Effects of multi-level governance characteristics on resilient flood risk management: Case study of Kerala floods

By
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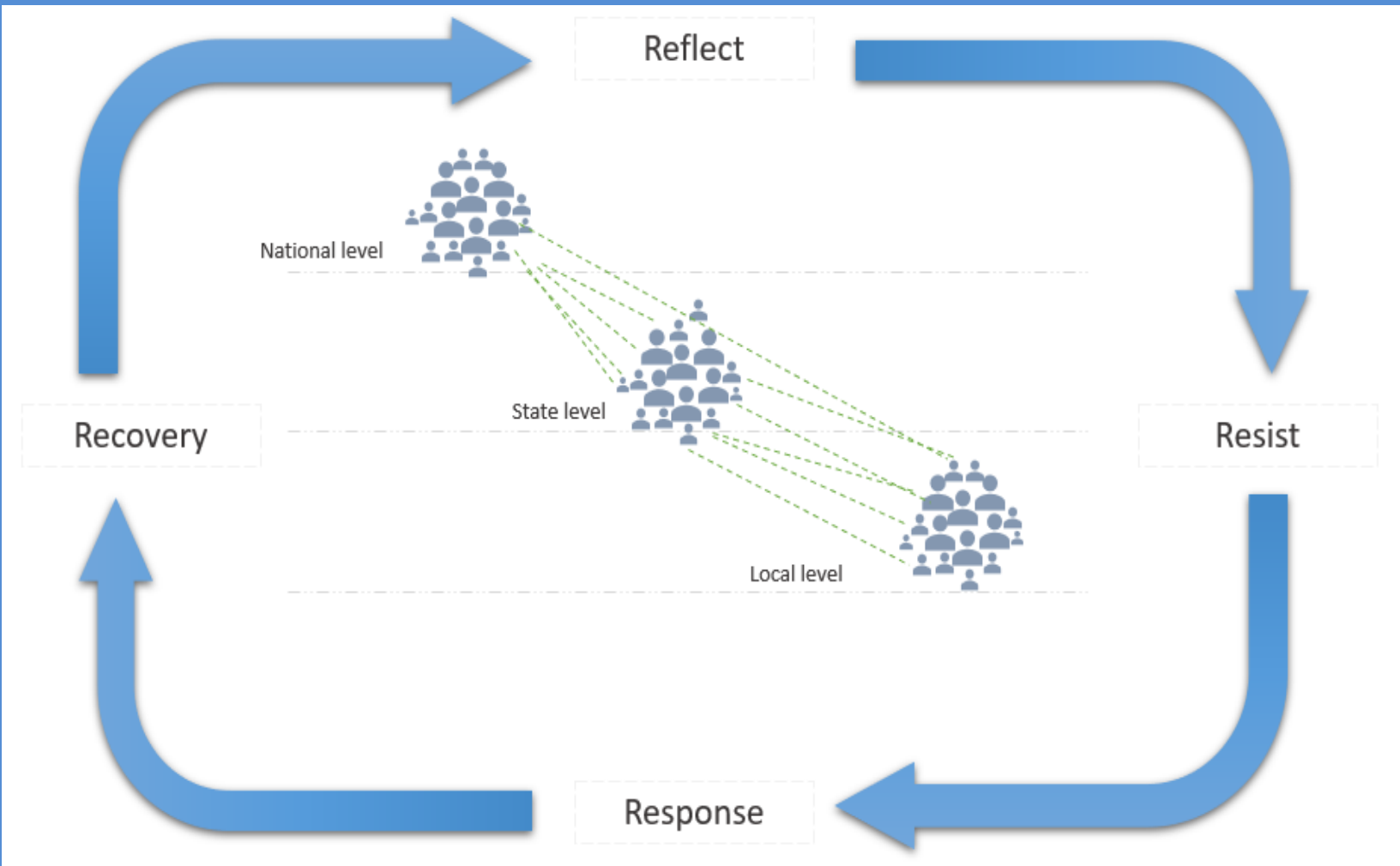

ACKNOWLEDGEMENT

I came to the Netherlands in 2018 for my study and during that period, Kerala, the state in India where I was born was facing one of the most catastrophic floods. Many of my distant family members were extremely affected by the floods and at that moment I felt quite helpless. When the time came to finalize my thesis topic, I was certain that I wanted to contribute to the study on Kerala floods.

First and foremost, I would like to thank Dr. Bert Enserink for being a constant support and guide. He has been a great advisor since the very beginning of masters. Next, I would like to thank Dr. Amineh Ghorbani for her guidance and support. The comments she gave have been of great help and she is someone I look upto for her work and the way she carries herself. I would like to thank Dr. Justyna Tasic for reviewing my work and providing feedback on ways to improve the content. I would like to further thank Dr. Alexander Jachnow for his insights on the Kerala floods.

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This journey would not have been possible if it wasn't for my family who never fails to remind me that they are here to support me. I have been tremendously blessed with families here in the Netherlands who are basically my home away from home. Keeping the most special for last, I would like to thank my God Almighty for all these wonderful people and experiences. He deserves all praises.

As the second year of my master's in Engineering and Policy Analysis (EPA) is coming to an end, I feel extremely overwhelmed with memories and emotions. It has been a roller coaster ride but I embrace all the ups and downs with at most pride and gratitude.

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EXECUTIVE SUMMARY

Kerala is the South-western state in the Malabar coast of India that experiences floods. The disaster management in this state is response-centric and the 2018 floods indicated the need for a transition from a response-centric approach to a resilient flood risk management (FRM) approach. According to Vincent Ostrom, multi-level governance (MLG) is required for the effective provision of a public good or service and when considering FRM to be a public good/service, it can be inferred that MLG is required for the effective provision of FRM. Kochi, the largest urban agglomeration in Kerala and the location of interest for this research, has a MLG structure and yet does not have an effective resilient FRM system due to the governance issues within FRM.

This research is aimed towards adding an additional layer to the existing researches within the domain linking MLG and FRM by taking a data-driven modelling perspective. In order to achieve this, the existing system is viewed as a complex adaptive system (CAS). The existing flood risk governance arrangements (FRGA) were modelled with the help of MAIA (Modelling Agent Systems based on Institutional Analysis) metamodel and Agent-Based Model (ABM) to derive insights about the characteristics of MLG relevant to the governance issues faced by the resilient FRM in Kochi. The results revealed that the existing power distribution among the State, District and Local authorities must be changed to ensure a better resilient FRM system. Furthermore, the results revealed that the network formation among local communities, non-governmental organizations (NGOs) must be encouraged.

POLICY RECOMMENDATIONS

- *Monitor the implementation stage*: The existing structure must acknowledge and incorporate the need for monitoring the implementation stage of the policies developed.
- *Provide clarity on responsibilities*: The existing structure must acknowledge and accommodate the need for a better clarity on the responsibilities of decision-makers.

- *Power allocation*:
    - When considering the definition of resilience to be the ability of system to absorb shocks and show the least fluctuations, the recommendation is to ensure a power distribution set up where the District authority has the highest power followed by the Local authority and State authority.
    - When considering resilient FRM cycle to involve distinct phases, the recommendation is to adopt "policy switching" which is defined in this research as the approach of considering a combination of policies in terms of power distribution such that the requirement of each phase is addressed.
    - In general, the recommendation is that the District and Local authorities must be more involved in the decision-making within resilient FRM cycle.

In terms of **scientific contribution**, this research took a data-driven modelling perspective to bridge the gaps between - governance issues, resilient FRM and MLG by using the case study on Kerala floods to show the application of the study. With respect to Kerala, in addition to adopting a data-driven modelling perspective, the scientific contribution involves an empirical study of the FRGA in Kerala. In terms of **societal contribution**, this research paves a path for informing the stakeholders on the impacts the existing governance structure can have on resilient FRM, which is a long-term goal as per the post disaster needs assessment (PDNA).

The main limitation of the research is that the dimensions used to evaluate the overall system is assumed to have equal weightages and hence the determination of the weightages of these dimensions can be accommodated in the future work.

1. INTRODUCTION

This chapter is aimed towards introducing the research problem, knowledge gaps, research questions, methods to answer the research questions and finally a brief on the structure of the thesis.

1.1. RESEARCH PROBLEM

1.1.1. BACKGROUND: KERALA FLOOD 2018

Kerala is the south-western state on the Malabar coast of India. In addition to being recognized as the best governed state in the country, (Indo-Asian News service, 2018) Kerala is well-known for its abundant water and mineral resources, internationally recognized social development figures and opulent monsoons (Tharoor, 2019). Even though the mentioned recognitions would create the expectation for Kerala to have a well developed water management system, that is not the situation. From 1 June to 20 August 2018, the quantity of rainfall increased by 140 percent in comparison to the normal level of rainfall and this resulted in floods, causing damage to both life and property (Oommen et al., 2018). The disaster management system in Kerala is response-centric (Shaharban & Rathnakaran, n.d.) and the floods emphasized structural constraints with respect to institutional capacity, policy and planning, financing, standards, access to data and public services which resulted in Kerala being unprepared for severe natural calamities or climate change (Chandran & Paul, 2019). The impacts from the floods indicate that a simple response-centric approach would not be enough and that a resilient flood risk management (FRM) approach must be established.

1.1.2. RESILIENT FLOOD RISK MANAGEMENT

At this point, it was important to understand the terms or concepts - resilience, FRM and resilient FRM. This will give rise to the first major progress in the research which is about understanding the structure of the resilient FRM cycle, the phases it constitutes and the indicators that can be used to evaluate the resilient FRM.

In the context of disaster risk, resilience of a system exposed to hazards is the ability to resist, absorb, accommodate, adapt to, transform and recover from the impacts of the hazard efficiently ensuring

the preservation and restoration of its essential basic performance through risk management (UNISDR, 2009). FRM as defined by Plate (2002) is the planning and management of the existing flood risk situation such that the flood risk decreases, disasters are controlled, and the impacts are minimized. Batica et al. (2013) introduces resilience into FRM and discusses that resilient FRM is about incorporating resilience characteristics into traditional FRM. Batica et al. (2013) proposes the different phases within the resilient FRM cycle and this research makes use of the improvised version of this resilient FRM cycle which would include four phases - reflect, resist, response and recovery. Batica et al. (2013) further discusses the five dimensions or Key Performance Indicators (KPIs) that can contribute to evaluating resilience and this research would make use of the improvised version where the five dimensions considered would be - social, economic, environmental, technical and institutional.

1.1.3. MULTI-LEVEL GOVERNANCE

Inspired by the work of Geaves & Penning-Rowsell (2016), the research will adopt the perspective that FRM is a public good or service. According to Vincent Ostrom, for effective provision of a public good or service Multi-level governance (MLG) is required and furthermore, MLG contributes to managing resilience (Djalante, Holley, & Thomalla, 2011).

In order to understand MLG, it is important to first define what governance would mean in the context of FRM. According to Renn et al. (2011), risk governance comprises 'both institutional structure and the policy process that guide and restrain collective activities of a group, society or international community to regulate, reduce or control risk problems. When introducing risk governance in the context of flood it gives rise to Flood Risk Governance Arrangement (FRGA) which is the analysis of the actors, rules, resources and discourses that contribute to multi-scale approaches to flood risk management (Alexander et al., 2016).

MLG theory highlights that the aspirations of non-state entities can influence policy-making and these non-state entities have a role to play in decision making. The multi-level aspect in this type of governance structure lies within the fact that for mobilization the relevant levels are not just the national or supranational levels but also other levels such as the sub-national level (Piattoni, 2009). The involvement of stakeholders from both vertical (links between the higher and the lower levels

of government) and horizontal (cooperative setup between entities within the same level) dimensions results in a complex network of relationships (OECD, n.d.). Flooding is not "merely" a water problem. It is the interaction between the human sub-system and flood sub-system (discussed in section 2.3). Social system is inherently complex in nature due to the involvement of individuals who have their personal agenda or strategies in order to achieve their personal goal. This complexity in relationships enables to define human-flood system as a *complex system*. Furthermore, in the case of resilient FRM, for the reason that it accommodates characteristics of resilience which involve learning and adapting, it can be derived that the human-flood system within the context of resilient flood risk management is a Complex Adaptive System (CAS). Furthermore, in order to identify intervention points a better understanding of these relationships are necessary (OECD, n.d.) due to which this research will take a CAS perspective.

1.1.4. SCOPE OF THE STUDY

Urban agglomerations are the epicenters for economic growth and development. The occurrence of disasters like floods can affect such agglomerations in ways that cannot be foreseen. This idea served as an inspiration to focus the research on such an area in Kerala. The metropolitan city of Kochi is the largest urban agglomeration in Kerala with a MLG structure and this becomes evident from the involvement of stakeholders from different levels – National authorities, State authorities, District authorities, the local-self government (grassroot layer), NGOs and community initiatives. Even with a MLG structure, the catastrophe that the 2018 flood resulted in shows that there are some issues which contribute to the inability in the provision of an effective FRM. The analysis of Parsons & Skinner (2018) and Chattopadhyay & Harilal (2017) helped with confirming that it is institutional incapacity and assumption of the system to be static in nature which contributed to the catastrophe. This gives rise to the third major progress in the research which is the confirmation that it is indeed the governance structure which needs attention and that there are certain issues within the MLG structure.

1.1.5. EXISTING GOVERNANCE ISSUES

For this research the report of Singh et al. (2018) is used to identify the issues with the governance structure of Kerala FRM. This report is considered as a major reference because the analysis in the report was carried out with the help of extensive stakeholder interviews and hence gives an analysis closer to reality. The issues discussed by Singh et al. (2018) that the research would further focus on are as follows:

- The government authorities were unable to give precise answers for questions pertaining to preparedness, dam management, dissemination of information between different levels of the government, early warning systems, immediate relief measures to be taken, the roles and responsibilities of the authorities
- The governance at the level of the local-self-governments is the strongest and it is from this layer that most of the data for official policies are collected yet this participative grassroot layer of governance was not involved in the preparedness phase and was not informed prior to releasing water from the dams
- The privatization of fragile areas of mountains, mangroves and wildlife resulted in the degeneration or erosion of coastal zones and the loss of livelihood
- The government authorities ignored to support and coordinate with non-government organizations and voluntary social welfare institutions that were making efforts at the grassroot layer to aid disaster management

1.2. RESEARCH GAP

Based on the work of Geaves & Penning-Rowsell (2016), this research takes the perspective that FRM is a public good/service. According to Vincent Ostrom, polycentric governance (Type II MLG (Hooghe & Marks, 2010)) is required for the effective provision of public good/service. Furthermore, according to Djalante, Holley, & Thomalla (2011) MLG helps with managing resilience. Based on the above, this research considers that for the effective provision of resilient FRM, MLG is required.

To the best of my knowledge, there has been limited research on MLG in the context of resilient FRM even though it is apparent that MLG is required for resilient FRM.(Vedeld et al., 2016) has made use of MLG framework to elaborate on the governance of scale of climate adaptation (focusing on FRM), (Dieperink et al., 2018) has discussed about the mechanisms that contribute to creating coordination among the different levels in MLG for managing urban flood resilience, (Bisaro et al., 2020) has explored the multilevel public funding arrangements in Coastal flood risk reduction (CFFR) and (Thaler & Levin-Keitel, 2015) has carried out an empirical study on the multi-level stakeholder engagement in FRM. However, there has been no research that focusses on a real world case study taking a data-driven modelling perspective to discuss the impacts of an existing MLG structure on resilient FRM. Furthermore, within the context of Kerala, there has been no empirical research on the existing FRGA.

As taking a modelling perspective helps with understanding systems better and supports with identifying intervention points for achieving goals (van Dam et al., 2012), this research will take data-driven modelling perspective to study the impact of an existing MLG structure on resilient FRM. With regards to Kerala floods, this research will provide an empirical study of the FRGA in Kerala.

Figure 1.1. summarizes the research process followed prior to the framing of research questions.

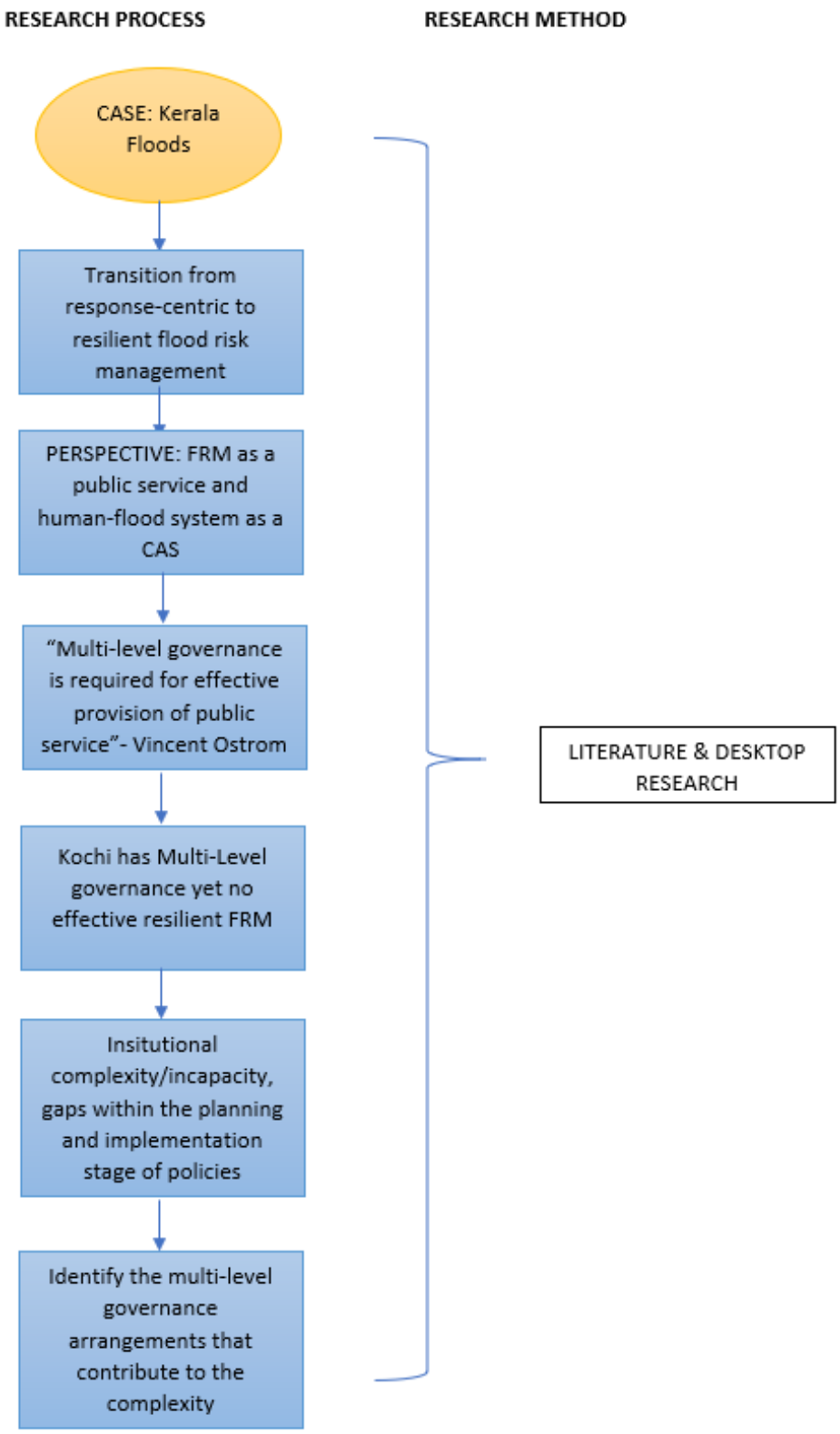


Figure 1.1. The research process followed prior to framing research questions

1.3. RESEARCH QUESTIONS

Based on the knowledge gap identified, the main research question would be:

What are the impacts of multi-level governance on resilient flood risk management in Kerala?

The sub-questions that would be used to answer the main research question are as follows:

1. How can resilience be incorporated and evaluated within the Flood Risk Management context?

To answer this question, primarily the definition of resilience in the context of FRM was determined. Furthermore, to be able to study a system and impacts of certain elements or events on that system, there are Key Performance Indicators (KPIs) required and hence the indicators for evaluating resilient FRM systems were determined. Answering this question will help with taking a step further on developing a picture as to what resilient flood risk management would mean in this research and deciding the evaluative structure for resilient FRM.

2. Which multi-level governance characteristics are relevant for resilient flood risk management?

MLG has several characteristics and for simplicity of the research it is important to narrow down the characteristics that must be focused on. Firstly, the general characteristics of MLG will be identified from related research work. When talking about the characteristics relevant for resilient FRM, the objective is to look at the resilient FRM aspect in Kerala from the perspective of the governance issues that have been discussed previously and further identify the characteristics of MLG these issues can be associated with. Answering this question helps with establishing a link between the identified governance issues and the MLG characteristics.

3. What are the existing Flood Risk Governance Arrangements (FRGA) in Kerala?

After identifying the governance issues and the associated characteristics of MLG, in order to get a better perspective on how these governance issues fit within the existing governance arrangement, it is important to prepare the complete picture of the existing governance arrangement. Answering this specific question contributes to understanding the real situation with the FRM in Kerala and

helps with establishing that the system is not static in nature but rather dynamic. This further helps with identifying the model parameters.

4. How can the Flood Risk Governance Arrangements be modelled?

To answer this question, a conceptual model will be prepared first prior to developing an Agent-Based model (ABM). The conceptual model is prepared using the meta-model called Modelling Agent systems based on Institutional Analysis (MAIA) (Ghorbani, Bots, Dignum, & Dijkema, 2013) which through its five structures - collective structure, constitutional structure, physical structure, operational structure and evaluative structure provide an in-depth understanding of the stakeholders, institutions, physical components, operational components and the KPIs. Thus, by answering this question using the conceptual model, a guiding structure can be created which would aid in developing the ABM during the modelling phase.

5. What are the impacts of multi-level governance characteristics on resilient flood risk management?

To answer this question, the conceptual model in MAIA and ABM can be used. The ABM is developed using both the qualitative and quantitative data procured during the desktop research carried out to understand the FRGA in Kerala. Upon the simulation of the model, quantitative results are generated and insights can be gathered from the data. In addition to the ABM, the conceptual model can also be used to study the impacts qualitatively. The reasoning behind separating this sub-question from the main research question is that the answer to this sub-question would be the simulation results (quantitative data) and the qualitative results from the conceptual model. The answer to the main research question would be the insights gathered upon the analysis of the data (discussion of the results). Furthermore, by discussion of the results, the intention would be to derive conclusions and provide recommendations with respect to the MLG characteristics relevant for the governance issues.

1.4. APPROACH

The methods associated with the research questions were briefly mentioned below the respective sub questions but to summarize:

- **Sub question 1: " How can resilience be incorporated and evaluated within the Flood Risk Management context? "** will be answered through literature research. Previous studies pertaining to resilient FRM will be looked into and improvised based on interpretation and the requirement of this study.
- **Sub question 2: " Which multi-level governance characteristics are relevant for resilient flood risk management?"** will be answered by first identifying the general characteristics of multi-level governance and the governance issues pertaining to the FRM in Kerala. Then, the identified governance issues will be linked to certain characteristics of MLG based on the interpretation of the governance issues.
- **Sub question 3: " What are the existing Flood Risk Governance Arrangements (FRGA) in Kerala?"** will be answered through desktop research where the resources would include formal documents (Examples: documents on the disaster management act, coastal zone management norms and documents on land utilization act), newspaper articles and published reports.
- **Sub question 4: "How can the Flood Risk Governance Arrangements (FRGA) be modelled?"** will be answered with the help of the meta-model MAIA which supports the modeling phase by providing a complete layout of the existing FRGA and hence giving a better perspective on what must or can be modelled.
- **Sub question 5: "What are the impacts of multi-level governance characteristics on resilient flood risk management?"** will be answered with the help of both MAIA conceptual model and the ABM. This sub-question was intended towards briefing on the qualitative results from the conceptual model and the quantitative results from the ABM. The main research question is distinguished for this sub-question as the main research question is more of the higher/ broader perspective on the results obtained.

Figure 1.2. shows the research flow diagram summarizing the research questions, the methods to be used and the expected outcomes

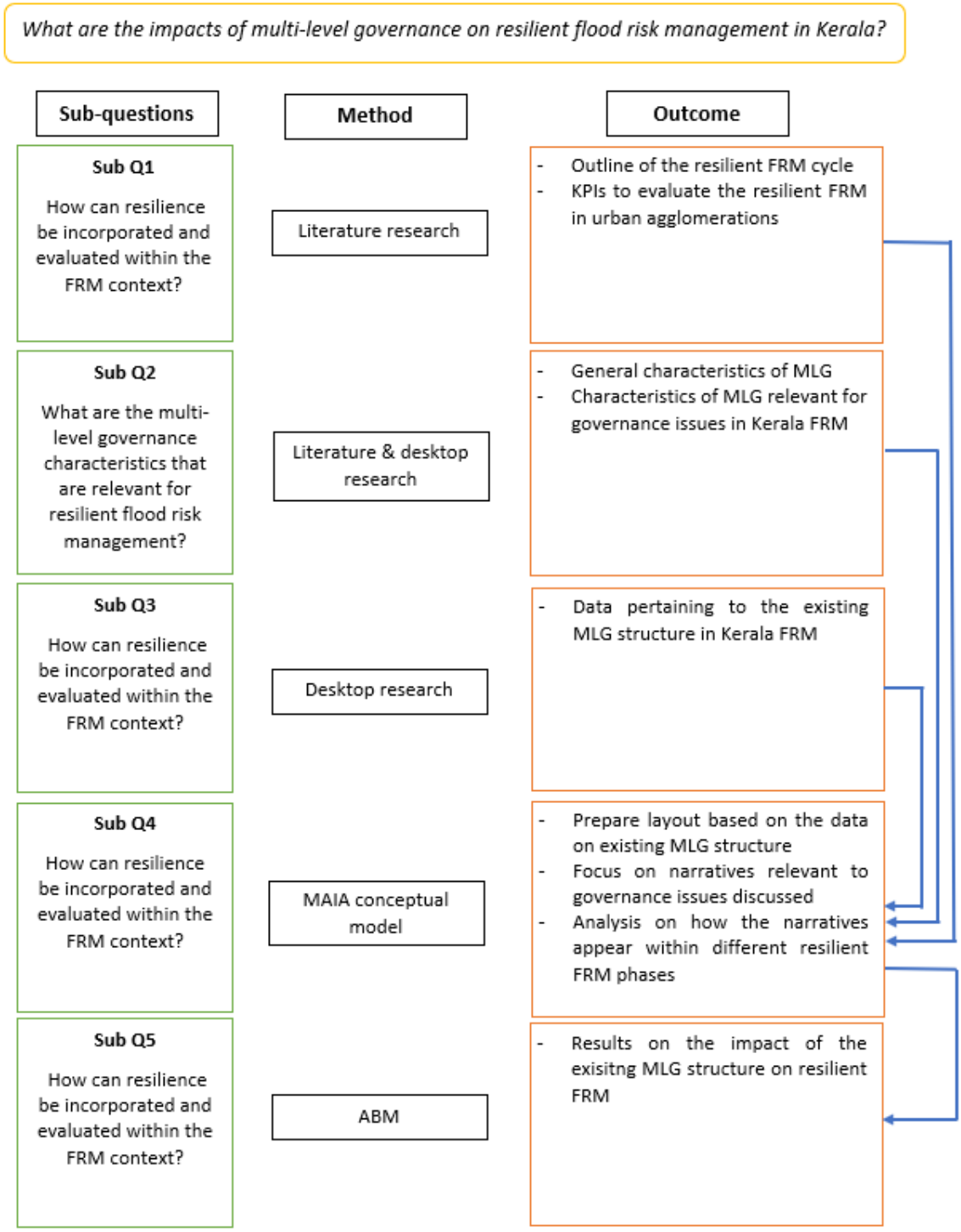


Figure 1.2. Research flow diagram

1.5. RESEARCH CONTRIBUTION

In terms of **scientific contribution**, this research aims to take the previous researches which emphasize on the importance of MLG in FRM a step further by looking into the impacts of MLG on resilient FRM taking a data-driven modelling perspective. This research will bridge the gaps between - governance issues, resilient FRM and MLG by using the case study on Kerala floods to show the application of the study. With respect to Kerala, in addition to adopting a data-driven modelling perspective, the scientific contribution involves an empirical study of the FRGA in Kerala.

In terms of **societal contribution**, the research aims to inform the stakeholders on the impacts the existing governance structure can have on resilient FRM. Even though the Post Disaster Needs Assessment (PDNA) report for Kerala floods addresses the importance of resilient FRM, allowing governance issues to persist and not being aware of the impacts these governance issues can have on the long-term goal of resilient flood risk management can result in the delay of achieving this long-term goal. Therefore, even though the case of Kerala floods 2018 is considered as the starting point for the research, the results of this research would be oriented towards a more long-term goal.

1.6. THESIS STRUCTURE

Chapter 2 - Methodology aims to discuss the research methods that are used for answering the research questions.

Chapter 3 - Theoretical background introduces the theories that are applied in the research.

Chapter 4 - Related research discusses the core concepts and answers the sub-question “How can resilience be incorporated and evaluated within the FRM context?”

Chapter 5 - Case study gives an overview of Kerala floods and governance issues that motivated the research.

Chapter 6 - Setting the context presents various aspects of the Kerala FRM that the conceptual model and ABM model would be dealing with. This chapter introduces the different narratives and gives a better understanding of what would be discussed in the modelling phase.

Chapter 7 - Conceptual model paves a path for the development of the ABM. This chapter helps with answering two sub-questions: “What are the existing FRGA in Kerala ?” and “How can the FRGA be modelled?”

Chapter 8 - Model formalization discusses the model parameters and elaborates on the set-up of the ABM

Chapter 9 - ABM results showcases the results from the ABM model and shares insights on these results in order to identify the discussion points

Chapter 10 - Discussion is aimed towards forming a structured dialogue with regards to the Kerala resilience FRM based on the results obtained

Chapter 11 - Conclusion gives the final set of remarks on the research and the findings

Chapter 12 - References include the list of literature discussed in the research

2. METHODOLOGY

This chapter is aimed towards discussing the research methods for answering the research questions. Even though, these methods were introduced briefly in the previous chapter, it is important to elaborate on these methods.

2.1. LITERATURE RESEARCH

Literature research will be used in order to gain in-depth understanding of the terms and concepts associated with resilience, MLG and resilient FRM. This method helps with identifying the most precise ways to link the mentioned terms and concepts. Literature research will support with tackling the research gap by linking these different terms/concepts and will contribute to identifying the different perspectives the research can take in order to answer the research questions. Furthermore, this method will help with identifying the most suitable theories/concepts which can explain the narratives better and will contribute to conveniently validating the perspectives the research takes with regards to what the system looks like. In terms of research questions, literature research would help with answering:

Sub question 1: How can resilience be incorporated and evaluated within the FRM context?

Sub question 2: What are the multi-level governance characteristics that are relevant for resilient flood risk management ? . To be more specific, literature research would be used to answer the first part of this sub-question by contributing to identifying the general characteristics and concepts relevant for MLG

2.2. DESKTOP RESEARCH

Desktop research will be used to get a better clarity on the events or dynamics within the human-flood system and thus will contribute to developing a narrative of the events that must be elaborated or modelled in order to understand the system better. The desktop research would include gathering data from formal documents (Examples: documents on the disaster management act, coastal zone

management norms and documents on land utilization act), newspaper articles and published reports.

For this research the report of Singh et al. (2018) will be used extensively to elaborate the issues with the governance structure of Kerala FRM. This report is considered as a major source of reference because the analysis in the report was carried out with the help of extensive stakeholder interviews and hence gives an analysis closer to reality. The data collected from the desktop research would be used to build the conceptual model in MAIA.

It was necessary that during the desktop research different types of sources would be made use of since one specific kind of document does not express the different perspectives to be considered. For example, formal documents mostly discuss what the "ideal" situation could look like. In order to get a perspective on the "real" situation, reports or newspaper articles would be considered as reliable sources. The formal documents (Examples: documents on the disaster management act, coastal zone management norms and documents on land utilization act) would help with identifying some of the decision makers and the institutions governing the FRM system in Kerala. The newspaper articles would help with identifying a different side of the story and give insights on the experiences of the stakeholders (decision makers and the affected communities). Furthermore, published reports would help with gathering professional analysis on the situation with Kerala floods. Desktop research would help with answering:

Sub question 2: What are the multi-level governance characteristics that are relevant for resilient flood risk management ? To be more specific, desktop research would be used to answer the second part of this sub-question by contributing to identifying the governance issues within the Kerala FRM. The relevant MLG characteristics would thus be the characteristics associated with the governance issues.

