Innovative approach to assess and reduce vulnerability of Nepal's housing stock

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Abstract

With large number of vulnerable houses, Nepal faces a huge extant risk from future earthquakes. While compliance to the national building codes is increasing for the new buildings, existing non-code compliant buildings pose a huge threat to the occupants. It has been difficult to promote retrofitting of residential buildings in major urban and urbanizing cities across Nepal. The reasons for this are multi-fold: i) massive volume of existing buildings; ii) requirement of proper physical structural assessment by experienced engineers to determine the safety of the structure or necessity of structural strengthening - retrofitting or demolishing; and iii) absence of practical guidelines and skilled manpower for implementing retrofitting solutions.

After the 2015 Gorkha earthquakes in Nepal, a large-scale building survey was conducted using digital hand-held tablets for more than 1 million buildings in the region hit by the quakes. The massive dataset contains geo-coded information of building characteristics such as typology, damage to structural elements and overall damage level. This data was primarily used to categorise damage to houses and identify the affected house-owners' eligibility for the Government's housing reconstruction grant.

With support from UNDP Asia Pacific Regional iData Initiative, UNDP Nepal utilized this massive dataset from the earthquake affected region, and prototyped a Vulnerability Scoring model that can be used to prioritise potentially vulnerable buildings for interventions to reduce their vulnerability. The outcome of the prototyping suggests that, with a good level of confidence, this model can be applied to different municipalities to assess vulnerability of existing housing stock to promote the interventions for risk reduction and mitigation[1] focused on over 1.4 million mud-bonded houses which are the most vulnerable or the 1 million cement bonded houses. The study offers an innovative approach to addressing Nepal's challenge through prioritizing of buildings for retrofitting.

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Background

The 2015 earthquakes in Nepal resulted in a large-scale casualty of more than 9,000 and collapse of over 700,000 private houses in 31 districts. Much of the deaths and loss of properties derived from the structural failure of the buildings. Lack of building code compliance both in urban and rural area was a contributing factor.

Recent scientific researches by the Durham University[2] and the study by Japan International Cooperation Agency[3] suggested that Nepal has to contend with the risk of another large-scale earthquake in the near future. Millions of buildings across Nepal face vulnerability to future seismic events. Now, the need of the hour is to prioritize interventions to reduce this vulnerability. We

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[1] Basic information of building typology is required

[2] *Measuring Earthquake Disaster Risk in Nepal to aid Humanitarian Contingency Planning, Durham University, March 2017*

[3] *The Project for Assessment of Earthquake Disaster Risk for the Kathmandu Valley in Nepal - Draft Final Report, JICA, February 2018*

cannot fail to apply the lessons learned from the recent earthquakes.

After the Udaypur earthquake (eastern Nepal) in 1988, which resulted in 721 casualties, UNDP supported the Government of Nepal to prepare the National Building Codes. The building codes were prepared in 1994. However, only after the issuance of the Building Act in 2006, enforcement of the codes was made possible in municipalities. Meanwhile, since majority of the municipalities are still rural (landscape, condition of infrastructure and economic activities), a functional building permit system, which is the only instrument that ensures structural safety through enforcement of the building code, is yet to be established.

Simple risk mitigation approach through strict implementation of the building codes will only avoid creation of new risks by ensuring new buildings are safe. It will not address risk posed by huge stock of existing unsafe buildings such as the 1.4 million houses built of stone/bricks with mud mortar or even the 1 million houses built with cement mortar which lack seismic safety features.

So far, in many of the urban and urbanizing municipalities, their efforts have been focused on enforcement of the building codes for newly constructed buildings (though there are more to be done), and many of the rural municipalities have not implemented building codes. The Government's post-2015 earthquake housing reconstruction programme will also increase the number of houses that comply with building codes in the earthquake-affected areas.

However, there is little focus on the existing vulnerable structures. The matter of fact is that, with countless number of houses already built without strong seismic measurement, it would be costly and almost impossible to try to structurally assess them all to undertake retrofitting. Yet, the risk posed by this unsafe building stock needs to be addressed.

Objective of the study

The key question is how better the issue of retrofitting can be prioritised, particularly by understanding the risks associated with many of the existing buildings.

In the aftermath of the 2015 earthquakes, the Government of Nepal's National Reconstruction Authority conducted a large-scale structural survey for more than 1 million buildings to assess the conditions of houses of the affected population and determine the eligibility and coverage for the government subsidy program for housing reconstruction. Nepal is probably the first country to conduct such thorough housing survey on this scale after a disaster. The data includes characteristics and patterns of damages based on the building structures and geo-location. This dataset offers a large volume (1million+ data points) and granularity (across 31 earthquake-affected districts).

Our assumption was that such dataset could help us understand the characteristics and trend of damages to various categories of buildings, as well as interaction between damage and external conditions such as slope, and soil conditions. If the analysis is viable, it could be extrapolated to the other locations beyond the earthquake-affected area.

