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SUSTAINABLE APPROACHES ON BUILDING INVENTORY SURVEY AND SEISMIC RISK ASSESSMENT OF THE MUNICIPALITIES IN NEPAL

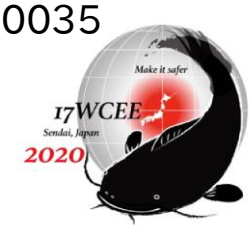
S. Wagle [1], S. R. Bhattarai [2], A. Poudel [3], S. Singh [4], B. R. Shrestha [5], K. Bhattarai [6], S. Pradhan [7]

[1] *Structural Engineer, National Society for Earthquake Technology- Nepal (NSET), swagle@nset.org.np*
[2] *Civil Engineer, National Society for Earthquake Technology- Nepal (NSET), sbhattarai@nset.org.np*
[3] *Civil Engineer, National Society for Earthquake Technology- Nepal (NSET), apoudel@nset.org.np*
[4] *Civil Sub-Engineer, National Society for Earthquake Technology- Nepal (NSET), ssingh@nset.org.np*
[5] *GIS Officer, National Society for Earthquake Technology- Nepal (NSET), buddhishrestha@nset.org.np*
[6] *Graduate Student, Asian Institute of Technology (AIT), kapil1490@gmail.com*
[7] *Structural Engineer, National Society for Earthquake Technology- Nepal (NSET), spradhan@nset.org.np*

Abstract

Nepal lies in a high seismic zone and is suffered from large earthquakes from time to time. Nepal is posed to high earthquake risk in terms of human casualties due to existing physical and social vulnerabilities with continued vulnerable building construction. 2015 Gorkha Earthquake left Nepal with huge damage in the affected areas. Many studies have indicated that the losses could have been minimized if the seismic risk assessment and planning had been done. On the other hand, Nepal does not have developed building inventory data system. This encourages the development of methods to collect, evaluate and respond from these events. So the purpose of this study is to develop a method for collecting building inventory of municipalities of Nepal to create an exposure model as an input for the evaluation of seismic risk and conducts loss estimations. Furthermore, this paper also studies the process of developing building inventory with the help of open-source platforms. Building taxonomy of the Global Earthquake Model (GEM) Foundation was used as a reference for the localization of the structural attributes in the context of Nepal focusing on a comprehensive classification scheme relevant to seismic performance of buildings and social attributes. The local surveyors were trained to these attributes before the survey. The open-source tool, Kobo toolbox (humanitarian cloud server) was used for the storage of the building inventory data collected during the survey with the GPS location, including features to improve and upgrade the collected data in QGIS. Open Quake Engine developed by GEM Foundation was used to calculate the existing seismic risk of the municipality which will help in planning future disaster mitigation strategies. Through the National Society for Earthquake Technology- Nepal (NSET)'s program, building inventory data of five municipalities were collected. In this study, the inventory data collected from these municipalities are used to evaluate the seismic risk and loss estimations. This study will develop a comprehensive exposure model of building and population in the study areas and estimates the casualties and probable losses from the potential seismic hazard. From this study, the standard procedure for updating the building information is developed, tested and recommended which are integrated into the building permit process of the municipalities where the information of new constructions is updated regularly.

Keywords: Building Inventory Model; Sustainability; Risk Assessment; Open platform; Disaster Risk Planning



2. Background

There are various methodologies developed for building inventory databases globally through different approaches with a distinct level of accuracy and reliability. Jaiswal et al. [1] have developed a global building inventory database with distribution of building classes for rural and urban areas, at a national scale.

Nepal is highly susceptible to the occurrence of large earthquakes and past studies have suggested a need for seismic risk assessment and proper future planning in preparedness and effective response after a disaster. Currently, plans at local levels are prepared on individual judgments and knowledge due to the lack of existing facts and information. This scenario demands the need for the development of building inventory data system at municipalities. Since no prior building inventory survey methods are in use at municipalities, this effort will provide a standard procedure for building an inventory survey. This system will provide essential information on buildings built at a municipality which will provide assistance to policy and decision-makers at municipalities in the preparation of future plans and programmed in preparedness and effective response after a disaster occurrence. When this system is incorporated within the municipalities building permit system, regular updates and additions can be done to the system, and real-time informations are extracted from the system. Building inventory data will assist in seismic risk assessment and loss estimations to best prepare for probable occurrences of next seismic events.

The seismic risk assessment helps to develop awareness in the community developing the maps for different seismic hazard and loss estimation data which gives a clear reason for individuals, businesses, and policymakers to act now to prevent devastating losses in the future. Seismic risk assessment output obtained from this study provides a powerful tool for private industry, government officials, and the general public to initiate in drafting mitigation policies and programs. This seismic risk tool can help in identifying the areas of greatest vulnerability within the municipality to inform decisions and actions. The risk maps presented from this study not only helps in the preparedness planning of the municipalities but also helps in post-disaster for effective response planning. The rescue operation can be prioritized based on the relatively high seismic risk in the municipality due to which we can minimize the loss of life and property. Based on the seismic risk assessment of the municipalities the planning of the municipalities can be made effective and avoid the construction in a seismically high-risk area or the municipality planner can recommend safer construction considering the hazard.

The United Nations Disaster Relief Office has defined vulnerability in the mathematical formulation used in the risk assessment which has been agreed by many authors [2]. According to this the risk in specified time period (T) can be expressed mathematically as,

$$R = | (H \otimes V) \otimes E| \quad (1)$$

Where,

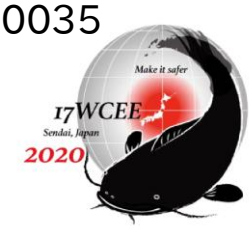
R is the probability of exceedance of risk in terms of loss of exposure.

