Vulnerability Assessment Methods for Land Subsidence Prone Areas – A Case Study: Matale Municipal Council Area

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ABSTRACT : Hazard, Vulnerability and Risk are generic terms in disaster management that are used frequently for taking decisions in development planning. Vulnerability assessment requires gathering of various data that are consist of various fields and various methods are used to calculate the vulnerabilities.

Several incidents of land subsidence were recorded in the Matale Municipal Council Area and it became necessary to assess the vulnerability of the settlements for developing a resilient built environment.

This paper discusses the vulnerability assessment methodology used and the results of the assessment that were conducted in the Matale Municipal Council Area. Two types of vulnerability assessment methods were developed; community based vulnerability assessment and computer based vulnerability assessment. Community based vulnerability assessment describes the community ideas and how they feel uncertainties on their buildings and territory. The data were obtained through a community survey, which was conducted in a systematic random sample in the Matale Municipal Council Area. Technical assessment is based technical evaluations based on available secondary data and its analysed outputs.

Based on the analysis few recommendations were made to reduce the vulnerabilities of the Matale Municipal Council Area.

***Key Words**: Vulnerability Assessment, Land Subsidence*

1 INTRODUCTION

The first landslide incident was recorded in 1995 in Matale area and thereafter a land subsidence incident was recorded in 2005. Several months after 2004 tsunami, the observation of unusual water fluctuation in existing wells, tube wells in Nagolla, Madawala, Ulpotha and Ukuwela area in Matale was made. National Building Research Organisation (NBRO) started the land subsidence investigations and social surveys to identify the possible impact areas in Matale. As a result, in 2008 NBRO developed a land subsidence hazard susceptibility map of the affected area.

The technical coorperation with Norwegian Geotechnical Institute (NGI), Oslo- Norway was started in 2012 November to enhance the professional and technical capacities of NBRO to identify and assess the land subsidence and landslide hazards in Matale area. Ground Penetrate Radar (GPR) system had been donated to NBRO to investigate the land subsidence hazards and numbers of automated rain gauges were installed in identified locations to monitor the rainfall, soil moisture, temperature and other parameters which are relevant to assess the ground conditions in problematic areas.

2 PRESENT SITUATION OF MATALE

Matale District is located in the Central Province and a large proportion of the district belongs to the dry zone. Geomorphologically, the study area lies virtually at the centre of Sri Lanka and has an undulating topography. The area lies on Western foothill of well-known Knuckles mountain range and an eastern foothill of Makulessa range. Sudu Ganga is flowing in the eastern side close to study area. The major rock types found in the areas are Garnet-Sillimanite-Biotite with interlayered Charnokitic gneiss. Dolamitic Marble is the prominent rock type in the area, which are inter layered or mobilized into surrounding rocks.

While considering the existing statistics of the area and the population size, a map of the land subsidence area was generated by using the data obtained from Census and Statistics Department (2001) and NBRO field survey data. According to statistics, the whole Matale Municipal Council area appear to suffer from the land subsidence incidence; therefore, the total population of 41,929 is suffering from the direct threat. Based on the preliminary survey conducted by NBRO, the following areas of Grama Niladhari Divisions (GN Divisions) in Matale MC Area are facing the land subsidence hazard.

Table 1: Land area according to Grama Niladari Divisions

GN Name	GN code	Area (Sq Km)
Oya Pahala	352H	0.1119
Gongawala	352B	0.3451
Sinhala Town	352A	0.3061
Hulangamuwa South	353	0.1417
Hulangamuwa North	353B	0.3868
Diyabubula	352F	0.3950
Nagolla	353A	0.0870
Maligathenna	352C	0.3251
Malwatta	352D	0.0262
Kaludewala	350C	0.2623
Aluvihare	327	0.9524
Harasgama	350	0.0002
Mandandawela	350A	0.3638
Parawatta	350B	0.5602

Land use types are the key factors affecting to the economy. According to the preliminary survey by NBRO, following amounts of land are affected on land subsidence. Therefore, most of the cultivation lands are found to be affected by land subsidence.