The objective of the study is to prototype a model of structural damages from the earthquake-affected region and test the algorithm in different municipalities to understand the potential vulnerability of the buildings in view of the future earthquakes. The result of the prototyping potentially helps informing the municipalities about the risks that they face, and enable them to prioritize the possible interventions of risk mitigation and reduction.

The data analytics were undertaken in partnership with the Tribhuvan University, Institute of Engineering through a team of structure/earthquake engineer, statistician, GIS expert, soil engineer, and data mining expert. This initiative is part of the UNDP Asia Pacific Regional iData Programme, and this was financially supported by the Government of Denmark.

Data

Three types of data set were used to undertake the analytics.

a. Building Data from 31 earthquake affected districts (Building.sav): The building data was collected after the 2015 earthquakes as part of the structural damage and socio-economic survey to understand the extent of damages and characteristics of 1,052,948 buildings. The data was utilized to determine the eligibility of government housing grant for reconstruction. Socio-economic aspect of the survey data was omitted from the dataset and only structural data was used in the analysis. Each data point is geo-referenced (*WGS 84 Datum and projection system*).

b. Soil Data: Global and National Soil and Terrain Digital Database (SOTER) in the absence of finer resolution data was utilised. Soil composition and profile attributes were generated to aid geo-technical parameter analysis.

c. Topographic data: Topographic data was obtained through Department of Survey was utilized. Road, river, contour and spot height information was extracted to generate Digital Terrain Model (DTM) for the 31 earthquake-affected districts to layer with the other dataset for analysis.

Methodology and Process

Data preparation

The building survey data was originally collected in the form of WGS84 Datum, and this was re-projected in Modified UTM central Meridian 84 projection system and Everest Datum to align with the topographic data projection system. Similarly, soil data locational aspect was re-projected in line with the topographic data.

Data cleaning

Some of the building structural survey data which was missing GPS location was eliminated from the data base. Further, some more data discrepancies observed in database had to be taken care. In data analysis, Superstructure typology and Damage Categories were some of the most critical information. The database showed that almost all the buildings had more than one types of superstructure. For example, a building of which superstructure was categorized as adobe/mud construction also had additional description of mud-mortar and others. Data entry system was made in a way that the enumerators could enter more than one superstructure types while this section is supposed to have only one type. Supposedly, the building structure was hybrid (contains more than one typology) and the information were entered accordingly. However, multiple description for the building superstructure complicates the data analysis. Hence, those data points with multiple superstructure typologies were cleaned to have only one typology which is the weakest of all the selected.

Similarly, on the building damages, different categories of damages (foundation, corner separation, diagonal cracking, in-plane-failure of walls carrying floor/roof, out-of-plane failure of walls not carrying floor/roof, gable wall collapse, column failure, beam failure, infill/partition wall damage, staircase, parapets, and cladding/glazing) were registered at different degree (Sever-Extreme; Moderate-heavy; and Insignificant or Low) for each building. To reduce complexity of data analysis, only overall damage grade was utilized for each structure, and segregation of damage categories of different parts of building was not taken into consideration.

Development of model, and determination of vulnerability-level of buildings

The key to the model development was to establish Vulnerability Scoring System that is applicable and tested in the real earthquake scenario. The study applied the data analysis procedure developed by Arya (2011, *"Rapid Structural and non-structural Assessment of School and Hospital Building in SAARC countries"*), and the scoring methodologies of Federal Emergency Management Agency (FEMA) 154: *Rapid Visual Screening of Buildings for Potential Seismic Hazards.* In doing so, building typologies that are unique to Nepal, topological and soil parameter were taken into account.