H is the probability of exceedance of a certain level of Seismic hazard.

V is the vulnerability (tendency of exposure to suffering damage)

E is the exposure of the element in risk (buildings in this study)

This paper presents the development of building inventory data survey systems in five different municipalities of Nepal i.e. Bharatpur, Birendranagar, Birtamode, Vyas, and Bhimdatta. This building inventory is then used to develop an exposure model for seismic risk assessment and planning of the municipalities. This paper highlights the major findings in the building inventory survey and recommends the sustainable approach in the municipalities of Nepal and other similar developing countries, which can be used in disaster risk reduction and preparedness planning of municipalities. Furthermore, the seismic risk assessment of the municipalities carried out in this study helps the RDM planner to effectively plan in the municipalities.



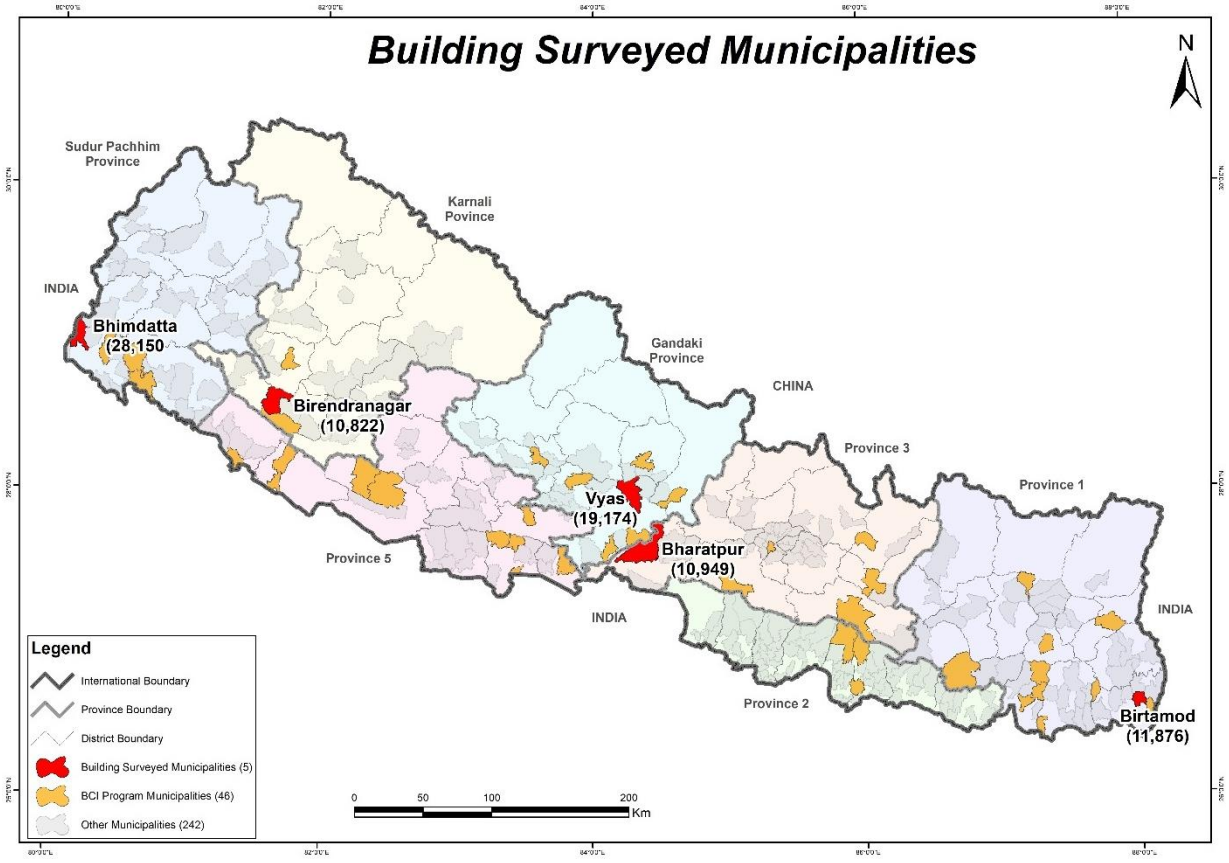


Fig. 1 – Map showing the study area (municipalities) of Nepal

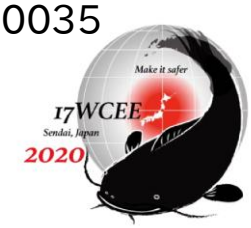
3. Objectives

The purpose of this study is providing a tool for developing an action plan on earthquake risk management, risk-sensitive land use plan of municipalities and making the communities earthquake resilient, ensuring sustainable development in the municipality. The specific objectives are,

- Develop a sustainable approach of building inventory data survey methodology and integrate it into the municipality's development process.
- Develop a seismic risk assessment of the municipalities and sensitize the local stakeholders in DRM planning.

4. Study and Approaches

Building Inventory Survey was conducted at municipalities to collect essential data for the development of an action plan on earthquake risk management and risk-sensitive land use plan of municipalities. Previous studies on building inventory surveys conducted internationally were consulted and the methodologies used in those studies were remodeled to suit local context at municipalities. For the development of questionnaire of the survey Global Earthquake Model (GEM) taxonomy was used as a reference for localizing the building attributes in the context of Nepal. The open-source platform, Kobo toolbox was used to collect the building data. The use of locally available human resources at the municipality was done for the accuracy of data and data collection. These local non-technical persons from the municipalities were given training on data collection before deploying them in the field. The surveyors were continuously supervised and guided by the technical team for minimizing the error in the data survey.



