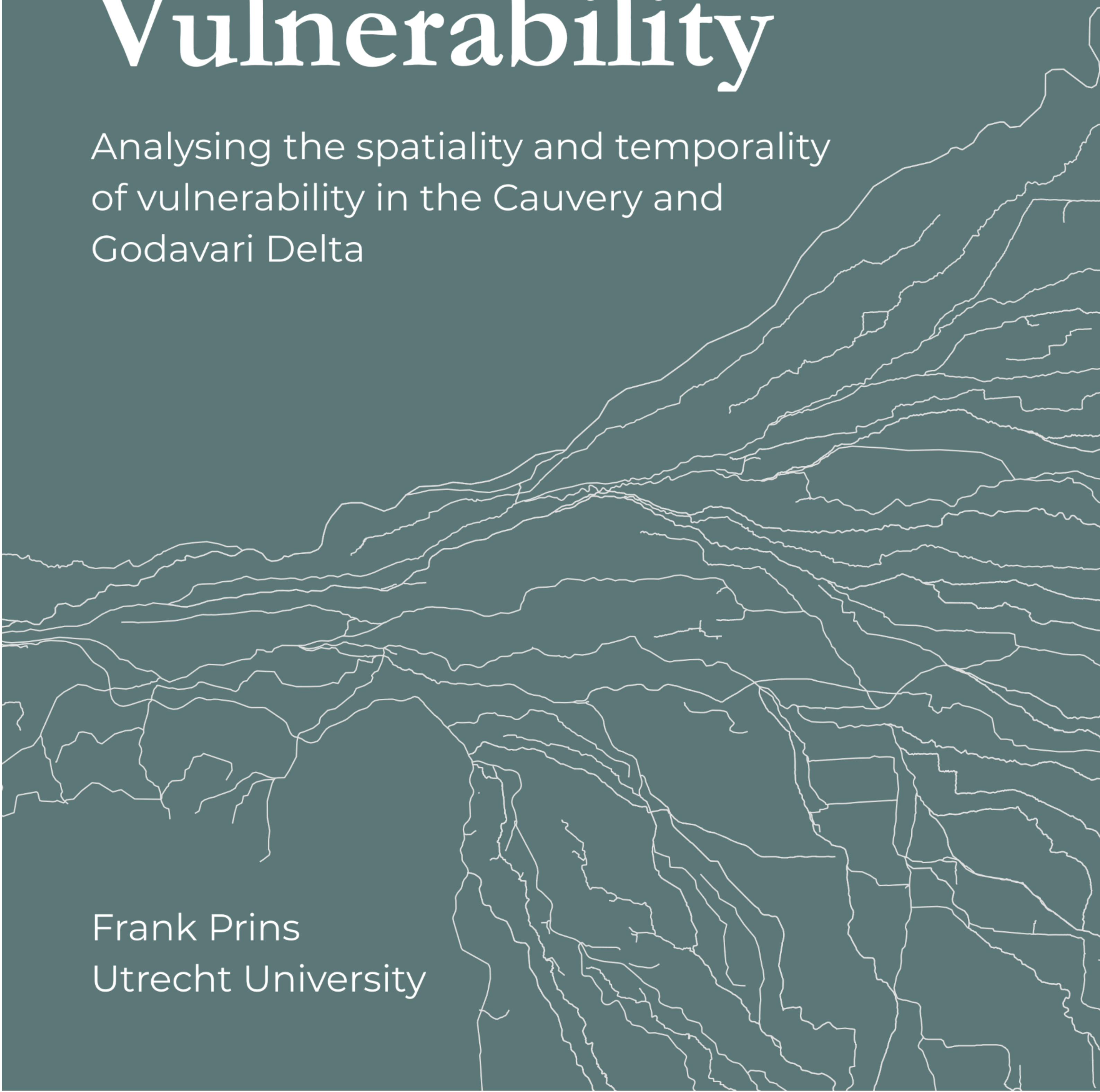
Uncovering Landscapes of Vulnerability

Analysing the spatiality and temporality of vulnerability in the Cauvery and Godavari Delta



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Cover: stream network of part of the Cauvery Delta. Made by author.

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Abstract

Indian coastal deltas, such as the Cauvery and Godavari Delta, consist of the world's critical disaster risk hotspots. An important dimension of disaster risk is the societal conditions of vulnerability, consisting of the capacity to anticipate, cope with, resist, and recover from the impacts of a natural hazard. Vulnerability denotes a multidimensional concept encompassing many social, economic, political, and cultural conditions that differ through time and space. This research provides the first assessment of vulnerability in the Cauvery and Godavari Delta, as it aims to uncover the spatial and temporal dynamics of vulnerability in the two deltas. For this research, the Indian Delta Vulnerability Index was developed to measure and map the multidimensional level of vulnerability using secondary government data from 2011. Furthermore, a literature study and local expert consultations were used to better understand the spatial and temporal production of vulnerability. Three main conclusions emerge. First, a cross-delta vulnerability gradient was observed in both deltas, with the tail-end regions of the Cauvery and Godavari Deltas identified as significant vulnerability hotspots. Secondly, it was found that historical patterns of irrigation, agricultural productivity, marginalisation, and social differentiation shape the current vulnerability landscapes. Thirdly, the production of vulnerability was found to be shaped by complex spatial-temporal dynamics. Further comprehensive analysis across the two deltas is recommended to improve our understanding of the production and reproduction of the vulnerability landscapes.

Key words: Vulnerability; Spatiality; Temporality; Cauvery; Godavari; Delta; India

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List of Abbreviations

ATREE	Ashoka Trust for Research in Ecology and the Environment
CDIS	Cauvery Delta Irrigation System
CRED	Centre for Research on the Epidemiology of Disasters
DRR	Disaster Risk Reduction
GOI	Government of India
GP	Gram Panchayat
IDVI	Indian Delta Vulnerability Index
IPCC	Intergovernmental Panel on Climate Change
SDG	Sustainable Development Goal
UNISDR	United Nations Office for Disaster Risk Reduction
VI	Vulnerability Index

1 | Introduction

1.1 A Story of Drought and Destruction

Typically, January is a time for celebrations and festivities in the Cauvery Delta, a large coastal river delta in Tamil Nadu, South India. In this month, millions of farmers in the delta celebrate the Pongal Festival: a multi-day Tamil harvest festival to celebrate the end of the winter solstice and, of course, a successful harvest. Homes are decorated, sweet rice dishes are shared with family and friends, and people are entertained by music and games. At least, that is normally the case. January 2017, however, was not a normal month in the Cauvery Delta. The delta was experiencing its worst drought in 140 years (Yamunan, 2017). After the failure of two successive monsoon rains, agricultural production had plummeted in the delta by more than 50%. Farmers, who in general could harvest three paddy crops annually, counted themselves lucky if they even succeeded one harvest in that year (ibid.). The drought had widespread impacts on the agricultural communities. For many, the failed harvests resulted in a complete lack of income and employment (Govindarajan, 2017). Farmers were forced to take out loans, leading to mounting debts. Out of pure despair, hundreds of farmers committed suicide. Other farmers were reported to suffer deadly heart attacks just by the mere sight of their barren lands (Hardikar, 2017). Indeed, these were no times to celebrate the Pongal, as there was no successful harvest to celebrate (Govindarajan, 2017).

A little more than a year later, in November 2018, the rural communities in the Cauvery Delta had to deal with another force of nature. Cyclone Gaja had wreaked havoc across the delta. The strong winds and heavy rains of the cyclone – described by the village elders as the worst in over half a century – killed 45 people, destroyed thousands of houses and caused extensive agricultural damage (Ganesan, 2018). Once again, a natural hazard had affected the farmers in the delta, destroying crops and property, leading to loss of income, and causing human suffering (Ravichandran, 2020). The occurrence of natural disasters in Indian deltas, such as the Cauvery Delta, is not exceptional. Natural hazards, such as drought, floods, and cyclones, have had widespread and adverse impacts on ancient and modern deltaic societies (Leroy, 2020; Roy, 2012). In the last 20 years, nearly 80.000 people have been killed in India by natural hazards, of which many were located in the hazard-prone deltas (CRED, 2020). This research looks at the risk and vulnerability to natural hazards in two Indian deltas: the Cauvery and Godavari Delta.

1.2 Deltas as Hotspots of Risk

Coastal deltas, such as the Cauvery and Godavari Deltas, consists of vital socio-ecological systems in the global south (Nicholls *et al.* 2020). Due to their nutrient-rich sediment deposits and other ecosystem services, coastal deltas have attracted human settlement for thousands of years and nurtured the foundation of human civilisations (Pennington *et al.* 2016). Today, coastal deltas support more than 275 million people in the global south, of which more than 150 million live in Indian deltas (Edmonds *et al.* 2020). Despite its considerable advantages to human societies, deltas are also environments that are highly susceptible to natural hazards. Deltaic landforms are, by nature, exposed to fluvial and coastal flooding (Ibánez *et al.* 2019), exposed to cyclones and tropical storms (Woodruff *et al.* 2013), and prone to drought or saline intrusion (Hagenlocher *et al.* 2018).

In an influential study, Tessler *et al.* (2015) analysed the risk of natural disasters in major coastal deltas worldwide. The study highlighted the apparent contrast in disaster risk between deltas in the global north and south, as deltas in the global south were found to have significantly more risk of natural disasters (figure 1.1). Furthermore, the study underlined the disaster risk of coastal deltas in India, as all five of the major Indian deltas that were analysed – the Krishna (1st), Ganges-Brahmaputra (2nd), Brahmani (3rd), Godavari (4th), and Mahanadi Delta (10th) – ranked among the ten deltas with the highest disaster risk worldwide (Tessler *et al.* 2015)[1]. The high disaster risk of Indian deltas was not only explained by a high exposure to multiple natural hazards but also by the socio-economic conditions in the delta. Indian deltas are associated with large, rural populations, of which many rely directly on the deltaic ecosystem services to sustain their livelihoods related to agriculture, aquaculture, or fisheries (Edmonds *et al.* 2020; De Souza *et al.*

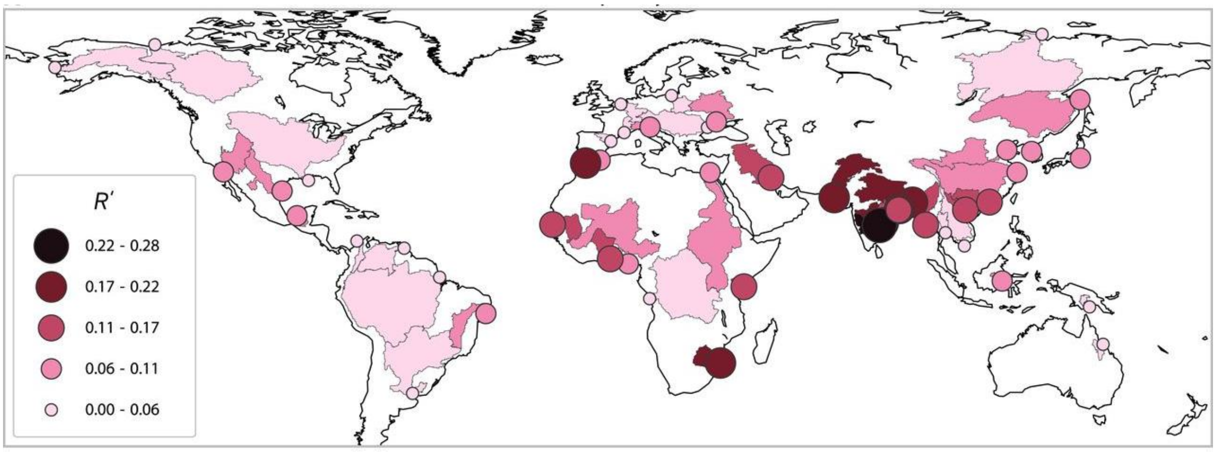


Figure 1.1 Global Delta Disaster Risk. Retrieved from Tessler et al. (2015).

[1] Tessler *et al.* (2015) did not analyse the disaster risk of the Cauvery Delta.

2015). Furthermore, the rural communities in Indian deltas often experience impoverished living conditions, economic underdevelopment, poor housing infrastructure, and limited access to public services (Das *et al.* 2021; De Souza *et al.* 2015). Together, these conditions make the rural communities in Indian deltas more susceptible to the impacts of natural hazards, therefore exacerbating the disaster risk in these areas (Tessler *et al.* 2015). In other words, this means that these rural communities are more likely to experience a devastating loss of income, disruption of their livelihoods, property damage, or human suffering, as the experiences in the Cauvery Delta illustrated (Ganasan, 2018; Govindarajan, 2017).

Over the last thirty years, Indian coastal deltas – like other deltas in the global south – have increasingly been recognised as some of the critical disaster risk hotspots globally due to the intersection of natural hazards with large concentrations of vulnerable, poor, and marginalised people (De Souza *et al.* 2015; Milliman *et al.* 1989; Sebesvari *et al.* 2016). Moreover, the disaster risk in the deltas is expected to increase in the coming decades. Firstly, in the deltas in the Global South, more people will be exposed to natural hazards due to continuing population growth (United Nations, 2019). Next, the severity of the natural hazards is exacerbated by human activities. To accommodate their needs, humans have engineered rivers, exploited subsurface resources, and changed the land cover (Edmonds *et al.* 2020). These activities have resulted in widespread reductions in river sediment supply, coastal erosion, and land subsidence (Syvitski *et al.* 2009). Also, upstream economic development, dam development, and unsustainable groundwater exploitation negatively impact freshwater resources in the delta, making the region more prone to water scarcity (Loc *et al.* 2021; Murshed and Kaluarachchi, 2018). Furthermore, climate change is expected to increase the frequency and severity of natural hazards, including tropical cyclones (IPCC, 2021; Mora *et al.* 2018). All in all, the combination of a densely populated hazard-prone environment, low socio-economic development, and exacerbating social and environmental changes make Indian coastal deltas global hotspots of disaster risk (Sebesvari *et al.* 2016).

1.3 Risk Reduction and Vulnerability

Due to the high disaster risk, alongside projections of risk intensification, there is an urgent call among academics and policymakers to reduce the disaster risk in Indian deltas, among others (Sebesvari *et al.* 2016). Disaster Risk Reduction (DRR) encompasses all strategies to reduce the damages, casualties, and other adverse impacts of future natural hazards by identifying, reducing, and adapting to all conditions that create the risk of natural disasters (UNISDR, 2015). Further, it aims to support and improve the resilience of societies in the face of natural hazards in a sustainable way (ibid.). Due to the interconnection between natural hazards and exposed communities' social and economic development, DRR plays an integral part in the progress towards sustainable development (UNISDR, 2015; Wisner *et al.* 2012).

Understanding the different elements and causal factors of disaster risk forms the foundation of any strategy of DRR (McBean, 2012). Without a developed comprehension of disaster risk, DRR strategies are often found to be ineffective or maladaptive (Magnan *et al.* 2016; UNISDR, 2015). It has long been recognised that for the characterisation of disaster risk, a holistic approach needs to be followed, in which the natural and social sciences are integrated (McBean, 2012). Nevertheless, the majority of research related to natural disasters and risk focuses principally on the natural processes that trigger natural disasters (Wisner *et al.* 2012; Wolters and Kuenzer, 2015). Such research consists mainly of remote sensing or hazard probability mapping. The role of socio-economic, political, or cultural factors in the causation of natural disasters are often neglected or insubstantially understood (Wisner *et al.* 2012; Wolters and Kuenzer, 2015).

However, differences in societal conditions such as wealth and class, caste, education, gender, and health often explain natural disasters' differential impact among the affected communities. On a global scale, natural disasters are found to disproportionately affect Middle- and Low-Income countries: more than 90% of all disaster-related deaths occur here (CRED, 2020). Too, these divergent impacts are found on a more local scale. In the 1970s, O'Keefe *et al.* (1976) found such large disparities in the mortality, damage, and recovery between Guatemala City's poor and middle class after the 1976 Earthquake that the event was dubbed as a 'class-quake' (Wisner *et al.* 2004). Similarly, the aftermath of Hurricane Katrina (2005) exposed the highly differentiated risk of Mississippi Delta's population related to race, ethnicity, and gender (Bankoff, 2006). Similar evidence was found in the Irrawaddy Delta (Myanmar) (Warr and Aung, 2019), the Godavari Delta (India) (O'Hare, 2001), or the Chao Praya Delta (Thailand) (Marks *et al.* 2020), among others.

In disaster-related studies, the concept of vulnerability captures the socio-economic, political, and cultural conditions and processes that influence people's capacity to cope with natural hazards (Wisner *et al.* 2004). The intersection between a population in a socially produced condition of vulnerability and a natural hazard produces a natural disaster. Therefore, the study of vulnerability should be considered with at least the same degree of importance that is devoted to understanding and addressing natural hazards, given the critical role vulnerability plays in the construction of disaster risk (Wisner *et al.* 2004; UNISDR, 2015). An in-depth analysis of the conditions and processes of vulnerability could contribute to understanding who is vulnerable, where, and most importantly, why this vulnerability exists. This knowledge can be leveraged to identify special need population groups, observe geographic areas with a significant vulnerable population, and recognise harmful socio-economic processes (Wisner *et al.* 2004). Hence, vulnerability studies could foster progress in achieving successful DRR interventions or policies (UNISDR, 2015; Wisner *et al.* 2012). Consequently, I argue that the study of vulnerability to Indian deltas would contribute to the understanding of the disaster risk of Indian deltas and could thus advance DRR in these areas.

1.4 Knowledge Gaps

Despite the frequent evidence and wide acknowledgement of Indian deltas as significant disaster risk hotspots, the urgent call for successful DRR, and the noticed importance of understanding vulnerability for successful DRR, vulnerability studies to Indian deltas are scarce. Most research focuses only on the Ganges-Brahmaputra Delta (e.g., Das *et al.* 2021; Rabby *et al.* 2019) or has analysed vulnerability conditions at the Indian coastline at a larger spatial scale (e.g. Maiti *et al.* 2015). Delta-specific vulnerability studies of other river deltas in India are missing. Although the study of Maiti *et al.* (2015) identified deltaic districts in the Cauvery, Godavari, Krishna, and Mahanadi Delta as highly vulnerable, no information exists about the differential vulnerability within these Indian deltas. Still, research on the Ganges-Brahmaputra Delta indicates that significant vulnerability inequalities exist within the delta (Das *et al.* 2021; Rabby *et al.* 2019).

Additionally, vulnerability studies are increasingly being criticised for being static (Singh *et al.* 2017; Wolters and Kuenzer, 2015). Whereas studies of the natural processes of hazards encapsulate the dynamic nature (e.g., Mora *et al.* 2018), only a few vulnerability studies account for its temporal dynamics (e.g., Cutter and Finch, 2008; Das *et al.* 2021). Most vulnerability studies provide a snapshot of the current level of vulnerability, independent of socio-economic changes or ongoing processes (Wolters and Kuenzer, 2015). Nevertheless, vulnerability is inherently a dynamic concept as it varies from region to region, from community to community, among individuals, and over time (Adger, 2006). Rather than a stagnant characteristic of people, vulnerability is an outcome of social relations, constantly changing and adapting to societal developments (Bankoff, 2013). Hence, vulnerability is not only a product of the present but equally a product of the past. These temporal components of vulnerability are rarely incorporated in vulnerability studies, whilst insights into these dynamics could uncover the (temporally distant) underlying processes that explain the structural differences in vulnerabilities among communities (Bankoff, 2013; Fawcett *et al.* 2017; Ribot, 2014).

Although it is essential to consider the spatial and temporal dynamics when analysing vulnerability, current studies rarely do so. However, I argue that incorporating these dynamics into vulnerability research could significantly benefit the understanding of which communities are vulnerable, where, and how this vulnerability is produced and reproduced. In turn, this knowledge could benefit DRR by gaining better insights into the (local) conditions and processes that create the disaster risk of a particular place or region.

1.5 Research Aim

This research contributes to the knowledge gaps by conducting a holistic vulnerability study in two Indian deltaic risk hotspots: the Cauvery and Godavari Delta. This research aims to uncover the spatial and temporal dynamics of vulnerability in two disaster risk hotspots in India. The research objectives are to analyse the spatial patterns of vulnerability in the Cauvery and Godavari Delta and understand the most important temporal processes that have produced the differential patterns of vulnerability in the two deltas. The following main research question is formulated to steer this research:

> RQ: How are vulnerability landscapes being produced and reproduced in the Cauvery and Godavari Delta?

To fulfil the research aims, this study employs a mixed-methods approach, in which the quantitative assessment of vulnerability is combined with a qualitative literature study and expert interviews. As a result, this research contributed towards a holistic understanding of which, where, and how communities' vulnerability to natural hazards in the Cauvery and Godavari Delta are distributed. In addition, this analysis gains insight into how the vulnerability landscapes of both deltas are produced, uncovering important societal drivers of vulnerability.

This research is innovative in three ways. First, by assessing the communities' vulnerability in the Cauvery and Godavari Delta, this research conducts the first vulnerability assessment in these two risk hotspots. Second, this research is the first study that attempts to systematically quantify the level of vulnerability on a village level in India. Earlier Indian vulnerability studies that applied a quantitative approach operated solely at a larger spatial scale (e.g., mandal or district) (Das *et al.* 2021; Maiti *et al.* 2015; Singh *et al.* 2017). Third, this research is the first to place the present vulnerability in a historical Indian context by assessing the temporality of vulnerability in the two deltas.

The findings of this research contribute to a better understanding of vulnerability, and consequently disaster risk, in two disaster risk hotspots of the world (De Souza *et al.* 2015). These insights could contribute towards any delta level DRR intervention in the Cauvery and Godavari Deltas to reduce people's vulnerability to natural hazards here. In addition, this knowledge can be leveraged to foster progress in achieving the United Nations' Sustainable Development Goals (SDGs), including SDGs 1 (No Poverty), 2 (No Hunger), 6 (Clear Water and Sanitation), 11 (Sustainable Cities and Communities), and 13 (Climate Action) (Sebesvari *et al.* 2016; UNISDR, 2015). This way, this research could contribute towards sustainable disaster risk reduction in the two deltas, and thus help to reduce the impacts of future natural hazards that have severely affected the deltaic population in the Cauvery and Godavari Deltas in the past.

1.6 Research Outline

This research is organised as follows. First, in Chapter 2, the main theories and concepts of this research are explored. Here, the theoretical demarcation of the concept of vulnerability is elaborated upon, as is the conceptual framework used in this research to analyse vulnerability in the Cauvery and Godavari Delta. Also, the research questions of this study are presented in Chapter 2. Next, Chapter 3 provides a brief introduction of the two deltas. After this, the methodology is described in Chapter 4. Here, both the employed quantitative and qualitative research methods are explained. Besides this, the limitations of this research are discussed in this chapter. Then, in Chapters 5 and 6, the results of this research are presented, consisting of the quantitative and qualitative analysis of the vulnerability landscape in the Cauvery and Godavari Delta. These results will be further discussed in Chapter 7. Finally, Chapter 8 concludes this research.

