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RESEARCH ARTICLE

Assesse the level of vulnerability in Sri Lankan coastal areas to climate exaggerated disasters: Application of Analytical Hierarchical Process (AHP) and Geographic Information System (GIS)

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Abstract

This paper demonstrated a method to assess the level of vulnerability for climate exaggerated disasters applying AHP (Analytical Hierarchical Process) and GIS (Geographic Information System). Sri Lankan cities have faced severe impacts of climate change over past years. Past records of daily temperature and rainfall data reveals significant changes of temperature and rainfall patterns during last two decades. Coastal urban areas of Sri Lanka were identified as most exposed areas for climate exacerbated disasters since they concentrate larger proportion of urban population and economic infrastructures. Identification of level of vulnerability plays an important role in decision making process.

AHP builds a hierarchy of items using comparisons between items expressed as a matrix where, paired comparisons produce weighting scores. It was used to calculate the weights based on the vulnerability of each climate exaggerated disaster on key sector groupings considered critical for national development. GIS was used to identify the distribution of level of vulnerability among each coastal DSD and for spatial representation of the assessment. Result showed that Negambo, Batticalo, Mundalama, Kalpitiya, Tangalle and Ambalantota are the DSDs with highest level of vulnerability

Introduction

Sri Lankan cities face severe impacts of climate change over past years. 40 years records of daily temperature data reveals a strong trend of temperature increase during last two decades compared to previous two decades. As an example, 0.4-0.5 ^{0}C of temperature increase showed in Batticaloa within last two decades. Similarly, rainfall analysis reveals a strong trend of monsoon rainfall increase (ex: 28% in Batticaloa and 34% Negombo) and correspondent increase of occurrence of minor floods. Showing the changing trend of rainfall increase, Batticoloa experienced the largest flood in recent past (100 years) in December 2010-January 2011 caused fatalities, property losses. Apart from that, sea level rise is another climate change impact is sea level rise that can be experiences within coming decades as modeled by studies done previously (ex: 15%-20% of total population in Negombo and Batticaloa are vulnerable to 1.14m sea level rise as modeled for 2040) (Bandara et la, 2013).

Coastal areas have always been densely populated because of the possibilities they offer for transportation and trade (UNFPA, 2009). Coastal urban areas of Sri Lanka occupies about 3/4 of Sri Lanka's urban population and 80% of economic infrastructure networks. Yet settlements in these locations have also been exposed to a variety of natural hazards – including from sea-level rise, flooding, salination of water resources, storm surges, cyclones, and droughts – and are likely to become increasingly vulnerable as a consequence of climate change (UNFPA, 2009). Both urban disasters and environmental hot spots are already located disproportionately in low-lying coastal areas (Pelling 2003). Further, 'the coastal zone accounts for 43% of the nation's GDP so impacts on coastal settlements translate into substantial impacts on the nation's economy (Disaster management Centre, 2010 cited in Sector Vulnerability Profile, 2010 p-11). Flooding and strong winds are the most pressing climate exacerbated disaster in Sri Lanka and it severely affects coastal urban areas which agglomerate urban activities and population. The magnitude of the problem increase as a large proportion of coastal towns heavily depend on natural resources for livelihood as fishing and tourism.

With the identification of climate change impacts of coastal urban areas and considering the magnitude of the problem, there comes a need of adaptation measures to minimize the impacts of such natural disasters. Adaptation measures vary with the situation and the level of vulnerability of each location. Apart from that, assessing the level of vulnerability of key sector groupings considered critical for national development would lead to determine, to what extent the attention should pay for each sector to reduce the impacts of climate exaggerated disasters. The identification of level of potential key vulnerabilities is intended to provide guidance to decision-makers. Level of vulnerability on key sectors that are critical for national development is important in preparation of urban development plans. Identification of level of vulnerability would emphasize the precedent need in including climate change adaptation actions such as resource allocation, disaster management, capacity development etc. for each sector to reduce the effect of vulnerability to climate exaggerated disasters in the process of decision making.

Modern day decision-making has been inherently complex when many factors have to be weighed against competing priorities. (Alexander, 2012) Thomas Saaty has developed one of the modern tools, the Analytic Hierarchy Process (AHP) within last 30 years that was used to assess, prioritize, rank, and evaluate decision choices. AHP builds a hierarchy (ranking) of decision items using comparisons between each pair of items expressed as a matrix where, paired comparisons produce weighting scores that measure how much importance items and criteria have with each other (Alexander, 2012).AHP is a method that was developed to optimize decision making for situations with mix of qualitative, quantitative, and sometimes conflicting factors that are taken into consideration.