The building and occupant information obtained from the survey were used to develop an exposure model. Fragility and vulnerability functions for each building typology obtained from the survey are taken from the past studies of Guragain et. al., 2012 [3] and HAZUS [4]. The open-source platform OpenQuake, developed by Global Earthquake Model (GEM) Foundation [5] was used for the seismic risk assessment and loss estimation of municipalities. Being an open-source, OpenQuake tool was globally used in many countries. The site parameter (Vs30 data) for this study was taken from the United States Geological Survey (USGS) data. In this study, the adaptation of a globally used tool was done to fit into local context which can be easily used in DRM planning in the future.

The sustainability of building inventory and seismic risk assessment depends upon the open-access of the tool used, the locally acceptable and compatible method, and the capacity of the municipality to update it regularly. For this the local representative's participatory approach was undertaken to take views from all necessary decision-makers and planners at the local level, thus creating a result to enable similar understanding among all the representatives involved.

5. Scope

The survey was conducted in five municipalities of Nepal namely, Bharatpur in 2015, Birendranagar in 2016, Birtamode in 2017, Vyas in 2018 and Bhimdatta in 2019. As seen in Fig-1, these municipalities are selected from the project implementation area of the National Society for Earthquake Technology (NSET)- Nepal representing a different part of the country. This study will provide the idea of different building construction practices in different parts of Nepal. As all the data are acquired through interviews, the reliability of data depends upon the reliability of the surveyor and the responder. During the data survey, the detail information of only residential buildings was surveyed. For public buildings and in the building where the house owner or the interviewer could not be met, the only information that could gather by visual inspection was collected. The open-source platforms such as Open Street Mapping (OSM), Google Earth, QGIS, Kobo toolbox, OpenQuake tools were used in this study so that municipalities can easily use these platforms in the future for updating. For seismic risk assessment of the municipalities, a potential seismic hazard source for that municipality was taken and the loss estimation was done in the deterministic approach. The seismic source taken in this study was the line source of 50 km rupture length on the Main Frontal Thrust (MFT) near the study area.

6. Methodology

6.1 Methodology of the Survey

The governing question for building attributes of the survey was based on the international practices building taxonomy developed by GEM. Some building attribute was added for the suitability of the local context of Nepal. The free open-source tool for data collection i.e. Kobo Toolbox was used for the data collection. The questions developed were inserted accordingly. All the building footprint was digitized before the field survey from high-resolution latest satellite images from google-earth. During that period the unique ID was given to each building. The technical students and social mobilizers available locally were used for the survey. The number of surveyors were determined according to the time requirement. The three days training curricula consisting of theoretical and practical knowledge for data collection was developed by NSET. The training includes mapping of building footprints, description of questionnaires, use of the mobile application and onsite social tips for survey.

After training, surveyors were mobilized in field with printed google earth maps sheet and questionnaire form on mobile. The surveyor filled the questionnaire in mobile application by interviewing the house owner or person to meet at the house. This questionnaire uses the same unique ID for the corresponding building footprint ID and is used to interlink the building attributes to GIS file with the preexisting footprint information. They verified the building footprint in the field and update the building footprint in the sheet if needed. Every day the verified form data was uploaded via the internet. Surveyor mobilization, survey planning, data quality

check, and buildings footprint digitization correction were done by the supervision of the NSET technical team. The open-source QGIS was used for the reporting of data in GIS with a building footprint. The surveyed data in excel and building footprint with all attributes in QGIS was integrated into municipalities database system. The following diagram shows the overall workflow.