Sub question 3: "What are the existing Flood Risk Governance Arrangements (FRGA) in Kerala?"

2.3. INTERVIEW

The interview will be conducted with a policy researcher who has been extensively involved in the stakeholder workshops associated with the Kerala floods. The insights gathered from the interview

would be used to gain better understanding of the dynamics with the FRM in Kerala and in analyzing the FRM system from a qualitative perspective. The interview would be used to answer :

Sub question 3: "What are the existing Flood Risk Governance Arrangements (FRGA) in Kerala?"

2.4. AGENT-BASED MODELLING

ABM follows the agent paradigm according to which a system consists of several interacting social entities and technical subsystems (van Dam et al., 2012). ABM models socio-technical systems and throws light into the dynamics and structural changes arising from the interactions in the system (van Dam et al., 2012). In this research ABM is used to study the interactions between the stakeholders involved in the FRGA of Kerala and further used to study the influence of MLG characteristics on resilient FRM. The motivation behind using ABM is for its ability to capture the dynamic nature and it would give a better understanding of the Complex Adaptive Systems (CAS) perspective which the research adopts to study human-flood interactions . Furthermore, the FRM in Kerala is a complex system due to the presence of multi-level stakeholders with personal agendas and ABM as a tool can contribute to capturing this social complexity. ABM would be used to answer:

Sub-question 5: "What are the impacts of multi-level governance characteristics on resilient flood risk management?"

2.4.1. MODELLING AGENT SYSTEMS BASED ON INSTITUTIONAL ANALYSIS

In order to develop an ABM model a conceptual model is required and in this research, the conceptual model will be developed using the meta-model MAIA (Ghorbani et al., 2013) which is representative of Ostrom's Institutional Analysis and Development (IAD) framework and it works on the principle that social interactions are influenced by institutional arrangements. As a result, it takes norms, culture, personal values and preferences into consideration as they are key aspects of a social system. The objective of using MAIA is to prepare a layout of the complexity within the system of interest and identify those aspects of the system that must be modelled to capture the essence of the dynamics. MAIA meta-model is organized into five structures - collective structure, constitutional structure, physical structure, operational structure and evaluative structure. The motivation behind

using MAIA for the conceptual model is because primarily it has been established that institutions are crucial within human-flood interactions (Section 4.3) and MAIA as a conceptual model gives significance to institutions that guide the behaviour of stakeholders in an action arena. The MAIA conceptual model would be used to answer :

Sub question 4: "How can the Flood Risk Governance Arrangements (FRGA) be modelled?"

3. THEORETICAL BACKGROUND

For the remaining sections of the research, certain theories would be discussed in order to get a better perspective on the narratives the research would focus on. This chapter is aimed towards introducing the theories that would be discussed in the upcoming sections.

3.1. MULTI-LEVEL GOVERNANCE

With the increase in frequency of disasters like floods, a typical top-down approach would not be sufficient to tackle disaster risks in urban agglomerations. The empirical demonstration that public services are efficiently provided under the system of multiple and overlapping or decentralized jurisdictions led Vincent Ostrom to introduce the concept of polycentricity (McGinnis & Walker, 2010). As FRM has been identified as a public good/service, it can be derived that for an efficient FRM, multiple and overlapping jurisdictions are required. MLG contributes to internalizing externalities corresponding to the provision of public goods and in addition to capturing the formal institutions, it enables the study of informal institutions governing interactions (Hooghe & Marks, 2010).

Polycentricity which is type II MLG (Hooghe & Marks, 2010) is characterized by (Nagendra & Ostrom, 2012):

- The capability of elements to make mutual adjustments limited by a general set of rules yet ensuring that each element behaves independent of other elements;
- The ability to reduce opportunistic behavior and establish a sense of common understanding among the citizens;
- The ability to reduce the free-riding behavior of the wealthy.

Furthermore, a MLG approach allows governmental units to compete and cooperate, interact and learn from one another, and responsibilities assigned to the different governmental levels are scaled to the public services provided (Cole, 2015). The multilayer or polycentric institutions have a

significant impact on the capacity to manage resilience as it promotes self-organization and formation of networks (Djalante, Holley, & Thomalla, 2011).

In addition to internalizing externalities and finding a middle ground between top-down and bottom-up approaches, MLG offers flexibility by accommodating the changes in citizen preferences, enhances problem solving capacities and prevents cross-jurisdictional spillover by clustering competencies that are spread across jurisdictions (Hooghe & Marks, 2010).

Establishing MLG comes with challenges or rather requires answers to certain questions relating to the method that can be adopted for such governance to evolve considering the differences in the priorities, actors and aspirations at different levels. Furthermore, it is vital to tackle the lack of stakeholder involvement in the decision-making process through institutional repositioning (Chattopadhyay, S., & Carilal, 2017).

3.1.1. IDENTIFICATION OF RELEVANT MLG CHARACTERISTICS

Based on the above discussion on MLG, the governance issues mentioned in Section 1.1.5. were linked to certain characteristics of MLG. This is done because Kochi having a MLG structure can contribute to several discussion points pertaining to the structure but in order to scope down the research, the discussion points would revolve around the MLG characteristics relevant to the governance issues discussed.

- The governance issue regarding government authorities being unable to give precise answers pertaining to their roles and responsibilities can be associated with the overlapping jurisdictions aspect of MLG. i.e; there are overlapping functions due to which government authorities lack clarity on who is in-charge of what.
- The governance issue of the Local self government not being involved in the decision-making can be associated with the characteristic of decentralization in MLG structure. The fact that the local-self government was not involved in the preparedness phase questions the power distribution aspect of decentralization and how power is distributed across the different levels of government when it comes to decision-making

- The governance issue of the privatization of ecologically sensitive areas can be an indication that there is opportunistic behaviour and this is in contrary to what MLG can offer. i.e; reduction in opportunistic behaviour
- In multi-level governance, the decision-making capabilities are distributed across stakeholders in different levels (vertical dimension) and stakeholders within the same levels (horizontal dimension) (Sielker, 2016). The governance issue of the ignorance of social welfare institutions in that case would not be representative of a MLG structure

In conclusion, the research would focus on the MLG characteristics pertaining to the governance issues faced within the Kerala flood risk management system. The characteristics of focus would be - overlapping jurisdictions, power distribution aspect of decentralization, opportunistic behaviour and the involvement of stakeholders from both horizontal and vertical dimensions. Thus, through this research, the objective thus becomes to be able to make conclusions regarding these identified characteristics and identify intervention points.

3.2. GRAMMAR OF INSTITUTIONS

The significance of the grammar of institutions is that it is primarily based on the perspective that institutions govern human behaviour and these institutions constitute components. These components highlight a specific syntax which helps in differentiating institutions into formal rules, norms and shared strategies (Crawford & Ostrom, 1995). The grammar of institutions constitute five components, namely - **A**ttributes, **D**eontic, a**I**m, **C**ondition and **O**r else where *Attributes* indicate to whom the institution applies to, *Deontic* refers to - may (to be permitted), must (obliged) and must not (forbidden), *aIm* refers to a specific action that follows the *Deontic* and *Or else* refers to the consequence for not following the rule. While shared strategies are written as [Attributes][aIm][Condition], norms are shared strategies plus the Deontic component and rules are norms plus the Or else component. In this research, the grammar of institutions will be used to structure/ differentiate the institutions governing the human-flood interaction within the Kerala FRM system.

3.3. SOCIAL PROOF THEORY

Social proof is an informational influence(or descriptive norm) that takes form when individuals are unclear about the way they must behave during situations and can result in herd behaviour - where people follow others (Behavioral economics, n.d.). Studies indicate that possessing information about the way others behave (social proof) results in greater compliance within collectivist cultures (Cialdini et al., 1999)

One of the governance issues pertaining to Kerala FRM that have been discussed is the ignorance of authorities to involve social welfare initiatives (discussed in section 1.1.5.). In the research, this issue is associated with the characteristic of MLG that highlights the importance of involving stakeholders from the vertical and horizontal dimensions. Furthermore, this involvement can be depicted or observed in the form of a network that includes stakeholders from both horizontal and vertical dimensions. The intention behind introducing the social proof theory in this case would be to justify the reason behind stakeholders joining the network.

4. RELATED RESEARCH

In addition to discussing the core concepts , this chapter contributes to answering the sub-question :

- *How can resilience be incorporated and evaluated within the Flood Risk Management context?*

4.1. DISASTER RISK MANAGEMENT

To begin with, UNISDR(2016) defines disaster risk as the function of hazard, exposure, vulnerability and capacity that can result in the loss of life and property within a system, society or a community. Hazard is the process, phenomenon or human activity which results in the loss of life and property. In this case, flood is a socio-natural hazard as it is a consequence of both natural and anthropogenic factors. Exposure is the tangible element in the flood prone areas, vulnerability is the susceptibility of these elements to floods and capacity refers to the strengths, attributes and resources within a system that contributes to the tolerance of the system to the hazard it is exposed to UNISDR(2016). According to Warfield (n.d.) the goals of disaster management include: 1) Reducing, or avoiding losses from hazards, 2) Assuring immediate assistance to victims and 3) Achieving rapid and effective recovery. The disaster management cycle has four phases (Warfield, n.d.):

- Mitigation: Equipping society across all aspects in anticipation of a disaster
- Preparedness: Having a layout prior to the disaster on how to respond to a disaster event
- Response: Carrying out initiatives to reduce the hazards created by a disaster
- Recovery: Making the efforts to return the community back to normal state

4.2. FLOOD RISK MANAGEMENT

FRM as defined by Plate (2002) is the planning and management of the existing flood risk situation such that the flood risk decreases, disasters are controlled, and the impacts are minimized. In addition to natural causes, flood disasters are consequences of social, economic and political causes. The increase in frequency and severity indicates that FRM requires regular monitoring and attention (Bruijn, 2005). Furthermore, to the engineering or technical aspects taken care of by the engineers,

the decision process must involve social groupings of a society, from the political authorities to the people who are directly affected by the floods (Plate, 2002). It has been identified that in general flooding is not an issue pertaining to just the water management system as the decisions associated with the flood prone areas have impacts on landscape and urban planning. This indicated the need for a cross sector work which involves the coordination and cooperation of specialists from different areas of expertise (Flood Manager E-Learning, n.d.).

4.2.1 RESILIENT FLOOD RISK MANAGEMENT

Resilience can be described as complex for the reason that it has different definitions in different contexts. Folke et al (2010) gives a detailed insight into the terms associated with resilience:

"*Resilience is the capacity of the system to absorb disturbances and reorganize while undergoing change so as to still retain essentially the same function, structure and feedback, and therefore identity, that is, the capacity to change in order to maintain the same identity*".

From above, the association of resilience with the elements of disaster risk function such as exposure, hazard and capacity can be understood but the association with vulnerability is not explicit. Vulnerability refers to the implications from the system's ability to cope with the hazard (Proag, 2014) and manage its adverse impacts UNISDR (2016). Improving the ability to cope would imply that the system has better ability to resist, absorb, accommodate, adapt, transform and recovery. Thus, by improving resilience the system or community can be made less vulnerable to a hazard.

Folke et al. (2010) gives a better insight on resilience by defining specified resilience and general resilience. While the former is the resilience "of what, to what" which deals with the resilience of a specific part of the system, specific control variable or shock, the latter is the resilience pertaining to any and all parts of the system and all types of shocks. Recovery and resilience are sometimes considered similar but while recovery is about restoring the system to the initial state, resilience leads to reorganization of a system that retains the identity but has adapted and transformed with the help of information from past experiences (Platt, Brown, & Hughes, 2016).

When adding resilience to FRM, it is about incorporating the characteristics of resilience into the traditional FRM cycle (Batica et al.,2013). While the traditional FRM includes - *Preparedness,*

Response and Recovery (Fig, 4.1.), a resilient FRM cycle would include – *Relief*, *Resist, Response, Recovery* and *Reflect* (Fig. 4.2.). In this research, the features of the first two elements of the cycle are aggregated and represented as Resist phase for simplicity and due to the similarities in the definitions of the *Relief* and *Resist* phases (Fig 4.2). Table 4.1. gives a brief on the phases involved in the resilient FRM cycle. Adapted from Batica et al. (2013).

Furthermore, Batica et al. (2013) studies the resilience of urban systems to flood through five dimensions – social, economic, institutional, physical and natural. In this research the natural dimension and physical dimension is adapted to environmental dimension and technical dimension respectively.

Table 4.1. Function of the resilient FRM phases. Adapted from Batica et al. (2013)

Resilient FRM element	Implementation phase	Description
Resist	Before the flood	Mitigate flood risk and enhance threshold capacity by adaptation measures to limit flood damage and ensure ease of response and recovery
Response	During the flood	Implement crisis management measures
Recovery	After the flood	Restore damaged infrastructures and livelihoods, and support communities
Reflect	After/Before the flood	Increase awareness, engagement and adaptive capacity by learning and transforming. Management at all levels – policy level, professional and public participation

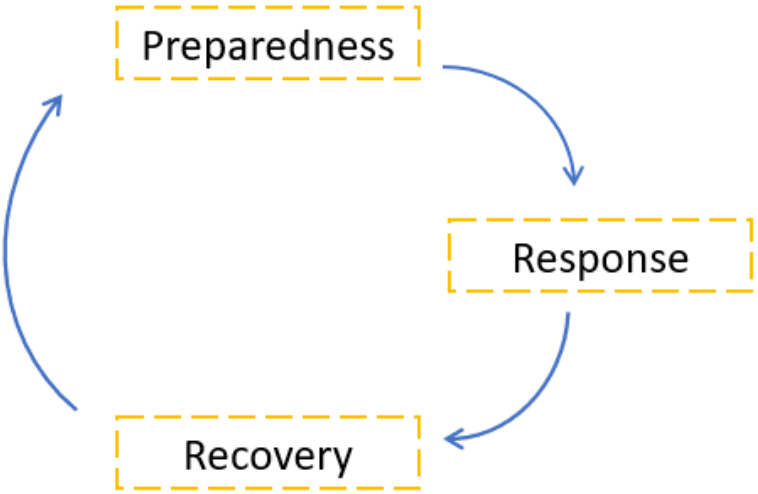


Figure 4.1.. Traditional flood risk management cycle

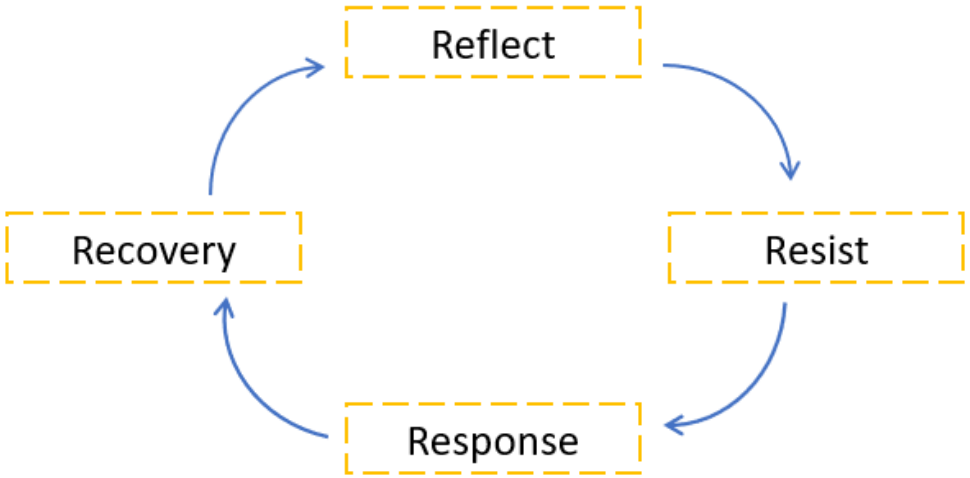


Figure 4.2. Resilient flood risk management cycle (adapted from Batica et al., 2013)

4.3. HUMAN-FLOOD INTERACTIONS AND INSTITUTIONS

The river system and nature of the floods, shape the society and hence the FRM option has numerous impacts not just from technical and economic but also from social and political viewpoint (Viglione et al., 2014). It is due to this ability of floods to influence society which triggers the need to discuss human-flood interactions. Sivapalan et al. (2012) introduced the term socio-hydrology which is the

interactions within human-water systems as it is understood that people and their actions are part of the water cycle dynamics.

This concept was then introduced in the context of floods (Di Baldassarre et al., 2013) in order to conceptualize the interactions and feedback mechanisms between hydrological and social processes in settled floodplains. Abebe et al. (2019) further brought to notice that when developing flood models, it is important to consider that the decision-making individuals within the "human-subsystem" which is rooted in and interacts with the "physical subsystem" have their behavior limited by institutions – norms, habits and laws.

Heitz et al. (2009) highlights that to analyze the efficiency of policies associated with FRM, it is important to understand how the various stakeholders perceive risks and what they know about the situation. The level of risk perception is influenced by several parameters associated with psychological, social, economic, temporal or institutional factors. Thaler & Levin-Keitel (2015) mentions that stakeholder engagement is dependent on the power relationship and awareness, understanding the relationship between the national authorities and the local stakeholders, who has the power, who does not and how the stakeholders make use of the power they possess.

FRM depends on the awareness of the local communities about their involvement in the decision-making process where local engagement is closely related to their social capacity which includes aspects such as knowledge, motivation/self-interest, networks, organization and procedural capacity (Thaler & Levin-Keitel, 2015). In this study FRM will be described as a public service/good. According to (Geaves & Penning-Rowsell, 2016) FRM when identified as public priority good (services vital for public well being irrespective of the characteristics) public awareness corresponding to flood risk elevates even though conflicts regarding service provision and maintenance persists. However, when FRM is considered as a 'pure' public good (demonstrates non-rivalry and non-excludability) the emerging public participation does not contribute to increasing public awareness of flood risk or encourage investment in private protection measures.

When discussing stakeholders, the role of institutions becomes more significant as these institutions play a major role in determining the actions and behaviour of the stakeholders. This brings insights on the reasons behind these actions and the implications they can have on the system. Thus,

indicative of the need for institutional analysis. To ensure the utilization of the complete potential of institutional analysis, it is suggested to investigate the functional and structural tiers, organization of governance functions, and the formulation of key institutional rules, as the central aspects of institutional design of governance solutions (Paavola, 2007).

According to Driessen et al. (2016), governance perspective of FRM is important as it contributes to: (i) adding value to the natural and technical science perspectives and (ii) enhancing the understanding of the society's coping mechanism. Vincent Ostrom during his discussions with W.Ross Ashby realized that governance systems are required to be as complex as the physical and economic systems that the governance systems are meant to govern (Mcginnis & Ostrom, 2011) .

4.4. MULTI-LEVEL GOVERNANCE

MLG is about acknowledging that political authority and institutional competence is less dependent on the formal constitutional powers given to the state and more about achieving goals through coordinated resource management between the stakeholders from different levels (Guy Peters & Pierre, 2001). There are previous researches that have discussed MLG in the context of floods and to the best of my knowledge (Vedeld et al., 2016) has made use of MLG framework to elaborate on the governance of scale of climate adaptation (focusing on FRM), (Dieperink et al., 2018) has discussed about the mechanisms that contribute to creating coordination among the different levels in MLG for managing urban flood resilience, (Bisaro et al., 2020) has explored the multilevel public funding arrangements in Coastal flood risk reduction (CFFR) and (Thaler & Levin-Keitel, 2015) has carried out an empirical study on the multi-level stakeholder engagement in FRM. Additional discussion points with regards to MLG have been discussed in section 3.1.

Figure 4.3. gives the overview of the literature research in order to give a better understanding of this chapter

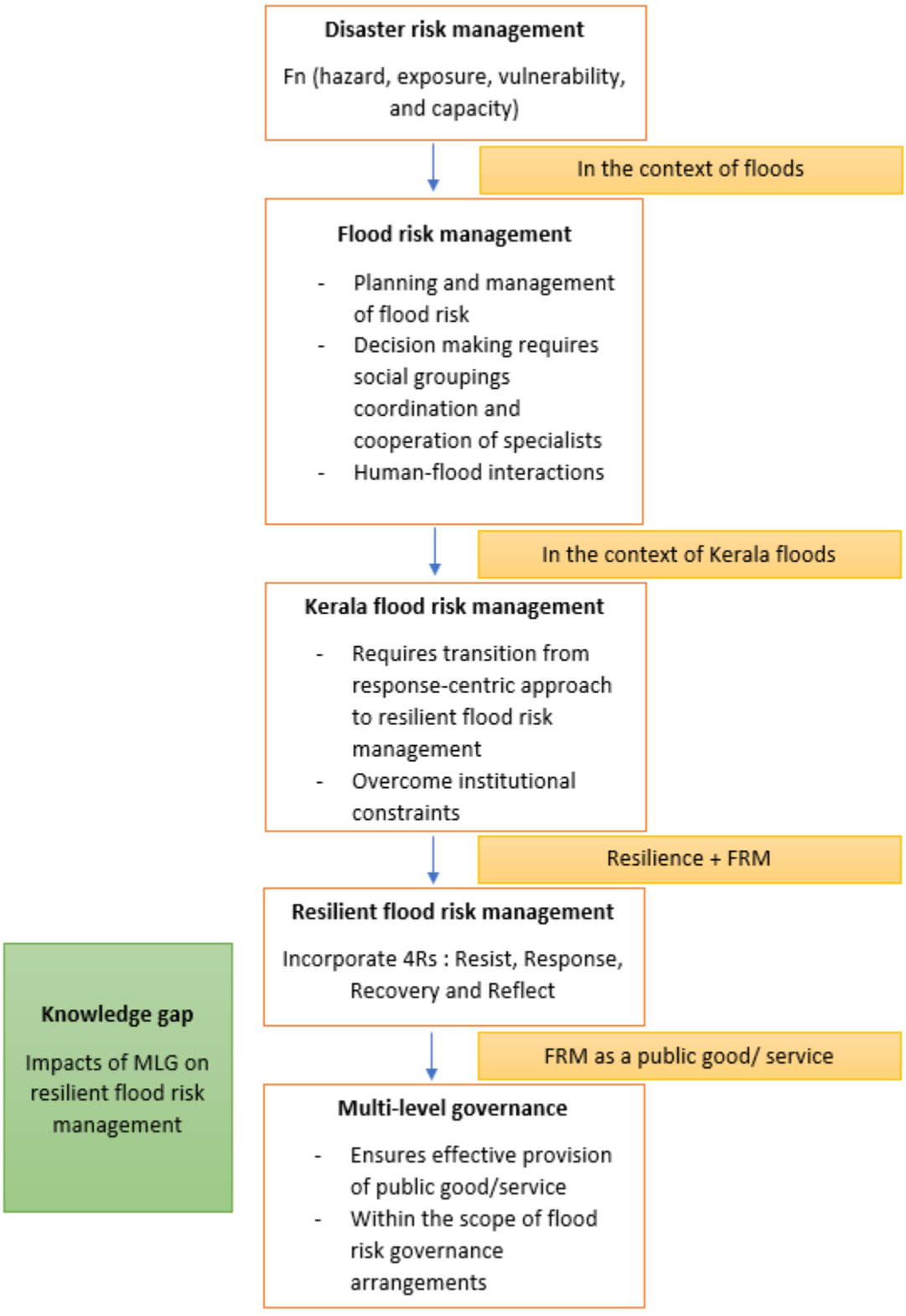


Figure 4.3. Overview of the literature research

5. CASE STUDY

This chapter is intended towards sharing information on Kerala floods. This case is the starting point and motivation behind the research and hence this chapter is an introduction to where the research begins.

Figure 5.1. Submerged houses (Left) and rescue operation (Right)

The Kerala flood in 2018 is described as the most catastrophic flood in history since the 1924 flood and this elevated the concerns of the public with respect to disaster management (Nowfal & Sarath, 2018). The media reported the loss of 500 lives and evacuation of over a million people (Chandran, 2019). Agriculture, tourism and fisheries contribute to 30% of the total GDP of the state and these sectors were affected the most during the 2018 flood (Jacob, 2019). This was an eye opener for the state indicating the need to act and determine remedial measures to tackle the issue. Figure 2.1. is intended towards providing a better understanding of the seriousness of the disaster.

5.1. VULNERABILITY OF KERALA

In general, Indian regions are vulnerable due to – climate change, high population in the coastal area, growth in population, rapid and uneven development, monsoon and other uncertainties (Mathew, Trück, & Henderson-Sellers, 2012). With respect to Kerala, in addition to the impacts of climate change, the state is facing consequences of outdated dam management, increase in mining, development in Western Ghats mountain range and lack of prediction systems (Padma, 2018).

The change in monsoon patterns and characteristics as a result of global warming contributes to the vulnerability of the state and the authorities who criticized eco-activism realized the importance of discussing an eco-friendly lifestyle after the impacts of the 2018 flood (Jacob, 2019). As per the National Water Policy, National Disaster Management Authority guidelines, dams were supposed to be used for flood control and moderation but none of the dams were operated during the period. The high reservoir storage and abrupt release of water in the absence of an Emergency Action Plan (EAP) for dams had contributed to exacerbating the adverse effects of flood (The Hindu, 2019). Furthermore, widening of riverbanks due to unregulated sand mining has been a major concern (J, Anilkumar, 2014). According to Sekhar & Jayadev, (2003) even though as per the Industrial policy statement, the mining and production of minerals is to the public sector, it allows selective entry of the private sector. Furthermore, the Kerala government leased out 17 kilometers of state-owned land to Kerala Rare Earths and Minerals Limited (KREML) which has majority of its stake held by Kochi-based private sector company to carry out sand and mineral mining. This decision faced several criticisms due to the vague arguments put forth by the ministers, politicians and scientists involved and this gave reasons to doubt for corruption and conspiracy (Sekhar & Jayadev,2003).

On August 31st, 2011, Gadgil commission, an environmental research commission named after Chairman Madhav Gadgil submitted a report emphasizing on the strategies to inhibit environmental degradation. The report identified Ecologically Sensitive Zones (ESZs) and highlighted the importance of not allowing polluting industries to function in the ESZ (Shrivastava, 2015). Further, the report predicted that natural calamities like floods would escalate if these strategies are not implemented (India Today Web Desk, 2018). However, this report was opposed by states, politicians and farmers' organizations who feared that this would have an adverse impact on development (Suchitra & Sambhav, 2015).

5.2. URBAN DEVELOPMENT AND GOVERNANCE IN KOCHI

Large urban agglomerations contribute to economic growth and development of the developing countries. This research investigates governance arrangements in the metropolitan city of Kochi, in Kerala. Kochi is a port city located in the district of Ernakulam on the south-western coast of Kerala

in India. In addition to being the most highly graded city in the state, it is acknowledged as the biggest urban agglomeration and the most densely populated city in Kerala (World Population Review, n.d.). Kochi is the one of the fastest growing second-tier metros in India and the rapid development in information technology, tourism and international trade makes Kochi the commercial hub of Kerala (Kochi Travel Guide, n.d.). In addition, it is also a major financial, industrial and shopping hub (Directorate of Industries and Commerce, n.d.).

5.2.1. ENVIRONMENTAL DAMAGE AND FLOODS

However, Kochi as a city faces its very own set of hurdles – low carrying capacity of the intra-urban and suburban routes, unrestricted development of large areas as urban extensions because of urbanization, unscientific planning in urban infrastructure development and lack of proper connection of different types of transportation (Kochi Metro Rail Limited, n.d.).

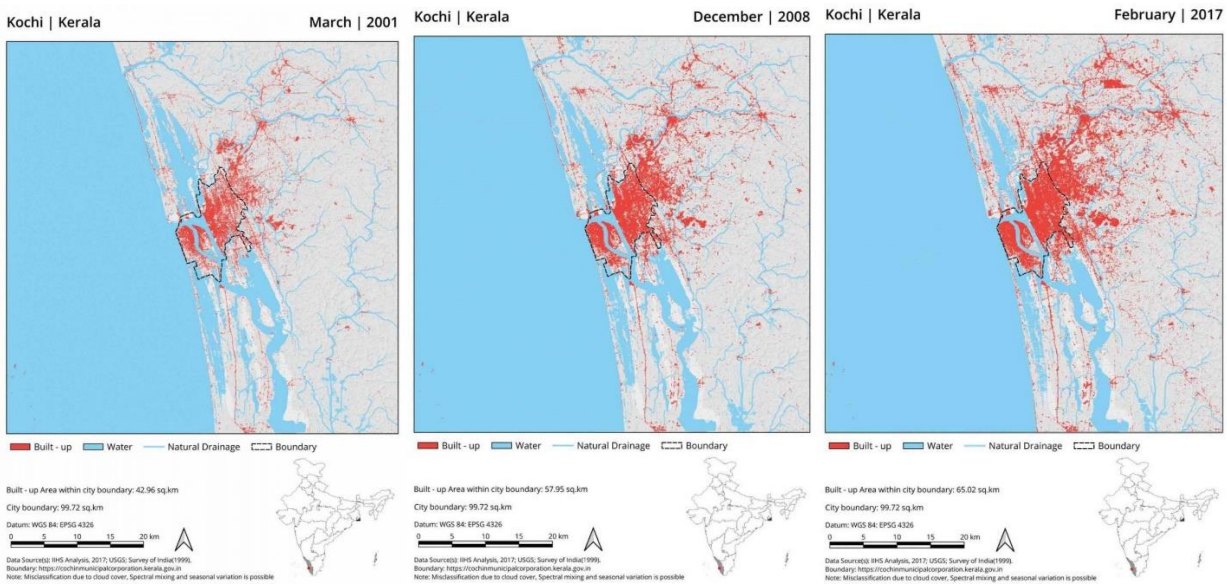


Figure 5.2. Urbanization in Kochi. Kochi in 2001 (left), Kochi in 2008 (center) and Kochi in 2017 (Right). [Data sources: IIHS Analysis, 2017 ; USGS; Survey of India (1999)]

Kochi does not have an efficient waste management system and there is a significant growth in urbanization. As a result, the water bodies are polluted, the width and depth of the canals are reduced. The significant number of constructions reduces the permeability of the ground (S, A., Kumar, K., & Malladi, T., 2019). Furthermore, constructions are built without prior risk assessment.

Kochi International Airport is one such example where the space for the airport was made by realigning natural water channels and the location of the airport is only a few hundred meters away from the Periyar river (Misra, 2018). In addition, with respect to elevation the airport is at river level and during the 2018 Kerala flood, the airport being at a lower elevation than some of the areas in the North, served as a collection tray for the runoff from the North (Misra, 2018). Both the highs and lows of Kochi indicates institutional complexity. The impacts a natural calamity like flood can have on the city would determine the contribution the city can make towards development. Thus, this research would be focusing on the port city of Kochi.

5.2.2. POLYCENTRIC GOVERNANCE ISSUES

In the case of metropolitan governance, the fact that it discusses the interactions between public stakeholders, private organizations, interest groups and the civil society paints a polycentric governance character to metropolitan governance (Pethe et al., 2012). According to Parsons & Skinner (2018), the 2018 flood showed that there must be cooperation among governments, both regional and national, along with agencies and first responders. In the case of Kochi when it comes to disaster management, the multi-level governance aspect becomes more evident from the involvement of authorities from the grassroot layer, district level, state level and national level. The experience with Kerala flood 2018 indicated the requirement for a more effective communication and public engagement to develop flood risk literacy and the need to understand the dynamic nature of the system as the flood risk assessments previously considered was a static, steady-state system which did not prove to be representative of the real-life case (Parsons & Skinner, 2018).

According to Chattopadhyay & Harilal (2017), In addition, the policies and guidelines developed in Kerala generally turn out to be unsuccessful at the implementation stage and multi-level governance can contribute to addressing majority of the technical & institutional issues and establish a balance between ‘bottom-up’ & ‘top-down’ approaches as all issues pertaining to flood cannot be captured at a single level (Chattopadhyay & Harilal, 2017). Thus, it can be inferred that even though the metropolitan city of Kochi has a polycentric nature to the governance structure, there are certain gaps that must be bridged to overcome the hurdles contributing to ineffective flood risk management. Upon identifying the gaps in the multi-level governance characteristics, it then

becomes important to see if implementing the improvements would significantly add value to the existing flood risk management structure.