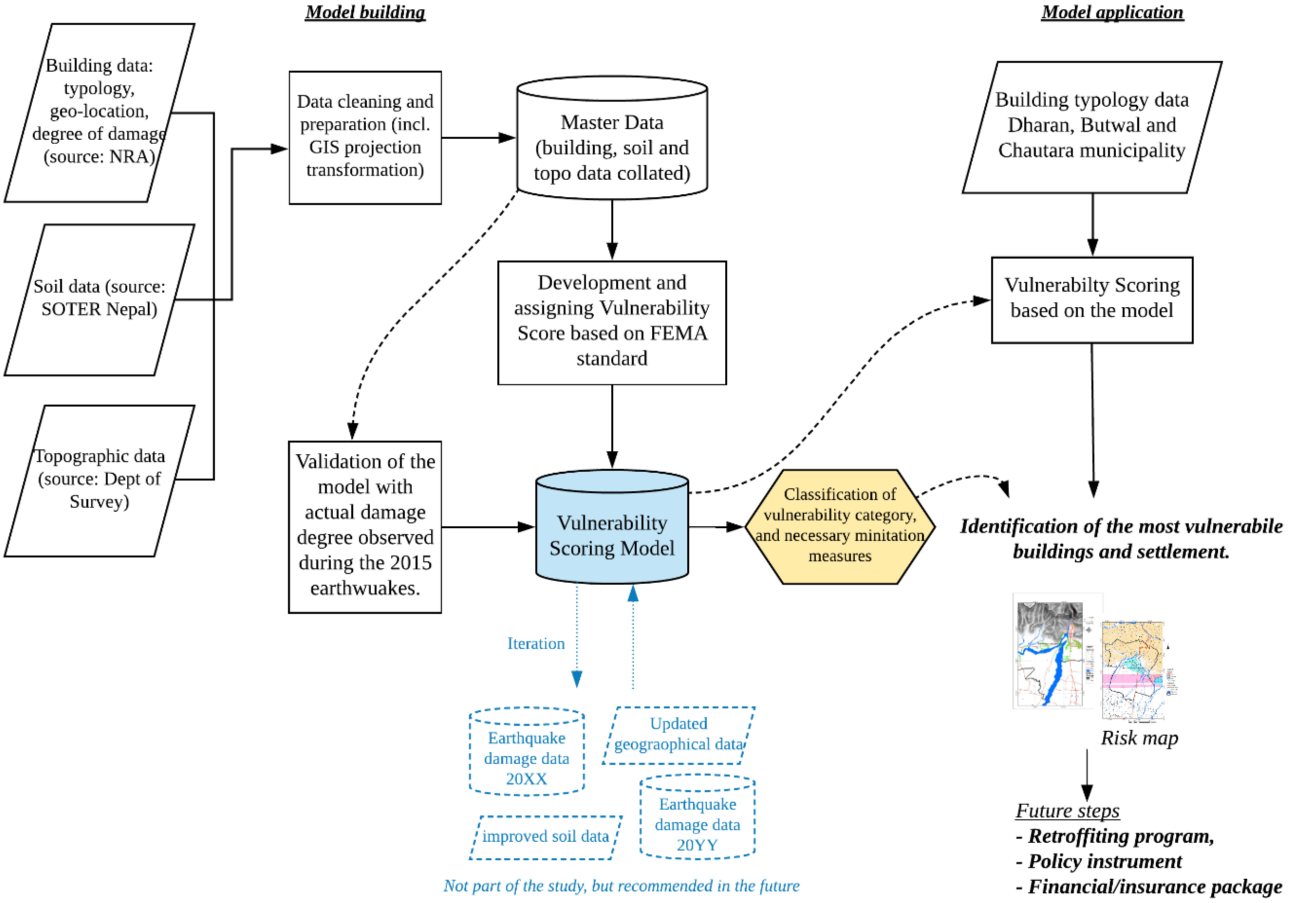
Building typologies used in the analysis include the following nine categories:

1. Adobe/mud construction
2. Random Rubble masonry in mud mortar
3. Dry-stone masonry
4. Stone masonry in cement mortar
5. Brick masonry in mud mortar
6. Brik/Block masonry in cement mortar
7. Timber/Bamboo buildings
8. RC non-engineered
9. RC engineered building based on materials used, vertical and lateral load carrying systems

For every building typology, basic scores were assigned considering moderate seismic hazard intensity (intensity considered for Gorkha Earthquake), building types, lateral load resisting system and observed building performance during the earthquakes.

Score Modifiers determines overall vulnerability-level of each building considering other parameters such as soil type[4], building height, ground slope, distance from river, age of building and building foundation type. Table 1 summarizes the vulnerability score assignment.

Figure 1: Study Work Flow diagram



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[4] FEMA 154,6 Rapid Visual Screening (RVS) procedure categories of soil types (A: Hard Rock, B Average Rock, C Soft Rock/Dense Soil, D. Stiff Soil, and E. Soft Soil) were adopted. The soil type C, D and E are considered as having negative effect on seismic safety, hence brings negative score modifiers.

Table 1: Vulnerability Scoring System

		Basic Building Type								
Parameters	Construction Type	Adobe/Mud Construction	Random rubble Stone Masonry in Mud Mortar	Dry Stone (Rubble)	Stone-Cement Mortar	Mud Mortar - Brick	Cement Mortar-Brick	Timber/ Bamboo	RC (Non-engineered)	RC (Engineered)
	Basic score	**1.6**	**2**	**2.1**	**2.5**	**2.3**	**3.2**	**4**	**3.4**	**3.4**
Height of Building	<= 3 floor	0	0	0	0	0	0	0	0	0
	> 3 floor	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Ver. Irregularities										
Hor. irregularities										
Soil Type	Soil type A (not mention in Soter)	0	0	0	0	0	0	0	0	0
	Soil type C	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
	Soil type D	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
	Soil type E	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
slope of ground	< 5 degree	0	0	0	0	0	0	0	0	0
	5 - 15 degree	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
	15- 30 degree	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
	30 and above	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Distance from River	< 100 M	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
	>100 M	0	0	0	0	0	0	0	0	0
Age	< 20 years	0	0	0	0	0	0	0	0	0
	> 20 years	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Foundation (MM-mud mortar; CM-cement mortar)	MM- Stone/Brick	-0.1	-0.1	-0.1	NA	-0.1	NA	-0.1	NA	NA
	CM - Stone/Brick	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	NA	NA
	RC	0	0	0	0	0	0	0	0	0
	Bamboo/Timber	NA	NA	NA	NA	NA	NA	-0.2	NA	NA
Plan irregularity	regular	0	0	0	0	0	0	0	0	0
	irregular	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1