Table 2: Land area as a percentage to total cultivation

Land Area	Area (Sq m)	Percentage to total Land Uses (in Matale)
Coconut	6,863.20	100.0%
Chena	235,469.20	100.0%
Home Garden	407,247.27	45.2%
Other Plantations	43,974.51	18.0%
Paddy	30,206.85	91.4%
Rubber	129,665.38	70.8%
Streams	30,731.53	90.4%

In the previous studies conducted covering nearly 3000 houses in seriously affected GN divisions of Matale district, the following structural problems were identified.

1. Foundations of 53% of the total buildings surveyed are found to be cracked as result of land subsidence
2. 63% of the houses had marble foundations and 54% among them were found to be damaged.
3. 30% houses has plinth beams and cracks were not reported in these houses.
4. 70% houses did not have plinth beams out of which 77% were found to be cracked.

In this survey, 94% of houses were recorded to have cracks in walls and 45% of the cracks were wider than 10mm. Following observations were also made;

1. 71% of houses have no tie beams
2. 53% of houses have not lintels
3. 36% of houses were built with large bricks and among them 97% of houses were cracked.

3 METHODOLOGY

The disaster "Crunch Model", is used to understand and react to people's vulnerability to disasters. The model is able to take into consideration how the community experience different levels and types of vulnerability to disasters. The model has two dimensions; hazard and vulnerability. It indicates that a disaster happens only when a hazard affects vulnerable people which influence the disaster risk. Therefore the level of disaster risk depends on the magnitude of the hazard and degree of vulnerability of the people.

Three layers of social processes that cause vulnerability are:

Underlying/ root causes that include pre conditioning factors such as poverty and lack of access to resources brought about by the nature of prevailing power structures and political/economic systems.

Forcing factors/ Dynamic pressures that include lack of necessary institutions, training, skills and investment, population growth, urbanization, decline in soil productivity and environmental degradation.

Fragile/ unsafe conditions that include Fragile physical environment: risk prone location, unprotected buildings and infrastructure, Fragile local economy: livelihoods at risk, low income levels, Vulnerable community members and lack of disaster preparedness.

The root causes lead to dynamic pressures that explain how the unsafe conditions have arisen and persisted.

4 VULNERABILITY ASSESSMENT

Vulnerability is a planning perspective on the settlements which helps to identify the settlements behavior during the hazard situation. More often, settlements issues were the exact vulnerabilities during rise in the hazard situation. This argument formed to assess the settlements vulnerability in the hazard prone environment.

Two methods were used to calculate the vulnerability at the site; 1. Computer based analysis, 2. Community based analysis

4.1 *Computer Based analysis of Vulnerability*

In the thesis reviewed to determine the methodology for the vulnerability assessment, the following components have been suggested.

1. Societal Analysis
2. Economic Analysis
3. Environmental Analysis
4. Critical Facility Analysis
5. Mitigation Opportunity Analysis

4.1.1 Societal Analysis

In this analysis, consider the social elements which affect from the landslide and land subsidence. Under this analysis following sub – analysis will be identified.

4.1.1.1 Settlement Hierarchy (Scalogram)

Settlements hierarchy is needed to conduct identification of the settlement level. The higher ranked settlements have various activities and it has higher vulnerability than lower ranked settlement. This hierarchy will be conducted by sub region/ node vice.

Each settlements have different activities and based on the availability the settlement defining will be analyzed. Mostly, settlements are concentrated to the road node areas.

4.1.1.2 Demographic Condition

Demographic condition of the area is needed to consider in detail level. The vulnerability of human settlements means analysis of human settlements by its characteristics. Therefore, considering the previous analysis, following characteristics will be analyzed in this assessment;

1. Gender ratio
2. Age groups
3. Disability
4. Growth rate
5. Type of employment
6. Education level
7. Available infrastructure facility
8. Household size

4.1.1.3 Building Characteristics

Building strengthening level is a kind of vulnerability reduction. The available category of data is census and statistics data on GN wise on permanent, semi-permanent and temporary house categories.

Therefore, after assessing the building characteristics in GN wise, this value will be entered into net human settlement area in per GN.