5.3. STAKEHOLDERS

The Kerala FRM involves several stakeholders. In order to prepare a list of stakeholders, a desktop research was conducted which involved reviewing formal documents (Examples: documents on the disaster management act, coastal zone management norms and documents on land utilization act), newspaper articles and published reports. From these various sources, stakeholders were identified based on how often they have been mentioned or discussed. Furthermore, stakeholders for this study were chosen by ensuring that the interactions in vertical and horizontal dimensions of multi-level governance can be captured and governance issues can be addressed. The initial set of stakeholders and their roles are discussed in Appendix A.

5.4. INTERVIEW WITH POLICY RESEARCHER

The interview conducted was a semi-structured interview where some general questions were asked and based on the answers, additional questions were asked. The insights from the interview is highly significant due to the role of the interviewee in the Kerala floods. The interviewee is a policy researcher who was highly involved in the relief, rescue missions of Kerala flood 2018 and was involved in conducting a series of stakeholder workshops. These workshops with approximately 400 participants were intended towards mobilizing stakeholders and developing a handbook that would help people in preparing for such disasters in a more effective way. The insights gathered from the interview have been summarized in this section.

- Responsibility and power: There is a lack of clarity as to who is responsible to find the solution with regards to specific issues. India has multi-level governance structure and when a specific District faces a problem, the District authority must take immediate action but the current system is such that the District corporation do not have enough power to make the immediate decisions. Furthermore, the differences in power results in conflicts and this further leads to a situation where no one takes responsibility at the end. The local body must

be given more power in the decision-making arena and they must be allowed the right for resource mobilization. The current situation is such that the local body is completely dependent on the state authority for resources and capacity management.

    - NGOs, clubs and community organizations in addition to the government play a vital role in ensuring a coordinated first response.

- Organization: Just like the health department or Public Works Department (PWD), a department must be dedicated for dealing with floods. The current system is such that there is a committee where the chairperson is chosen and this chairperson may not be from the specific city he/she is assigned to. The disadvantage here is that the chairperson may not have a clear idea about the city he/she is working for. Similarly, when it comes to assigning a town planner, the person may not be from that specific city and hence has less knowledge about the city.
    - Civil engineers are normally appointed as town planners or urban transport mobility experts. This results in adverse effects because the perspective of a civil engineer and town planning engineer would be different. Recent updates suggest that urban mobility experts are being recruited after severe pressure from students towards the government. However, so far they have not become a part of the system and hence the effects from their expertise are not yet explicit.
- Knowledge: The city of Kochi lacks institutional memory which is basically the data from history that tells how this crisis was dealt with previously. Kerala has not carried out any significant studies with regards to the Kerala floods and this is an important aspect because if such studies are not carried out, the disaster is likely to occur again.
    - The workshops indicated that the decision-makers lack knowledge or expertise on how to tackle the situation. Irrespective of the literacy rate in Kerala, there lacks local research indicative of scientific action. The main focus has always been on the social action
    - Majority of the people in the communities are aware about how high the water can rise in their locality and even though this is good knowledge, there is no system which works towards capturing this knowledge.

- Execution: Even though Kerala has several projects discussed which would ideally make the current system more effective, the execution of these projects is questionable. The structure of the project reports indicates lack of skillset.

5.5. CASE STUDY DATA INPUT TO THE MODEL

The Kerala flood in 2018 is described as the most catastrophic flood after the flood in 1924 which created a dialogue among the policy makers regarding the need for a transition from a response-centric approach to a resilient FRM approach (Shaharban & Rathnakaran, n.d.). Since, it is apparent that Kerala flood 2018 is the point which created a dialogue regarding the existing FRM , this research uses that specific case to identify the different narratives that would help with creating the complete picture of the FRGA. Section 5.1. discusses the various reasons which contribute to the vulnerability of Kerala to floods. This discussion is taken as the motivation to bring forth the narratives pertaining to these reasons in both the MAIA conceptual model and ABM. The interview would be used as a justification for the narratives.

6. SETTING THE CONTEXT

This chapter is aimed towards discussing the different aspects of Kerala FRM that the conceptual model and ABM model would be dealing with.

6.1. INFORMATION AVAILABILITY: COMMODITY CONTRIBUTING TO DECISION MAKING

It was important that the model discusses the information available in the system because in addition to the contribution of information in the foundation for coordination and decision-making during emergency situations, information has significance in the impact and needs assessment (Pan American Health Organization, 2009). Within the context of disasters there are different points about information that becomes evident:

- *Improves trust and credibility*: The government authorities within the country, international organizations, affected communities and media require information in various forms (figures, reports, analysis and recommendations) to carry out their responsibilities or roles during the period of disasters in order to have a definite plan or action.
- The form of information provided during a disaster reflects the multidisciplinary nature of that disaster.
- Participation and effectiveness of multi-level actors can support the affected communities by offering accurate and relevant information at the right time. In addition the effectiveness of the communication methods utilized can enhance the dialogue and partnerships formation.
- In addition to contributing towards offering effective response, information and communication assist in resource mobilization, enhancing visibility and in offering a helping hand to the affected communities.

However, for effective communication and information dissemination, technical resources and human capital (skillset) is required (Pan American Health Organization, 2009). In addition to skillset it is also important to consider the level of corruption among government authorities because for

instance, recent discussions indicate that for the failure to produce utilization certificates, the central government will not provide any further funds for flood relief (The Hindu, 2020)

The types of information to focus on were determined from the disaster management policies (Government of Kerala, n.d.). The model will look at three types of information - information dissemination that results from the updates that authorities share amongst each other, the forecast information and the vulnerability information. Figure 6.1. gives a brief on the categories of information the model would focus on.

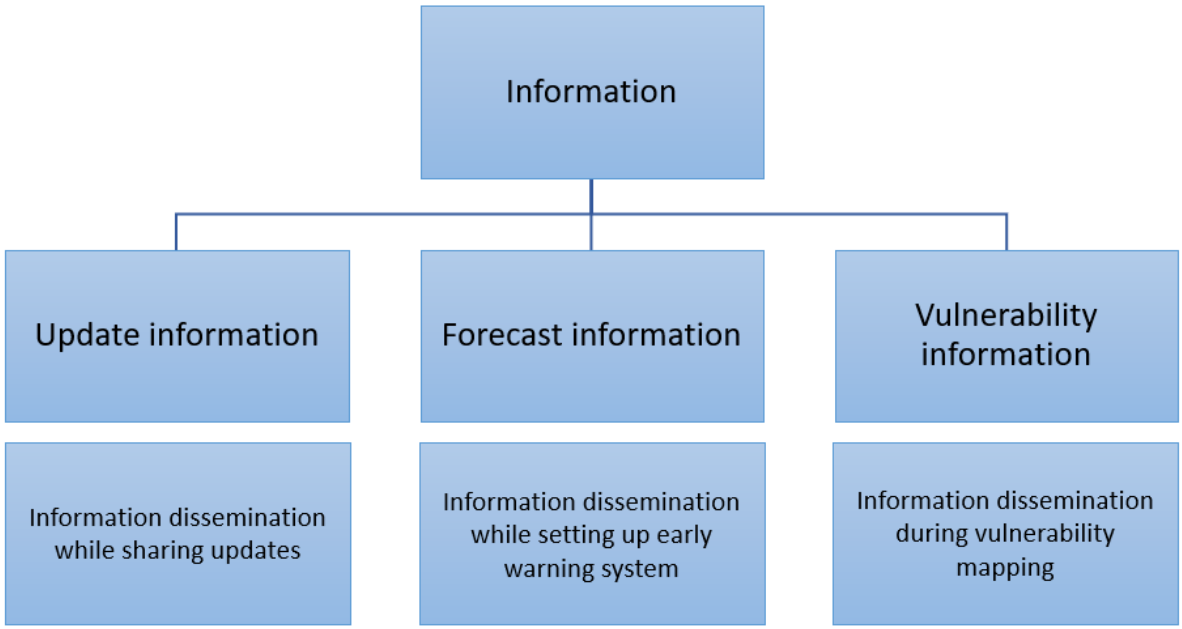


Figure 6.1. Information categories focussed in the model

To begin with, "Update information" from Figure 6. discusses the information dissemination resulting from sharing updates. National Disaster Management Authority (NDMA), State Disaster management Authority (SDMA), District Disaster management Authority (DDMA) and Kochi Municipal Corporation (KMC) during the different phases of the FRM share updates and knowledge/experiences with each other. This aspect of sharing updates is with reference to the disaster management policies (Government of Kerala, n.d.).

The "Forecast information" from Figure 6. is representative of the Early Warning System (EWS). EWS is defined by UNISDR (2009) as "the set of capacities mainly - knowledge, monitoring, analysis and

forecasting, dissemination of alerts and warnings, and local capabilities that are required to disseminate warning information at the right time to individuals, communities and organizations in order for them to prepare and act effectively towards hazards." From the disaster management policies (Government of Kerala, n.d.) , it is clear that the State Disaster Management Authority (SDMA) is responsible for setting up the EWS. The India Meteorological Department (IMD) plays the key role in providing information pertaining to rainfall and temperature. Even though there are other organizations that are involved in the process of issuing the EWS such as Indian National Centre for Ocean Information (INCOIS), Geological Survey of India, etc (Taru Leading Edge Pvt.Ltd., 2014), the model will focus on IMD as the source of forecast information and SDMA as the authority which receives the first hand information from IMD. Furthermore, the SDMA shares this forecast information to the District authority and District authority shares this information to the Local body. The review of early warning systems in Indian cities (Taru Leading Edge Pvt.Ltd., 2014), shows that the development stage of the EWS from the aspect of local body involvement needs improvement where specifically, the development stage of institutional mechanism for the local authority in the EWS framework is very low and requires significant development.

The "Vulnerability information" from Figure 6. is representative of the information gathered during vulnerability mapping. The disaster management policies (Government of Kerala, n.d.) discusses vulnerability mapping and highlights that there are overlapping jurisdictions to some extent due to the involvement of SDMA, DDMA and KMC.

In conclusion, information availability within the system is one of the aspects of flood risk management which can be discussed and information dissemination depends on certain properties of government authorities - skillset and corruption.

6.2. CAPACITY DEVELOPMENT

According to the Capacity for Disaster Reduction Initiative (CADRI) there are two types of capacities - functional capacity and technical capacity. The *capacity to engage stakeholders* is a category of functional capacity which discusses the ability to encourage, mobilize stakeholders and create partnerships or networks and is not associated with a specific sector. The technical capacity on the

other hand is associated with a specific sector such as modelling and forecasting or operating early warning systems, conducting risk assessments, accessing relief centers, dam maintenance etc . It is thus important to look at both functional and technical capacities. Figure 6.2. shows the two categories of capacities that would be focused.

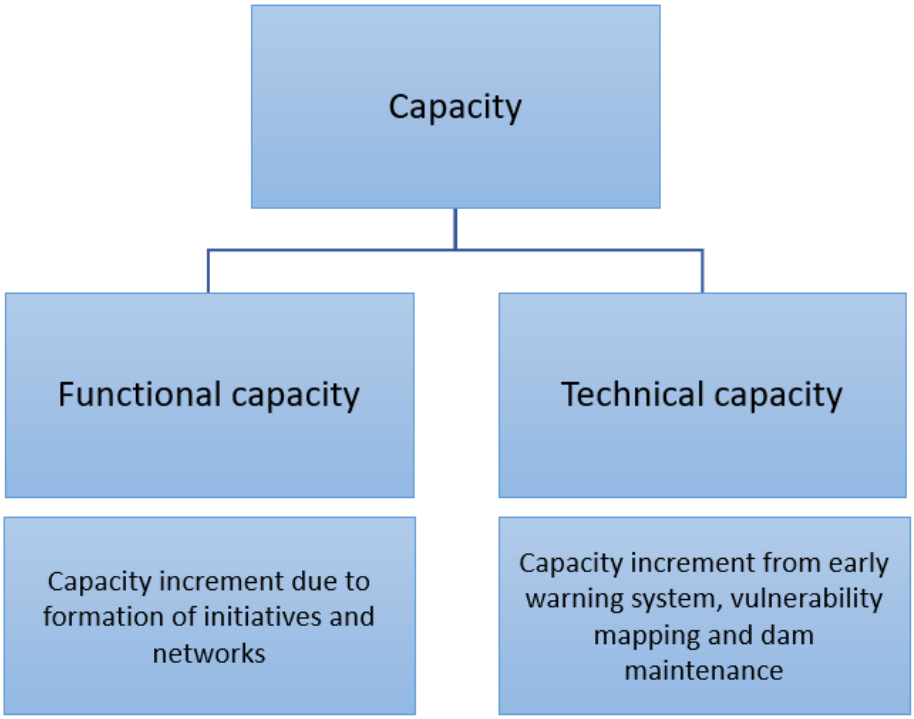


Figure 6.2. Capacity categories focused in the model

6.3. ENVIRONMENTAL DAMAGE

The vulnerability of Kerala as a result of environmental damage from irregular urbanization is one of the concerns. When discussing about this issue, it is important to consider the following points:

- Firstly, as per the Kerala Land Utilisation Order, 1967, when permission for an establishment is requested for a specific land area, it is not just the status of that land area which must be accounted for, but also the adverse effects the establishment can have on the neighbouring properties. Therefore, it is important to ensure that a specific establishment does not affect or disturb the neighbouring properties.

- Secondly, as per the Coastal Regulation Zone (CRZ) norms by the Kerala Coastal Zone Management Authority (KCZMA), within 50 meters from the High Tide Line (HTL) even though the existing dwelling units can remain, there should be no new constructions permitted. Therefore, any new construction made within the limit of 50 meters from the HTL can be considered to be unauthorized or constructed illegally.

Kochi had 343 unauthorized constructions by around 2020 (The Economic Times, 2020) and 47 heavy industries by 2013 - 2014 (Directorate of Industries and Commerce, n.d.). Assuming that these were constructed or set up since 1958 (the year Ernakulam was formed) , there were approximately 7 illegal / unauthorized constructions made every year.

6.4. NETWORK FORMATION

One of the characteristics of MLG which is relevant for the study of Kerala FRM is regarding the importance of involving stakeholders from both vertical and horizontal dimensions (with reference to section 3.5.). This can be observed as a multi- level stakeholder network of social welfare initiatives.

6.4.1. ENERGY

The idea behind using “energy” as a property for multi-level stakeholder networks is inspired by the work of (Ghorbani & Bravo, 2016) and in this research it would represent the welfare of the network and this can include monetary or non-monetary resources. In the case study the assumption made is that if new members join an existing network, there is an increment in the overall energy of the network. Furthermore, if a government authority joins the network, there would be an increment in the overall energy of the network.

In addition to the increment in the energy of the network, the local community members who encounter the network have an increment in the individual functional capacity even though they do not join the network. This is to indicate the spreading awareness aspect mentioned in the disaster management policies (Government of Kerala, n.d.).

6.4.2. CREATION AND EXPANSION

As we are discussing the energy of the network, it is important to discuss the creation and expansion of this network which contributes to the increment in energy. Berkes et al. (2004) discusses "trigger" events as the reasons that motivate community members to begin an initiative and "catalytic" events as the reasons that contribute to expanding and sustaining the created initiatives. For this case, the model considers the "trigger" event to be the environmental damage from unauthorized constructions in the ecologically sensitive zones and "catalytic" events to be the support from local NGOs, government authorities and the willingness of community members to join/support the initiatives. The catalytic events result in the increment in welfare of the initiative network and this is shown by the increment in energy of the network. Figure 6.3. provides a brief on the events that are crucial for the creation and expansion of initiatives. With regards to initiative expansion, the social proof theory would be considered. Social proof is also known as a heuristic and indicates that the decision-making process of an individual is influenced by the people the individual is around (Henderson, 2017).

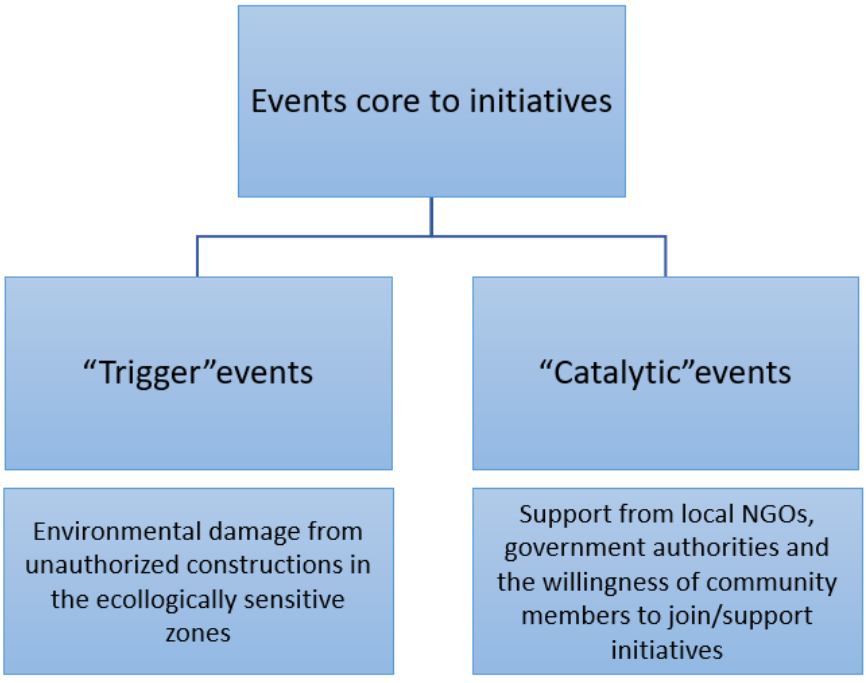


Figure 6.3. Events core to creating, expanding and sustaining initiatives in the model

6.5. DAM MANAGEMENT

The Kerala State Electricity Board (KSEB) is responsible for dam maintenance and production of hydro-power which almost half of the state depends on (Basak et al., 2018). However, the dam maintenance depends on two factors - heavy rain and the profit minded attitude of KSEB(The Hindu, 2020) . Since improper dam management contributed to Kerala being vulnerable, it can be considered that the dam maintenance contributes to technical capacity.

6.6. RELIEF CENTER CREATION AND MAINTENANCE

As per the disaster management policies (Government of Kerala, n.d.), the District Disaster Management Authority(DDMA) is responsible for setting up relief centers and Kochi Municipal Corporation(KMC) is responsible for maintaining resources pertaining to disaster management (assuming relief centers to be one of the resources). Relief centers are accessed by the communities during floods and this can result in an increment in the technical capacity.

6.7. POWER DISTRIBUTION

The reason behind considering power distribution of decentralization (characteristic of MLG) is because the work of Singh et al. (2018) explains how the decisions made by the SDMA is prioritized over the decisions of District or Local authorities. Furthermore, the report emphasizes that in the real case, the Local authority has almost no involvement in the phases prior to flood even though the Local authority contributes largely to policy development with the help of the community knowledge the Local authority has. Here, it can be seen that there is an implicit hierarchy and it is not representative of a decentralized multi-level governance structure. This specific part of the story line is the motivation behind the assumption that authorities can be given “low”, “medium”or “high”power. This is more of a qualitative data and in the modeling phase this qualitative data would have to be translated into quantitative data in order to ensure that the power distribution aspect is captured in the model. Furthermore, this power distribution aspect can play a significant role when it comes to overlapping responsibilities as per the disaster management policies (Government of Kerala, n.d.) and since the policies do not very explicitly mention who will be in-charge in case of

overlapping responsibilities, the model assumes that authority with the high power would be in-charge or in case of equal power, the authorities would work together.

6.8. OVERVIEW ON CONTEXT

In conclusion to this section about setting the context or boundary, the following points were can be derived:

- The major events/areas of FRM that would be considered are - information dissemination, capacity development, dam management, network development representing the social welfare initiatives, creation and maintenance of relief centers, environmental damage due to unauthorized constructions and the power distribution aspect that helps with decisions pertaining to overlapping functions
- Information dissemination involves three types of information: Update information (information shared among authorities on knowledge/ experience), forecast information (information shared within the early warning system) and vulnerability information (information collected from local communities during vulnerability mapping.
    - Information dissemination depends on the corruption and skillset of the authorities involved
    - Information dissemination pertaining to forecast information and vulnerability information results in the increment of the technical capacity of the flood risk management system since they involve technical activities
- Dam management depends on heavy rain and the profit minded attitude of the KSEB
    - Dam management results in the increment of the technical capacity of the flood risk management system as it is a technical activity
- Social welfare initiative can be represented as a network which begins with “trigger”event (environmental damage in this case) where community members starts an initiative and the expansion of the network depends on “catalytic”events (support from NGOs, community members and government authorities)
    - The network has “energy”representing the welfare of the network which increments due to “catalytic” events.

- The network results in the increment of functional capacity as networks are a result of mobilization of stakeholders
- As it has been established that the corruption of the authorities has a role to play, it is assumed that the willingness of authorities to join the network depends on corruption of the authority

- Relief centers are created by the DDMA and maintained by the KMC.
  - When community members access the relief centers or when KMC maintains the relief centers, there is an increment in the technical capacity of the flood risk management system since setting up and maintaining relief centers are technical activities.

7. CONCEPTUAL MODEL

This chapter contributes to answering two sub-questions of the research:

- *What are the existing Flood Risk Governance Arrangements (FRGA) in Kerala?*
- *How can the Flood Risk Governance Arrangements (FRGA) be modelled?*

As discussed in the methodology section (Chapter 4) MAIA meta-model is organized into five structures - collective structure, constitutional structure, physical structure, operational structure and evaluative structure and in the remainder of this chapter, these five structures would be elaborated extensively. Prior to discussing the five structures, first of all it is important to decide the context. i.e; What are the most crucial areas of the FRM cycle the model can discuss or which areas of the FRM cycle would be discussed in the model. This is the point in the research where a boundary is decided. The model would be extremely complex if it were to capture the entire system and hence certain aspects of the FRM are considered based on :

- Firstly, ensuring that the governance issues pertaining to Kerala are discussed
- Secondly, ensuring that at least some events within each of the resilient flood risk management cycle are discussed
- Thirdly, ensuring that all the five dimensions defining resilience - social, economic, environmental, technical and institutional would be discussed in the model and that the events would have a certain impact on any of the five dimensions.
- Lastly, ensuring that most of the activities involved in FRM are discussed (source: disaster management policies (Government of Kerala, n.d.))

7.1. MODEL OVERVIEW

The major events/areas of FRM that would be considered based on the discussion in Chapter 6 are - information dissemination, capacity development, dam management, network development representing the social welfare initiatives, creation and maintenance of relief centers, environmental damage due to unauthorized constructions, the power distribution aspect that helps with decisions pertaining to overlapping functions and the cost involved in offering these services. Then, these

events/ areas within FRM were segregated or organized into the different phases of the resilient FRM cycle. Figure 7.1. gives the layout on events that would occur in each of the phases.

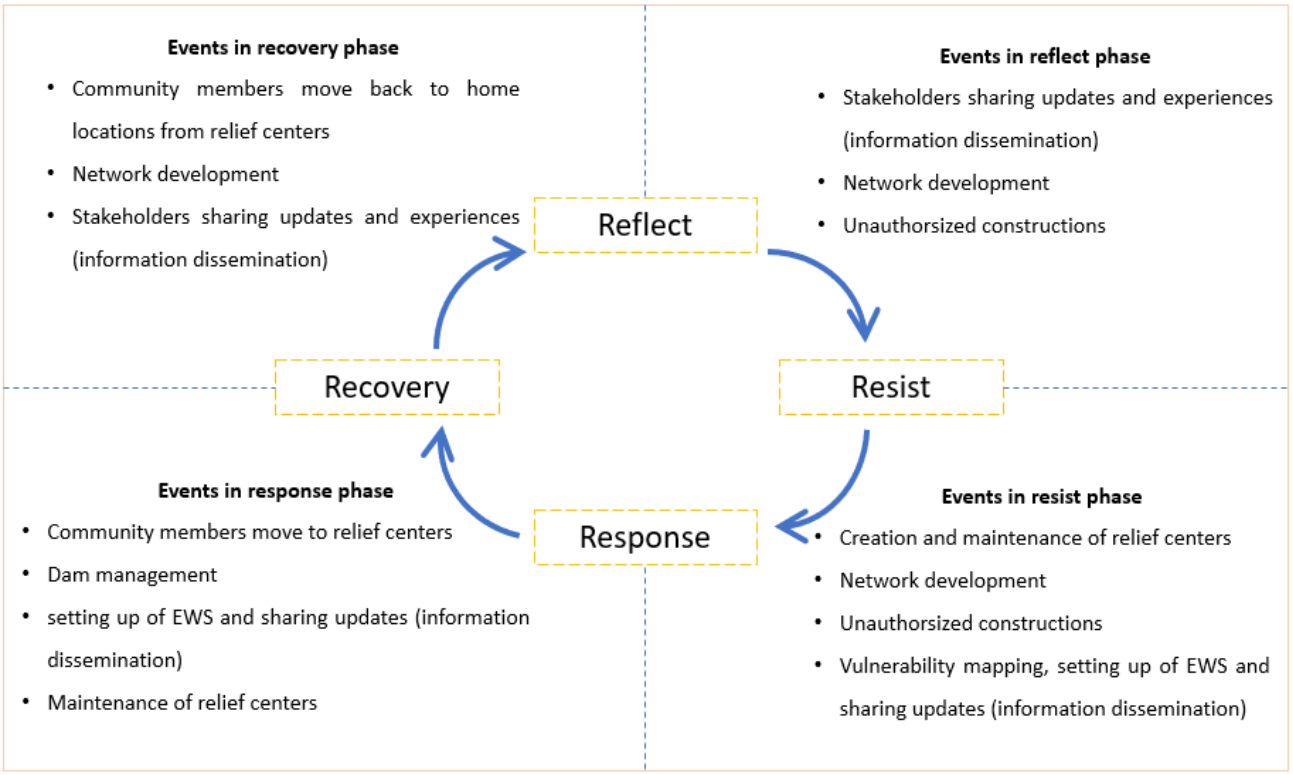


Figure 7.1. Events core to creating, expanding and sustaining initiatives in the model

Each event in each phase involves a specific FRGA (analysis of the actors, rules, resources and discourses that contribute to multi-scale approaches to flood risk management (Alexander et al., 2016)) and in order to be able to study the impacts of the existing FRGA (In case of Kochi the existing FRGA is a MLG structure) it is important to discuss the actors, rules, resources and discourses involved in each of the events within the four different phases of the resilient FRM. The conceptual model in MAIA is thus aimed to prepare a layout of the existing FRGA and then the information from the conceptual model will be used to develop the ABM model.

The MAIA conceptual model constitutes five structures namely – collective structure, constitutional structure, physical structure, operational structure and evaluative structure. Each of these five structures will contribute to preparing the layout of the FRGA and the information pertaining to the Kerala FRM that would be discussed in each of the structure is as follows:

- Collective structure: The agents (actors) involved in the FRGA is a part of a social system where these agents have certain roles and properties that are exclusive to them. The collective structure will describe the agents that are involved in the events that take place within the different phases of the resilient FRM cycle. The agents would then be organized from a MLG perspective into National level, State level, District level and Local level so that it gives a better perspective about the agents in both the horizontal and vertical dimensions.
- Constitutional structure: As discussed, FRGA is the analysis of actors, rules, resources and discourses. While the collective structure will throw light on the actors and their respective attributes, the constitutional structure will discuss the institutions – rules, norms and shared strategies that govern the behaviour/interactions of the actors within the social system these actors are a part of. These institutions would be discussed with the help of grammar of institutions (discussed in section 3.2.).
- Physical structure: In addition to discussing the agents, their attributes and the institutions that govern their behaviour/interactions, it is important to discuss the physical components that contribute to explaining the FRGA better. The physical components for the model will be decided based on the narratives of the various events to be discussed within the different phases of the resilient FRM.
- Operational structure: This structure is intended towards capturing the dynamics within the system by giving a better understanding of how the agents, their roles and physical components together are responsible in giving rise to the events within the resilient FRM cycle. The operational structure will constitute four action arenas – resist phase, reflect phase, response phase and recovery phase which would further constitute action situations based on the events within each of the phases.
- Evaluative structure: This structure is intended towards discussing the variables or KPIs that would help with answering the main research question and establishing the model validity. The main research question of the research is “What are the impacts of MLG characteristics on resilient FRM?”. When talking about impacts, KPIs are vital in order to study the impacts. As discussed in section 4.2.1. there are five dimensions which can contribute to evaluating resilient FRM of an urban agglomeration – social dimension, technical dimension, economic

dimension, environmental dimension and institutional dimension. The events within the different phases of the resilient FRM will result in changes within the different dimensions that will be used to evaluate the resilient FRM.

Now that a brief is provided on the overview of the model, it is important to elaborate on the five structures within MAIA within the context of the Kerala FRM.

7.2. COLLECTIVE STRUCTURE: ACTORS AND THEIR ATTRIBUTES

In order to study the collective structure, a desktop research was conducted where formal documents, newspaper articles and reports were reviewed to shortlist stakeholders of Kerala flood risk management. The multi-level nature of the decision-making setting was evident from the extensive list of stakeholders. The primary set of stakeholders were identified from the document pertaining to disaster management policies (Government of Kerala, n.d.) and then based on the various FRM activities discussed within the policies, the stakeholders associated with those activities were identified from newspaper articles and other formal documents (Land utilization order and coastal zone management zone). The list of stakeholders was basically associated with the context as discussed in section 7.1. For the simplicity of the model that is to be developed, the list of stakeholders can be first simplified and then clustered. The simplification was done based on how often a specific stakeholder was mentioned in the formal documents, newspaper articles and reports. Furthermore, the stakeholders were clustered based on their similarities in roles & responsibilities but at the same time ensuring that there are stakeholders from both horizontal and vertical dimensions in order to have heterogeneity within the system of consideration.

When discussing risk, there is a need for identifying those actors who can impose risks and the threshold of the people to such imposition (Stirling, 2010). After simplification and prior to clustering, a P-I matrix (Enserink et al., 2010) was created based on the list of stakeholders identified in section 2.3. to get an idea about how actors differ based on power (resources) and interest (Figure 7.2.).

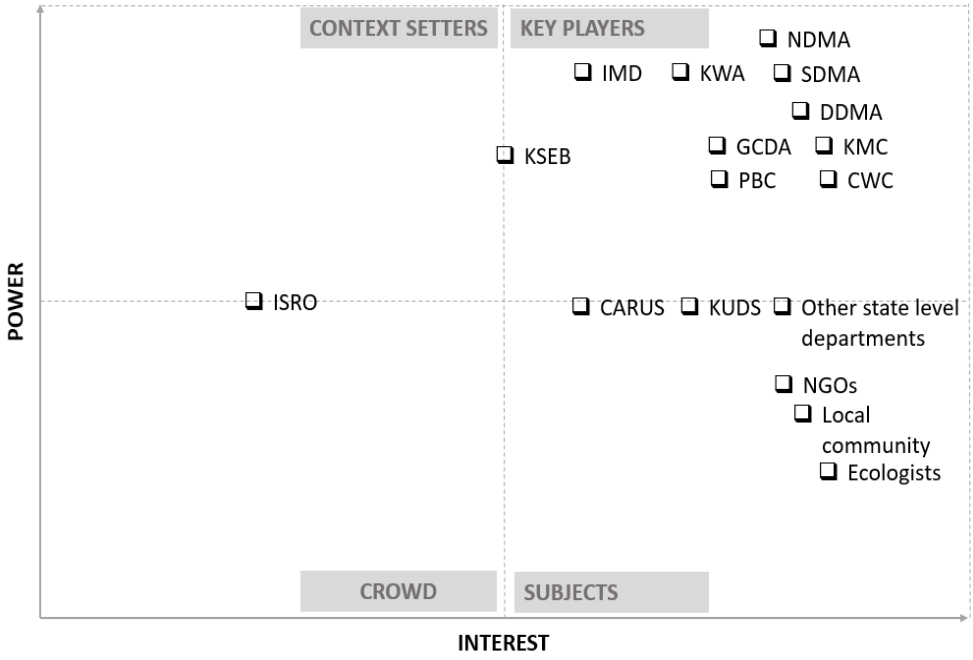


Figure 7.2. P-I matrix

Table 7.1. summarizes the simplified and clustered agents to be considered. This gives the finalized set of agents to be considered for the model.