Validation of the model

The next step was to check to what extent this scoring can indicate the real vulnerability of the buildings considering the actual scenario of how building behaved during the 2015 earthquakes. The building structural survey data gathered after the earthquake comes with five grades of overall damage.

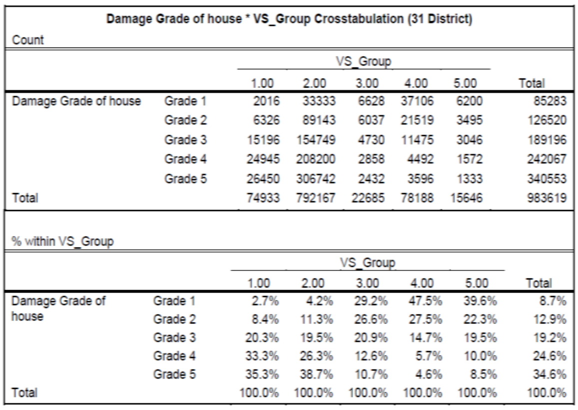
Grade 1*: Negligible to slight damage. No structural damage. Slight non-structural damage.*
Grade 2*: Moderate damage. Slight structural damage. Moderate non-structural damage.*
Grade 3*: Substantial to heavy damage. Moderate structural damage. Heavy non-structural damage.*
Grade 4*: Very heavy damage. Heavy structural damage. Very heavy non-structural damage.*
Grade 5*: Destruction. Very heavy structural damage.*

Utilizing SPSS, strength of relationship between the assigned Vulnerability Scores (based on the building typologies and other geological and topographical characteristics) and the actual damage grade from the 2015 earthquakes was examined. When cross-tabulating Vulnerability Scores (VS) and Damage Grade (DG) were categorized into five groups.

VS-1: score 0.0 – 0.8
VS-2: score 0.8 – 1.6
VS-3: score 1.6 – 2.4
VS-4: score 2.4 - 3.2
VS-5: score 3.2 – 4.0

Table 2 shows the cross tabulation of Vulnerability Scores and Damage Scores given for the entire 31 earthquake-affected districts.

The following bar-chart (Figure 2) exhibits the correspondence between higher Vulnerability Score category (eg. VS-5) and the proportion of the buildings given better Damage Grade (eg. D Grade 1), as well as between lower Vulnerability Score category (eg. VS-1) and severer Damage Grade (eg. D Grade 5).



Damage Grade of house * VS_Group Crosstabulation (31 District)

Count

		VS_Group					
		1.00	2.00	3.00	4.00	5.00	Total
Damage Grade of house	Grade 1	2016	33333	6628	37106	6200	85283
	Grade 2	6326	89143	6037	21519	3495	126520
	Grade 3	15196	154749	4730	11475	3046	189196
	Grade 4	24945	208200	2858	4492	1572	242067
	Grade 5	26450	306742	2432	3596	1333	340553
Total		74933	792167	22685	78188	15646	983619

% within VS_Group

		VS_Group					
		1.00	2.00	3.00	4.00	5.00	Total
Damage Grade of house	Grade 1	2.7%	4.2%	29.2%	47.5%	39.6%	8.7%
	Grade 2	8.4%	11.3%	26.6%	27.5%	22.3%	12.9%
	Grade 3	20.3%	19.5%	20.9%	14.7%	19.5%	19.2%
	Grade 4	33.3%	26.3%	12.6%	5.7%	10.0%	24.6%
	Grade 5	35.3%	38.7%	10.7%	4.6%	8.5%	34.6%
Total		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 2: *Cross tabulation of VS and DG for the 31 earthquake affected districts*

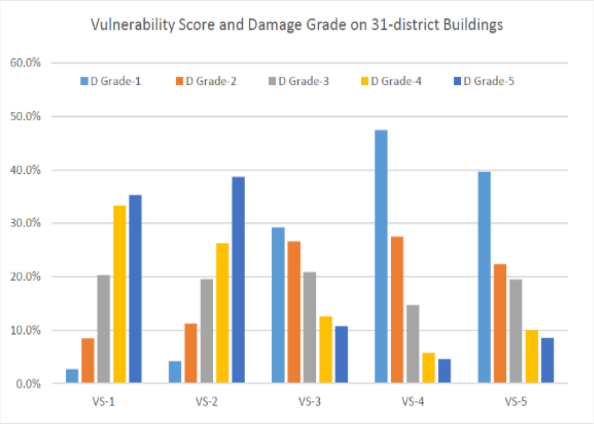
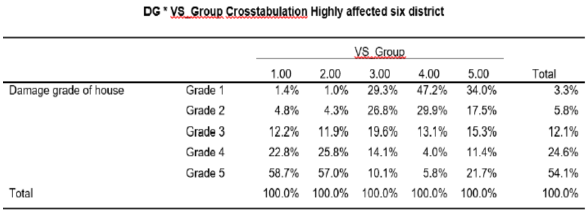


