DEVELOPMENT OF A RESILIENCE MEASUREMENT TOOL TO EVALUATE THE COMMUNITY RESILIENCE

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DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Abstract

The frequency of disasters and emergencies has increased rapidly during the past few decades and it is necessary to conduct more research in this field to improve the knowledge levels and capacities of individuals/systems. And subsequently this can assist policy makers. Instead of managing disasters after the outbreak, in the present situation the researchers are more concerned about improving the resilience of communities to face impacts. Under this background, methods to measure community resilience are vital because it can be used to identify the vulnerable communities and resilience scores can be used in the decision-making process. To assist the process, this research aims to develop a universal tool to quantify the levels of resilience of communities to the impacts.

From the literature, indicators which are relevant to resilience measurements were listed, suitable indicators were filtered and then the method of measurement was defined. Overall, 108 indicators have been listed on this scorecard under five main capital domains, including, social, economic, physical, human and environmental. This list was sent to the experts and the index was refined based on the expert comments. To provide the resilience score, two types of scoring methods (Community Resilience Scores - CRS_1 and CRS_2) have been introduced in this dissertation where the first method uses a general approach to calculate the resilience and the second method uses a more descriptive approach including the four main disaster management phases (Mitigation, Preparedness, Response and Recovery). The scoring method has been defined to calculate the overall resilience, resilience to floods and resilience to droughts. The method has not validated yet and open for researchers to test this method.

However, applicability of the tool is explained using a few case studies and these cases show the overall resilience values, values for resilience for floods and droughts in some selected regions in Sri Lanka. From the case studies, the overall resilience values (CRS_1) show that social and environmental resilience is higher in the rural areas compared to the urban areas while the economic and physical resilience is higher in the urban areas compared to the rural areas. According to the CRS_2 the response stage shows lower scores in many of the selected regions. Similarly, using the values of the proposed two matrices (CRS_1 and CRS_2), gaps in the major capital domains in a given administrative region can be identified and this is important to undertake further developments and for allocation of resources. The proposed scoring method can be used to prepare resilience level maps and to identify vulnerable regions as well.

The study can be extended to improve the index to measure the resilience to other disasters, including hurricanes, landslides, tsunamis and other coastal hazards.

Key words: Disaster resilience; Resilience index; Resilience measurements; Resilience evaluation; Indicators

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LIST OF ABBREVIATIONS

Abbreviation	Description
CDRF	Community Disaster Resilience Framework
REDI	Resilience to Emergencies and Disasters Index
SDGs	Sustainable Development Goals
CRS	Community Resilience Score
DSD	Divisional Secretariat Division
DM	Disaster Management
DRR	Disaster Risk Reduction
CRS	Community Resilience Score

1.0 INTRODUCTION AND STRUCTURE OF THE THESIS

1.1 Background

The change of climate has become one of the major problems the world is facing. As a result of climatic changes and all the related factors, the sea level has risen at a rate of 1.8 mm/year during past few decades [1]. And the magnitude and the frequency of disasters like floods, droughts, hurricanes, earthquakes wildfires is on increase. Under these circumstances, not only in Sri Lanka, but many parts of the world face emerging issues and crisis from time to time. The extent of economic damage the world has faced during past years clearly depicts the criticality of these issues.

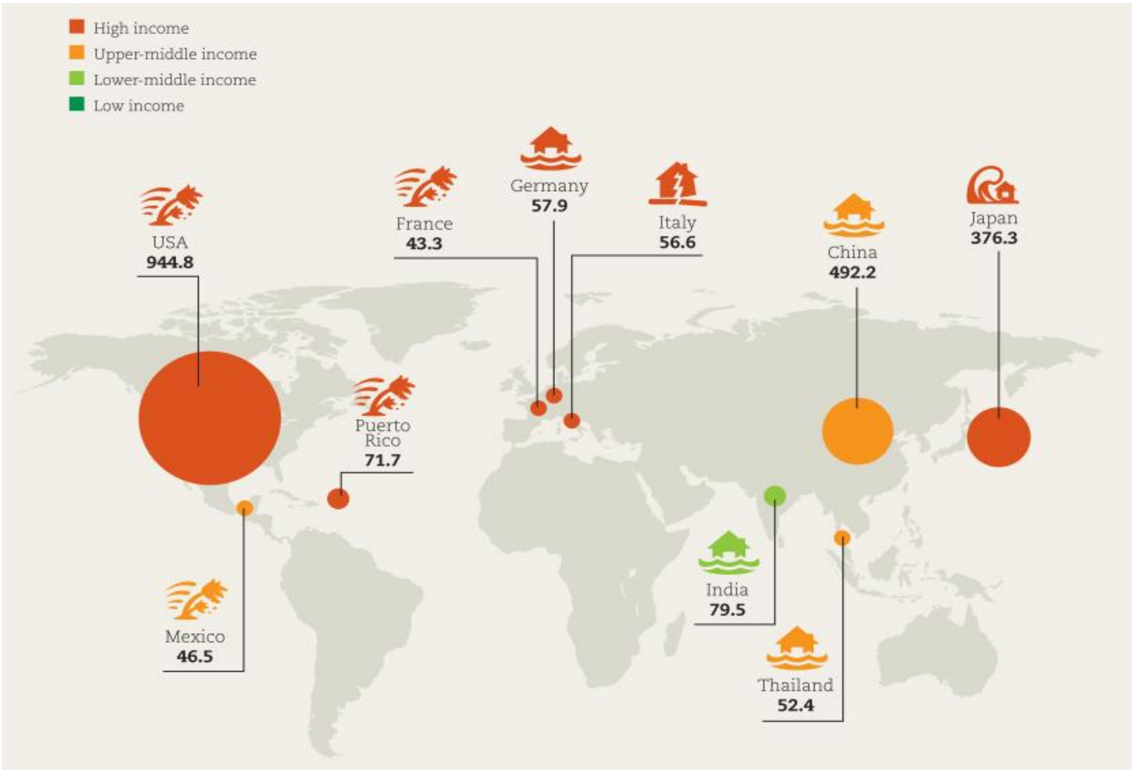

Figure 1.1: Top 10 countries in the world in terms of absolute losses due to disasters (billion US$) 1998 – 2017

(Source: Geoscience Frontiers Why would sea-level rise for global warming and polar ice-melt 2019 [2])

Disaster types responsible for the majority of losses are earthquake, tsunami, storm, flood, drought and extreme temperatures. However, when the economic damage is considered compared to the GDP, the impact for some countries is extensive as shown in the Figure 2.

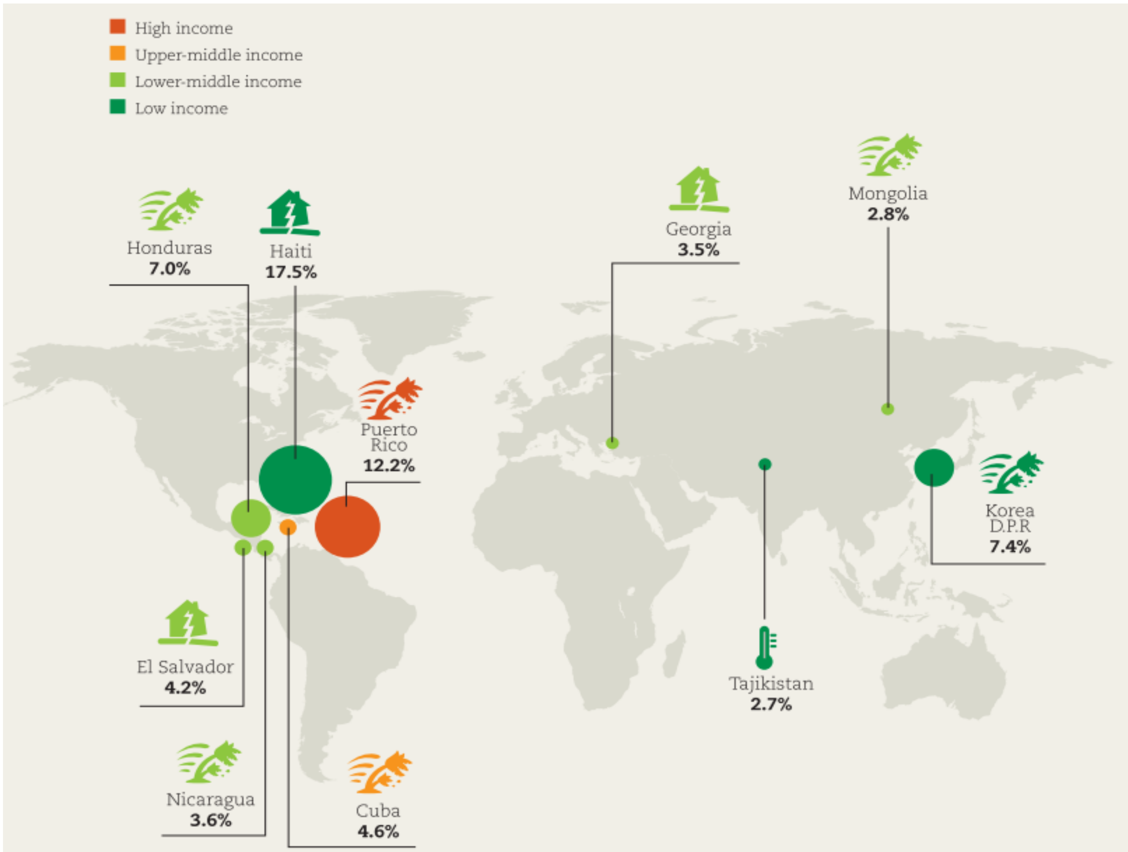

Figure 1.2: Top 10 countries in terms of average annual percentage losses relative to GDP

(Source: Geoscience Frontiers Why would sea-level rise for global warming and polar ice-melt 2019 [2])

The disaster types considered to assess the damage in Figure 1.2 are earthquake, tsunami, storm, flood, drought and extreme temperatures. Overall, when the disasters relevant to the period 1998-2017 is considered, the list includes; floods (43.4%), storms (28.2%), earthquakes (7.8%), extreme temperature (5.6%), landslides (5.2%), drought (4.8%), wildfire (3.5%) and volcanic activity (1.4%). Within this period, a total of 747, 234 deaths has been recorded [2]. The damage from floods in Sri Lanka are as in the Figure 3, 4 and 5.

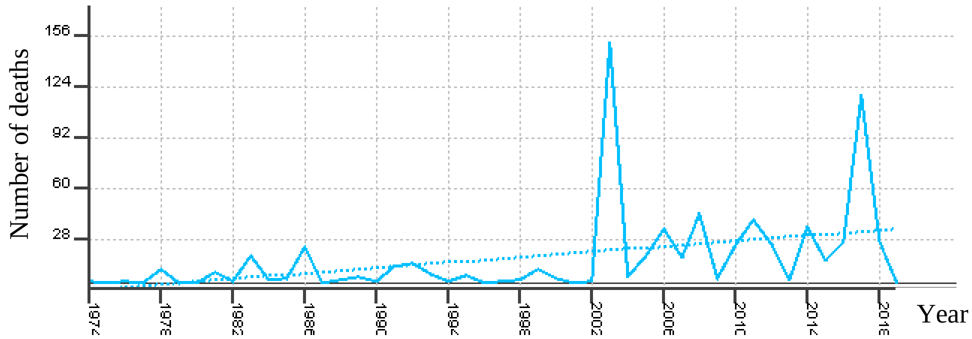

Figure 1.3: Deaths from floods 1974 – 2018

(Source: Disaster Information Management system in Sri Lanka 2019 [3])

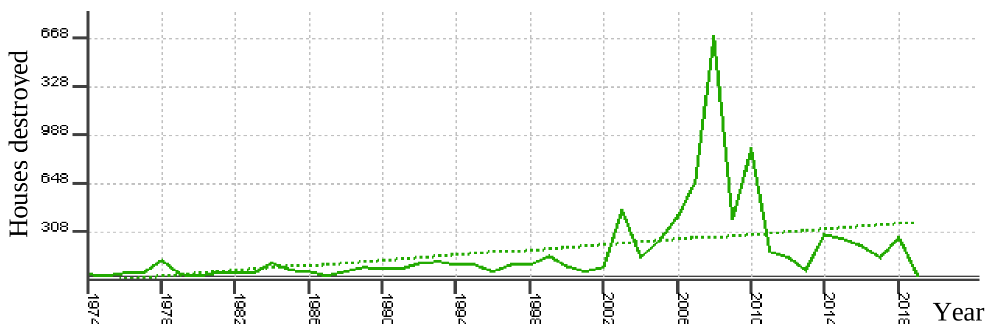

Figure 1.4: Houses destroyed, Houses Damaged 1974 – 2018

(Source: Disaster Information Management system in Sri Lanka 2019 [3])

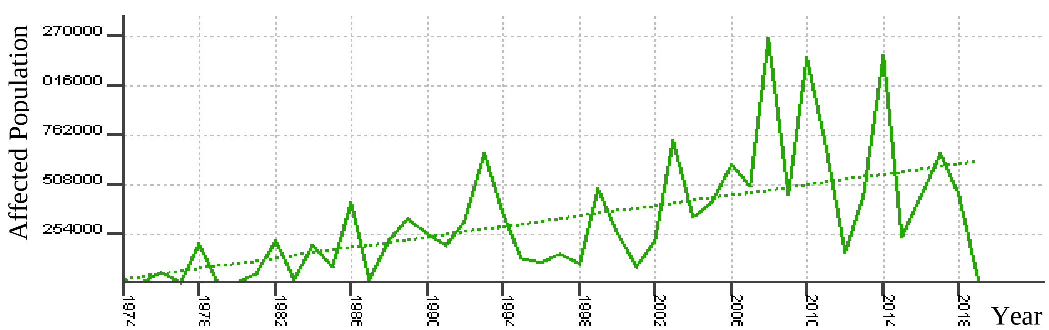

Figure 1.5: Affected Population from Floods 1974 – 2018

(Source: Disaster Information Management system in Sri Lanka 2019 [3])

The rapid increase of the damage due to droughts is as per Figures 6 and 7 [2].

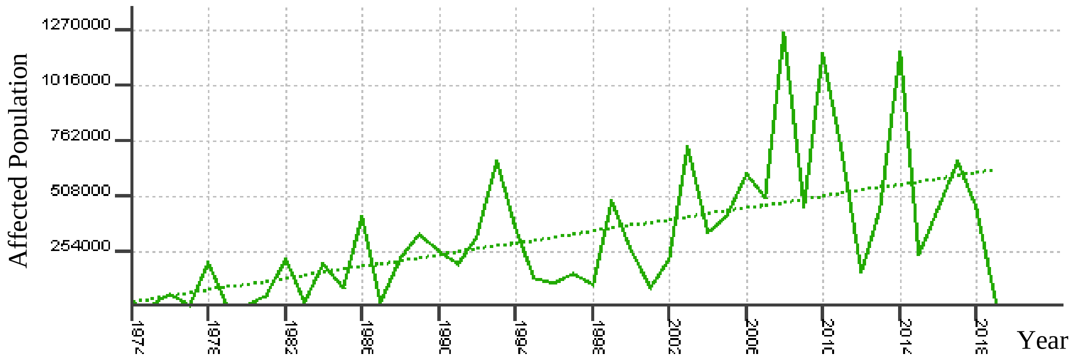

Figure 1.6: Affected population from droughts 1974-2018

(Source: Disaster Information Management system in Sri Lanka 2019 [3])

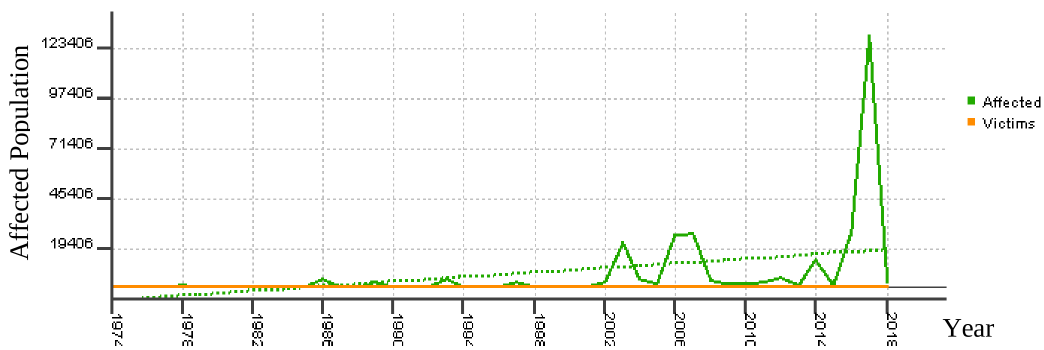

Figure 1.7: Affected population from land-slides 1974-2018

(Source: Disaster Information Management system in Sri Lanka 2019 [3])

To face these issues, the world needs to find new solutions and should make sure that the impact of disasters will not have a significant impact on the economic development. To propose solutions, the policy makers should have an idea about the level of resilience of communities to the impacts. To understand the levels of resilience of communities, resilience measurements are important.

1.2 Problem statement

The application of resilience has been growing in the hazard literature from the recent past. With this growing trend, some questions that have emerged are: can the resilience be measured? And what is the method to measure the resilience? There is very little research on this topic and it is questionable whether we have methods to comprehensively assess the resilience of communities to disasters. And also, identification of levels of resilience of communities before, during and after an impact is important to identify whether they are moving forward or lagging behind. This research intends to fill this gap by developing a universal tool to assess resilience of communities so that it can assist the decision making process.

1.3 Scope of study

Discussions about resilience building are frequent from recent times and now more emphasize has been given to building resilient communities and thereby to reduce the magnitude of emergency management. Many researchers have developed tools and frameworks to measure the resilience of communities to disasters/hazards. But very little work has been done to evaluate the overall resilience of communities. In-fact, the focus of this thesis will be to develop a tool to evaluate the overall resilience of communities including the resilience for disasters. Disaster resilience is a sub-set of the community resilience and the relationship is shown in the Figure 6.

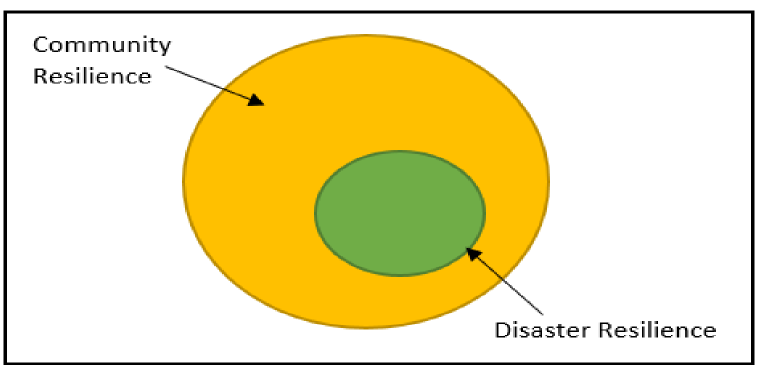

Figure 1.8: Relationship between community resilience and disaster resilience

1.4 Research objectives

The main objective of this research is to develop an index to evaluate the overall resilience of communities. To achieve this objective, three specific objectives have been defined.