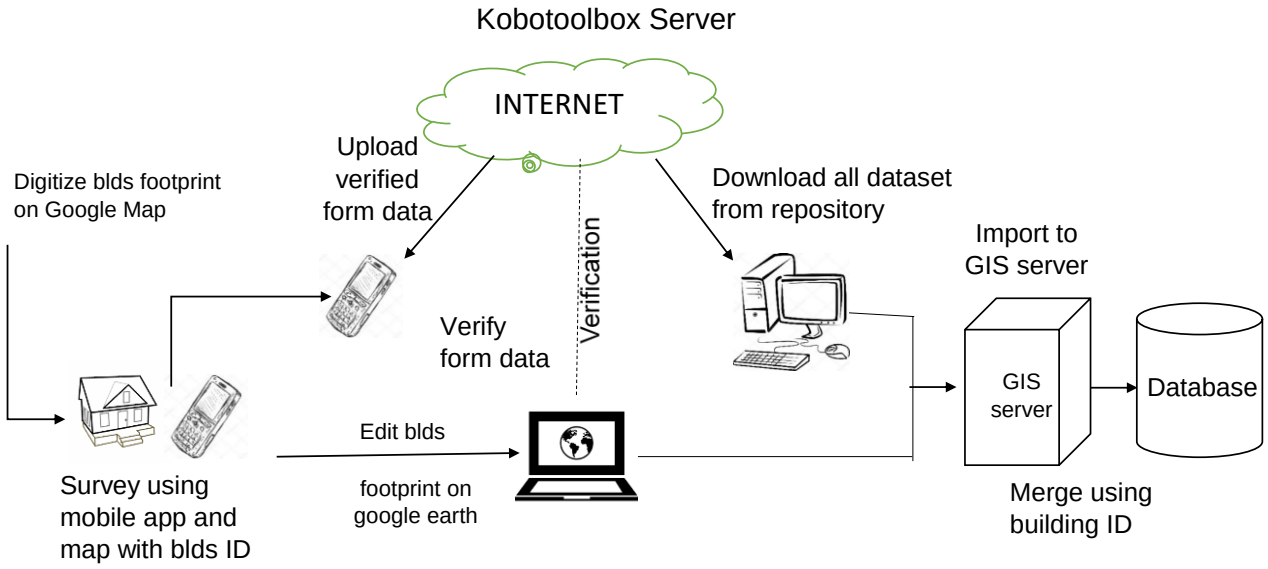


Fig. 2 – Building Inventory Data Survey Flowchart

6.2 Methodology of Data Analysis

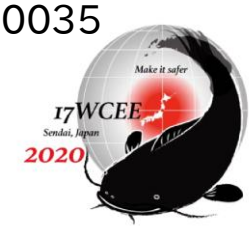
All the data collected from the survey were collected through the open-source tool, Kobo toolbox and stored in its respective humanitarian cloud server before analysis. These collected data were retrieved from the server and were analyzed using a standard spreadsheet and data analysis packages. Discussion was held to gather the necessary information and results required for municipalities. Municipality and ward wise status of building stories, building typologies, and other essential attributes were prepared. Ward wise maps were prepared to reciprocate essential information on each ward of municipality maps. Furthermore, the building typologies based on the different land slope provided information of buildings proportions in each land slopes. The day and night occupants based on building typologies provide the information about the proportion of occupants in different building typologies.

6.3 Integration of these data and process into the municipalities system

Data collected and results generated from the process are integrated into the municipality system. This integration will also facilitate to bring different surveys conducted at the municipality in a single platform. GIS maps are developed for municipalities for each essential parameter. These results are used in the development plan and programs at municipalities. Building information attributes are added to building footprints GIS data. This building information is added to google earth and open street map platforms for future use. To create a sustainable process, the system is developed to continuously update the existing building information along with the addition of newly constructed building information. This system developed in municipalities will be integrated with the building permit process of municipalities, thus the information of new construction will automatically be fed into this data system. This is envisioned to replace the process of physical surveys in the field.

6.4 Seismic Risk Assessment of Municipalities

Seismic risk assessment of municipalities of Nepal involves analysis of the level of seismic hazard of the municipalities, building vulnerability and exposure. Defining the seismic risk in the municipalities and



building vulnerability plays an important role in minimizing the physical consequences during future seismic events. The exposure developed from the building inventory data survey was categorized in terms of different building typology and the corresponding fragility functions for each building typology was taken from the past studies [3] [4]. The potential seismic hazard source for different municipalities are identified. For this study, the 50 km rupture length of the Main Frontal Thrust (MFT) near the study area is taken as a line source of seismic hazard. This line source is taken since this is the youngest and major seismic source in this region [6]. Since the site condition plays a major role in the risk assessment, the site parameter (Vs_{30}) data is taken from USGS. These exposures, fragility, vulnerability, site parameters, and hazard sources are fed into the OpenQuake tool to run seismic hazard assessment for the municipalities. The output is generated in terms of PGA map, number of casualties in day and night and the level of building damaged by defined earthquake in the study area. The generated output demonstrates the potential seismic risk area within the municipalities. Finally, the generated output in the form of the map was presented to the municipalities planner and stakeholders to sensitize the seismic risk in their locality. This will help the municipalities planners in DRM planning and risk-sensitive land use planning, which ultimately minimize the losses in future disaster events.

7. Findings

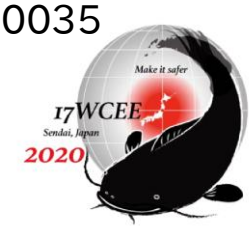
The use of open-source tool in developing countries like Nepal aid in its effective use and help in the sustainability of the work due to easy access by everyone. The localization of global practice in the local context has helped better understand and easily adopting the method and tool by the local users. The involvement of municipality in the process of developing exposure data and initiation in the development of the system for updating this information enforces the ownership and endorsement of the process by the municipality which will ultimately sustain the system. The development and demonstration of seismic risk of municipality with the involvement of municipal planners help in risk reduction and risk-sensitive land use planning, preparedness planning and contingency ineffective response after a disaster.

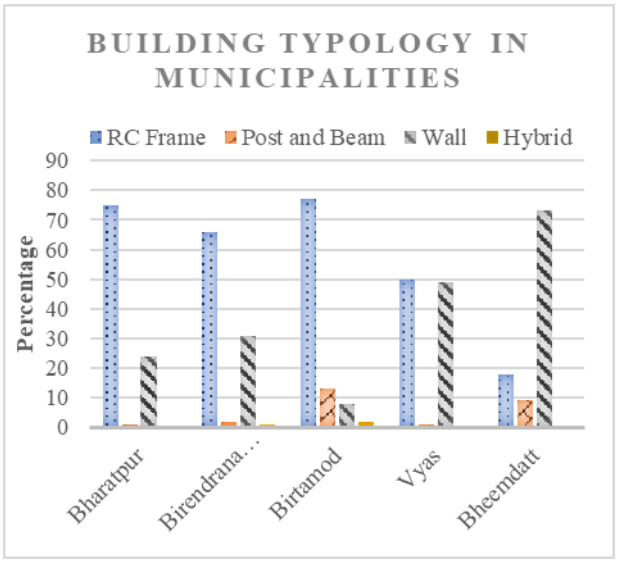
Detail analysis of the data collected from the building inventory surveys in municipalities was conducted to extract some essential results. These results will provide municipalities with crucial information for the development plans. With the development of the Building Inventory Data Survey (BIDS) tool, each municipality will be facilitated with their own desired results which can assist them in future planning works like risk sensitive land use planning, road network expansion, DRM planning etc.