Figure 2: *Bar chart of VS and DG association for all 31 affected districts*

The same analysis was done for cross tabulation was undertaken for the six most severely affected districts. Table 3 and Figure 3 demonstrates the result of the analysis of association between Vulnerability Score and Damage Grade.



DG * VS_Group Crosstabulation Highly affected six district

		VS_Group					
		1.00	2.00	3.00	4.00	5.00	Total
Damage grade of house	Grade 1	1.4%	1.0%	29.3%	47.2%	34.0%	3.3%
	Grade 2	4.8%	4.3%	26.8%	29.9%	17.5%	5.8%
	Grade 3	12.2%	11.9%	19.6%	13.1%	15.3%	12.1%
	Grade 4	22.8%	25.8%	14.1%	4.0%	11.4%	24.6%
	Grade 5	58.7%	57.0%	10.1%	5.8%	21.7%	54.1%
Total		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 3: *Cross tabulation of VS and DG for the 6 most severely affected districts*

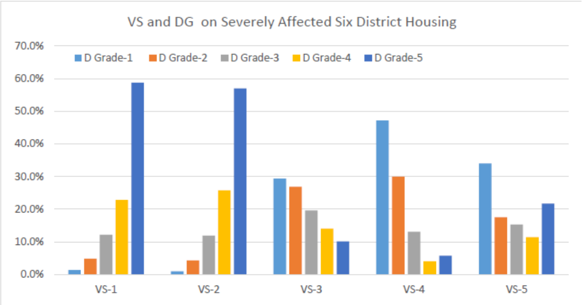


***Figure 3**: Bar chart of VS and DG association for the 6 most severely affected districts*

Figure 3, which is the result of the analysis only for the 6 severely affected districts, shows that majority of the buildings categorized with higher vulnerability (VS-1, VS-2) correspond with the actual Damage Grade that was higher (D Grade 5).

Finally, Chi-square test was conducted for hypothesis testing and to examine the level of association between the two variables i.e. Vulnerability Score and actual Damage Grade, for the data for the 31 affected-Districts and 6 severely affected districts.

Null hypothesis and alternative hypothesis:

$$H_0 = VS\ is\ not\ associated\ with\ DG$$

$$H_1 = VS\ is\ associated\ with\ DG$$

Results

The Chi-square test rejected the null-hypothesis, and (as it is demonstrated in Table 4 and Table 5) there is significant relationship between the two variables; *Vulnerability Score* and *Damage Grade* $[\boldsymbol{P\ value(Asymptotic\ Significance) < 0.05}]$.

It concludes that there is a good level of confidence in the application of the Vulnerability Scoring model.

Table 4: Chi-Square Tests - VS and Dg Association for 31 Districts Building Data

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-square	254683.811(a.)	16	0.000
Likelihood Ratio	193879.241	16	0.000
Linear-by-Linear Association	159303.599	1	0.000
N of Valid Cases	983619		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 1356.56.

Table 5: Chi-Square Tests - VS and Dg Association for 6 severely affected Districts Building Data

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-square	144441.303(a.)	16	0.000
Likelihood Ratio	71000.256	16	0.000
Linear-by-Linear Association	76765.911	1	0.000
N of Valid Cases	402419		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 11.95.

The data analytics also generated the profiles of the building stocks and the trend of damages in relation with rural building typology and other geographical features in different earthquake affected areas.

It emphasized the significant vulnerability of the buildings with stone masonry with mud mortar or drystone masonry without appropriate structural re-enforcement measures.

The buildings with timber and bamboo structure showed relative strength to stone masonry with mud mortar and drystone masonry. Similarly, few stone masonry in cement-mortar collapsed. This could recommend promotion of particular building typologies in rural setting, or even triggers innovative structural retrofitting methodology to protect the most vulnerable existing structure.

Application of the model

The study applied the tested Vulnerability Scoring model in the three municipalities (Dharan, Butwal and Chautara), of which two did not experience the 2015 earthquakes.

Based on the structural engineers' expert knowledge on performance of the buildings at the time of the Gorkha earthquakes, the vulnerability scores were categorized into four levels with suggested mitigation measures.

Vulnerability Score	Suggested action
2.75 <	No intervention required
2.0 - 2.75	Minor repair required
1.5 - 2.0	Major repair (strengthening of structure) required
< 1.5	Demolish the building

In Dharan municipality, Butwal municipality, and Chautara municipality, a sample of at least 500 buildings with different building typologies were analyzed using the same scoring algorithm. The result shows different concentration of vulnerability in each municipality.