The specific objectives of the research include the following:

- To identify the relevant indicators to measure the overall resilience of communities to the impacts
- To develop an universal tool to quantify the resilience
- To study the applicability of the resilience measurement tool

1.5 Outcomes

This dissertation focuses to operationalize the concept of community resilience by providing a tool (Community Resilience Score – CRS) to quantify the concept of resilience. The proposed two output matrices are important to identify vulnerable regions and to identify the gaps in DRR. These two matrices can be used in the decision making process and to support the process of resource allocation.

1.6 Arrangement of the thesis

This dissertation includes seven chapters, including the introductory chapter. Figure 1.9 graphically illustrates the flow of the chapters. The chapter 1 set the tone for the dissertation by providing the background, problem statement, scope of study, research objectives and the outcomes. The chapter 2 focuses on defining the terms related to resilience and identifying the tools and frameworks relevant to resilience measurements. Chapter 3 describes the research methodology and the development of the tool is in the fourth chapter. Fifth chapter includes the case studies and the sixth chapter summarize the findings. The last chapter list out the literature used for the development of the index.

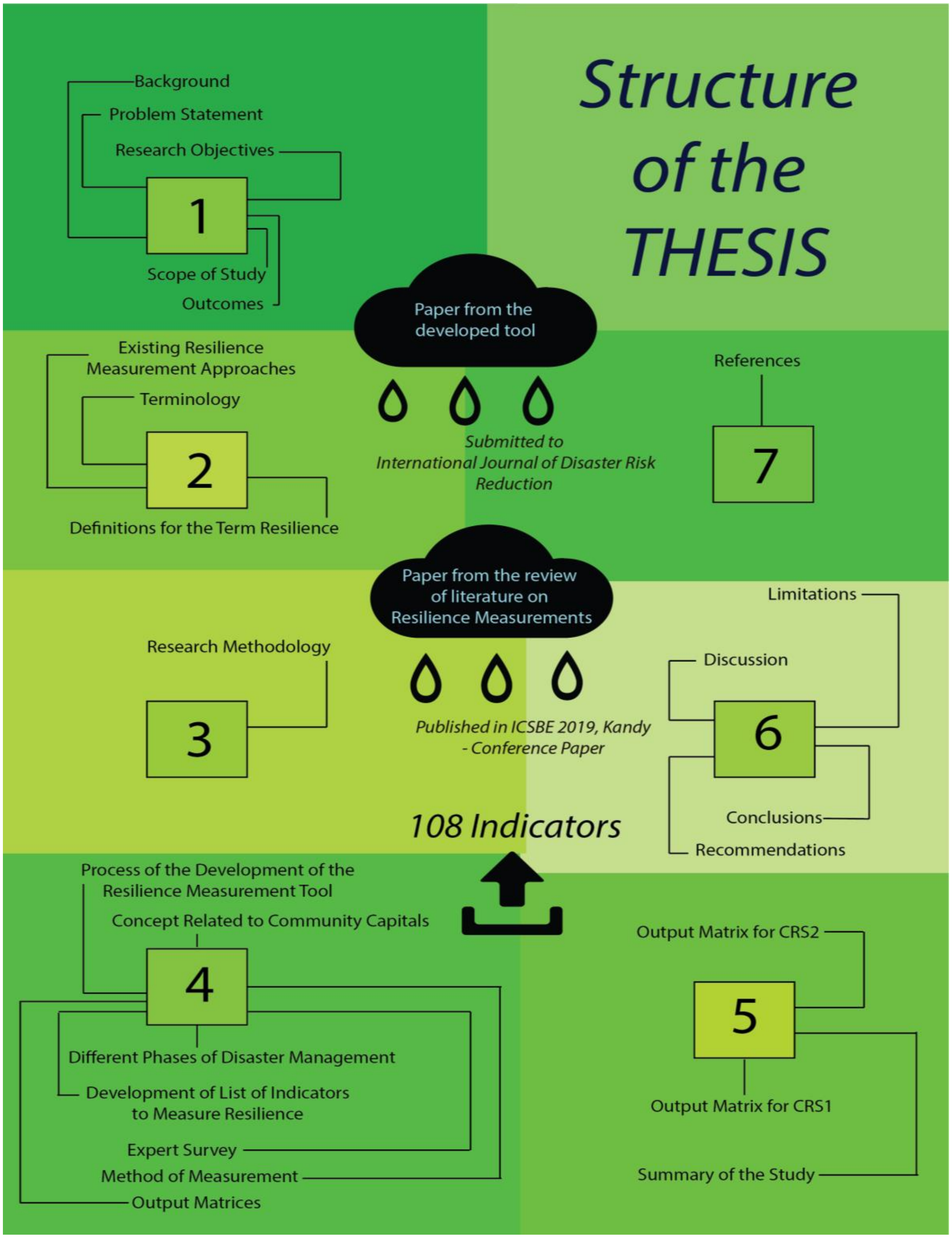

Figure 1.9: Structure of the dissertation

2.0 LITERATURE REVIEW

2.1 Introduction

The literature review composed of two sections. The first part focuses on identifying terminologies and definitions related to the term resilience and the second part focuses on identifying the important tools and frameworks related to the resilience measurement. Then the last part of the chapter includes the summary of the reviewed tools and frameworks used for the development of the index.

2.2 Important aspects of community resilience

There are various terminologies related to resilience and it is necessary to have a thorough understanding about these to proceed with related research works. Thus, the main terminologies and the definitions related to resilience are discusses in this chapter.

2.2.1 Terminology

Community: A group of people with dissimilar attributes but connected by social ties, share common views and joint actions in geographical regions or settings [4].

Resilience: Ability to anticipate, absorb, accommodate or recover from hazards in an efficient and timely manner through restoration, preservation or improvement of structures and functions. [5] .

Disaster: A serious disruption of the activities of a community or a society including widespread human, economic, environmental or material losses and impacts, which exceeds the capability of the affected society or community to cover using its own resources. [5]

Hazard: A serious phenomenon, human activity substance or condition that may cause loss of life, injury or other health influences, loss of livelihoods and services, property damage, environmental damage or social and economic disruption. [5]

Emergency: This term is used interchangeably with the term disaster, as, for example, in the context of biological and technological hazards or health emergencies, which, however, can possibly relate to hazardous events that do not cause in the serious disruption of the activities of a society or community. [6]

Disaster Management: The planning, organization and application of measures preparing for, responding to and recovering from disasters. [6]

Disaster Risk: The potential loss of life, injury, damaged or destroyed assets which could occur to a society, system or a community in a given period of time, determined probabilistically as a function of exposure, hazard, capacity and vulnerability. [6]

Disaster Risk Reduction: Disaster risk reduction is targeted at preventing new and reducing prevailing disaster risk and managing residual risk, all of which contribute to resilience strengthening and therefore for the attainment of sustainable development. [6]

Mitigation: The minimizing or lessening of the adverse impacts of a hazardous event. [6]

Preparedness: The capacities and knowledge developed by governments, response and recovery organizations, individuals and communities to effectively anticipate, respond to and recover from the impacts of disasters. [6]

Early warning system: An integrated system of hazard monitoring, prediction, forecasting disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, businesses, governments and others to take timely action to lower disaster risks in advance of hazardous events. [6]

Evacuation: Moving people and assets temporarily to safe places before, during or after the outbreak of a hazardous event in order to safeguard them. [6]

Prevention: Measures and activities to avoid existing and new disaster risks. [6]

Recovery: The improving or restoring of health and livelihoods, as well as economic, physical, cultural, social and environmental assets, activities and systems of a disaster -

affected community, aligning with sustainable development and "build back better", to prevent or reduce future disaster risk. [6]

Preparedness: The capacities and knowledge developed by governments, response and recovery organizations, individuals and communities to effectively anticipate, respond to and recover from the impacts of disasters. [6]

Rehabilitation: The restoration of facilities and basic services for the functioning of a society or a community affected by a disaster. [6]

Vulnerability: The conditions determined by physical, economic, environmental and social factors or processes which increase the susceptibility of an individual, a community, systems or assets to the impacts of hazards. [6]

Exposure: The situation of people, housing, infrastructure, production capacities and other tangible human assets located in hazard-prone areas.

2.2.2 Definitions for the term resilience

1) Capacity to resist, absorb, accommodate to and recover from the effects of hazards in timely and efficient manner through preservation and restoration of functions and structures [7]
2) Ability to anticipate, absorb, accommodate or recover from hazards in an efficient and timely manner through preservation, restoration or improvement of structure and functions [5]
3) An inherent as well as acquired condition achieved by managing risks over time at household, individual, community and societal levels in ways that minimize costs, sustain development momentum, build capacity to manage and maximize transformative potential [8]
4) Resilience can be defined as the capacity of a community, its members and the systems that facilitate its general activities to adapt in ways that maintain functional relationships in the presence of significant disturbances [9]

5) Ability to prevent, withstand, recover from and learn from the influence of extreme weather hazards [10]
6) (a) The degree of change a system can undergo (The amount of extrinsic force a system can sustain) and still remain within the same level of attraction

   (b) The level to which the system is capable of self-organization

   (c) The degree to which the system can build the capacity to learn and adapt. [11]
7) The capacity of a household to bounce back to a previous community activity level after an impact [12]
8) The ability of an ecological system to absorb disturbance and change, and still maintain the same relationships that control the system's behavior. [13]
9) It is understood as the ability to bounce back and come to a stable state in which a given entity existed before an impact [14]

2.3 Existing resilience measurement approaches

Various organizations are working to manage disasters, but only a few are involved with improving the resilience of communities. Having an idea about the level of resilience is important to identify vulnerable communities and thereby it can be used as a guidance to allocate resources for the improvement of the communities.

Defining resilience capacity of a particular community to a given impact is a challenging task because it involves multiple indicators from different fields of study. To integrate all these aspects, need to identify the overall picture of the resilience. However, when defining resilience, the indicators used to define resilience to floods can vary from indicators used to define resilience to droughts.

2.3.1 Mayunga Method

This method which was developed by Joseph Stephen Mayunga focuses on measuring the community resilience for disasters. He has initially developed this multi-dimensional model to measure the disaster resilience in the US Gulf coast. This research has basically focused to develop a theoretically driven index to measure the resilience of coastal communities for disasters.

Mayunga has considered 4 capitals when developing his tool to measure the resilience. These include social capital, physical capital, human capital and economic capital. Under these main four capital domain, 75 indicators has been listed which can be used to measure the resilience. The summary of his Community Disaster Resilience Framework (CDRF) is as per the Figure 9:

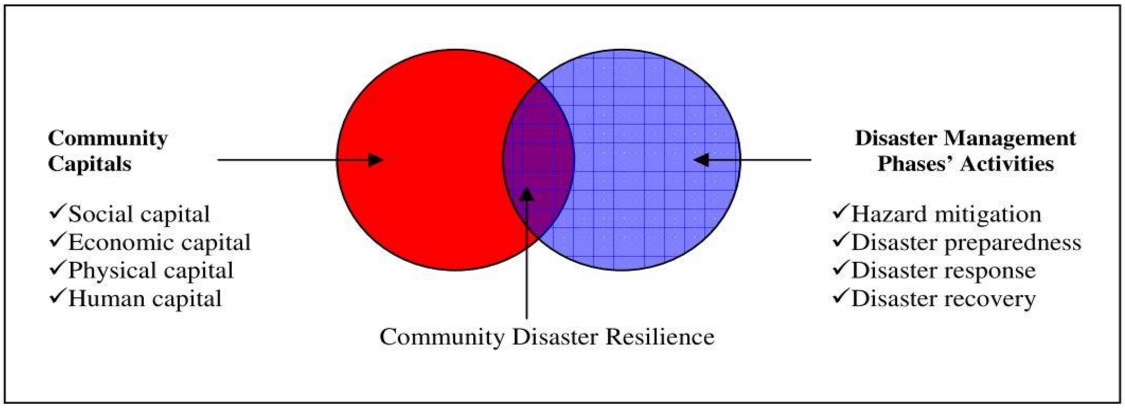

Figure 2.1: Community Disaster Resilience Framework (CDRF)

(Source: Measuring the measure| A multi-dimensional scale model to measure community disaster resilience in the US Gulf Coast region 2009 [15])

The CDRF tries to integrate the disaster management phases with the community capitals to develop a platform on which indicators for disaster resilience can be developed. These indicators are useful to measure the overall disaster resilience of communities. The relationship between the community capitals and disaster phases can be shown as in the Figure 8.

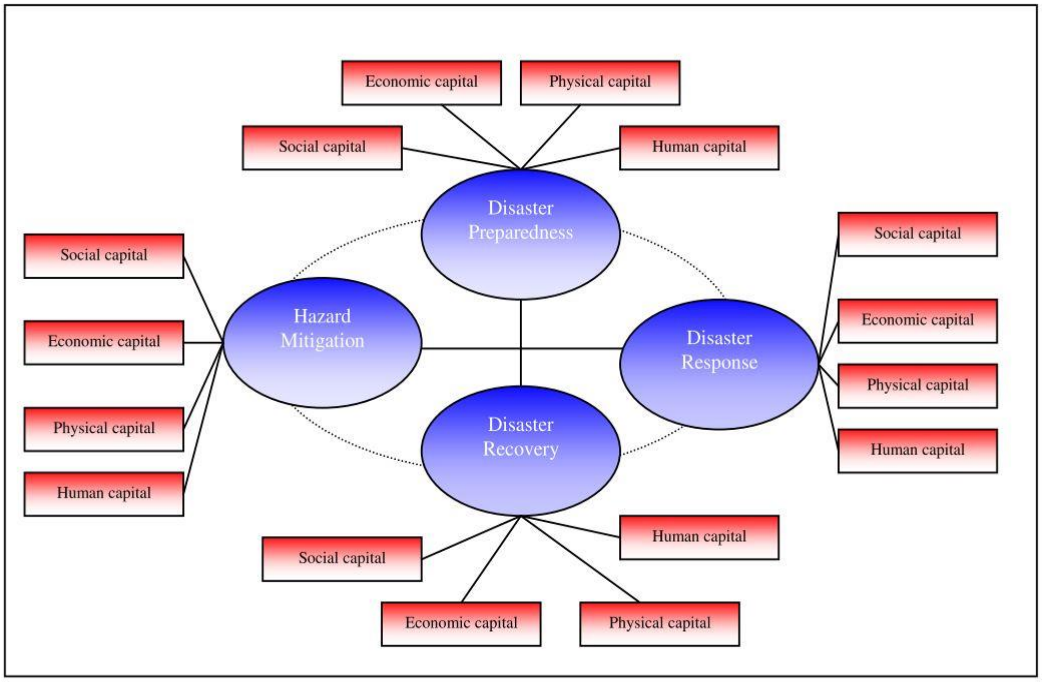

Figure 2.2: Relationship between the community capitals and disaster phases

(Source: Measuring the measure| A multi-dimensional scale model to measure community disaster resilience in the US Gulf Coast region 2009 [15])

2.3.2 REDI Scorecard

Further, the author has mentioned that the REDI can be used across multiple dimensions when it comes to prioritizing investments and funding endeavours. Initially this scorecard was developed for the New York City and 24 indicators have been used to evaluate the resilience score. The indicators are listed under four main capitals.

1.) Social infrastructure and community connectivity

2.) Physical infrastructure

3.) Strength of the economy

4.) Conditions of the Environment.

These indicators also assigned with a +1 or -1 weight depending on the influence of the variable to the resilient capacity of a particular neighbourhood. (If a higher variable value enhances the resilience (+1) is given and if a higher variable value decrease resilience (-1) is given).

By default, equal weights are given for the indicators in this model, but the model can accommodate different weights depending on the priorities. The definition of the REDI score is shown by the equation 1:

$$REDI_j = \frac{1}{n}\sum_{i=1}^{n}(W_i x\, Z_{ij}) \quad \text{......(1)}$$

Where, $REDI_j$ depicts the relevant score of the selected locality j, number of indicator variables is shown by n, weightage for the indicator i is shown by W_i, the normalized value relevant to the i^{th} indicator in j^{th} locality is given by the Z_{ij}. The Z_{ij} is defined by the equation 2:

$$Zij = \frac{X_{ij} - X_{ik}}{\sigma_{ik}} \quad \text{......(2)}$$

Where the value of the i^{th} indicator for the j^{th} locality is shown by X_{ij} and mean value for the i^{th} indicator for k^{th} region ($j \in k$) is shown by X_{ik}. σ_{ik} Shows the standard deviation of the i^{th} indicator for the region k.

This methodology has been successfully validated considering the hurricane sandy and it is said to be a comprehensive framework to quantify the level of resilience. In the fore-mentioned study, they have normalized the REDI scores to the range 1-100 where, 1 represent the least resilience and 100 represent the highest resilience.

2.3.3 Disaster Resilience Scorecard for cities

The United Nations Office of Disaster Risk Reduction (UNISDR) launched the campaign to make cities resilient in 2010 because of the increase of risk lined to the urbanization and to enhance the strength of local governments to reduce these risks [16]. According to [17], a resilient city is one with strong leadership, coordination, up-to-date on knowledge about hazards, having adequate financial plans, proper urban planning, effectively applying building regulations, protecting and monitoring natural ecosystems within the city territory, culture of mutual help and social connectedness, effective disaster response, rehabilitation and reconstruction strategies and post-disaster recovery.

An evaluation of the ten essentials of a resilient city was done by an expert group of 50, in December 2014 and they proposed a new set of ten essentials at the 3rd UN world conference on Disaster Risk Reduction in 2015 in Sendai, Japan. Pilot tests were carried out in 20 cities and the results were then used to revise the set of ten essentials and the final list of indicators were established. Based on the scorecard, if a certain city has the defined characteristics, that city is believed to perform better. The campaign to build cities resilient is based on several objectives such as 1.) Raising awareness among citizens and governments about urban disaster risk and the role of the local government, 2.) Doing investment wisely and improve the political profile related to risk reduction and budget allocations, 3.) Planning development projects more safely, sharing tools and best practices, monitor the progress using the indicator checklist.

Several aspects have been considered in the measurement of resilience of cities, these include Hyogo Framework priority actions [18], 10 essentials of city resilience framework, 5 levels of progress and Sendai framework of actions [19]. The five priority actions from the Hyogo framework considered for the city resilience framework are 01.) Making DRR a priority, 02.) Taking actions for known risks, 3.) Building awareness and understanding, 4.) Risk reduction, 5.) Prepare and ready to act. Including all these aspects, the ten-point essentials checklist [20] was introduced. Under these 10 priority actions, altogether 50 sub-indicators have been defined to evaluate the resilience of cities for disasters. The defined levels or the rating of progress include; Level 5 - **Comprehensive** attainment, high commitment and capability to sustain at all levels, Level 4 - **Substantial** attainment, some deficiencies, Level 3 - Progress is **not substantial**, some commitment and capacities to achieve DRR, Level 2 - **Relatively small** or incomplete achievement, Level 1 - **Minor** achievement, need planning and actions to improve.