Table 7.1. Agents considered for the research

Agent	Representing
National Disaster Management Authority(NDMA)	National Disaster Management Authority, Central Water Commission (CWC, India Meteorological Department (IMD), Indian Space Research Organization (ISRO), Centre for Advanced Research in Urban Studies (CARUS) and Ministry of Environment and Forest Affairs)
State Disaster Management Authority(SDMA)	State Disaster Management Authority, state level departments and Kerala urban development society (KUDS))

Kerala State Electricity Board (KSEB)	Kerala State Electricity Board, Kerala Water Authority (KWA)
District Disaster Management Authority (DDMA)	District Disaster Management Authority (DDMA)
Kochi Municipal Corporation (KMC)	Kochi Municipal Corporation, Great Cochin Development Authority (GCDA)
Non-Governmental Organizations (NGOs)	Non-Governmental Organizations and ecologists assuming that NGOs raise concerns on environmental issues
Local communities	Local communities
Private Building Contractors Association (PBCA)	The private building corporations that is involved in constructions

Fig 7.3. is aimed to give an idea about the different agents chosen for the research from a multi-level perspective

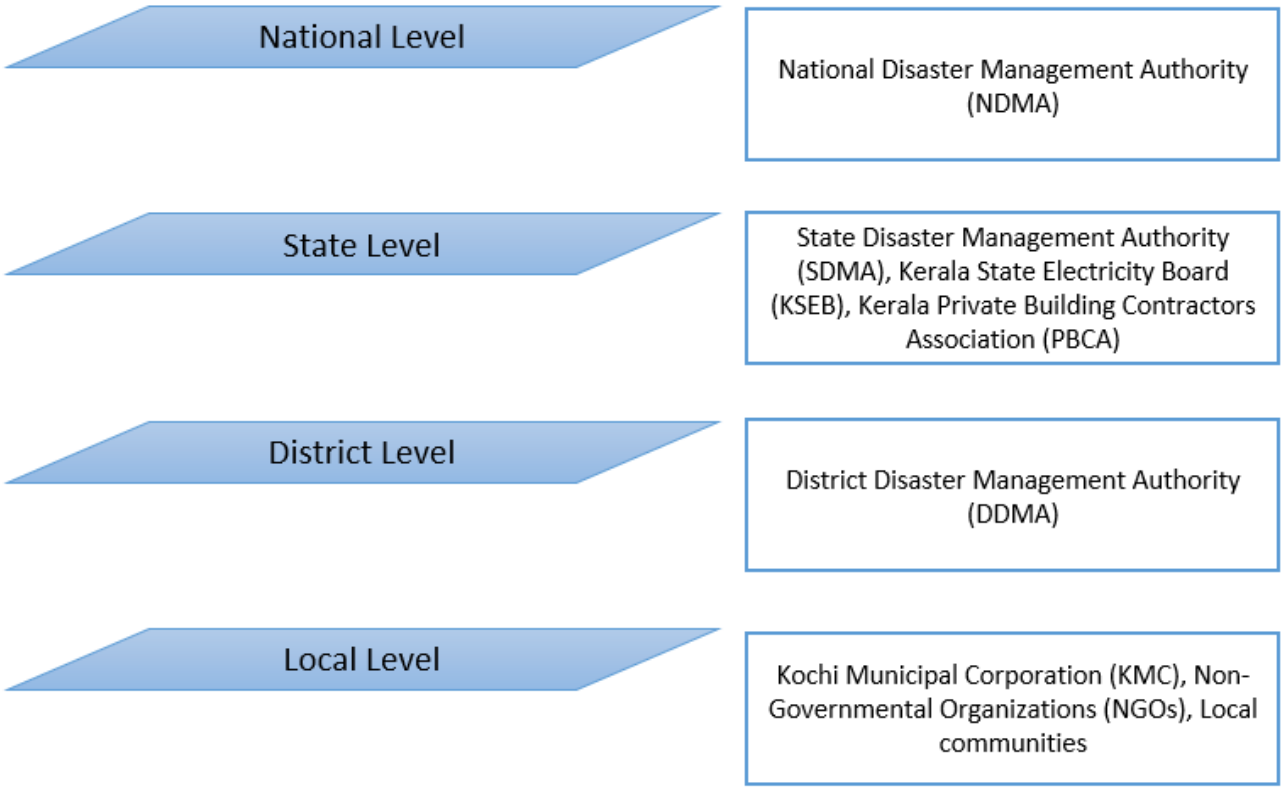


Figure 7.3. The selected agents from a multi-level perspective

Now that agents have been identified, it is important to discuss the properties and behaviour of these identified agents. Appendix B summarizes the collective structure. It is important to note that the PBCA would not be specifically represented as an agent and hence would not have specific properties but rather the event on unauthorized constructions would be carried out in the model representing their decisions.

7.3. CONSTITUTIONAL STRUCTURE: THE SOCIAL CONTEXT

Constitutional structure constitutes the discussion about the institutions involved in the FRGA. It makes use of the grammar of institutions (discussed in Chapter 3) which is based on the idea that institutions are representative of the regularities of human actions in situations The research makes use of the constitutional structure to qualitatively analyze the institutional dimension of resilience. Appendix C discusses the rules, norms and shared strategies identified in the case of Kerala FRM and

these are the institutions that would be modeled. These institutions discussed in Appendix C are a part of the larger set of institutions that are present in the actual case study.

7.4. PHYSICAL STRUCTURE: THE PHYSICAL ASPECTS OF THE SYSTEM

With respect to the Kerala FRM system to be modelled, some of the relevant physical aspects to be considered would include - *unauthorized constructions, dam location, mangrove locations, backwater fishing locations, the ecologically sensitive zones corresponding to the mangrove and backwater fishing locations and the relief centers.* The *unauthorized constructions* which are the constructions made violating the Coastal Regulation Zone (CRZ) norms (Kumar, 2019) in *ecologically sensitive zones* results in a certain amount of environmental damage. The *backwater fishing locations* in addition to contributing towards demarcating ecologically sensitive zones, are also job locations of fishermen in Kochi. The *relief centers* are created during the phase before the flood and the local communities move to relief centers during floods.

7.5. OPERATIONAL STRUCTURE: THE DYNAMICS OF THE SYSTEM

With regards to the dynamics of the system, in order to ensure that the model to be developed does not compose of a large number of components, the stakeholders of focus were narrowed down and also the interactions within the system. For example, in the recovery phase the research mainly looks at information dissemination between stakeholders while sharing updates and the initiative formation of community members. To discuss the operational structure of the Kerala FRM, the action situations can be classified based on the phases of the resilient FRM cycle that the action situation takes place in.

REFLECT PHASE

- The SDMA, DDMA and KMC (Precondition: once a week on a working day) updates the NDMA, SDMA and DDMA respectively regarding the progress and this results in the overall increase in “update information” shared within the system

- The SDMA/ DDMA/ KMC (Precondition: higher power) takes responsibility for decisions pertaining to constructions that can result in higher vulnerability and SDMA/ DDMA/ KMC (Precondition: higher power and corrupted or ready to take risk) allows constructions which can result in environmental damage
- Community members (Precondition: home location or job location in close proximity to the location with environmental damage) start an initiative and functional capacity of community members due to initiatives increases.
- Community members (Precondition: higher urge to join the initiative(based on social proof theory) and closer to initiative members) join the initiative and the overall energy of the network increases. Furthermore, the functional capacity of individuals who encounter the initiative members (irrespective of the fact that they join the network or not) increases indicating that awareness has been spread.
- The SDMA/ DDMA/ KMC (Precondition: no corruption or low risk taking) supports the initiative and the overall energy of the initiative network increases.

RESIST PHASE

- The SDMA, DDMA and KMC (Precondition: once a week on a working day) updates the NDMA, SDMA and DDMA respectively regarding the progress and this results in the overall increase in information shared within the system
- The SDMA/ DDMA/ KMC (Precondition: higher power, not corrupted or not willing to take risk and high skill set) takes responsibility for vulnerability mapping amongst local communities and this results in the increase of vulnerability information in the system and contributes to the technical capacity of the flood risk management system.
- The SDMA/ DDMA/ KMC (Precondition: higher power) takes responsibility for decisions pertaining to constructions that can result in higher vulnerability and SDMA/ DDMA/ KMC (Precondition: higher power and corrupted or ready to take risk) allows constructions which can result in environmental damage.

- Community members (Precondition: home location or job location near the location with environmental damage) start an initiative and capacity of community members due to initiatives increases.
- Community members (Precondition: higher urge to join the initiative(based on social proof theory) and closer to initiative members) join the initiative and the overall energy of the network increases. Furthermore, the functional capacity of individuals who encounter the initiative members (irrespective of the fact that they join the network or not) increases indicating that awareness has been spread.
- The SDMA/ DDMA/ KMC (Precondition: no corruption or low risk taking) supports the initiative and the overall energy of the initiative network increases.
- The DDMA (precondition: resist phase) creates relief centers. This results in the increment of the technical capacity of the flood risk management system
- The KMC (Precondition: no corruption or low risk taking) maintains the relief centers and results in the increment of the technical capacity of the flood risk management
- The SDMA, DDMA and KMC (Precondition: low skill set) receives technical assistance from NDMA, SDMA and DDMA respectively and this results in the increase in the overall skill set of the agent

RESPONSE PHASE

- The SDMA, DDMA, KMC (Precondition: there is heavy rain) updates the NDMA, SDMA and KMC respectively regarding the progress and visits relief centers more frequently. This results in the overall increase in update information shared within the system
- The community members move to the relief centers during this period and this results in the increase in the technical capacity of the flood risk management system
- The KMC (Precondition: no corruption or low risk taking) maintains the relief centers and results in the increment of the technical capacity of the flood risk management

RECOVERY PHASE

- The SDMA, DDMA and KMC (Precondition: once a week on a working day) updates the NDMA, SDMA and DDMA respectively regarding the progress and this results in the overall increase in update information shared within the system

- The SDMA/ DDMA/ KMC (Precondition: higher power) takes responsibility for decisions pertaining to constructions that can result in higher vulnerability and SDMA/ DDMA/ KMC (Precondition: higher power and corrupted or ready to take risk) allows constructions which can result in environmental damage.
- Community members (Precondition: home location or job location near the location with environmental damage) start an initiative and capacity of community members due to initiatives increases.
- Community members (Precondition: higher urge to join the initiative(based on social proof theory) and closer to initiative members) join the initiative and the overall energy of the network increases. Furthermore, the functional capacity of individuals who encounter the initiative members (irrespective of the fact that they join the network or not) increases indicating that awareness has been spread.
- The SDMA/ DDMA/ KMC (Precondition: no corruption or low risk taking) supports the initiative and the overall energy of the initiative network increases.
- The community members (Precondition: absence of heavy rains) move to the home location and continue working at the job locations

To begin with, the duration of the different phases within the FRM cycle must be decided for the model. Even though in the realistic scenario the period of one FRM cycle may vary, the model will consider that one FRM cycle would take one year to complete (52 weeks). Kerala has the Southwest monsoon period from June to August (keralatourism, n.d.) and it is during this period that the flood occurred in 2018. Therefore, the decision with regards to the duration of the different phases in the FRM cycle began with deciding the duration of the response phase to be within the week 24 and week 40 of a year (monsoon period). However, since the idea was to accommodate the FRM cycle within a year, the response period was decided to be from week 31 to week 39 so that the other phases have ample amount of time for completion. It was further assumed that the cycle begins with the reflect phase so that there is a starting point for the model. Therefore with the above considerations, the four different phases within the FRM cycle are shown in Table 7.2.:

Table 7.2. Duration of the different FRM phases

Starting week	Phase
Week now = 1	Reflect phase
Week now = 13	Resist phase
Week now = 31	Response phase
Week now = 40	Recovery phase

Now, as it is clear that certain weeks constitute a specific phase, it is important to define what these weeks would look like in the model. As a more realistic approach, each week can be considered to have 7 days. The first 5 days of every week can be the working days while the remaining 2 days of every week can be non-working days. This differentiation of working and non-working days was considered so that the majority of the activities of government officials are carried out during working days unless in the response phase during which there is no distinction between working and non-working days. Furthermore from the perspective of the community members , the model aims to show that during working days the community members approach job locations (backwater locations or companies) and during weekends the community members take a walk in the neighbourhood or meet other community members. Since vulnerability mapping is basically the interaction between the responsible government authority with the local community members in order to capture the vulnerable locations, the model assumes that vulnerability mapping occurs during non-working days where the government authority goes to the location with the maximum number of community members.

Now, as it is clear as to what a week would look like, it is important to define what a day would look like. The trial began with considering one day to be 24 hours like in the real-life scenario but it was noticed that agents when moving to different target locations based on a schedule, reached the final destination within 12 hours. Furthermore, it was noticed that in terms of computation, it was faster considering one day to be 12 hours. Hence, the number of hours in a day was decided to be 12 and each hour had 60 minutes as in the real-life scenario.

Now, as it is clear as to what a day and hour would look like, it is important to discuss what 1 tick would mean in this case. The number of minutes 1 tick would define was decided based on how many steps an agent can take when moving towards the target locations. Trial was carried out by setting one tick with different values of minutes. At the same time, the idea was to ensure that agents did not travel impractical distances within each tick. Therefore, after several trials of combinations for ticks, it was decided that one tick would be 15 minutes. This also ensured that agents reached the locations in their schedule.

The working hours during each day was decided with the idea that people would normally have daytime and night time. Therefore, agents begin to execute the schedule when the hour is 1 and the final target in the schedule is set at hour 6. Between hour 6 and hour 12 the agents approach their final target (basically the location where the agents began the schedule from which can be called as the home location) and remain at the home location until hour 1 of the next day.

The agents behave based on the events in the phases and Fig 7.4. gives a brief on what happens during each tick. The highlighting in red is to indicate that there are events from the FRM phases that occur here and these events are elaborated in section 7.5.2. through narratives and flow charts showing the FRM events.

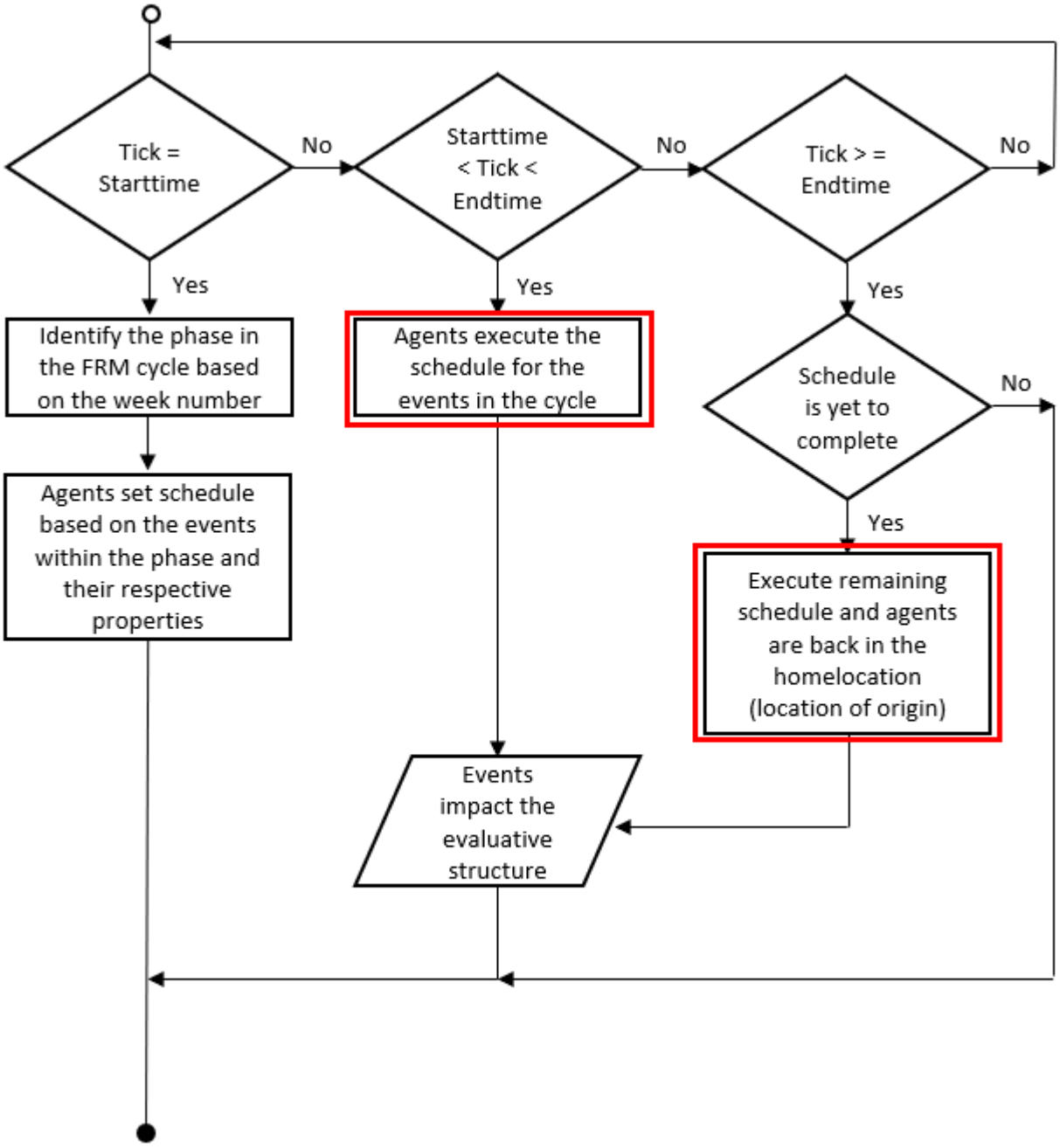


Figure 7.4. Flow diagram indicating what happens in one tick

7.5.1. ASSUMPTIONS FOR THE MODEL

Prior to discussing the narrative of the model, the assumptions that have been considered must be discussed so that the narratives are clearer. Even though some of the assumptions have been mentioned in previous sections in order to complete certain explanations, this section would give an overview of all the assumptions that would be considered in the model

- One FRM cycle takes one year for completion and the cycle begins with the reflect phase
- According to IMD there is 70% probability that monsoon rainfall in Kerala can result in Floods (indiaglitz, 2020)
- Population of fisherfolk is approximately 3 % in accordance with the current population (P, A., V., & R, K., V.,2014). This difference in occupation is reflected on the job location of community members.
- There is a 69 % probability that government authorities are corrupt. This is considered based on the data that suggests that there is a 69 % chance in India for government authorities to take bribe (Ospina & Roser, 2019)
- Even though the disaster management policies mention that KMC is responsible for maintaining resources during FRM, it is not explicit as to what these resources are and hence it is assumed that relief centers are some of the resources that KMC must maintain during FRM.
- Power among government authorities is distributed as “low”, “medium” and “high”. (As discussed in Section 7.1.)
- In case of overlapping responsibilities, the model assumes that authority with the high power would be in-charge or in case of equal power, the authorities would work together as it is not explicit in the disaster management policies (Government of Kerala, n.d.) who will be in-charge.
- The NDMA has enough skill set and is not corrupted. This is assumed because in the disaster management policies (Government of Kerala, n.d.) NDMA is portrayed as an overarching

authority and is only involved in monitoring policies unless in the response phase NDMA assists with relief operations.

- The government authorities have the required budget for carrying out the activities. The budget is different for different phases within the FRM cycle (Government of Kerala, 2013) but since not all activities within the FRM can be discussed in the research, it did not seem realistic to assume the distribution of budget for each activity considered in the research. This was decided keeping in mind that the research would have more to convey with fewer quantitative assumptions. However, since the economic dimension of resilience must be discussed, instead of assuming the budget, the model accounts for a certain cost for each activity just so that the model can give an idea about the costs involved.
- When it comes to "vulnerability information "it is important to capture the fact that local self-government has better opportunities of gathering effective information from the local communities since it is responsible for only one city and is involved in the public participation at the grassroot layer (Singh et al., 2018). This can be incorporated in the narrative by including three levels of information "small", "medium", and "high" where when local self government collects information from community members directly, the level of information is "high" while when district or state authorities collect the information from community members, the level of information is "medium" and "low "respectively.
- The information from the community members is very important in human - flood interactions and hence not carrying out vulnerability mapping (information collecting activity that involves direct interaction with community members) results in a negative impact on information collected
- When government authorities update experiences amongst each other, there is no cost involved. This is considering that these updates can be shared via a G2G (Government to Government) e-governance system (cleartax, 2019) and does not require additional expertise unlike for vulnerability mapping or EWS

- Not carrying out dam management can have a negative impact on technical capacity. This was considered because Kerala does not have EAP for dams (Rocha, Jadhav & Mukherjee, 2018) and that contributes largely to the loss of life and property.
- Community members who have their home location or job location close to the environmental damage, starts the initiative. This is considering that individuals are concerned about the impacts of environmental damage on their livelihood
- Since the involvement of NGOs was discussed in Singh et al. (2018), the model considers that the NGOs join the network once it has started
- The non-initiative members have the urge to join community initiative by a probability of 0.6 Based on Appendix E. i.e; There is a 60% chance that the social proof theory applies to the non-initiative member when encountered by an initiative member during the normal day-to-day activities)
- From a range of 1 to 10 the threshold skill set for government authorities is 6 and this threshold was decided based on sensitivity analysis discussed in Table A in Annex
- Vulnerability mapping occurs during non-working days and as a result the government authority goes to the location with the maximum number of community members for carrying out vulnerability mapping.
- When non-initiative members encounter initiative members during day-to-day activities, even if they do not join the network, their functional capacity increases. This is assuming that even if they do not join, they are now aware of the environmental damage from unauthorized constructions
- With the EWS and dissemination of forecast information, corruption is not involved but only skillset. The EWS setup involves not just one government authority but rather involves three disaster authorities (SDMA, DDMA and KC) and one governmental organization (IMD). Hence, the assumption is that the authorities must carry out the responsibilities as there are less opportunities to be corrupt and not be caught. However, when considering skillset, it is

assumed that with a lower skill set, there is less positive impact on the technical capacity and forecast information while with higher skill set, there is more positive impact on the technical capacity and forecast information

- Government authorities share updates with each other once a week during a weekday. However, during the Response phase, if there is heavy rain they update each other more often.
- Unlike the vulnerability mapping and early warning system, which would contribute to the technical dimension of resilience, the information from sharing updates would contribute to the social dimension of resilience since updating information can be related to more about the engagement of stakeholders.
- The government authorities have the urge to join community initiative by a probability of 0.4 based on Appendix E i.e. There is a 40% chance that the government authorities will join the initiative network
- If the government authorities join the initiative network, the environmental damage decreases. This is considering that when government authorities join the network, they are obligated to bring about a change with respect to the concern
- The members within the initiative network, at the end of every year (last week) decide if they still like to continue within the network. It is considered that government authorities have 60 % chance of continuing while citizens have 40 % chance of continuing. These values are decided based on the sensitivity analysis discussed in Appendix E.

7.5.2 NARRATIVES

The narrative for the model would be described with the help of flow diagrams and in order to avoid complexity, the flow diagrams would be discussed not as a single chart but separate flow charts based on the different activities within the system as discussed in Section 7.1. The events are - information dissemination, capacity development, dam management, network development representing the social welfare initiatives, creation and maintenance of relief centers, environmental

damage due to unauthorized constructions and the power distribution aspect that helps with decisions pertaining to overlapping functions. Figure 7.5. gives the overall idea of how the agents function in the model.

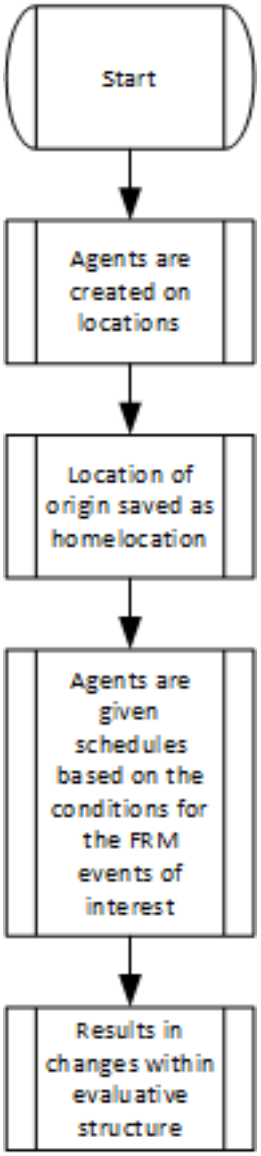


Figure 7.5. Overview of how the agents function in the model

INFORMATION DISSEMINATION

Government authorities update each other once a week unless in the response phase, they update each other five times a week when there is heavy rain and chances of flood. In the model, the

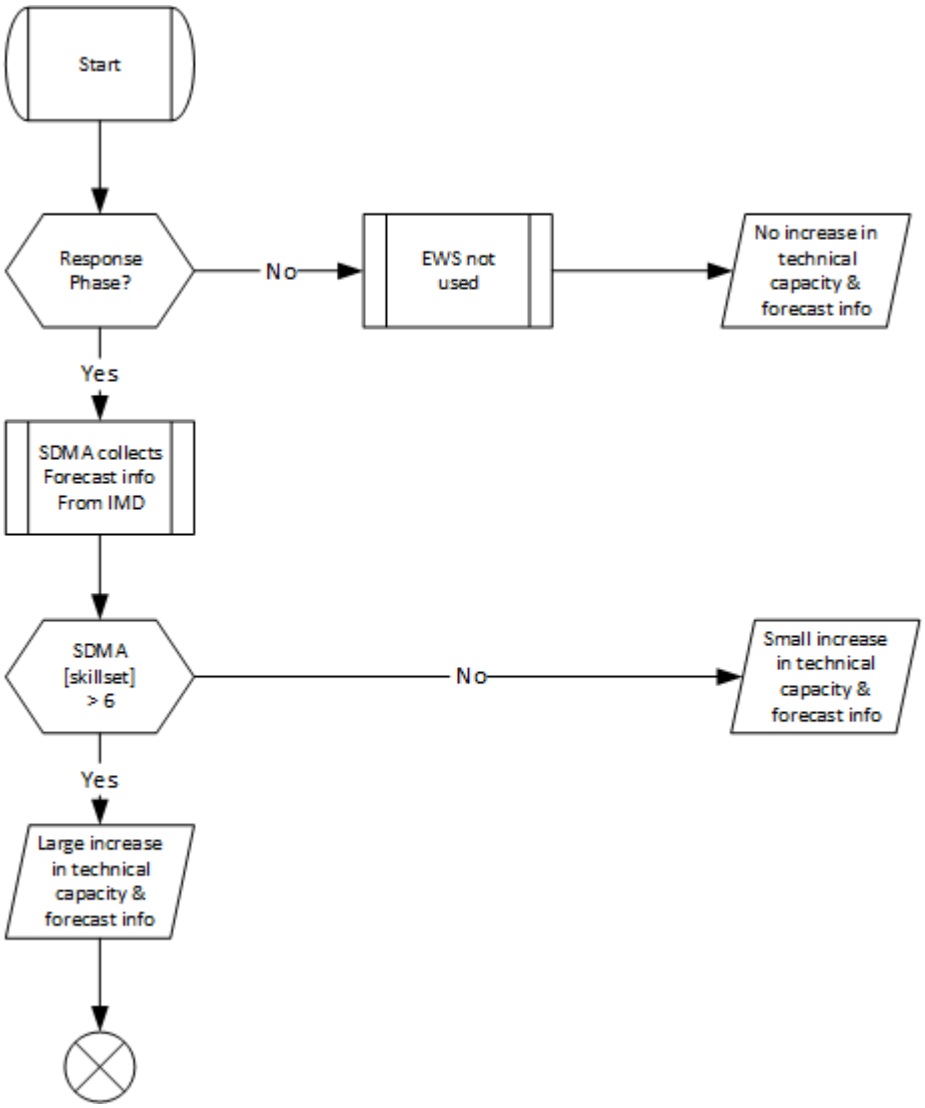
updating information event is organized by using a Bernoulli distribution that would decide the day on which this updating activity would take place. For example, PBernoulli (1 / 7) reports that one day out of seven days the agent has to have a specific schedule (a list) based on which the agents would approach the target location. On the day the agent must participate in the updating activity, if that agent moves to the target in the schedule list, there is an increment in the overall "update information" available in the system.

When it comes to "vulnerability information"it is important to capture the fact that local self-government has better opportunities of gathering effective information from the local communities since it is responsible for only one city and is involved in the public participation at the grassroot layer (Singh et al., 2018). This can be incorporated in the narrative by including three levels of information "small", "medium", and "high" where when local self government collects information from community members directly, the level of information is "high" while when district or state authorities collect the information from community members, the level of information is "medium" and "low"respectively. In addition to the different levels of information it is considered that carrying out vulnerability mapping results in a positive impact while not carrying out vulnerability mapping results in negative impact. Furthermore, carrying out vulnerability mapping would involve some cost as it involves going to locations and seeking technical expertise. Figure 7.6. shows the code snippet that discusses the value and impact of vulnerability information.

```
to-report info_effect [ direction quality ] ; direction = pos/neg , quality = small/medium/high
  if direction = "pos" [
    (ifelse
      quality = "small" [ report 1 ]
      quality = "medium" [ report 2 ]
      quality = "high" [ report 3 ]
    )
  ]
  if direction = "neg" [
    (ifelse
      quality = "small" [ report -1 ]
      quality = "medium" [ report -2 ]
      quality = "high" [ report -3 ]
    )
  ]
end
```

Figure 7.6. Impact of the amount and quality of information

With respect to the “forecast information” collected during the early warning system. The information flow begins at the IMD who is the source for forecast information. The SDMA collects information from IMD. The information effect at this point depends on the skillset and not the corruption level (as mentioned in the assumptions for the model). With a higher skill set (above 6), the effect would be “high”and with lower skillset (below 6), the information effect would be “low”. The value for these effects is similar to vulnerability mapping and the values can be identified from Figure 7.5. Furthermore, the SDMA shares the forecast information to the DDMA and the DDMA shares this forecast information to the KC. Figure 7.7. is a flow chart that is aimed to give a better perspective on narrative of forecast information.



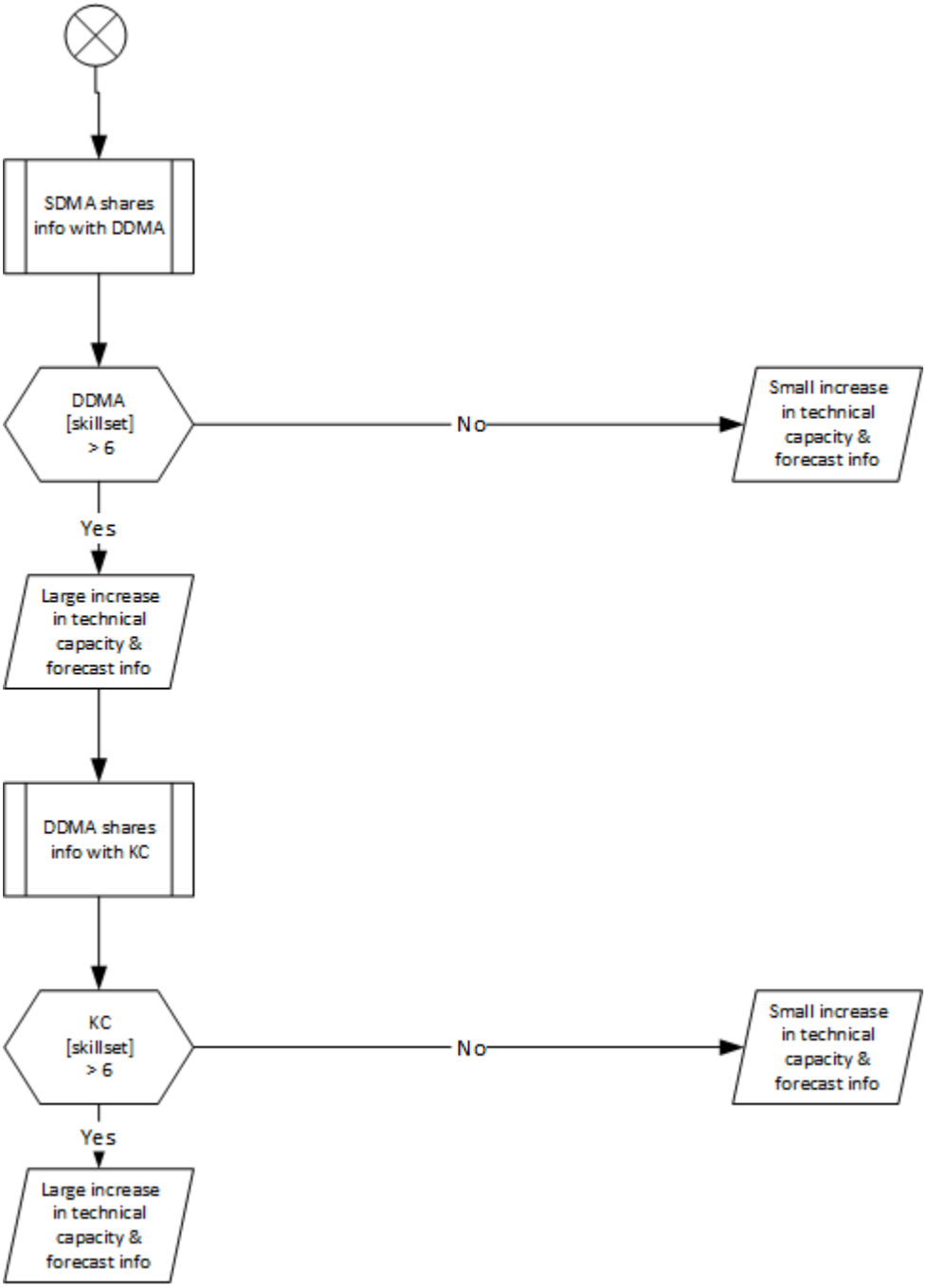


Figure 7.7. Flowchart on forecast information

ENVIRONMENTAL DAMAGE

Environmental damage is the result of unauthorized constructions. Construction decisions are made in phases other than the response phase since during that period people are focussed on tackling issues pertaining to heavy rain. The building corporation decides location for construction and if the chosen location is within the ESZ (as discussed there would be 7 unauthorized constructions in a year), permission is sought from the authority. The decision maker for this decision is decided based on the power distribution due to the overlapping functions within the disaster management policies. Furthermore, if the decision maker is corrupted, there would be an unauthorized construction or else there would not be an unauthorized construction. Figure 7.8. is a flow chart that is aimed to give a better perspective on narrative on environmental damage.