AHP is a widely used tool as a multi-criteria decision analysis method that solves decision making problems. A study done by Pedcris M. Orencio and Masahiko Fujii, 'A Localized Disaster-Resilience Index to Assess Coastal Communities Based on an Analytical Hierarchy Process (AHP)' has proposed a novel approach to develop a tool for quantifying disaster resilience in the Philippines by synthesizing national-level disaster resilience components using the Analytic Hierarchy Process. Study emphasizes that as a decision system, the AHP is valuable for using human cognition in determining the relative importance among a collection of alternatives using paired comparisons. It was found that the tool is effective when assigning weights for indicators of disaster risks and vulnerability indices or when ranking risk factors in a flood risk assessment model. In this study, the AHP was used to determine the criteria and elements that best described a disaster-resilient coastal community at the local level by subjecting the components of a risk management and vulnerability reduction system in the Philippines (Orencio, 2013).

Correspondingly, numerous previous studies could be found using AHP as a tool for different fields. AHP has used for mapping landslide hazard and susceptibility by Ayalew (2005), Ercanoglu, (2008), Gorsevski (2006) and Yalcin (2008). To rank different coastal protection options, Chang et al. (2012) has applied this method. The study done by Yin (2012) 'National assessment of coastal vulnerability to sea-level rise for the Chinese coast' is an application of AHP for physical coastal vulnerability assessment.

Geographic Information System (GIS) is a computer-based tool for mapping and analyzing existent things and events that happen on earth. Maps are the primary media of geographical information and the elementary objects manipulated in GIS and they are graphic representations of geographic features, generalized by mathematical rules and represented by visual symbols for different purposes (Wei, 2000). Simultaneously, maps imply the distributions, states and association of diverse natural or social phenomena. GIS is used in this study to indicate the distribution and better spatial representation of level of vulnerability in coastal DSDs.

With understanding of the need of identification of level of vulnerability to climate change and the, this study attempts to assess the level of vulnerability to climate exaggerated disasters in Sri Lankan Coastal Areas using Analytical Hierarchical Process (AHP) and Geographic Information System (GIS).

1. Methodology

Identification of key sector groupings considered critical for national development and climate exaggerated disasters, it was done based on a study carried out in Sri Lanka to support the government initiative to adapt key sectors in the economy and safeguard Sri Lanka's national interest against climate change threats by Ministry of Environment, Sri Lanka.

Identified key sectors are;

1. Human Settlements Sector
2. Transport Infrastructure Sector
3. Tourism Sector
4. Drinking Water Sector
5. Irrigation Sector
6. Paddy Sector
7. Plantation Sector
8. Fishery Sector
9. Livestock Sector

Climate exaggerated disasters

1. Drought
2. Flood
3. Landslide Exposure
4. Sea Level Rise (Ministry of Environment, Sri Lanka, 2011)

Following diagram shows the adopted methodology for this study. AHP was used to calculate the weight for each