7.1 Building Inventory Data Survey (BIDS) of five municipalities

The following graphs in Fig-3 are the major key attributes of buildings surveyed at five municipalities. From the result, the major construction practice in most of the municipalities is Reinforced Concrete buildings and the majority of buildings are less than 3 storied. The result also demonstrates the rate of building construction in the past decade is very high, from which we can say that the rapid urbanization has begun in recent years in these municipalities.

From the collected data of these municipalities, the key level of detail required to collect in the context of Nepal was also analyzed. From the study, it was found that building attributes information that is required varies from place to place. The exact replication of the global practice does not work for Nepal. The major key information that needs to collect during building survey in Nepal are building materials, load resisting system, slope type, foundation type, floor type, wall type, roof type, age of building, number of story (above and below ground), day and night occupants and occupancy detail, owner detail, plinth area of building, year of construction and cost of building. With the help of this information, we can analyze the data and also have a seismic risk assessment and loss estimation of that area. However, depending on the objective of the data other parameters can be added in the questionnaire.





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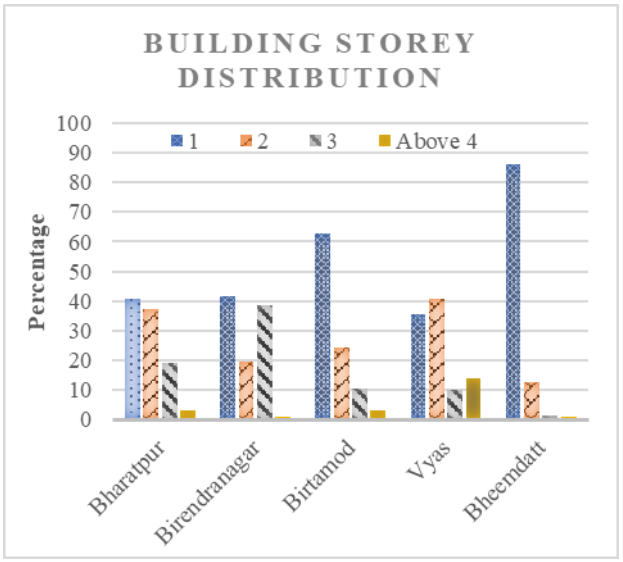

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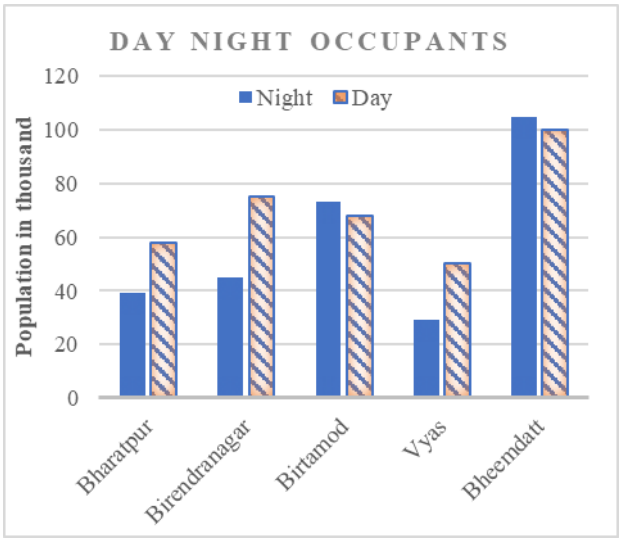

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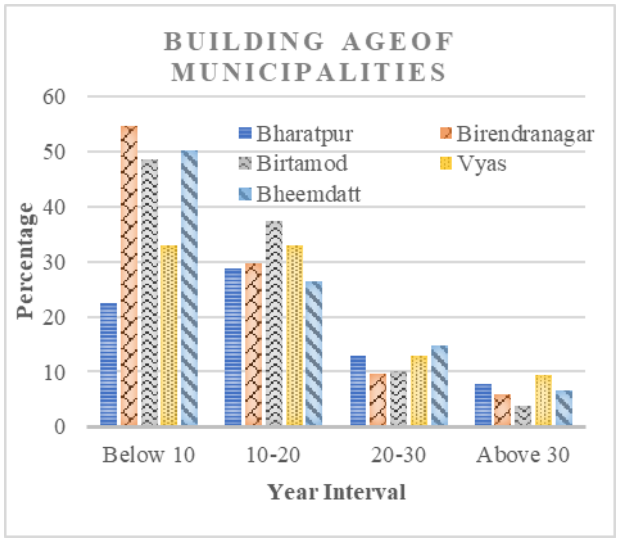
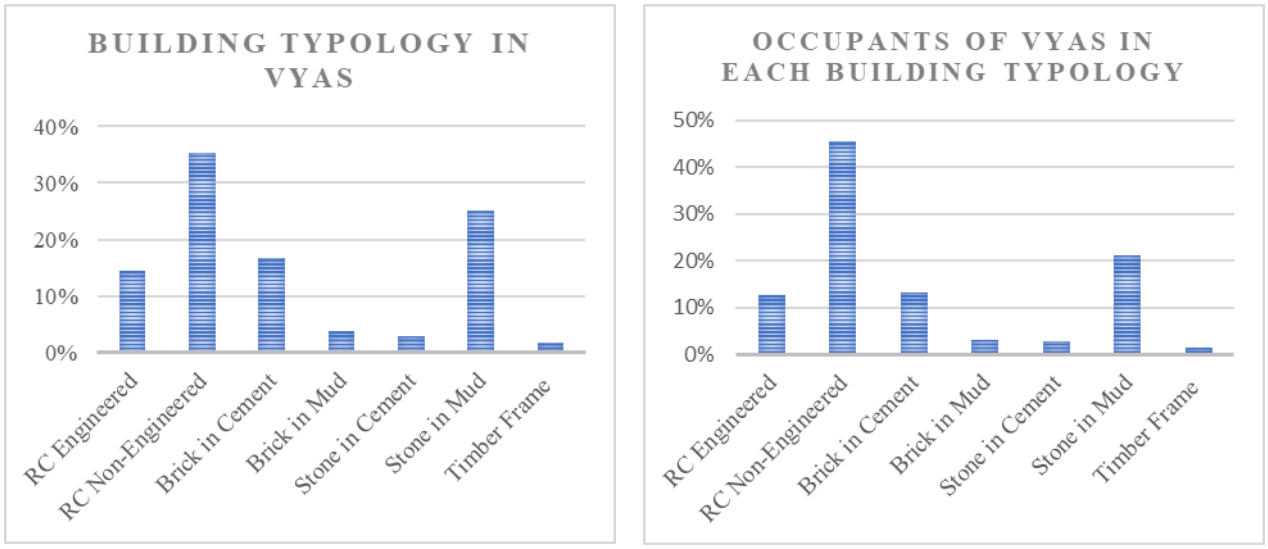