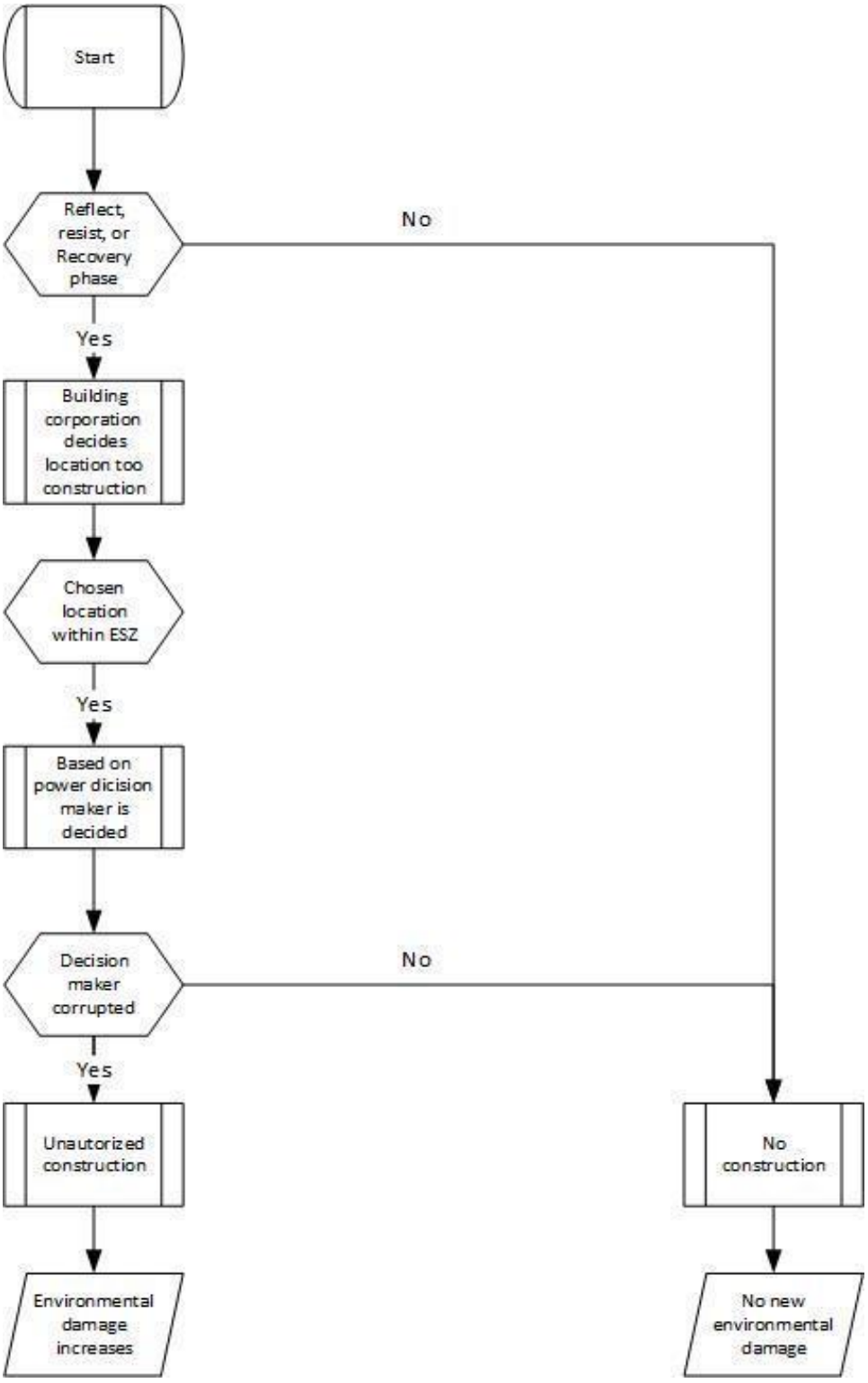
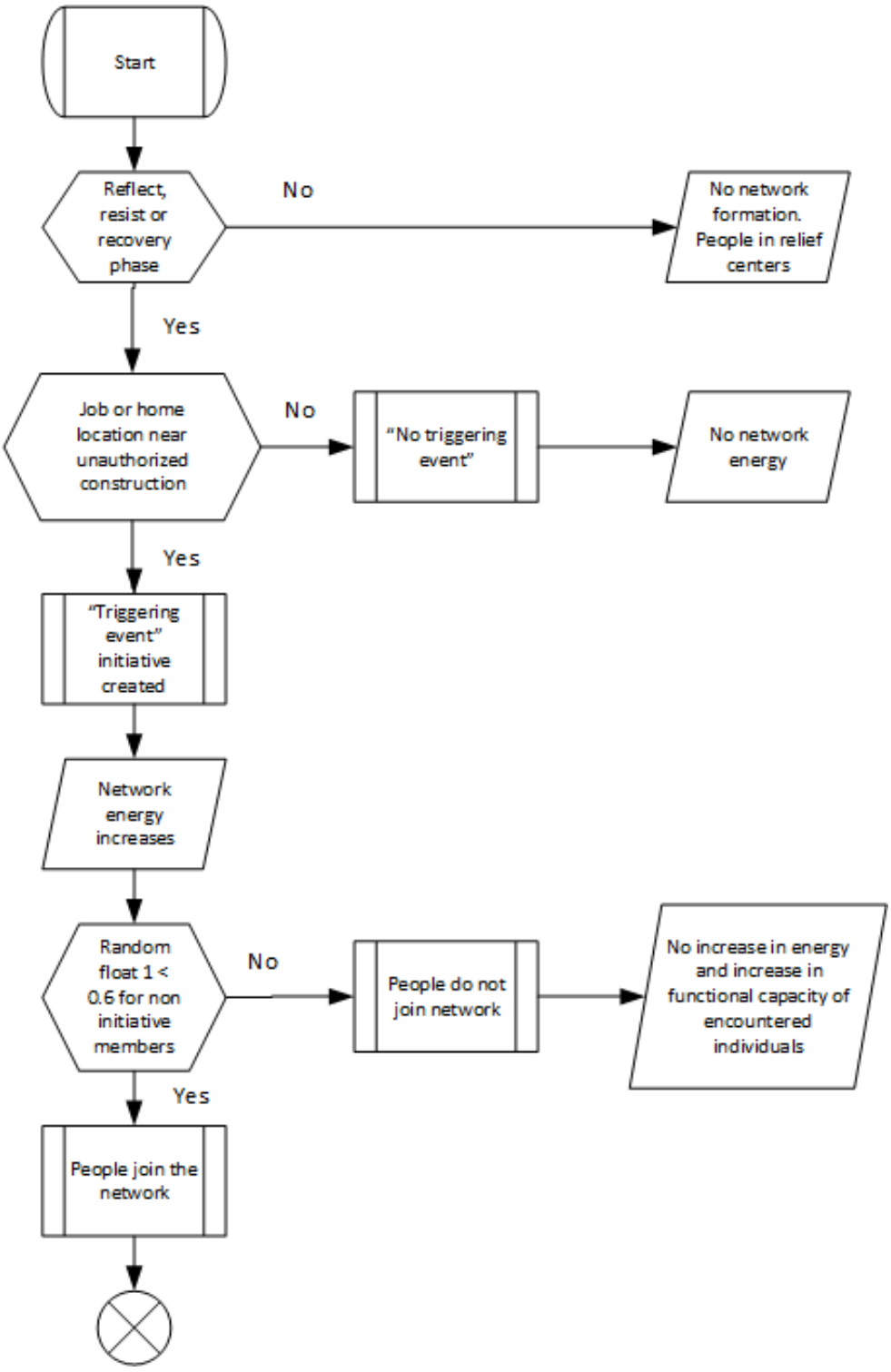


Figure 7.8. Flowchart on environmental damage

NETWORK FORMATION AND EXPANSION

The formation of initiative is a result of a "triggering event"which in this case is the environmental damage due to unauthorized constructions. Thus, this results in the first network of community members who have their home location or job location within 100 units radius of the source of environmental damage (unauthorized construction). Furthermore, the members in the initiative network have the potential to have influence on individuals (non-initiative members) whom they encounter during day to day activities. This is to imply the social proof theory (influence on information from others) and those individuals who have been influenced by the information would join the existing network. There is an increment in energy of the network and functional capacity of individuals. The government authorities join based on probability and if they are not corrupted. Having additional members in the network results in the increment of network energy. If the government authority joins the network, the environmental damage reduces. Figure 7.9. shows the flow chart indicating the network formation and expansion.


Start
Reflect, resist or recovery phase
No
No network formation. People in relief centers
Yes
Job or home location near unauthorized construction
No
"No triggering event"
No network energy
Yes
"Triggering event" initiative created
Network energy increases
Random float 1 < 0.6 for non initiative members
No
People do not join network
No increase in energy and increase in functional capacity of encountered individuals
Yes
People join the network

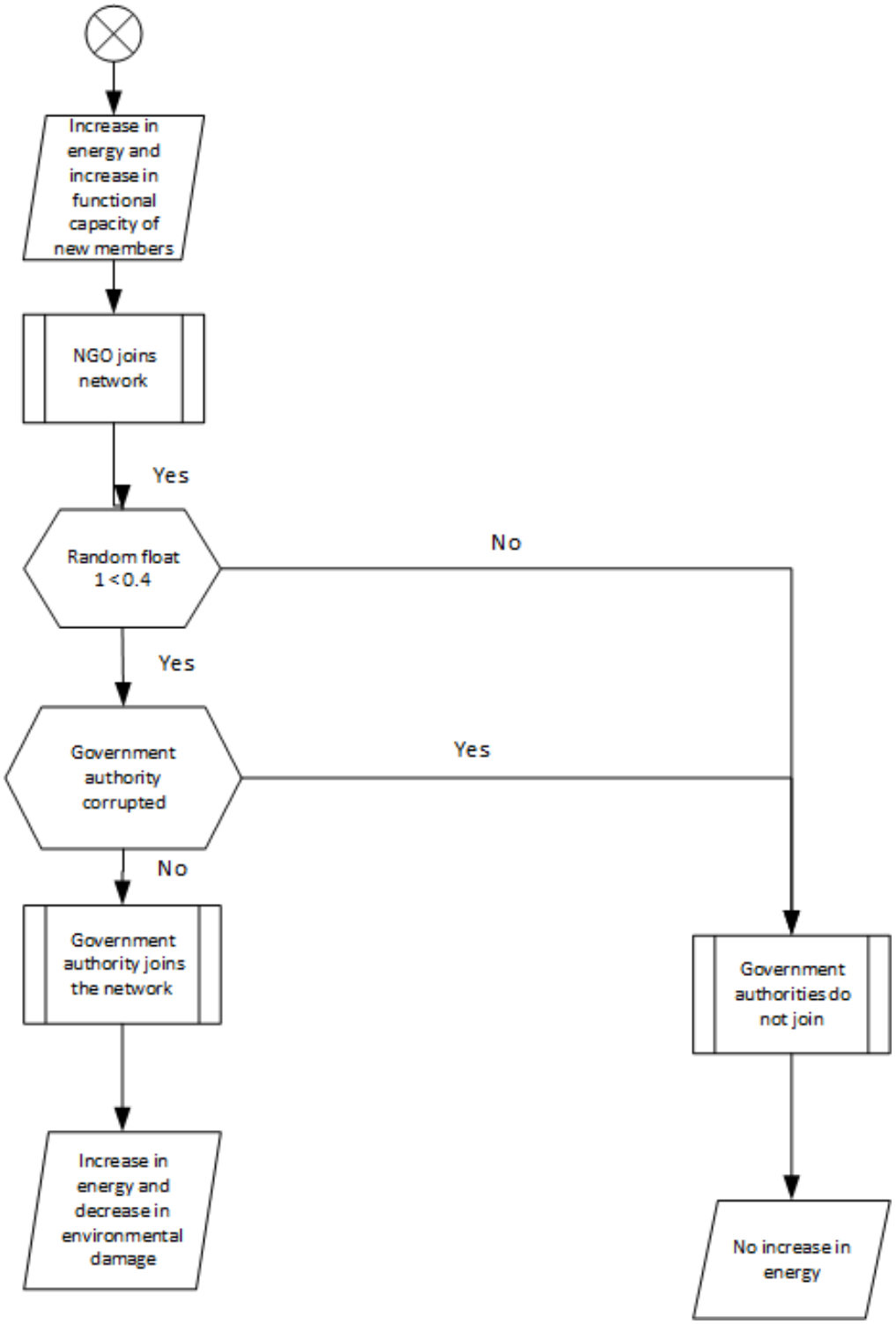


Figure 7.9. Flowchart on network formation and expansion

DAM MANAGEMENT

In the response phase, when there is heavy rain KSEB is responsible to manage the release of water from dams. But, if KSEB is profit minded, officers do not visit the dams or release the water. On the other hand if KSEB is not profit minded, the officers visit the dams. Visiting the dam results in the increment of technical capacity but not visiting the dam results in the decrease of technical capacity. Figure 7.10. is a flow chart that is aimed to give a better perspective on narrative on dam management.

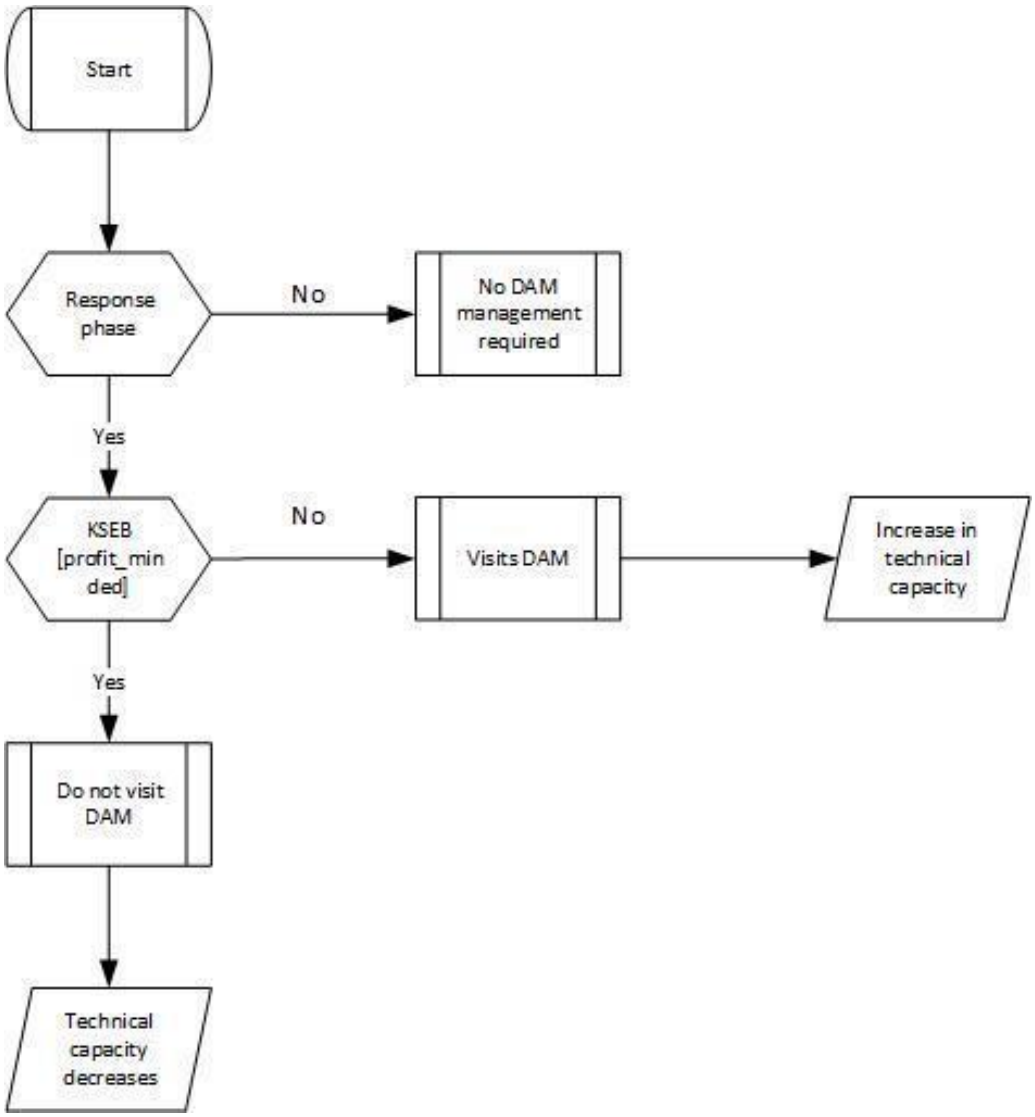


Figure 7.10. Flowchart on dam management

7.6. EVALUATIVE STRUCTURE: KEY PERFORMANCE INDICATORS

During the different phases of the resilient flood risk management cycle, the five dimensions of resilience - social, technical, environmental, economic and institutional would be evaluated. Table 7.3. discusses the dimensions for evaluating resilience.

Table7.3. Dimensions to evaluate resilience. Adapted from Batica et al. (2013)

Dimension	Evaluating parameters
Institutional Evaluation of the existing governance structure and the institutions that guide the agents (constitutional structure of MAIA) to behave in a certain way during the events of interest within the FRM	The research considers the qualitative nature of institutions that guide the behaviour of agents and hence the institutional dimension would be evaluated qualitatively. The institutions are inputs to the ABM model.
Social Evaluation of the engagement and mobilization of stakeholders, creation of partnerships or networks	Connections within the community ● The capacity that local communities gain from initiative networks (functional capacity). ● Information dissemination among stakeholders when they interact with each other to share updates about the situation with flood risk management **Social dimension = sum (normalized (functional capacity) + normalized (update information))**
Economic Evaluation of the expenses involved in carrying out activities in FRM	Costs incurred ● Costs involved in providing technical assistance, vulnerability mapping, creating & maintaining relief centers and dam maintenance **Economic dimension = normalized (costs incurred)**

Technical Evaluation of the technical activities of interest within the FRM	Technical aspects of FRM • Vulnerability information available , forecast information available , increase in technical capacity from dam maintenance and relief centers **Technical dimension = sum (normalized (forecast info) + norm (vulnerability info) + normalized (technical capacity))**
Environmental Evaluation of the consequences from illegal constructions	Environmental damage from unauthorized construction **Environmental dimension = sum (environmental damage)**
Overall resilience	**Resilience = Sum (Social dimension + Technical dimension - Economic dimension - Environmental dimension)**

8. MODEL FORMALIZATION

This chapter discusses the model parameters in detail and elaborates on the experimental setup for the Agent-Based Model

8.1. MODEL PARAMETERS

8.1.1. SENSITIVITY ANALYSIS

For the model development phase, even though most of the parameters were set based on literature, there were five parameters which did not have qualitative or quantitative data to support the assumptions. Hence, a sensitivity analysis was carried out for setting the threshold skillset, the percentage chance of government authorities joining and leaving the initiative network, and citizens joining and leaving the initiative network. The analysis was carried out using the BehaviourSpace in NetLogo. Since the difference in the resultant values were minimal, a tabulation of the values and the corresponding statistics seemed to deliver more clarity on the choice of values for the parameters. Appendix E discusses the sensitivity analysis.

8.1.2. PARAMETERIZATION

Since the MAIA (Modelling Agent systems based on Institutional Analysis) conceptual model has helped with identifying the system and its components, it is now important to emphasize on the model parameters that would enable to capture the narratives discussed in the conceptual model. Appendix D. discusses the model parameters.

8.2.EXPERIMENTATION

8.2.1. VISUAL SETUP

First of all, NetLogo was the software used in order to develop the Agent-Based Model. In order to give a better understanding of the ecologically sensitive zones (mangrove locations and backwater fishing locations), job locations, the locations of government authorities, the map of Kochi was used

to create the background. The motivation behind having this visual setup was also because as a trial, an individual not familiar with modeling was encouraged to take a look at the set up and it was interesting to see that such a setup helps even people who are not familiar with the case to have a better perspective of the case study.

Figure 8.1. shows the initial visual setup of the ABM.

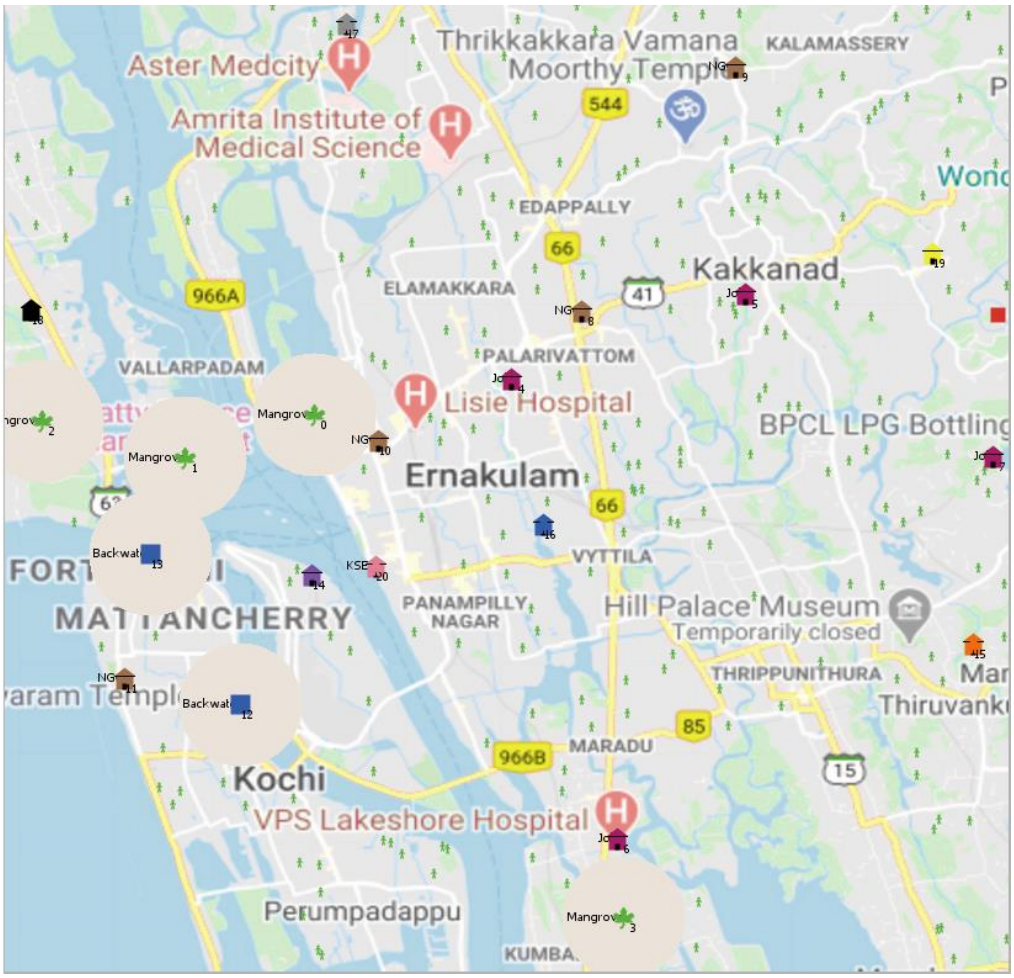


Figure 8.1. Visual setup of the model

8.2.2. MODEL DURATION

As mentioned earlier, one FRM cycle was considered to take one year for completion. One run of the model accounts for two years , i.e; two FRM cycles, due to two reasons:

- Firstly, In the model, all the narratives (examples: narrative on vulnerability mapping, narrative on early warning system etc) start at the beginning of the year and stop or complete by the end of the year except the narrative on network formation and expansion. This was considered because in reality, an existing network cannot die overnight unless there is a drastic "trigger"event. Hence, in the model, the impact of the network from the first year is carried to the second year if the network exists after the first year (based on conditions). This can further help with seeing a clear impact of energy from networks on resilience (if any).
- Secondly, the model was run for several years to see how the output was progressing and noticed that after the second year the output was steady and no unexpected changes occurred and hence the duration of one run was decided to be for two years or two FRM cycles.

8.2.3. EXPERIMENT SETTINGS

The experiment settings were made within BehaviourSpace of NetLogo.

The three levers for the model are - power allocated for DDMA, power allocated for SDMA and power allocated for KC. Singh et al. (2018) explains how the decisions made by the State Disaster Management Authority is prioritized over the decisions of District or Local authorities in the real life scenario. Furthermore, the report emphasizes that in the real case, the Local authority has almost no involvement in the phases prior to flood even though the Local authority contributes largely to policy development with the help of the community knowledge the Local authority has. Here, it can be seen that there is an implicit hierarchy and it is not representative of a decentralized multi-level governance structure. This specific part of the story line is the motivation behind the considering that authorities can be given "low", "medium"or "high"power. This is more of a qualitative data and in the modeling phase this qualitative data would have to be translated into quantitative data in order to ensure that the power distribution aspect is captured in the model. Furthermore, this power distribution aspect can play a significant role when it comes to overlapping responsibilities as per the disaster management policies (Government of Kerala, n.d.) and since the policies do not very explicitly mention who will be in-charge in case of overlapping responsibilities, the model assumes

that authority with the high power would be in charge or in case of equal power, the authorities would work together.

This distribution of power as “low”, “medium” and “high”are translated in the model with the values of 2, 3 and 4 respectively. It is important to notice that these values are used only for comparison purposes to understand which authority has high, medium or low authority and these values are not directly involved in the estimation of any numerical value.

In order to reduce the computation time, there were three experiments carried out and these three experiments were differentiated by keeping the power allocated to DDMA constant and varying the power allocated for SDMA and KC. As a result, three data sets were expected. Table 8.1. gives an idea on the experiments.

Table 8.1. Different experiments in the model to reduce computation time

Experiment No.	Lever_power_DDMA	Lever_power_SDMA	Lever_power_KC	Reps	Runs
1	2	[2, 3, 4]	[2, 3, 4]	10	90
2	3	[2, 3, 4]	[2, 3, 4]	10	90
3	4	[2, 3, 4]	[2, 3, 4]	10	90
Total Runs	**270**				

During the experiments, the parameters monitored were: Weeknow (to get an idea about the different phases and the progressing of data during these phases), vulnerability_info, technical_capacity, social_capacity, economic_dimension, forecast_info, info_value, environmental_dimension, opportunistic, increment_energy.

8.2.4. DATA ANALYSIS APPROACH

Each of the three datasets (dataset 1 with Lever_power_DDMA = 2, dataset 2 with Lever_power_DDMA = 3 and dataset 4 with Lever_power_DDMA = 4) had the values for the sub-

indicators of the four main resilience indicators or dimensions (social, economic, environmental and technical) as discussed in Table 7.4. The sub-indicators were first normalized in order to ensure that there is a common ground for comparison and then aggregated by averaging (assuming equal weightages to the sub-indicators) to estimate the respective indicators. The motivation behind this step was to get an aggregate resilience value.

Resilience = Sum (social dimension + technical dimension – economic dimension – environmental dimension)

where,

- Social dimension is **normalized(info_value) + normalized(social_capacity)**
- Technical dimension is **normalized(technical_capacity) + normalized(forecast_info) + normalized(vulnerability_info)**
- Environmental dimension is **normalized(environmental_dimension)**
- Economic dimension is **normalized(economic_dimension)**

The data obtained from the model would be used to gather insights on the characteristics of MLG relevant for the governance issues. Thus, the discussion would involve sharing insights on the power allocation aspect of decentralization, opportunistic behaviour of agents and influence of social initiative network. Since, there is no clarity on the weightages of the indicators used in evaluating the resilient FRM in urban agglomerations, this research accounts for two sets of discussions : 1) discussion on the four main indicators without aggregating them into an overall resilience value and 2) discussion on the overall resilience value which is obtained by aggregating the four dimensions – social dimension, technical dimension, environmental dimension and economic dimension (assuming equal weightages for the four dimensions). The intention behind having a discussion without aggregating the dimensions into an overall resilience value is because the determination of the weightages for the main dimensions would require an extensive analysis to determine which dimension is more or less important than the other when its comes to the case of Kochi. The intention behind having a discussion by aggregating the dimensions is because even though it is assuming

equal weightages to all the four dimensions, having a discussion with respect to an overall resilience value enables to gather a better overview when discussing about resilient FRM.

8.3. VERIFICATION AND VALIDATION

In order to verify the model, the guiding principle was to basically check if the narrative is satisfied and the agents behave in the way it is described in the conceptual model. Verification was carried out in four steps:

1. Recording and tracking agent behaviour
    a. In order to track the behaviour of the agent, print statements were added to the code. For example, to print “illegal” if there is an unauthorized construction, print “SDMA has started the schedule”/”DDMA has started the schedule”/ “KC has started the schedule”/”citizen has started the schedule when the agent is heading to its first target. Similarly print statements were added to confirm if the agents are reaching the final location in the schedule. Further, when relief centers are created a print statement “relief center is created “was shown in the common center. With regards to the network formation involved in the local initiative, the print statement “expansion” was used in order to be informed when community members joined the initiative created. The print statements allowed to verify that the agents were taking the path it was
2. Single-agent testing
    a. In order to confirm if agents behaved as per the conditions associated with the decision making, print statements were made use of to identify for example if the government official has a higher power or is corrupted. Then based on this information if we observe the model, we can see that if the agent is corrupted and of higher power, there is a large probability for not carrying out responsibilities and getting involved in illegal activities. In order to show this the print statements “ SDMA shows opportunistic behaviour”/ “DDMA shows opportunistic behaviour”/”KC shows opportunistic behaviour” were made use of and they appeared in the command

center. Further, in the case of KSEB, the print statement “KSEB is profit-minded” helped with identifying the kind of behaviour the agent would display.

3. Interaction testing in a minimal model
    a. The SDMA, DDMA and KMC offices are modelled as agents for a better structure and as mentioned previously when the agents approach their targets from the schedule, print statements were used to ensure that the targets were approached. Similarly, for vulnerability mapping, the agent in-charge of the activity as per the model approaches the location with the maximum number of citizens and to ensure that the model executed this part, the print statement “carried out vulnerability mapping “was used.
4. Multi-agent testing:
    a. The model was allowed to run for the whole intended period to see if all the components of the model blend well together. In addition, this is a process that was done throughout the modelling procedure where with every new addition of an aspect into the model, it was made to run once to see if the model did not show any abnormal behaviour.