2 | Theoretical Framework

This research aims to uncover the spatial and temporal dynamics of vulnerability in the Cauvery and Godavari Delta. This way, this research could contribute towards a better understanding of vulnerability in the two deltas, and therefore could be leveraged to foster progress in sustainable disaster risk reduction in two of the world's disaster risk hotspots. In this research, it is first necessary to discuss the main concepts. Therefore, this chapter discusses the main theories and concepts that are used in this research. First, the concept of disaster risk is discussed. Next, the concept of vulnerability is explained and defined. Here, special attention is given to the concept's historical antecedents, characteristics and conditions, and main critiques. After this, the relationships of vulnerability with space (spatiality) and time (temporality) are debated. Finally, this chapter concludes with the presentation of this research's conceptual framework.

2.1 Natural Disaster Risk

2.1.1 Natural Disasters

Natural disasters are adverse events resulting from the natural events or phenomena of the Earth, i.e. natural hazards such as droughts, floods, earthquakes, or cyclones (Rodríguez *et al.* 2018). Natural disasters result in human, economic, or environmental losses and are associated with a (temporary) disruption in the functioning of society (Kreps, 1998; Rodríguez *et al.* 2018). Over the last twenty years, natural disasters claimed approximately 1.23 million lives (an annual average of 60.000), affected more than 4 billion people, and led to approximately US$ 2.97 trillion in economic losses worldwide (CRED, 2020). There is no consensus regarding the threshold of scope and magnitude that determines whether an event is a disaster or not. It is argued that many of the world's natural disasters are 'neglected' or invisible as they do not receive the amount of media coverage or aid assistance as other events, yet cause severe social disruption (Wisner and Gaillard, 2009). Therefore, in this research, a natural disaster refers to a situation involving a natural hazard that has consequences in terms of damage, livelihood disruption or casualties that are too great for the people to deal with on their own, independent of the magnitude of this event (Wisner *et al.* 2012).

2.1.2 Production of Disaster Risk

For a long time, natural disasters have been perceived as a mystery of the natural world (Van Bavel *et al.* 2020). Later, natural disasters were mainly understood through a lens of environmental determinism: natural disasters were solely attributed to the unavoidable forces of nature, or even the Act of God(s) (ibid.). Nowadays, it is generally noted that natural disasters are not only caused by nature, but also by societal factors. Therefore, natural disasters often depict a situation involving a natural hazard and a human population in a socially and economically produced condition of vulnerability (Rodríguez *et al.* 2018). Theoretically, a natural disaster cannot occur if there is a natural hazard but no vulnerable population, nor if there is a vulnerable population but no hazard (Wisner *et al.* 2004). Therefore, the risk of natural disasters refers to the probability of a natural hazard multiplied by the impact if that hazard occurs. The relationships between disaster risk (DR), hazard (H), and people's vulnerability (V) can be schematised in the following pseudo-equation:

$$DR = H \times V$$

Disaster risk captures the duality between the natural environment (H) and human society (V). Due to the spatial variability of nature and human societies, humans are not equally exposed to natural hazards, nor are they equally vulnerable to those hazards (Wisner *et al.* 2004). Consequently, disaster risk is not evenly distributed globally: some areas tend to endure a higher disaster risk than others (De Souza *et al.* 2015). The higher disaster risk could be explained by a higher probability of the occurrence of natural hazards (H) (e.g., hazard-prone environments as coastlines, earthquake faults, or steep mountain slopes), a higher level of vulnerability (V) (e.g., areas with large marginalised communities or low socio-economic development), or a combination (Wisner *et al.* 2004).

2.2 Vulnerability

As stated before, the concept of vulnerability denotes the socio-economic conditions that could turn a natural hazard into a natural disaster. Over the last decades, vulnerability has evolved into a fundamental concept to understand and explain the societal processes that translate a natural hazard into a natural disaster (Wisner *et al.* 2004). This research also centres around the concept of vulnerability. However, vulnerability is described as a fuzzy concept, interpreted and explained in different ways (Adger, 2006; Gibb, 2018). Therefore, the historical roots of vulnerability are explored to better position the concept in the academic landscape before further defining the concept.

2.2.1 Historical Antecedents

Kelly and Adger (2000) traced the linguistic origins of vulnerability back to the ancient Roman Empire, to the use of the Latin *vulnus*, meaning 'wound', and *vulnerare*, 'to wound'. More specifically, vulnerability is derived from *vulnerabilis*. Romans used this term to describe the state of a soldier lying wounded on the battlefield, thus prone to further attack (Kelly and Adger, 2000). In this classical sense, vulnerability was defined by the existing state (the wounded soldier) and not by potential future stress (any further attack).

It was not until the mid-twentieth century that scholars began to use the concept of vulnerability in relation to natural hazards and disasters (Rodríguez *et al.* 2018). Shortly after World War II, scholars used vulnerability within a notion of environmental determinism, called the (geo)physicalist approach. Herein, vulnerability was used to describe the post-disaster conditions in a society or community, contrary to the Roman understanding (box 1) (Gibb, 2018). The physicalist approach considers natural disasters as unavoidable extreme natural events occurring independently from society. It assumes that the net impact of these disasters can only be reduced by applying scientific expertise and technological solutions, echoing a Western modernist way of thinking (Gibb, 2018). Consequently, to reduce vulnerability, the physicalist school promoted structural engineering projects as a way to tame nature, such as the construction of dams, levees, floodwalls, anti-seismic constructions, and irrigation projects (O'Brien *et al.* 2007).

Box 1. Geophysicalist Vulnerability and the Three Little Pigs

Bankoff (2006) illustrates the essence of the physicalist paradigm of vulnerability with the help of the classic fairy tale of James Halliwell-Phillipps: the story of the *Three Little Pigs*. In this story, each pig tries to withstand the big, bad wolf – depicting strong winds – by using different technologies. The lazy one builds a house out of straw, the not so lazy one out of wood, and the industrious one out of brick. And then came the big, bad wolf, blowing away the houses of straw and wood. Only the story's hero, the clever brick-laying third pig, withstands the winds and triumphs the wolf.

The physicalist paradigm of vulnerability is reflected in two ways in this story. Firstly, the story of the Three Little Pigs portrays vulnerability as an outcome: a condition of susceptibility following a hazard (Bankoff, 2006). The third pig withstands the wolf and is, therefore, less vulnerable than the other two pigs. Secondly, the third pig is less vulnerable through his application of appropriate technology and knowledge and is therefore in the position to offer his help to his less resourceful and forward-thinking counterparts (Bankoff, 2006; Gibb, 2018). Unknowingly, the third pig as conformed to the modernist, and technocratic beliefs of the physicalist scholars.

In the 1970s, critical opposition emerged to challenge the dominant physicalist understanding of vulnerability. Despite the promotion of technological fixes, the physicalist solutions were ineffective in reducing human suffering as natural disasters continued to increase in the 1960s and 1970s. This trend could not be explained by improved media coverage, a growing human population, or merely the bad luck of being in the wrong place at the wrong time (Bankoff, 2001). However, evidence emerging from the Global South did provide an alternative explanation. O'Keefe *et al.* (1976) were among the first to question the naturalness of natural disasters. This publication followed the 1976 Guatemala Earthquake, an event in which the disparities in mortality, damage, and recovery between Guatemala City's poor and middle class were so apparent that it was dubbed a 'class-quake' (O'Keefe *et al.* 1976; Hewitt, 1983). According to O'Keefe *et al.* (1976), these disparities were evidence that societal conditions played a prominent role in the occurrence of natural disasters. To paraphrase O'Keefe *et al.* (1976): all natural hazards may be an Act of God, but all natural disasters are shaped by society.

These findings were underlined by the influential works of Sen (1981) and Hewitt (1983), who found that everyday socio-economic interactions and structures, embedded in broader historical relations, better explained the nature, causes, and consequences of natural disasters than solely geophysical processed did. An analysis of these social factors could explain why natural hazards were found to impact different groups of people differently, as was observed in Guatemala City. The findings of O'Keefe *et al.* (1976), Sen (1981), and Hewitt (1983), among others, led to the development of an alternative, critical, and people-centred explanation of natural disasters: the social understanding of vulnerability. In this paradigm, vulnerability is considered as the everyday condition of susceptibility to natural hazards, independent of the actual occurrence of these hazards (Gibb, 2018; Wisner *et al.* 2004). In doing so, this understanding of vulnerability echoes the classical perspective, as both perspectives consider vulnerability as a condition prior, not subsequent, to a hazard (Kelly and Adger, 2000).

2.2.2 Defining Vulnerability

The opposing development of the physicalist and social paradigms of vulnerability has led to conflicting perspectives on the same concept. Consequently, vulnerability is now interpreted, conceptualised, and applied in many ways in different academic fields, including disaster studies, food security, political ecology, (sustainable) development, climate and global environmental changes, and social-ecological systems (Adger 2006; Gibb, 2018). The fundamental conceptual differences, alongside varying research objectives and methodology, have resulted in a myriad of definitions of vulnerability. Birkmann (2006), for instance, found more than 25 different definitions to describe vulnerability. For this reason, vulnerability is often perceived as a fuzzy and challenging concept (Adger, 2006). Additionally, the different interpretations of vulnerability inherently lead to different proposed solutions, policies, and responses (O'Brien *et al.* 2007). Whereas the physicalist paradigm mainly proposes technological fixes to reduce vulnerability, the social paradigm mainly argues that socio-economic adjustments are the solution to reduce the inequities that create vulnerability (ibid.).

This research intends to understand better the role of socio-economic conditions and dynamics that (partly) constitute the disaster risk in the Cauvery and Godavari Delta. Therefore, in this research, vulnerability is understood following the social paradigm[2]. In this paradigm, Wisner *et al.*'s definition of vulnerability has become the general standard (Gibb, 2018). According to this definition, vulnerability denotes:

> 'the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard' (Wisner *et al.* 2004, p.11).

Vulnerability thus involves a combination of factors, conditions, and processes that determines the degree of risk someone is put by a hazard (Wisner *et al.* 2012). Before elaborating on these conditions of vulnerability in the following subchapter, it is first essential to explain further what vulnerability entails to prevent any misconception. Firstly, vulnerability encompasses solely human conditions and refers not to buildings (unsafe), political situation (unstable), economies (fragile), or landforms (hazard-prone) (Wisner *et al.* 2004). While all of these elements indeed influence one's vulnerability, they cannot be vulnerable on themselves. The concept of vulnerability is only retained for human conditions; otherwise, the concept of vulnerability is in danger of becoming a catch-all term for any condition related to a disaster, losing its analytical capacity (Wisner *et al.* 2004).

Secondly, vulnerability refers to an ex-ante condition. Echoing the ancient Roman understanding, vulnerability refers to an everyday condition, independent of the occurrence of a potential hazard (Kelly and Adger, 2000). This means that everyone, at any time, lives in a condition of vulnerability.

2 In this paradigm, vulnerability is variously called 'social', 'structural', 'contextual', 'starting-point', or 'type II' vulnerability (Gibb, 2018). Hereafter, the term 'vulnerability' refers to this understanding, unless otherwise noted.

Further, any measure of vulnerability has a predictive value. Analysis of the level of vulnerability indicates to what extent someone can anticipate, cope with, resist, and recover from the impact of a natural hazard when this event would materialise (Wisner *et al.* 2004).

Thirdly, the concept of vulnerability exists on a spectrum, meaning that everyone has a certain degree of vulnerability. Furthermore, vulnerability involves varying magnitudes: some people are more vulnerable than others. Consequently, the condition of vulnerability cannot simply be reduced to a dichotomy of being vulnerable or not. Rather, any measure of people's vulnerability is compared to 'someone' (e.g., other people, households, communities, or notions). For example, the socio-economic conditions that make a Dutch community relatively vulnerable may result in an entirely different measure of vulnerability in an Indian context. In other words, any measure of vulnerability is influenced by its comparative context and should therefore always be considered when analysing vulnerability.

2.2.3 Critique on Vulnerability

Although most academics view the development of the notion of vulnerability as an enrichment to academic thinking on hazards and disasters, the concept is also fundamentally criticised from different perspectives (Gibb, 2018; Ford *et al.* 2018). The most significant critiques on the concept of vulnerability are voiced by social scientists drawing on constructionist theory. In their view, the concept of vulnerability, as all subjects in the social sciences are, is a product of historically, socially, and politically created 'ways of seeing and thinking' (Wisner *et al.* 2004). As such, vulnerability denotes not an objective concept but reflects cultural and ideological values stemming from its historical roots. Bankoff (2001) characterises modernist approaches related to disaster, risk, and vulnerability as a historically neo-colonial discourse that still reflects a colonial imagination of 'other' regions or communities. The classification of vulnerable regions is merely a continuation of the denigration of the dangerous 'other', similar to seeing large regions of the world as disease-ridden, poverty-stricken, or underdeveloped (Bankoff, 2001). Likewise, Marino and Faas (2020) state that vulnerability naturally leads to 'othering': the different labelling and threatening of social groups that are essentially different from another social group.

Furthermore, Marino and Faas (2020) state that vulnerability results in the over-simplification, homogenisation and victimisation of communities. As vulnerability inherently emphasises people's weaknesses or limited capacities (e.g., limited income, lack of knowledge, or absence of political capital), there is a risk of reducing these people to all passive or even incapable victims (Bankoff, 2001; Marino and Faas, 2020). Gibb (2018) refers to these critiques as the 'Achilles heel of vulnerability': as the concept is underlain with ideology, it is susceptible to ideological assault or appropriation whilst reproducing damaging discourses on Western hegemony.

Despite these flaws, the baby should not be thrown out with the bathwater. Wisner *et al.* (2004) counter the critiques by arguing that rejecting the concept of vulnerability does not improve practice, either in disaster prevention or post-disaster management. Instead, vulnerability studies should aim to minimise the flaws of the notion. By profoundly questioning the production of vulnerability and the roles of power, marginalisation, and social differentiation in its production, the concept of vulnerability could offer possibilities to scholars to minimize the fundamental critiques while emphasising the importance of justice (Gibb, 2018). This way, I argue, vulnerability could be a useful concept to understand the linkages between socio-economic conditions and natural disasters and translate these insights into recommendations that could contribute towards the reduction of disaster risk.

2.3 Conditions of Vulnerability

After defining vulnerability, the logical next question is: what conditions shape one's vulnerability? This question is the foundation of all vulnerability research, yet a simple answer cannot be provided. Bankoff *et al.* (2013) refer to this as the simple-complex paradox of vulnerability: the description of the conditions of vulnerability can be both straightforward, related to poverty or the lack of resources, or complex, referring to a myriad of interrelated risks originating from the interplay of global and local societal processes.

According to the definition of Wisner *et al.* (2004), it is evident that vulnerability refers to the capacity of people to anticipate, cope with, resist, and recover from the impacts of a natural hazard. These capacities are related to a range of livelihood assets that allow people to respond to changing circumstances, the ability to generate and assess knowledge and information, and the social relationships among people (Clay, 2017; Wisner *et al.* 2012). These elements are strongly related to the livelihood resources that are required to sustain people's basic needs, including good living conditions, income, education, health, and social networks, as these resources shape the adaptive and coping capacity that constitutes the level of vulnerability (Clay, 2017; Wisner *et al.* 2012). Vulnerability is therefore related to, but distinct from, poverty, with the latter described as a condition in which mutually reinforcing social, economic, and political processes that undermine households' capability to achieve valued goals (Eriksen and O'Brien, 2007; Taylor 2013). Still, vulnerability and poverty are separated: the poorest members of society are not necessarily the most vulnerable and vice versa, although the two conditions are frequently mutually reinforcing (Makoka and Kaplan, 2005; Taylor, 2013).

Moreover, vulnerability encompasses the institutional environment that dictates the access and entitlement to assets, capitals, and capacities in a given society (Gibb, 2018). Indian economist Amartya Sen was among the first to highlight the role of these institutions. Using historical examples of famines in Bengal, the Sahel, and Bangladesh, Sen showed that famines could occur even in the absence of absolute food shortages: it was not the overall food availability but a person's ability to acquire and exchange resources within a given society – i.e. their entitlements – that determine whether or not they could eat (Sen, 1981). In Sen's view, vulnerability involves entitlement failure, and social differentiation is both a cause and consequence of vulnerability (Gibb, 2018). This notion is echoed by Pelling (2001), who argues that the differences in the allocation and distribution of resources throughout society inherently is one of the root causes of people's vulnerability. According to this perspective, the process of marginalisation is the intermediary that translates vulnerability into the differential impacts of natural disasters (Gibb, 2018).

Marginalisation is defined as the exclusion of specific individuals and groups from economic, social, or political resources (Pelling, 2001). Marginalisation results in the social inequalities in a given society, such as class, gender, race, caste, religion, health, disability, and other social cleavages, that influences people's control over basic needs and rights, which in turn, shapes people's capacity to anticipate, cope, or adapt to a natural hazard (Gibb, 2018; Pelling, 2001). Inherently, vulnerability reflects the distribution of power in a society, which drives the processes of marginalisation and inequality. Evidence from Guatemala (O'Keefe *et al.* 1976), the Philippines (Gaillard *et al.* 2007), Nepal (Hülssiep *et al.* 2021), the United States (Bankoff, 2006), and Mexico (Collins, 2010) stresses how marginalisation and vulnerability can act as the transformative agent that unfolds a hazard into a disaster.

Besides this, Taylor (2013) emphasises the role of marginalisation in the production of vulnerability, drawing from evidence in rural communities in Andhra Pradesh, India. Taylor shows that the vulnerability of households is strongly conditioned by the uneven control over critical productive assets such as land, water, labour, and credit between classes, genders and along caste lines (Taylor, 2013). These power relationships create a stratified human landscape in which the access to assets, and therefore vulnerability, are unequally distributed. Furthermore, it showcases how the dominant groups create relative security for themselves through their power relationships and control while simultaneously creating the vulnerability of other social groups (Taylor, 2013). These processes underline how socially produced marginalisation influences how vulnerability is distributed throughout society (Pelling, 2001).

All in all, vulnerability is understood as a multidimensional concept consisting of many social, economic, cultural, and political conditions. These conditions are not static, nor do they fall out of the sky (Adger, 2006). Instead, the societal conditions of vulnerability are dynamic and exist in relationships to space and time. In the following subchapters, these spatial and temporal relationships are discussed.

2.4 Spatiality of Vulnerability

Vulnerability is inherently linked to space. Due to spatial variations of environmental and socio-economic processes, vulnerability differs from place to place. In this research, the spatiality of vulnerability refers to all relationships between vulnerability and space. In conceptualising these relationships, a distinction can be made between the spatial distribution of vulnerability and the spatial production of vulnerability.

2.4.1 Spatial Distribution of Vulnerability

Spaces of vulnerability refer to the spatial distribution of vulnerability in a given geographic area. Watts and Bohle (1993) were among the first to conceptualise the spaces of vulnerability. They considered how the socio-economic, political, and historical vulnerability processes were not equally distributed across space. To explain this spatial differentiation of vulnerability, Watts and Bohle introduced the concept of spaces of vulnerability, referring to the place-specific characteristics of the localities in which vulnerability manifests itself (Cutter, 1996; Watts and Bohle, 1993). Vulnerability is locationally driven, meaning that locational factors (e.g., site-specific geomorphological, hydrological, or socio-economic conditions) shape the vulnerability in a given place (Cutter, 1996; Etzold and Sakdapolrak, 2016).

As a consequence, differences in locational factors result in a spatial differentiation of vulnerability. The localities can further serve as a 'container' to capture this spatial distribution. This way, a place-based analysis of vulnerability can reveal 'vulnerable places': localities in which a relatively high level of vulnerability is manifested (Etzold and Sakdapolrak, 2016; Preston *et al.* 2011).

2.4.2 Spatial Production of Vulnerability

The spatiality of vulnerability, however, moves beyond the spatial distribution of vulnerability. Space is understood as not only a section of the Earth's surface, but also as a socially produced environment, continuously being 'in the making'. As a result, humans are producing specific geographies, creating spatial relationships that, in turn, shape our societies, economies, cultures, and natural environments (Etzold and Sakdapolrak, 2016). Consequently, the spatiality of vulnerability is not solely an outcome of unequal spatially distributed conditions and processes but also a driving force in the production of vulnerability.

While the importance of place-specific vulnerability cannot be underestimated, the vulnerability of people is not bounded by site-specific factors (Eakin *et al.* 2009). Instead, vulnerability is also linked in social space, referring to all the relationships, interconnections, and networks that connect social practices through space (Etzold and Sakdapolrak, 2016). Because of this, places of vulnerability must not be seen in isolation but can only be understood in their connection to other places. The spatial relationships connect the social practices between different localities, shaping the socio-economic context in which vulnerability manifests itself (Etzold and Sakdapolrak, 2016). The important implication of these spatial relationships is that changes in one place could have consequences for the other place, linking vulnerability between spatially distant groups of people (Eakin *et al.* 2009).

Consequently, vulnerability has become a nested and teleconnected phenomenon, in which independent actions of people can have synergistic or contrary effects at a broader scale and in different places (Eakin *et al.* 2009). Due to globalisation, this interconnectedness has intensified over the last decades. Adger *et al.* (2009) identified three mechanisms that link people's vulnerability across space: economic market linkages, the flows of resources, people, and information, and biophysical linkages and feedbacks. Through these linkages, local livelihoods and vulnerability are both interconnected to global processes (O'Brien and Leichenko, 2000) and translocal conditions (Zoomers and Van Westen, 2011). To illustrate, Ayele and Degefa (2019) and Eriksen and Silva

(2009) found how global economic fluctuations influence the local vulnerability of smallholder farmers in Africa. Another example by Islam and Herbeck (2013) illustrates how migration creates translocal livelihoods that connect the vulnerability of fishery households in Bangladesh to the socio-economic conditions of migrant places. These are merely a few examples of the ways spatial linkages connect the conditions of vulnerability in one place to distant places.

The above examples further showcase that vulnerability exists in a dynamic multi-scalar landscape as vulnerability is produced by the social interactions between local, regional, and global processes (Turner *et al.* 2003). However, it should be noted that the spatiality of vulnerability is always locally rooted, meaning that people's vulnerability in certain places fundamentally rests on the specificity of spatial linkages across the different spatial scales (Etzold and Sakdapolrak, 2016; O'Brien and Leichenko, 2000). This way, the localities' local conditions ultimately produce the local differentiations in the spaces of vulnerability.

2.5 Temporality of Vulnerability

Similar to the relation to space, the concept of vulnerability is an intrinsically dynamic concept that only exists in relation to time. As vulnerability arises out of processes of marginalisation and social differentiation, vulnerability inherently has historical roots. Addressing vulnerability, therefore, requires understanding the temporal geographies of these socio-economic conditions (Eakin *et al.* 2009). Nevertheless, the temporal aspects of vulnerability remain one of the least studied aspects of vulnerability, even though the temporality of vulnerability creates the dynamic nature of the concept (Wisner *et al.* 2012). Vulnerability is not a static condition but changes over time in varying directions: increasing, decreasing, accelerating, oscillating, concentrating, or diffusing (Bankoff *et al.* 2013). Moreover, these changes occur at different time scales: cyclical, short-term, and long-term dynamics.