For example, in Dharan, 548 buildings (97.3%) of the sampled building had vulnerability score above 2.75 which requires no intervention required. 11 buildings are scored between 2.0 and 2.75 and requires minor repairs. Only 4 buildings fall under 1.5 - 2.0 vulnerability score and need major repair.

	Score category	Number	%
Dharan Municipality	0- 1.5	0	0.0%
	1.5 - 2.0	4	0.7%
	2.0 -2.75	11	2.0%
	above 2.75	548	97.3%
	Total	563	100.0%

Table 6: Dharan municipality vulnerability profile

In Butwal municipality, 388 out of 519 buildings (74.8%) had the score more than 2.75 and requires no intervention. 119 buildings that were identified as vulnerability score 2.0 – 2.75 still require attention for minor repair. 11 buildings were given score 1.5 – 2.0 for major repair, and 1 building was identified as very vulnerable and require demolish.

	Score category	Number	%
Butwal Municipality	0- 1.5	1	0.2%
	1.5 - 2.0	11	2.1%
	2.0 -2.75	119	22.9%
	above 2.75	388	74.8%
	Total	519	100.0%

Table 7: Butuwal municipality vulnerability profile

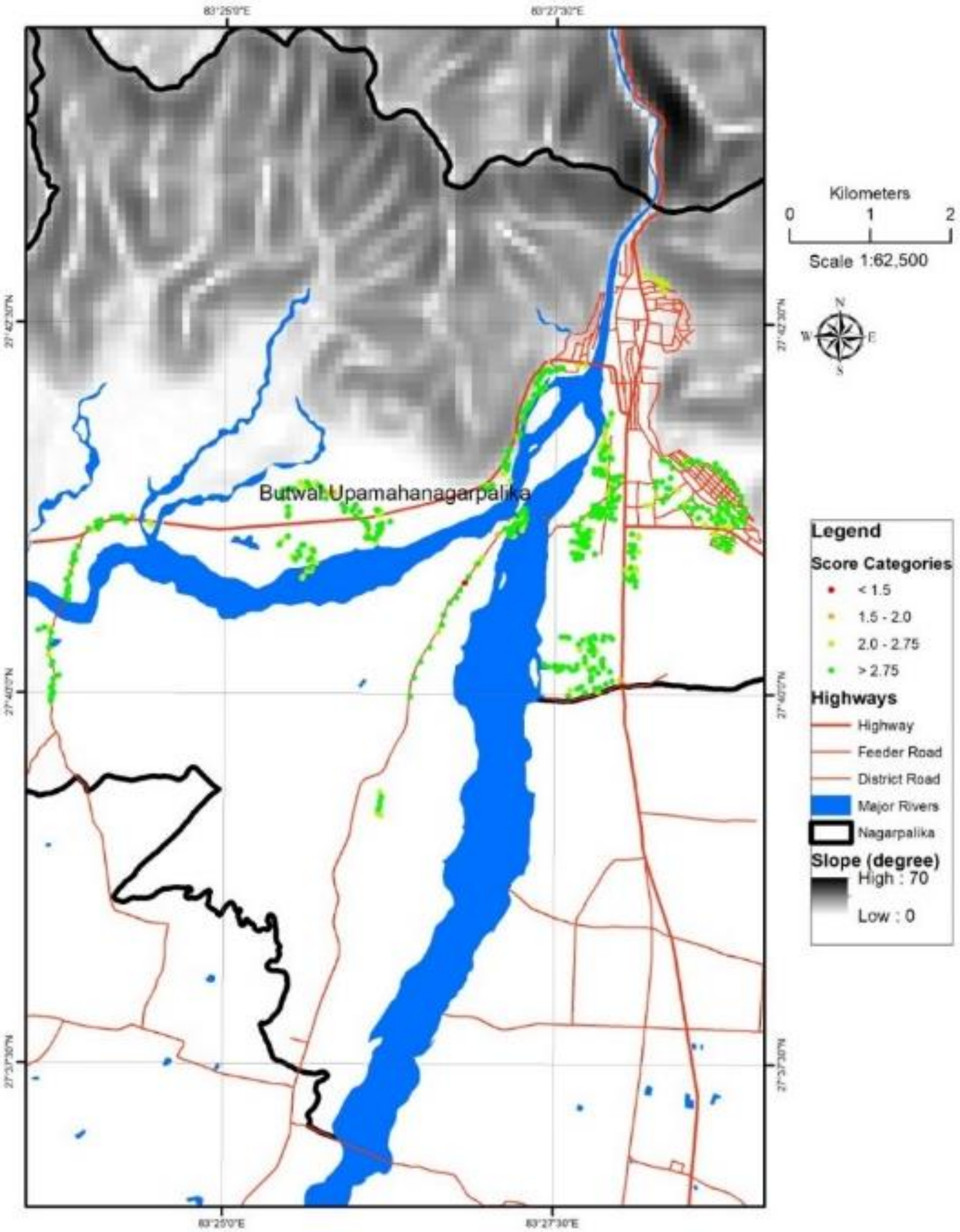
Chautara municipality is the municipality affected by the 2015 earthquakes. 223 out of 500 buildings (44.6%) are given vulnerable score 0-1.5, and recommended to be demolished. 57 buildings are in the category of 1.5 – 2.0 and require major structural strengthening. Minor repair is suggested for 103 buildings, and 117 buildings (23.04%) are considered least vulnerable.