The validation of the model is performed by comparing the model with the real-life situation. Primarily, it is the formal and informal institutions identified that have been used to determine the kind of behaviour agents would adopt during the model. This to a large extent validates how realistic the model is. Furthermore, the model uses qualitative or quantitative data from the real-life situation for events that occur in the model and the choices the agents make.

9. ABM RESULTS

This chapter discusses the results obtained from the ABM model that was developed to study the impacts of the existing governance arrangements on resilient FRM

9.1. RESULTS OVERVIEW

Overview of the overall progression of the main indicators can provide a broad picture of the results on the four main dimensions.

9.1.1. OVERVIEW OF DIMENSIONS

In order to simplify the findings on the progression of the different dimensions, the normalized values of the dimensions were distinguished as “low”, “medium” and “high” where “low” implies values below 0.3, “medium” implies values between 0.3 and 0.6 and “high” implies values above 0.6. The ideal observation would be to have “high” social dimension, “high” technical dimension, “low” environmental dimension and “low” economic dimension. However, the results reveal that the current governance arrangement (demonstrated in the model) do not yield that result. What the “best” result would mean in the context of Kerala FRM might require further study but assuming that the “low”, “medium” and “high” follows the demarcation mentioned , two of the results with better results have been highlighted in Table 9.1. In Table 9.1. the results were grouped based on the social, technical and environmental dimensions and summarized based on the mean of the economic dimension.

Table 9.1. Overview of the model results on the four main dimensions

social dimension	technical dimension	environmental dimension	economic dimension
low	low	low	0.056604375
medium	low	low	0.094040186
low	low	high	0.099117914
low	low	medium	0.101103946
medium	low	medium	0.165182609
low	medium	high	0.210404762
low	medium	medium	0.226989628
medium	low	high	0.246190476
high	medium	low	0.256324568
medium	medium	low	0.289654398
low	medium	low	0.299327419
high	low	low	0.324233882
high	low	medium	0.4
high	low	high	0.452876488
medium	medium	medium	0.470588984
medium	medium	high	0.476240088
medium	high	medium	0.48274344
medium	high	high	0.513526231
low	high	low	0.521680604
high	medium	medium	0.585301175
high	high	medium	0.594819048
high	medium	high	0.620362484
medium	high	low	0.795416129
high	high	low	0.82570043
high	high	high	0.866238807

9.1.2. OVERVIEW OF RESILIENCE

Appendix F (Figure A) shows the progression of resilience over the 270 runs where the results from the dataset with Lever_power_DDMA = 2 is shown in red while the results from the datasets with lever_power_DDMA = 3 and lever_power_DDMA = 4 are shown in green and blue respectively. The intention behind the plot was to give an idea about how the overall resilience progressed over the total number of runs but since the plot is of a large data and since the FRM cycle was segregated into different phases based on weeks, a plot that shows the progression of resilience over weeks could give a better clarity. Thus, a box plot was created to show the value of resilience over the weeks.

Figure 9.1. shows the box plot the value of resilience over 104 weeks (two years) and the enlarged version of this image is shown in Appendix F (Figure B) for more clarity.

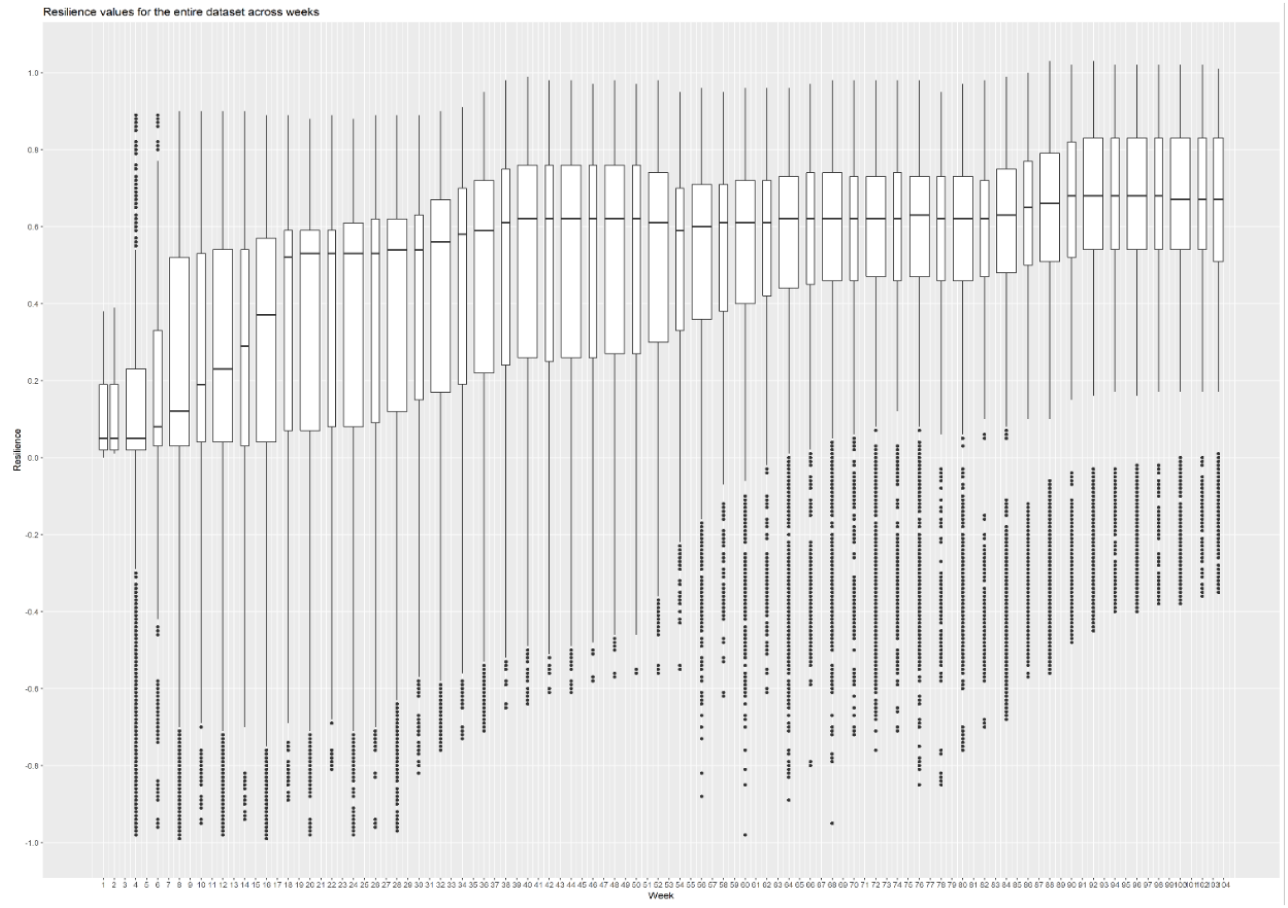


Figure 9.1. Progression of resilience value across two years (104 weeks)

In order to reduce the congestion, the data was grouped by every two weeks for the combined dataset (including datasets with Lever_power_DDMA = 2, Lever_power_DDMA = 3 and Lever_power_DDMA = 3). The immediate observation from the box plot was that the value of median for resilience increases until week 18 and from then the median appears to be more or less steady. A better interpretation with respect to the context is that the resilience of the system increases during the reflect phase and further until five weeks into the resist phase after which resilience values do not show sudden peaks. Most importantly, after the first cycle (after week 52) even with the beginning of a new FRM cycle, there are no sudden shifts in the values for median of resilience similar to the values in the beginning of the first year (first cycle).

9.2. POWER ALLOCATION

Based on the governance issue that highlighted the need for allocating more power/authority to the local body, this research has accommodated the power allocation aspect of decentralization in the ABM model that was developed. This section on power allocation is intended towards identifying discussion points about the power allocation aspect of the Kerala FRGA.

9.2.1 POWER ALLOCATION BASED ON DIFFERENT DIMENSIONS

As discussed in section 9.1.1. Based on the results on the existing FRGA, two of the best combinations are:

- "medium" social dimension, "medium" technical dimension, "low" environmental dimension and "low" economic dimension
- "high" social dimension, "medium" technical dimension, "low" environmental dimension and "low" economic dimension

Considering the above combinations, the power distributions associated with the combinations were determined. Table 9.2. shows the levers associated with the mentioned combinations and the description associated with the levers.

Table 9.2. Power allocation associated with the best combinations

Power_KC	Power_SDMA	Power_DDMA	Description
2	2	4	Highest power to District and lower equal power to State and Local
2	3	4	Highest power to District, second highest to State and lowest to Local
2	2	2	Equal power
3	2	4	Highest power to District, second highest to Local and lowet to State
4	2	3	Highest power to Local, second highest to District and lowest to State
4	3	3	Highest power to Local and lower equal power to State and District

From Table 9.2. the general idea that can be derived is that the better results for the dimensions are observed when there is higher power allocated to the District or Local authorities when compared to the State authority or when the authorities are given equal power.

9.2.2 POWER ALLOCATION BASED ON OVERALL RESILIENCE

The overall resilience was determined by aggregating the dimensions – social, technical environmental and economic. Top three power allocation options were identified based on the overall resilience value and the intention behind looking into the top three instead of the "best" power allocation option is in order create a discussion based on the power allocation options that can result in better overall resilience. Figure 9.2. gives the box plot for the top three policies and Figure 9.3. gives the progression of resilience over 104 weeks (two years) for the top three policies. Appendix F (Figures C and D) shows the enlarged version of Figure 9.2. and Figure 9.3. respectively.

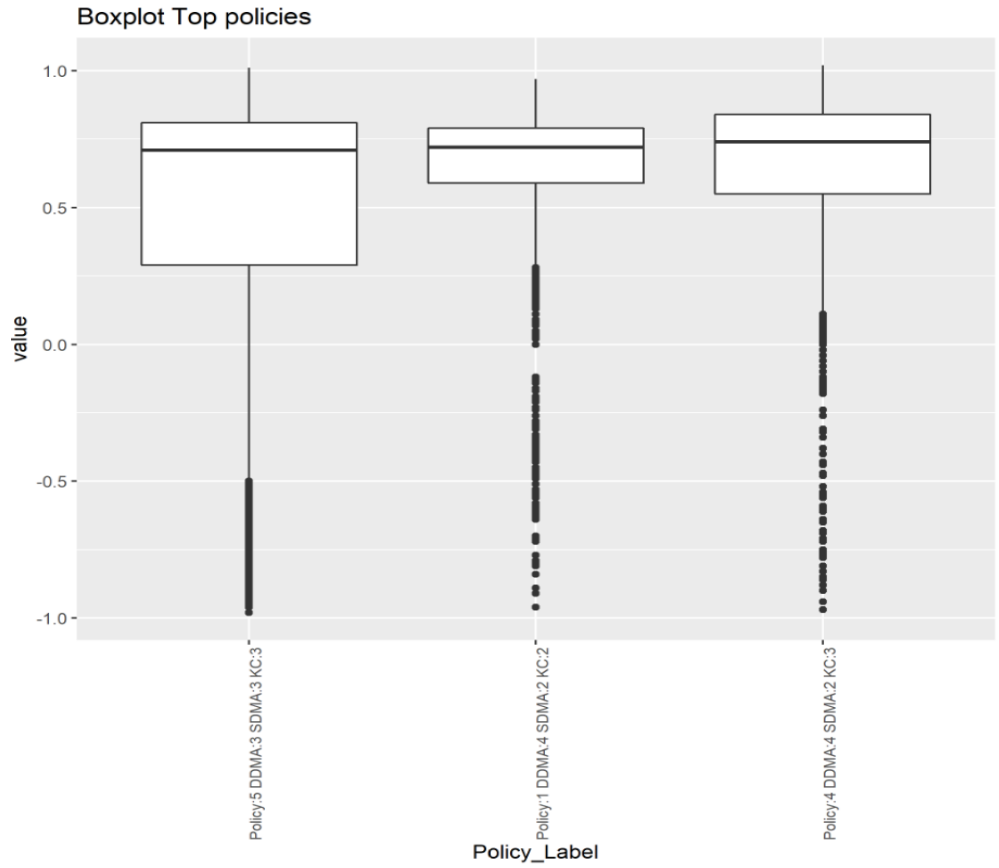


Figure 9.2. Top three policies

The top three policies for power distribution based on overall resilience are as follows:

- **Equal power to DDMA, SDMA and KC**
- **Higher power to DDMA and equal lower power to SDMA and KC**

- **Highest power to DDMA, second highest power to KC and lowest power to SDMA**

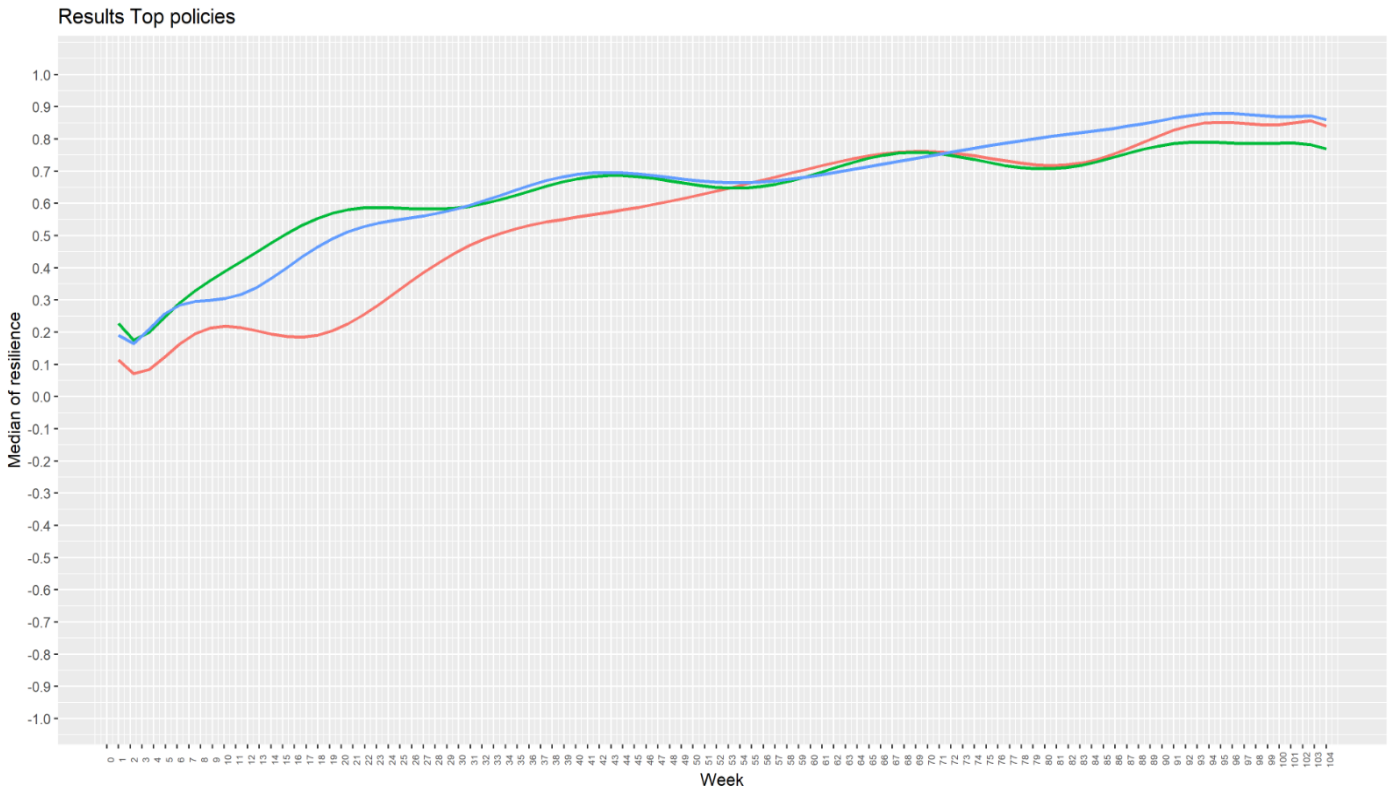


Figure 9.3. Progression of resilience over 104 weeks for the top three policies

In Figure 9.3. the progression of resilience over 104 weeks (two years) for the top three policies can be observed where:

- The plot in **Red** is the policy where **equal power is given to DDMA, SDMA and KC**
- The plot in **Green** is the policy where **higher power is given to DDMA while SDMA and KC has lower but equal power**
- The plot in **Blue** is the policy where **higher power is given to DDMA, second highest power to KC and lowest power to SDMA**

Here, it can be noticed that the plot in **Red** representing the policy which gives equal power to all the three authorities has a steeper slope than the other two policy options. Until the beginning of the response phase, it is the policy with higher power to DDMA and equal but lower to SDMA and KC that performs best in terms of resilience. However, from the beginning of the response phase until

the end of the first cycle it is the policy with highest power to DDMA, second highest power to KC and lowest power to SDMA that performs best in terms of resilience value.

From the beginning of the second year until the middle of the resist phase, the policy which gives equal power to DDMA, SDMA and KC performs the best in terms of resilience after which the policy which gives highest power to DDMA, second highest power to KC and lowest power to SDMA performs best until the end of the second cycle. Table 9.3. gives a summary of the power distribution aspect per FRM phase.

Table 9.3. The power distribution aspect per FRM phase

Phase	Power distribution
Until response phase of the first cycle	**higher power is given to DDMA while SDMA and KC has lower but equal power**
From response phase till the end of the first cycle	**higher power is given to DDMA, second highest power to KC and lowest power to SDMA**
From beginning of second cycle (second year) to the mid of resist phase	**equal power is given to DDMA, SDMA and KC**
From mid of resist phase to the end of the second cycle	**higher power is given to DDMA, second highest power to KC and lowest power to SDMA**

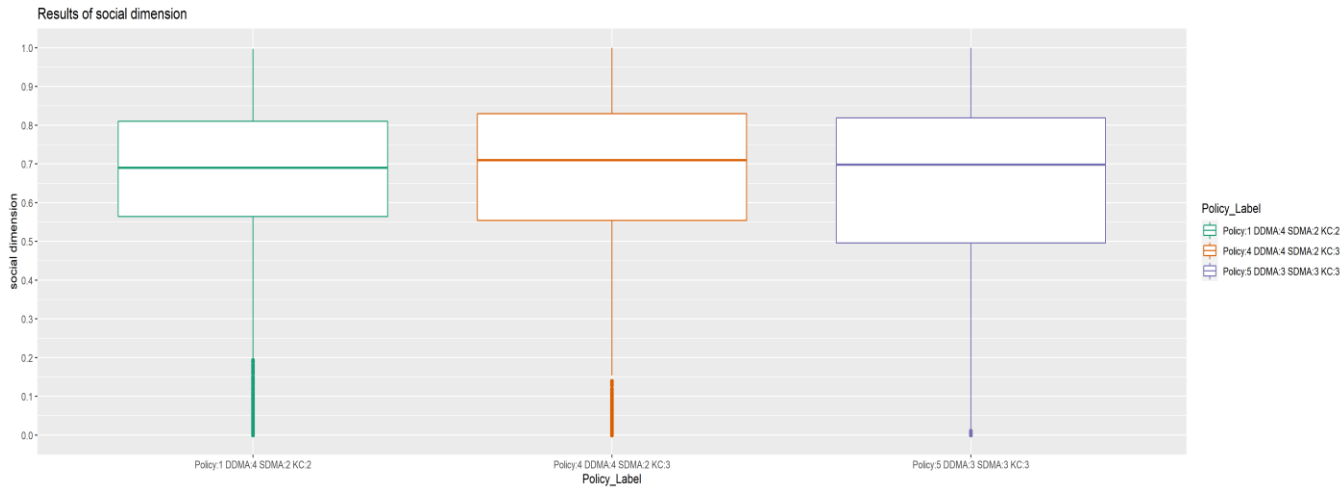
From above there are two main points to consider:

- **First key point** : from an overall perspective, if considering resilience to be the ability to absorb shocks and have the necessary mechanisms to not show severe fluctuations, the

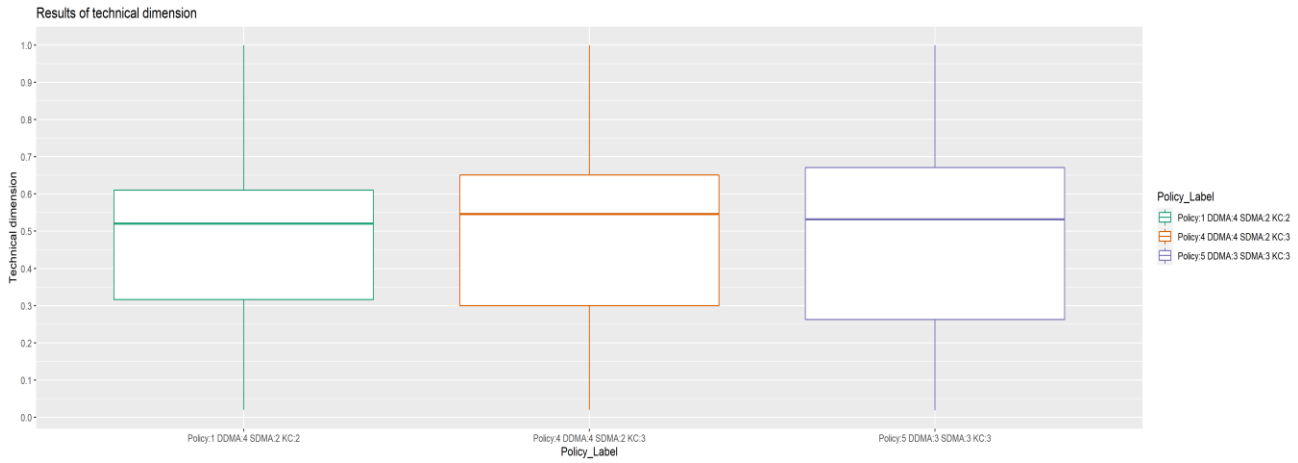
policy (highlighted in blue in figure 9.3.) which gives highest power to DDMA, second highest power to KC and lowest power to SDMA would be an ideal choice

- **Second key point** : unlike the previous perspective, if FRM is observed as process which involves distinct phases where each phase is observed separately, there is no one best power distribution but rather a combination of policies in terms of power distribution that must be adopted because the observations from the plots show that each phase has a different requirement in terms of power allocation and "policy switching" is required from one phase to another. Hence, "policy switching" is a term introduced in this research as the approach of switching power allocation options from one phase to another.

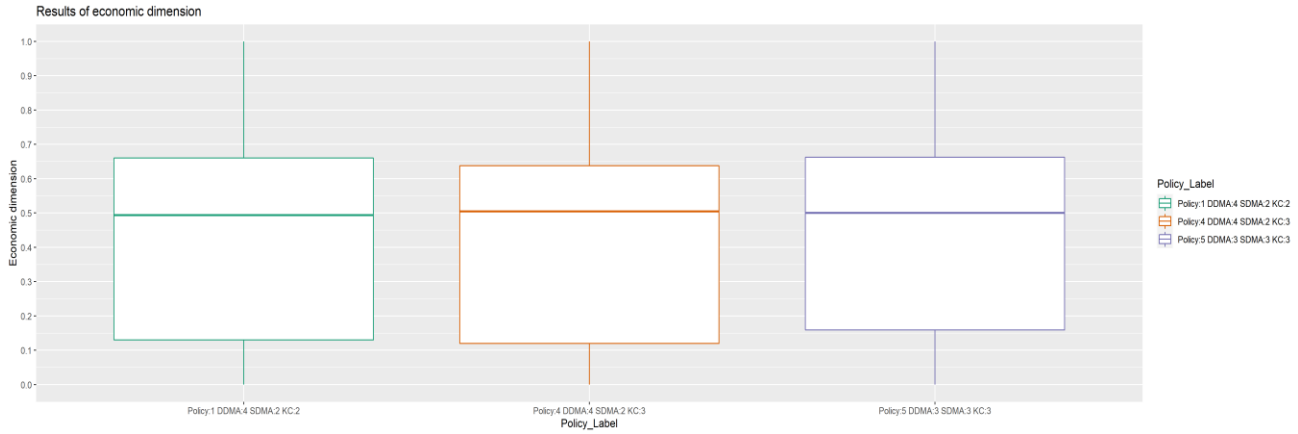
As the top three power allocation options were identified based on overall resilience, it is now important to see how each of these top three power allocation options performed in terms of the different individual dimensions.



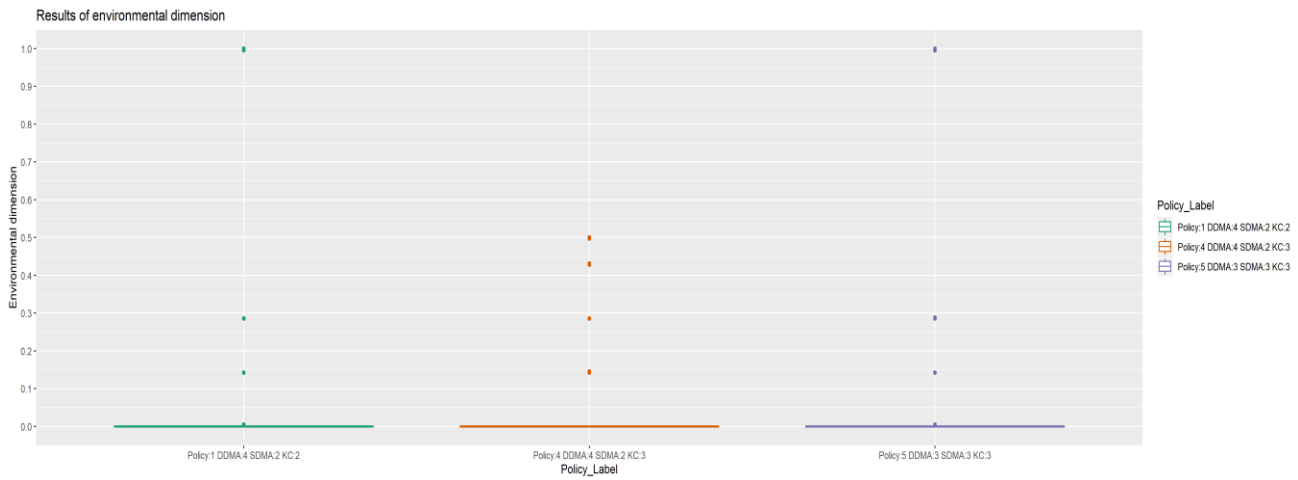
A) Social dimension



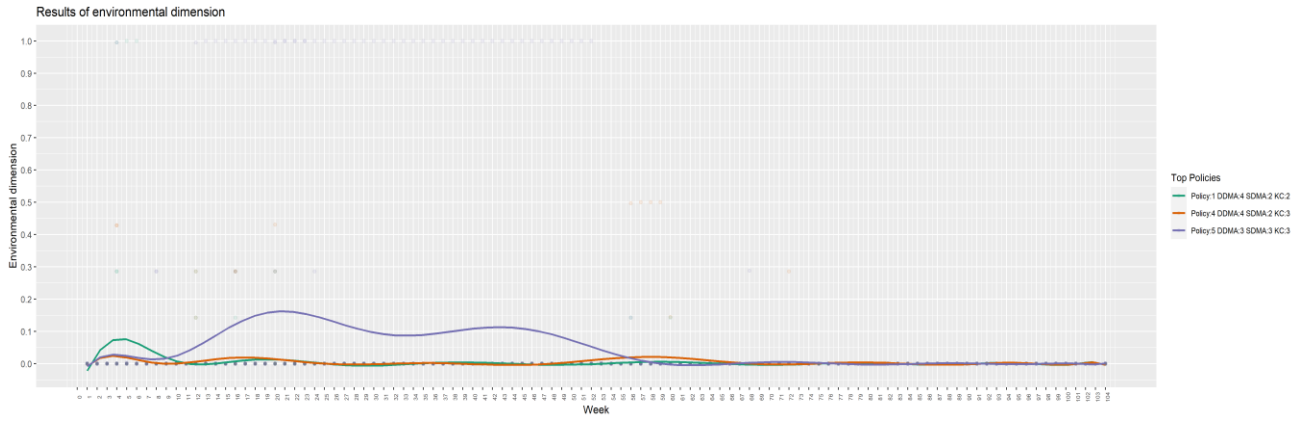
B) Technical dimension



C*) Economic dimension*



D) Environmental dimension (box plot)



E) Environmental dimension

Figure 9.4. A) Social dimension results of the top three power allocation options , B) Technical dimension results of the top three power allocation options, C) Economic dimension results of the top three power allocation options, D) Environmental dimension results of the top three power allocation options (box plots) and *E) Environmental dimension results of the top three power allocation options*

In all the box plots of Figure 9.4., on the left we have the box plot for the power allocation option which involves giving the highest power to the District authority, lower but equal power to State and Local Authorities. In the center we have the box plot for the power allocation option which involves giving the highest power to the District authority, second highest power to Local authority and lowest power to State authority. On the right we have the box plot for the power allocation option which involves giving equal power to the State, District and Local authorities.

Figure 9.4. A) shows the social dimension results of the top three power allocation options. The results reveal that for better results with respect to the social dimension, the power allocation option which gives highest power to the District authority, second highest power to Local authority and lowest power to State authority is preferred. Figure 9.4. B) shows the technical dimension results of the top three power allocation options. The results reveal that for better results with respect to the technical dimension, the power allocation option which gives highest power to the District authority, second highest power to Local authority and lowest power to State authority is preferred. Figure 9.4. C) shows the economic dimension results of the top three power allocation options. The results reveal that for better results with respect to the technical dimension, the power allocation option which gives highest power to the District authority, second highest power to Local authority and

lowest power to State authority is preferred. Figure 9.4. D and E shows the environmental dimension results of the top three power allocation options. Since the values in general are low, two different plots were made to get a better picture. The results reveal that for better results with respect to the technical dimension, the power allocation option which gives highest power to the District authority, second highest power to Local authority and lowest power to State authority is preferred

9.3. INFLUENCE OF THE NETWORK ENERGY

In order to analyze the impacts of initiative networks, the model considered the networks formed by local residents, NGOs and government authorities. The intention behind considering the narrative of networks were to analyze the aspect of the FRGA that deals with the governance issue which highlights the characteristic of MLG on the involvement of stakeholders from horizontal and vertical dimensions. In this section, based on the results obtained from the model, discussion points would be identified with regards to initiative networks. Figure 9.5. shows the visual representation of networks in the model.