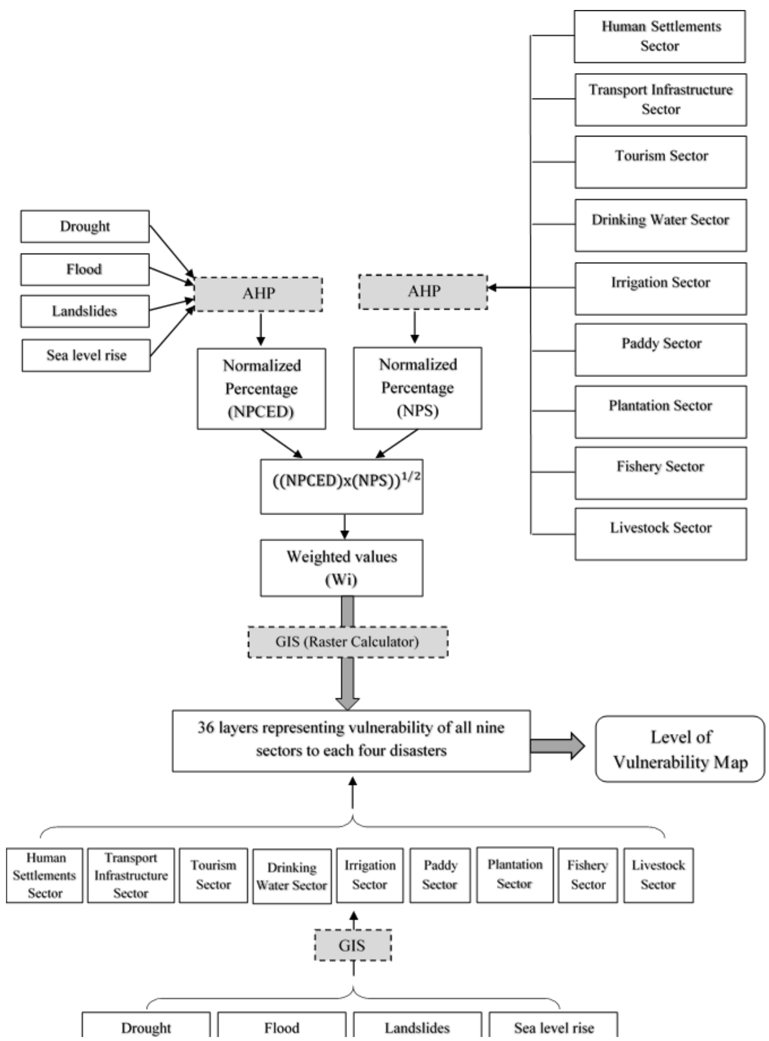

Fig 1. Methodology of the study

sector vulnerability to climate exaggerated disasters and the calculated weight was assigned by using GIS.

Steps of the methodology are described further.

Required data on above mentioned key sectors were as arranged based on exposure to climate change vulnerability of each different sector. To determine the weight of each sector, they are compared together in a 1-9 ordinal scale as mention in Table 1.

This weight factor is determined based on collected opinions of professionals in each relevant field. A sample of 50 professionals were engaged in this task Table 2.

The study area of this study has been selected as Divisional Secretariats Divisions (DSDs) along the coastal line of Sri Lanka. The availability of GIS database was important to carry out this task. Data has been collected from Climate Change Vulnerability Data Book (Ministry of Environment, Sri Lanka January 2011). The available GIS data is largely based on publicly available data sources. According to the Ministry of Environment, for GIS mapping the basic methodology has been adopted to develop indices for exposure, sensitivity, and adaptive capacity relevant to each given sector. These three indices were then combined to create a composite sector-specific vulnerability index. This has not been done for Northern and Eastern provinces due to complete and comparable data sets of relevant indicators could not be obtained (North and East census data is not available) since this has been used 2001 National Census data. Batticaloa District has been taken in to the account using considerable complete data sets based on past studies.

Spatial data has been employed according to Ministry of Environment's GIS map data. It has identified the vulnerable areas for different disasters in each sectors. Vulnerable areas have been classified according to the type of vulnerability under five categories. 1-9 sectoral ordinal scale has been used to measure the pair-wise comparison of climate exaggerated disasters. Values were assigned based on expert's opinion and supervision. Table 3 shows the results of Pair-wise comparison on climate exaggerated disasters factor. Further, Pair-wise comparison has done on Sector as same as the climate exaggerated disasters analysis. Table 3 shows the result of Pair-wise comparison on climate exaggerated disasters.

To determine the weight of each factor, those were compared together in a 1-9 ordinal scale as shown in Table 4. As the result of the analysis matrices are created, in this case two matrices are created and components of each matrices are positive and regarding the "reverse condition" in AHP, there will be an inverse value of the particular components, that mean if the weight of i in relation to j equals to k, the weight of j in relation to i will equal to 1/k.

After developing a comparison matrices Normalized Score has been calculated by dividing each value of a column by its total. Then Cumulative Normalized Score is calculated by adding all the components of each row, it has been done for climate exaggerated disasters matrix and the sector matrix. Once it has been done, the percentage values can be obtained by dividing each component of Cumulative Normalized Score by its sum and multiplying by 100. For instance, for the Drought row; Cumulative Normalized Score = (1/6.53) + (0.2/1.68) + (3/7.33) + (5/16) = 0.99, once it was converted to percentage value, (0.99/4)*100=25%. Here Normalized Percentage of climate exaggerated disasters is named as NPCED and Normalized Percentage of Sector is named as NPS. Finally, to identify the priority and calculate the weighted value of the factors, each factor has been multiplied by each sector and calculated the square root of the value ($((\mathrm{NPCED})\mathrm{x}(\mathrm{NPS}))^{1/2}$). Further, to calculate the weight factor (Wi) that value has been converted to the percentage by dividing the each value by its sum and multiplying by 100. Table 6 shows the weighted value of the factors. The consistency of each factor on each sector was investigated. Basic judgments were made based on expert's knowledge and experience and it helped to identify the level of vulnerability to climate exaggerated disasters in each sector. In order to determine the spatial consistency in real ground, resulted weights were used in GIS.