(d)

Fig. 3 – Building Inventory Data Survey detail in five Municipalities

Looking into the detail of one of the municipalities, in this paper, we have presented the detail of the Vyas Municipality. In the Fig-4, the building typology detail and number of occupants in the respective building typology are presented for Vyas. It shows that the RC buildings are the most common building type constructed in Vyas municipality which are non-engineered buildings and most occupants are in these buildings. This can be key information for the municipality to focus on these building types rather than the timber structure during DRM planning and mitigation activity which can minimize the loss drastically in future disaster events.

Analyzing the data of Vyas municipality on slope perspective, most of the RC buildings are built on flat slope. While most of the stone in mud buildings are built on medium and steep slopes. More than half of the current occupants in municipality stay in RC buildings, 45% of them on Non-Engineered ones. Similarly, there is also a good proportion of people staying at the brick in cement and stone in mud buildings.



(a) (b)

Fig. 4 – Building Inventory Data Survey detail in Vyas Municipality

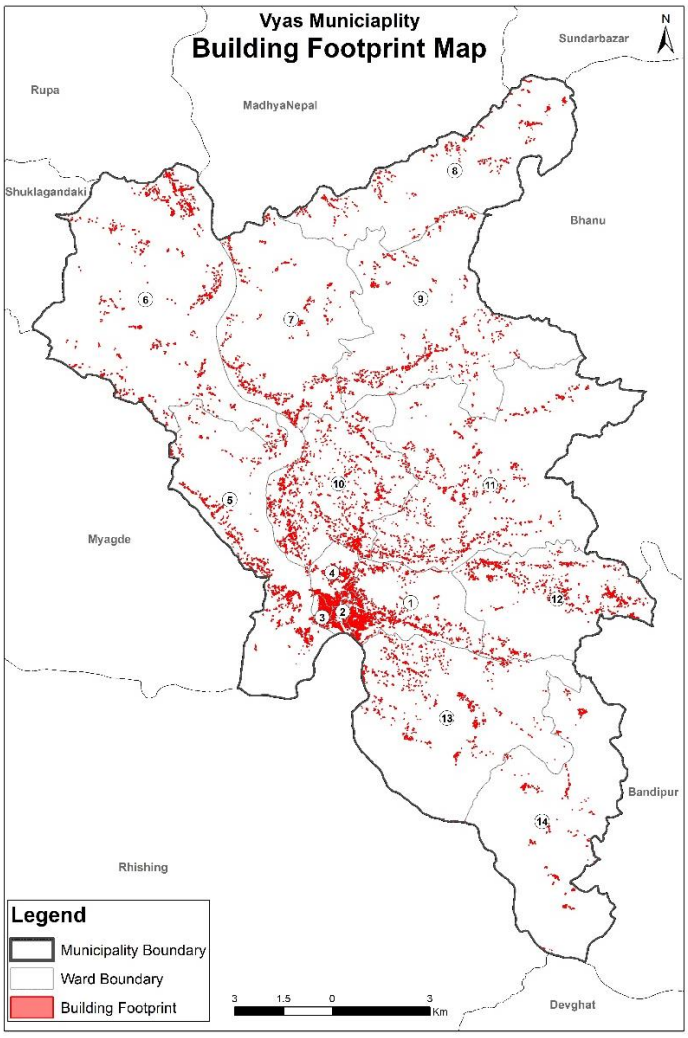


Fig. 5 – Building footprint of Vyas Municipality

7.2 Seismic Risk Assessment of Vyas municipality

Based on the above-mentioned methodology of seismic risk assessment, the risk in every municipality is obtained. The deterministic seismic hazard maps of municipalities are presented in Peak Ground Acceleration (PGA). The risk and losses due to scenario earthquake in the municipalities are presented in maps which includes the number of building damage and level of damage for each building typology inward level. The risk assessment also estimates the number of dead and injured populations from the considered earthquake in each ward of municipalities in day and night. This output of the risk assessment gives the clear idea for the DRM planner about the extent of damage and loss in the municipalities and help in DRM planning. The number of buildings damaged typology wise will help to identify the most vulnerable structures in the municipality, which can be a planning tool for mitigation. The PGA map will help to identify the relatively high seismic risk area, which ultimately helps in risk-sensitive land use planning. The output of this study also helps in awareness-raising in the community sensitizing them the potential seismic risk in their community. The need of strengthening the existing structures and initiating the new safer constructions will be felt by the local people. This will ultimately help in minimizing the loss in the future earthquake making the communities earthquake resilient, ensuring sustainable development in the municipality. The outputs of the seismic risk assessment in one municipality (Vyas Municipality) are shown below.

