Hazard Risk Assessment and Management Methodologies Review: Sri Lanka

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DOI: 10.29322/IJSRP.9.07.2019.p91110
http://dx.doi.org/10.29322/IJSRP.9.07.2019.p91110

Abstract **-** Sri Lanka has 65,000 sq.km of land area with many areas prone to natural hazards. The last decades have witnessed the occurrence of an increased number of natural hazards in Sri Lanka. Due to the Climate changes and inappropriate land use changes have been increased natural hazards in Sri Lanka. It is important to study the assessment and management methodologies. The main objective of this study was identifying literatures about hazard assessment and management methodologies in Sri Lanka. Only data were collected based on scientific publications reviewed from 1994 to 2018 is broken down into domain types: geophysical hazard and hydro-meteorological events. This research has done the most affected geographical areas and proposes a different risk assessment and management strategies that will support more suitable management measures and stakeholders participation.

Index Terms - Hazard, Geophysical, Hydro- meteorological, Risk assessment, Stakeholders

I. INTRODUCTION

Sri Lanka has an area of 65,000 square kilometers and a population of 18.7 million (Department of Census and Statistics 2001). Last year's natural hazards have been increased 22 times during the last two decades, mainly due to increased hydro – meteorological disasters. In terms of frequency disasters affecting the people and the economy, the flood is the highest (56%), drought (18%), winds (10%) and landslides 16%) (www.desinventar.lk). Natural hazard impacts have been considerably affected the economy and development gains. Disaster management center in Sri Lanka evaluated losses and damages social sector (1,940 million rupees or 38%), productive sector (2,574 million rupees or 51%), infrastructure (5,058.9 million rupees or 51%) (www.desinventar.lk)..

In Sri Lanka natural hazard types can be divided into two main types, namely meteorological hazard (winds, forest fires, floods, drought), geological hazard (Landslide, tsunami). The most frequent natural hazards that affect Sri Lanka are droughts, floods, landslides, cyclones, vector borne epidemics (malaria and dengue), and coastal erosion (Tissera 1997). Tsunamis are infrequent but have caused severe damage. Recent understanding of the tectonics of the Indian Ocean region points to an increasing risk of earthquakes (Dahanayaka, 2004).

The main objective of this study was identifying literatures about hazard risk and management in Sri Lanka. Only data were collected through literature review.

II. METHODOLOGY

A. Geological Hazard Methodologies In Sri Lanka

Based on scientific publications, prevalent risk assessment and management methodologies are reviewed year from 2000 to present and categorized into two hazard event groups: hydro-meteorological and geophysical. The main objective of this study was identifying critical comparisons of analyzing risk assessment and methodologies are presented in order to highlight main differences and common points and to identify gaps for future development and research.

These two main groups address the impacts and risk and analyze criteria based on varying assumptions. Table 1.1 is designed with the conceptual framework expressed in each risk assessment or management method – specifically risk, hazard, vulnerability and exposure concepts and their application to the specific natural hazard under examination.

Table 1.1: Structure of the criteria used with definition - literature review

Criteria	Definition
Objective	Purpose of the research.
Analytical approach	Specifies the kind of analysis employed in the method.
Input and output	Reports the applied tools and models and describes the input data used in the analytical approach and how the method's results are presented – extended detailing of the final output of every step of the method.
Strengths (S) and weaknesses (W)	Highlights strong points and limitations of the method.

III. FINDINGS

A. Geophysical Hazard

Geophysical hazards include landslides, avalanches, earthquakes and volcanic eruptions; landslide events account for some of the most relevant hazards in Sri Lanka. In Sri Lanka landslide include two main characteristics: (1) material involved landslide (rock, earth) and (2) type of movement landslide (falls, topples, slides, spreads, flows). Landslides are closely connected with hydro-meteorological hazards, as storms can be often linked as a main cause. Landslides are a major threat to human life, property, buildings, infrastructure and natural environments – especially in the hilly regions in Sri Lanka. The landslide susceptibility is spread over the entire hilly region of Sri Lanka, namely in seven districts; Badulla, Nuwara Eliya, Kandy, Kalutara, Ratnapura, Kegalle, Matale , Matara and Galle (National Building Research Organization – NBRO, 2003).

B. Landslide Hazard Methodologies In Sri Lanka

A methods review of the predominant landslide hazards is presented in Table 1.2 and is broken down using the criteria described from Table 1.1.