GIS was used to model the relative measure of overall vulnerability of each DSD along the costal belt

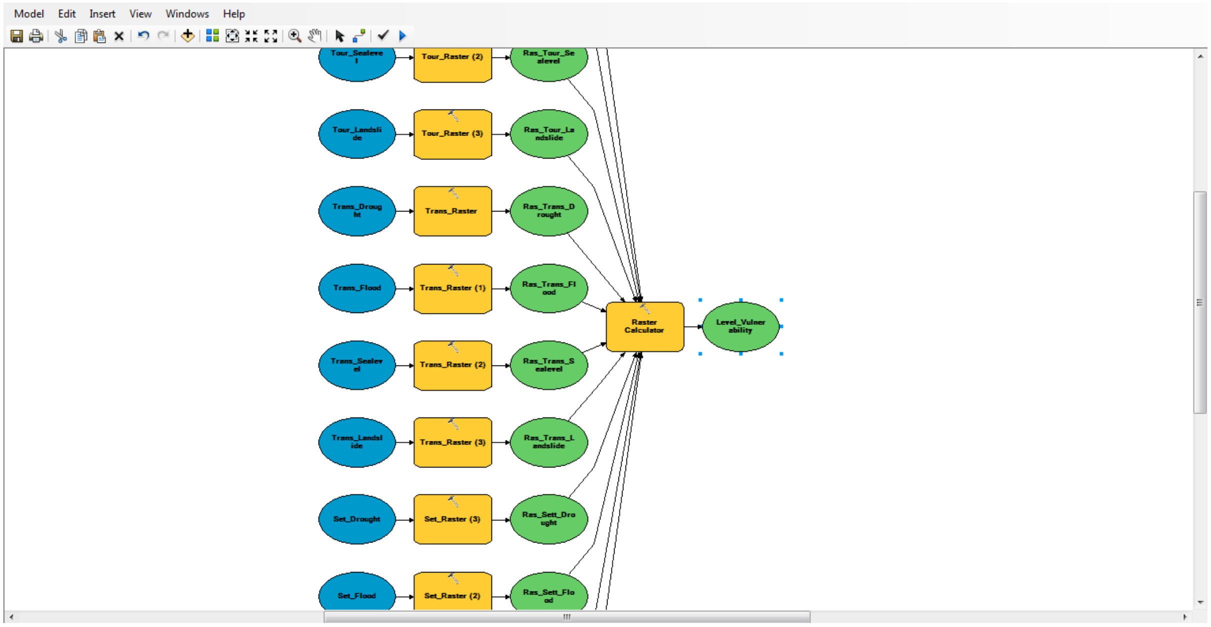

Fig 2. GIS model to calculate the level of vulnerability

Each layer of sectoral vulnerability for climate exaggerated disasters were given the calculated values (weight -Wi) from above mentioned methodology using AHP were assigned using Raster Calculator and all the 36 layers were combined together to determine the most and least vulnerable areas.

Above series of maps shows the level of human settlement sector vulnerability for each climate exaggerated disasters; drought, flood and sea level rise. Landslide vulnerability in is none since coastal DSDs are located in a low-line area. So the landslide vulnerability map is not shown here. This is the series of maps in relation to human settlements sector. Same process is done for all the other 8 sectors and vulnerability of each sector to four disasters were assessed.