2.5.1 Cyclical dynamics

Cyclical changes of vulnerability refer to the short-term recurrent variations that affect the conditions of vulnerability. For example, in the Global South, rural livelihoods and food security are dominated by seasonality (Blackmore *et al.* 2021; Dercon and Krishnan, 2000). The seasonal fluctuations influence the harvest, impacting essential livelihood assets such as income, labour, and access to food (Dercon and Krishnan, 2000). In turn, these dynamics have a profound impact on farmers' vulnerability. This is especially true for smallholder farmers, who are often most dependent on their agricultural production to sustain their livelihoods (Blackmore *et al.* 2021). However, the cyclical dynamics of vulnerability often go unnoticed for outsiders, as the seasonality of vulnerability has, in general, no major effect on the average year-to-year vulnerability (Dercon and Krishnan, 2000).

2.5.2 Short-term dynamics

Temporal dynamics in the short-term (i.e. year to decadal-scale) have more profound lasting impacts on communities' changing vulnerability (Bankoff *et al.* 2013). For example, a study by Cutter and Finch (2008) on changing levels of vulnerability in the United States over the last 50 years emphasises the role of urbanisation, economic development, migration, and population change in the decadal dynamics of vulnerability. Similar results were found in China (Zhou *et al.* 2014) and Chile (Bronfman *et al.* 2021). Furthermore, it was found that natural hazards themselves can also act as agents of change to people's vulnerability. Differences in the recovery and response to hazardous events, as well as environmental degradation, can further exacerbate inequalities in vulnerability (Das *et al.* 2021; Veira *et al.* 2020). Natural hazards are, thus, not only events that intersect with a population's vulnerability but also agents of change regarding vulnerability through required social, economic, or political adjustments (Wisner *et al.* 2012).

2.5.3 Long-term dynamics

Most temporally distant are the long-term dynamics of vulnerability. These processes refer to the root causes of vulnerability and represent interrelated and widespread processes within the society and economy (Bankoff *et al.* 2013). These root causes are profoundly intertwined with contemporary social and cultural ideologies, assumptions, norms, and values and are often invisible or taken for granted by the people concerned (Wisner *et al.* 2004). One of the first studies that addressed the long-term dynamics of vulnerability was Oliver-Smith's (1994) essay on the 1970 Yungay Earthquake of Peru. Oliver-Smith (1994) argued that the question of time is a crucial aspect of any consideration of vulnerability, as it is the people's adaptation (or maladaptation) over time to the changing social-ecological environment that determines their vulnerability. In the case of the 1970 Yungay Earthquake, the disaster was as much a product of the region's historical (under)development, traced back by Oliver-Smith 500 years to the socio-economic and political consequences of the Spanish conquistadors, as it was of the earthquake itself (Oliver-Smith, 1994).

The study highlights the long-term dynamics that ultimately affects the contemporary conditions of vulnerability. Consequently, to thoroughly understand the patterns of vulnerability in a particular region, the long-term dynamics should not be neglected (Bankoff *et al.* 2013).

2.5.4 Temporality and Scale

The different temporal dynamics in which processes of vulnerability operate in a multi-scalar temporal landscape (De Vries, 2011). The temporal processes of vulnerability move at different speeds, creating a multi-dimensional temporal landscape that stretches from the past to the present. In this temporal landscape, vulnerability is a dynamic concept shaped by a combination of many long-term, slow-acting and short-term, fast-acting processes (De Vries, 2011; Wisner *et al.* 2004). Inherently, the temporal landscape is related to the multi-scalar social landscape of vulnerability, in which temporality influences the multidimensional spatial relations that produce vulnerability (Eakin *et al.* 2009).

2.6 Conceptual Framework

Figure 2.1 shows the conceptual framework to organise vulnerability theory that is used in this research. Natural disasters can be understood as the interaction between natural hazards and vulnerability. Vulnerability denotes the societal conditions that contribute to the production of a natural disaster (subchapter 2.1) (Wisner *et al.* 2004). Vulnerability consists of a myriad of socio-economic, political, and cultural conditions that are shaped by processes of marginalisation and social differentiation (subchapters 2.2 and 2.3) (Gibb, 2018; Taylor, 2013; Wisner *et al.* 2004). These processes shape the spatiality and temporality of vulnerability. These dynamics range from long-term and large-scale changes to short-term and small-scale changes (subchapters 2.4 and 2.5). (Bankoff *et al.* 2013; Eakin *et al.* 2009). As figure 2.1 shows, these social conditions, spatiality, and temporality of vulnerability are interconnected. This means that the vulnerability of communities is continuously being produced and reproduced through these interconnections, as one changing condition will affect other conditions (Eakin *et al.* 2009). Whether a natural disaster occurs (the question mark in figure 2.1) depends on the level of vulnerability combined with the probability of a natural hazard: i.e., disaster risk (Wisner *et al.* 2004).

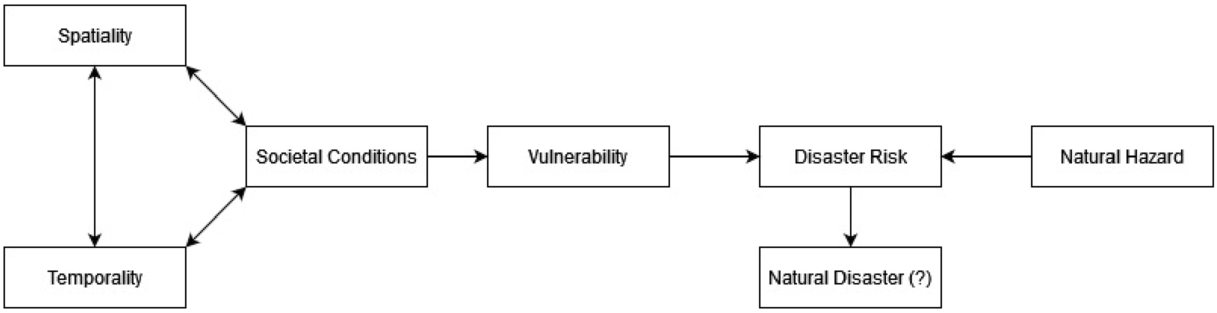


Figure 2.1. Conceptual Framework. In this framework, spatiality denotes all scalar dynamics (e.g., global, regional, or local) of vulnerability. Similarly, temporality denotes all temporal dynamics (e.g., cyclical, short-term, or long-term changes).

To understand vulnerability in a particular region, one should therefore gain insight into the societal conditions that together encompass the conditions of vulnerability, the way spatiality influences these social conditions, how temporality affects these social conditions, and how these processes are intertwined (figure 2.1). This way, the vulnerability landscape(s) will be uncovered.

2.7 Research Questions

By using the presented conceptual framework, this research aims to uncover the spatial and temporal dynamics of vulnerability in two disaster risk hotspots in India: the Cauvery and Godavari Deltas. To guide this research, the following central research question is formulated:

RQ: How are vulnerability landscapes being produced and reproduced in the Cauvery and Godavari Delta?

This overarching research question is answered on account of three sub-questions:

SQ1: What is the current spatial distribution of vulnerability in the Cauvery and Godavari Delta?

SQ2: How have socio-economic temporalities contributed to the vulnerability landscape in the Cauvery and Godavari Delta?

SQ3: How have land-use temporalities contributed to the vulnerability landscape in the Cauvery and Godavari Delta?

By answering SQ1, this study gains insights into the spaces of vulnerability of both deltas: i.e. how vulnerability is spatially distributed across the two deltas, highlighting both hotspots and coldspots of vulnerability. SQ2 and SQ3 further explore the found patterns of vulnerability by analysing how socio-economic and land-use changes have produced and reproduced the vulnerability landscape in the Cauvery and Godavari Delta across time. This way, the temporality of vulnerability will be assessed. Together, the three sub-questions answer the main RQ, in which the holistic vulnerability landscape of both deltas is thus assessed.

3 | Study Areas

This research consists of two case studies of South Indian coastal deltas: the Cauvery Delta and the Godavari Delta. The Cauvery Delta case study consists of an extensive analyse of vulnerability in this delta, in which the spatiality and temporality will be researched in-depth. The Godavari Delta case study is less elaborate and is used as a control case. This chapter provides a short description of both deltas.

3.1 Cauvery Delta

The Cauvery Delta is a coastal river delta located in Tamil Nadu, South India (figure 3.1). The Cauvery Delta is situated at the mouth of the 80.000 sq. km Cauvery river basin, culminating in the Bay of Bengal. The Cauvery (or Kaveri) river – an 800 km long river flowing through Karnataka and Tamil Nadu – is seen as one of the seven holy rivers in India, sacred to the people and worshipped as the Goddess Kaveriamma (Arni and Henry, 2009). The Cauvery Delta encompasses an area over 4000 sq. km and consists of the districts Thanjavur, Thiravurur, Nagapattinam, and Mayiladuthurai, and parts of Tiruchirappalli District. According to the latest Population Census, the delta inhabits 6.569.701 people, of which 61% are rural communities[3] (Government of India, 2011a).

These rural communities mainly depend on agriculture for their livelihoods. Paddy is the principal crop in the delta, consisting of more than 50% of the total cultivated area (Paramasivan and Pasupathi, 2016). The intensive agriculture in the delta is supported by an extensive canal irrigation network dating back more than 1800 years. This canal network irrigates more than 75% of the irrigated area in the Cauvery Delta (Stacey and Visweswaran, 2013). For centuries, this irrigation network in the delta has supported intensive paddy cultivation; hence the Cauvery Delta is also known as the 'rice bowl of Tamil Nadu' (Arni and Henry, 2009). Today, more than 80% of the rural livelihoods in the delta are dependent on agriculture (Government of India, 2011a). The agricultural communities in the Cauvery Delta are threatened by several environmental threats, including drought, flooding, and cyclones (Ganesan, 2018; Yamunan, 2017). Similarly, groundwater depletion and salinisation are occurring in the delta (Srinivasan, 2019).

3 Rural communities are defined by the Government of India as: any administrative area that was not classified as 'urban'. Urban tracts were defined as either Statutory Towns (units defined by statute as urban), or as Census Towns, satisfying the criteria of: i) a minimum population of 5000; ii) 75% and above of the male main working population being engaged in non-agricultural pursuits; and iii) a population density of at least 400 persons per sq. km (Government of India, 2011).

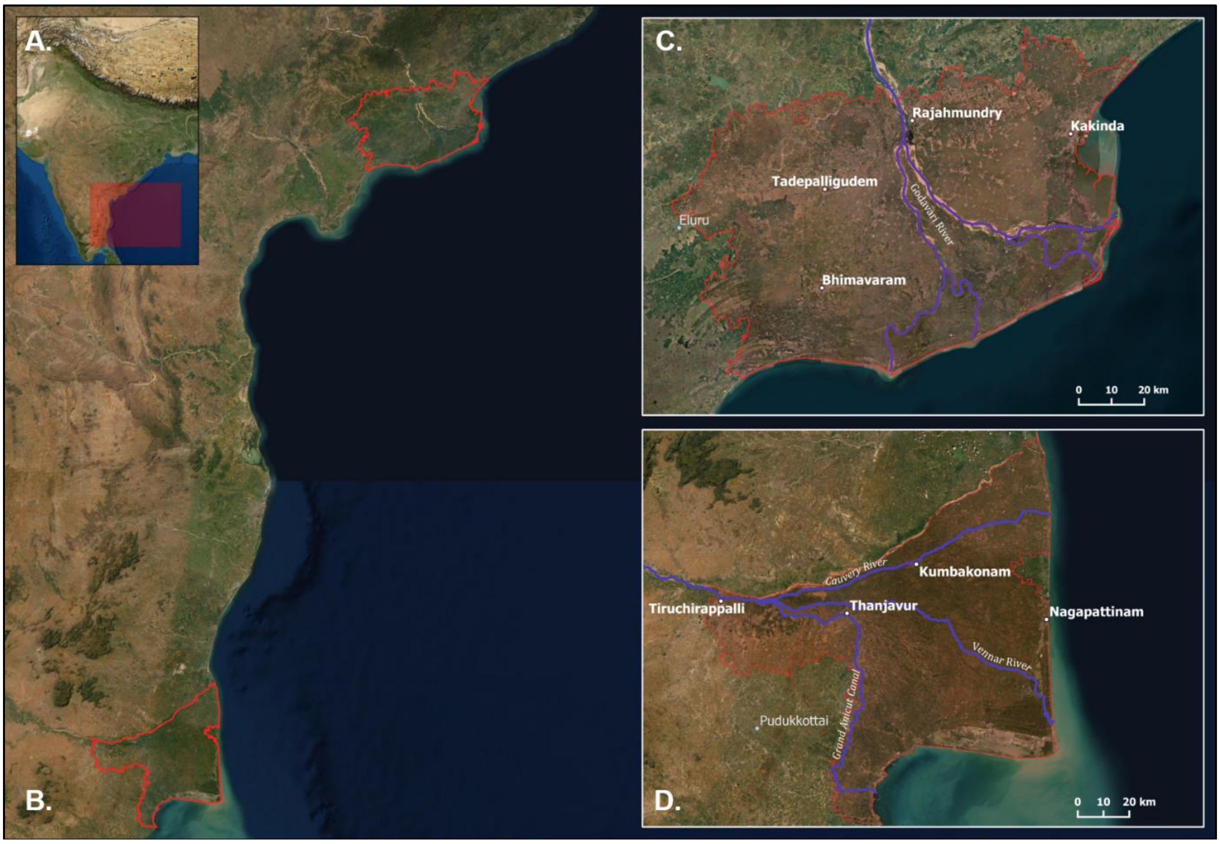


Figure 3.1: Location of the Cauvery and Godavari Delta. A: Overview of India. B: Location of the two deltas on the Coromandel Coast. C: Overview of the Godavari Delta. D: Overview of the Cauvery Delta. Satellite imagery from ESRI/NASA. Cities are mapped (C and D) with more than 100.000 inhabitants according to the 2011 Census.

3.2 Godavari Delta

The Godavari Delta is a coastal river delta located in the state of Andhra Pradesh (figure 3.1). The Godavari Delta is located at the mouth of the 1465 km long Godavari river (India's second-largest river after the Ganges) adjacent to the Bay of Bengal. The river is the second-largest in India in peninsular India regarding length, catchment area and discharge; consequently, it has been dubbed the *Daskhina Ganga*: the Ganges of the South. The Godavari enters the coastal flood plains near the city of Rajahmundry (or Rajamahendravaram), where it builds a fan-delta spread over 5800 sq. km (Rao *et al.* 2015).

Similar to the Cauvery, the Godavari has strong religious and cultural significance as the river is sacred to Hindus. Historically, the Godavari Delta has been a region of economic and political importance due to its productive soils and location close to the Krishna Delta, another important delta in South India. The Godavari Delta consists of large parts of the West- and East-Godavari Districts and Krishna District and is inhabited by 6.107.910 people, of which 82% live in rural areas

(Government of India, 2011a). In the delta, paddy cultivation is the main agricultural activity, supported by a canal irrigation network dating back to the construction of the Dowleswaram Barrage in 1850.

The Godavari Delta is found to be at high risk of cyclones and flooding events. According to Chakraborty and Joshi (2016), the Godavari deltaic districts belong to the most flood-prone districts of India. Furthermore, Mohapatra *et al.* (2012) classified the Godavari districts as the most cyclone-prone districts of India. This is illustrated by Cyclone 07B, which made landfall over the Godavari Delta in 1996. The cyclone caused over 1000 deathly casualties, damaged over 640.000 houses and led to 61.624 million Rs of economic losses (O'Hare, 2001). Due to the low-lying area, high population density, and relatively low economic development (in terms of GDP), the Godavari Delta is typified by Tessler *et al.* (2015) as one of the coastal deltas most at risk for climate change worldwide. The disaster risk in the Godavari Delta is exacerbated by land subsidence due to groundwater extraction, mining, and sediment trapping in the Godavari basin (Syvitski *et al.* 2009; Rao *et al.* 2015). Besides flooding, droughts are becoming a frequent issue in the Godavari Delta increasingly. The study of Dixit *et al.* (2021) indicates that the risk of future drought events in the Godavari Delta is likely to intensify with climate change.

The Cauvery and Godavari Delta are two deltas that share key characteristics associated with deltaic risk hotspots (De Souza *et al.* 2015). Both deltas have large rural populations dependent on agriculture. Furthermore, both deltas are susceptible to multiple natural hazards. Besides this, the deltas have a similar population size and share the feature that the agricultural practices in the delta are primarily dictated by major irrigation systems. Despite the regional importance of the Cauvery and the Godavari Delta, their large population, and their susceptibility to natural hazards, no vulnerability analysis exists in either delta.

4 | Methodology

This research aims to uncover the spatial and temporal dynamics of vulnerability in the Cauvery and Godavari Delta by answering the main research question: 'How are vulnerability landscapes being produced and reproduced in the Cauvery and Godavari Delta?'. To answer the research question, a mixed-methods research is conducted. In this chapter, the methodology of the research is discussed. First, an overview is provided of the research design, in which the quantitative as qualitative research methods are introduced. Next, the quantitative research method, a vulnerability index to quantify vulnerability, is discussed. After this, the qualitative methods are elaborated. Finally, this chapter ends with a consideration of the limitations of this study.

4.1 Research Design

To uncover the vulnerability landscapes of the Cauvery and Godavari Delta, this study consists of a mixed-methods approach, combining both quantitative and qualitative research methods. The added value of a mixed-method approach has been widely established in vulnerability studies (Roelen and Campfield, 2015). It integrates the benefits of both quantitative and qualitative methods and allows the study of vulnerability from a more holistic perspective.

To better understand the vulnerability landscapes of the Cauvery and Godavari Delta, this research adopts a quantitative approach to measure the level of vulnerability. In this research, vulnerability is measured by the use of a vulnerability index (VI). Vulnerability refers to a multidimensional concept encompassing a series of societal conditions. This theoretical multidimensionality makes vulnerability a non-observable phenomenon, as it cannot be directly be observed, unlike, for instance, temperature, amount of precipitation, or monthly income (Hinkel, 2011). By using quantitative indicators, a non-observable phenomenon can still be operationalised. Herewith, an observable variable is used as a proxy to measure a theoretical non-observable variable. An index is formed by aggregating multiple observable variables into a single scalar indicator. This way, the 'non-observable' level of vulnerability can still be quantified, taking its multidimensional character into consideration (Hinkel, 2011).

To illustrate the use of such indicators, the United Nations uses the Human Development Index (HDI) to measure the non-observable concept of 'human development', with the use of the observable measures 'life expectancy', 'years of schooling', and 'GNI per capita' (UNDP, 2020).

Similarly, indices are widely used by scholars to quantify, measure, and analyse vulnerability in different geographical, socio-economic, and environmental contexts (Otto *et al.* 2017; Wolters and Kuenzer, 2015). For this study, a unique VI was created to measure the level of vulnerability in Indian deltas, taking the research focus and theoretical demarcation into account. These results are used to map the level of vulnerability and expose the spatial differences of vulnerability in the Cauvery and Godavari Delta. This process is elaborated in subchapter 4.2.

To better understand and situate the results of the quantitative analysis, a qualitative literature study was performed. By conducting a literature study, contextual insight was attained into the socio-economic and historical contexts of the Cauvery and Godavari Deltas. These insights helped to improve the interpretation of the found patterns of vulnerability. Furthermore, the literature allowed for a depiction of how vulnerability has been produced through time by analysing the main socio-economic developments. In addition to the literature study, several local experts of the Cauvery Delta were consulted to understand the local context better. These qualitative research methods are further explained in subchapter 4.3.

As mentioned in chapter 3, two case studies have been performed in this research: a more detailed study of the Cauvery Delta and a smaller control study of the Godavari Delta. The implications of these different case studies are elaborated upon in subchapter 4.4, along with other research limitations.

4.2 The Indian Delta Vulnerability Index

As mentioned before, a VI is a method to quantify and measure the level of vulnerability. Both scholars and practitioners apply VIs to quantify vulnerability, identify vulnerability hotspots, and communicate these findings (Hinkel, 2011; Wood *et al.* 2021). VIs are used in research on vulnerability in the Ganges-Brahmaputra (Das *et al.* 2021), Mekong (Tran *et al.* 2017), Yangtze (Chen *et al.* 2013), and Mississippi Delta (Anderson *et al.* 2019), among others. Within the Indian context, VIs were used in the context of drought (Balaganesh *et al.* 2020), cyclones (Mohapatra *et al.* 2012), and COVID-19 (Mohanty, 2020), as well as in state-specific vulnerability assessments of Arunachal Pradesh (Maiti *et al.* 2017) and Kerala (Shaji, 2021). Although the VIs used in the studies mentioned above contain valuable insights, they could not be replicated in this research due to conceptual, geographic, technical, and data-specific disparities. For instance, indicators used in these VIs considered the probability of natural hazards, biophysical characteristics (e.g., beach slope, or distance to the coast), could only be attained via a questionnaire, or were unattainable for the spatial scale in which this research operates. Considering that the application of VIs are dependent on the theoretical demarcation of vulnerability, and consequently, the local context, I developed a unique to reflect the focus of this research.

To quantify and expose the vulnerability landscape in the Cauvery and Godavari Delta, I developed the Indian Delta Vulnerability Index (IDVI). Figure 4.1 shows the steps that were undertaken to obtain the IDVI. To obtain the IDVI, the construction of the index was divided into four main phases: set-up, data processing, index aggregation, and vulnerability analyses. Each phase consists of multiple research steps, following the method described by Rufat *et al.* (2019) (figure 4.1). The construction of the IDVI consists of an iterative process: meaning that the applied methodology was continuously refined and improved during the research period. The following text briefly explains the research steps taken in the four phases, after which they are elaborated upon in the subsequent sections. In the set-up phase, the framework of the IDVI was designed (section 4.2.1). The IDVI consists of a hierarchal framework to represent the different dimensions of vulnerability. The index was designed for community-level analysis in the two deltas. Based on academic

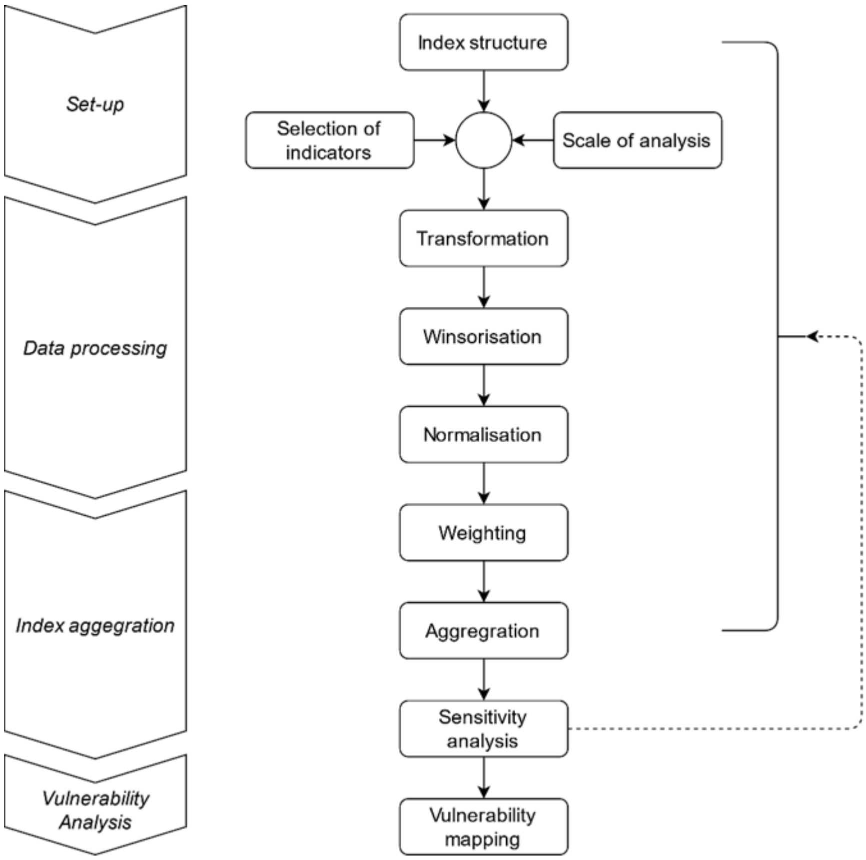


Figure 4.1: Vulnerability Index construction flowchart. Adapted from Rufat *et* al. (2019). The dotted line illustrated the iterative process of the index construction

literature and criteria of theoretical consistency, feasibility, commonality, and distinctiveness, variables and indicators were selected. In the data processing phase (section 4.2.2), the obtained variable values were transformed, winsorised, and normalised to make them comparable and aggregable. After this, all variables and indicators' weighting was determined before combining all components into the single scalar index (section 4.2.3). In addition, a sensitivity analysis was conducted, and improvements to the IDVI were made if necessary. Finally, the IDVI was used to analyse social vulnerability using different mapping techniques (section 4.2.4).