Dhanushka at.al (1) has (2015) been used quantitative method for the identifying landslide risk and mapping for the Sri Lanka. This study has been developed human settlement map using of overlaying method, weighted method and pairwise ranking method use to weighting the human settlement categories. Mapping process has been carried out by using QGIS which is an open source GIS application. The analyzed data included past satellite images they have been helped identifying building density, open spaces and land uses. Using weighted and pairwise methods has been developed risk maps as high risk, medium and low risk. This risk map will be used for environmental investment in guide plan for the development, early warning system and gathering further information on demographic and housing.

Deheragoda at.al (2) (2003) studied social survey among the landslide affected families in the Kotapola DS division in the Matara District of the Sri Lanka. In this study, questionnaire, case studies, geographical coordinates method were used for identifying landslide affected and vulnerable locations in the Kotapola area. SINMAP model was used mainly used to predict landslide vulnerability for the future. This study will be help regional awareness programme for the Sri Lanka and for the relocation programme.

Virajh et.al(3) (2012) has been studied susceptibilities to shallow landslide occurrence in the Kalawana Divisional division in Rathnapura District. This study used two data collection methods such as fieldwork and laboratory test. An analytical Hierachical process has been used for the development of the attributes map.GIS data sets have combined by weighted average analysis (WAA), landslide susceptibility map of the study area have been created. The resulting information have compared with the landslide susceptibility map derived through the SINMAP model. Both outputs are useful for better understanding of landslide susceptibility and they will be helpful for the reduction and mitigation of future landslide hazards of the study area.

Edirisooriya (4) (2018) was created a landslide zone map using of SINMAP model to the Elaphatha Divisional division of the Rathnapura district. This model found 87% stable, 7% marginal and 5.62% having unstable land of the study area. This data are very important for the development and planning activities of the study area.

Weerasingha et.al (5) (2006) studied a deterministic slope stability predicting tool for landslide vulnerability assessment in the Ratnapura town area. Slope stability analysis model – SINMAP was used in this study. Further GIS technology was used for producing DEM and stability Index grid theme based on 1:10,000 scale contour data. The major output of the SINMAP model is the Stability Index grid theme, which can be used as a landslide hazard zonation map. The model also provides slope area plot charts and statistical summary for each calibration region in the study area facilitating the data interpretation. The results of this study indicate about 72% reliability in predicting slope instability in the selected study area. The output of this result should be significant for the geotechnical and geological evaluation of the site and implementing of the remedial measures and restricted land use practices to the unstable areas. However, it is important to increase the awareness of people who utilize the mountainous areas, in general, regarding the possible causes of slope instability and the importance of applying better land use practices and construction practices.

Prasannaa (6) (2018) studied risk assessment for the high land slide hazard area in Hali Ella GN division in Badulla district. This paper assessed risk according to the frequency, magnitude, and type of hazard and the vulnerability and exposure. Data were collected through secondary and primary data collection methods. stratified samples, house-by-house survey , participatory GIS procedures , building footprint maps have been employed to acquire socio-economic information of both the buildings and inhabitants accommodate in risk buildings of the study area. This paper has been found livelihood of the families rely on lands in landslide prone areas , majority of the houses are not designed by professionals and are constructed without obtained approval from relevant authorities ,majority of the houses not obtain clearance for construction in landslide prone areas, nearly half share of houses locate on steep slope (>31°) terrain , majority of housing units have no drainage system available to discharge rain water ,access road to nearly one third of the housing units have the possibility of damage by disaster and nearly two third of the housing units have no alternative roads to reach their houses, inhabitants in nearly two third of the housing units do not receive instructions on disaster preparedness. The resulting information should be applying formulate and practice risk-based land use planning, develop preparedness plans, early warning systems and hold regular public preparedness drill to enhance the knowledge and ability of the local community to predict, prepare, and respond and to cope with the effect of disasters.

In the study conducted by Kaleela et.al (7) (2017) examines impact of landslide on environment and socio economy in the Badulla district. Primary and Secondary data were used to collect the qualitative and quantitative information. Primary data has been gathered through the observation, group discussion, direct interview and field visit. This methodologies found physical and human factors mainly affected increasing of landslide in the Badulla district of Sri Lanka.