4.1.1.4 Assessment of Building regulations

The building regulations were developed for development of standard life style in the settlement. Therefore, need to assess the settlements layout pattern in detail to identify the vulnerability. This analysis will be conducted in grid base and minimum size of the grid will be 50 m.

Indicator	Measurements	Method of Analysis
Plot Size	If answers should be more than 300 sq m (12 p) then it achieve the standard. Regular building: 300 sq m (12 p) or 150 sq m (6 p). High rise buildings:1000 sq m (40 p)	There are lack of data to identify the exact plot sizes. Therefore, make Theysian polygon from existing building pattern (by using cadastral maps) and then calculate: (Area of Theysian polygon)/ (# of buildings)
Road Frontages	If answer equal or less than 25 then it is up to standard. Building frontage: 150 sq m to 6 m frontage. 300 sq m to 12 m	Calculate: (Area of Theysian polygon)/ (Road length)
Plot Coverage	Regular buildings standard : less or equal to 66% Commercial and industrial standard : less or equal to 80%	Calculate: (Area of building)/ (Area of Theysian Polygon) %
Elevation of building	Human settlements should not developed more than 1000m elevations.	Identify the elevation levels with the buildings.
Slope of the buildings	Buildings cannot be constructed more than 60% slopes.	Identify the slope angles and building locations.
Constructions in Environmental reservations	Buildings cannot be constructed in reservation areas; River/ canal Road/ railway Forest/wild life/ sanctuary Other	Identify the reservation areas and building locations.

4.1.2 Economic Analysis

Economic activity destruction due to landslide and land subsidence will be analysed in this section.

4.1.2.1 Land values

Land values will be identified according to the land uses in the area. These values represent the level of vulnerability in the area

4.1.2.2 Land resource analysis

The land resources will be identified and valuate according to the land use types. Therefore, in general terms, the exposure of the area is land area multiplied with Cost or benefits per unit area.

4.1.2.3 O-D Matrix (Transportation)

Transport analysis will be needed for identify the connectivity and the distance azimuth matrix for different nodes in the settlements. These analyses are conducted in spatially and need to identify the importance of the nodes.

4.1.3 Environmental Analysis

How the built landscapes will affect from the land subsidence and landslides. These indicators measure in field surveys and secondary data.

Drainage Pattern: Get the details for drainage pattern; open drains close drains in the area and assess the water flows in the area.

Effect on climate: Assess the air temperature changes, Air movement changes,

4.1.4 Critical Facility Analysis

Assessment of critical facilities in the settlements, which disrupted the lifestyle immediately. This analysis is done by either GN wise or spatially. Main facilities of the area are categorized as water, electricity, food storages, health, search & rescue and availability of disaster management plan of the area.

4.1.5 Mitigation Opportunity Analysis

Assessment of the mitigation options in the area, which helps to reduces the vulnerability. There are several indicators considered in the analysis; following are the indicators and method of the analysis.

Level of disaster awareness in the area	No of disaster awareness programmes conducted in the area and number of participants
% of un occupied safer slopes in the area	% of un occupied safer slopes in the area based on the LHMP maps.
Ratio of income and expenditure of relevant local authority	Analysis the LA budget
Level of built environment management	% of LA budget allocated for development activities in the area.

Vulnerability = ∑ (Societal Analysis, Economic Analysis, Environmental Analysis, Critical Facility Analysis, Mitigation Opportunity Analysis)

4.2 *Community Based Vulnerability Assessment*

A questionnaire survey was conducted to gather the socio economic status of the sample households. Data were collected using a structured questionnaire and it covered;

Part A - Respondent Background / Demographic Condition of Household

Part B - Respondent Livelihood and Assets Information

Part C - Water and Sanitation

Part D - Safety Assessment and Site Observations

Part E - Hazard Risks

Part F – Disaster Preparedness, Resilience

4.2.1 Sampling method

The study adopted a Rasoft formula sampling procedure in selecting households to administer the structured questionnaire.

This formula takes into consideration factors such as the estimate prevalence (or response distribution) of the variable under investigation, the margin of error or the level of variability that the investigator is willing to accept, and the confidence level or the risk of identifying a result that is outside the margin of error. In table the estimated sample size for 8526 of total occupied households units based on a response distribution of 50% with margin of error set at 5% and confidence level set at 90%. According that calculation the sample size is about 368. Out of that 25 of occupied households will be studied for the in-depth analysis.