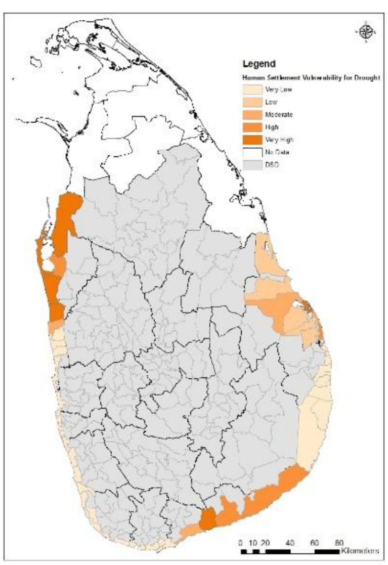

Fig 3. Human settlement Vulnerability for Drought

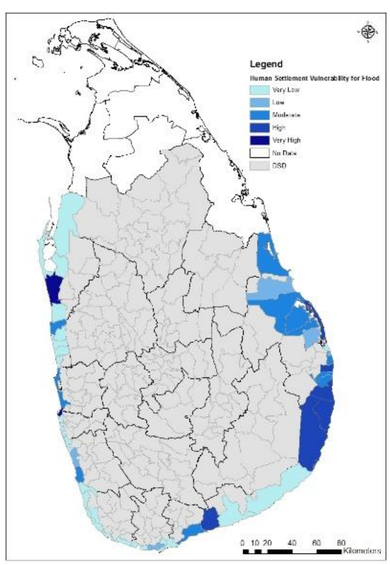

Fig 4. Human settlement Vulnerability for Flood

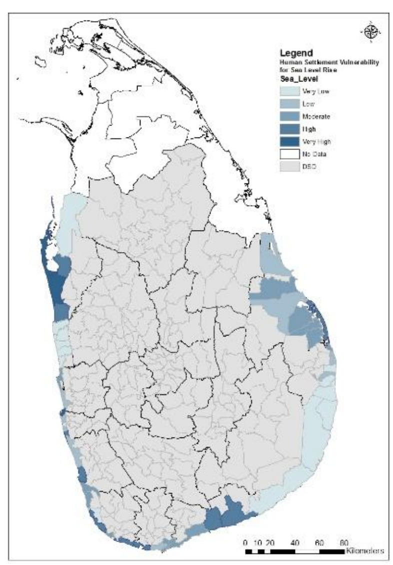

Fig 5. Human settlement Vulnerability for Sea Level Rise

Finally, the output map was resulted which shows the most and least vulnerable DSDs along the coastline.