4.2.1 Set-up phase

The set-up phase consisted of creating the index structure, determining the scale of analysis, and selecting suitable variables and indicators. The index structure denotes the way all variables and indicators are organised within the index. In this research, the IDVI is structured by a hierarchical design. In this hierarchical structure, the variables are separated into (sub-)indices that share the underlying conditions of vulnerability (Tate, 2012). This way, the IDVI represents the different theoretical dimensions of vulnerability (Rufat *et al.* 2019). Besides the better representation of the multidimensionality of vulnerability, hierarchical models were found to show more robustness to the selection and measurement of variables compared to more data-driven inductive vulnerability models (Rufat *et al.* 2019; Spielman *et al.* 2020; Tate, 2012).

Table 4.1 represents the hierarchical structure of the IDVI. The index is composed of 8 indicators, representing the different conditions of vulnerability. These indicators were constructed by 25 variables, ranging from 1 variable for the indicator 'Education' to 6 variables for 'Standard of Living'. Further, table 4.1 shows the complete list of all variables of the IDVI, including motivation for inclusion. The indicators and variables of the IDVI were identified through the conceptualisation of vulnerability (chapter 2) and previous applications of VIs in academic literature. Earlier studies of vulnerability in a deltaic or Indian context were taken as the point of departure.

To ensure that the indicators and variables of the IDVI are viable proxies for the different conditions of vulnerability, they were selected based on criteria of theoretical consistency, feasibility, commonality, and distinctiveness. Firstly, the theoretical consistency was considered: variables were only included if they sufficiently measured the condition it aimed to assess. The feasibility depended on data availability and accessibility: only data that was possible to obtain and process in the timeframe of this research were included. Hence, this data was confined to the use of secondary census data collected by the Government of India. In addition, variables were only included if data were available for both the Cauvery and Godavari Delta at the community level. For this reason, data that was only available at the taluk or district level (e.g., statistics such as infant mortality or GDP per capita) was not included in this research. Lastly, the distinctiveness of variables was considered to prevent multicollinearity within the indicators, which would lead to double-counting of similar phenomena and, consequently, reduce the accuracy and robustness of the index (Spielman *et al.* 2020) (Appendix 1).

As already mentioned, the scale of analysis in this research is at the community level. In this research, vulnerability is quantified with the IDVI at the community level to reflect best the local spatial differences in vulnerability within the Cauvery and Godavari Delta. The units of analysis in this research are the administrative units of Gram Panchayats (GPs). GPs represent the lowest administrative area in India with a governance function, consisting of one or multiple villages. A GP is a political institute at the grassroots level responsible for a range of primary administrative, socio-economic, and judicial functions, such as maintaining local infrastructure, providing primary education, and local justice (Besley *et al.* 2007). Herewith, GPs are the smallest unit of intervention from an institutional perspective for potential adaptation measures (ibid.).

In total, 1514 and 1010 GPs of respectively the Cauvery and Godavari Delta were analysed using the IDVI. However, not all GPs of the two deltas were included in the analysis due to conditions of missing data, uninhabited census tracts, or missing GP codes. These GPs were excluded from the analysis and treated as 'missing data'. Furthermore, the GPs do not consist of any urban census tracts. Consequently, no urban tracts in the two deltas were incorporated in this vulnerability analysis. The exclusion of urban census tracts from the analysis was also an intentional choice, as the vulnerability conditions in the city differ from the conditions in rural areas, related to the dependence on climate-sensitive livelihoods as agriculture, among others (Singh *et al.* 2017). As the vast majority of the Cauvery and Godavari Delta is rural, the primary focus of the analysis is naturally rural census tracts. Lastly, the IDVI could only be obtained for the latest census year in India: 2011. Due to the lack of data availability at the community level, the IDVI could not be consistently applied using earlier census data (e.g., 2001 or 1991). The implications of this are further discussed in chapter 4.4.

Table 4.1. Description of IDVI indicators and variables

Indicators	Variables		Rationale
Demography	*Population Density*	Number of people per square kilometre	Areas with higher population density are more exposed to natural hazards (Das *et al.* 2021)
	Household Size	Average number of people per household	Households with large number of people have limited resources and more (work) responsibilities that reduces the adaptive capacity (Adger, 1999; Cutter, 2003; Das *et al.* 2021)
	No 15-59	Percentage of households with no member of age 15-59	Persons in vulnerable age groups (children and elderly) are more susceptible to the impacts of natural hazards (Cutter, 2003; Ngo, 2001; Wisner *et al.* 2012)
	Disabled population	Percentage of disabled persons to total population	Disabled persons are more susceptible to the impacts of natural hazards (Cutter, 2003; Hemingway and Priestley, 2006; Wisner *et al.* 2012)
Gender	*Female population*	Percentage of females to total population	Females are found to be more vulnerable to natural hazards due to their family care responsibilities and limited resources (Cutter, 2003; Das *et al.* 2021; Rahman, 2013; Wisner *et al.* 2012)
	Gender Literacy Gap	Difference (in percentage) in literacy rate between men and women	Gender inequality exacerbate the vulnerable position of females (Rahman, 2013; Wisner *et al.* 2012)
Education	*Illiteracy rate*	Percentage of illiterates to total population	Illiteracy or lower level education constraints the access to, and the ability to understand, adaptation or recovery information (Das *et al.* 2021; Muttarak and Lutz, 2014; Wisner *et al.* 2012)
Standard of Living	*Unsafe Drinking Water*	Percentage of households with no access to safe drinking water sources to total population	Households with no access to safe drinking water, electricity connection, sanitation, bathroom, modern cooking fuels, and kutcha housing live in marginal living conditions. These households are more susceptible to the impacts of natural hazards (Cutter, 2003; Das *et al.* 2021; Hagenlocher *et al.* 2018; O'Hare, 2001)
	No Electricity Connection	Percentage of households with no electricity connection to total population	
	No Sanitation	Percentage of households with no sanitation facilities in their premise to total population	
	No Bathroom	Percentage of households with no bathrooms to total population	
	No Modern Cooking Fuels	Percentage of households using no modern cooking fuels to total population	
	Kutcha Housing	Percentage of households with kutcha housing to total population	
Economic Productivity	*Non-Workers*	Percentage of non-working people to total population	Non-workers workers have limited resources and adaptive capacities (Das *et al.* 2021; Myers *et al.* 2008)
	Marginal Workers	Percentage of marginal workers to total population	Marginal workers have limited resources and adaptive capacities (Hagenlocher *et al.* 2018; Myers *et al.* 2008)
Agriculture	*Agricultural Labourers*	Percentage of agricultural labourers to total population	Agricultural labourers are more senstitive to natural hazards and changes (Pandey *et al.* 2010)
	No Mechanised Wheelers	Percentage of households with no access to mechanised agricultural wheelers	Rural households with no access to modern agricultural technologies tend to have limited resources (Cutter, 2003; Pandey *et al.* 2010)
	Marginal Landholdings	Percentage of total landholdings smaller than 1 ha to total landholdings	Marginal landholdings have limited resources and adaptive capacities (Cutter, 2003; Hagenlocher *et al.* 2018)
Income and Assets	*Under Rs. 5000*	Percentage of households with monthly income smaller than Rs. 5000 to total population	People with low incomes have less access to resourses and less capacities to adapt, sustain, or recover from hazard impacts (Adger, 1999; Cutter, 2003; Das *et al.* 2021; Hagenlocher *et al.* 2018)
	No Banking Services	Percentage of households with no access to banking services to total population	No access to banking services reduces the access to resources and assets (Fatemi *et al.* 2017)
	No Mobile Telephone	Percentage of households with no access to a mobile telephone to total population	Households with no mobile telephone have limited resources and less access to information (Fatemi *et al.* 2017
	No Motorised Vehicles	Percentage of households with no access to motorised vehicles to total population	Households with no motorised vehicles have limited resources and assets (Cutter, 2003; Hagenlocher *et al.* 2018)
	No Refrigerator	Percentage of households with no refrigerator to total population	Households with no refrigerator have limited resources and income assets (UNDP, 2020)
Caste	*Caste Population*	Percentage of scheduled caste (SC) population to total population	SC population are more susceptible to hazard impacts due to marginalisation and limited political power (Taylor, 2013; O'Hare, 2001).
	Caste Literacy Gap	Difference (in percentage) in literacy rate between SC and non-SC households	Caste inequality exacerbate the vulnerable position of SC groups (Taylor, 2013; O'Hare, 2001).

Notes.

• All variables are in percentages, with the exception of population density (persons per sq. km.) and average household size (number of people).

• All variables show a positive (+) functional relationship with social vulnerability, meaning the higher the value, the higher the social vulnerability.

Data Sources: Population Census of India. Housing Census, Socio Economic and Caste Census, Agricultural Census (Government of India (2011a) (2011b) (2011c) (2011d))

4.2.2 Data processing

Once all data for each variable of the IDVI was obtained, the raw values were processed to make them comparable and aggregable. First, data transformation was practised to make the variables' representation consistent. This was either done by calculating the percentage of the total population or the percentage of the total land surface (table 4.1). A different data transformation method was applied for the variables 'population density' and 'average household size' (table 4.1).

Next, the transformed data was winsorised to reduce the effect of possible outliers. Winsorisation is the process of limiting extreme values within a dataset by setting these values to a specific percentile (Dixon and Yuen, 1974). In this research, 90% winsorisation was used, meaning that all data below the 5th percentile was set to the 5th percentile, and data above the 95th percentile was set to the 95th percentile. This way, it was ensured that the dataset was less skewed at either end of the spectrum (Appendix 2). Consequently, the IDVI is more robust to outliers, enabling a more accurate analysis of the level of vulnerability. Following the winsorisation, the IDVI data was normalised to a standard measurement unit to compare and aggregate variables expressed in different measurement units (Boulanger, 2008). The data was normalised using linear normalisation (or Min-Max scaling):

$$z_i = \frac{x_i - x_{min}}{x_{max} - x_{min}}$$

Where x_i is the raw variable value for Gram Panchayat i, and x_{min} and x_{max} represent the relative minimum and maximum raw variable values for all GPs of the respective delta for the concerning variable. The fraction in this formula normalises all GP values, placing them on a scale from zero to one. With linear normalisation, the normalised values thus depend on the range of the data (Boulanger, 2008). For this reason, linear normalisation was applied two times: once using the maximum and minimum values per delta to analyse the differential vulnerability within the respective delta, and once using the range values of both deltas combined to compare the differential vulnerability across the two deltas.

4.2.3 Data aggregation

Following the data processing phase, the variables were aggregated into a single indicator to quantify the level of vulnerability. Before aggregation, the relative weight of each variable and indicator had to be determined. The weighting of variables and indicators in an index is primarily a democratic issue (Boulanger, 2008). This problem is especially true for vulnerability indices, as there is often no solid theoretical justification for weighting one indicator more than another (Hinkel, 2011; Rufat *et al.* 2019; Tate, 2012). In the case of the Cauvery and Godavari Delta, no evidence exists that a particular indicator should weigh more than others, given that disaster- or vulnerability-related studies in these regions are lacking. For this reason, all eight indicators are presumed as equally important to the production of vulnerability. Therefore, an equal weighting scheme was used[4].

The final aggregation of all normalised values into the 'overall' vulnerability measure was two-fold due to the hierarchical design. First, the normalised variable values were combined into a singular indicator value, denoting one of the eight conditions of vulnerability in this research. Second, the average value for all the respective variables was calculated to aggregate the variables into an indicator value. This calculation was done to preserve the normalised scaling (between 0 and 1) and compensate for the difference in the number of variables per indicator. Lastly, this aggregation process was repeated to accumulate all indicator values to find the final IDVI value, indicating the level of vulnerability for each GP.

However, as not all indicators of the IDVI are constructed by the same number of variables, certain variables did have a relatively higher weight than other variables. Therefore, a sensitivity analysis was performed to analyse the extent to which the different weights per variable influences the IDVI scores. The sensitivity analysis was performed by comparing the IDVI values with a control index in which all variables were given the same weight (essentially removing the hierarchical design of the IDVI). The sensitivity analysis found that the IDVI and control index were strongly positively correlated ($r = 0.94$). As a result of this, it can be concluded that the different weights of variables due to the hierarchical design do not result in a significantly different overall vulnerability score.

4 Multiple studies point to the importance of the weighting scheme for the robustness and accuracy of an index (Spielman *et al.* 2020; Tate, 2012). While this research follows an equal weighting scheme, the design of the IDVI enables other users their own weight to each variable or indicator.

4.2.4 Vulnerability analysis

With the final IDVI values, several mapping exercises were undertaken to quantitively analyse the spatial distribution of vulnerability in the Cauvery and Godavari Delta using QGIS software. The production of maps allows for an easy-to-understand visualisation, identification, and analysis of the spatial patterns of vulnerability, increasing this research's communicative value (Preston *et al.* 2011; UNISDR, 2015; Wood *et al.* 2021). Two types of maps were produced: a choropleth map illustrating the IDVI values and a spatial clustering map to highlight statistical spatial hotspots.

Spatial clustering maps were produced to determine the degree to which the level of vulnerability is correlated to itself across space (Anselin, 1995; Frazier *et al.* 2013). The spatial autocorrelation among the GPs was examined to analyse the similarity and dissimilarity in the spatial clustering of vulnerability in the two deltas. The spatial autocorrelation was calculated using the local indicator of spatial autocorrelation (LISA), or Local Moran's I. The Local Moran's I statistic measures the linear association between the IDVI value and the spatially weighted value of the same index and thus denotes the degree of spatial clustering of a variable (Anselin, 1995). By using the Local Moran's I in GeoDa software (Anselin *et al.* 2010), significant clusters (p-value < 0.05) of high IDVI values (high-high: hotspots), low values (low-low: coldspots) and spatial outliers (significant low values surrounded by significant high values and vice versa) were mapped.

4.3 Qualitative Research Methods

Besides the quantitative spatial analysis of vulnerability in the Cauvery and Godavari Delta using the IDVI, qualitative research methods were used to improve the interpretation of the vulnerability landscapes and further analyse the spatiality and temporality of vulnerability in these two deltas. Therefore, the qualitative research methods allow for a more holistic and in-depth comprehension of the conditions and processes of vulnerability in the two deltas.

A literature study was conducted to explain the socio-economic and historical context of the vulnerability landscape in the two deltas. Furthermore, the literature study was performed to shed light on the broad (historical) developments of the processes of vulnerability in order to understand the temporality of vulnerability. Academic and grey literature was searched using multiple search engines (e.g., Google, Google Scholar, Scopus, Web of Science, and JSTOR) to allow for a wide range of publications from different academic fields and years of publication. Furthermore, WorldCat was included as a search engine to include books (or book chapters) in the literature study. This literature study was used in a more 'narrative' way, instead of a systematic review consisting of strict criteria for inclusion. The reason is that this literature study was primarily explorative, as this research was the first to analyse the vulnerability landscapes of the Cauvery and Godavari Deltas. To fulfil the research aim, I argue, it was therefore unnecessary to include strict criteria for including publications or particular search queries.

Given that the Cauvery Delta case study was more in-depth, in addition to the literature study, several local experts of the delta were consulted to gain a better understanding of the local context here. This research was undertaken with the help of the Ashoka Trust for Research in Ecology and the Environment (ATREE). Within this organisation, the research project 'Pathways toward a sustainable and inclusive Cauvery Delta' is currently being undertaken[5]. Research results were regularly discussed with the responsible research team. Furthermore, the team has provided local insights into the context of the Cauvery Delta and have shed light on important local conditions and processes of vulnerability. Moreover, an online discussion has been held concerning the Cauvery Delta, agriculture, and vulnerability with professor K. Sivasubramaniyan of the Madras Institute of Development Studies. Prof. Sivasubramaniyan has a long expertise in the agricultural processes in the Cauvery Delta.

4.4 Limitations

This research has several limitations that should be taken into account. Firstly, the two case studies in this research consist of an in-depth analysis of the Cauvery Delta and a shorter control case study of the Godavari Delta. Because of this, only for the Cauvery Delta the spatiality and temporality of the vulnerability landscape are thoroughly analysed. However, due to time constraints, these in-depth analyses of the vulnerability landscape for the Godavari Delta could not be undertaken. Consequently, a more superficial vulnerability analysis leads to fewer recommendations for disaster risk reduction policies for the Godavari case.

The second limitation of this study is related to the quantification of vulnerability. As the IDVI relied on governmental census data for its variables, the selection of variables was naturally limited by the design of the governmental censuses. Although the census data was proven to be adequate to construct the IDVI, the primary goal of censuses is not to measure phenomena as vulnerability.

5 https://www.atree.org/projects/pathways-towards-sustainable-and-inclusive-cauvery-delta

Instead, census data is collected by the government to provide population characteristics and trends on a decennial basis. Consequently, certain relevant conditions of vulnerability, such as household health statistics or measures of social capital, are not covered in the Indian census. Therefore, these conditions could not be included in this research.

Additionally, the census data contained already formatted data, meaning that the census bureau already classified certain variables (e.g., grouping by age or caste groups). As a result, this research was restrained to these classifications as the unformatted data was not available. The limitations mentioned above regarding the use of census data influences the IDVI and, accordingly, the measure of vulnerability. However, as Smit and Wandel (2006, p. 289) state, the ultimate goal of a vulnerability assessment is not to produce a definite rating of a particular community's vulnerability but to attain information on the nature of vulnerability and its components, processes, and determinants. Therefore, despite the data constraints, this research still can provide imperative insights into the vulnerability landscape in the Cauvery and Godavari Delta with the available data.

Related to the issues above, the IDVI analysis in this research could only be performed with the most recent census data from 2011 because only for the 2011 Census data was available for all IDVI variables at the community level. For the older census (e.g., 2001 and 1991), 18 of the 25 IDVI variables were unavailable for the community level. Moreover, changes in village names, codes, and boundaries make it difficult to map the census data for the two case studies in a consistent way. Therefore, I decided not to include any census data of 2001 and 1991 for the vulnerability quantification. By only quantitatively analysing the vulnerability in the deltas for a single year, this research indeed only provides a snapshot of the vulnerability landscape and is thus in danger of becoming static (Ford *et al.* 2018; Wolters and Kuenzer, 2015). The inclusion of qualitative research, however, counters this issue. Hence, the spatial and temporal dynamics of vulnerability in the Cauvery and Godavari Delta are still incorporated in the analysis.

Further, another limitation of this research concerns the literature study, which only contained English publications. While English is an official language in India – and therefore, an English-only literature search still includes publications written by local Indian authors – this research fails to incorporate works written in other (local) languages, including Hindi, Tamil, and Telugu. In development studies, it is widely understood that including local, non-English publications could significantly improve the local understanding. However, given the scope and time of this research, it was not possible to include this.

5 | Vulnerability Landscape: Cauvery Delta

In this chapter, the vulnerability landscape of the Cauvery Delta is analysed. To understand the vulnerability landscape, first, the physical landscape of the Cauvery Delta is discussed. Next, the spatial distribution of vulnerability in the delta is analysed by assessing the IDVI results. Next, the temporality of the vulnerability landscape is explored by analysing the socio-economic and land-use changes in the delta. Finally, the chapter ends with a summary of the vulnerability landscape of the Cauvery Delta.

5.1 The physical landscape

In order to understand the vulnerability landscape of the Cauvery Delta, first, an introduction should be given to the physical landscape of the delta. The current physical landscape of the Cauvery Delta was formed in the Holocene as a response to the sea-level changes after the Late Glacial Maximum (Singh *et al.* 2015). The paleo beach ridges in the eastern delta are still evidence of this (figure 5.1a). The alluvium sediment deposits of the Cauvery distributaries formed the deltaic plain, consisting of fertile soils (Singh *et al.* 2015).

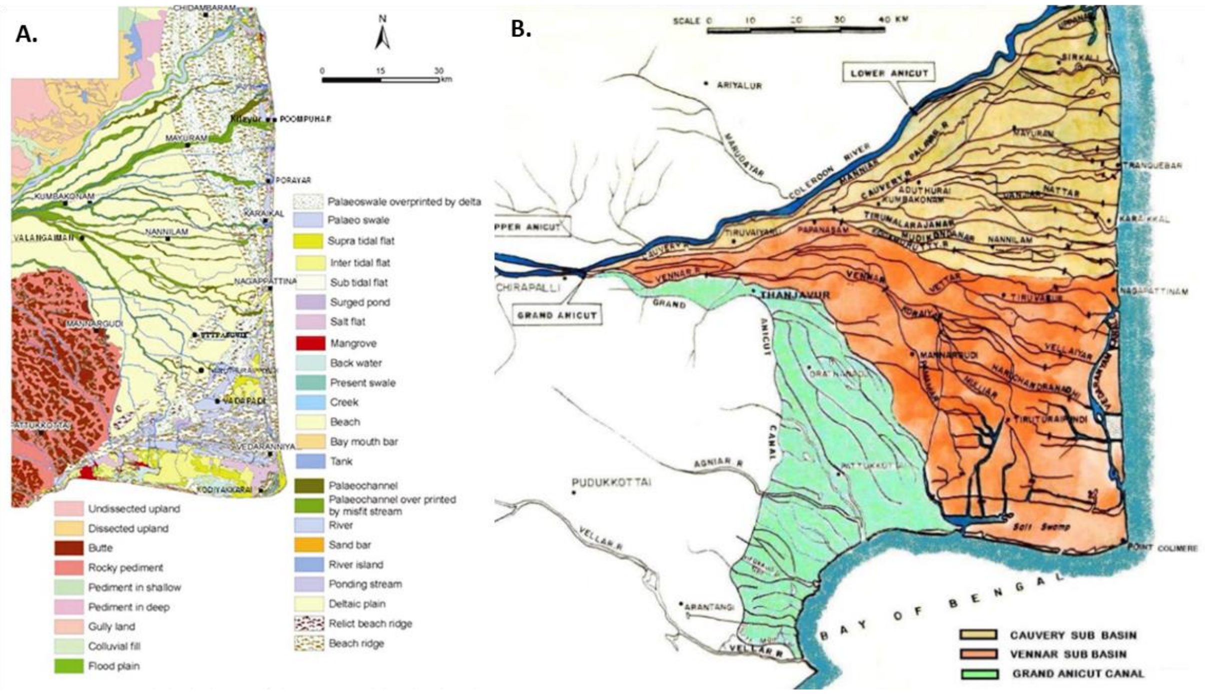


Figure 5.1. The physical landscape of the Cauvery Delta. A: The geomorphology of the delta (Singh *et al.* 2015); B. distribution of delta areas (Asian Development Bank, 2011).