4.3 *SAMPLE SURVEY OUTPUTS*

In view of the level of awareness of disasters among households, percentage of respondents aware about landslide, drought, flood, tsunami are 21%, 19%, 19% and 17% respectively. But the awareness on land subsidence seems to be very less (10%) when compared to other disasters.

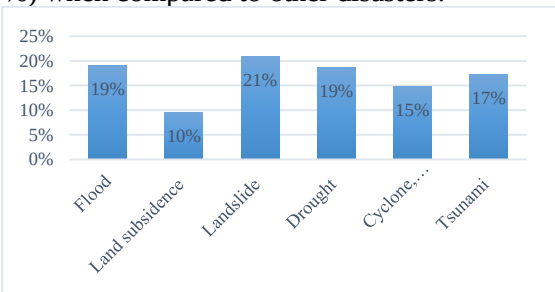

Fig. 01 Level of awareness on disasters

According to site observations, and based on the past assessments presently 10% of houses are at land subsidence risk category. The data also highlighted that 22 % of houses had cracks in the structure of the building.

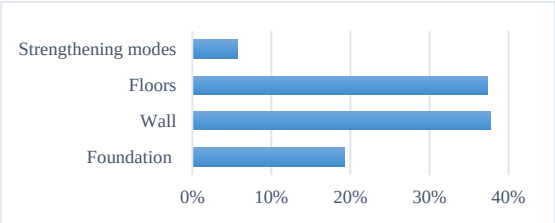

Fig. 02 Cracks in the structure of the buildings

It was noted in above context that, 24 % of the sample population have taken action to mitigate those through plastering the cracks. Nonetheless 58 % of the population has not taken any actions to mitigate cracks of the buildings. Though they have taken actions to mitigate the cracks, 30 % of respondents stated they are not confident about the correctness of the repair method that they used whereas 20 % of respondents have higher confident level about the use of a correct method.

When considering the type of terrain 2.9 % of houses are located in steep slopes, 9.7% of houses are in moderate slopes, 46% are in 11-17 degrees slopes and 38.1 % are in flat lands.

According to site observations, 3% stated that the buildings can be completely destroyed in a potential hazard situation and 9 % stated that the buildings can be partially damaged. Nonetheless 62 % stated buildings cannot be affected by potential hazard situation. When asked about the likely impacted areas of the buildings due to a potential hazard situation, majority of respondents stated that the sleeping area, gathering area, and service area of the houses can be mostly affected. Moreover nearly 5% of the buildings are more than 50 years old and a majority (i.e. 47 %) are from 11 to 20 years old. Following figure shows the age of the buildings. When considering the number of stories of the buildings, more than three fourths (77 %) of buildings are single- storied while only 20 % of buildings are two- storied buildings.

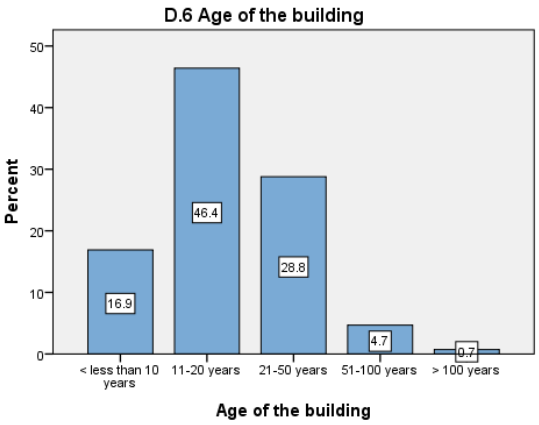

Fig. 03 Age of the building

Only a 14% of respondents have followed building construction guidelines when building their houses whereas a 68% of population had not followed any construction guidelines.

According to questionnaire survey, 6% stated their houses are located proximity to a limestone location. Therefore, the houses are most prone to sink holes or collapse.

Clay soils can be absorb large amount of water, when these soil dry out, they shrink and cause subsidence. When considering the soil layer, 6% of houses are constructed on or nearby a base layer of clay soil.