Altogether, 6000+ cities covering 180+ countries have signed to implement this disaster resilience scorecard of UNISDR which is very comprehensive. The assessment criteria use a qualitative analysis methodology. In the Sri Lankan context, a comprehensive assessment has been done using this scorecard method for the Batticaloa city and will be followed by many cities.

2.3.4 Sendai Framework of Action

Four priorities of action with respect to Sendai framework [19] can be identified for the measurement of resilience of cities [21]. These include;

Priority 1 – understanding the risk of disaster

Priority 2 – strengthening governance of disaster risk to manage disaster risk

Priority 3 - Investing in disaster risk reduction for resilience

Priority 4 - Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, reconstruction and rehabilitation.

And also, seven targets have been set under the Sendai framework for the purpose of disaster risk reduction; 1.) Reducing the global disaster morality, 2.) Reducing the affected population substantially, 3.) Reducing the direct loss of the economy due to the disasters compared to the global gross domestic production (GDP), 4.) Reduce damage to critical infrastructure and disturbances to service sector, 5.) Increase the number of countries with strategies for disaster risk reduction, 6.) Enhance international cooperation in developing countries, 7.) Improve multi hazard early warning systems.

Even though targets are there, Sendai framework does not provide a mechanism to qualitatively or quantitatively assess the resilience of the communities. In other words, it's a framework designed with set of targets and communities need to progress to attain these targets. In a holistic way the progress of the communities and building of resilience helps to mitigate climate change effects as well.

2.3.5 Holistic Community Resilience Framework

This framework suggests a method to evaluate the coping capacity of the communities considering a holistic approach [22]. Five dimensions have been defined to assess community resilience and those are 1.) Social, 2.) Economic, 3.) Infrastructural, 4.) Environmental and 5.) Institutional [7]. Each of these dimensions needs to be categorized into 4 phases of disaster management including mitigation, preparedness, response and recovery. The indicators need to be defined considering these criteria. Then weighting, consistency evaluation and correlation evaluation should be done to get the final community resilience index. Important aspects to consider in the process are; transformation of data into comparable scales, removal of indicators which are showing correlations, weighting, validation and testing. Further, the author highlights the importance of system dynamics modelling to assess the non-linearity in the interaction between the different dimensions.

2.3.6 Sustainable Development Goals

All the members of the United Nations adopted the SDGs in 2015 [23] to attain prosperity and peace for the people of the planet. There are 17 goals and under these goals altogether 126 targets have been set with 232 key indicators. In the global indicator list, it shows 244 indicators, but since 9 indicators has been repeated under different sections, the actual number of indicators is 232. Different countries can evaluate their performances based on the given key indicators which shows their level of resilience as well. The UN has been monitoring the progress of the countries and they have produced reports on this for 2016, 2017 and 2018.

2.3.7 INFORM Risk index

INdex **FO**r **R**isk **M**anagement (INFORM), identifies the countries that are at humanitarian crisis and need international assistant. The INFORM index has been developed by the Joint Research Centre of the European Union [24]. In the INFROM model, six functional levels have been defined under three dimensions (D_i); D_1.) Hazard and Exposure

(1.Natural, 2.Human), D_2.) Vulnerability (3.Socio-Economic, 4.Vulnerable groups), D_3.) Lack of Coping Capacity (5.Institutional, 6.Infrastructure). Under functional levels, altogether 17 components have been defined. To calculate the risk associated, the equation 3 has been used;

$$Risk = HE^{1/3} x\, V^{1/3} x\, LCC^{1/3} \quad \text{...(3)}$$

Where; HE – Hazard & Exposure, V – Vulnerability and LCP – Lack of Coping Capacity. In the aggregation of indicators, arithmetic averages have been used. Aggregation rules are applied to indexes at different levels in a hierarchical bottom-up way. The equation 4 is used for the calculations in arithmetic average method:

$$C_{AA}^{j} = \sum_{i=1}^{n^c} w_i^c s_i^j \quad \text{...(4)}$$

Where; s_i^j = ith sub component of component c relevant to jth country, C_{AA}^{j} = arithmetic average for component c of the jth country, n^c = Number of subcomponents for component c. The final risk values are normalized to the range 0-10 where; 0 represent no risk and 10 represent a very high risk.

2.3.8 Model of area-picture of potential threats

This framework has been developed after assessing vulnerabilities of critical infrastructure in the Baltic sea region [7]. The anticipated treats are divided into 3 layers in this framework;

1.) Layer of dynamic threats (shipping, port operations)

2.) Layer of static threats (electric cables, pipelines, wind farms, oil rigs)

3.) Layer of climatic hazards (air, winds, sea water, fog, waves, ice conditions, precipitation).

These three layers can be summed up to produce a risk map with different levels of risk for different grids on a map. In this approach, for the Baltic sea region, the scale has been divided into 6 levels.

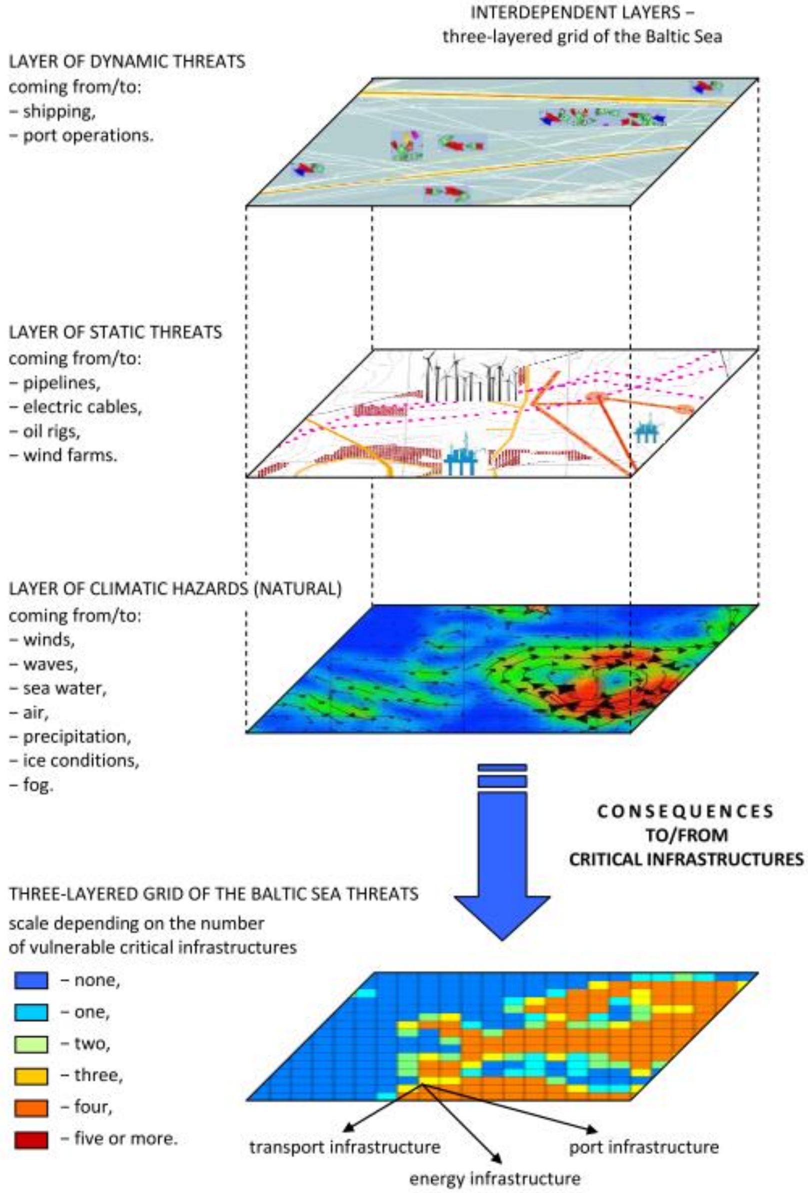

Figure 2.3: The model of area/picture of potential threats

(Source: D4.3 eu-circle resilience framework – final version 2018 [7])

2.3.9 I2UD's framework for climate change adaptation and resilience

Usually climate change policies are developed considering national level. This framework, which is developed by the Institute for urban development focuses on the local level. (Adaptation and Framework, 2014). This framework views the risk as a combination of three components;

1.) Exposure to natural hazards because of geographic locations

2.) Vulnerability to weather events due to socio-economic conditions

3.) Lack of capacity to adapt due to poor land management, insufficient infrastructure systems, and lack of proper policies.

The framework is composed of three components; 1.) People and the built environment, 2.) Location & Systems, 3.) Institutional development & community empowerment. It proposes a methodology to build the resilience against climate change, but however, it does not provide a way to quantify the resilience.

Figure 2.4: I2UD Resilience framework

(Source: Climate Change Adaptation and Resilience Framework 2014 [26])

2.3.10 PEOPLES Resilience Framework

The framework provides the basic idea to develop models to assess resilience using a quantitative method. It is possible to combine this framework with infrastructural, environmental, economic or any other quantitative model to forecast future scenarios. Seven main dimensions are defined in this framework which are relevant for the evaluation of the resilience of communities; 1.) **P**opulation, 2.) **E**nvironmental, 3.) **O**rganizational, 4.) **P**hysical, 5.) **L**ifestyle, 6.) **E**conomic, 7.) **S**ocial/Cultural [27]. The authors highlight that these dimensions should be kept as baseline dimensions and sub-categories has to be reviewed by countries. Based on the social structure of each country, the dimensions can be emphasized, deemphasized or eliminated using the weighting factors. Addressing the less resilient dimensions or sub categories will be very helpful in the process making high resilient communities.

2.3.11 City Resilience Framework

This framework has been developed to identify aspects of resilience in cities [7]. According the framework, a resilient system has seven characteristics; 1.) Reflective, 2.) Robust, 3.) Redundant, 4.) Flexible, 5.) Resourceful, 6.) Inclusive and 7.) Integrated. Four main categories are defined to classify resilience aspects in this framework; 1.) Health & Wellbeing, 2.) Environment & Infrastructure 3.) Economy & Society, 4.) Leadership & Strategy. Altogether, there are 12 defined indicators under these four domains.

2.3.12 Community Resilience Framework of Sri Lanka

This framework is developed by Disaster Management Centre (DMC), Sri Lanka to develop resilient communities through governance, participation, representation and leadership [28]. The sub systems in this framework are 1.) Social sub system, 2.) Physical sub system, 3.) Economic sub system, 4.) Human sub system and 5.) Environmental sub system. Under these main sub systems, DMC has listed 30 potential indicators (Capital – 14 and Capacity - 16) based on the CoBRA model of UNDP [29]. However, not having a way to quantify the resilience of the Sri Lankan communities is the main issue of this framework.

Figure 2.5: Sri Lankan community resilience framework

(Source: Community Resilience Framework Sri Lanka 2015 [28])

2.4 Summary of the important tools and frameworks

Table 2.1: Summary of the tools/frameworks used in the development of the CRS tool

Tool/ Framework	Description
Mayunga Method (CDRI) [15]	• 4 Main capital domains (Social, Economic, physical & Environmental) • 75 Indicators
REDI Scorecard [30]	• 4 Main domains (Social infrastructure & Community connectivity, Physical infrastructure,

	Strength of the economy, Conditions of the environment) • 24 Indicators
Disaster Resilience Scorecard for cities [31]	• 10 Essentials • 50 Indicators
Sendai Framework [19]	• 4 Priorities of action • 7 Targets • 13 Guiding principles
Sustainable Development Goals (SDGs) [23]	• 17 Goals • 126 Targets • 232 Indicators
Inform Risk Index [32]	• 3 Dimensions (Hazard & exposure, Vulnerability, Lack of coping capacity) • 6 Functional levels (Human, Natural, Socio-economic, Institutional, Infrastructure, Vulnerable groups)
Model of area-picture of potential threats [7]	• 3 Layers (Dynamic threats layer, Static threats layer, Climatic hazard layer) • Framework
I2UD's framework for Climate Change Adaptation and Resilience [7]	• 3 Components (People & built environment, Location & systems, Institutional development & Community empowerment)
PEOPLES Resilience Framework [27]	• 7 Dimensions (Population, Environmental, Organizational, Physical, Lifestyle, Economic, Social/ Cultural)
City Resilience Framework [33]	• 7 Characteristics • 4 Domains (Health & wellbeing, Infrastructure & environment, Economy & society, Leadership & strategy) • 12 Indicators

Community resilience framework, Sri Lanka [28]	• 5 Sub systems (Social, Physical, Economic, Human, Environmental)
Community Assessment of Resilience Tool (CART) [34]	• 2 Main domains (Economic development, Social capital) • 17 Indicators
Resilience Index Measurement and Analysis (RIMA) [12]	• Conceptual framework
The tracking Adaptation and Measuring Development (TAMD) framework [35]	• Twin track approach (Climate Risk Management – Institutional, Policy, Capacity, Development Performance – Vulnerability indicators, Development indicators)
USAID framework for measuring community resilience [36]	• Framework with 6 dimensions (Income and food access, adaptive capacity, assets, social capital and safety nets, nutrition and health, governance)
Oxfam GB multi-dimensional approach to resilience measurements [37]	• Framework with 5 dimensions (livelihood viability, contingency resources and support access , innovative potential, social and institutional capability, integrity of natural and built environment)
City resilience framework [38]	• Framework with 3 dimensions (**People** – Societal consequences, Historical context, Community emergency effects, **Technology** – Infrastructure Tech/Data, People Tech/Data, Resource access Tech/Data, **Process –** People/ Technology integration, Program management , Program implementation)
Holistic community resilience framework [22]	• Framework with five dimensions (Social, Economic, Infrastructure, Environmental, Institutional)

3.0 RESEARCH METHODOLOGY

3.1 Introduction

This section describes the methodology followed in the dissertation. Initially a literature review was conducted and then based on that indicators relevant to measure resilience were identified. Then the method of measurement was defined. Then the developed tool was validated and refined with the expert opinion. Finally a few case studies were conducted to see the applicability of the index.

3.2 Methodology flow chart

The methodology is described in the Figure 3.1

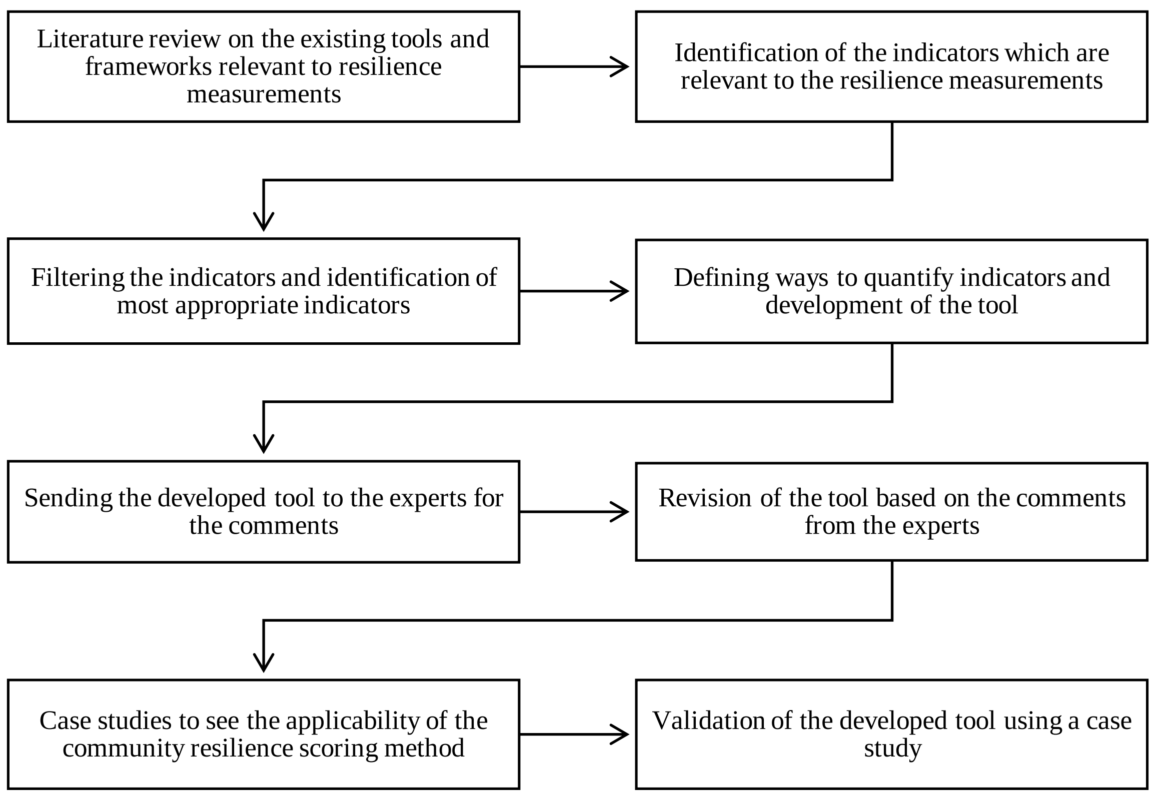

Figure 3.1: Research methodology flow chart

4.0 DEVELOPMENT OF THE TOOL TO MEASURE COMMUNITY RESILIENCE

4.1 Introduction

This chapter includes about the development process of the resilience measurement tool. First part of the chapter briefly describes the process of the development of the resilience index. Then the community capitals and the different phases of disaster management are defined. After that, the process of development of the indicator list and the proposed definitions related to the method of measurements is described. Finally the last part of the chapter describes the proposed output matrices which represent the resilience scores.