	Score category	Number	%
Chautara municipality	0- 1.5	223	44.6%
	1.5 - 2.0	57	11.4%
	2.0 -2.75	103	20.6%
	above 2.75	117	23.4%
	Total	500	100.0%

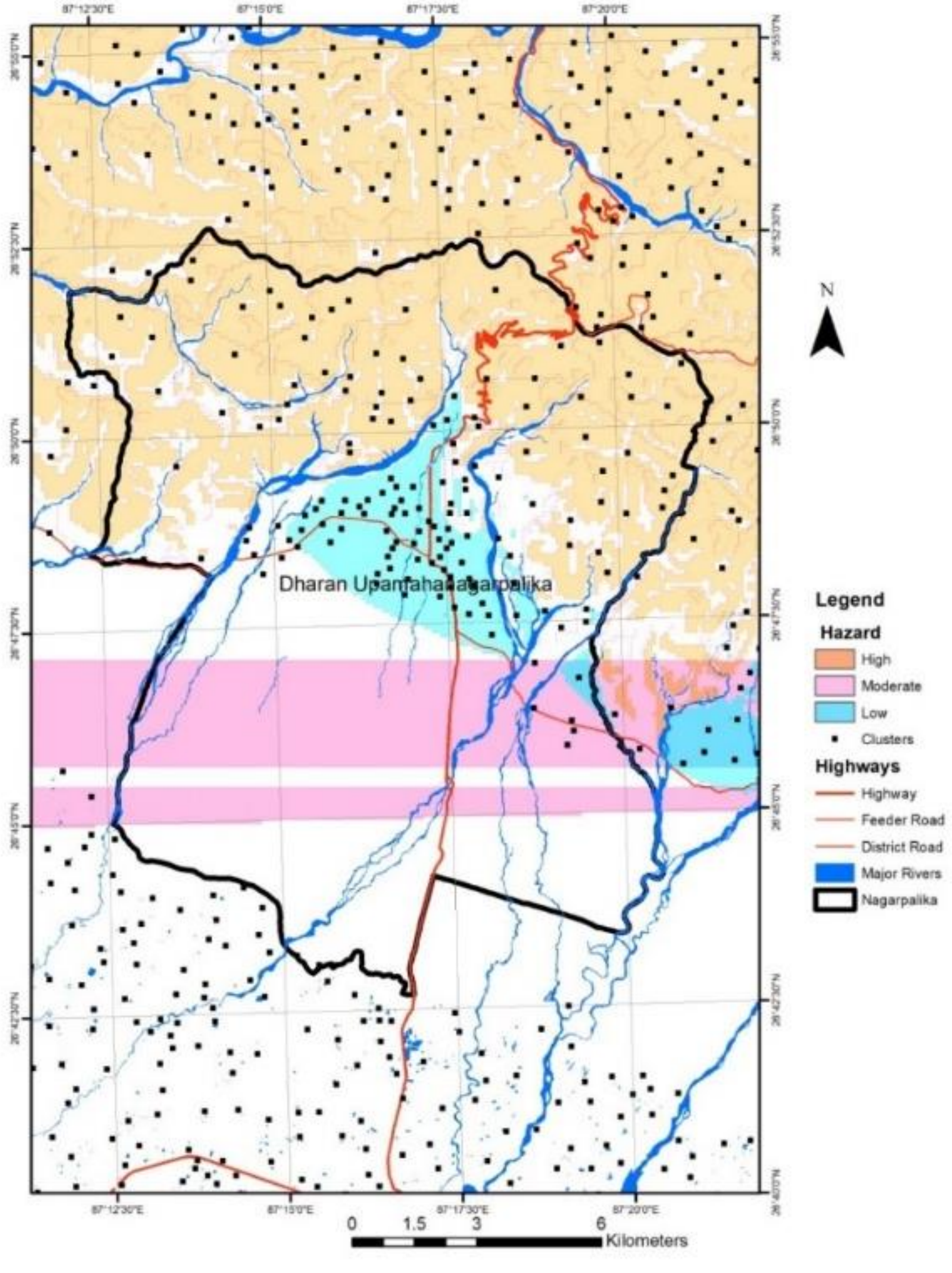
Table 8: Chautara municipality vulnerability profile

As demonstrated in the three municipalities, the Vulnerability Scoring model can be used to simply identify the vulnerability of respective houses or settlement.