4% of respondents stated they have noticed drainage leakages in the underground drainage system in the recent past surrounding the property.

Regarding preparedness for natural disasters 82% stated that they are completely unprepared for natural disasters. However, only 4 % stated that they are prepared for natural disasters.

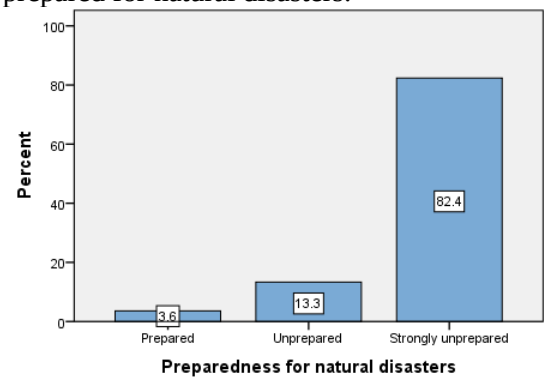

Fig. 04 Preparedness for natural disasters

When considering people's preparedness level for future natural disasters, 93 % stated that overall community has not prepared for future natural disasters even though majority stated that community's level of preparedness has not changed over the past three years. While nearly 1 % stated that community has prepared for future natural disasters due to awareness activities such as hazard awareness classes, mock drills and drainage cleaning activities have been conducted in their community.

5 CALCULATION OF VULNERABILITY

A questionnaire survey was developed for the collection of the demographic data such as age groups, housing characteristics, livelihood, water and sanitation facilities, disaster records, vulnerability groups, evacuation centers, evacuation routes and preparedness information etc. For the vulnerability assessment, these variables were divided according to degree of vulnerability and weighted each indicator according to the magnitude

of the hazard and vulnerability of the people (as mentioned in the Fig 05).

Fig. 05 Weighted Disaster Crunch Model

The vulnerable settlements were identified based on developing vulnerability scoring matrix using equation below. For this purpose, Arc GIS and excel spreadsheets were used for the calculation and map preparation.

$$\text{Vulnerability Score} = \frac{\sum \text{Indicators with increasing vulnerability}}{\sum \text{Indicators with decreasing vulnerability}}$$

Through the equation above, the vulnerability status of each settlement was calculated. That has spatially recognized by exporting the calculated vulnerability scores in excel database to GIS database. Through the interpolation of a raster surface from points using an inverse distance weighted (IDW) technique, the vulnerability of settlements in Matale MC area has been calculated.

The final maps of Human settlement vulnerability from primary and secondary data (Fig. 06 and Fig. 07) were converted to raster data set with the size of 50 m grid and each map was reclassified into five classes such as very high to very low vulnerability. Derived two maps were overlaid with the raster calculator to generate the final vulnerability map.

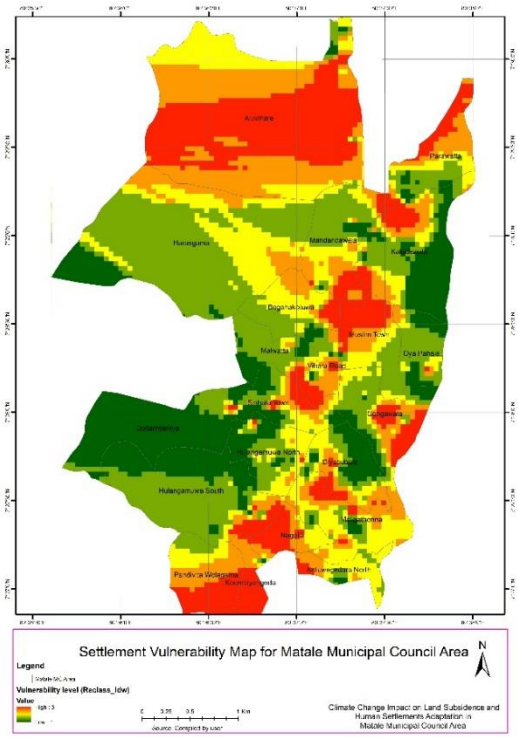

Fig. 06 Settlement Vulnerability Map for Matale MC Area derived from primary data