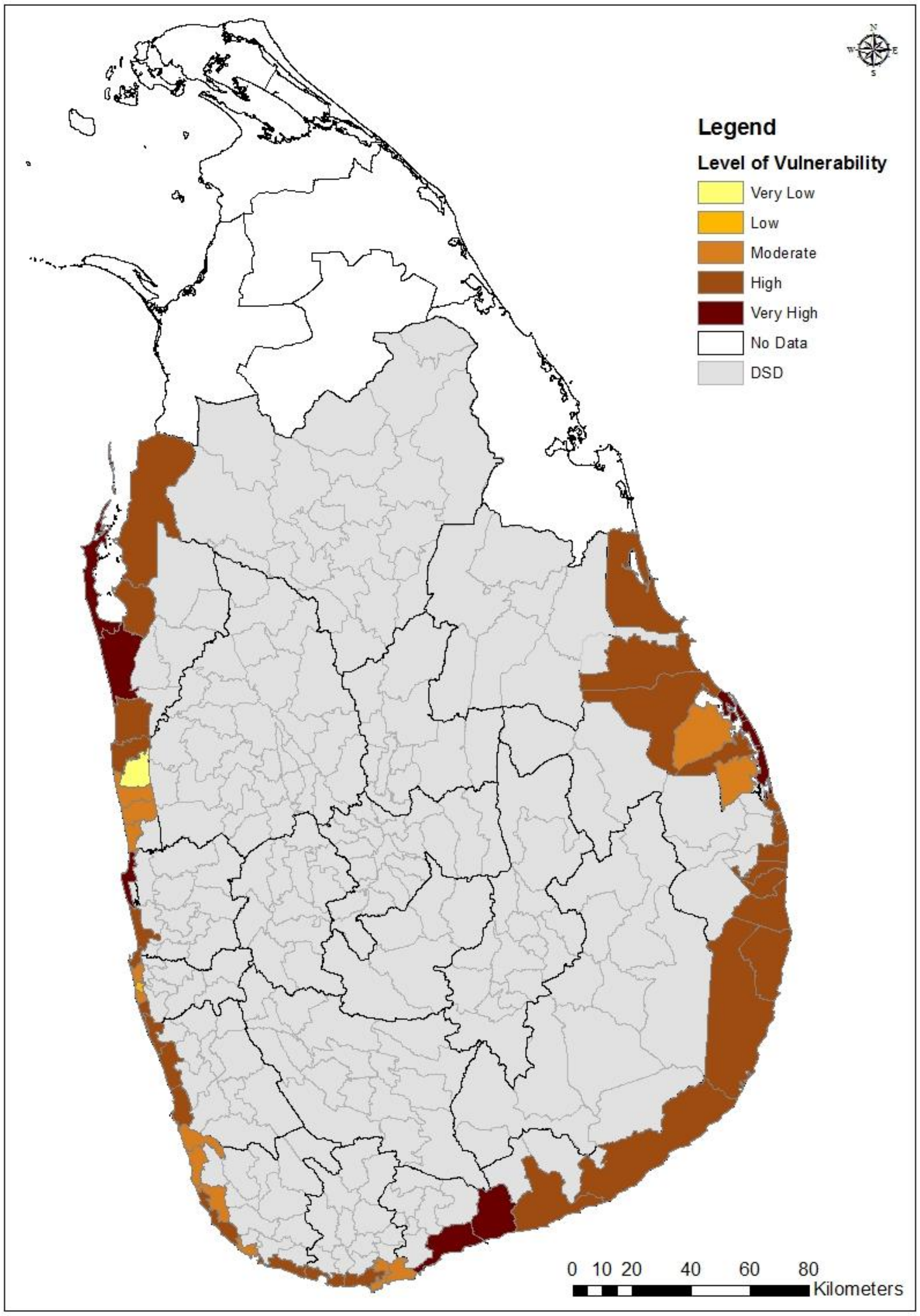

Fig 6. Map of vulnerability to climate exaggerated disasters in Sri Lankan Coastal Areas

Figure 6 shows the level of vulnerability of Sri Lankan Coastal DSDs to climate exaggerated disasters Analyses revealed that Negambo, Batticalo, Mundalama, Kalpitiya, Tangalle and Ambalantota DSDs showed very high level of vulnerability compared to other DSDs. Madampe showed very low vulnerability, since does not have a direct contact with the sea. When all DSDs were taken in to the account most of the coastal DSDs showed comparatively moderate level of venerability for climate exaggerated disasters. Accordingly, this study proved that there is a significant vulnerability for coastal areas of Sri Lanka on climate exaggerated disasters and their level of impacts.

2. Conclusion

Using the methodology of measuring vulnerability, it can be suggested to identify the level of vulnerability for almost all the sectors to what the climate change will impact on. Most of the studies have done to identify the level of vulnerabilities for one specific sector. This concept helps to identify the level of vulnerability to climate exaggerated disasters in each DSD along the coastal belt. Level of vulnerability is not calculated for DSDs in Northern and Eastern provinces due to unavailability of data. Expert's participation was important when assigning the values for comparison which enabled to improve the reliability and accuracy of the analysis. As one approach, this study was capable to show the level of vulnerability of all climate exaggerated disasters in all sector groupings that were identified as critical for national development.

Table 1: Nine level scale for binary comparison of different factors

Importance	Weight
1	equal weight
2	equal – moderate
3	moderate
4	moderate – strong
5	strong
6	strong-very strong
7	very strong
8	very strong- extremely strong
9	extremely strong

Table 2 Selected Professionals regarding their field of expert

Experts Area	No of participants
Urban Planning	10
Housing	8
Transport Planning & Engineering	7
Disaster Management	10
Agriculture & Livestock	8
Tourism	7
Total	**50**

Table 3 Summary Results of Pair-wise comparison on climate exaggerated disasters

Factors	Drought	Flood	Landslide Exposure	Sea Level Rise
Drought	1.00	0.20	3.00	5.00
Flood	5.00	1.00	3.00	7.00
Landslide Exposure	0.33	0.33	1.00	3.00

Sea Level Rise	0.20	0.14	0.33	1.00
Total	**6.53**	**1.68**	**7.33**	**16.00**

Table 4 Nine level scale for binary comparison of different factors

Importance	Weight
1	equal weight
2	equal – moderate
3	moderate
4	moderate – strong
5	strong
6	strong-very strong
7	very strong
8	very strong- extremely strong
9	extremely strong