The fertile sediments of the deltaic plains created an environment highly suitable for agriculture. For this reason, around 300 BC, human settlements shifted in the delta area from the surrounding highlands to the deltaic plains (Abraham, 2003). According to an ancient adage, the Cauvery Delta was so productive that the space which an elephant needs to lie down was sufficient to feed an entire family[6] (Bohle, 1983). However, the fertile sediment deposits came at a price. Again and again, the Cauvery waters would inundate the floodplain, destroying farmers' crops and dwellings (Bohle, 1983). Consequently, local Tamils have described the delta as *punal nadu*, 'the land of the floods'. In addition, the floods constantly changed the courses of the delta branches, creating a highly uncertain situation that allowed little continuity in either settlement or cultivation (Singh *et al.* 2015).

The situation of high uncertainty was changed due to human adjustments to the physical landscape. Under the rule of the Chola Dynasty[7], extensive hydraulic measures were undertaken. In the 2nd century AD, the Grand Anicut Dam was constructed near Tiruchirappalli. As one of the oldest water-regulator structures in the world, the Grand Anicut served to 'tame' the Cauvery, divert its waters across the delta, and create an extensive irrigation network (Bohle, 1985). This irrigation system, referred to as the Cauvery Delta Irrigation System (CDIS), consisted of a large-scale canal system that supported agricultural development in the delta (figure 5.1b). With the construction of the CDIS, the physical landscape of the delta was modified. At the Grand Anicut Dam, the Cauvery river was split in two. The Cauvery river continued its course in north-eastern direction, whereas the distributary Vennar river flowed in an easterly direction to the Bay of Bengal. The two rivers created a subdivision in the deltaic plains into the separate the Cauvery sub-basin and the Vennar sub-basin (figure 5.1b). Together, these two form the Old Delta[8].

The development of the CDIS throughout history was not linear. Until 1300, Chola rulers expanded the irrigation system by digging new irrigation channels and constructing new flow-over weirs (Bohle, 1983). After the collapse of the Chola Dynasty, the development of the CDIS stagnated. In the 18th century, the CDIS had become largely unmaintained and decayed after decades of political upheaval and regional conflicts (Bohle, 1985; Van Schendel, 1991). In the 19th century, the CDIS again was restored by the British colonial rulers. British engineers renovated the

[6] Moreover, the Cauvery is derived from 'Ka' and 'Viri', meaning 'one who brings abundance where she flows'. This emphasises the significance of the river for the agricultural activities.
[7] The Chola Dynasty was a thalassocratic Dravidian dynasty that ruled the Cauvery Delta between the 4th century BC until the 13th century AD. Under the rule of *Karikala Cholan*, the CDIS was built.
[8] In some studies, the deltaic Cauvery sub-basin is referred to as the Old Delta. In this research, the Old Delta refers to parts of the delta that consisted of the early irrigation system of the Grand Anicut: i.e. the Cauvery and Vennar sub-basin.

Grand Anicut Dam, restored and deepened the irrigation channels, raised river dams, and improved the water regulation and distribution in the Old Delta (Bohle, 1983; Van Schendel, 1991). In the 1930s, the last major expansion of the CDIS was completed, extending the irrigation system beyond the 'traditional' limits of the Old Delta. As part of the Mettur-Cauvery Project, the Grand Anicut Canal was dug near the Grand Anicut Dam to divert surplus water of the newly constructed Mettur reservoir (190 km west of the delta) (Bohle, 1985). The Grand Anicut Canal enabled canal irrigation in nearly 120.000 ha of the traditionally rainfed area east and south of the Old Delta (Bohle, 1983). This newly irrigated area was incorporated into the CDIS as the New Delta (figure 5.1b).

Although nowadays part of the Cauvery Delta, the New Delta is geomorphologically different from the Old Delta. Whereas the Old Delta is part of the deltaic plain of the Cauvery, consisting of alluvium deposits, the New Delta mainly consists of older Mesozoic and Tertiary sediments (Singh *et al.* 2015) (figure 5.1a). Furthermore, the New Delta is higher in elevation and contains less fertile soils than the Old Delta. Looking at the physical landscape of the Cauvery Delta, the region can thus be subdivided into three different areas: the Cauvery sub-basin, the Vennar sub-basin (together forming the Old Delta), and the New Delta. In these regions, canal irrigation formed the lifeblood of the Cauvery Delta for centuries (box 2).

Box 2. Agricultural Development in the Cauvery Delta

The creation of the CDIS had profound impacts on the agricultural practices in the Cauvery Delta. In the stage of origin of the deltaic system, nearly 100.000 – 150.000 ha of paddy cultivation was made possible by the CDIS, of which approximately 5% was under double-cropping (Bohle, 1983). Between 850-1300 AD, when the CDIS was expanded under the Chola Rulers, the paddy area under cultivation almost doubled to 200.000 – 220.000 ha (Bohle, 1983). However, after the decay of the Chola Dynasty, agricultural development stagnated. At the end of the 18th century, the Cauvery Delta experienced a period of decay. In 1780/1781, the Grand Anicut Dam was destroyed by Mysore ruler Haidar Ali (Bohle, 1985). Without the water regulation works, a series of destructive floods decreased agricultural production by more than 85% (Bohle, 1983).

The restoration and later expansion of the CDIS by the British administration saw a significant increase in agricultural activities in the Cauvery Delta. Between 1800 and 1947, the area under paddy cultivation had grown from 220.000 ha to 436.000 (98% increase), while the paddy production increased from 207.000 to 899.000 tonnes (334% increase). Furthermore, the area under double-cropping has increased from ca. 5% to ca. 20% (Bohle, 1983).

From the 1960s onwards, another major agricultural development took place in the Cauvery Delta. Under the Green Revolution, new rice varieties, chemical fertilisers, and pesticides increased the yield in the delta. Furthermore, the introduction of well-irrigation improved both the agricultural production, as the area under cultivation. By the late 1970s, the Cauvery Delta produced more than 1.150.000 tonnes paddy, while the paddy under cultivation had grown to almost 500.000 ha (Bohle, 1983). In addition, construction of thousands of tubewells enabled the irrigation with groundwater, instead of canal water. For this reason, the agricultural practices in the delta became more disconnected of the CDIS. Still, the majority of the landholdings in the Cauvery Delta remained dependent on canal irrigation, and the CDIS characterises the delta to this day.

5.2 Spaces of Vulnerability

Taking the physical landscape of the Cauvery Delta into account, the spatial distribution of vulnerability in the delta was analysed using the IDVI. First, the IDVI was used to quantify the level of vulnerability for all Gram Panchayats (GPs) in the delta. Next, these values were mapped to uncover the spaces of vulnerability. Finally, two maps were produced: a percentile map to compare the distribution of the IDVI values for the GPs and a spatial clustering map to uncover statistical vulnerability hot- and coldspots. The descriptive statistics and maps for all 25 IDVI variables and 8 indicators are found in Appendices 3, 4, and 5.

5.2.1 Spatial distribution of IDVI indicators

To analyse the spatial distribution of vulnerability in the Cauvery Delta, all eight IDVI indicators were first mapped (figure 5.2). The percentile choropleth map shows the distribution of five percentile classes of the given indicator across the delta, indicating the location of villages with a relatively low or high value of vulnerability according to the IDVI. The spatial clustering maps show which GP has a statistically significant high or low IDVI value using the Local Moran's I statistic and is, therefore, used to identify significant vulnerability hot- or coldspots (Anselin, 1995). Besides the two maps, table 5.1 shows the Local Moran's I statistics, indicating the magnitude of spatial clustering, the percentage of GPs that are identified as a significant hot- or coldspot, and the statistical significance.

Figure 5.2 indicates that the spatial distribution for the eight IDVI indicators differs as not all indicators show similar spatial patterns. For example, some GPs have high vulnerability values for indicator X but low vulnerability values for indicator Y. Similarly, the IDVI indicators show particular areas with respectively high and low vulnerability scores. Figure 5.2 shows that indicator 'Demography', for instance, has relative low scores in the southwestern part of the delta, whereas the north-eastern part shows relative high values of the indicator. To further assess the statistical significance of the spatial distribution of the IDVI indicators, the Local Moran's I was mapped to identify statistical spatial clusters. The Local Moran's I statistic showed that all eight IDVI indicators had Moran's I values greater than zero (with a statistical significance of 95%), meaning that significant spatial clusters were found (Anselin, 1995) (table 5.1). In figure 5.2, the vulnerability hotspots are typified as 'High-High', whereas the vulnerability coldspots are typified as 'Low-Low'.

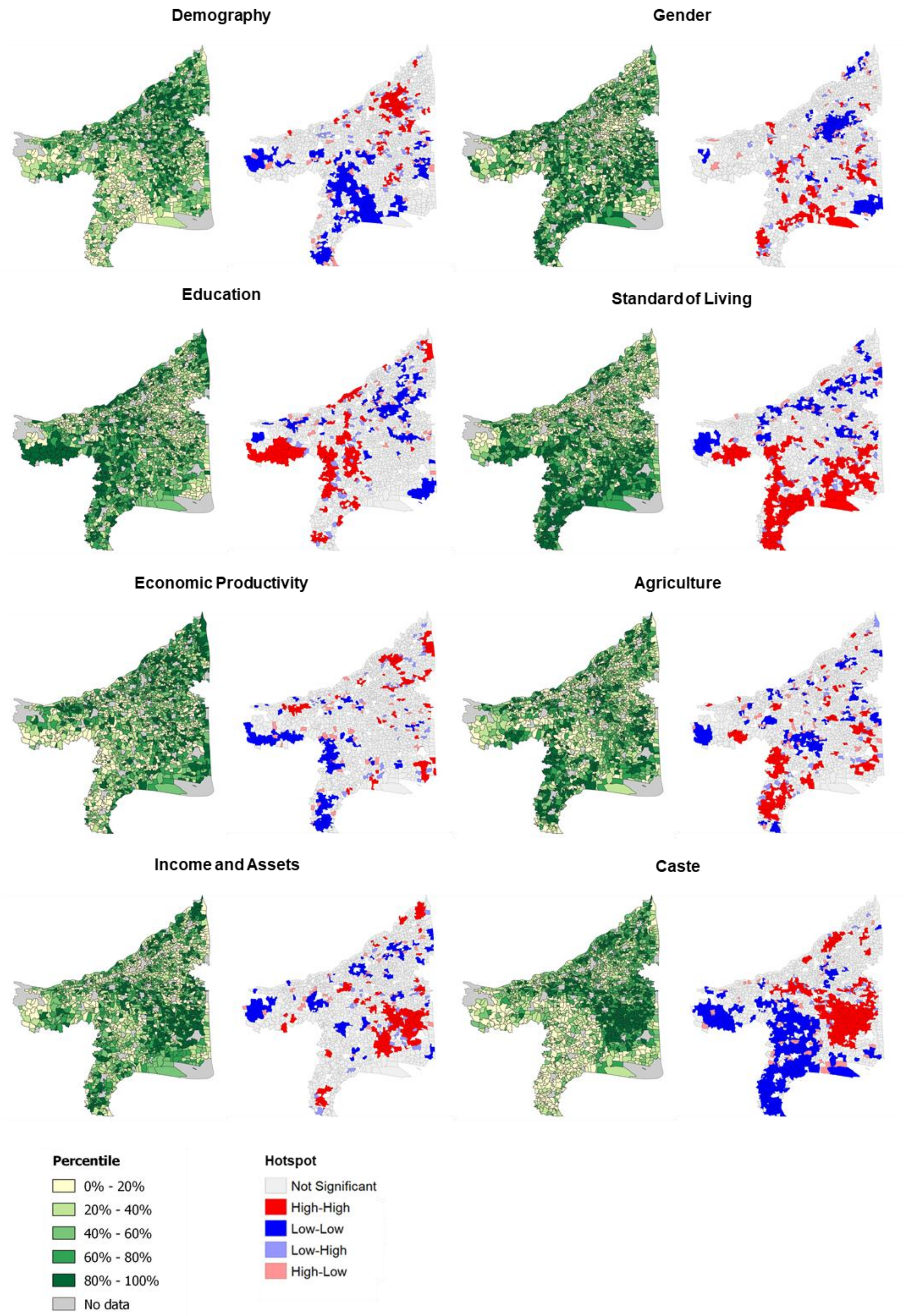


Figure 5.2. Spatial distribution of the IDVI indicators

Table 5.1. Univariate Moran's I analysis. Values closer to 1 indicate stronger spatial clustering. Local Moran's I at a significance level of 0.05.

Indicator	Moran's I	HH Clusters (%)	LL Clusters (%)	Correlation
Demography	0.291	8.12	11.71	0.157*
Gender	0.231	7.65	8.32	0.468*
Education	0.309	10.38	10.58	0.588*
Standard of Living	0.410	15.58	11.19	0.646*
Economic Productivity (Work)	0.180	6.39	6.86	0.024
Agriculture	0.257	9.65	7.46	0.470*
Income and Assets	0.338	12.45	8.06	0.751*
Caste	0.564	19.04	18.97	0.499*

*Found significant at the 0.99 significance level

The extent of spatial clustering varies between the IDVI indicators. The indicator 'Caste' showed the most substantial level of spatial clustering (Moran's I: 0.564) in the Cauvery Delta, whereas indicator 'Economic Productivity' showed the weakest spatial clustering (Moran's I: 0.180) (table 5.1). Figure 5.2 shows that for certain indicators, particular spatial patterns can be observed. For example, the indicators 'Caste' and 'Income and Assets' show a clear distinction between the Old Delta (and particularly the Vennar sub-basin) and the New Delta. For these indicators, vulnerability hotspots (High-High) are found in the Vennar sub-basin, whereas vulnerability coldspots (Low-Low) are situated in the New Delta and northern deltaic areas, among others. Other indicators, such as 'Standard of Living', indicate a distinction between the northern and southern parts of the Cauvery Delta.

5.2.2 Spatial distribution of vulnerability

Together, the eight IDVI indicators represent the multidimensional level of vulnerability in the Cauvery Delta. Figure 5.3 shows the spatial distribution of the overall level of vulnerability in the delta. Similar to the IDVI indicators, the final IDVI scores are not evenly distributed across the Cauvery Delta. Figure 5.3a shows that in the south-eastern part of the delta – the tail-end region of the Vennar sub-basin – relatively high levels of vulnerability are found by the IDVI analysis. The lowest levels of vulnerability in the Cauvery Delta are more equally distributed across the delta, with most villages with low levels of vulnerability found in the northern part of the delta. With a Local Moran's I value of 0.319, the spatial distribution of vulnerability in the Cauvery Delta was found to be significantly clustered (Anselin, 1995). Figure 5.3b underlines that the GPs in the tail-end region of the Vennar sub-basin have significantly high levels of vulnerability. Here, a statistical vulnerability hotspot was identified containing 110 GPs, consisting of a population of 225.681 according to the 2011 Census (5.6% of the total rural deltaic population). Other vulnerability hotspots are located in the Cauvery sub-basin, adjacent to the Cauvery river.

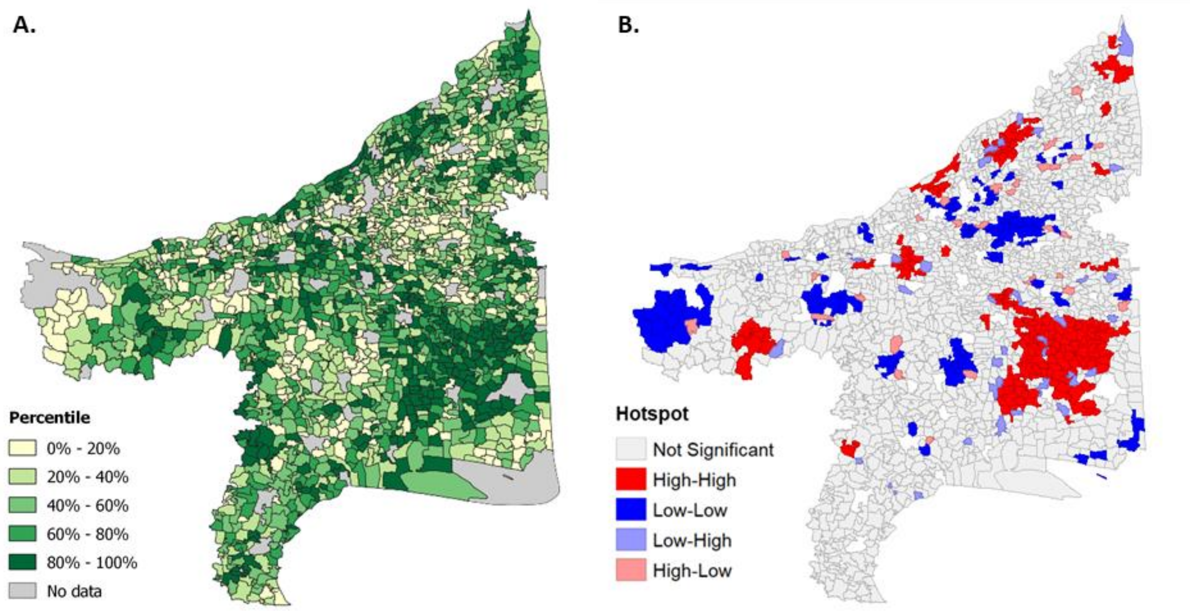


Figure 5.3. Vulnerability levels in the Cauvery Delta. A: percentile map. B: Local Moran's I map

Here, 31 GPs with a population of 78.608 (1.96% of the total rural deltaic population) were found to have significant high vulnerability values. The significant vulnerability coldspots are more evenly distributed throughout the Cauvery Delta (figure 5.3b). These coldspots are mainly located in the northern part of the delta near urban centres as Tiruchirappalli, Thanjavur, and Kumbakonam. In total, 212 of the GPs were classified as significant vulnerability coldspots by the Local Moran's I analysis, consisting of a population of 465.904 (11.6% of the total rural deltaic population).

When comparing the spatial distribution of the overall vulnerability measure (figure 5.3) with the spatial distribution of the eight IDVI indicators (figure 5.2), it is noticeable that the final vulnerability measure shows similar patterns as the indicators 'Standard of Living', 'Income and Assets', and 'Caste': in all these measures, the tail-end region of the Vennar sub-basin shows the highest values. A Pearson's correlation analysis further shows that these indicators were strongly correlated with the final vulnerability score, meaning a significant relationship exists between the overall vulnerability in the Cauvery Delta and these indicators (table 5.1). In particular, 'Standard of Living' (r = 0.646) and 'Income and Assets' (r = 0.751) is highly correlated with the overall vulnerability scores in the Cauvery Delta.

All in all, the spatial analysis of the vulnerability landscape of the Cauvery Delta indicates that the Vennar sub-basin, particularly the tail-end region of this deltaic area, contains the highest levels of vulnerability of the delta. These high vulnerability values are found to be mainly the result of low socio-economic conditions (i.e. indicators 'Standard of Living' and 'Income and Assets') and the presence of large (marginalised) caste communities (i.e. indicator 'Caste). In the subsequent subchapters, the temporality of this spatial vulnerability landscape will be further explored by analysing the temporality of the socio-economic and land-use conditions in the Cauvery Delta. This way, the found spatial patterns of vulnerability will be better understood.

5.3 Socio-Economic Temporalities

The differential socio-economic conditions that create the spatial patterns of vulnerability in the Cauvery Delta have been produced and reproduced since the beginning of civilisation in the area. Therefore, understanding how these socio-economic conditions have developed over time helps to understand how the vulnerability landscape in the Cauvery Delta is produced. The socio-economic temporalities in the delta can be broadly categorised into three periods: the pre-colonial, colonial, and post-colonial eras. In this subchapter, the socio-economic developments in these three periods will be discussed before linking the temporality to the spatiality of vulnerability in the delta.

5.3.1 Pre-Colonial Era

The origins of the current Cauvery deltaic society can be traced back to the construction of the Grand Anicut Dam and its irrigation system in the 2nd century AD (as discussed in subchapter 5.1). The construction of the CDIS supported significant agricultural and economic development in the region, allowing the Chola society to flourish (Bohle, 1983). Due to its agricultural and economic importance, the delta became the political, economic, cultural, and religious centre of the Chola Empire (Bohle, 1983; Bohle, 1985). The political, socio-economic, and technological resources that were required to establish, maintain, and expand the CDIS indicate the existence of a 'hydraulic civilisation' (Wittfogel, 1957), only made possible by the centralistic, hierarchical organisation of the Chola Empire (Bohle, 1983). Paddy cultivation was the backbone of this Chola society, as the Cholas relied on the fertile plains of the Cauvery Delta to feed their bureaucrats, soldiers, and temple priests and, most importantly, bring in revenue to fund the Empire's expenditures (Bohle, 1983; Van Schendel, 1991).

In order to support the Cholas' political, cultural, and military power, a large-scale revenue system was implemented in the Cauvery Delta. In this revenue system, the Chola rulers relied on local institutions to integrate the deltaic communities into the broader political system and bring in revenue. The central feature in this system was a clear differentiation between those who controlled the agricultural land and those who worked on it (Van Schendel, 1991). As a result, a highly stratified agrarian society developed in the Cauvery Delta. In this society, the caste system played a crucial role. Those who controlled the land, the mirasidari, belonged to upper caste groups and controlled the landless, lower caste cultivators (Subbarayalu, 2010). The mirasidari consisted of circa 10% of the total population, of which one-third belonged to the elevated Brahmin caste and the rest to other upper caste groups (Van Schendel, 1991).