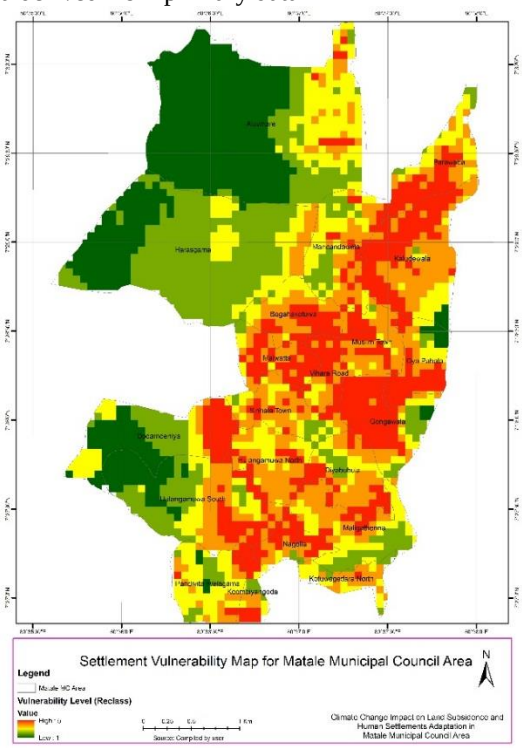

Fig. 07 Settlement Vulnerability Map for Matale MC Area derived from secondary data

As shown in below figure, the vulnerability zones range from low vulnerability in green, through medium vulnerability areas in orange, to areas of higher vulnerability in red colour. Matale city centre and its immediate vicinity shows high vulnerability while Aluviharaya, Harasgama and Dodamdeniya have low vulnerability level.

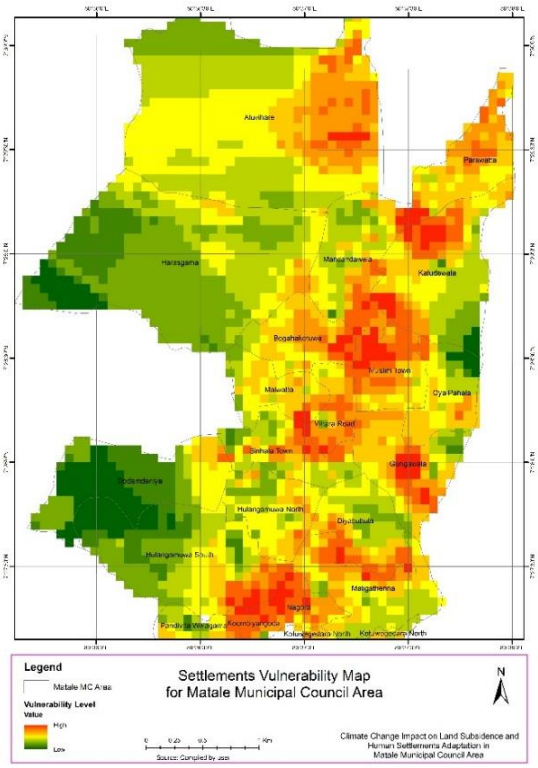

Fig. 07 Composite map of settlement vulnerability base on primary and secondary data

6 CONCLUSION

1. Vulnerability assessment provides the details of vulnerable elements of the city. These elements will be damaged or destroyed when they face any hazard event.
2. As per the planning purpose, the indicators for vulnerability increasing should be minimized and indicators for vulnerability decreasing should be maximised.
3. Matale MC needs to enhance followings for reduce the vulnerability of the city:
    a. Knowledge of the community on;
        i. Hazard
        ii. Building construction methods/ techniques
    b. Improve the drainage network;
        i. Maintain the natural drainage network
        ii. Repair and maintain the man-made drainage networks
    c. Improve the governance pattern;
        i. Monitor the building regulations in the existing building
        ii. Strictly follow the building construction standards/ UDA guidelines for the buildings/ Reservations
        iii. Control the development over the steep slope areas/ follow the NBRO guidelines.
        iv. Promote high-rise buildings for city limits and control the land fragmentations.

7 ACKNOWLEDGEMENT

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