not ductile detailed	R6	1-3
11	RC2M		R6	4-7
12	RC3L	RC frame with URM infills earthquake forces considered in the design and ductile detailed.	R6	1-3
13	RC3M		R6	4-7
14	RC3H		R6	8+

Table – 4 Damage Probability Matrix for Nagpur City MBTs [17]

MBT	MSK/ EMS Intensity	Damage Probability (%)									
		Lower Bound Damage Scenario					Upper Bound Damage Scenario				
		Gr1	Gr2	Gr3	Gr4	Gr5	Gr1	Gr2	Gr3	Gr4	Gr5
AM1	VI	15	10	0	0	0	55	20	0	0	0
	VII	18	17	55	10	0	0	0	80	20	0
	VIII	0	18	17	55	10	0	0	0	80	20
	IX	0	0	43	42	15	0	0	23	22	55
	X	0	0	0	45	55	0	0	0	0	100
	XI	0	0	0	0	100	0	0	0	0	100
	XII	0	0	0	0	100	0	0	0	0	100
MC1,	VI	15	10	0	0	0	55	20	0	0	0

MBT	MSK/ EMS Intensity	Damage Probability (%)									
		Lower Bound Damage Scenario					Upper Bound Damage Scenario				
		Gr1	Gr2	Gr3	Gr4	Gr5	Gr1	Gr2	Gr3	Gr4	Gr5
MC2	VII	75	15	10	0	0	25	55	20	0	0
	VIII	0	35	55	10	0	0	0	80	20	0
	IX	0	0	75	15	10	0	0	25	55	20
	X	0	0	43	42	15	0	0	23	22	55
	XI	0	0	23	22	55	0	0	0	0	100
	XII	0	0	0	0	100	0	0	0	0	100
MC3L, MC3M, RC1L, RC1M	VI	10	0	0	0	0	20	0	0	0	0
	VII	52	10	0	0	0	67	20	0	0	0
	VIII	35	55	10	0	0	0	80	20	0	0
	IX	0	75	15	10	0	0	25	55	20	0
	X	0	0	75	15	10	0	0	25	55	20
	XI	0	0	30	55	15	0	0	0	45	55
	XII	0	0	0	0	100	0	0	0	0	100
RC2L, RC2M	VII	10	0	0	0	0	20	0	0	0	0
	VIII	0	10	0	0	0	0	20	0	0	0
	IX	75	15	10	0	0	25	55	20	0	0
	X	0	75	15	10	0	0	25	55	20	0
	XI	0	0	75	15	10	0	0	25	55	20
	XII	0	0	0	0	55	0	0	0	0	100
RC3L, RC3M, RC3H	IX	45	10	0	0	0	40	20	0	0	0
	X	75	15	10	0	0	25	55	20	0	0
	XI	0	75	15	10	0	0	25	55	20	0
	XII	0	0	0	0	55	0	0	0	0	100

Based on the DPMs values tabulated in Table-4 and the percentage distribution of MBTs in different socioeconomic clusters, the damage ratios for all the possible intensities i.e. VI to XII were calculated. The damage ratio for all the six clusters are show in Fig.16 to 21.