4.2 Process of the development of the resilience measurement tool

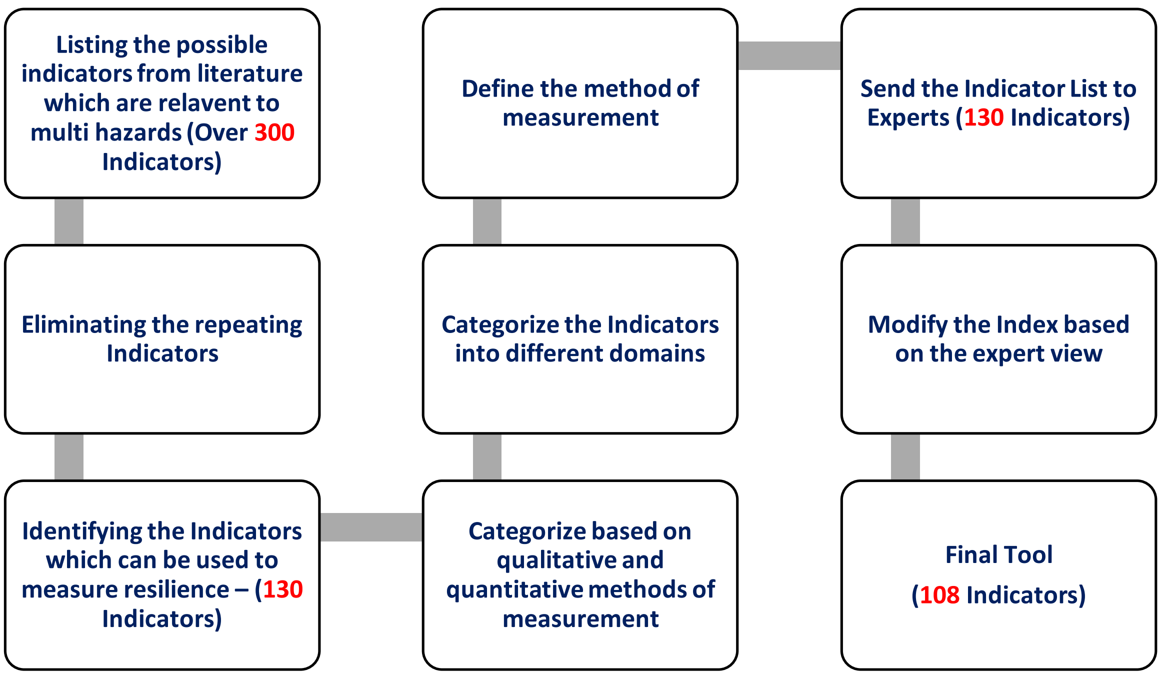

Figure 4.1: Development process of the resilience measurement tool

Measuring community resilience is a very broad field and it is necessary to identify the all the possible indicators to produce the index.

The approach followed in developing the index is explained below:

- All the possible indicators from the literature were listed
- Repeating indicators were eliminated
- Indicators which can be used to measure the community resilience were identified (In the initial phase 130 indicators were identified)
- Categorize based on qualitative and quantitative methods of measurement
- Categorize the indicators under the five selected domains (Social capital, Physical capital, Economic capital, Human capital and Environmental capital)
- The method of measurement was defined
- The list of indicators was sent to the experts to review
- Index was modified based on the expert views
- Final index was produced

4.3 Concept related to community capitals

The indicators to measure the overall resilience of a given community has been defined under five main capitals including social, physical, economic, Human and Environmental.

Disaster resilience should be built considering every discipline and these can be broadly categorized into the community capitals. The resilience of a community depends on its ability to fully utilize the major forms of capitals. The major forms of capitals are described below.

4.3.1 Social Capital

Social capital includes aggregate of possible resources which are linked together. This is characterized as a collection of community involvement and the social cohesion that emerge when such participation is regular [39]. Community networks are very important in case of emergency situations because they can provide resources and pay a big role in making resilient systems.

4.3.2 Economic Capital

Financial resources that are used to support the livelihoods of people. [40] This includes businesses, income, credit and savings. These resources are important to improve the capacity and the ability of groups, individuals and communities to resist disaster impacts and recover fast.

4.3.3 Physical Capital

This refers to the built environment, including residential buildings, industrial and commercial buildings. Also include water, transport, telecommunication facilities and electricity [15]. Physical capital is important because physical infrastructure such as dams, roads, bridges and communication systems are necessary for the functioning of a community.

4.3.4 Human Capital

Knowledge and skills of people living in the community [41]. Specially, the knowledge and skills of people about the hazards can be helpful in building resilience of communities to disasters.

4.3.5 Environmental Capital

Environmental capital include natural resources useful for the existence and livelihoods of living beings, including trees, land, water, wetlands, mangroves, minerals and etc. [41]

4.4 Different phases of disaster management

The activities undertaken during the disaster management phases are described in this section. These include disaster mitigation, disaster preparedness, disaster response and disaster recovery.

4.4.1 Disaster Mitigation

This phase focusses to prevent the occurrence of disasters and eliminate the long term risk to lives and property [42]. Mitigation activities focus to prevent the occurrence of disasters before they happen or to reduce the likelihood of occurrence. These mitigation activities can be structural or non-structural. These activities include implementing building code designs and construction practices, undertake development activities away from vulnerable areas, protecting vegetation, sand dunes, wetlands and ecological things.

4.4.2 Disaster Preparedness

Activities to protect lives of humans and property when disaster threats cannot be controlled by mitigation measures. [15] Such activities should be planned in places that are vulnerable to disaster impacts and resources need to be prepared to face any kind of emergency situation. Disaster preparedness activities include exercises and drills as well.

4.4.3 Disaster Response

Activities that are performed during the disaster situation [15]. These activities focus to protect the affected population and reduce the damages from the impact. The activities include; warning the population about secondary impacts, evacuating vulnerable population, conducting rescue operations, providing foods and medical care for the required.

4.4.4 Disaster Recovery

Activities done to get back to normal, including repair, rebuild [42]. These activities can extend until the community come back to the usual equilibrium state.

4.5 Development of list of Indicators to measure resilience

The indicator list was developed after carefully reviewing the literature and with expert views. The initially identified number of indicators is as per the Table 2.

Table 4.1: Initially identified indicators

Main Domain	Quantitative Indicators	Qualitative Indicators	Total Indicators
Social Capital	27	20	47
Economic Capital	8	6	14
Physical Capital	14	24	38
Human Capital	6	10	16
Environmental Capital	10	5	15
Total	65	65	130

4.6 Expert Survey

The initially identified set of indicators was validated with the expert opinion. All these experts have the experience and expertise in disaster resilience, disaster risk reduction and management sector. They represent both the industrial and academic sectors. The experts are from the following organizations:

Industrial Organizations

- Ministry of Irrigation and Water Resources, Sri Lanka
- Mahaweli Authority, Sri Lanka
- Irrigation Department, Sri Lanka
- National Building Research Organization (NBRO), Sri Lanka
- Red Cross Sri Lanka

Academic Institutions

- University of Moratuwa, Sri Lanka
- University of Colombo, Sri Lanka
- University of Peradeniya, Sri Lanka

- University of Ruhuna, Sri Lanka
- University of Huddersfield, UK
- University of Central Lancashire, UK
- Tallinn University of Technology, Estonia

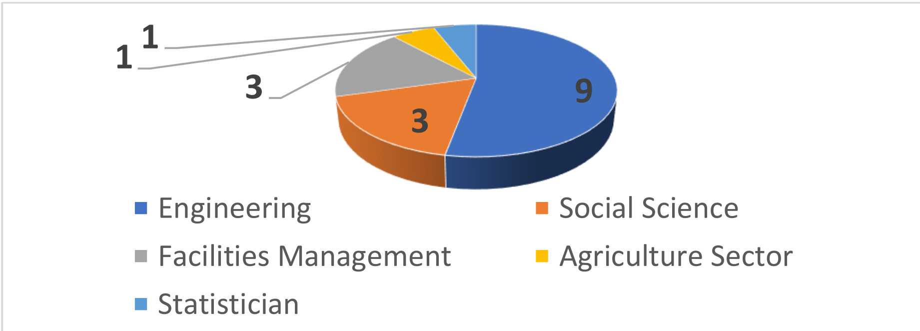

Figure 4.2: Fields of expertise of the experts

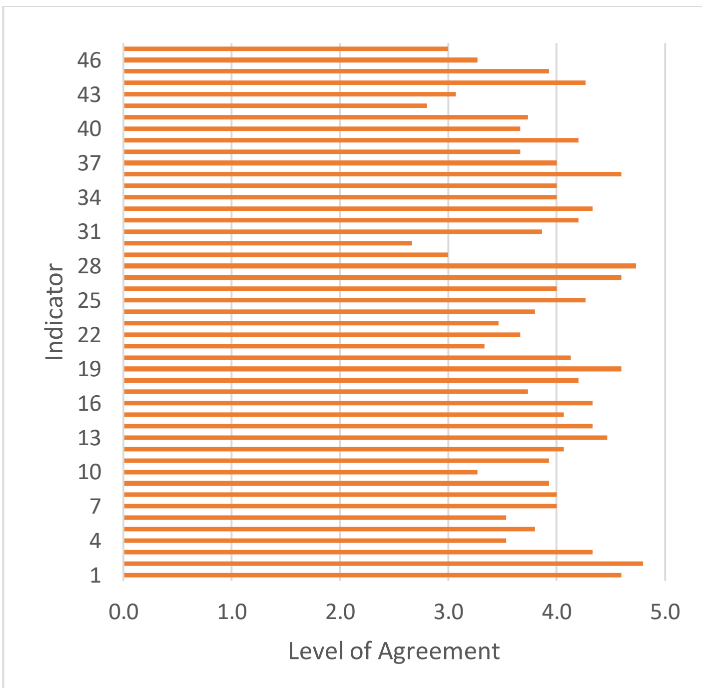

Figure 4.3: Level of agreement for the social capital indicators

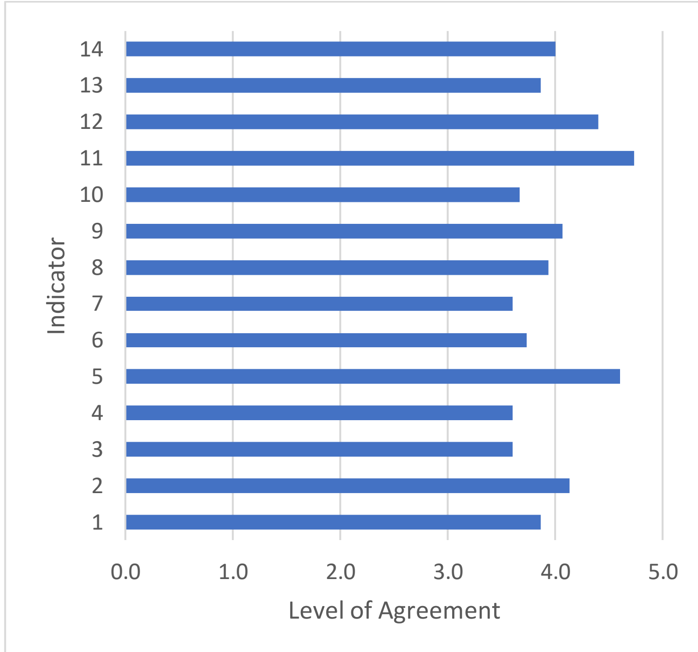

Figure 4.4: Level of agreement for the economic capital indicators

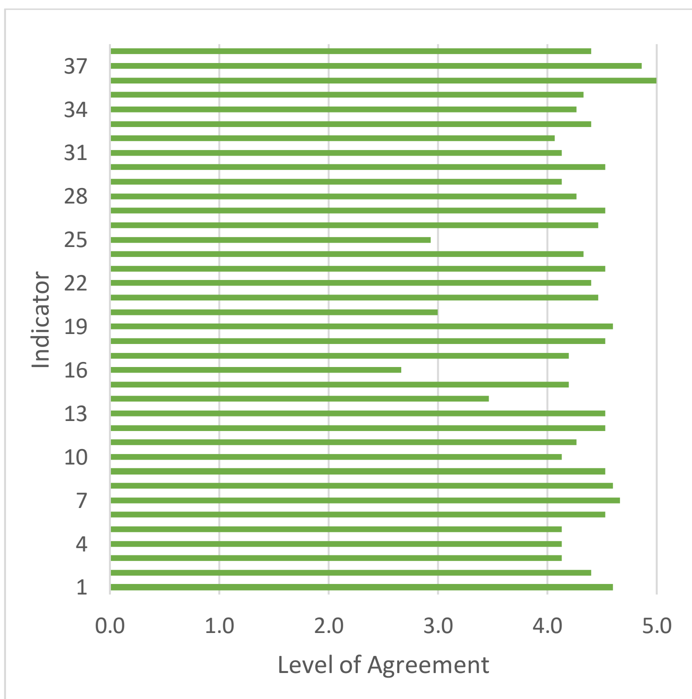

Figure 4.5: Level of agreement for the physical capital indicators

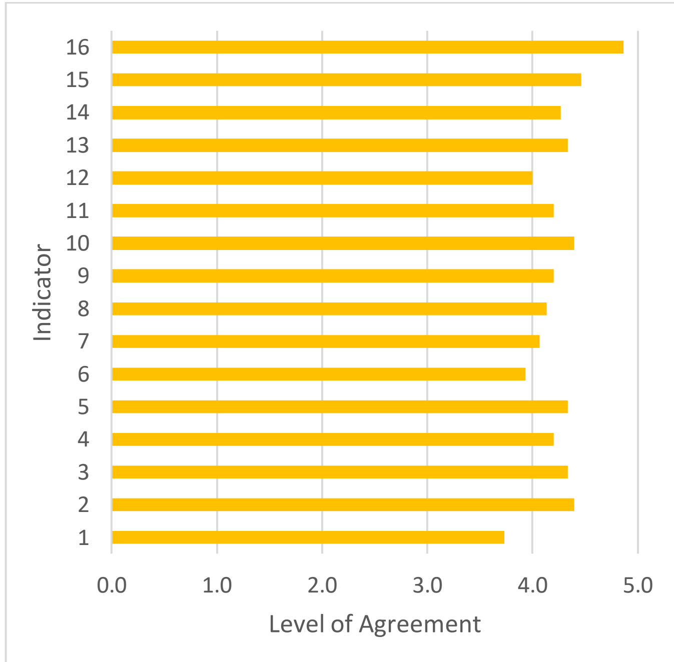

Figure 4.6: Level of agreement for the human capital indicators

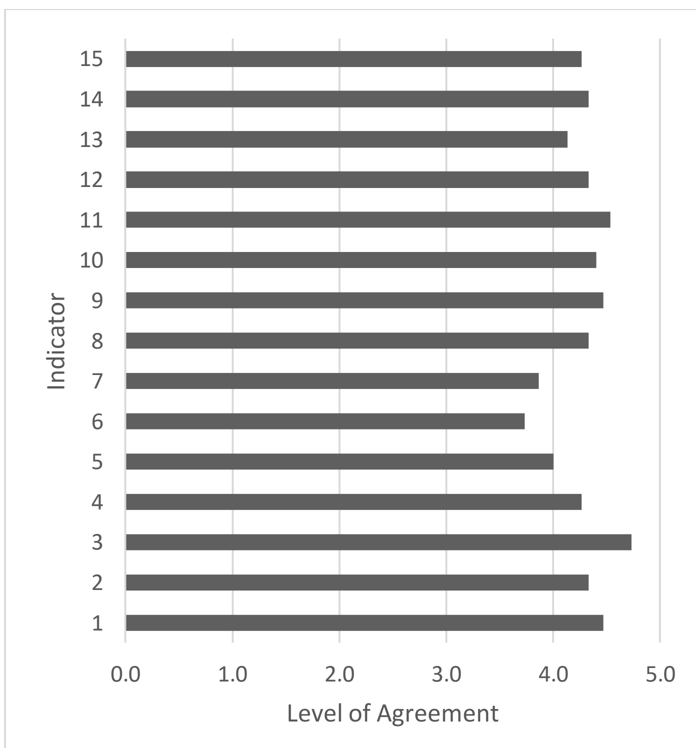

Figure 4.7: Level of agreement for the environmental capital indicators

From the expert survey, indicators with scores less than 3 (below average) were eliminated. Apart from that few indicators which convey the same meaning were eliminated. Finally, the refined list of indicators is as per the Table 4.2.

Table 4.2: Refined list of indicators

Main Domain	**Qualitative Indicators**	**Quantitative Indicators**	**Total Indicators**
Social Capital	18	16	34
Economic Capital	7	5	12
Physical Capital	14	18	32
Human Capital	6	10	16
Environmental Capital	10	4	14
Total	55	53	108

To keep the dissertation to a manageable extent, initially from the indicator list, the indicators which are important to measure the resilience related to floods and droughts were identified. These are as per the Table 4.3 below:

Table 4.3: The number of indicators relevant to floods and droughts

Main Capital	Number of Indicators			
	Drought		Floods	
	Quantitative	Qualitative	Quantitative	Qualitative
Social Capital	8	12	9	12
Economic Capital	7	5	7	5
Physical Capital	7	7	9	14
Human Capital	1	9	1	10
Environmental Capital	6	4	5	1
Total	29	37	31	42
	66		**73**	

4.7 Method of Measurement

Two methods of measurement are proposed as CRS_1 and CRS_2 to assess the resilience capacity of a community. The CRS_1 provide an overall score without considering the four main disaster management phases. Using this method, an overall picture of the resilience of the communities can be obtained. The CRS_2 uses a detailed method including the four main phases of disaster management.

$$CRS_1 = \frac{\sum_{i=1}^{5} W_i D_i}{\sum_{i=1}^{5} W_i} \quad \text{.....(5)}$$

$$D_i = \frac{\sum_{j=1}^{n} w_{ij} K_{ij}}{\sum_{j=1}^{n} w_j} \quad \text{....(6)}$$

$$CRS_1 = \frac{\sum_{i=1}^{5} W_i (\sum_{j=1}^{n} w_{ij} K_{ij})}{\sum_{i=1}^{5} (\sum_{j=1}^{n} w_{ij})} \quad \text{....(7)}$$

Two scores are given for CRS_1 as CRS_1 Positive (**CRS_{1P}**) and CRS_1 Negative (**CRS_{1N}**). Here D_i = i^{th} *Capital Domain*, W_i = Weightage for the i^{th} Capital Domain, w_{ij} = Weightage for the j^{th} indicator of the i^{th} Capital Domain, K_{ij} = Value for the j^{th} indicator of the i^{th} Capital Domain.

Two scores are given for CRS_2 as CRS_2 Positive (**CRS_{2P}**) and CRS_2 Negative (**CRS_{2N}**). A weight of 1 has been given to all the disaster management phases to calculate the CRS_2.

$$CRS_2 = (MPS + PPS + RPS + RePS)/4 \quad \text{....(8)}$$

(MPS – Mitigation Phase Score, PPS - Preparedness Phase Score, RPS – Response Phase Score, RePS – Recovery Phase Score)

The score for each indicator is given between 0 and 1. And an impact sign is given for each indicator. If the indicator improve the resilience capacity, a score of +1 is given and if the indicator reduces the resilience capacity, a score of -1 is given. CRS_P and CRS_N is calculated separately for indicators with positive impact signs and indicators with negative impact signs. If a given indicator is not applicable to the selected context, the impact mark will be zero.

4.8 Definition of the indicators under main phases of DM

The relevant indicators under each phase of the disaster management are described in the Table 4.4 Indicators which are relevant to measure floods and droughts are expressed as D and F.