Bandara et.al (8) (1994) studied landslides in the Badulla district. This paper discussed the relationship between geological conditions, rainfall, and land use and slope patterns with causes for landslides in the study area. Field investigation method was used in this study and it was found that most of the landslides originated from the soil of superficial colluviums, residual and weathered rock areas. Further, this study examined the rate of landslide occurrence in the scrap and the dip slope areas respectively.

C. Hydro-Meteorological Hazards Sri Lanka

Hydro-meteorological hazards comprise primarily of foods, storms, water scarcity, extreme temperature events and forest fires. Floods are the most common type of natural disaster in Sri Lanka and they contribute to almost 50% of the total disaster occurrences in the country that devastate lives and property year after year. The district of Colombo, Gampaha Ratnapura Galle ,Matara Kalutara , Ampara , Polonnnaruwa , Trincomale are inundated by floods during the South –western monsoon period and North – eastern monsoon period. Floods have killed about 350 people between 1994 and 2010 and left almost 3.5 million people homeless.

D. Flood Hazard Risk Assessment Methodologies In Sri Lanka

A methods review of the predominant hydro-meteorological hazards are presented in Table 1.2 and is broken down using the criteria described from Table1.1. Within the reviewed papers, a varying definition of risk is provided; authors define risk using different parameters and assumptions. Kumari et.al (1) (2018) studied the qualitative flood risk assessment for the Western Province of Sri Lanka. Risk index was used for this study, which was purely based on weighted parameters. Risk index calculated according to the hazard index, exposure index, and vulnerability index. Accordingly, have been developed flood hazard map, exposure map and social vulnerability map. Populations in 08 (0.9%) GN Divisions are socially at high flood risk, but out of those 08, only 01 is with very high flood hazard and only 04 are with high flood hazard. The results of the economic risk analysis indicate that the population in 01 (0.1%) GN divisions are economically at very high risk of flood, the population in 65 (7.1%) GN Divisions is at high risk. Generated flood risk maps are instrumental in identifying the GN Divisions with high flood risk and can be utilized for determining the appropriate disaster

mitigation options prior to implementing the planned developments for the area. The derived information supports for making decisions on preparedness planning, early warning and other measures which can be implemented for increasing the adaptive capacity of a vulnerable population, and reducing their disaster risk. The outcome of the study also provides provisions for allocating sufficient funds for disaster relief and post disaster rehabilitation.

Edirisooriya (2) (2018) developed the inundation map using of Gumble model for the Ratnapura Divisional Secretariat area (DSD). The main methodology applied in this study was a geographical information system and used digital elevation model, 21 year flood heights records. Throughout this study low, moderate and high flood hazard map and probability of inundation maps for 5 ,10 ,20 30 40 ,50 and 100 years were developed. The results of the inundation maps found 64.3% of the study area comes under the high hazard zone. These include Ratnapura town, Ratnapura town west, Godigamuwa,Thiriwanaketiya and Weralupe. These inundation maps are useful for flood emergency management, implementation of relief and rehabilitation programs,

Soolangaarachi et.al (3) (2005) did a flood hazard assessment for the Rathnapura Municipal Council area. This assessment included a land use zonation map that was developed using secondary data as well as primary data generated through field information. Rajapakse (4) (2003) developed a flood hazard map for the Ratnapura city based on secondary and primary data. This study attempted at developing a plan to minimize damages to life and property caused by floods in Ratnapura city. Liyanarachchi et.al (5) (2006) studied the flood situation in the Ratnapura area. This study was developed digital elevation model and that base developed inundation level in the Rathnapura Municipal Council area. Throughout this study, low moderate and high flood hazard maps were developed. These inundation maps will be useful for policy planners.

Dilhani1 et.al (6) (….) studied flood risk mitigation strategies in vernacular dwelling in the Rathnapura district. Data have been collected through 15 case studies. Case studies have been analyzed using chronological analysis methods. Five parameters have been identified to develop flood risk mitigation strategies of the study area.These parameters are location and orientation, plan configuration, substructure super structure and services. This study has identified the absence of modern materials and professional knowledge in the case study area of the district. Accordingly, this study will be used for the development of materials and construction practices in the flood risk areas in Sri Lanka.