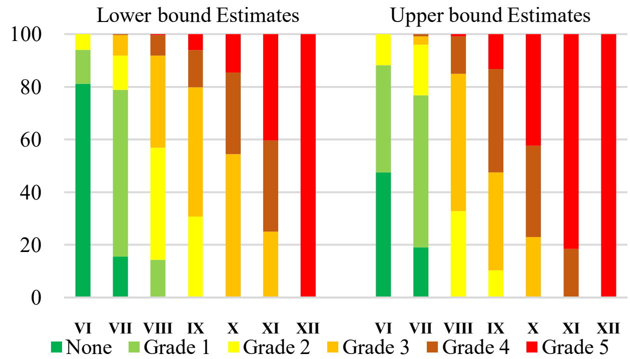

Fig. 16 Damage Ratios for Typical SC

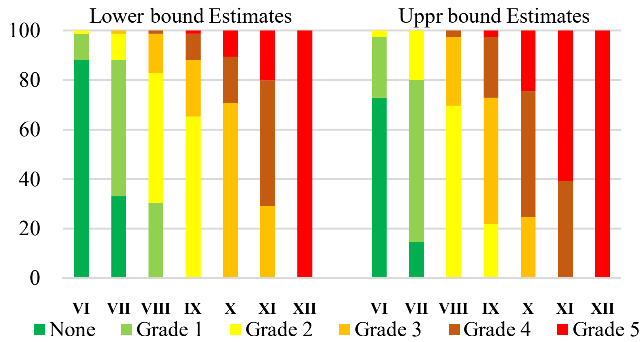

Fig. 17 Damage Ratios for Typical LC

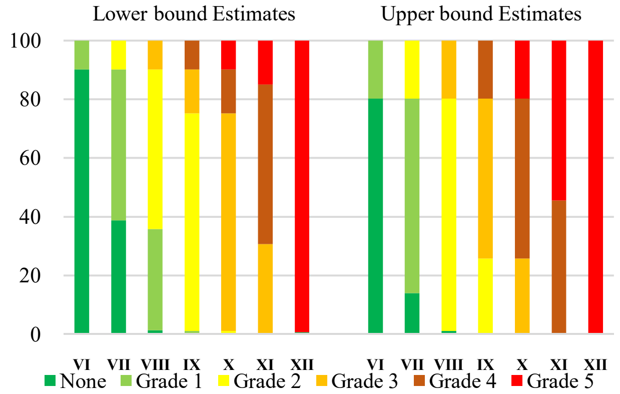

Fig. 18 Damage Ratios for Typical LMC

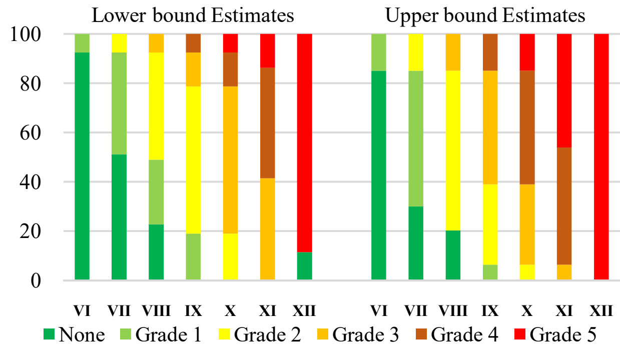

Fig. 19 Damage Ratios for Typical UMC

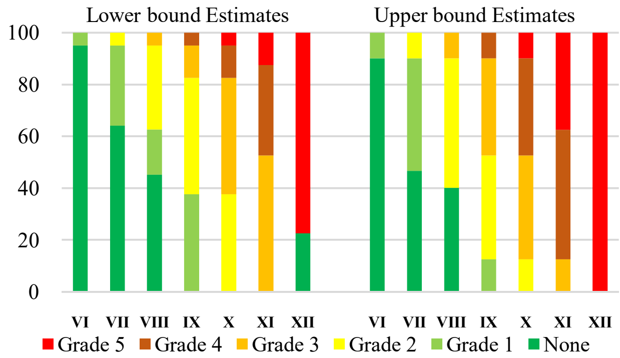

Fig. 20 Damage Ratios for Typical HC

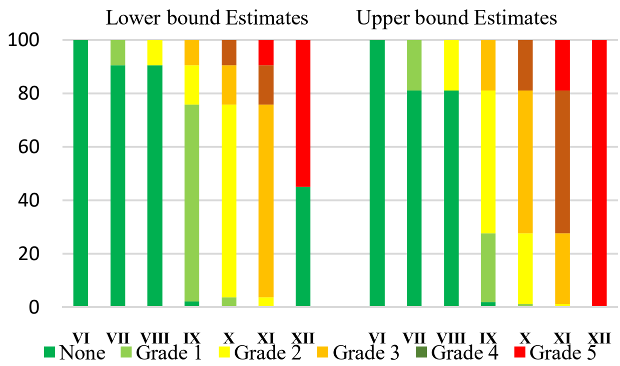

Fig. 21 Damage Ratios for Typical GC

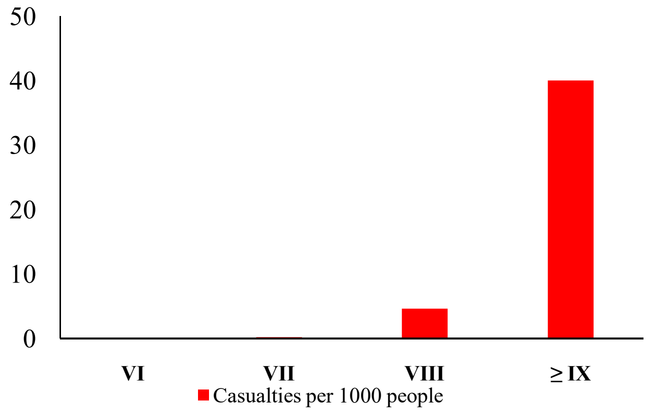

Fig. 22 Casualties per 1000 People for Different Seismic Intensities

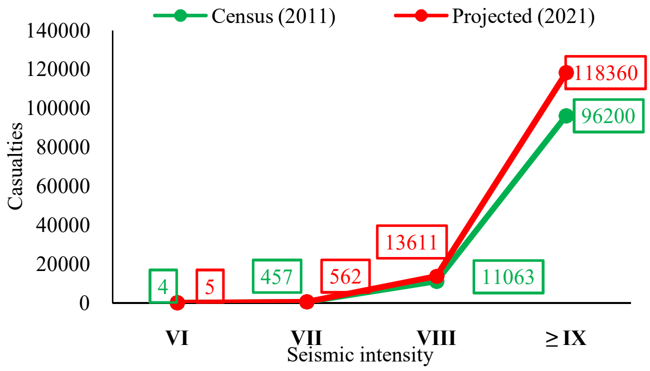

Fig. 23 Life-loss Based on Census 2011 vs. Projected Population Data for 2021

Table - 5 Fatality Rate and Macroseismic Intensity Relationship

Intensity	VI	VII	VIII	≥IX
Fatality rate	1.8 x10^{-6}	1.9 x10^{-4}	4.6 x10^{-3}	4.0 x10^{-2}

7. Life Loss Estimation

Jaiswal and Wald [18] considered some of the deadliest occurred earthquakes all around the globe to establish country specific empirical fatality model based on the resulting fatalities from these extreme events. The term fatality rate is the ratio of total fatalities to the total population exposed at a particular seismic intensity. Using the fatalities rates given for India in Table-5, life loss were calculated subjecting the city to different macroseismic intensities. Fig. 22 shows the number of casualties per 1000 people for different intensities. And Fig. 23 shows the total number of casualties for Nagpur city under different seismic scenarios.

8. Conclusions and Recommendations

The seismic risk for Nagpur city is assessed using ArcGIS i.e. GIS platform. Housing settlements are not evenly distributed across the city and even within the same ward, socioeconomic clustering is done for a precise assessment, satellite imagery comes handy in easy identification of different