Table 4.4: List of indicators for measuring resilience

Index Item	Mitigation	Preparedness	Response	Recovery
Social Capital				
Quantitative				
1.) Dependent Population **(D, F)**	✓	✓	✓	✓
2.) Homeless population **(D, F)**	✓	✓	✓	✓
3.) Criminal Records	✓	x	x	x
4.) Disable Population **(F)**	✓	✓	✓	✓
5.) Registered Voters	✓	✓	✓	✓
6.) Stability of Political Organizations **(D, F)**	✓	✓	✓	✓
7.) Life expectancy	✓	✓	✓	✓
8.) Population growth rate	✓	✓	✓	✓
9.) Proportion of urban population living in informal settlements, slums or inadequate housing **(D, F)**	✓	✓	✓	✓
10.) Employment percentage in the age group (18-65)	✓	✓	✓	✓
11.) Employment percentage in with age < 18 and age > 65	✓	✓	✓	✓
12.) Proportion of population covered by a mobile network, by technology **(D, F)**	x	x	✓	x
13.) Percentage of population with major communicable diseases **(D, F)**	✓	✓	✓	✓
14.) Percentage of population with major non-communicable diseases **(D, F)**	✓	✓	✓	✓
15.) Malnutrition percentage **(D, F)**	✓	✓	✓	✓
16.) Maternal mortality ratio	✓	x	x	x
17.) Under-five mortality rate (per 1000 live births)	✓	x	x	x
18.) Suicide mortality rate per 100,000 population	✓	x	x	x

Qualitative				
19.) Proportion of population that feel safe walking alone around the area they live	✓	✓	✓	✓
20.) Population Density **(D, F)**	✓	✓	✓	✓
21.) Gender equality	✓	✓	✓	✓
22.) Social equality (Civil rights, freedom of speech, property rights, equal rights to and access to social services) **(D, F)**	✓	✓	✓	✓
23.) Reach of warning to the public **(D, F)**	x	x	✓	x
24.) Counselling and personal support arrangements (D, F)	x	x	x	✓
25.) Language Barriers	x	✓	✓	✓
26.) Adult Social Services Centers **(D, F)**	✓	✓	✓	✓
27.) Child Social Services Centers **(D, F)**	✓	✓	✓	✓
28.) Density of Residential Developmental Disabilities Services Centers **(D, F)**	✓	✓	✓	✓
29.) Social Stability and Security **(D, F)**	✓	✓	✓	✓
30.) Availability of disaster risk reduction strategies **(D, F)**	✓	✓	✓	x
31.) Emergency response plans **(D, F)**	x	✓	✓	x
32.) Support of NGOs **(D, F)**	✓	✓	✓	✓
33.) Impact of religious organization	x	x	✓	✓
34.) Social connectedness **(D, F)**	✓	✓	✓	✓
Economic Capital				
Quantitative				
1.) Population percentage with a life insurance **(D, F)**	x	x	x	✓
2.) Income levels of the individuals (GNI/Capita) **(D, F)**	✓	✓	✓	✓
3.) The level of gross government debt as a percentage of its GDP **(D, F)**	✓	✓	✓	✓
4.) Gini index for income inequality **(D, F)**	✓	✓	✓	✓
5.) Consumer Price Index (CPI) **(D, F)**	✓	✓	✓	✓
6.) Research and development expenditure as a proportion of GDP **(D, F)**	✓	x	x	✓
7.) Proportion of population below the international poverty line ($ 1.90 per day) **(D, F)**	✓	✓	✓	✓
Qualitative				
8.) Availability of financial resources and contingency funds **(D, F)**	✓	✓	✓	✓

9.) Mean household per capita income **(D, F)**	✓	✓	✓	✓
10.) Allocation of funds to build resilience to disasters **(D,F)**	✓	✓	X	✓
11.) Proportion of total government spending on essential services (education, health and social protection)	✓	✓	✓	✓
12.) Self-Sufficient economy (Produced goods and services using natural resources, sustainable agriculture and renewable energy) **(D, F)**	✓	✓	✓	✓
Physical Capital				
Quantitative				
1.) Percentage of the buildings which have been built by following proper regulations **(F)**	✓	✓	✓	X
2.) Proportion of building designs that have adopted sustainable design concepts **(D)**	✓	✓	✓	X
3.) Percentage of earthquake resistant structures	✓	✓	✓	X
4.) Temporary shelters **(F)**	X	X	✓	✓
5.) Number of Hospital beds per 1000 population **(F)**	X	✓	✓	✓
6.) Level of the facilities of the schools (access to - electricity, internet, computers, materials for students with disabilities, basic drinking water, single sex basic sanitation facilities (Level of Facilities))	✓	✓	✓	✓
7.) Level of facilities of the universities	✓	✓	✓	✓
8.) Percentage of housing units with electricity **(D, F)**	✓	✓	✓	✓
9.) Percentage of housing units with vehicles **(D, F)**	X	X	✓	✓
10.) Proportion of population using safely managed drinking water services **(D,F)**	✓	✓	✓	✓
11.) Percentage of population using safely managed toilet facilities **(D,F)**	✓	✓	✓	✓
12.) Percentage of population with access to internet **(D, F)**	X	X	✓	X
13.) Radio Broadcasting **(D, F)**	X	X	✓	X
14.) Television Broadcasting **(D, F)**	X	X	✓	X
Qualitative				
15.) Shelters for storms including tornados and hurricanes **(F)**	X	✓	✓	X
16.) Storm water holding tanks and flood barriers **(F)**	✓	✓	✓	X
17.) Sea walls and barriers for required coastal areas	✓	✓	✓	X
18.) Environmental protection and consulting establishments **(D, F)**	✓	✓	X	X

19.) Quality and the level of facilities of the hospitals **(D, F)**	x	x	✓	✓
20.) Availability of sufficient fire stations with fire fighters and equipment **(D)**	x	✓	✓	x
21.) Sufficient hotel and motel facilities	x	x	✓	x
22.) Regulated childcare facilities	x	x	✓	x
23.) Quality of private transportation systems **(F)**	x	x	✓	x
24.) Quality of the public transport systems **(F)**	x	x	✓	x
25.) Quality of the road network & rail system **(F)**	x	x	✓	x
26.) Effectiveness and efficiency of the organizations devoted to safeguard the lives and property of the people (Police Stations) **(F)**	x	x	✓	✓
27.) Construction related establishments **(F)**	x	x	x	✓
28.) Quality of the sewer system **(F)**	x	✓	✓	x
29.) Number of patients per ambulance **(D, F)**	x	x	✓	x
30.) Rescue teams with enough facilities (Helicopters, Vehicles) to respond to emergency situations **(D, F)**	x	x	✓	x
31.) Availability and the effectiveness of early warning system **(D, F)**	x	✓	✓	x
32.) Availability of Hazard and vulnerability maps **(D, F)**	✓	✓	✓	✓
Human Capital				
Quantitative				
1.) Percentage population who have completed Tertiary Education	✓	✓	✓	✓
2.) Percentage of population who have received secondary education	✓	✓	✓	✓
3.) Literacy rate of the population (Reading and writing)	✓	✓	✓	✓
4.) Percentage of population with computer literacy	✓	✓	✓	✓
5.) Patients per Doctor (PPD) **(D, F)**	x	x	✓	✓
6.) Proportion of teachers in 1.) Pre-Primary, 2.) Primary, 3.) Lower Secondary, 4.) Upper secondary education who have received at least the minimum organized teacher training	✓	✓	✓	✓
Qualitative				
7.) Scientists employed in R & D sector **(D, F)**	✓	✓	x	✓
8.) Skilled laborers in the construction and maintenance sector **(F)**	x	x	x	✓
9.) Volunteer force **(D, F)**	x	x	x	✓
10.) Armed forces **(D, F)**	x	x	✓	✓

11.) Qualified engineers in civil, electrical, energy and industrial sector **(D, F)**	✓	✓	✓	✓
12.) Availability of skilled fire fighters **(D, F)**	X	X	✓	X
13.) Health care support workers **(D, F)**	X	X	✓	X
14.) Environment protection workers **(D, F)**	X	✓	✓	X
15.) Training of professionals to emergencies **(D, F)**	X	✓	✓	X
16.) Emergency Drills - Disasters, Hazards (Percentage of population trained) **(D, F)**	X	✓	X	X
Environmental				
Quantitative				
1.) Forest coverage **(D, F)**	✓	X	X	X
2.) Green Space per Inhabitant **(D, F)**	✓	X	X	X
3.) Air quality Index	✓	X	X	X
4.) Percentage of renewable energy used from the total energy consumption **(D)**	✓	X	X	X
5.) Proportion of population with primary reliance on clean fuels and technology **(D)**	✓	X	X	X
6.) Proportion of bodies of water with good ambient water quality **(D)**	✓	✓	✓	✓
7.) Proportion of wastewater safely treated **(D, F)**	✓	✓	✓	✓
8.) Percentage of waste managed **(F)**	✓	✓	✓	✓
9.) Proportion of agricultural area under productive and sustainable agriculture	✓	X	X	X
10.) Proportion of land that is degraded over total land area **(F)**	✓	X	✓	X
Qualitative				
11.) The difference between the amount of CO2 produced and absorbed **(D)**	✓	X	X	X
12.) Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) **(D)**	✓	X	X	X
13.) Availability of water resources **(D)**	✓	✓	✓	✓
14.) Ecosystem services **(D, F)**	✓	X	✓	X

4.9 Definition of method of measurement

Measurement method is defined under two main categories as qualitative and quantitative. The measurement criteria clearly describe the way to evaluate the resilience score and the impact sign is used to identify the aspect that improve the resilience capacity and aspects that reduces the resilience capacity.

4.9.1 Social Resilience

The method of measurement for the indicators which are under the social capital are as per the Table 4.5

Table 4.5: Definition of the measurement criteria for indicators under the social capital

No	Indicator	Measurement Criteria	Impact Sign (1, 0, -1)	Remarks
Quantitative (Data Driven)				
1	Dependent Population	Population percentage under age 18 = p1	-1	-
		Population percentage over age 65 = p2		
		Weightage for p1 -> w1 = 1		
		Weightage for p2 -> w2 = 1		
		S2 = p1w1 + p2w2		
2	Homeless population	Percentage	-1	-
3	Criminal Records	Percentage of murder cases per year per population during last 10 years = p1	-1	-
		Percentage of rape cases per year per population during last 10 years = p2		
		Percentage of robberies per year per population during last 10 years = p3		
		Percentage of other violent behaviors per year per population during last 10 years = p4		
		Weightage for pi = wi (i = 1,2,3,4)		
		S5 = p1w1 + p2w2 + p3w3 + p4w4		

4	Disable Population	Percentage	-1	-
5	Registered Voters	Percentage of registered voters from the eligible population	1	-
6	Stability of Political Organizations	Political stability index (Normalize between 0 and 1)	1	Political stability index [43]. For different regions of a country, suitable scoring should be used
7	Life expectancy	79 < age expectancy < 89 -> W = 1 76 < age expectancy < 79 -> W = 0.75 68 < age expectancy < 76 -> W = 0.5 age expectancy < 68 -> W = 0.25	1	From the world bank data set, first three quartiles has been used for the definition of the categories [44]
8	Population growth rate	Optimum growth rate based on the country/region: (+1 sign if satisfactory and -1 sign if not satisfactory)	1	-
9	Proportion of urban population living in informal settlements, slums or inadequate housing	Percentage	-1	-
10	Employment percentage in the	Percentage	1	-

	working age population			
11	Employment percentage in with age < 18 and age > 65	Population percentage with age < 18 = x1 Population percentage with age > 65 = x2 Weightage for x1 -> w1 Weightage for x2 -> w2 Can use w1 = w2 = 1 E3 = w1x1 + w2x2	-1	-
12	Proportion of population covered by a mobile network, by technology	Percentage	1	-
13	Percentage of population with major communicable diseases	Percentage	-1	[45]
14	Percentage of population with major non- communicable diseases	Percentage	-1	[45]
15	Malnutrition percentage	Percentage	-1	-
16	Maternal mortality ratio	Maternal mortality per 100,000 live births - quartile 1 = 14, quartile 2 = 54, quartile 3 = 229, Average = 162, Max = 882, Min = 3 Rate = 0 -> 0 Rate < 14 -> 0.25 14 < Rate < 54 -> 0.5 54 < Rate < 229 -> 0.75 Rate > 229 -> 1	-1	From the world bank data set, first three quartiles has been used for the definition of the categories [46]
17		Average = 30.3, Max = 127.2, Min = 2.1, Q 1 = 7.6, Q 2 = 18.2, Q 3 = 47.3	-1	From the world bank

	Under-five mortality rate (per 1000 live births)	Rate = 0 -> 0 Rate < 7.6 -> 0.25 7.6 < Rate < 18.2 -> 0.5 18.2 < Rate < 47.3 -> 0.75 Rate > 47.3 -> 1		data set, first three quartiles has been used for the definition of the categories [47]
18	Suicide mortality rate per 100,000 population	Average = 9.3, Max = 31.9, Min = 0.5, Q1 = 5.1, Q2 = 8.2, Q3 = 12.7 Rate = 0 -> 0 Rate < 5.1 -> 0.25 5.1 < Rate < 8.2 -> 0.5 8.2 < Rate < 12.7 -> 0.75 Rate > 12.7 -> 1	-1	From the world bank data set, first three quartiles has been used for the definition of the categories [48]
Qualitative Indicators				
19	Proportion of population that feel safe walking alone around the area they live	Percentage	1	-
20	Population Density	Qualitative Index (0, 0.25,0.5,0.75,1) - Depending on the optimum density of population for a given region.	1	-
21	Gender equality	Qualitative index (0, 0.25,0.5,0.75,1) based on the women's economic participation, education attainment, health and political empowerment.	1	-
22	Social equality (Civil rights, freedom of	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-

	speech, property rights, equal rights to and access to social services)			
23	Reach of warning to the public	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
24	Counselling and personal support arrangements	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
25	Language Barriers (Cities with high number of languages needs to settle for a language that most of the people can reach	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
26	Adult Social Services Centers	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
27	Child Social Services Centers	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
28	Density of Residential Developmental Disabilities Services Centers	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
29	Social Stability and Security	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
30	Availability of disaster risk reduction strategies	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
31	Emergency response plans	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
32	Support of NGOs	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
33	Impact of religious organization on	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-

	improving the good deeds			
34	Social connectedness	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-

4.9.2 Economic Resilience

The method of measurement for the indicators which are under the economic capital are as per the Table 4.6

Table 4.6: Definition of the measurement criteria for indicators under the economic capital

No	Indicator	Measurement Criteria	Impact Sign (-1,0,1)	Remarks
Quantitative (Data Driven)				
1	Population percentage with a life insurance	Population with a Complete insurance cover = x1	1	-
		Population with an average insurance cover = x2		
		Population with a 3rd grade insurance cover = x3		
		Weightage for x1 -> w1 = 1		
		Weightage for x2 -> w2 < 1		
		Weightage for x3 -> w3 < 1 (w3<w2)		
		E1 = w1x1 + w2x2 + w3x3		
2	Income levels of the individuals (GNI/Capita)	Population with low income = p1	1	Define the low income, middle income and high income based on
		Population with lower middle income = p2		
		Population with upper middle income = p3		
		Population with High income = p4		
		Weightage for p1 = w1		
		Weightage for p2 = w2		
		Weightage for p3 = w3		
		Weightage for p4 = w4 = 1		

		E4 = p1w1 + p2w2 + p3w3 + p4w4		the region of the study
3	The level of gross government debt as a percentage of its GDP	If percentage is greater than or equal to 100% --> Weightage = 1	-1	-
		Otherwise --> Weightage = Percentage		
		3% < Contribution < 7% --> 0.5		
		7% < Contribution < 16% --> 0.75		
		Contribution > 16% --> 1		
		1st, 2nd and 3rd quartiles were considered		
4	Gini index for income inequality	Gini Index < 32% --> 0.25	-1	[49]
		32% < Gini Index < 37% --> 0.5		
		37% < Gini Index < 41% --> 0.75		
		Gini Index > 41% --> 1		
5	Consumer Price Index (CPI)	if CPI = 100 --> 1	1	[50]
		if 100 < CPI < 109 --> 1		
		if 109 < CPI < 117 --> 0.75		
		if 117 < CPI < 136 --> 0.5		
		if CPI > 136 --> 0.25		
6	Research and development expenditure as a proportion of GDP	Average = 1.43, Min = 0.015, Max = 4.25, Q1 = 0.5, Q2 = 1.2, Q3 = 2.1	1	From the world bank data set, first three quartiles has been used for the definition of the categories [51]
		Rate < 0.5 -> 0.25		
		0.5 < Rate < 1.2 -> 0.5		
		1.2 < Rate < 2.1 -> 0.75		
		Rate > 2.1 -> 1		
7	Proportion of population below the	Percentage	-1	[52]

	international poverty line ($ 1.9 per day)			
Qualitative Indicators				
8	Availability of financial resources and contingency funds	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
9	Median household income	Qualitative index (0, 0.25, 0.5, 0.75, 1)- Based on the requirement of the community	1	-
10	Allocation of funds to build resilience to disasters	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
11	Proportion of total government spending on essential services (education, health and social protection)	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
12	Self-Sufficient economy (Produced goods and services using natural resources, sustainable agriculture and renewable energy)	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-

4.9.3 Physical Resilience

The method of measurement for the indicators which are under the physical capital are as per the Table 4.7

Table 4.7: Definition of the measurement criteria for indicators under the physical capital

No	Indicator	Measurement Criteria	Impact Sign (-1,0,1)	Remarks
Quantitative (Data Driven)				
1	Percentage of the buildings which have been built by following proper regulations	Percentage: Regulations – Building codes, Regulations by the Urban Authorities	1	-
2	Proportion of building designs that have adopted sustainable design concepts	Percentage	1	-
3	Percentage of earthquake resistant structures	Percentage	1	-
4	Temporary shelters	Percentage of the vulnerable population that can be covered with the available temporary shelters in an emergency	1	-
5	Number of Hospital beds per 1000 population	C1 = No of Beds > 7	1	[53]
		C2 = 5 < Beds < 7		
		C3 = 3 < Beds < 5		
		C4 = 1 < Beds < 3		
		C5 = Beds < 1		
		Weightages = Wi (I = 1,2,3,4,5)		
		W1 = 1, W2 = 0.8, W3 = 0.6, W4 = 0.4, W5 = 0.2		
6	Level of the facilities of the schools (access to –	Ni = School number	1	-
		Li = Level of facilities (Categorized into 4 levels)		

	electricity, internet, computers, materials for students with disabilities, basic drinking water, single sex basic sanitation facilities (Level of Facilities))	Weightages for Li = Wi = (0, 0.25, 0.50, 0.75,1) P7 = (Addition of the Level of facilities of the school)/Number of schools		
7	Level of facilities of the universities	Ni = University Number Li = Level of facilities (Categorized into 4 levels) Weightages for Li = Wi = (0, 0.25, 0.50, 0.75,1) P8 = (Addition of the Level of facilities of the universities)/Number of Universities	1	-
8	Percentage of housing units with electricity	Percentage	1	-
9	Percentage of housing units with vehicles	Percentage	1	-
10	Proportion of population using safely managed drinking water services	Percentage	1	-
11	Percentage of population using safely managed toilet facilities	Percentage	1	[54]
12	Percentage of population with access to internet	Percentage	1	-
13	Radio Broadcasting	Percentage of population that have the access to Radio broadcasting services	1	-
14	Television Broadcasting	Percentage of population that have the access to Television broadcasting services	1	-
Qualitative Indictors				
15	Shelters for storms including tornados and hurricanes	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-