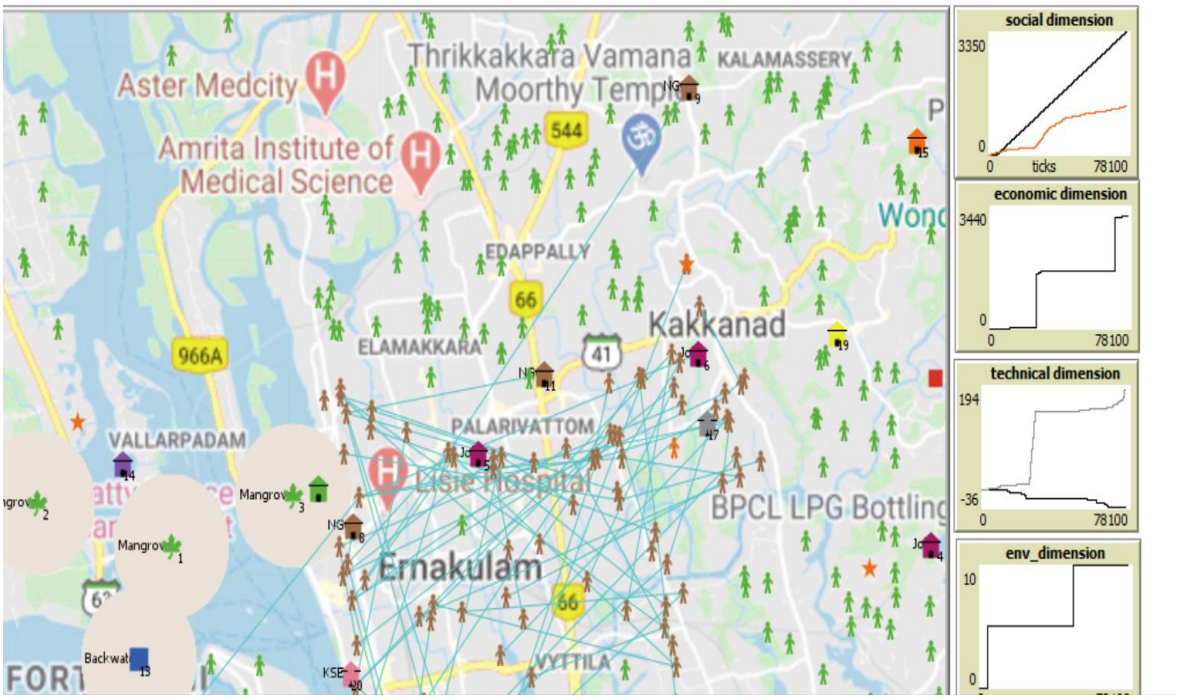


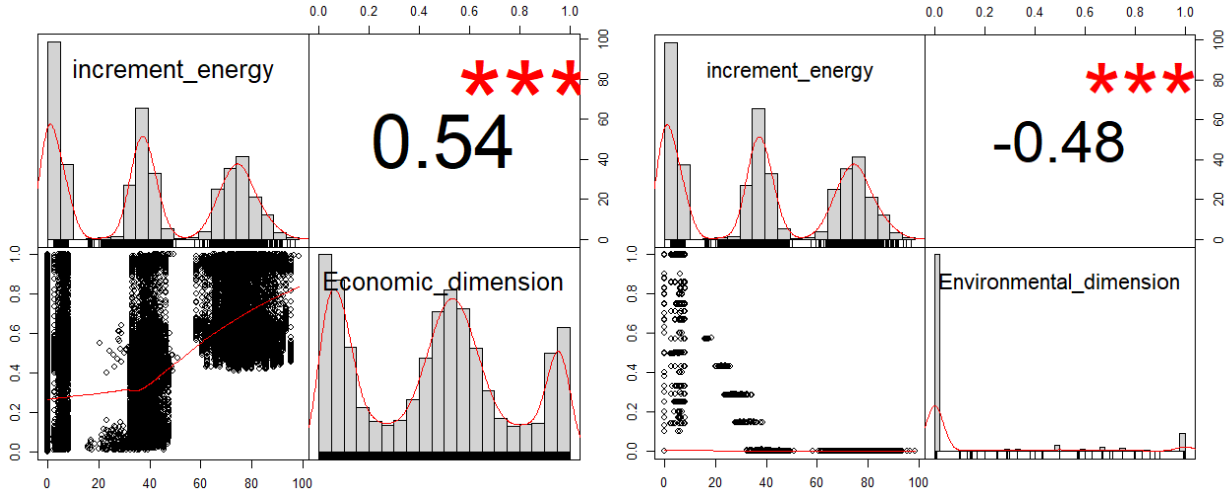
Figure 9.5. Visual representation of network formation in the ABM model

9.3.1 INFLUENCE OF NETWORK ENERGY ON DIFFERENT DIMENSIONS

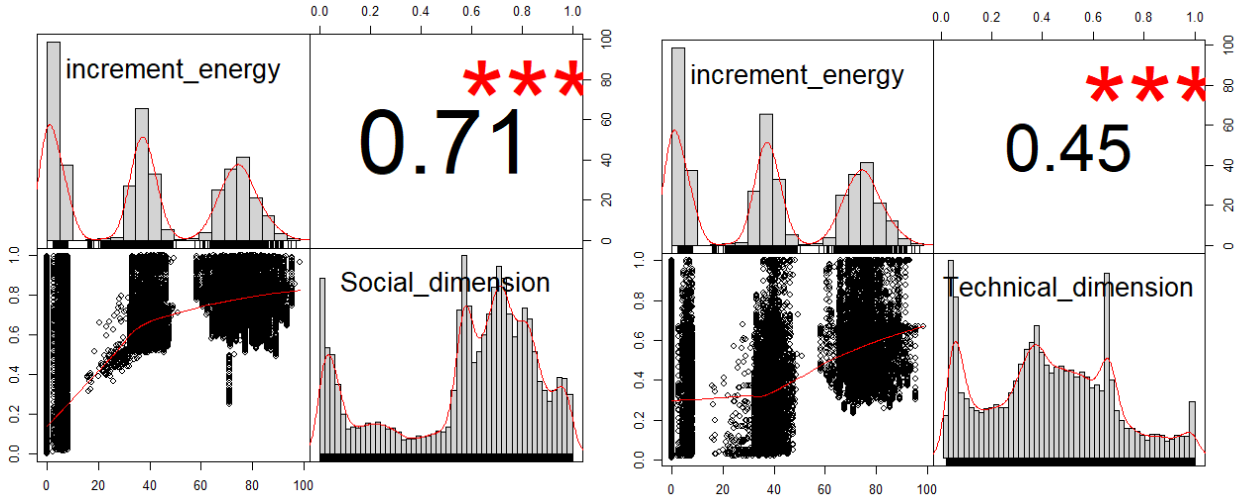
Primarily, network energy represents the welfare of the initiative network and this can include monetary or non-monetary resources. Table 9.4. and figure 9.6. gives the results of the correlation test carried out between network energy and the different dimensions. Based on the correlation results it can be observed that network energy has a positive impact on the social and technical dimensions while it has a negative impact on the economic dimension as it results in the increase in cost and it further has a negative impact on environmental damage which is the sub-indicator defining the environmental dimension. A positive change in the network energy has a tendency for a higher positive change in the social dimension followed by the economic and technical dimensions. The higher positive change in the social dimension can be justified by the fact that networks result in improving the social capacity of the people.

Table 9.4. Results for correlation tests between network energy and the different dimensions

Dimension	Correlation coeff.	95 % confidence		P-value
		Lower limit	Upper limit	
Economic	0.5435728	0.5352796	0.5517612	< 2.2e-16
Environmental	-0.4785432	-0.4875109	-0.4694745	< 2.2e-16
Social	0.7140739	0.7082932	0.7197588	< 2.2e-16
Technical	0.4476131	0.4382109	0.4569173	< 2.2e-16



A) B)



C) D)

Figure 9.6. A) Correlation between network energy and economic dimension, B) Correlation between network energy and environmental dimension, C) Correlation between network energy and social dimension and D) Correlation between network energy and technical dimension

9.3.2. INFLUENCE OF NETWORK ENERGY ON OVERALL RESILIENCE

The overall resilience was determined by aggregating the dimensions – social, technical environmental and economic. In order to understand the tendency of the overall resilience to change based on the network energy, a correlation test was carried out between the network energy and overall resilience. Table 9.5. and figure 9.7. shows the results of the correlation test between the network energy and overall resilience. From the correlation test results it can be observed that a positive change in the network energy has the tendency to change the overall resilience in high positive direction.

Table 9.5. Results for correlation tests between network energy and overall resilience

	Correlation coeff.	95 % confidence		P-value
		Lower limit	Upper limit	
Overall resilience	0.7263028	0.7207291	0.7317827	< 2.2e-16

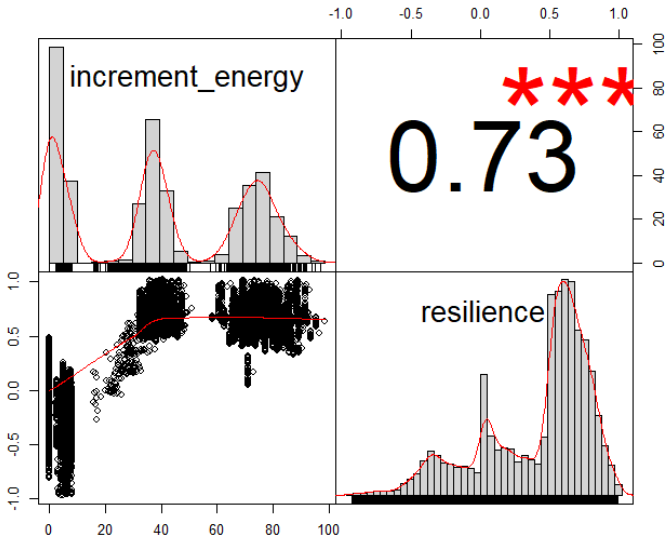


Figure 9.7. Correlation between network energy and overall resilience (aggregate of the dimensions)

9.4. OPPORTUNISTIC BEHAVIOUR OF AGENTS

In terms of the governance issue pertaining to opportunistic behaviour, the development of the conceptual model helped with identifying the opportunistic behaviour of the authorities involved in the FRM and therefore this specific element was incorporated in the ABM model that was developed. This specific element has been modelled to have a negative influence on certain events within the FRM, hence, it might be insightful to analyze the change in the overall resilience based on the opportunistic behaviour.

9.4.1. INFLUENCE OF NETWORK ENERGY AND OPPORTUNISTIC BEHAVIOUR OF AGENTS

Table 9.6. shows the regression results considering resilience to be the dependent variable while opportunistic behaviour and energy from networks to be independent variables. Opportunistic behaviour in the model is mainly represented by the decisions made by agents which can bring about a negative impact on some of the events within the FRM. Some of the agents representing were given the choice between carrying out their responsibilities and carrying out opportunistic behaviour. A regression was carried out to gain some insight on the influence of network energy and opportunistic behaviour of agents. Based on the regression results it can be inferred that the network

energy has a positive influence on overall resilience value and opportunistic behaviour has a negative influence on overall resilience value.

Table 9.6. Regression results

	Estimate	Std.Error	2.5 %	97.5%	Signif.codes
(Intercept)	0.1992055	0.0059006	0.18763548	0.210774582	***
Opportunistic	-0.0067867	0.0005395	-0.00784461	-0.005728846	***
Network energy	0.0081516	0.0001948	0.00776961	0.008533488	***
Multiple R-squared	0.4779				
Adjusted R-squared	0.4775				

10. DISCUSSION

The objective behind this section is to discuss the results, form a structured dialogue with respect to the Kerala flood risk management , align the overall insights gathered throughout the research and discuss the conclusions.

This research began with identifying the need for a transition from a response centric approach to a resilient FRM approach in Kerala. It was further identified that MLG helps with achieving resilient flood risk management. However, even though Kochi has a MLG structure, the 2018 floods and its consequent impacts on the life and property of people highlighted the importance of dealing with the institutional complexity that persists within the Kerala FRM. So, the research first identified the governance issues pertaining to Kerala FRM and then linked these issues to certain characteristics of MLG so that it gives a better understanding on the characteristics of MLG that the existing governance structure are struggling with. Furthermore, the existing governance structure was modelled giving emphasis on the narratives relevant for the MLG characteristics associated to the governance issues and the impacts of this governance setting on the resilience FRM was studied.

The research dealt with answering the main research question : “what are the impacts of MLG characteristics on achieving resilient flood risk management ?” . MLG has several characteristics that distinguishes itself but as the research gap indicates, there has not been a study taking a data-driven modelling approach which bridges the gap between the existing governance issues, MLG characteristics and resilient FRM, and hence this research focuses on the characteristics of MLG that are most relevant to the governance issues discussed. The main research question was tackled with the help of five sub-questions. From here on , in this chapter the answers obtained for each of the sub questions would be discussed in brief so that the flow of the information obtained while answering the questions are clearer.

Sub question 1: “ How can resilience be incorporated and evaluated within the Flood Risk Management context? “

This sub-question was answered through literature research or desktop research. Previous studies pertaining to resilient FRM were looked into and improvised based on interpretation and the

requirement of the study. The research thus considered the resilient FRM to include 4 phases : reflect, resist, response and recovery where reflect phase implied the implementation of activities that contributed to learning from experiences, resist phase implied the implementation of activities that would mitigate flood risk, response phase implied executing the crisis management measures and recovery phase implied executing activities that would help with restoring the community.

As the location of interest was decided to be the urban agglomeration of Kochi, the research was oriented towards identifying indicators that would help with evaluating resilient FRM in an urban agglomeration. The research thus considered five dimensions or indicators that could help with evaluating the resilient FRM. The five dimensions or indicators were : social dimension, technical dimension, economic dimension, environmental dimension and institutional dimension.

FRM as discussed previously as the planning and management of flood risk. The planning and management are carried out through various activities during the different phases of FRM. The research involved identifying some of those activities within the different phases of FRM in Kerala and studying the impacts of these narratives (from a governance perspective) on the five dimensions for evaluating the resilient FRM.

Sub question 2: " Which multi-level governance characteristics are relevant for resilient flood risk management?"

This question was answered through literature research and analysis of published reports. First, the general characteristics of MLG were identified and then the governance issues on Kerala flood were identified from reports . Then, the identified governance issues were associated with relevant characteristics of MLG based on the interpretation of the governance issues.

Identifying the governance issues helped with providing an understanding on the narratives that must be focused when looking at the impacts on resilience. Furthermore, identifying the MLG characteristics relevant for the governance issues helped with scoping down the research.

Sub question 3: " What are the existing Flood Risk Governance Arrangements (FRGA) in Kerala?"

This question was answered through desktop research where the resources were collected from formal documents (Examples: documents on the disaster management act, coastal zone management norms and documents on land utilization act), newspaper articles and published reports. The data collected from the various sources were used to develop the conceptual model in MAIA. The conceptual model further contributed to answering the next sub-question.

Sub question 4: "How can the Flood Risk Governance Arrangements (FRGA) be modelled?"

As mentioned previously, the Kerala FRM involves several narratives and the conceptual model helped with breaking down the complex system into simpler parts. This helped with having a much better perspective on what is actually happening in the system and how this system can be modelled.

Sub question 5: "What are the impacts of multi-level governance characteristics on resilient flood risk management?"

By impacts of MLG on resilient FRM, the intention was to look into how the existing FRGA (focusing on the narratives relevant to the governance issues) in Kerala can affect the resilience of FRM. The institutional dimension, due to its qualitative nature, was analyzed qualitatively with the help of a conceptual model and was incorporated in the ABM model. The remaining four dimensions of resilience - social dimension, economic dimension, environmental dimension, and technical dimension were analyzed quantitatively.

10.1. INSTITUTIONAL ASPECT OF RESILIENCE

Appendix C summarizes the rules, norms and shared strategies pertaining to Kerala FRM based on formal Disaster Management documents, reports and newspaper articles. Furthermore, there are land use regulations and coastal management norms that influence the system and these are discussed in Section 6.3. as they are relevant to the environmental dimension.

In the preliminary analysis, the formal and informal institutions give the impression that during the phases prior flooding, the NDMA is more of the overarching body that is involved in decision-making by contributing to laying down policies, monitoring the implementation of the policies, providing technical and financial assistance to the SDMA when required. During flood, NDMA supports the

relief operations and After flood, assists with the preparation of the Post Disaster Management Assessment. When it comes to implementation of the Disaster Management Act during the phases prior to flooding, the SDMA, DDMA, and KMC are given majority of the responsibilities out of which based on the report of Singh et al. (2018) and the interview discussed in section 5.4., the SDMA has the highest authority followed by DDMA and KC. **This indicates that there is a certain level of hierarchy.**

From the formal institutions identified, there are **overlapping responsibilities** that can be observed. For example, SDMA, DDMA and KMC are given the responsibility to ensure that constructions comply with standards and these authorities are further responsible for carrying out vulnerability mapping among the local communities. In case of such overlapping responsibilities there is no much clarity on how to decide who would have the authority. This lack of clarity on the responsibilities were further confirmed by the interview discussed in section 5.4.

When comparing the governance issues discussed in section 1.1.5. with the institutions from Appendix C it shows that even with sanctions in the rules, certain responsibilities are not being carried out. The difference between the "ideal" situation (the result of agents carrying out responsibilities) and the "real" situation (failure of agents to carry out responsibilities) highlights the importance of monitoring the implementation of formal institutions.

When evaluating from a MLG perspective, even though the formal policies pertaining to FRM lack certain clarity (for example in the case of overlapping responsibilities), these policies show the intention to portray the importance of a MLG structure for FRM. For example, the policies implicitly highlight the importance of including stakeholders from both horizontal and vertical dimensions, the policies attempt to reduce opportunistic behaviour by incorporating sanctions in the institutional statements, elaborating on the roles and responsibilities of stakeholders, clarifying how they must mutually adjust in order to deliver the required results, and the policies further emphasize on activities like vulnerability mapping which would enable to track community knowledge. However, the interview with the policy researcher highlights that **the current system does not capture such knowledge from local communities**. This brings us back to what was mentioned in the work of Chattopadhyay & Harilal (2017) about the failure of policies at the implementation stage. The failure of policies during the implementation stage was further highlighted in the interview with the policy

researcher. Thus, there are policies that represent MLG structure but these policies when put into action do not give the impact it is intended to give. Even though there are formal policies aimed towards guiding the system to an effective FRM setup, there are these implicit narratives or aspects - narrative on the environmental damage, narrative on the profit minded behaviour of authorities during dam management, the corruption or skill set aspects etc. that continue to persist. From a scientific perspective, **the different narratives re-emphasize on the importance of institutions in human-flood interactions** because it shows that managing a disaster risk is not as straightforward as writing down policies to follow but rather requires constant monitoring of the implementation of these policies and the narratives that might exist or emerge as a result of social complexity.

Both formal and informal institutions - rules, norms and shared strategies were analyzed during the development of the conceptual model. Flood is not merely a "water" problem but rather a situation that requires a multi-disciplinary approach which discusses both human sub-system and flood sub-system. Social system is already a complex system and hence a Complex Adaptive System (CAS) perspective is taken to deal with human-flood interactions in the Kerala floods case. The institutional dimension was key as it has already been emphasized that institutions have a major role to play when it comes to play when it comes to human-flood interactions.

Conclusion 1: Policies become ineffective during the implementation stage and hence the implementation of policies must be monitored.

Conclusion 2: There is a lack of clarity on who must take the responsibility and hence the current system must consider ensuring that clarity on responsibilities exist.

10.2. DISCUSSION OF THE RESULTS FROM ABM

Primarily, the ABM model investigated four dimensions or indicators that could evaluate resilience - social dimension, economic dimension, environmental dimension and technical dimension. Institutions were incorporated in the model as a part of the human-flood interactions that were to be modelled. The research of Batica et al. (2018) did not discuss how these dimensions or indicators for measuring resilience must be aggregated in order to have a complete picture of the. Hence, this research considered resilience to be the aggregated value of the four dimensions so that there is one

specific value that can be discussed. After obtaining the results from the model, attention was given to three main issues of the existing MLG structure in Kerala FRM - opportunistic behaviour of government authorities, the social welfare network aspect and the power allocation aspect of decentralization. As mentioned, these characteristics were decided based on the existing governance issues.

Even though opportunistic behaviour was pointed out as a governance issue in the literature research, during the development of the conceptual model, narratives on this opportunistic behaviour displayed by government authorities began to get clearer. These narratives were then used in the ABM model to give a complete picture of the situation with the governance arrangements involved in the Kerala FRM. In addition to the opportunistic behaviour, the conceptual model helped with creating a narrative for the involvement of stakeholders in social welfare initiatives in the form of a network. Thus, this narrative was also incorporated in the ABM model. Figure 9.1. shows that in the first cycle (first year), resilience of the system increases during the reflect phase and further until five weeks into the resist phase after which resilience values do not have sudden peaks (when observing the median). Most importantly, after the first cycle (after week 52) even with the beginning of a new FRM cycle, there is no drastic increase or decrease in the values for median of resilience unlike in the beginning of the first year (first cycle). A regression was carried out to get a better idea on the influence of opportunistic behaviour and energy from networks.

With regards to the discussion on the power allocation aspect of decentralization. It is important to notice here that by authority or power distribution, the research is mainly talking about the involvement or influence of a specific authority. In order to create a discussion with respect to power distribution, there were two perspectives adopted:

Perspective 1 - Based on definition of resilience : If resilience is the ability of a system to absorb shocks and have the necessary mechanisms to not show severe fluctuations, the policy on power distribution which gives highest power to DDMA, second highest power to KC and lowest power to SDMA would be an ideal choice as this policy option results in less fluctuations. This gives rise to the next conclusion.

Conclusion 3a: When considering the definition of resilience to be the ability of system to absorb shocks and show the least fluctuations, Kerala FRM requires a power distribution set up where the District authority has the highest power followed by the Local authority and State authority.

Perspective 2 – resilient FRM cycle involves distinct phases : If each of the phases within the resilient FRM cycle are to be dealt with as distinct phases, there is a need for "policy switching" which is a term used in this research to explain that FRM requires not one best policy in terms of power distribution but requires different combination of policies during different phases to ensure that the results are better.

Conclusion 3b: When considering resilient FRM cycle to involve distinct phases, there is a need for "policy switching" , the approach which acknowledges that in order to achieve better results there is no one best power allocation policy that can considered but rather requires different combinations of power allocation policies for different phases.

The results with respect to the power allocation policies support the claim made by Singh et al. (2018) and the policy researcher on the involvement of the District and Local authorities. It can be observed that the options highlight that the District and Local authorities must be equally involved or even more involved than the State authority in the decision-making process. This gives rise to the next conclusion or rather a confirmation of the analysis made in the report of Singh et al. (2018) and the policy researcher.

Conclusion 3c: The District and Local authorities must be equally or more involved than the State authority when it comes to the decision-making in the resilient FRM cycle.

10.3. POLICY RECOMMENDATIONS

Based on the discussion and conclusions, the research gives the following policy recommendations:

- When comparing the formal disaster management policies to the impact of Kerala floods on the affected communities, there is a gap between the "ideal" situation and the "real" situation. This triggers the need to discuss the analysis of Chattopadhyay & Harilal (2017) on

the failure of policies at the implementation stage. Thus, a structure needs to be set up to ensure that the implementation stage of the policies is monitored closely.

- There is a lack of clarity on the assignment of responsibilities among decision-makers and hence the current system must accommodate and acknowledge the need for a better clarity on responsibilities.
- The research has made three conclusions regarding power allocation in decentralization. These conclusions were made based on three different perspectives – 1) based on definition of resilience, 2) based on the idea that the resilient FRM cycle involves unique phases and 3) based on a general perspective about power allocation. The research considers the understanding that these different perspectives give rise to different discussion points:
    - When considering the definition of resilience to be the ability of system to absorb shocks and show the least fluctuations, the recommendation is to ensure a power distribution set up where the District authority has the highest power followed by the Local authority and State authority
    - When considering resilient FRM cycle to involve distinct phases, the recommendation is to adopt "policy switching" which is defined in the research as the approach of considering a combination of policies in terms of power distribution such that the requirement of each phase is addressed.
    - In general, the recommendation is that the District and Local authorities must be more involved in the decision-making within resilient FRM cycle.

11. CONCLUSION

This chapter is aimed towards discussing some final remarks on the research

11.1. CONCLUSION OF THE RESEARCH

Flooding is not merely a "water" problem but a situation which requires a multi-disciplinary approach due to the involvement of the human sub-system and flood sub-system. Social system is primarily complex in nature due to the interaction between individuals who have a personal agenda or a personal set of strategies to achieve a personal goal. When looking at human-flood interactions, the most effective way would be to adopt a Complex Adaptive Systems (CAS) perspective and to dive deep into the influence of institutions within such a system especially because these institutions contribute to explaining the behaviour of the stakeholders involved.

When discussing about achieving a long-term goal like resilient FRM, the mentioned human-flood interactions could be a deciding factor which would determine "when" this goal can be achieved. Even though the motivation behind making the attempt to set up an MLG structure is due to studies or experiences indicating that such a governance structure is required for achieving resilient FRM, the progress of such a governance structure must be monitored. It is important to see how this existing structure is when compared to the ideal structure and what kind of impact this existing governance structure can have on the long-term goal of achieving resilient FRM.

The research was done because of personal interest to contribute in the studies associated with achieving resilient FRM in Kerala, where I was born and due to my personal connections with many individuals and families who have been affected with the disaster in 2018. This research, has made two major contributions:

Even though previous studies have highlighted the importance of MLG in flood resilience or flood risk reduction, this research offers a **scientific contribution** by adding an additional layer to the existing studies by looking into the impacts of existing MLG arrangements on resilient FRM by taking a data-driven modelling perspective (focusing on discussions pertaining to the governance issues). In

addition, with respect to Kerala, this research takes an empirical and data-driven modelling perspective to study the FRGA.

In terms of **societal contribution**, I personally see this research as a way to communicate to the policy makers that there exist governance issues in Kerala FRM and when discussing the long-term goal of achieving resilient FRM, it is not enough to just identify that MLG is required to achieve the goal. It is important to see how the existing MLG structure would affect resilient FRM. This research is focused on Kerala floods but from a general perspective, when it comes to setting a long-term goal like resilient FRM even though there is literature to justify that MLG supports the provision of resilient FRM, studying the impacts of the existing MLG structure on achieving resilient FRM can give a better perspective on this long-term goal. With respect to the Kerala FRM, the case study of interest, results revealed that the that the existing power distribution among the State, District and Local authorities must be changed to ensure a better resilient FRM system. Furthermore, the results revealed that the network formation among local communities, non-governmental organizations (NGOs) must be encouraged.

11 .2. LIMITATIONS

The following are the limitations of the research:

- Due to the large number of stakeholders involved in the case, for the simplicity of the research the stakeholders were clustered and simplified. Even though this helped with the simplification of the research, when studying a complex system like the one discussed, this approach may not capture the entire social complexity
- The model assumes that one resilient FRM cycle takes one year but realistically it could be longer, incorporating this aspect of time may contribute to yielding more realistic results
- Even though institutions were used to model the behaviour of the agents, the institutional dimension was evaluated qualitatively and was not included when determining the overall resilience score from the model simulation data.
- Indicators such as the environmental dimension may have more sub-indicators that can define the indicator. i.e. it may not be just environmental damage that defines environmental

dimension of resilience, it could include for example, the amount of forest that can reduce the impact of the disaster. This research only considers one sub-indicator (environmental damage) for environmental dimension for the purpose of simplicity but to get a realistic measure more sub-indicators can be included.

11.3. FUTURE WORK

The future work can involve considering more or all the sub-indicators that can possibly define the dimensions - social, economic, environmental, technical, and institutional. The work can involve field work to gather data from the affected people and the decision makers. An interactive board game can be developed so that the case is more understandable for the decision-makers. This research made use of different dimensions to evaluate resilient FRM, however, to get realistic results it can be important to consider the weightages of these dimensions. Therefore, as a future work, the weightages for the different dimensions can be determined based on the case of interest.

APPENDIX

A. TABLE BRIEFING THE INITIAL SET OF STAKEHOLDERS AND THEIR RESPECTIVE ROLES

Stakeholder	Role
National Disaster Management Authority (NDMA)	Responsible for laying down Disaster Management policies in order to make sure that efficient response is provided to disasters (National Disaster Management Authority, n.d.)
State Disaster Management Authority (SDMA)	Top most authority in decision-making pertaining to Disaster Management and responsible for implementing and monitoring all the activities (Government of Kerala, n.d.)
District Disaster Management Authority (DDMA)	Responsible for implementing measures at the District level by complying to the guidelines given by the National and State authorities (Government of Kerala, n.d.)
Kochi Municipal Corporation (KC)	Responsible for ensuring the compliance to Disaster Management measures under the supervision of DDMA (Government of Kerala, n.d.)

Ministry of Environment and Forest Affairs (MoEFA)	Responsible for ensuring the implementation of policies pertaining to environment and forestry (Ministry of Environment, Forest and Climate Change, n.d.). Mentioned in the study as this authority is relevant for the governance issue on privatization of ecologically sensitive areas.
Central Water Commission (CWC)	Provides advice to the State government on flood control (Central Water Commission, n.d.)
Kerala Coastal Zone Management Authority (KCZMA)	Responsible for monitoring and regulating the activities within the Coastal regulation Zone (CRZ) (Kerala Coastal Zone Management Authority, n.d.)
Greater Cochin Development Authority (GCDA)	Responsible for making developmental decisions in the metropolitan area of Kochi (Greater Cochin Development Authority, 2020)
Private Building Contractors Association (PBCA)	Supporting sand mining with the claim that this activity helps with reducing the frequency of floods (Times of India, 2019)
India Meteorological Department (IMD)	Responsible for sharing forecast information(Government of Kerala, n.d.)
Kerala State Electricity Board (KSEB)	Responsible for dam management and

	hydro electric power generation (The Hindu, 2020)
Non- Governmental Organizations (NGOs)	This stakeholder was included due to the governance issue mentioned in (Singh et al., 2018) regarding the ignorance of NGOs and social welfare institutions
Local communities	Communities affected by floods
Ecologists	Considering the ecologists involved in the preparation of the Gadgil report

B. COLLECTIVE STRUCTURE OF MAIA CONCEPTUAL MODEL

Agent	Property	Behaviour
National Disaster Management Authority(NDMA)	Assumed to have enough skill set and is not corrupt	● Monitor, support and contribute to disaster management at National level (Government of Kerala, n.d.) ● Involve in the decision-making (Government of Kerala, n.d.)
State Disaster Management Authority(SDMA)	● Power ● Skillset ● Corrupt (Boolean Property)	● Monitor, support and contribute to disaster management at State level (Government of

		Kerala, n.d.) ● Involve in the decision-making (Government of Kerala, n.d.) ● Can potentially display opportunistic behaviour (The Hindu, 2020)
Kerala State Electricity Board (KSEB)	● Skillset ● Profit minded (Boolean property)	● Coordinate with the authorities to support disaster management through dam management (Basak et al., 2018) ● Can be profit minded and choose to retain water in the dams for a longer period of time (The Hindu, 2020)
District Disaster Management Authority (DDMA)	● Power ● Skillset ● Corrupt (Boolean Property)	● Monitor, support and contribute to disaster management at District level(Government of Kerala, n.d.) ● Involve in the decision-making (Government of Kerala, n.d.) ● Can potentially display

		opportunistic behaviour (The Hindu, 2020)
Kochi Municipal Corporation (KMC)	● Power ● Budget ● Skillset ● Corrupt (Boolean Property)	● Monitor, support and contribute to disaster management at Local level (Government of Kerala, n.d.) ● Involve in the decision-making(Government of Kerala, n.d.) ● Can potentially display opportunistic behaviour (The Hindu, 2020)
Non-Governmental Organizations (NGOs)	● urge to join community initiatives (Assuming that NGOs would join the initiative only when their values can be related to the values of the initiative)	● Support local initiatives whose values are similar to that of the NGO ● Can aid decision-making by supporting the concerns of local initiatives and addressing them. This part of the narrative is added to demonstrate the involvement of NGOs in the network as pointed out by Singh et al. (2018)

Local communities	● Occupation (Fisherman or not) The occupation aspect of the local communities were considered because in section 7.1. with regards to the narrative on environmental damage, there are norms with respect to CRZ (Coastal Regulation Zone) and when there are unauthorized constructions in that location, the backwater fishing locations can be affected which is a livelihood for fishermen.	● Cooperate with authorities and contribute to disaster management by sharing perspectives ● Create or join initiatives when events threaten the livelihood

C. SUMMARY OF THE INSTITUTIONS

Id	**A**ttributes	**D**eontic	a**I**m	**C**ondition	**O**r else
R1	NDMA	must	lay down policies for disaster management at National level	if following the Disaster Management Act	or else would be imprisoned or fined
R2	NDMA	may	approve plans prepared by departments of GoI	if plans are in accordance with the National plan	or else would be imprisoned or fined
R3	NDMA	may	lay down guidelines for ministries to integrate prevention or mitigation measures	if there are development plans and projects	or else would be imprisoned or fined
R4	NDMA	may	recommend provision of funds	if following the Disaster	or else would be imprisoned