clusters. GIS proved an essential tool, facilitating management, analysis, and illustration on a common platform. The resolution of satellite imagery available for India does not help in the identification of building’s features necessitating physical ground surveys or aerial photography using a drone assisted high definition camera, to support the data.

The study shows how irrespective of the IS1893-2016 [1] zonation, all the possible extreme earthquake hazards shall be included in the seismic risk evolution of any region.For anearthquake exactly fitting in IS1893-2016 [1]criteria i.e. intensity VI, the slum clusters and lower-income clusters may witness minor damage except this the city remains intact. With increased seismic intensity the same regions were found to be most vulnerable and susceptible to life threatening damage. As evident from the improved/better construction practices in the regions of higher socioeconomic status, damage to the buildings decreases as the socioeconomic status shift towards higher standards.

An earthquake of intensity VI or less can be easily passed away with negligible life loss. Seismic hazards turn into a disastrous event for higher intensities, for an intensity IX or more almost 100,000 people’s life can be on stake, most of which is concentrated in the central and north-east region of the city.The rising population exacerbate the situation, resulting in an even bigger number. The Eastern part of the city will be least affected under any given seismic hazard.

More detailed building footprint mapping and refined data such as soil site classification, essential facilities, transportation, and other lifelines will help in obtaining a more precise damage map. A similar study employing the analytical approach for the calculation of DPMs can also be performed.

Disclosures

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