16	Storm water holding tanks and flood barriers	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
17	Sea walls and barriers for required coastal areas	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
18	Environmental protection and consulting establishments	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
19	Quality and the level of facilities of the hospitals	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
20	Availability of sufficient fire stations with fire fighters and equipment	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
21	Sufficient hotel and motel facilities for visitors	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
22	Regulated childcare facilities	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
23	Quality of private transportation systems	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
24	Quality of the public transport systems	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
25	Quality of the road network & rail system	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
26	Effectiveness and efficiency of the organizations devoted to safeguard the lives and property of the people (Police Stations)	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
27	Construction related establishments – Architecture and	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-

	engineering establishments, Highway, street, and bridge construction establishments, Heavy and civil engineering construction establishments, Utility systems construction establishments, Building construction establishments, Civil Engineering Construction Establishments, Utility systems construction establishments, Landscape architecture and planning establishments			
28	Quality of the sewer system	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
29	Number of patients per ambulance	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
30	Rescue teams with enough facilities (Helicopters, Vehicles) to respond to emergency situations	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
31	Availability and the effectiveness of early warning system	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
32	Availability of Hazard and vulnerability maps	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-

4.9.4 Human Resilience

The method of measurement for the indicators which are under the human capital are as per the Table 4.8

Table 4.8: Definition of the measurement criteria for indicators under the human capital

No	Indicator	Measurement Criteria	Impact Sign (-1,0,1)	Remarks
Quantitative (Data Driven)				
1	Percentage population who have completed Tertiary Education	Percentage	1	-
2	Percentage of population who have received secondary education	Percentage of children below 18 with no education = p1	-1	-
		Percentage of children with Primary education only = p2	1	
		Percentage of children with Primary education + Secondary education = p3	1	
		Weightage for p1 = wi (I = 1,2,3)		
		S9 = p1w1 + p2w2 + p3w3	1	
3	Literacy rate of the population (Reading and writing)	Percentage	1	-
4	Percentage of population with computer literacy	Percentage	1	-
5	Patients per Doctor (PPD)	If PPD < 380 → W = 1	1	[55]
		If 380 < PPD < 900 → W = 0.75		
		If 900 < PPD < 4800 → 0.5		
		If PPD > 4800 → 0.25		
		1st quartile = 380		
		2nd quartile = 900		
		3rd quartile = 4800		

		Need to plot number of doctors' vs Performance in health care system to find the optimum numbers		
6	Proportion of teachers in 1.) Pre-Primary, 2.) Primary, 3.) Lower Secondary, 4.) Upper secondary education who have received at least the minimum organized teacher training	Percentage	1	-
Qualitative Indicators				
7	Scientists employed in R & D sector	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
8	Skilled laborers in the construction and maintenance sector	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
9	Volunteer force	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
10	Armed forces	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
11	Qualified engineers in civil, electrical, energy and industrial sector	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
12	Availability of skilled fire fighters	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
13	Health care support workers	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
14	Environment protection workers	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-
15	Training of professionals to emergencies	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-

16	Emergency Drills – Disasters, Hazards (Percentage of population trained)	Qualitative index (0, 0.25, 0.5, 0.75, 1)	1	-

4.9.5 Environmental Resilience

The method of measurement for the indicators which are under the environmental capital are as per the Table 4.9.

Table 4.9: Definition of the measurement criteria for indicators under the economic capital

No	Indicator	Measurement Criteria	Impact Sign (-1,0,1)	
Quantitative (Data Driven)				
1	Forest coverage	If percentage of forest cover > 30% -> Category 1 (C1)	1	-
		20% < If percentage of forest cover < 30% -> Category 2 (C2)		
		If percentage of forest cover < 10% -> Category 3 (C3)		
		Weightage for C1 = W1 = 1		
		Weightage for C2 = W2 = 0.67		
		Weightage for C3 = W3 = 0.33		
		For multiple regions, Percentage areas should be multiplied by the weightages and the addition is takes		
2	Green Space per Inhabitant	WHO Recommendation - Minimum of 9 sq. Meters of green space.	1	[56]
		C1 = Green space per Inhabitant > 50 sq. meters per person -> W1 = 1		

		C2 = 50 > Green space per Inhabitant > 9 -> W2 = 0.67 C3 = Green space per Inhabitant < 9 -> W3 = 0.33		
3	Air quality Index	Category 1 (C1) = Good -> W1 = 1 Category 2 (C2) = Moderate -> W2 = 0.83 Category 3 (C3) = Unhealthy for sensitive groups -> W3 = 0.67 Category 4 (C4) = Unhealthy -> W4 = 0.5 Category 5 (C5) = Very Unhealthy -> W5 = 0.33 Category 6 (C6) = Hazardous -> W6 = 0.17	1	[57]
4	Percentage of renewable energy used from the total energy consumption	Percentage	1	-
5	Proportion of population with primary reliance on clean fuels and technology	Average = 64.2, Max = 95, Min = 5, Q1 = 28, Q2 = 85, Q3 = 95 Rate < 28 -> 0.25 28 < Rate < 85 -> 0.5 85 < Rate < 95 -> 0.75 Rate > 95 -> 1	1	-
6	Proportion of bodies of water with good ambient water quality	Percentage		-
7	Proportion of wastewater safely treated	Percentage		-
8	Percentage of waste managed	Percentage		-
9	Proportion of agricultural area under productive and	Percentage		-

	sustainable agriculture			
10	Proportion of land that is degraded over total land area	Percentage		-
Qualitative Indicators				
11	The difference between the amount of CO_2 produced and absorbed	GHGs (Tons CO_2 Equivalent per capita) - (CO_2 absorbed by the vegetation per capita)	1 if positive	[58]
		Qualitative index (0.25, 0.5, 0.75, 1)	If negative = -1	
12	Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10)	Qualitative index (0.25, 0.5, 0.75, 1)	-1	-
13	Availability of water resources	Water availability per capita per year (Total River flow per year/ Total population)	1	-
		Qualitative index (0.25, 0.5, 0.75, 1)		
14	Ecosystem services	<u>Availability of the following services where applicable</u>	1	-
		1). Sand Dunes		
		2.) Coastal Wetlands		
		3.) Mangroves		
		4.) Reefs		
		5.) Rivers		
		6.) Lakes		
		7.) Natural Channels		
		8.) Aquifers		
		9.) Wetlands		
		Score Levels - (0, 0.25, 0.5, 0.75, 1)		

4.10 Output Matrices

The developed tool proposes two ways of quantifying resilience. The method 1 (CRS_1) is straightforward, where all the indicators are used for the calculation of the overall resilience. But when it comes to calculation of resilience to floods and droughts, only the relevant indicators should be used. Based on the impact sign of the indicator, two types of scores (positive and negative) are introduced.

The output matrix of the resilience evaluation tool is as follows:

Table 4.10: Output matrix for the CRS_1

Main Capital Domain	Positive Score (P)	Negative Score (N)
Social Capital (SC)	SC_P	SC_N
Economic Capital (EC)	EC_P	EC_N
Physical Capital (PC)	PC_P	PC_N
Human Capital (HC)	HC_P	HC_N
Environmental Capital (ENC)	ENC_P	ENC_N
CRS_1	**CRS_{1P}**	**CRS_{1N}**

CRS_{1p} and CRS_{1N} can be obtained by linear addition of the values under each domain. But depending on the priorities of the capital domains, weightages can be provided to the each capital domain before addition. In the case studies of this dissertation, simple linear addition has been used to calculate the resilience scores.

CRS_2 is the second method of quantifying the resilience. Here the scores are provided under four main phases of the disaster management cycle. This is important to identify the exact gaps in emergency management and allocation of resources. Similar to the CRS_1 method, in CRS_2 method also scoring method is defined with two positive and negative scores.

Table 4.11: Output matrix for the CRS_2

Main Capital Domain	Main Disaster Management Phases							
	Mitigation (M)		Preparedness (P)		Response (R)		Recovery (RE)	
	Positive (P)	Negative (N)	Positive (P)	Negative (N)	Positive (P)	Negative (N)	Positive (P)	Negative (N)
Social Capital (SC)	SC_{MP}	SC_{MN}	SC_{PP}	SC_{PN}	SC_{RP}	SC_{RN}	SC_{REP}	SC_{REN}
Economic Capital (EC)	EC_{MP}	EC_{MN}	EC_{PP}	EC_{PN}	EC_{RP}	EC_{RN}	EC_{REP}	EC_{REN}
Physical Capital (PC)	PC_{MP}	PC_{MN}	PC_{PP}	PC_{PN}	PC_{RP}	PC_{RN}	PC_{REP}	PC_{REN}
Human Capital (HC)	HC_{MP}	HC_{MN}	HC_{PP}	HC_{PN}	HC_{RP}	HC_{RN}	HC_{REP}	HC_{REN}
Environmental capital (ENC)	ENC_{MP}	ENC_{MN}	ENC_{PP}	ENC_{PN}	ENC_{RP}	ENC_{RN}	ENC_{REP}	ENC_{REN}
CRS2	CRS_{2MP}	CRS_{2MN}	CRS_{2PP}	CRS_{2PN}	CRS_{2RP}	CRS_{2RN}	CRS_{2REP}	CRS_{2REN}

Similar to the method used in the calculation of CRS_1, CRS_2 also can be calculated with simple linear addition. This simple addition method is used for the case studies in this dissertation. But based on priorities, different weightings can be assigned to the capital domains and for this further studies has to be undertaken.

When calculating the final CRS_2, the average scores under each disaster management phase can be used as per the equations 9 and 10.

$$CRS_{2P} = (CRS_{2MP} + CRS_{2PP} + CRS_{2RP} + CRS_{2REP})/4 \quad \ldots(9)$$

$$CRS_{2N} = (CRS_{2MN} + CRS_{2PN} + CRS_{2RN} + CRS_{2REN})/4 \quad \ldots(10)$$

5.0 CASE STUDIES – APPLICATION OF THE TOOL

5.1 Introduction

The developed tool was used to evaluate the resilience of some of the selected administrative regions. The administrative regions used for the case studies include 7 Divisional Secretariat Divisions (DSD) from two districts; Kurunegala District - Kurunegala, Maho, Polpithigama, Ahatuwewa, Abanpola and Colombo District - Kaduwela and Kolonnawa. Data related to the study were obtained from multiple organizations and websites.

The DSDs were selected based on 2 criteria

- Regions which have faced drought related issues – Selected DSDs in Kurunegela District
- Regions which have faced flood related issues – Selected DSDs in Colombo District

Apart from that, the resilience scores were determined for the entire country, Kurunegala District and Colombo District. For these 10 cases, the two matrices were prepared (CRS_1 and CRS_2).

Although there are 108 indicators to provide the overall resilience score, to limit the scope of the master's thesis, only a few of the indicators from the list were used for the case studies. The number of indicators used with the each DSD, District and overall country is as per Table 5.1:

Table 5.1: Number of Indicators used for the evaluation of overall resilience

Region	Social		Economic		Physical		Human		Environmental	
	+	-	+	-	+	-	+	-	+	-
Sri Lanka	11	1	3	4	11	0	9	0	5	0
Colombo District	9	5	1	3	10	0	9	0	6	0
Kolonnawa DS	7	4	0	3	7	0	4	0	4	0
Kaduwela DS	7	4	0	3	7	0	4	0	6	0
Kurungela District	9	5	1	3	10	0	9	0	6	0
Kurunegala DS	7	4	0	3	8	0	4	0	6	0
Maho DS	7	4	0	3	8	0	4	0	6	0
Polpithigama DS	7	4	0	3	8	0	4	0	6	0
Ehatuwewa DS	7	4	0	3	8	0	4	0	6	0
Abanpola DS	7	4	0	3	8	0	4	0	6	0

5.2 Output Matrix for CRS_1

5.2.1 Overall Resilience

The overall value for the level of resilience of the selected administrative areas are shown in Table 5.3 (Positive score) and Table 5.4 (Negative score). The colour code used in the matrices are as per Table 5.2.

Table 5.2: Colour code used in the matrices

	CRS > 0.8	0 >= CRS > -0.2
	0.6 < CRS <= 0.8	-0.2 >= CRS > -0.4
	0.4 < CRS <= 0.6	-0.4 >= CRS > -0.6
	0.2 < CRS <= 0.4	-0.6 >= CRS > -0.8
	CRS <= 0.2	-0.8 >= CRS > -1

Table 5.3: Overall resilience scores - Positive

Overall Positive	Sri Lanka	Kurunegala District	Colombo District	Kurunegala	Polpithigama	Ahatuwewa	Abanpola	Maho	Kolonnawa	Kaduwela
Social	0.432	0.528	0.333	0.643	0.679	0.679	0.679	0.679	0.357	0.357
Economic	0.531	0.875	0.875	0.875	0.750	0.750	0.750	0.750	0.750	0.750
Physical	0.647	0.645	0.769	0.776	0.546	0.550	0.551	0.554	0.632	0.637
Human	0.526	0.530	0.621	0.563	0.250	0.250	0.250	0.250	0.375	0.375
Environmental	0.640	0.734	0.510	0.469	0.694	0.652	0.694	0.610	0.510	0.510
Overall	**0.649**	**0.584**	**0.576**	**0.586**	**0.568**	**0.614**	**0.586**	**0.499**	**0.501**	**0.548**

It's clear that the overall resilience scores of the selected administrative regions are well below the overall resilience score for Sri Lanka. The selected DSDs are regions which have the threat of floods or drought. Thus, it could be the reason for having a lower score for these regions.

From the selected regions, Polpithigama, Ahatuwewa, Abanpola and Maho are rural areas and Kolonnawa & Kaduwela are urban areas. From the Table 5.3, the social resilience scores seem to be higher in rural areas compared to the urban areas. The unity and harmony among the village community in Sri Lanka could be the reason for this. The environmental resilience scores are also high in rural areas. But it is comparatively low in urban areas. The contamination of the environment in urban areas could be the main reason for this. Further, according to the matrix, the economic resilience seems to be high in Kurunegala (0.875) and Colombo (0.875) Districts compared to the score for the entire country (0.531) which suggest the fact that the above mentioned two districts perform better for the economy of the country. However, the overall resilience values of these two districts (0.584, 0.576) are lower than the overall resilience of the entire country (0.649). Further, the human factors seem to have the lowest scores and its' contribution to the overall resilience is significantly low. This can be clearly identified from the Figure 5.1. Most of the people in rural areas shift to urban areas for better jobs and this could be the main reason for the lower values for human resilience in rural areas.

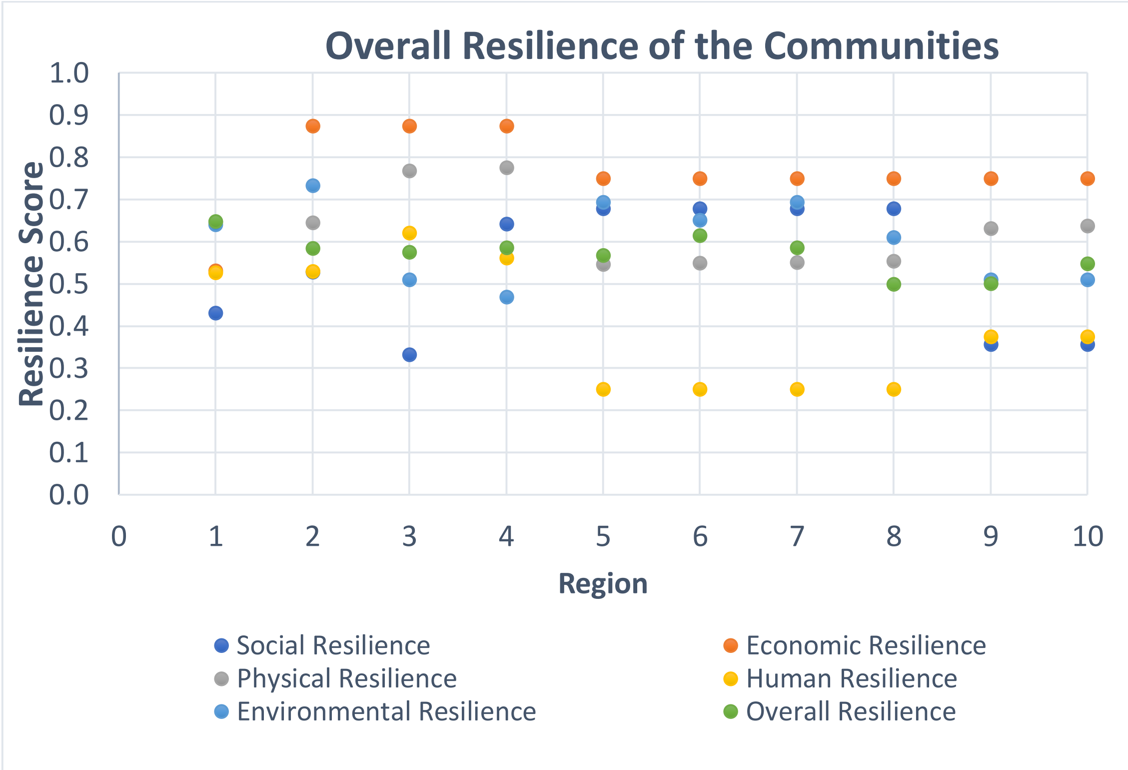

Figure 5.1: Overall resilience of the selected regions

1-Sri Lanka, 2 - Kurunegala District, 3 - Colombo District, 4 - Kurunegala DSD, 5 - Polpithigama DSD, 6 - Ahatuwewa DSD, 7 - Abanpola DSD, 8 - Maho DSD, 9 - Kolonnawa DSD, 10 - Kaduwela DSD

From the Figure 19, it is evident that the score for the economic capital is higher compared to other components and the scores for the human capital is the lowest. Further, the overall resilience scores for all the components are below 0.7 which clearly shows the levels of resilience of Sri Lankan administrative regions.