The mirasidari held all local power in the Cauvery Delta. Despite their local privileges, the mirasidari power was not unbounded. Even though the mirasidari appropriated the bulk of the harvest, organised irrigation, and directed the cultivators, they were still bounded to hand over half of their income to the state (Van Schendel, 1991). Still, the landless agrarian labourers did the majority of the agricultural work (Bohle, 1983). These marginalised labourers belonged mainly to Dalits, the lowest level caste groups such as the Pulaiyas and Paraiyas. Most of them were part of the 'adimai', a slave-like condition that obligated one to work for the mirasidari (Subburayalu, 2010). Although the adimai lived in the same village as the mirasidari, they were physically and socially separated from the other villagers due to the stigma of ritual pollution (Van Schendel, 1991). They were landless, owned no agricultural equipment and were described as extremely poor. In the stratified agrarian system, there was little place for individual or group mobility: the control of local resources, wealth, and power was entirely dominated by the mirasidari (Subbarayalu, 2010). The agrarian relationships in the Cauvery Delta were remarkably resilient. Despite the decline of the Chola Empire after 1300, and the changing political context that followed since, the mirasidari were neither displaced from the control of resources nor altered by new types of authority (Bohle, 1985). By 1799, when the Cauvery Delta became part of the British Colonial Empire, the social stratification in the agrarian deltaic communities had rarely changed.

5.3.2 Colonial Era

The stratified agrarian order in the Cauvery Delta, which originated under the Chola Empire, was long maintained in the colonial era. Attempts of the British administration to introduce the new 'ryotwari' taxation system were thwarted by the mirasidari, who were reluctant to give away their control of local resources (Munikumar, 2014; Van Schendel, 1991). Instead, the mirasidari and the colonial authorities struck a local compromise, ensuring the British's revenue, and the mirasidari of their power. This support of the colonial authorities of the local elite resulted in an intensification of the social stratification in the Cauvery Delta (Munikumar, 2014). Furthermore, the mirasidari profited financially from the increase in paddy cultivation due to the agricultural and hydraulic developments, increasing their wealth and power.

However, from the 1850s onwards, the local power of the mirasidari began to break down. Several factors can explain this decline. First, the colonial rulers restricted the mirasidari control of labour by abolishing the slave-like adimai relationships. Further, land taxation became increasingly a less important source of state revenue. Since the power of the mirasidari was legitimised by land revenue, they lost much of their raison d'être (Van Schendel, 1991). Furthermore, the introduction of private land ownership and the commercialisation of rice in a globalising economy resulted in the emergence of a market for land and labour in the Cauvery Delta (Bohle, 1983). Driven by market forces, a new middle-class of successful tenants emerged in the delta as new commercial groups and outsiders began to own land. Gradually, this resulted in the socio-economic blurring of wealth and power in the Cauvery Delta (Van Schendel, 1991).

Still, by the end of British rule, much of the political power and economic control was still held by the mirasidari. The lower caste population were, despite their legal emancipation, rarely in the position to challenge the local elite. Many former-adimai faced more job insecurity and were still dependent on individual landlords who offered them employment under very disadvantageous conditions (Van Schendel, 1991). The polarisation between a small number of privileged large-scale landholders and large numbers of marginal farmers – whose access to the basic resources of the agrarian economy was limited – also remained. By 1900, the proportion of landless labourers had surpassed 50% of the total population, while 84% of all land was owned by 14% of the total landowners (Bohle, 1985). In conclusion, the socio-economic change in the colonial era was by no means an abrupt or complete social transformation. Instead, the social change in the Cauvery Delta was a gradual process (Mumikumar, 2014; Van Schendel, 1991).

5.3.3 Post-Colonial Era

In the post-colonial era, the Cauvery Delta saw essentially a continuation of the societal developments that had emerged in the colonial period. More and more, agricultural labourers began to work as wage labourers in the Cauvery Delta. The agricultural developments in the post-colonial delta – the expansion of the agricultural area, the introduction of well-irrigation, and the increasing production of other cash crops – increased the employment opportunities for these wage labourers. Still, employment was irregular and seasonal, and underemployment was widespread (Gough, 1987; Van Schendel, 1991). Furthermore, the salary of local wage labourers was often meagre, despite government interference on wage rates. Consequently, the income and wealth of wage labourers had changed little after independence in most parts of the delta.

Furthermore, the local power of the mirasidari continued to decrease. The commercialisation of agriculture in the Cauvery Delta had created a new class of capitalist farmers: a group of relatively wealthy, large landowners who, as early adopters of new technologies, had reaped the full benefit of the innovations of the Green Revolution (Bohle, 1983; Gough, 1987). The development of this new wealthy agrarian class significantly weakened the traditional economic supremacy of the mirasidari. In addition, absenteeism among the mirasidari elite had become an important driver. From the colonial era onwards, the mirasidari members had migrated to the city to land themselves 'better' jobs and a more wealthy urban lifestyle. This absenteeism from the agricultural lands in the delta had decreased the kinship networks and traditions of commonality among the mirasidari in the delta (Van Schendel, 1991).

As a consequence of the decreased solidarity, the control of the mirasidari was increasingly defied by lower caste groups. As a result, the mirasidari fell back on terror to hold their own position. This can be illustrated by the 1968 Kilvenmani Massacre, an act of terror in which 40 lower caste wage labourers were burnt to death. Although the trigger of this event was a wage conflict, the massacre is mainly perceived as a symbolic attack on the legitimacy of the stratified agrarian order (Van Schendel, 1991). Because of this event, the mirasidari lost much of their support of authorities and lost power to continue to shape the agrarian relationships.

Despite the decrease of the mirasidari political and economic power, the legal emancipation of lower castes, and the increased social mobility, the socio-economic inequalities in the Cauvery Delta still maintained. Although the agrarian stratification was less legitimised by religious and traditional factors, it was now produced by economic reasons. As landless labourers were still dependent on the wealthy landowners for employment, the agrarian stratification between the affluent and poor was still evident in the Cauvery Delta (Gough, 1987; Van Schendel, 1991). Moreover, due to stagnating wages, and a simultaneous rise in the cost of living, it is argued that the situation of landless labourers has improved little over the decades (Bohle, 1985).

5.3.4 Socio-Economic Change and Space

All in all, the socio-economic temporalities of the Cauvery Delta over the last 1800 years describe a story in which the agrarian society in the delta is remarkably resilient. The uneven social patterns that had formed in the Chola Empire – a highly stratified social system formed along caste lines – persevered well into the 19th century. By the end of the colonial era, the agrarian society in the Cauvery Delta began to slowly transform. However, the inequalities within the delta between the wealthy landowners and poor agricultural labourers were maintained but were now primarily dictated by economic forces.

Likely, the socio-economic developments differed in the Cauvery Delta in scope and intensity from one village to the next (Van Schendel, 1991). However, broad geographic patterns could be observed in the delta. As previously mentioned, the biophysical and hydraulic conditions in the CDIS had historically benefited the agricultural productivity in the western, upstream part of the delta more than in the eastern, tail-end parts. Over the centuries, these differences in agricultural productivity have resulted in different social structures. Traditionally, settlement is older in the western Cauvery Delta due to more beneficial agricultural conditions. Here, older social structures with more elevated Brahmin mirasidari had resulted in stricter caste codes and a stronger stratified society than in the eastern delta, where settlement was less historical rooted and landlords had a less elevated status (Bohle, 1983; Bohle, 1985; Van Schendel, 1991).

In the colonial era, these societal differences between the western and eastern delta began to change. In the more urbanised and developed western delta, more social differentiation arose as the strengthening of the middle-class, absenteeism, and consequently relative more defiance of oppressive caste practices weakened the old societal hierarchy (Bohle, 1983). Van Schendel (1991) argues that this transformation could be traced back to the invasion of the Cauvery Delta by Haidar Ali's army in the 1780s, which had led to the mass deportation and killing of the adimai workforce in the western delta. These were replaced by middle-caste tenants from neighbouring districts, blurring the caste stratifications in the western delta (Van Schendel, 1991). The eastern delta escaped this upheaval and was left relatively unaffected. Consequently, the agrarian society in this part of the Cauvery Delta remained more stratified (Van Schendel, 1991). Besides this, the prevalence of larger landholdings in the eastern delta had resulted in less absenteeism. Therefore, the mirasidari's solidarity and control over local resources endured longer than in the western delta, further polarising the two different deltaic areas (Bohle, 1983; Van Schendel, 1991).

In the New Delta, the social structures are much less deeply rooted in (agrarian) history. This is because the lands in the New Delta only became intensively occupied and cultivated after the extension of the CDIS by the Grand Anicut Canal in the 1930s (Bohle, 1983). Consequently, the older caste and inequality patterns found in the (more) polarised Old Delta far less exist in the New Delta.

5.4 Land-Use Temporalities

The study of the socio-economic temporalities has shown that the eastern and western parts of the Cauvery Delta developed differently throughout history, forming the roots of the contemporary vulnerability landscape in the delta. The temporalities of agriculture and land-use in the Cauvery Delta are strongly related to these socio-economic developments. As previously mentioned in chapter 5.1 and box 2, the agricultural productivity in the Cauvery Delta is strongly linked to the development of its irrigation system. Historically, agricultural productivity has also shown a west-to-east gradation in the delta. Due to the timing and water supply of the Cauvery waters, lands in the western part of the delta, close to the main irrigation works, were generally more productive than the lands in the eastern tail-ends of the delta (Bohle, 1983). The eastern lands were more susceptible to changing water supplies as tail-end regions, and therefore were less productive. Until the 1900s, double-cropping was only possible in the western parts of the Cauvery Delta. In contrast, the agricultural lands in the eastern part of the delta were confined to a single harvest in a year.

In the 20th century, the traditional west-to-east gradation in agricultural productivity decreased due to agricultural and technological developments. Because of the extension and improved water regulation in the CDIS and the introduction of tube-well irrigation, the former unproductive lands in the eastern part of the delta could significantly enhance their agricultural productivity and convert the single-cropped area into double-cropped lands (Bohle, 1983; Van Schendel, 1991). These developments resulted in a significant increase in agricultural production, consequently forming the basis for higher profits in the delta (Bohle, 1983).

However, the increase in agricultural productivity in the eastern parts of the Cauvery Delta were proven relatively short as the deltaic hydrology began to change in the second half of the 20th century. From the 1950s onwards, the Cauvery basin experienced a significant increase in its human population: growing from 361 million in 1951 to 1027 million in 2001 (197% increase over 50 years) (Vanham, 2011). Because of population growth, urbanisation, and economic and agricultural development, the overall water demand increased significantly in the Cauvery basin (Lele *et al.* 2018). This has significant impacts on the water availability in the basin. Vanham (2011) found that the Cauvery basin's annual per capita water availability decreased from 1057 m^3 in 1991 to 848 m^3 in 2005 (ca. 20% decrease). As the final destination of the Cauvery flow, these socio-economic and hydrological upstream developments have resulted in a decreasing water flow for the Cauvery Delta. Now, in the pre-monsoon months, river flows do not reach the tail-end of the Cauvery Delta, unable to fill the irrigation canals. Because of this, farmers increasingly relied on groundwater irrigation, consequently overexploiting these groundwater resources (Vanham, 2011).

The decreasing water availability has resulted in a decrease in agricultural productivity. Figure 5.4 shows the recent change in paddy cultivation in the Cauvery Delta. The figure shows that for almost the entire delta, the area under double cropping has decreased between 2000 and 2019. The former double-cropped lands are reverted back to single-cropping, thus decreasing the annual agricultural production. Furthermore, paddy cultivation is replaced by other cash crops that require less water, such as coconut or groundnut. Other farmers seek different livelihood opportunities by either migrating, moving to aquaculture, or abandoning agriculture (Srinivasan, 2019).

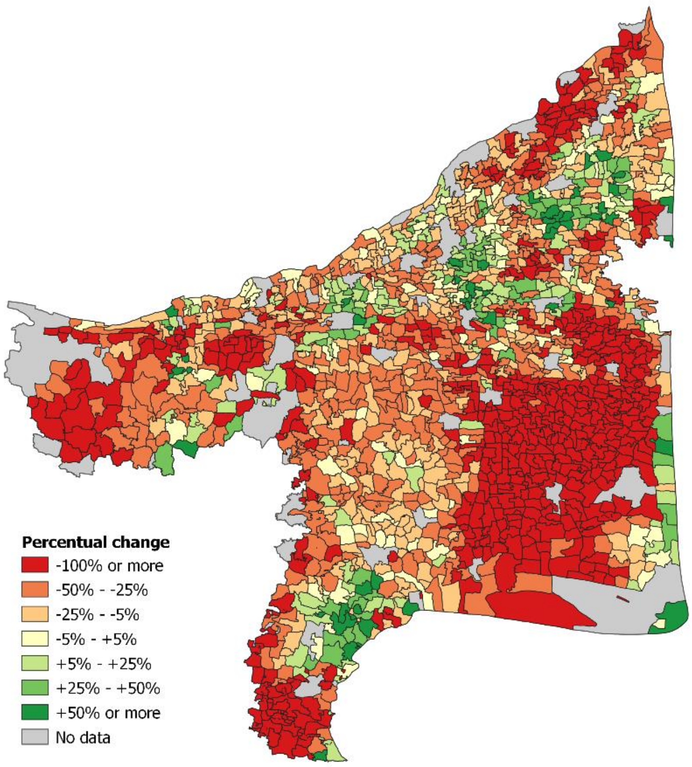


Figure 5.4. Change in area under double paddy cropping (2000-2019). Data source: LANDSAT / ATREE

Figure 5.4 also shows that the agricultural changes of the last decades are not equally spatially distributed. The figure shows that in the tail-end of the Vennar sub-basin, the decrease of the area under double paddy cropping is most severe across the Cauvery Delta. In the southern part of the Cauvery sub-basin, an area linear to the Cauvery river shows an increase in area under double paddy cropping between 2000 and 2019 (figure 5.4). This is, however, an exception: in most of the Cauvery Delta, the area under double cropping is decreasing.

5.5 The Vulnerability Landscape of the Cauvery Delta

In this chapter, the results of the analysis of the vulnerability landscape of the Cauvery Delta have been presented. The spatial analysis of vulnerability using the IDVI found significant inequalities within the delta at the community level. The highest level of vulnerability in the Cauvery Delta was found in the tail-end region of the Vennar sub-basin. The spatial patterns of vulnerability were further assessed by analysing the socio-economic and land-use temporalities in the delta. The research found several developments that have contributed to the production of the contemporary differential vulnerability landscape.

First, the analysis of the Cauvery Delta's socio-economic temporalities revealed that the inequalities within the delta have their roots in the Chola Empire, dating back more than 1800 years ago. In this era, an interconnected agrarian system evolved alongside the irrigation system, in which the origins lay for the current vulnerability landscape of the Cauvery Delta. The central feature of this agricultural system was the significant socio-economic differentiation between powerful landowners (the mirasidari) and the marginalised agricultural labourers (the adimai) (Subbarayalu, 2010; Van Schendel, 1991). These social inequalities persisted throughout the majority of history. Although social transformations in the 20th century changed the agricultural society, as the mirasidari lost their traditional supremacy, the socio-economic devide between the landowners and agricultural labourers persisted (Bohle, 1983; Gough, 1987; Van Schendel, 1991). The enduring social inequalities showcase how the affluent landowners use their power to maintain their local supremacy and control of local resources over time. In doing so, the landowners created and often exacerbated the vulnerability conditions for the dependent agricultural labourers.

Furthermore, this research found that a west-to-east gradient has traditionally existed in the Cauvery Delta in agricultural productivity. This gradation is related to the hydrological characteristics of the delta and its irrigation system, in which the eastern, tail-end regions of the delta are more susceptible to changing water supplies than the western parts close to the main irrigation works (Bohle, 1983). Whereas these differences in agricultural productivity initially resulted in a more stratified society in the west than the east delta, these differences became mirrored due to processes of social change in the colonial era. Now, the eastern parts of the delta had become relative more stratified than other deltaic regions, in which large caste communities had a marginalised position in society (Bohle, 1983; Bohle, 1985; Van Schendel, 1991). Nowadays, this west-to-east gradient is also observed in the spatial analysis of vulnerability in the delta (figure 5.3). Likely, the contemporary patterns of the vulnerability landscape of the Cauvery Delta are established through the different trajectories of social differentiation that occurred in the colonial era. This is also evident for the indicator 'Caste', which displays a stark contrast between the Vennar sub-basin (consisting of a large population of Scheduled Castes) and the New Delta (consisting of a small population of Scheduled Castes) (figure 5.2).

The socio-economic west-to-east gradient in the Cauvery Delta was further intensified by the hydrological and agricultural changes in the last fifty years. Due to socio-economic and environmental developments in the Cauvery basin, water availability in the delta has decreased (Lele *et al.* 2018; Vanham, 2011). Because of this, agricultural performance has decreased in the delta. It was found that the double-cropping of paddy, the primary agricultural produce of the Cauvery Delta, has significantly decreased over the last twenty years. Moreover, the analysis found that this decrease is the most prominent in the tail-end region of the Vennar sub-basin.

All in all, the analysis of the vulnerability landscape of the Cauvery Delta found that the Vennar sub-basin is the most prominent vulnerability hotspot of the delta. This can be explained by an extensive low caste community and relative low 'Standard of Living' and 'Income and Assets' indices. The temporalities of vulnerability of the Cauvery Delta showed that these patterns could be explained through historical developments, in which the eastern part of the delta has been historically less agricultural productive. Moreover, relative significant social differentiation, stemming back to the ancient Chola Empire, compared to other parts of the delta was observed from the colonial era. Therefore, the current spatial differences in the vulnerability landscape have likely been formed from this era. The spatial differences in the delta were further exacerbated by the economic developments linked to the Green Revolution, and environmental changes of the last fifty years. The Cauvery Delta case study illustrates how the vulnerability landscape is produced and reproduced throughout history, in which current patterns of vulnerability has historical roots.

6 | Vulnerability Landscape: Godavari Delta

In this chapter, the research results of the vulnerability analysis of the Godavari Delta is provided. As already mentioned, this analysis consists of a smaller, control study compared to the more extensive analysis of the Cauvery Delta. This chapter is structured as follows. First, the physical landscape of the Godavari Delta is introduced. After this, the IDVI results are discussed, analysing the spatial distribution of vulnerability in the Godavari Delta. Next, the temporal progression of vulnerability is shortly discussed. This chapter ends with a short summary of the vulnerability landscape of the Godavari Delta.

6.1 Physical Landscape

The Godavari Delta is a major wave-dominated delta with one of the largest sediment deliveries in the world (Rao *et al.* 2012). The Godavari Delta can be divided into two areas based on its geomorphology: the upper fluvial plain and the lower tidal plain (Rao *et al.* 2012). These differences are the result of the delta progradation after the sea-level changes after the Last Glacial Maximum and increased sediment supply due to agriculture and other human activities (Rao *et al.* 2015). The inland beach ridges illustrate these geomorphological changes (figure 6.1).

However, in the last decades, a significant decrease in sediment discharge has exacerbated coastal erosion in the delta, resulting in the shrinking of the Godavari delta plain (Rao *et al.* 2015). These changes are mainly the result of large-scale dam construction and water diversion (ibid.). Contrary to the Cauvery Delta, in the Godavari Delta, large-scale dam construction has its origins in the colonial period. In the pre-colonial Godavari Delta, no large-scale water management practices existed in the delta (Wilson, 2017). In this era, agriculture was solely dependent on the monsoon-dominated water supply of the Godavari river. Consequently, the agricultural practices were highly susceptible to droughts and floods. In addition, the minor small-scale irrigation works that were in place in the Godavari Delta were unmaintained and deteriorated. In 1837, British engineers observed that there was scarcely any single irrigation work in a respectable state in the region (Rao, 1988).

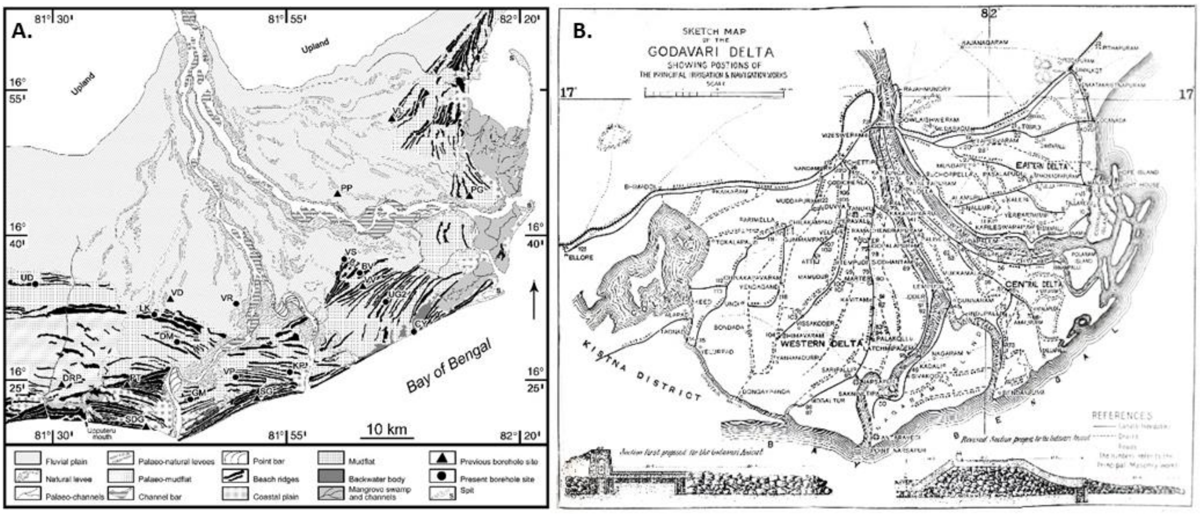


Figure 6.1. The Godavari Delta. A: Geomorphology of the delta (Rao *et al.* 2015). B: Principal irrigation infrastructure c. 1900 (Wikimedia Commons)

In this era, the agrarian economy in the delta was also in a state of decay, resulting from successive failures of monsoon rains, a depression in agricultural prices, and the Great Guntur Famine of 1832-1833 (Rao, 1988). In order to improve the agricultural production in the Godavari Delta, a dam was built near Rajahmundry. The Dowleswaram Barrage (renamed to the Sir Arthur Cotton Barrage) was completed in 1850. The dam created an irrigation system that enabled the storage of Godavari waters, decreased the risks of floods and enabled canal irrigation in large parts of the delta. Former dry plots (only rainfed) could be converted into irrigated wet lands, enhancing the area under paddy cultivation and the area under double-cropping (Rao, 1988). Nowadays, the irrigation system in the Godavari Delta can be subdivided into the western delta, central delta, and eastern delta (figure 6.1).

6.2 Spaces of vulnerability

Considering the physical landscape of the Godavari Delta, the spatial distribution of vulnerability was analysed using the IDVI. Figure 6.2 shows the spatial distribution for all eight IDVI indicators in the Godavari Delta. The descriptive statistics and maps for all 25 IDVI variables and 8 indicators are found in Appendices 3, 4, and 6. Figure 6.2 indicates that the indicators show different spatial patterns, both in terms of the extent of spatial clustering as spatial differentiation of high and low IDVI indicator values. The Local Moran's I analysis (table 6.1) indicates that the indicators 'Education' (Moran's I: 0.612) and 'Standard of Living' (Moran's I: 0.487) contain the most significant spatial clustering among the IDVI indicators. Furthermore, a north-to-south gradation can be observed with both indicators, with the northern parts of the Godavari Delta showing less vulnerability than the southern parts (figure 6.2).