				Management act	or fined
R5	NDMA	may	constitute advisory committee or sub-committees for efficient discharge of functions	if recommendations are required for disaster management	or else would be imprisoned or fined
R6	NDMA	may	provide technical assistance to State authorities	if preparing State disaster management plan	or else would be imprisoned or fined
R7	NDMA	may	promote education and awareness	if individuals lack knowledge and awareness about disaster management	or else would be imprisoned or fined
R8	SDMA	must	lay down policies for disaster management at State level	if following the Disaster Management Act	or else would be imprisoned or fined
R9	SDMA	may	approve plans prepared by departments of State government	if plans are in accordance with the National plan	or else would be imprisoned or fined
R10	SDMA	may	lay down guidelines for ministries to integrate prevention or mitigation	if there are development plans or guidelines	or else would be imprisoned or fined
R11	SDMA	may	recommend provision of funds	if following the Disaster Management act	or else would be imprisoned or fined
R12	SDMA	may	constitute advisory committee or sub-committees for efficient discharge of functions	if recommendations are required for disaster management	or else would be imprisoned or fined
R13	SDMA	may	provide technical assistance to District authorities	if preparing District disaster management plan	or else would be imprisoned or fined
R14	SDMA	may	examine vulnerability of	if in the	or else would

			different part in the State	preparedness or mitigation phases	be imprisoned or fined
R15	SDMA	may	provide general education, awareness and community training	if individuals lack knowledge and awareness about disaster management	or else would be imprisoned or fined
R16	SDMA	may	direct District or Local authorities to comply standards for constructions	if the constructions increases the vulnerability of communities towards flood	or else would be imprisoned or fined
R17	SDMA	may	ensure that the communication systems are in order and disaster management drills are carried out	if in the preparedness or mitigation phases of disaster management	or else would be imprisoned or fined
R18	DDMA	must	plan, coordinate and implement policies for disaster management in accordance with National and State plan	if following Disaster Management Act	or else would be imprisoned or fined
R20	DDMA	may	ensure vulnerable areas in the District are identified	if in the preparedness or mitigation phases of disaster management	or else would be imprisoned or fined
R21	DDMA	may	constitute advisory committee with experts of disaster management	if efficient discharge of functions are required	or else would be imprisoned or punished
R22	DDMA	may	provide directions to other authorities at District and local level	if in the preparedness or mitigation phases	or else would be imprisoned or fined
R23	DDMA	may	review the state of	if in the	or else would

			capabilities for responding to disaster & give directions for upgradation	preparedness or mitigation phases	be imprisoned or fined
R24	DDMA	may	organize specialized training programmes for officers and rescue workers	if in the preparedness or mitigation phases	or else would be imprisoned or fined
R24	DDMA	may	maintain and review EWS and dissemination of proper information to the public	if in the preparedness or mitigation phases	or else would be imprisoned or fined
R25	DDMA	may	direct authorities to comply standards for construction	if the constructions increases the vulnerability of communities towards flood	or else would be imprisoned or fined
R26	DDMA	may	identify buildings that can be used as relief centers	if in the preparedness or mitigation phases	or else would be imprisoned or fined
R27	DDMA	may	Encourage involvement of NGOs and social welfare institutions	if in the preparedness or mitigation phases	or else would be imprisoned or fined
R28	DDMA	may	Ensure that the disaster management drills are carried out	if in the preparedness or mitigation phases	or else would be imprisoned or fined
R29	KC	must	ensure that the officers and employees are trained for disaster management	if in the preparedness or mitigation phase	or else would be imprisoned or punished
R30	KC	must	ensure that the constructions comply to standards laid by	if the constructions increases the vulnerability of	or else would be imprisoned or punished

			National, State and District authorities	communities towards flood	
R31	KC	must	maintain resources pertaining to disaster management	if in the preparedness or mitigation phase	or else would be imprisoned or punished

Attributes	**D**eontic	a**I**m	**C**ondition
SDMA	may	encourage and coordinate with NGOs and social welfare institutions	if the initiatives can contribute to improving the FRM
KC	must	regulate land-use and construction	if in the development phase
KC	may	take any additional measure for disaster management	if required
KC	must	safeguard interests of the weaker sections of the society	if making development decisions
KSEB	must	ensure proper dam management	if in the monsoon period (response phase of FRM)

Attributes	a**I**m	**C**ondition
KSEB	focusses on the profit from maximizing the hydroelectric power generated	if in the monsoon period
Kerala Private Building Corporators Association (KPBCA)	support government initiatives	if the initiatives are aimed towards development

D. MODEL PARAMETERIZATION

NAME IN THE MODEL	NATURE	DESCRIPTION
Yearnow Weeknow Daynow Hournow Minutenow	Global	- variables to monitor the years, weeks, days, hours and minutes - Yearnow : min = 1 and max = 2 - Weeknow : min = 1 and max = 52 - Daynow: min = 1 and max = 7 - Hournow: min = 0 and max = 12 - Minutenow = 0 and max = 60
skillset	property	- random 11 assigned to SDMA, DDMA and KC in the beginning of the year - From a range of 0 to 10, 6 is the threshold required
corruption	property	- 69 % chance that the authority is corrupt - Assumption that NDMA is not corrupted
profit_minded	property	- 69 % chance that the authority is corrupt
opportunistic	Global	- counter variable monitoring the opportunistic behaviour in the system
transaction_cost	Global	- variable monitoring the expenses of the activities - Increments by 1 for every activity
info_effect	Function reporting values	- “pos””small”= 1 - “pos””medium”= 2 - “pos””high’= 3 - “neg””small”= -1 - “neg””medium”= -2 - “neg””high’= -3
info_value	Global	- variable with the overall updating information - increments based on the

		info_effect
vulnerability_info	Global	- variable monitoring the overall vulnerability information - increments based on info_effect
forecast_info	Global	- variable monitoring the overall forecast information - increments based on info_effect
capacity_individual	property of citizens	- technical capacity from technical activities
location_chosen	Global	- variable containing the patch for the construction
schedule	list containing the target locations	- ending location would be home location unless in response phase, people are in relief centers if there is heavy rain
is_fisherfolk	property of citizens	- 3 % fisherfolk
gov_join	property of government authorities	- indicating the chance that government would join the initiative network - set at 0.4 based on Table B
citizen_join	Property of citizens	- indicating the chance that citizens would join the initiative network - set at 0.6 based on Table C
Threshold _skillset	Property of government authorities	- set at 6 based on Table A in Annex
gov_cont	Property of government authorities	- indicating the chance that government authorities will continue within the initiative - set at 0.6 based on Table D in Annex

citizen_cont	Property of citizens	- indicating the chance that citizens would continue in the initiative network - set at 0.4 based on Table E in Annex
relief_location	Global	- location of relief centers that KC must maintain, and citizens must approach during response phase
capacity_from_initiative	property of citizens	- capacity from creation and expansion of network - increases by 1 when joins the network or encounters the initiative member
powerlist	Global	list containing the [Lever_power_KC, Lever_power_DDMA, Lever_power_SDMA]
social_capacity	Global	- Global variable with the is the sum of [capacity_from_initiative] of citizens - social_capacity was created for better clarity on the dimension it belongs to (social dimension)
economic_dimension	Global	- economic_dimension was created to show the progression of transaction_cost. The purpose if to have a better clarity that this is the economic dimension
technical_capacity	Global	- technical_capacity is the sum of [capacity_individual] of citizens - technical_capacity was created to have a better clarity that technical capacity of the system is the sum of individual technical capacity
environmental_dimension	Global	- environmental_dimension has environmental_damage but was

		created for better clarity

E. RESULTS OF SENSITIVITY ANALYSIS

The approach adopted to decide the values for the parameters were by first looking at which value gives the most ideal results. By ideal results the intention is to look at the value which gives the expected results in the KPIs. For example, to obtain higher resilience, we require higher values in social and technical dimensions while we require lower values in economic and environmental dimensions which represent the cost and environmental damage respectively. Secondly, the value which performs the best in the majority of the KPIs is chosen. Furthermore, the performance of the value in social dimension and technical dimension is given more preference due to the fact that there are more sub-indicators within these two dimensions unlike the economic or environmental dimension and by resilience we are looking at the aggregate of all the four dimensions.

THRESHOLD SKILLSET

When looking at the performance of the different values given to the threshold skill set against the KPIs, it can be observed that in the case of the KPI on social dimension, a threshold value of 6 gives the highest value for social dimension. In the case of technical dimension, a threshold value 6 gives the highest value and has lower variance coefficient when compared to the results from threshold values 2 and 4. In the case of economic dimension, both values 2 and 4 give lower values on the KPI. Finally, in the case of environmental dimension a threshold value of 8 gives the lowest value for environmental dimension. Thus, it was decided that the threshold skill set in the model would be set to 6 considering that this value yields best performance in the majority of the KPIs. Table A shows the analysis for the parameter of threshold skill set.

Threshold skillset vs social dimension							
value	average	median	stdev	q25	q50	q75	variance coeff
2	0,261	0,249	0,162	0,150	0,249	0,341	0,620
4	0,254	0,247	0,148	0,151	0,247	0,334	0,582
6	0,268	0,250	0,170	0,156	0,250	0,347	0,635
8	0,257	0,247	0,154	0,150	0,247	0,340	0,599
Threshold skillset vs technical dimension							
2	0,589	0,580	0,290	0,354	0,580	0,881	0,492
4	0,589	0,580	0,281	0,360	0,580	0,863	0,478
6	0,589	0,580	0,274	0,370	0,580	0,853	0,465
8	0,565	0,559	0,231	0,399	0,559	0,747	0,409
Threshold skillset vs economic dimension							
2	0,498	0,534	0,319	0,167	0,534	0,780	0,640
4	0,498	0,534	0,319	0,167	0,534	0,780	0,640
6	0,500	0,535	0,319	0,170	0,535	0,786	0,638
8	0,499	0,537	0,319	0,167	0,537	0,788	0,639
Threshold skillset vs environmental dimension							
2	0,0000928	0	0,00136	0	0	0	14,6
4	0,00336	0	0,0571	0	0	0	17,0
6	0,00204	0	0,0440	0	0	0	21,6
8	0,0000859	0	0,00114	0	0	0	13,3

Table A: Analysis of for the threshold skill set parameter

CHANCE OF GOVERNMENT JOINING THE INITIATIVE NETWORK

When looking at the performance of the different values given to the “chance of government joining” against the KPIs, it can be observed that in the case of the KPI on social dimension, a value of 0.2 gives the highest value for social dimension but however considering the variance coefficient, the value of 0.4 can be considered. In the case of technical dimension, a value 0.4 gives the highest value and has lowest variance coefficient. In the case of economic dimension, a value of 0.4 for “chance of government joining” gives the lowest value for the KPI. Finally, in the case of environmental dimension a threshold value of 0.2 gives the lowest value for environmental dimension. Thus, it was decided that “chance of government joining” in the model would be set to 0.4 considering that this value yields best performance in the majority of the KPIs. Table B shows the analysis for the parameter of “chance of government joining”.

Government join vs social dimension							
value	average	median	stdev	q25	q50	q75	variance coeff
0.2	0,296	0,256	0,209	0,157	0,256	0,380	0,707
0.4	0,252	0,246	0,143	0,150	0,246	0,333	0,568
0.6	0,248	0,246	0,137	0,150	0,246	0,330	0,551
0.8	0,245	0,243	0,128	0,150	0,243	0,330	0,522
Government join vs technical dimension							
0.2	0,577	0,56	0,275	0,36	0,560	0,850	0,477
0.4	0,588	0,579	0,266	0,38	0,579	0,840	0,453
0.6	0,585	0,576	0,270	0,37	0,576	0,846	0,462
0.8	0,583	0,580	0,269	0,37	0,580	0,839	0,462
Government join vs economic dimension							
0.2	0,498	0,531	0,319	0,166	0,531	0,789	0,641
0.4	0,497	0,533	0,320	0,166	0,533	0,780	0,643
0.6	0,501	0,538	0,319	0,170	0,538	0,790	0,636
0.8	0,500	0,540	0,319	0,170	0,540	0,780	0,638
Government join vs environmental dimension							
0.2	0,000189	0	0,00222	0	0	0	11,7
0.4	0,00281	0	0,0523	0	0	0	18,6
0.6	0,00199	0	0,0440	0	0	0	22,0
0.8	0,000572	0	0,0231	0	0	0	40,4

Table B: Analysis of the “chance of government joining” parameter

CHANCE OF CITIZENS JOINING THE INITIATIVE NETWORK

When looking at the performance of the different values given to the “chance of citizens joining” against the KPIs, it can be observed that in the case of the KPI on social dimension, a value of 0.6 gives the highest value for social dimension. In the case of technical dimension, a value 0.6 gives the highest value for the KPI. In the case of economic dimension, the value of 0.8 gives lower value for the KPI . Finally, in the case of environmental dimension a value of 0.4 gives the lowest value for KPI. Thus, it was decided that the “chance of citizens joining” in the model would be set to 0.6 considering that this value yields best performance in the majority of the KPIs. Table C shows the analysis for the parameter of “chance of citizens joining”.

Citizen join vs social dimension							
value	average	median	stdev	q25	q50	q75	variance coeff
0.4	0,253	0,246	0,148	0,150	0,246	0,337	0,584
0.6	0,267	0,250	0,168	0,156	0,250	0,346	0,630
0.8	0,260	0,247	0,159	0,151	0,247	0,34	0,613
Citizen join vs technical dimension							
0.4	0,583	0,574	0,267	0,374	0,574	0,840	0,458
0.6	0,584	0,573	0,271	0,370	0,573	0,846	0,464
0.8	0,583	0,570	0,272	0,370	0,570	0,840	0,467
Citizen join vs economic dimension							
0.4	0,499	0,537	0,318	0,170	0,537	0,781	0,638
0.6	0,500	0,538	0,319	0,168	0,538	0,783	0,639
0.8	0,498	0,530	0,320	0,167	0,530	0,784	0,642
Citizen join vs environmental dimension							
0.4	0,0000863	0	0,00114	0	0	0	13,2
0.6	0,00195	0	0,0430	0	0	0	22,1
0.8	0,00214	0	0,0453	0	0	0	21,1

Table C: Analysis of the “chance of citizens joining”parameter

CHANCE OF GOVERNMENT CONTINUING IN THE INITIATIVE NETWORK

When looking at the performance of the different values given to the “chance of government continuing” against the KPIs, it can be observed that in the case of the KPI on social dimension, a value of 0.8 gives the highest value for social dimension. In the case of technical dimension, a value 0.4 gives the highest value for the KPI. In the case of economic dimension, the value of 0.6 gives lower value for the KPI . Finally, in the case of environmental dimension a value of 0.6 gives the lowest value for KPI. Thus, it was decided that the “chance of government continuing” in the model would be set to 0.6 considering that this value yields best performance in the majority of the KPIs. Table D shows the analysis for the parameter of “chance of government continuing”.

Government continue vs social dimension							
value	average	median	stdev	q25	q50	q75	variance coeff
0.2	0,260	0,249	0,158	0,156	0,249	0,34	0,609
0.4	0,258	0,249	0,156	0,153	0,249	0,339	0,603
0.6	0,255	0,246	0,150	0,15	0,246	0,34	0,590
0.8	0,267	0,25	0,170	0,154	0,25	0,346	0,636
Government continue vs technical dimension							
0.2	0,583	0,572	0,268	0,370	0,572	0,840	0,460
0.4	0,588	0,580	0,266	0,380	0,580	0,835	0,452
0.6	0,583	0,570	0,276	0,369	0,570	0,850	0,473
0.8	0,579	0,567	0,271	0,367	0,567	0,840	0,469
Government continue vs economic dimension							
0.2	0,501	0,540	0,318	0,170	0,540	0,784	0,636
0.4	0,500	0,536	0,319	0,167	0,536	0,780	0,638
0.6	0,496	0,527	0,320	0,166	0,527	0,784	0,644
0.8	0,499	0,538	0,319	0,167	0,538	0,783	0,640
Government continue vs environmental dimension							
0.2	0,0000921	0	0,00125	0	0	0	13,6
0.4	0,0000932	0	0,00131	0	0	0	14,1
0.6	0,0000898	0	0,00124	0	0	0	13,8
0.8	0,00529	0	0,0720	0	0	0	13,6

Table D: Analysis of the “chance of government continuing”parameter

CHANCE OF CITIZENS CONTINUING THE INITIATIVE NETWORK

When looking at the performance of the different values given to the “chance of citizens continuing” against the KPIs, it can be observed that in the case of the KPI on social dimension, a value of 0.6 gives the highest value for social dimension. In the case of technical dimension, a value 0.4 gives the highest value for the KPI. In the case of economic dimension, the value of 0.8 gives lower value for the KPI . Finally, in the case of environmental dimension a value of 0.4 gives the lowest value for KPI. Thus, it was decided that the “chance of citizens continuing” in the model would be set to 0.4 considering that this value yields best performance in the majority of the KPIs. Table E shows the analysis for the parameter of “chance of citizens continuing”.

Citizen continue vs social dimension							
value	average	median	stdev	q25	q50	q75	variance coeff
0.4	0,261	0,250	0,162	0,153	0,250	0,339	0,620
0.6	0,261	0,250	0,160	0,154	0,250	0,343	0,614
0.8	0,258	0,247	0,154	0,150	0,247	0,340	0,598
Citizen continue vs technical dimension							
0.4	0,590	0,580	0,264	0,380	0,580	0,840	0,448
0.6	0,580	0,577	0,272	0,367	0,577	0,840	0,468
0.8	0,579	0,563	0,275	0,360	0,563	0,850	0,474
Citizen continue vs economic dimension							
0.4	0,500	0,540	0,318	0,169	0,540	0,783	0,636
0.6	0,500	0,537	0,319	0,168	0,537	0,787	0,639
0.8	0,496	0,530	0,320	0,166	0,530	0,781	0,644
Citizen continue vs environmental dimension							
0.4	0,0000929	0	0,00124	0	0	0	13,3
0.6	0,00360	0	0,0591	0	0	0	16,4
0.8	0,000484	0	0,0200	0	0	0	41,4

Table E. Analysis of the “chance citizens continuing” parameter

F. ADDITIONAL FIGURES

Figure A shows the progression of resilience over the 270 runs where the results from the dataset with Lever_power_DDMA = 2 is shown in red while the results from the datasets with lever_power_DDMA = 3 and lever_power_DDMA = 4 are shown in green and blue respectively

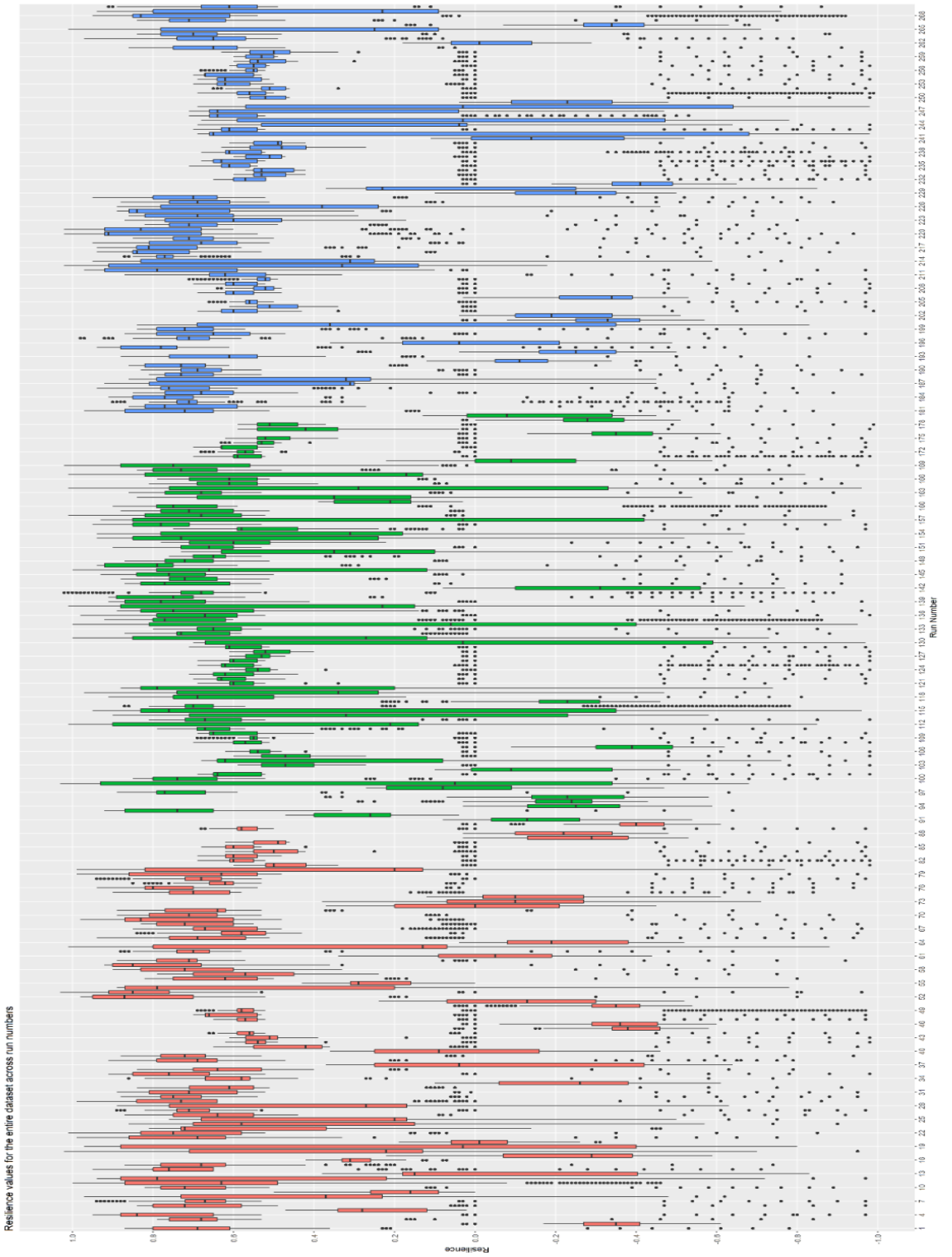

Resilience values for the entire dataset across run numbers
Resilience
Run Number

Figure B shows the enlarged box plot for the values of resilience over 104 weeks (two years).

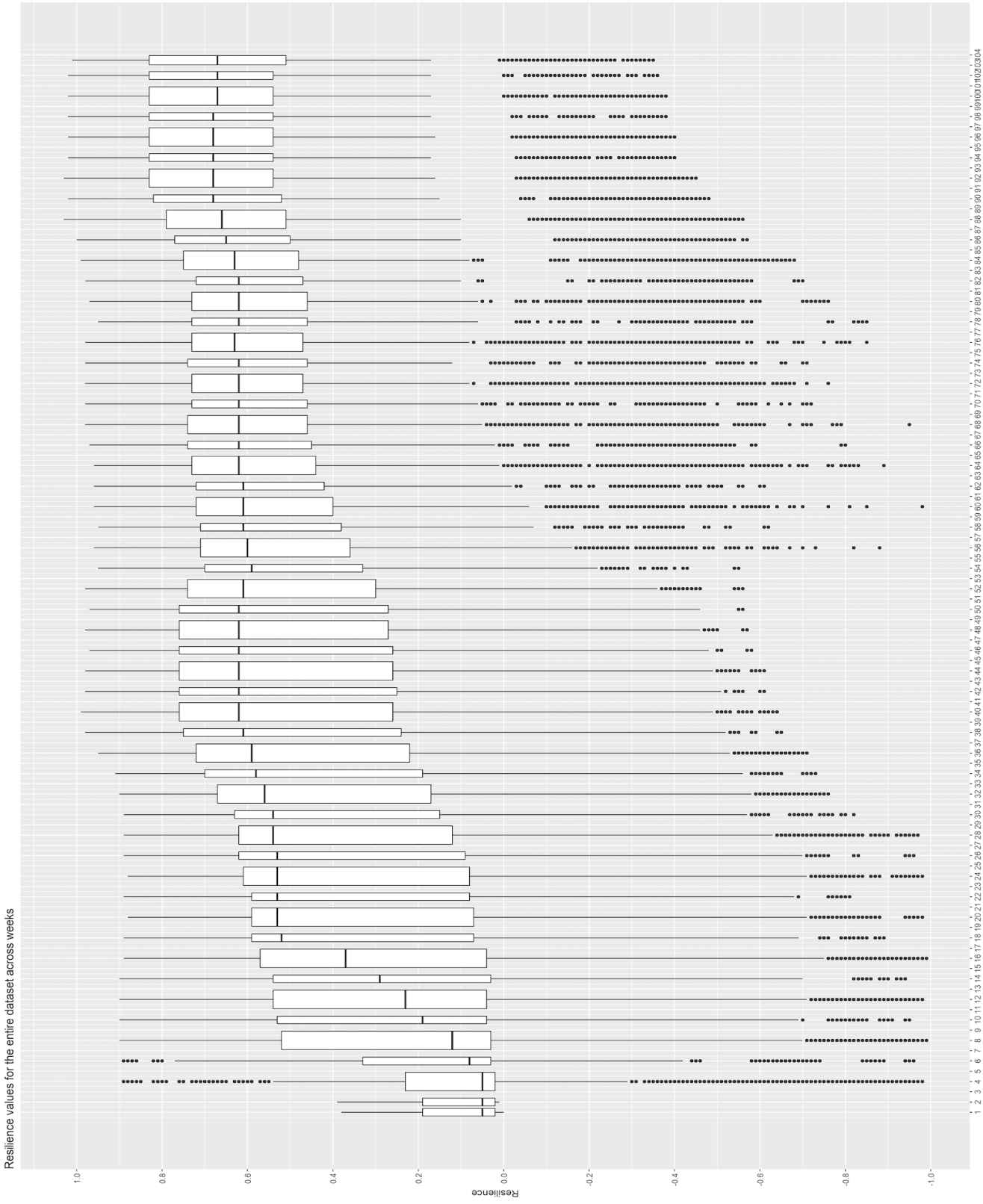


Figure C. The box plot for the top three policies

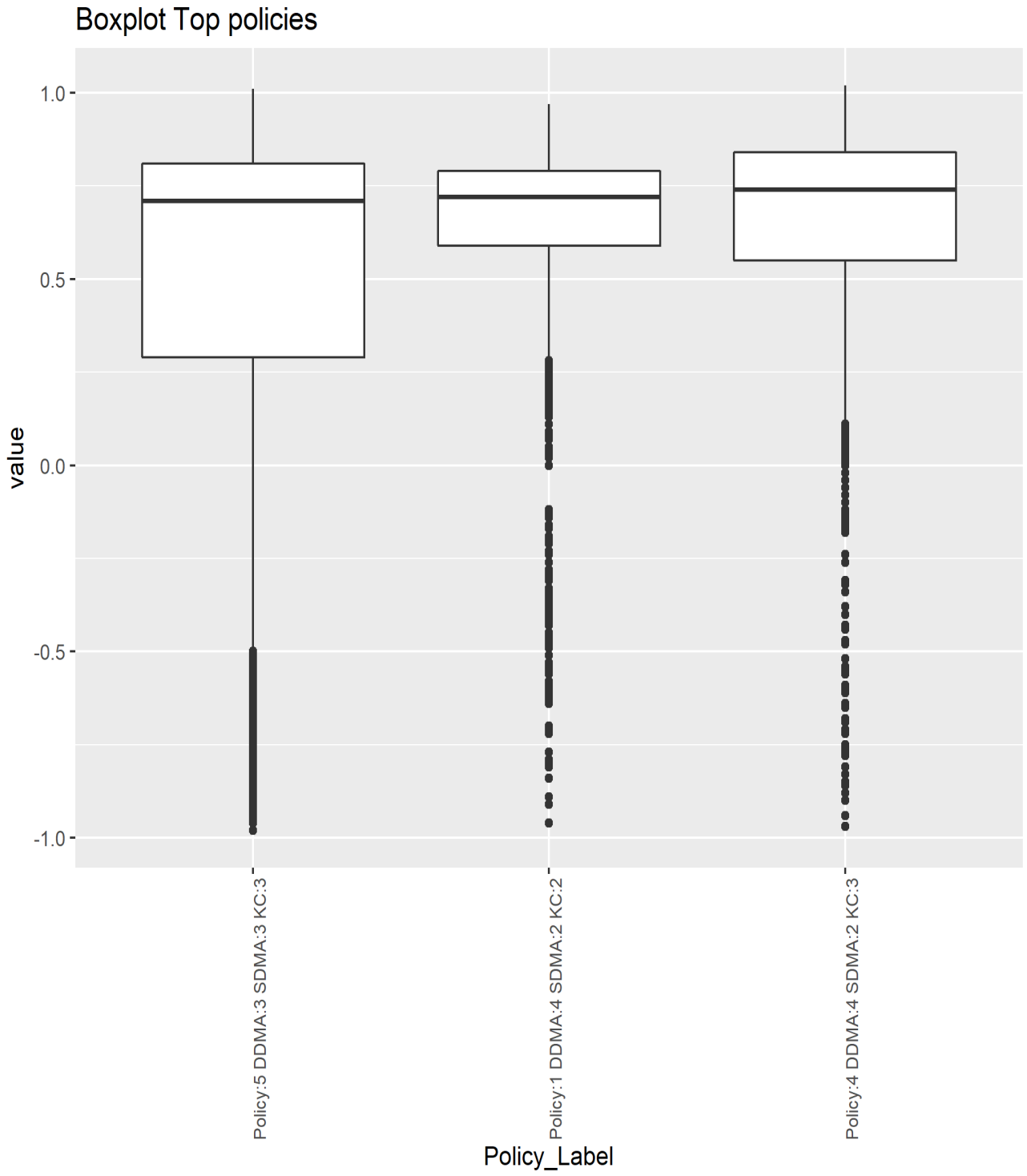
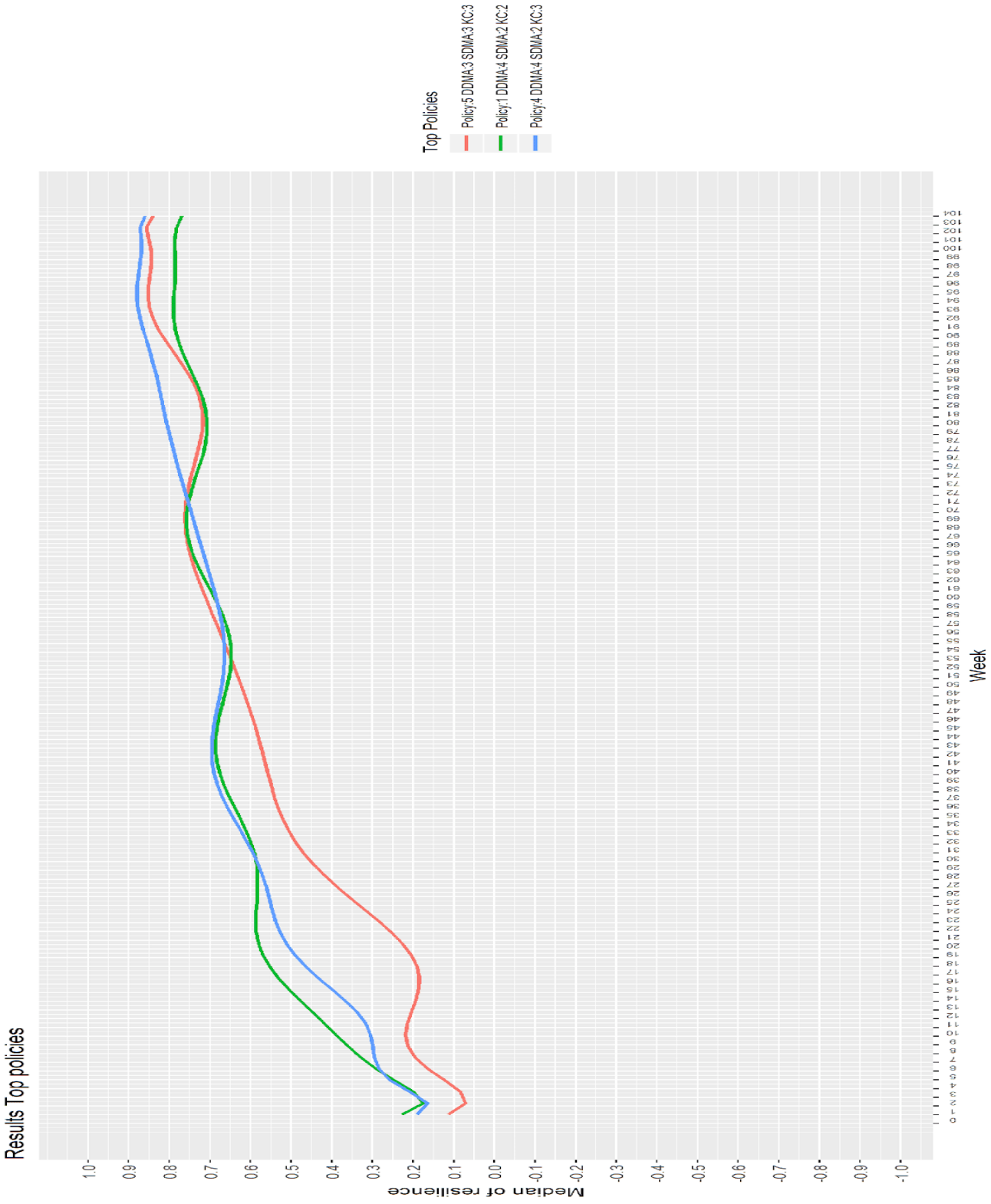


Figure D. The progression of resilience over 104 weeks (two weeks) for the top three policies



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