Table 5.4: Overall Resilience Score – Negative

Overall Negative	Sri Lanka	Kurunegala District	Colombo District	Kurunegala	Polpithigama	Ahatuwewa	Abanpola	Maho	Kolonnawa	Kaduwela
Social	-0.311	-0.299	-0.240	-0.348	-0.349	-0.350	-0.350	-0.352	-0.287	-0.281
Economic	-0.402	-0.332	-0.325	-0.324	-0.340	-0.337	-0.337	-0.335	-0.330	-0.326
Physical	-	-	-	-	-	-	-	-	-	-
Human	-	-	-	-	-	-	-	-	-	-
Environmental	-	-	-	-	-	-	-	-	-	-
Overall	**-0.338**	**-0.345**	**-0.344**	**-0.344**	**-0.344**	**-0.311**	**-0.272**	**-0.305**	**-0.300**	**-0.339**

The negative resilience scores show the aspects that reduce the resilience levels of communities. For the initial assessment (CRS_1 matrix) only two capital domains were considered. According to the study, the scores for the aspects that reduce the resilience levels seems to be more or less similar.

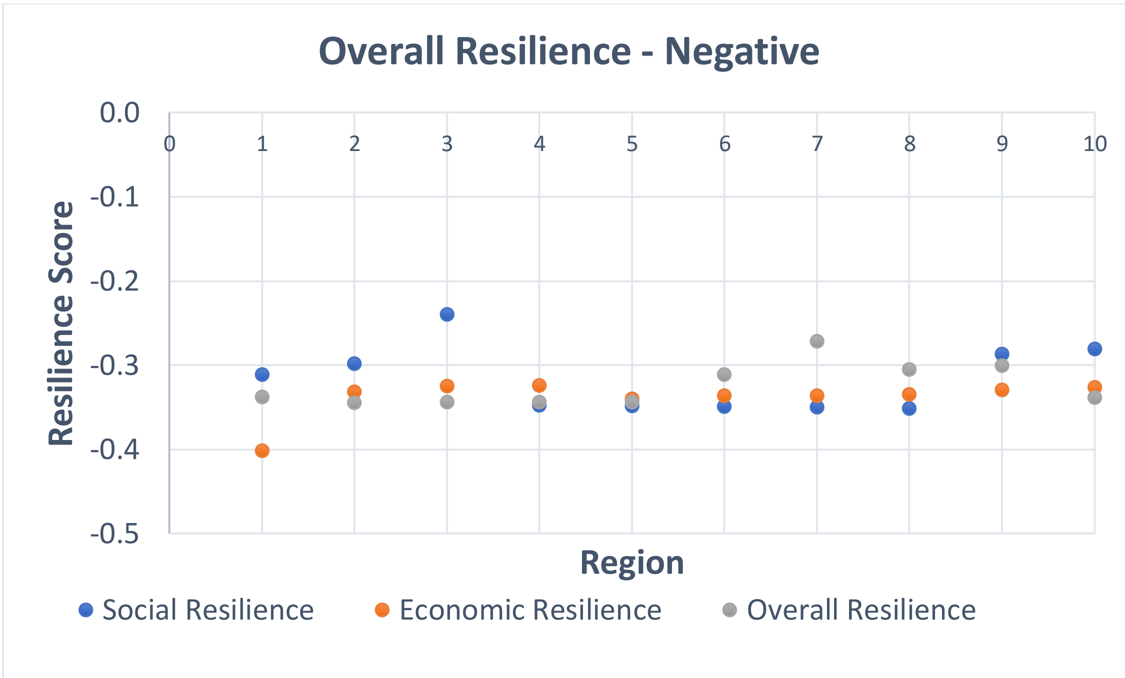

Figure 5.2: Overall Resilience Score – Negative

1-Sri Lanka, 2 - Kurunegala District, 3 - Colombo District, 4 - Kurunegala DSD, 5 - Polpithigama DSD, 6 - Ahatuwewa DSD, 7 - Abanpola DSD, 8 - Maho DSD, 9 - Kolonnawa DSD, 10 - Kaduwela DSD

5.2.2 Resilience for Floods

Table 5.5: Resilience for floods – Positive

Flood Positive	Sri Lanka	Kurunegala District	Colombo District	Kurunegala	Polpithigama	Ahatuwewa	Abanpola	Maho	Kolonnawa	Kaduwela
Social	0.700	0.700	0.450	0.700	0.700	0.700	0.700	0.700	0.350	0.350
Economic	0.531	0.875	0.875	0.875	0.750	0.750	0.750	0.750	0.750	0.750
Physical	0.651	0.645	0.707	0.796	0.587	0.586	0.587	0.592	0.732	0.742
Human	0.438	0.438	0.563	0.563	0.250	0.250	0.250	0.250	0.375	0.375
Environmental	0.763	0.873	0.538	0.475	0.875	0.813	0.875	0.813	0.538	0.538
Overall	**0.669**	**0.622**	**0.609**	**0.622**	**0.610**	**0.682**	**0.607**	**0.517**	**0.519**	**0.620**

From the selected regions, the resilience to floods is lowest in Maho and Kolonnawa. However, although Kolonnawa region subjected to frequent floods, Maho does not face flood situations. In the development of this matrix equal weightings were used for all the capitals. But this example clearly shows the necessity to have different weightings for different capital domains when calculating the final score. However, the scores under different capitals can be used to identify the strong aspects and week aspect of resilience. For example, although social and human resilience is weak in Kaduwela and Kolonnawa, the economic and physical resilience is high. This could be due to the location of these areas close to the economic capital of the country. In Polpithigama, Ahatuwewa, Abanpola and Maho which are rural areas, the Environmental resilience is very high. On the other hand, the resilience scores for the environmental domain is low for Kaduwela, Kolonnawa regions which are urban areas.

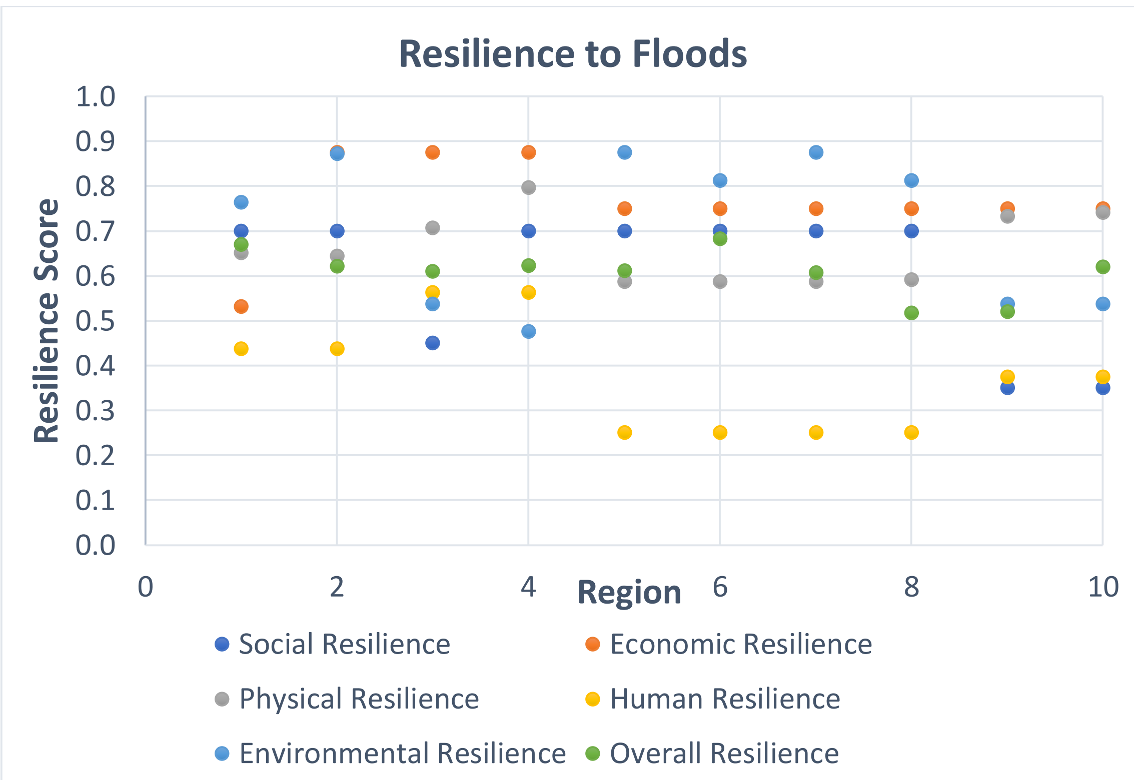

Figure 5.3: Resilience for Floods – Positive

1-Sri Lanka, 2 - Kurunegala District, 3 - Colombo District, 4 - Kurunegala DSD, 5 - Polpithigama DSD, 6 - Ahatuwewa DSD, 7 - Abanpola DSD, 8 - Maho DSD, 9 - Kolonnawa DSD, 10 - Kaduwela DSD

Table 5.6: Resilience for Floods – Negative

Flood Negative	Sri Lanka	Kurunegala District	Colombo District	Kurunegala	Polpithiga	Ahatuwewa	Abanpola	Maho	Kolonnawa	Kaduwela
Social	-0.305	-0.331	-0.234	-0.445	-0.447	-0.449	-0.450	-0.453	-0.325	-0.312
Economic	-0.402	-0.332	-0.325	-0.324	-0.340	-0.337	-0.337	-0.335	-0.330	-0.326
Physical	-	-	-	-	-	-	-	-	-	-
Human	-	-	-	-	-	-	-	-	-	-
Environmental	-	-	-	-	-	-	-	-	-	-
Overall	**-0.373**	**-0.383**	**-0.382**	**-0.382**	**-0.382**	**-0.332**	**-0.279**	**-0.328**	**-0.320**	**-0.353**

Even though positive aspects are higher in rural regions (Polpithigama, Ahatuwewa, Abanpola and Maho), the negative aspects of resilience are lower. Lack of access to facilities could be the reason for this.

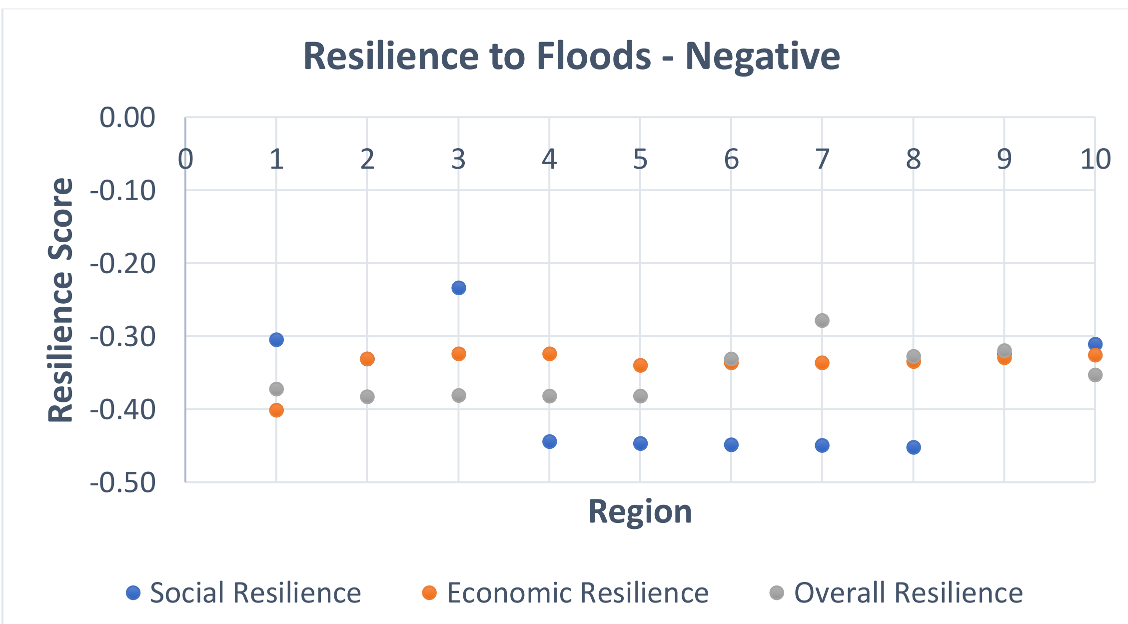

Figure 5.4: Resilience to Floods – Negative

1-Sri Lanka, 2 - Kurunegala District, 3 - Colombo District, 4 - Kurunegala DSD, 5 - Polpithigama DSD, 6 - Ahatuwewa DSD, 7 - Abanpola DSD, 8 - Maho DSD, 9 - Kolonnawa DSD, 10 - Kaduwela DSD

5.2.3 Resilience for Droughts

Table 5.7: Resilience for Drought – Positive

Drought Positive	Sri Lanka	Kurunegala District	Colombo District	Kurunegala	Polpithigama	Ahatuwewa	Abanpola	Maho	Kolonnawa	Kaduwela
Social	0.500	0.700	0.450	0.875	0.875	0.875	0.875	0.875	0.438	0.438
Economic	0.531	0.875	0.875	0.875	0.750	0.750	0.750	0.750	0.750	0.750
Physical	0.671	0.652	0.740	0.827	0.562	0.560	0.562	0.570	0.927	0.966
Human	0.438	0.438	0.563	0.563	0.250	0.250	0.250	0.250	0.375	0.375
Environmental	0.563	0.682	0.414	0.364	0.632	0.582	0.632	0.532	0.414	0.414
Overall	**0.656**	**0.603**	**0.589**	**0.603**	**0.576**	**0.651**	**0.572**	**0.484**	**0.487**	**0.541**

The lowest resilience score is from Maho DSD, which has faced several issues due to drought related problems. Apart from that Polpithigama, Abanpola, Kolonnawa and Kaduwela also show lower scores. This clearly shows the requirement of providing different weightings to different capital domains.

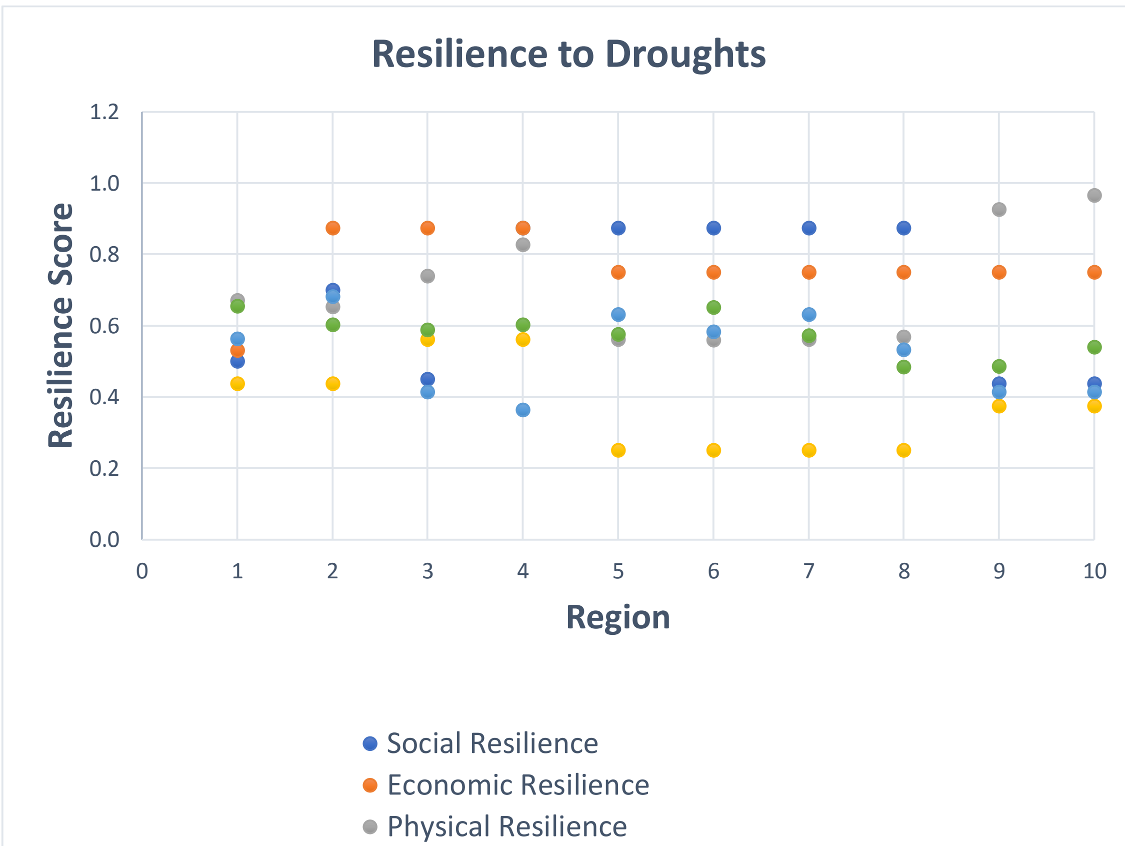

Figure 5.5: Resilience for Drought – Positive

1-Sri Lanka, 2 - Kurunegala District, 3 - Colombo District, 4 - Kurunegala DSD, 5 - Polpithigama DSD, 6 - Ahatuwewa DSD, 7 - Abanpola DSD, 8 - Maho DSD, 9 - Kolonnawa DSD, 10 - Kaduwela DSD

Table 5.8: Resilience for Drought – Negative

Drought Negative	Sri Lanka	Kurunegala District	Colombo District	Kurunegala	Polpithiga	Ahatuwewa	Abanpola	Maho	Kolonnawa	Kaduwela
Social	-0.226	-0.225	-0.158	-0.445	-0.447	-0.449	-0.450	-0.453	-0.325	-0.312
Economic	-0.402	-0.332	-0.325	-0.324	-0.340	-0.337	-0.337	-0.335	-0.330	-0.326
Physical	-	-	-	-	-	-	-	-	-	-
Human	-	-	-	-	-	-	-	-	-	-
Environmental	-	-	-	-	-	-	-	-	-	-
Overall	**-0.373**	**-0.383**	**-0.382**	**-0.382**	**-0.382**	**-0.271**	**-0.229**	**-0.328**	**-0.320**	**-0.304**

Similar to the scores for the resilience for floods, the scores in the above Table 5.8, shows lower negative values in the social capital of the rural areas. These negative scores are important to get an idea about the areas which need improvements.