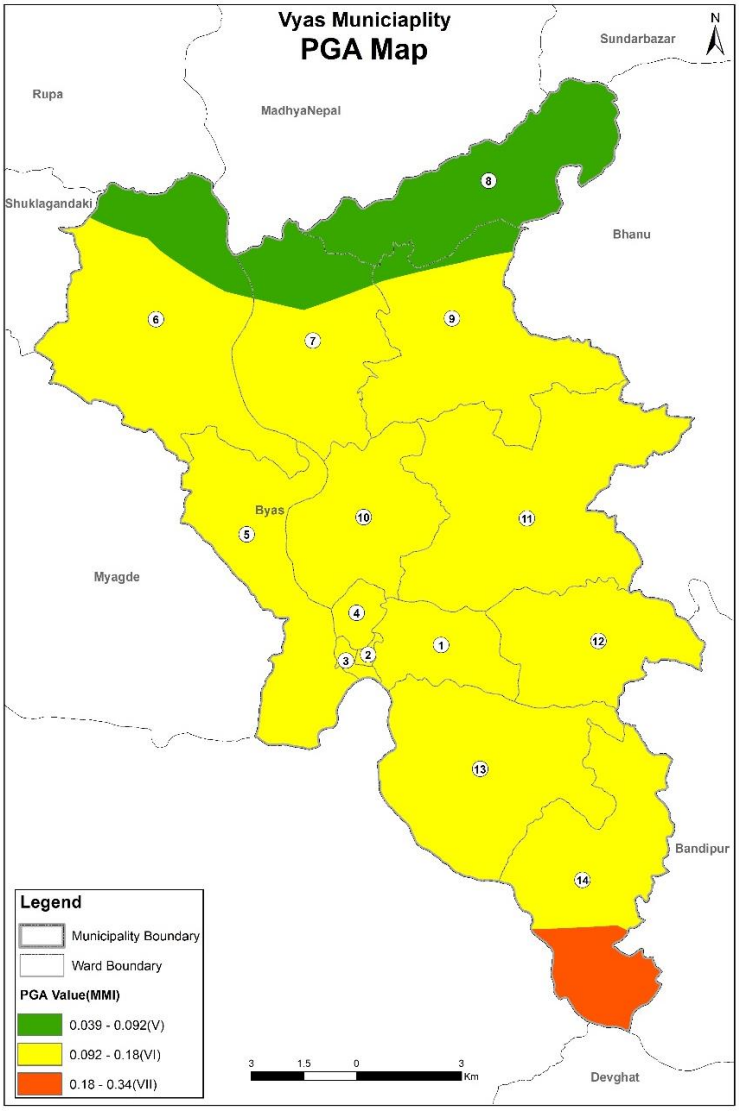


Fig. 6 – PGA map for Vyas Municipality

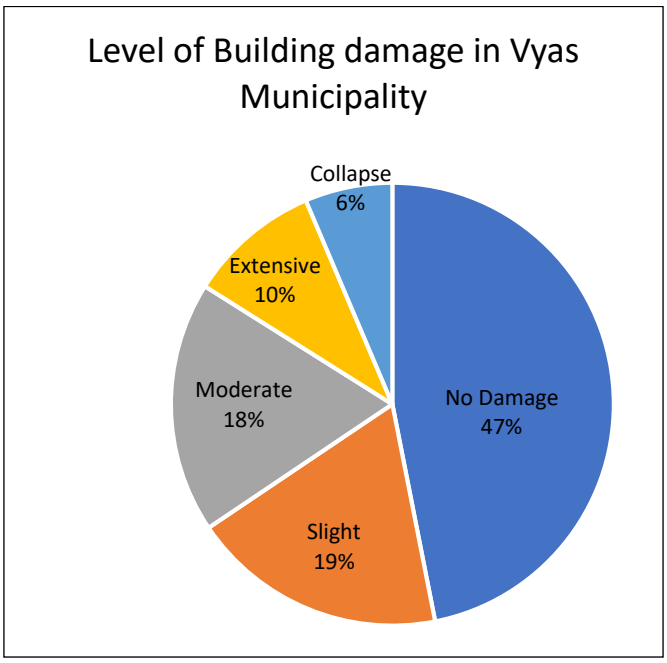
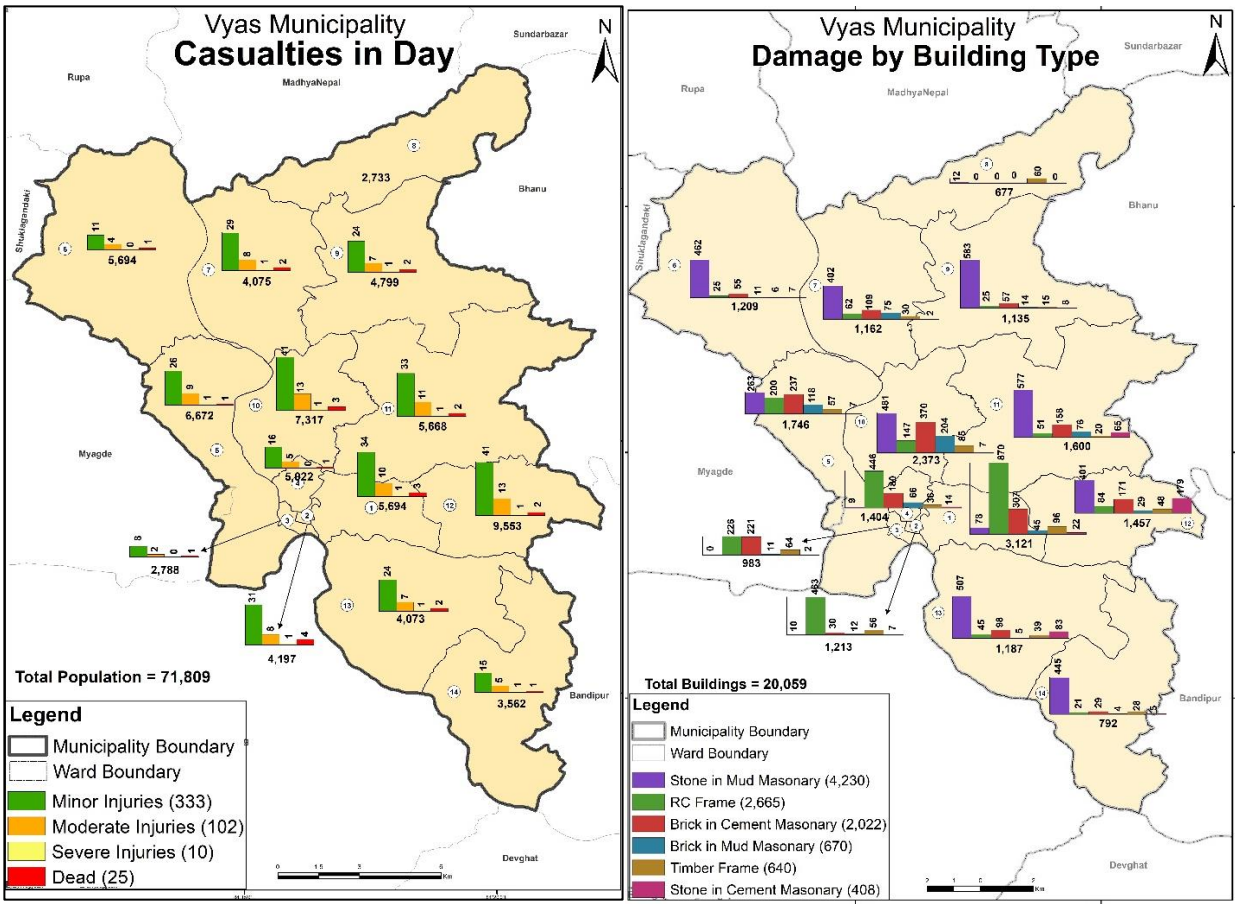


Fig. 7 – Building damage level in scenario earthquake for Vyas Municipality



(a) (b)

Fig. 8 – (a) Casualties during the daytime, (b) Number of building damaged in scenario earthquake under different typology of Vyas Municipality

7.3 Development of a sustainable system

The survey in the above municipalities was conducted in different years. Surely, the number of buildings in each municipality has increased in these durations. Further increase in some of the surveyed municipality areas due to state restructuring has increased the building number. Normally, around 500-1000 buildings are constructed in each municipality and most of these buildings are passes through the existing building permit process in municipalities. These building permit process might operate from ward level in each municipality or their respective municipality offices. Further records are to be kept of the buildings missed from previous surveys. Dynamic systems to append and edit the current records are provided to each municipality and certain personnel are trained to use it. This system is incorporated in building permit system regulation [7] of the municipality. In the current system, the property tax of existing land and buildings is paid to the municipality annually in a fiscal year. Most of these are paid in certain periods of a year. If the system update and data entry works could be done in these durations, the system would have up to date records of buildings in municipalities.

8. Conclusions and Recommendations

From the detailed analysis of the data collected from the building inventory surveys in municipalities, it was found that building attributes information that is required varies from place to place. The exact replication of the global practice does not work for Nepal. The technical aspects and the global practices should be localized with the involvement of the local stakeholders which will be easily adopted and become sustainable.

From this study, the survey methodology comprising with minimal technology and local human resource was developed using the open-source tool (Kobo toolbox) which suits the developing countries.

From the building inventory survey result, the major construction practice in most of the municipalities is Reinforced Concrete buildings and the majority of buildings are less than 3 storied. Most of the buildings in these municipalities are constructed in recent years, which signifies the urbanization has started in the last decade.

The building survey system development with the municipality involvement and integrating into the municipality building permit process will automatically update the building information system.

The development of different seismic risk scenarios in the municipality and presenting the losses in the community can help in sensitizing the local people easily and effectively in risk reduction activities. The demonstration of risk model developed jointly with the local people of the municipality can be an effective tool to raise awareness and for the DRM plan.

9. Acknowledgments

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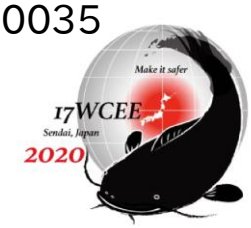

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