It enables generation of hazard map for particular settlement and municipality and take steps for risk mitigation and reduction measures, such as prioritizing the settlements for retrofitting programs and other subsidies or financial packages to promote house owners to undertake necessary intervention (i.e. loans and insurance). Examples of risk map are demonstrated through Risk Map 1 and Risk Map 2 in the following page.



***Risk Map 1**: Butwal Municipality, distribution of buildings according to vulnerability*



Risk Map 2: *Dharan Municipality Vulnerability and Risk map*

Discussion

Nepal is one of the few countries that undertook door-to-door building damage data collection across all the earthquake affected areas. The database of more than 1 million buildings surveyed has more potential than just identifying the beneficiaries for the government housing reconstruction grant. The major achievement of this data analytics was to take advantage of such massive, readily-available, dataset and prototype a model to predict the level of vulnerability for the building based on the basic characteristics of the building (typology, height, foundation and age of building); soil type; and topographical features (slope and distance from the river).

The country is witnessing high rate of urbanization with heavy investment in new housing and other structures, which demands safety of these investment and protection of development gains. It is equally important to reduce risk to existing building stock from future disasters, to minimize economic, physical and life loss that will impede the process of urbanization and sustainable development.

As demonstrated in the Application section, the model can be easily used in other municipalities by using the data of existing building stock to identify potential vulnerability of certain geographical area. This would help both house owners and municipalities to be aware of potential risks in their locality and facilitate prioritization of resource allocation to mitigate such risk.

Even in absence of data on existing building stock, the algorithm can help prioritise vulnerable buildings through generation of potential risk maps for various building typologies. In addition, the geo-coded building stock made available in the database serves as the baseline for the respective local municipalities for risk-sensitive town development.

The vulnerability assessment model can be potentially integrated in the existing electronic-building permit system (eBPS), which is implemented in 6 municipalities in Nepal with support from UNDP. eBPS is an automated web-based application software suite which has been developed to assist municipalities to improve their current building permit process. This is an effective, transparent and efficient system to monitor and evaluate the current state of building constructions in a municipal area. The algorithm developed by this study can be the initial step of eBPS that enables the designers and house owners to understand the level of vulnerability of the house being designed, to undertake necessary precautionary or correction measures. Madyapur Thimi municipality started integrating Vulnerability Scoring in the establishment of their eBPS.

The model could and should be further improved in the future. In the iData Vulnerability Scoring model, analysis was done based on the seismic hazard intensity of the 2015 Gorkha earthquake which was *moderate*. Hence, making the model compatible to different intensities of earthquakes can be a next step. Data from the future earthquake disaster should be made available and added for further calibration.

Quality and granularity of other data such as topography and soil information also influence the result or accuracy of the model. For the iData model, SOTER was the only available digital soil data in Nepal. SOTER is mainly used for agriculture purpose, and does not necessarily provide information on geology, and it excludes non-agricultural land. When and where a better digitized soil data is available, it should be added to the model. Similarly, proximity to water sources may change over a period of time as river course is modified after heavy rain or flood. Hence, there is a need of periodically updating geographical characteristics in the future.

As the model is further trained with more data and become rigorous, it would benefit multiple aspects of risk reduction and mitigation. Beyond informing the public and policy makers, the model can also facilitate the interests of insurance industry in the future.

Finally, while the development of a viable model was the major outcome of the initiative, the process of the data analytics gave us multiple learnings. The data analysis team spent significant amount of time for data preparation and cleaning process due to the confusions in and redundancies of variables that were used to categorize the building typology as well as damage level for different components of the building. This points to the room for improvement in the damage data collection system, and accuracy in the actual data collection on the ground at the time of future earthquake disasters.

Conclusion

The experiment through the iData initiative demonstrates an innovative way forward in identifying the ‘suspects’ of vulnerable buildings that require attention. The algorithm built by utilizing massive post-earthquake database of more than 1million houses surveyed by the Government of Nepal, as well as soil and slope data, helps identification of vulnerable buildings in the case of moderate intensity earthquake.

The study confirmed the applicability of such model to other municipalities to generate indicative risky buildings or settlement and thereby to put in place necessary targeted policy measures and allocate financial resources. It is recommended that further data (pre and post-earthquake) is fed into the model for improved prediction of vulnerability in the future. Overall, the outcome of this study offers significant potential in supporting actions or decisions by the policy makers, citizens and other parties who promote disaster risk reduction in Nepal.

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United Nations Development Programme in Nepal

Empowered lives.
Resilient nations.

The United Nations Development Programme (UNDP) has been working in Nepal over two decades to promote seismic risk reduction. Together with the Government of Nepal, UDNP supported Development of Nepal Building Codes, introduction of electronic building permit systems and promoting risk sensitive land use planning in urbanizing municipalities.