Table 5 Summary Results of Pair-wise comparison on Sector

		1	2	3	4	5	6	7	8	9
Human Settlements Sector	**1**	1.00	5.00	7.00	3.00	7.00	5.00	9.00	7.00	9.00
Transport Infrastructure Sector	**2**	0.20	1.00	7.00	3.00	5.00	7.00	9.00	7.00	9.00
Tourism Sector	**3**	0.14	0.14	1.00	0.14	0.20	0.14	0.20	0.14	0.20
Drinking Water Sector	**4**	0.33	0.33	7.00	1.00	7.00	5.00	9.00	5.00	9.00
Irrigation Sector	**5**	0.14	0.20	5.00	0.14	1.00	3.00	5.00	0.33	5.00
Paddy Sector	**6**	0.20	0.14	7.00	0.20	0.33	1.00	7.00	3.00	9.00
Plantation Sector	**7**	0.11	0.11	5.00	0.11	0.20	0.14	1.00	0.14	1.00
Fishery Sector	**8**	0.14	0.14	7.00	0.20	3.00	0.33	7.00	1.00	5.00
Livestock Sector	**9**	0.11	0.11	5.00	0.11	0.20	0.11	1.00	0.20	1.00
Total		**2.38**	**7.18**	**51.00**	**7.91**	**23.93**	**21.73**	**48.20**	**23.82**	**48.20**

Table 6 Priority and weighted value of the factors

Priority and weighted value of the factors	$((NPCED)x(NPS))^{1/2}$	Weighted value (Wi)	Priority
Human Settlements Sector Vulnerability to Drought Exposure	28%	6%	3
Human Settlements Sector Vulnerability to Flood Exposure	42%	8%	1
Human Settlements Sector Vulnerability to Landslide Exposure	21%	4%	5
Human Settlements Sector Vulnerability to Sea Level Rise	13%	3%	6
Transport Infrastructure Sector Vulnerability to Drought Exposure	23%	5%	4
Transport Infrastructure Sector Vulnerability to Flood	34%	7%	2

Priority and weighted value of the factors	$((NPCED)x(NPS))^{1/2}$	Weighted value (Wi)	Priority
Exposure			
Human Settlements Sector Vulnerability to Landslide Exposure	18%	3%	6
Transport Infrastructure Sector Vulnerability to Sea Level Rise	11%	2%	7
Tourism Sector Vulnerability to Drought Exposure	6%	1%	8
Tourism Sector Vulnerability to Flood Exposure	9%	2%	7
Tourism Sector Vulnerability to Landslide Exposure	5%	1%	8
Tourism Sector Vulnerability to Sea Level Rise	3%	1%	8
Drinking Water Sector Vulnerability to Drought Exposure	21%	4%	5
Drinking Water Sector Vulnerability to Flood Exposure	31%	6%	3
Drinking Water Sector Vulnerability to Landslide Exposure	16%	3%	6
Drinking Water Sector Vulnerability to Sea Level Rise	10%	2%	7
Irrigation Sector Vulnerability to Drought Exposure	13%	3%	6
Irrigation Sector Vulnerability to Flood Exposure	19%	4%	5
Irrigation Sector Vulnerability to Landslide Exposure	10%	2%	7
Irrigation Sector Vulnerability to Sea Level Rise	6%	1%	8
Paddy Sector Vulnerability to Drought Exposure	15%	3%	6
Paddy Sector Vulnerability to Flood Exposure	22%	4%	5
Paddy Sector Vulnerability to Landslide Exposure	11%	2%	7
Paddy Sector Vulnerability to Sea Level Rise	7%	1%	8
Plantation Sector Vulnerability to Drought Exposure	8%	2%	7
Plantation Sector Vulnerability to Flood Exposure	12%	2%	7
Plantation Sector Vulnerability to Landslide Exposure	6%	1%	8
Plantation Sector Vulnerability to Sea Level Rise	4%	1%	8
Fishery Sector Vulnerability to Drought Exposure	14%	3%	6
Fishery Sector Vulnerability to Flood Exposure	20%	4%	5
Fishery Sector Vulnerability to Landslide Exposure	10%	2%	7
Fishery Sector Vulnerability to Sea Level Rise	6%	1%	8
Livestock Sector Vulnerability to Drought Exposure	8%	2%	7
Livestock Sector Vulnerability to Flood Exposure	12%	2%	7
Livestock Sector Vulnerability to Landslide Exposure	6%	1%	8
Livestock Sector Vulnerability to Sea Level Rise	4%	1%	8

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