TABLE 1.1 : LANDSLIDE HAZARD METHODOLOGIES REVIEW IN SRI LANKA

Author and year	**Objective**	**Methodology**	**Research out put**	**Strength**

Dhanushka at.al (1) – 2015	Identifying landslide risk in Sri Lanka .	Quantitative methods. (overlaying, weighted, pairwise ranking), QGIS.	Human settlement map, risk map.	S- Environmental investment. - Risk map further information on demographic and housing, early warning system.
Deheragoda at.al (2) 2003.	Social survey among the landslide affected families .	Questionnaire , case studies, Geographical coordinates **M –** SINMAP	Understanding of landslide probability(probability map), social and physical impacts .	S - Regional awareness, relocation purpose. W. - Time, Communication problem .
Virajh et.al (3) 2012	Susceptibilities to shallow landslide occurrence	Field work, laboratory test ,GIS, Hierachical processes. **M**-SINMAP,	Understanding of landslide susceptibility(Attribute map, landslide susceptibility map).	S - Reduction and mitigation of future landslide hazards. Development and planning activities
Edirisooriya (4) 2013	Identifying landslide zone map using of SINMAP model.	Geographical coordinates , GIS **M**-SINMAP,	Understanding of landslide susceptibility (DEM landslide susceptibility map.)	Geotechnical and geological evaluation, site and implementing of the remedial measures and restricted land use practices to the unstable areas.
Weerasingha et.al (5)	Deterministic slope stability predicting tool for landslide vulnerability assessment in Rat	DEM, stability index gride, GIS. **M**-SINMAP	Understanding of landslide susceptibility (Slope map, plot chart, stability map).	
Prasannaa (6) 2018	Risk assessment for the high land slide hazard area in Hali Ella GN division in Badulla district.	House by house survey, PRA.	Livelihood of the families rely on lands in landslide prone areas.	**S**-Formulate and practice risk-based land use planning, develop preparedness plans, early warning systems and hold regular public preparedness drill to enhance the knowledge and ability of the local community.
Kaleela et.al (7) 2017	Impact of landslide on environment and socio-economy in the Badulla district.	observation, group discussion, direct interview and field visit	Physical and human factors, mainly affected increasing of landslide in the Badulla district	
Bandara et.al (8) 1994	Landslides locations in the Badulla district.	Field investigation method.	Landslides originated from the soil of superficial colluviums, residual and weathered rock areas.	

TABLE 1.2: FLOOD HAZARD METHODOLOGIES REVIEW IN SRI LANKA

Author and year	Objective	Methodology	Research out put	Strength
Kumari et.al (1) 2018	Qualitative flood risk assessment for the Wetern Province of Sri Lanka.	Risk index (hazard index, exposure index, and vulnerability index.	Populations in 08 (0.9%)GN Divisions are socially at high flood risk , population in 01 (0.1%) GN divisions is economically at very high risk of flood.	flood risk maps can be utilized for determining the appropriate disaster mitigation options.
Edirisooriya (2) 2018	Developed the inundation map for the Ratnapura DS division.	Field data , Flood level data , GPS data. M- Gumbal model.	Flood inundation maps probability of inundation map.	Flood emergency management, implementation of relief and rehabilitation programmes,
Soolangaarachi (3) 2005	Flood hazard assessment for the Rathnapura Municipal Council area.	Secondary data, primary data.	Land use zonation map.	
Rajapakse (4) 2007	Developed a flood hazard map for the Ratnapura city.	Secondary and primary data.	Inundation map.	Developing a plan to minimize damages to life and property.
Liyanarachchi et.al (5) 2006.	Developed a flood hazard map for the Ratnapura MC area.	Inundation leavel, M- digital elevation model and that base developed inundation level.	Inundation map.	Inundation maps will be useful for policy planners.
Dilhani1 et.al (4) 2016	Risk mitigation strategies in vernacular dwelling in the Rathnapura district	15 case studies.	Identified absence of modern materials and professional knowledge in the case study area.	Development of materials and construction practices in the flood risk areas.

IV. CONCLUSIONS

Based on the review, the existing assessment and management methodologies for the two domains denote natural hazards under given reference to recent analysis and discussion of scientific publications. The analyzed papers are focused only landslide and flood hazards.

This research done the most affected geographic areas and proposes a different risk assessment and management strategies that will be support more suitable management measures (e.g. cost - effectiveness) and stakeholders' participation (e.g. Public participation through workshops)

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