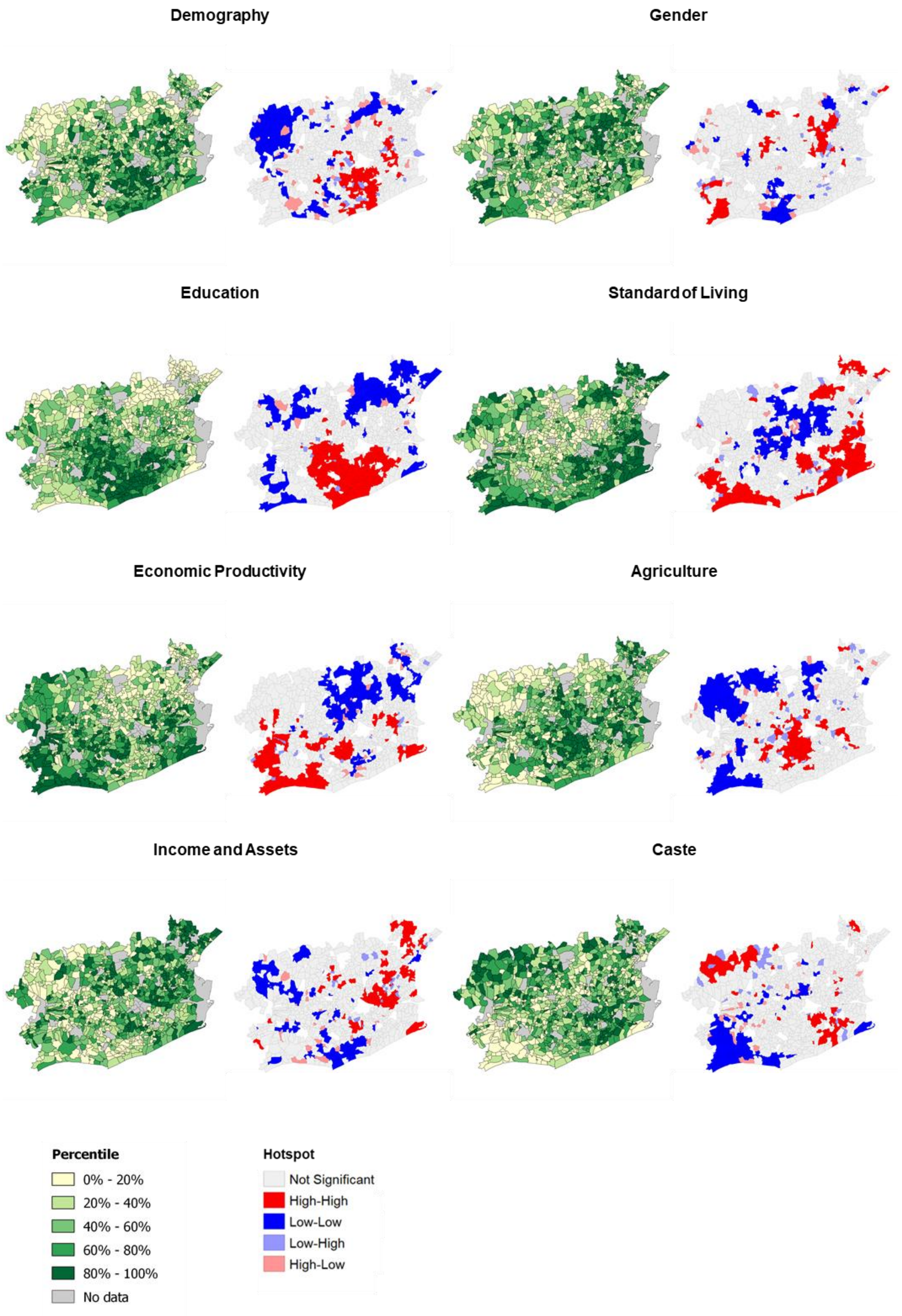


Figure 6.2. Spatial distribution of IDVI indicators

Table 6.1. Univariate Moran's I analysis. Values closer to 1 indicate stronger spatial clustering. Local Moran's I at a significance level of 0.05.

Indicator	Moran's I	HH Clusters (%)	LL Clusters (%)	Correlation
Demography	0.285	10.29	10.69	0.326*
Gender	0.172	6.63	6.93	0.329*
Education	0.612	22.67	15.44	0.294*
Standard of Living	0.487	17.72	15.15	0.457*
Economic Productivity (Work)	0.381	11.78	16.14	0.461*
Agriculture	0.386	10.50	12.38	0.532*
Income and Assets	0.361	11.78	11.58	0.412*
Caste	0.274	8.02	7.82	0.418*

*Found significant at the 0.99 significance level

Looking at the spatial variations of the IDVI vulnerability scores for the Gram Panchayats in the Godavari Delta, the same north-to-south gradation can be observed as with the indicators 'Education' and 'Standard of Living' (figure 6.3a). Overall, the IDVI finds that the northern parts of the Godavari Delta have relatively low levels. In contrast, the southern parts of the delta have relatively high levels of vulnerability. With a Local Moran's I value of 0.465, the spatial distribution of vulnerability is significantly clustered in the Godavari Delta (Anselin, 1995). The largest vulnerability hotspot (High-High) of the Godavari Delta is located in the central deltaic region, located between the main distributaries of the Godavari river (figure 5.3b). This hotspot encompasses 145 GPs, consisting of a total population of 651.110 (13.08% of the deltaic rural population). The most significant vulnerability coldspot (Low-Low) in the Godavari Delta is located in the western deltaic area, consisting of the area northeast of the city of Rajahmundry. This vulnerability coldspot consists of 78 GPs with a total population of 598.304 (12.02% of the total deltaic rural population) (figure 5.3b).

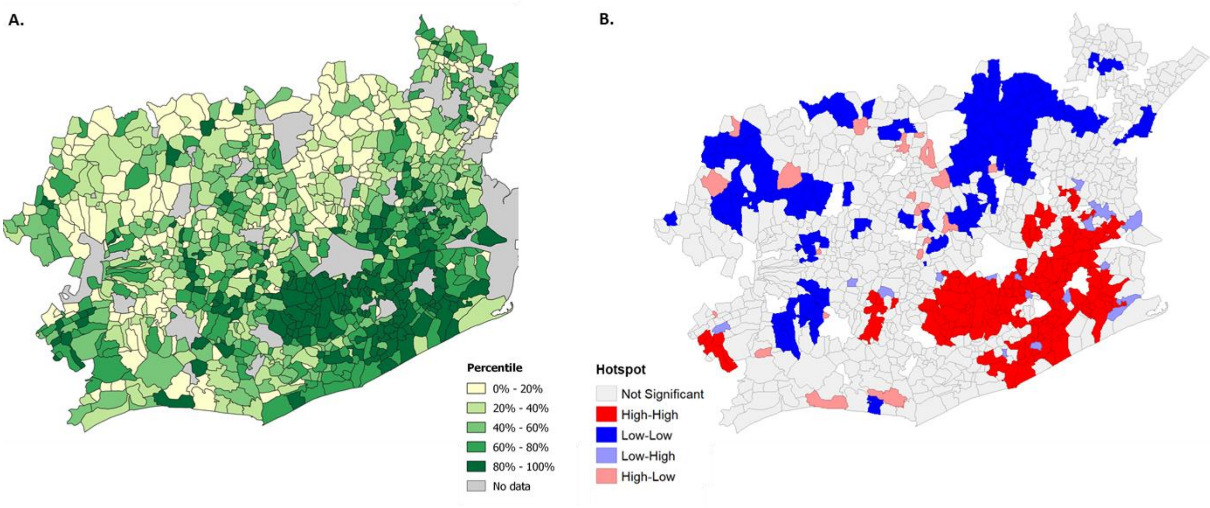


Figure 6.3. Vulnerability levels in the Godavari Delta. A: percentile map. B: Local Moran's I map

To compare the spatial distribution of the overall vulnerability measure (figure 6.3) with the spatial distribution of the eight IDVI indicators (figure 6.2), a Pearson's correlation analysis was conducted (table 6.1). This analysis shows that all eight IDVI indicators have a weak to moderate positive correlation with the overall vulnerability measure (*r* between 0.25 and 0.50). Indicator 'Agriculture' (r = 0.532) has the most significant relationship with the overall IDVI. The indicator 'Education' (r = 0.294) has the weakest significant relationship with the overall IDVI. However, no significant discrepancies are found between the eight IDVI indicators in terms of the correlation coefficient, meaning that no particular indicator is significantly more correlated with the overall vulnerability score than other indicators. Instead, all eight indicators have a similar relationship to the overall IDVI, causing the vulnerability in the Godavari Delta not to be explained by a particular dimension of vulnerability.

6.3 Production of Vulnerability

As already mentioned, the Godavari Delta case study was a minor case study compared to the Cauvery Delta case. For this reason, the literature study of the spatiality and temporality of the vulnerability landscape of the Godavari Delta is less profound. Nevertheless, this research has identified important vulnerability processes that have contributed to the production of the current spatial differences in vulnerability in the Godavari Delta.

6.3.1 Agricultural Development

The Godavari Delta had always been attractive to political regimes throughout history because of its productive agricultural lands (Stoddart, 2010). However, before the construction of the Dowleswaram in the 1840s, the state of agriculture in the Godavari Delta was highly susceptible to fluctuations in the monsoon rains (Rao, 1988). Consequently, in the early 1800s, a series of poor harvests following flood events had resulted in devastating famines in the delta and surrounding areas (Wilson, 2017). The local colonial administration had calculated that the population of the Godavari Delta had declined from 738.000 to 561.000 between 1821 and 1843 due to the combination of death and out-migration (ibid.). Decreasing population, food security issues, high amounts of poverty, and a decline in the region's land revenue led to the decision of the British rulers to act to improve the agricultural yield in the region: the construction of the Dowleswaram Barrage and its extensive deltaic irrigation system was the result of this (Rao, 1988).

The construction of the Dowleswaram Barrage brought major social, economic, and political changes to the Godavari Delta (Stoddart, 2010). The irrigation system improved control of water resources and water usage, significantly enabling agricultural lands to increase their agricultural production (Stoddart, 2010; Rao, 1988). In addition, the construction of the Dowleswaram Barrage and its irrigation system further brought the construction of roads, bridges, and canals. These infrastructural improvements enhanced market access and helped boost economic prosperity in the region (Stoddart, 2010; Wilson, 2017). As a result, by the early 1900s, the Godavari Delta belonged to the most affluent regions in colonial India (Wilson, 2017).

The agricultural developments mainly centred around the central floodplains of the Godavari Delta near Rajahmundry. Here, close to the Dowleswaram Barrage, the majority of the canal irrigation was situated (figure 6.1b). Consequently, this deltaic area could profit the most from the hydrological, agricultural, and infrastructural developments during the colonial era (Rao, 1988; Stoddart, 2010; Wilson, 2017). On the other hand, in the southern tail-end regions of the Godavari Delta, the irrigation system was less (or not) developed (Rao, 1988). As a consequence, this area of the Godavari Delta could profit less from the agricultural improvements.

6.3.2 Socio-Economic Development

The construction of the irrigation system in the Godavari Delta shaped the intertwined relationships between political power and water in the delta. At the construction of the Dowleswaram Barrage, most landholders in the Godavari Delta were ryotwari peasants (Wilson, 2017). Although in the delta, several powerful landholders existed (e.g., the zamindari and inamdari landholders), most landholders in the delta were peasants who had been given property rights by the British administrators. Still, the ryotwari peasants were a diverse group, differing in social, economic, and political power (Stoddart, 2010).

The differences between the ryotwari peasants changed with the hydrological and agricultural changes in the Godavari Delta from the 1850s onwards. A smaller group of upper ryotwari peasantry, mainly consisting of Kamma caste households, were able to significantly benefit from the increase in agricultural production in the delta (Prasad, 2015). With the increasing commercialisation of agriculture, the upper ryotwari found themselves significantly improving their economic status, accumulating more capital, enhancing their landholdings, accessing broader markets, and growing political power (Stoddart, 2010). These accelerating social changes were detrimental for the lower, more marginalised peasantry. This group was unable to benefit from the economic and agricultural development in the Godavari Delta, and became increasingly dependent on the upper peasantry for employment or agricultural assets (Rao, 1988; Stoddart, 2010).

After the independence of India, the agrarian relationships in the Godavari Delta further transformed into capitalist relations between the landowners and cultivators (Prasad, 2015). In this rural transformation, the upper peasantry further profited from the capitalisation of agriculture, increasing the social differentiation within the Godavari Delta (Prasad, 2015; Stoddart, 2010). The Green Revolution exacerbated these inequalities. Because of their socio-economic position, the capitalist farmers in the delta could benefit from the new agricultural technologies and utilise new agricultural techniques of high-yield inputs, irrigation technologies, and mechanised agricultural vehicles to maximise their profits (Parthasarathy and Pothana, 1983; Upadhya, 1988). A longitudinal analysis of Winchester *et al.* (2001) found that in the Green Revolution, rich and medium households increased their asset base (e.g., income, land, ploughs, or animals). This way, the rich-peasant class was thus able to consolidate, or even increase, their economic and political power. Poorer households, however, were not in this position (Winchester *et al.* 2001). For these households with less economic resources, the adaptation of Green Revolution techniques was 'high-risk', in contrast to the more affluent households, for whom the adaptation of Green Revolution techniques resulted in 'high-value' agriculture (Upadhya, 1988).

6.4 The Vulnerability Landscape of the Godavari Delta

In this chapter, the results of the analysis of the vulnerability landscape of the Godavari Delta have been presented. The spatial analysis of vulnerability using the IDVI found significant inequalities within the delta, in which the levels of vulnerability showed a strong north-to-south gradation. Surrounding the city of Rajahmundry and the Dowleswaram Barrage, large significant vulnerability coldspots have been identified. In the southern tail-end regions of the Godavari Delta, the highest levels of vulnerability were found.

It is very likely that the origins of the contemporary vulnerability landscape lay with the construction of the Dowleswaram Barrage in the 1840s. The literature study found that the construction of the Barrage, and the connected irrigation system, have profoundly impacted the Godavari Delta. The agricultural developments, boosted by the extensive irrigation system, enabled a group of the upper peasantry to accumulate wealth and political power (Stoddart, 2010; Prasad, 2015; Wilson, 2017). Post-independence, this group was able to further enhance their control over local resources and assets through the increasing commercialisation of agriculture and new technologies of the Green Revolution (Prasad, 2015; Upadhya, 1988; Winchester *et al.* 2001). Although little is known about the spatial variations of the agrarian society in the Godavari Delta, the social transformations likely were the strongest in the main irrigated lands in the centre of the delta, close to the main water regulator works at Rajahmundry. The tail-end regions of the delta, traditionally the least productive agricultural zone, could not reap the full benefits of the agricultural developments (Rao, 1988). Henceforth, the spatial differences within the Godavari Delta were emerging related to the agricultural productivity of the lands.

All in all, the analysis of the vulnerability landscape of the Godavari Delta found that the largest cluster of highly vulnerable communities is found in the southern tail-end region of the delta. No particular IDVI indicator could solely explain this spatial pattern. Moreover, the spatial distribution of vulnerability is the result of a multidimensional combination of vulnerability conditions. These conditions have their origins in the colonial era, in which the agrarian society emerged in the Godavari Delta that is still visible today.

7 | Discussion

7.1 Discussion

This research aimed to uncover the spatial and temporal dynamics of vulnerability in two disaster risk hotspots in India: the Cauvery and Godavari Delta. The research found that significant spatial differences exist in the level of vulnerability across the delta in both cases. Although the societal and geographic contexts of the two deltas differ, in both the Cauvery and Godavari Delta, the most prominent vulnerability hotspots are located in the tail-end region of the delta. In the Cauvery Delta, the tail-end region of the Vennar sub-basin is identified as the most vulnerable. In the Godavari Delta, the southern tail-end region of the Godavari is identified as the most vulnerable. The cross-shore vulnerability gradient across the delta, with more vulnerable people living near the coast, was also found in vulnerability assessments of the Ganges-Brahmaputra Delta (Das *et al.* 2021; Rabby *et al.* 2019). The identification of the tail-end regions as the most vulnerable is likely related to their hydrological characteristics. In general, tail-end regions of river deltas are more susceptible to changing water supplies, water scarcity, and saltwater intrusion, among others (Nicholls *et al.* 2020). Therefore, tail-end regions generally are less fertile, and therefore less agricultural productive. As agricultural productivity is strongly linked to the well-being of rural communities (Irz *et al.* 2001), it influences the conditions that comprise the level of vulnerability.

Related to the hydrological characteristics of the delta, the Cauvery Delta case study found how hydrological spatial linkages helped produce the vulnerability landscape in the delta. It was found that the water availability, and therefore agricultural performance, in the Cauvery Delta was influenced by societal developments in the broader (upstream) Cauvery basin, as evidence shows that upstream social, economic, and environmental changes impact the vulnerability conditions downstream (Lele *et al.* 2018; Vanham, 2011). These spatial linkages underline the multi-scalarity of vulnerability, as vulnerability conditions in the Cauvery Delta were not found to be produced only by local processes but also by broader, regional interactions (Etzold and Sakdapolrak, 2016; Turner *et al.* 2003). These findings emphasise that while vulnerability may be experienced locally, the production and reproduction of the vulnerability conditions themselves are not necessarily local (Eakin *et al.* 2009).

Moreover, this research found that the temporality of vulnerability plays a critical role in understanding the vulnerability landscape. In both the Cauvery and Godavari Delta case studies, it was found that the patterns of vulnerability are deeply rooted in history. In addition, both case studies found that the origins of the vulnerability landscapes are strongly linked to the construction and development of the canal irrigation systems in the deltas. In the Cauvery and Godavari Delta, it was found that the agricultural surpluses that were created by the agricultural and irrigational developments enabled landowners to accumulate social, economic, and political power (Stoddart, 2010; Subbarayalu, 2010). Because of this, a stratified rural society emerged in the deltas in which elite landowners held control over all key agricultural assets such as land, irrigation, and labour (Prasad, 2015; Van Schendel, 1991). The agricultural labourers, who worked on the landowners' lands, were excluded by the powerful landowners, creating relationships of marginalisation.

There exist, however, an important difference between the origins of social differentiation between the Cauvery and Godavari Delta. In the Cauvery Delta, the patterns of rural differentiation can be traced back to the Chola Empire, more than 1800 years ago. Here, the powerful landowners, the mirasidari, were part of the political system of the Chola Empire (Bohle, 1983). Their powerful position in the Cauvery society was legitimised by the overarching political and religious power (Bohle, 1985; Subbarayalu, 2010). Thus, the raison d'être of the mirasidari was rooted in political and caste relationships throughout the delta. By maintaining the stratified agrarian system along caste lines, the mirasidari could uphold their powerful position for more than 1500 years.

In contrast, the origins of agrarian social differentiation in the Godavari Delta are less ancient, as the absence of an extensive irrigation system prevented large-scale agricultural development in the delta until the 1840s. In this era, the rural population mainly consisted of peasant farmers, who cultivated their marginal landholdings under different colonial land systems. With the construction of the Dowleswaram Barrage and the large-scale canal network, and consequently the agricultural development that followed, the upper peasantry was able to enhance their position in the Godavari rural society by enhancing their agricultural asset base (Stoddart, 2010; Wilson, 2017). As a result, social differentiation emerged in the Godavari Delta. Contrary to the Cauvery Delta, the differentiation emerged as the consequence of the development of the upper peasantry, rather than imposed by the larger political rulers.

In the 20th century, the patterns of social differentiation in the Cauvery and Godavari Delta fully transformed into capitalist landowner-landless labourer relationships. As first adaptors of the new

Green Revolution technologies, wealthy landholders maintained, and even expanded, their control over resources and labour. By enhancing their control of irrigation, land, credits, steeds, and other institutional sources, the wealthy landowners preserved their supremacy over less affluent social groups to this day (Prasad, 2015; Upadhya, 1988; Van Schendel, 1991; Winchester *et al.* 2001).

These findings on the development of social differentiation in the Cauvery and Godavari Deltas echo the conclusions of Taylor (2013). In his study on relational vulnerability in Andhra Pradesh, Taylor (2013) found how dominant groups create relative security for themselves through their power relationships and control over agricultural assets while simultaneously creating vulnerability for other social groups. The analysis of the temporality of vulnerability in the Cauvery and Godavari Delta underline these findings. Throughout history, it was found that, in general, the wealthy and powerful landowners could maintain and accumulate their wealth at the cost of dependent, marginal agricultural labourers. Consequently, it highlights how the processes of marginalisation and social differentiation produce and reproduce the conditions of vulnerability that influences people's vulnerability today (Pelling, 2001).

The analysis of the spatiality and temporality of vulnerability in the Cauvery and Godavari Delta highlights how a myriad of spatial-temporal interactions contribute to the development of a complex vulnerability landscape. Within a delta, multiple trajectories exist that result in differential vulnerability. In the Cauvery Delta, two major different temporal vulnerability trajectories were observed that evolved over time into a division in the vulnerability landscape. From the colonial era onwards, more significant social inequalities were observed in the tail-end regions than in the western regions of the delta. These social inequalities, combined with adverse environmental and agricultural changes, have resulted in the current differential vulnerability landscape. These findings underline the importance of analysing the multi-scalar temporal and spatial linkages to holistically understand (the production of) a vulnerability landscape.

7.2 Research Limitations

Although some of the research limitations are already discussed (chapter 4.4), several research conditions have likely influenced the results of this research. Therefore, there is a need to address these issues. Firstly, to analyse and quantify the level of vulnerability in the Cauvery and Godavari Delta, the Indian Delta Vulnerability Index (IDVI) was developed for this research. Considering that the IDVI was used as the 'instrument' to quantify the level of vulnerability, the measure of vulnerability is inherently shaped by the design of this index. For instance, for the quantification of vulnerability, this research was constricted to using governmental census data. As collecting data at the community scale is a costly and time-consuming exercise, almost all quantitative vulnerability studies rely on census data to quantify vulnerability (Hinkel, 2011; Wolters and Kuenzer, 2015). However, the use of census data prevents the inclusion of (proxies of) vulnerability conditions or dimensions that are not measured in the governmental censuses. For this reason, vulnerability conditions regarding health or social capital, for instance, could not be included in the IDVI.

Likely, the exclusion of particular vulnerability conditions has implications for the accuracy of the measure of vulnerability in this research. In particular, the absence of any measure of social capital imposes a limitation on this research. Social capital is an essential community resource that can help people share physical, financial, or social resources in times of need, significantly enhancing their capacity to adapt or recover from the impacts of natural hazards (Hawkins and Maurer, 2010; Fraser, 2021). Moreover, as with each variable and indicator, social capital differs spatially across the delta, from communities with substantial social capital to insubstantial social capital (Fraser, 2021). Thus, the inclusion of a community-level measure of social capital would significantly enhance the understanding of the local conditions of vulnerability in the delta.