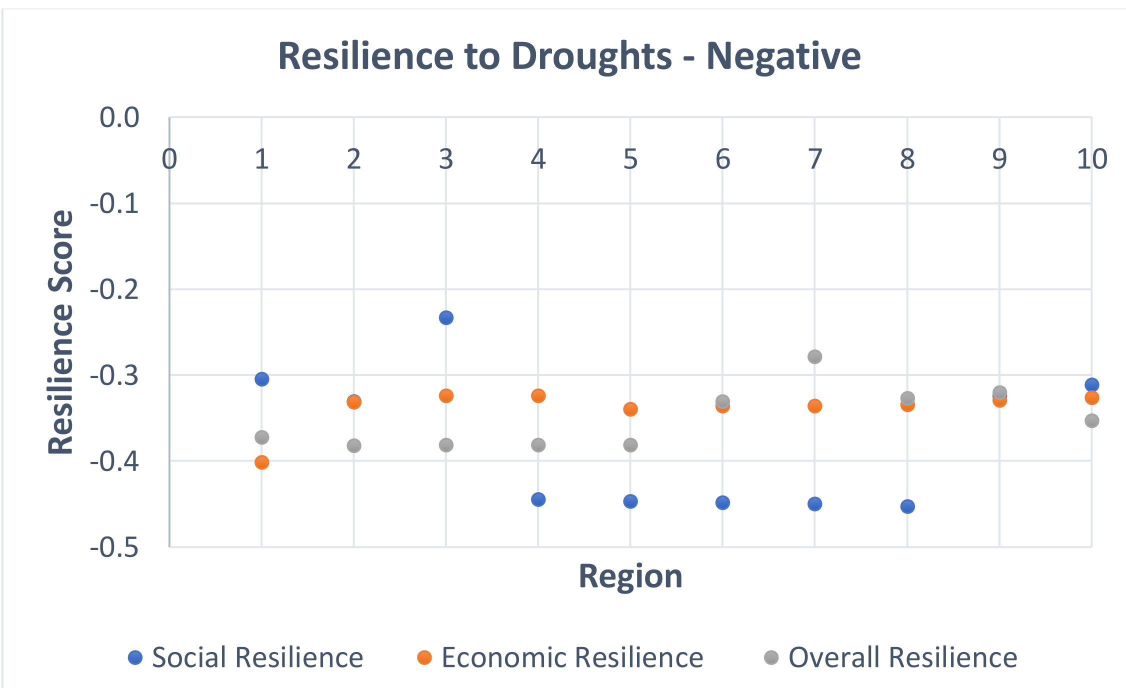

Figure 5.6: Resilience for Drought – Negative

1-Sri Lanka, 2 - Kurunegala District, 3 - Colombo District, 4 - Kurunegala DSD, 5 - Polpithigama DSD, 6 - Ahatuwewa DSD, 7 - Abanpola DSD, 8 - Maho DSD, 9 - Kolonnawa DSD, 10 - Kaduwela DSD

5.3 Output Matrix for CRS_2

The Community Resilience Score 2 (CRS_2) is the details matrix developed to identify the level of resilience of communities under the four main phases of disaster management.

Table 5.9: Overall resilience of Sri Lanka under different phases of disaster management

Main Capital Domain	Sri Lanka							
	Mitigation		Preparedness		Response		Recovery	
	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Social Capital	0.826	-0.342	0.826	-0.179	0.776	-0.179	0.776	-0.179
Economic Capital	0.667	-0.402	0.875	-0.402	0.875	-0.402	0.531	-0.402
Physical Capital	0.906	-	0.764	-	0.647	-	0.814	-
Human Capital	0.540	-	0.534	-	0.561	-	0.534	-
Environmental Capital	0.640	-	0.850	-	0.850	-	0.850	-
CRS2	0.701	-0.360	0.726	-0.268	0.686	-0.268	0.686	-0.268

From the four phases of DM, the overall scores for mitigation phase and preparedness phase are above 0.7 but for response and recovery phases, the scores are below 0.7. The lack of coordination between the government institutions which are responsible for DM could be a reason for this. The CRS_2 for Sri Lanka is important to identify the gaps in DM in Sri Lanka and subsequently research could be more focused to find more meaningful solutions.

Table 5.10: Overall resilience of Kurunegala District under different phases of disaster management

Main Capital Domain	Kurunegala District							
	Mitigation		Preparedness		Response		Recovery	
	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Social Capital	0.792	-0.374	0.792	-0.247	0.744	-0.247	0.744	-0.247
Economic Capital	0.875	-0.332	0.875	-0.332	0.875	-0.332	0.875	-0.332
Physical Capital	0.959	-	0.845	-	0.645	-	0.907	-
Human Capital	0.544	-	0.538	-	0.565	-	0.538	-
Environmental Capital	0.734	-	0.870	-	0.747	-	0.870	-
CRS2	0.739	-0.356	0.730	-0.298	0.672	-0.298	0.732	-0.298

When the Kurunegala district is considered, the lowest overall score is for the disaster response phase. Other phases show overall scores over 0.7.

Table 5.11: Overall resilience of Colombo District under different phases of disaster management

Main Capital Domain	Colombo District							
	Mitigation		Preparedness		Response		Recovery	
	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Social Capital	0.493	-0.290	0.493	-0.234	0.495	-0.234	0.459	-0.234
Economic Capital	0.875	-0.325	0.875	-0.325	0.875	-0.325	0.875	-0.325
Physical Capital	0.980	-	0.922	-	0.769	-	0.922	-
Human Capital	0.598	-	0.620	-	0.667	-	0.584	-
Environmental Capital	0.510	-	0.870	-	0.747	-	0.870	-
CRS2	0.627	-0.303	0.699	-0.279	0.683	-0.279	0.658	-0.279

Colombo district shows comparatively low scores under all the four main DM phases (Scores below 0.7). Colombo is the district with the highest population density is Sri Lanka and this could be the main reason for this.

Table 5.12: Overall resilience of Kurunegala DSD under different phases of disaster management

Main Capital Domain	Kurunegala DS							
	Mitigation		Preparedness		Response		Recovery	
	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Social Capital	0.688	-0.463	0.688	-0.320	0.667	-0.320	0.625	-0.320
Economic Capital	0.875	-0.324	0.875	-0.324	0.875	-0.324	0.875	-0.324
Physical Capital	0.9795	-	0.903	-	0.776125	-	0.903	-
Human Capital	0.250	-	0.500	-	0.667	-	0.375	-
Environmental Capital	0.4687	-	0.8700	-	0.6633	-	0.8700	-
CRS2	0.635	-0.394	0.765	-0.323	0.725	-0.323	0.713	-0.323

In Kurunegala DSD, the least score for the resilience is from the mitigation phase. Other phases show comparatively good scores.

Table 5.13: Overall resilience of Polpithigama DSD under different phases of disaster management

Main Capital Domain	Polpithigama DS							
	Mitigation		Preparedness		Response		Recovery	
	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Social Capital	0.813	-0.465	0.813	-0.394	0.750	-0.394	0.708	-0.394
Economic Capital	0.750	-0.340	0.750	-0.340	0.750	-0.340	0.750	-0.340
Physical Capital	0.934	-	0.706	-	0.546	-	0.789	-
Human Capital	-	-	0.125	-	0.333	-	0.250	-
Environmental Capital	0.694	-	0.750	-	0.667	-	0.750	-
CRS2	0.719	-0.402	0.663	-0.354	0.608	-0.354	0.675	-0.354

In Polpithigama, the overall score under the mitigation phase is good (over 0.7). But under other phases, the score is comparatively low with least score calculated from the response phase. The low scores for response and recovery phases could be due to the issues in the management process.

Table 5.14: Overall resilience of Ahatuweawa DSD under different phases of disaster management

Main Capital Domain	Ahatuwewa							
	Mitigation		Preparedness		Response		Recovery	
	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Social Capital	0.813	-0.466	0.813	-0.398	0.750	-0.398	0.708	-0.398
Economic Capital	0.750	-0.337	0.750	-0.337	0.750	-0.337	0.750	-0.337
Physical Capital	0.949	-	0.716	-	0.550	-	0.799	-
Human Capital	-	-	0.125	-	0.333	-	0.250	-
Environmental Capital	0.652	-	0.750	-	0.583	-	0.750	-
CRS2	0.704	-0.401	0.665	-0.352	0.598	-0.352	0.677	-0.352

In Ahatuwewa, the score under the response phase is very low (below 0.6) and this clearly highlights the necessity to improve the activities which are under this phase of the DM.

Table 5.15: Overall resilience of Abanpola DSD under different phases of disaster management

Main Capital Domain	Abanpola							
	Mitigation		Preparedness		Response		Recovery	
	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Social Capital	0.813	-0.467	0.813	-0.400	0.750	-0.400	0.708	-0.400
Economic Capital	0.750	-0.337	0.750	-0.337	0.750	-0.337	0.750	-0.337
Physical Capital	0.953	-	0.719	-	0.551	-	0.802	-
Human Capital	0.000	-	0.125	-	0.333	-	0.250	-
Environmental Capital	0.694	-	0.750	-	0.667	-	0.750	-
CRS2	0.721	-0.402	0.666	-0.353	0.609	-0.353	0.677	-0.353

Similar to Polpithigama and Ahatuwewa, a good score is calculated for the mitigation phase for Abanpola DSD. But other phases of DM show comparatively low scores.

Table 5.16: Overall resilience of Maho DSD under different phases of disaster management

Main Capital Domain	Maho							
	Mitigation		Preparedness		Response		Recovery	
	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Social Capital	0.813	-0.469	0.813	-0.406	0.750	-0.406	0.708	-0.406
Economic Capital	0.750	-0.335	0.750	-0.335	0.750	-0.335	0.750	-0.335
Physical Capital	0.968	-	0.728	-	0.554	-	0.812	-
Human Capital	0.000	-	0.125	-	0.333	-	0.250	-
Environmental Capital	0.610	-	0.625	-	0.500	-	0.625	-
CRS2	0.690	-0.402	0.649	-0.353	0.588	-0.353	0.662	-0.353

In the case of Maho, the lowest resilience score is observed under the Response stage. This is slightly varied from Polpithigama, Ahatuwewa and Abanpola DSDs which are also similar to Maho by climate.

Table 5.17: Overall resilience of Kolonnawa DSD under different phases of disaster management

Main Capital Domain	Kolonnawa							
	Mitigation		Preparedness		Response		Recovery	
	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Social Capital	0.313	-0.350	0.313	-0.325	0.375	-0.325	0.292	-0.325
Economic Capital	0.750	-0.330	0.750	-0.330	0.750	-0.330	0.750	-0.330
Physical Capital	0.961	-	0.961	-	0.737	-	0.961	-
Human Capital	0.000	-	0.375	-	0.500	-	0.250	-
Environmental Capital	0.510	-	0.870	-	0.747	-	0.870	-
CRS2	0.516	-0.341	0.597	-0.328	0.596	-0.328	0.529	-0.328

The level of resilience under all four phases of DM are to the lower side for the Kolonnawa DSD. Kolonnawa has suffered from flood related issues during the past few years and these scores reflect the gaps in the community activities. The scores strongly suggest the requirement to improve all the four phases of the DM.

Table 5.18: Overall resilience of Kaduwela DSD under different phases of disaster management

Main Capital Domain	Kaduwela							
	Mitigation		Preparedness		Response		Recovery	
	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Social Capital	0.313	-0.343	0.313	-0.312	0.375	-0.312	0.292	-0.312
Economic Capital	0.750	-0.326	0.750	-0.326	0.750	-0.326	0.750	-0.326
Physical Capital	0.981	-	0.981	-	0.744	-	0.981	-
Human Capital	0.000	-	0.375	-	0.500	-	0.250	-
Environmental Capital	0.510	-	0.870	-	0.747	-	0.870	-
CRS2	0.518	-0.336	0.600	-0.320	0.598	-0.320	0.532	-0.320

The Kaduwela DSD, which is located adjacent to the Kolonnawa DSD also shows very similar scores to Kolonnawa. This area has also suffered from flood related issues during the past few years.

Figure 5.7: The overall resilience scores for different regions under main four phases of disaster management

Here 1, 2, 3 and 4 refers to mitigation, preparedness, response and recovery phases. The overall resilience score under different phases of DM of different regions can be seen as lesser compared to that of the entire country.

5.4 Summary of the study

5.4.1 Community Resilience Score 1 (CRS_1)

From the overall results, the CRS_{1P} is below 0.6 for all the regions except for Ahatuwewa where the score is 0.614. All these regions are vulnerable to either droughts or floods and this explains the tendency of moderate scores. When the overall country is considered, the CRS_{1p} is 0.649.

The negative scores for CRS_1 represent the aspects that reduce the resilience capacity of the communities. Here lower scores represent the aspects that need to be highly concentrated to achieve high resilient capacities of communities.

The resilience scores for floods can be seen as low in flood affected areas. But even in some areas which have not been affected by floods during past years, the scores seem to be in the lower side. This error could possibly be eliminated by proposing different weighting for the different capital domains based on the significance. Even for the indicators, suitable weightings can be used to calculate the CRS. This is even true for the case of resilience to droughts.

5.4.2 Community Resilience Score 2 (CRS_2)

The overall results suggest that Sri Lanka is less resilient during the disaster response and recovery phases. When it comes to the Kurunegala district, the score in the response stage is the lowest (0.672). However, the mitigation stage is found to be the least resilient stage for the Colombo District. The overall results suggest that the rural areas seem to be less resilient during the response and recovery stage and the urban areas are less resilient during the mitigation phase. These are rough observations from the case studies covered in this dissertation. Further, Figure 25 clearly depicts that from the selected administrative regions, Kolonnawa and Kaduwela show the least resilience capacities. This is clearly understood from the historical evidences as well because these two regions have severely suffered from flood related conditions during past years.

However, it is necessary to conduct more studies to arrive to a better conclusion about this. Similar to the issue had with the CRS_1, even in the CRS_2 approach, better results could be achieved by providing different weightings for different capital domains based on the priorities.

6.0 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The main objective of this research is to improve the current understanding on the concept of community resilience by developing a theoretical framework to measure resilience of communities to the impacts. To accomplish this objective several steps were followed and this chapter briefly describes these steps by taking the specific objectives outlined in the chapter 1. Based on the developed framework and the findings from the case studies, this chapter draws conclusions, proposes recommendations and subsequently describes the limitations of the proposed resilience measurement method.

6.2 Discussion

This section briefly describes the three specific objectives followed in the development of the resilience measurement tool and summarizes the major findings.

6.2.1 Identification of the relevant indicators

A comprehensive literature review was conducted to identify the resilience measurement approaches and from the literature survey, over 300 indicators which are relevant to resilience measurement were identified.

To categorize the indicators into the groups, five main capital domains were identified. These include social capital, economic capital, physical capital, human capital and the environmental capital. These capital domains were defined and the indicators were categorized into the five domains based on the definition. Further, the indicators were categorized into the four main phases of disaster management based on the definitions in the chapter 4. Initially identified indicator list includes 130 indicators. Then these indicators were sent to the experts form the industry and academia and the list was refined with the comments from them. The final tool includes 108 indicators.

6.2.2 Development of the resilience measurement tool

The second specific objective focuses on the development of the resilience measurement tool. The initially identified list of indicators was further categorized into two types as quantitative indicators (data driven) and qualitative indicators. For quantitative indicators, the method of measurement was defined based on data from main international organizations, including the World Bank, UN, WHO, UNISDR and etc. The score for qualitative indicators were defined in 0.25 increments.

The score for each indicator is between 0 and 1 and an impact sign has been given for all the indicators. If an indicator improves the resilience, the impact sign is +1 and if an indicator reduces the resilience, the impact sign is -1. If the indicator is not relevant to the region of the study, the sign is 0.

From the proposed two types of matrices, CRS_1 provides an overall figure of the resilience of communities without considering the phases of disaster management. This score reflects how strong a particular community is and how much they can depend on their available resources. Having scores under five capital domains is important to identify the strengths and weaknesses in the overall community resilience. The CRS_2 provides a detailed assessment of the resilience of a given community. In-fact CRS_2 can be used to identify vulnerable regions, to identify areas for investments, track the progress of the development with respect to different dimensions, and to assist the policy makers in the decision making process. Although the proposed method has not validated yet, the case studies suggest the strength of the CRS tool in the process of identifying the resilient levels of different administrative regions.

6.2.3 Applicability of the resilience measurement tool

To see the applicability of the developed tool, a few case studies were conducted considering 7 DSDs from 2 Districts and the entire Sri Lanka was also considered for the study. The output CRS_1 matrix highlights the vulnerable areas and the CRS_2 matrix highlights the gaps in DRR in the selected regions.

Only a selected number of indicators were used for the application in this study. The major findings from the application of the proposed resilience measurement tool are as follows:

Table 6.1: Major findings from the case studies

Main findings	Possible reasons
Overall resilience of Sri Lanka is higher than the overall resilience scores of Kurunegala and Colombo districts	Colombo and Kurunegala are densely populated areas and the available resources could be not enough for the functioning of the communities
Social resilience is comparatively higher in rural areas than the urban areas	People are more connected in rural areas
Economic resilience is comparatively higher in urban areas than the rural areas	More contribution for the economy is from the urban areas
Physical resilience is comparatively higher in urban areas than the rural areas	More funding is concentrated on urban development
Environmental resilience is comparatively higher in rural areas than the urban areas	High contamination levels in urban areas
Human resilience is very low in all the regions. However, human resilience in the rural areas is comparatively lower than the urban areas	Migration of educated people from rural areas to urban areas
According to CRS_2, response and recovery stages have lower scores compared to the other two stages in Sri Lanka	Lack of financial allocations for resilience building
In Kurunegala district, the response stage has the lowest score of resilience	DRR management issues
In Colombo district, mitigation score is the lowest	Not allocating enough resources to mitigate impacts
In rural areas (Ahatuwewa, Abanpola, Polpithigama and Maho), the response score is the lowest	DRR management issues
In urban areas (Kolonnawa and Kaduwela), the mitigation score is the lowest	Not allocating enough resources to mitigate impacts

6.3 Conclusions

Community Resilience Score (CRS) tool is a new approach to measure the level of resilience of communities defined by administrative boundaries. The proposed approach includes two types of resilience scores to provide the overall resilience and resilience under different phases of disaster management. Initially three kinds of scores have been defined under each of the CRS scoring methods, including, overall resilience score, the resilience score for floods and resilience score for droughts. Under each of these categories, positive and negative scoring methods have been proposed.

The CRS method can be used with any defined area, country or a region. The case studies show its applicability in different administrative regions. The CRS matrix can showcase the strong and weak aspects of resilience and thus it could be used as a tool in the decision making process and allocation of resources. Even it is possible to use this scoring method when allocating international funds and grants for the developing countries.

6.4 Limitation

It is very difficult to propose a universal method to calculate the resilient levels because, the criteria for resilience could differ from region to region. And provision of weightings to the different indicators and different domains is challenging.

This dissertation proposes qualitative and quantitative indicators for the resilience measurements. Even though assessments with quantitative indicators are straightforward, the assessments with qualitative indicators may vary depending on the person who is doing the assessment.

6.5 Recommendations for future work

This dissertation has identified the possible indicators to measure the overall resilience of communities defined by an administrative area and from all the proposed indicators relevant indicators to floods and droughts has been identified separately. But the study does not focus on measuring resilience to other disasters, including hurricanes, landslides, tsunamis and other coastal hazards. In-fact further studies need to be undertaken to identify the indicators relevant to the other disasters from the proposed list and if required, need to refine the proposed tool.

And also it is required to validate the proposed method with some disaster/hazard data and this could be a possible future research area. Apart from that it is recommended to use weightings with different capitals and indicators based on their significance.

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