In addition, this research analyses vulnerability using the lowest administrative units in India: Gram Panchayats (GPs). The measure of vulnerability is determined by the aggregated data in these units. Consequently, the GP values are influenced by both the shape and scale of the administrative unit (Rabby *et al.* 2019). These issues denote the modifiable areal unit problem (MAUP), which encompasses all issues in which the results of data aggregation are dependent on a 'modifiable areal unit'. This means that when the shape and scale of the administrative units are changed (e.g. replaced by taluk units), the found spatial patterns are likely to change to a certain degree. Furthermore, as only aggregated GP data could be used for analysis, this research cannot gain insights into the differential vulnerability within the GPs. Likely, the level of vulnerability differs within vulnerability between more and less vulnerable households, similar to the found differential vulnerability between villages across the delta. Insights of within village inequalities in vulnerability would significantly enhance the understanding of the local production of vulnerability, and would therefore inherently contribute towards a better understanding of the general patterns of vulnerability in the region.

7.3 Recommendations

For future research, several recommendations can be made to enhance the understanding of the vulnerability landscapes of the Cauvery and Godavari Delta. First, the quantification of vulnerability could be improved by including more indicators in the IDVI. As mentioned, this research did not include important vulnerability dimensions such as health or social capital due to the lack of data availability. To further improve the accuracy of the spatial analysis, it is recommended to include such indicators in future research. In addition, this research only quantified the level of vulnerability in the Cauvery and Godavari Delta using 2011 Census Data. In order to quantitatively analyse the temporal changes in vulnerability in the two deltas, future research should aim to compare the findings of this study with a spatial analysis of vulnerability using 2021 Census Data. This way, the temporal trajectories of vulnerability could be uncovered, providing insights into the spatial-temporal trends of vulnerability on a decennial scale. In addition, future research should focus on the validation of the IDVI. Validating the index would improve the accuracy and sensitivity of the IDVI, therefore making it a better tool to measure vulnerability. This can be done, for instance, by comparing the IDVI with disaster impact data at different spatial scales and analysing to what extent the index is successful in predicting the differential impacts of natural hazards.

Furthermore, to thoroughly understand the vulnerability landscape of the Cauvery and Godavari Delta, a more detailed assessment of vulnerability is required for the deltas. Alongside the quantitative assessment of vulnerability and disaster risk, local qualitative assessment of vulnerability is required to gain insights into how the deltaic communities experience socio-economic changes, how their livelihoods are shaped, and what their own perspectives and experiences of vulnerability are. Multiple studies indicate that local people often have different notions of vulnerability and experience the conditions of vulnerability according to their own culture (Preston *et al.* 2011; Wisner *et al.* 2012). Such insights into the local conditions and experiences of vulnerability would greatly benefit the understanding of vulnerability. Moreover, qualitative assessment on the local scale could provide insights into the temporalities of vulnerability through longitudinal village studies.

In addition, this research recommends that future research should aim to holistically assess the disaster risk in the Cauvery and Godavari Delta by taking a social-ecological approach, in which both societal vulnerability and the (probability of) occurrence of natural hazards are incorporated.

This research is only limited to the analysis of the societal vulnerability dynamics. In order to understand the disaster risk, a social-ecological analysis of both social and environmental conditions could identify which areas in the delta have the highest risk of natural disasters. This could further highlight potential hotspots to policymakers where adaptation policies are most needed. Furthermore, such social-ecological analysis could identify whether the observed vulnerability hotspots in the two deltas also contain the highest probability of natural hazards, or significant discrepancies exist in the delta between societal vulnerability and environmental risk.

For policymakers, this research has identified significant vulnerability hotspots in the Cauvery and Godavari Delta in the tail-end regions of both deltas. These vulnerability hotspots signify the deltaic regions in which the communities' capacity to anticipate, cope with, resist, and recover from the impact of natural hazards is significantly lower than in other deltaic communities. Because of this, it is recommended to prioritise these areas for adaptation measures and capacity building strategies. Moreover, this research found that the societal production and reproduction of vulnerability is deeply rooted in history and is strongly linked to social differentiation in the delta. These processes are constructed in a system of multi-scalar spatial-temporal linkages. To successfully reduce vulnerability, policies should address these root causes and dynamics of vulnerability and take into account the multi-scalarity through which vulnerability is produced. Therefore, it is recommended that policies should aim to reduce social marginalisation and harmful agricultural differentiation, whilst taking broader spatial-temporal processes into account.

8 | Conclusion

The Cauvery and Godavari Delta in India consist of two of the critical disaster risk hotspots worldwide. This research aimed to uncover the spatial and temporal dynamics of vulnerability in these two disaster risk hotspots in India. The following main research question was formulated: 'How are vulnerability landscapes being produced and reproduced in the Cauvery and Godavari Delta?'.

A mixed-methods approach was employed to answer the research question to both quantitatively assess and map the level of vulnerability, and qualitatively assess the spatiality and temporality of vulnerability in the two deltas. The research found that vulnerability is unevenly distributed across the delta. In both the Cauvery and Godavari Delta, the highest levels of vulnerability were located in the tail-end regions of the delta. Furthermore, it was found that in the vulnerability landscape was shaped by historical patterns of irrigation, agricultural productivity, and social differentiation. Moreover, the research found that over time, a relational dynamic exists between landowners and landless agricultural labourers. The power relations between these two social groups have created disparate vulnerability conditions as landowners created relative for security for themselves through their control of land and labour. The power relations between landowners and landless labourers are resilient: even if the societal context changed over time, relational vulnerability remained. In other words: in general, the less vulnerable remained less vulnerable at the cost of the more vulnerable.

These results signify that vulnerability in the Cauvery and Godavari Delta are continuously being shaped by resilient patterns of unevenly distributed socio-economic conditions. In order to reduce vulnerability in disaster risk hotspots as Indian deltas, these inequalities and power relations should be first addressed. In order to contribute towards the in-depth understanding of the vulnerability landscape in Indian deltas such as the Cauvery and Godavari Delta, more research is needed to understand the local, everyday conditions and experiences that shape vulnerability on a local scale.

Bibliography

Adger, W. N. (1999). Social vulnerability to climate change and extremes in coastal Vietnam. *World Development 27*(2), 249-269.

Adger, W. N. (2006). Vulnerability. *Global Environmental Change 16*(3): 268-281.

Adger, W. N., Eakin, H. & Winkels, A. (2009). Nested and teleconnected vulnerabilities to environmental change. *Frontiers in Ecology and the Environment 7*(3): 150-157.

Anderson, C. C., Hagenlocher, M., Renaud, F. G., Sebesvari, Z., Cutter, S. L. & Emrich, C. T. (2019). Comparing index-based vulnerability assessments in the Mississippi Delta: Implications of contrasting theories, indicators, and aggregation methodologies. *International Journal of Disaster Risk Reduction 39*: 101128.

Anselin, L. (1995). Local indicators of spatial association – LISA. *Geographical analysis 27*(2): 93-115.

Anselin, L., Syabri, L. & Kho, Y. (2010). GeoDa: an introduction to spatial data analysis. In: *Handbook of applied spatial analysis* (pp. 73-89). Springer, Berlin, Heidelberg.

Arni, C. & Henry, O. (2009). Cauvery basin: its culture, places of historical significance, birth place, climate, precipitation, catchment, tributaries, state-wise spread, landuse. Retrieved from https://www.indiawaterportal.org/articles/cauvery-basin-its-culture-places-historical-significance-birth-place-climate-precipitation

Asian Development Bank (2011). *TA 7417-IND: Support for the National Action Plan on Climate Change Support to the National Water Mission: Appendix 4*.

Ayele, L. & Degefa, T. (2019). Linking local vulnerability to global sesame market price: The case of temporary rural-rural migrants from Quarit district, Ethiopia. *Research in Globalization 1*: 100004.

Balaganesh, G., Malhotra, R., Sendhil, R., Sirohi, S., Maiti, S., Ponnusamy, K., & Sharma, A. K. (2020). Development of composite vulnerability index and district level mapping of climate change induced drought in Tamil Nadu, India. *Ecological Indicators 113*: 106197.

Bankoff, G. (2001). Rendering the world unsafe: 'vulnerability' as Western discourse. *Disasters 25*(1): 19-35.

Bankoff, G. (2006). The Tale of the Three Pigs: Taking Another Look at Vulnerability in the Light of the Indian Ocean Tsunami and Hurricane Katrina. Retrieved from: https://items.ssrc.org/understanding-katrina/the-tale-of-the-three-pigs-taking-another-look-at-vulnerability-in-the-light-of-the-indian-ocean-tsunami-and-hurricane-katrina/

Bankoff, G., Frerks, G. & Hilhorst, D. (2013). *Mapping Vulnerability: Disasters, Development and People.* Routledge: London

Besley, T., Pande, R. & Rao, V. (2007). Political Economy of Panchayats in South India. *Economic and Political Weekly 42*(8): 661-666.

Birkmann, J., 2006a. Measuring vulnerability to promote disaster-resilient societies: Conceptual frameworks and definition, in: Birkmann, J. (Ed.), Measuring Vulnerability to Natural Hazards: Toward Resilient Societies. United Nations University Press, Tokyo, JPN.

Blackmore, I., Rivera, C., Waters, W. F., Ianotti, L. & Lesorogol, C. (2021). The impact of seasonality and climate variability on livelihood security in the Ecuadorian Andres. *Climate Risk Management 32*: 100279.

Bohle, H. G. (1983). The Cauvery Delta: An Investigation into History and Determinants of Agrarian Development and Rural Under Development. *The Indian Geographical Journal 58*(1): 29-46.

Bohle, H. G. (1985). From Centre to Periphery: Changing Spatial Structures in Rural South India, 985-1985. *GeoJournal 10*(1), 5-15.

Boulanger, P. (2008). Sustainable development indicators: a scientific challenge, a democratic issue. *S.A.P.I.EN.S 1*(1): 45-59.

Bronfman, N. C., Repetto, P. B., Guerrero, N., Castaneda, J. V. & Cisternas, P. C. (2021). Temporal evolution in social vulnerability to natural hazards in Chile. *Natural Hazards 107*: 1757-1784.

Chen, W., Cutter, S. L., Emrich, C. & Shi, P. (2013). Measuring social vulnerability to natural hazards in the Yangtze River Delta Region, China. *International Journal of Disaster Risk Science 4*: 169-181.

Clay, N. (2018). Integrating livelihood approaches with research on development and climate change adaptation. *Progress in Development Studies 18*(1): 1-17.

Collins, T. W. (2010). Marginalization, Facilitation, and the Production of Unequal Risk: The 2006 *Paso del Norte* Floods. *Antipode 42*(2): 258-288.

CRED (2020). Human cost of disasters: An overview of the last 20 years 2000-2019. https://reliefweb.int/sites/reliefweb.int/files/resources/Human%20Cost%20of%20Disasters%202000-2019%20Report%20-%20UN%20Office%20for%20Disaster%20Risk%20Reduction.pdf

Cutter, S. L. (1996). Vulnerability to environmental hazards. *Progress in Human Geography 20*(4): 529-539.

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social Science Quaterly 84*(2): 242-261.

Cutter, S. L. & Finch, C. (2008). Temporal and spatial changes in social vulnerability to natural hazards. *PNAS 105*(7): 2301-2306.

Das, S., Hazra, S., Haque, A., Rahman, M., Nicholls, R. J., Ghosh, A., Ghosh, T. … & de Campos, R. S. (2021). Social vulnerability to environmental hazards in the Ganges-Brahmaputra-Meghna delta, India and Bangladesh. *International Journal of Disaster Risk Reduction 53*: 101983.

De Souza, K., Kityi, E., Harvey, B., Leone, M., Murali, K. S. & Ford, J. D. (2015). Vulnerability to climate change in three hot spots in Africa and Asia: key issues for policy-relevant adaptation and resilience-building research. *Regional Environmental Change 15*(6): 747-753.

Dercon, S. & Krishnan, P. (2000). Vulnerability, seasonality and poverty in Ethiopia. *The Journal of Development Studies 36*(6): 25-53.

De Vries, D. H. (2011). Temporal vulnerability in hazardscapes: Flood memory-networks and referentiality along the North Carolina Neuse River (USA). *Global Environmental Change 21*(1): 154-164.

Dixit, S., Tayyaba, S. & Jayakumar, K. V. (2021). Spatio-temporal variation and future risk assessment of projected drought events in the Godavari River basin using regional climate models. *Journal of Water & Climate Change*: to be published: jwc2021093.

Dixon, W. J. & Yuen, K. K. (1974). Trimming and winsorization: A review. *Statistische Hefte 15*(2-3): 157-170.

Edmonds, D. A., Caldwell, R. L., Brondizio, E. S. & Siani, S. M. O. (2020). Coastal flooding will disproportionately impact people on river deltas. *Nature Communications 11*: 4741.

Eriksen, S., & O'Brien, K. (2007). Vulnerability, poverty and the need for sustainable adaptation measures. Climate Policy, 7(4), 337–352.

Eriksen, S., & Silva, J. A. (2009). The vulnerability context of a savanna area in Mozambique: household drought coping strategies and responses to economic change. *Environmental Science & Policy 12*(1): 33-52.

Etzold, B. & Sakdapolrak, P. (2016). Socio-spatialities of vulnerability: towards a polymorphic perspective in vulnerability research. *Die Erde 147*(4): 234-251.

Fatemi, F., Ardalan, A., Aguirre, B., Mansouri, N., & Mohammadfam, I. (2017). Social vulnerability indicators in disasters: Findings from a systematic review. *International Journal of Disaster Risk Reduction 22*: 219-227.

Fawcett, D., Pearce, T., Ford, J. D. & Archer, L. (2017). Operationalising longitudinal approaches to climate change vulnerability assessment. *Global Environmental Change 45*(7): 79-88.

Fraser, T. (2021). Japanese social capital and social vulnerability indices: Measuring drivers of community resilience 2000-2017. *International Journal of Disaster Risk Reduction 52*: 101965.

Frazier, T. G., Thompson, C. M., Dezzani, R. J. & Butsick, D. (2013). Spatial and temporal quantification of resilience at the community scale. *Applied Geography 42*: 95-107.

Gaillard, J. C., Liamzon, C. C. & Villanueva, J. D. (2007). 'Natural' disaster? A retrospect into the causes of the late-2004 typhoon disaster in Eastern Luzon, Philippines. *Environmental Hazards 7*(4): 257-270.

Ganesan, S. (2018, 24 november). Tamil Nadu's Cauvery delta districts, where Cyclone Gaja swirled through, are picking up the pieces. Retrieved from https://www.thehindu.com/news/national/tamil-nadu/tamil-nadu-cauvery-delta-districts-where-cyclone-gaja-swirled-through-are-picking-up-the-pieces/article25587103.ece

Gibb, C. (2018). A critical analysis of vulnerability. *International Journal of Disaster Risk Reduction 28*(6): 327-334.

Gough, K. (1987). Socio-economic change in Southeast India, 1950s to 1980s. *Journal of Contemporary Asia 17*(3): 276-292.

Government of India (2011a). 2011 Census: Population Enumeration Data. Retrieved from https://censusindia.gov.in/2011census/population_enumeration.html

Government of India (2011b). 2011 Census: House listing and Housing Data. Retrieved from https://censusindia.gov.in/2011census/hlo/HLO_Tables.html

Government of India (2011c). Socio Economic and Caste Census 2011. Retrieved from https://secc.gov.in/

Government of India (2011d). 2010-2011 Agriculture Census. Retrieved from https://agcensus.dacnet.nic.in/

Govindarajan, V. (2017). No harvest, no festive cheer: It's a black Pongal for drought-hit farmers in the Cauvery delta. Retrieved from: https://scroll.in/article/826545/no-harvest-no-festive-cheer-its-a-black-pongal-for-drought-hit-farmers-in-the-cauvery-delta

Hagenlocher, M., Renoud, F., Haas, S. & Sebesvari, Z. (2018). Vulnerability and risk of deltaic social-ecological systems exposed to multiple hazards. *Science of The Total Environment 631-632*(8): 71-80.

Hardikar, J. (2017). Distress and death in the delta. Retrieved from: https://ruralindiaonline.org/en/articles/distress-and-death-in-the-delta/

Hawkins, R. L., & Maurer, K. (2010). Bonding, bridging and linking: How social capital operated in New Orleans following Hurricane Katrina. *British Journal of Social Work 40*(6), 1777-1793.

Hemingway, L., & Priestley, M. (2006). Natural hazards, human vulnerability and disabling societies: A disaster for disabled people?. *Review of Disability Studies: An International Journal*, 2(3).

Hewitt, K. (1983). *Interpretations of Calamity*. Allen and Unwin Inc.: Boston, London, Sydney.

Hinkel, J. (2011). Indicators of vulnerability and adaptive capacity: towards a clarification of the science-policy interface. *Global Environmental Change 21*(8): 198-208.

Hülssiep, M., Thaler, T., & Fuchs, S. (2021). The impact of humanitarian assistance on post-disaster social vulnerabilities: some early reflections on the Nepal earthquake in 2015. *Disasters*, *45*(3), 577-603.

Ibánez, C., Alcaraz, C., Gaiola, N., Prado, P., Trobajo, R., Benito, X. … Syvitski, J. P. M. (2019). Basin-scale land use impacts on world deltas: Human vs natural forcings. *Global and Planetary Change 173*: 24-32.

IPCC (2021). Climate Change 2021: The Physical Science Basis. Working Group I contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Irz, X., Lin, L., Thirtle, C. & Wiggins, S. (2001). Agricultural productivity growth and poverty allevation. *Development Policy Review 19*(4): 449-466

Islam, M. M. & Herbeck, J. (2013). Migration and Translocal Livelihoods of Coastal Small-scale Fisheries in Bangladesh. *The Journal of Development Studies 49*(6): 832-845.

Kelly, P. M. & Adger, W. N. (2000). Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change 47*(4): 325-352.

Kreps, G. A. (1998). Disaster as systemic event and social catalyst. In E. L. Quarantelli (ed.), *What is a disaster: Perspectives on the question* (pp. 31-55). London: Routledge

Lele, S., Srinivasan, V., Thomas, B. K. & Jamwal, P. (2018). Adapting to climate change in rapidly urbanising river basins: insights from a multiple-concerns, multiple-stressors, and multi-level approach. *Water International 43*(2): 281-304.

Leroy, S. A. (2020). Natural Hazards, Landscapes and Civilizations. *Reference Module in Earth Systems and Environmental Sciences*. Retrieved from 10.1016/B978-0-12-818234-5.00003-1

Llorente-Marrón, M., Díaz-Fernández, M., Méndez-Rodríguez, P. & Gonzales, R. A. (2020). Social vulnerability, gender and disasters: the case of Haiti in 2010. *Sustainability 12*(9): 3574.

Loc, H. H, Van Binh, D., Park, E., Shrestha, S., Dung, T. D.. Son, V. H. … & Seijger, C. (2021). Intensifying saline water intrusion and drought in the Mekong Delta: From physical evidence to policy outlooks. *Science of The Total Environment 757*: 143919.

Magnan, A. K., Schipper, E. L. F., Burkett, M., Bharwani, S., Burton, I.., Eriksen, S. … & Ziervogel, G. (2016). Addressing the risk of maladaptation to climate change. *WIREs Climate Change 7*(5): 646-665.

Maiti, S., Jha, S. K., Garai, S., Nag, A., Bera, A. K., Paul, V. … & Deb, S. M. (2017). An assessment of social vulnerability to climate change among the districts of Arunachal Pradesh. *Ecological Indicators 77*: 105-113.

Maiti, S., Jha, S. K., Garai, S., Nag, A., Chakravarty, R., Kadian, K. S. … & Upadhyay, R. C. (2015). Assessment of social vulnerability to climate change in the eastern coast of India. *Climatic Change 131*: 287-306.

Makoka, D. & Kaplan, M. (2005). Poverty and Vulnerability – An Interdisciplinary Approach. Retrieved from https://mpra.ub.uni-muenchen.de/6964/1/MPRA_paper_6964.pdf

Marino, E. K., & Faas, A. J. (2020). Is Vulnerability an Outdated Concept? After Subjects and Spaces. *Annals of Anthropological Practice 44*(1): 33-46.

Marks, D., Connell, J. & Ferrara, F. (2020). Contested notions of disaster justice during the 2011 Bangkok floods: Unequal risk, unrest and claims to the city. *Asia Pacific Viewpoint 61*(1): 19-36.

McBean, G. A. (2012). Integrating disaster risk reduction towards sustainable development. *Current Opinion in Environmental Sustainability 4*(1): 122-127.

Milliman, J. D., Broadus, J. M., & Gable, F. (1989). Environmental and Economic Implications of Rising Sea Level and Subsiding Deltas: The Nile and Bengal Examples. *Ambio 18*(6): 340-345.

Mohanty, S. K. (2020). Contextualising geographical vulnerability to COVID-19 in India. *The Lancet Global Health 8*(9): E1104-E1105.

Mohapatra, M., Mandal, G. S., Bandyopadhyay, B. K., Tyagi, A., & Mohanty, U. C. (2012). Classification of cyclone hazard prone districts in India. *Natural Hazards 63*(3): 1601-1620.

Mora, C., Spirandelli, D., Franklin, E. C., Lynham, J., Kantar, M. B., Miles, W. … & Hunter, C. L. (2018). Broad threat to humanity from cumulative climate hazards intensified by greenhouse gas emissions. *Nature Climate Change 8*(12): 1062-1071.

Murshed, S. B. & Kaluarachchi, J. J. (2018). Scarcity of fresh water resources in the Ganges Delta of Bangladesh. *Water Security 4-5*: 8-18.

Muttarak, R., & Lutz, W. (2014). Is education a key to reducing vulnerability to natural disasters and hence unavoidable climate change?. *Ecology and Society 19*(1): 42

Ngo, E. B. (2001). When disasters and age collide: Reviewing vulnerability of the elderly. *Natural Hazards Review* 2(2): 80-89.

Nicholls, R. J., Adger, W. N., Hutton, C. W. & Hanson, S. E. (2020). *Deltas in the Anthropocene*. Palgrave Macmillan: Cham, Switzerland

O'Brien, K., Eriksen, S., Nygaard, L. P. & Schjolden, A. (2007). Why different interpretations of vulnerability matter in climate change discourse. *Climate Policy 7*(1): 32-88.

O'Brien, K., & Leichenko, R. (2000). Double exposure: assessing the impacts of climate change within the context of economic globalization. *Global Environmental Change 10*(3): 221-232.

O'Hare, G. (2001). Hurricane 07B in the Godavari Delta, Andhra Pradesh, India: vulnerability, mitigation and the spatial impact. *Geographical Journal 167*(1): 23-28.

O'Keefe, P., Westgate, K. & Wisner, B. (1976). Taking the naturalness out of natural disasters. *Nature 260*: 566-567.

Oliver-Smith, A. (1994). The Five Hundred Year Earthquake: Natural and Social Hazards in the Third World (Peru) (pp. 31-48). In: A. Varley (ed.): Disasters, Development and Environment. Wiley: Chichester.

Otto, I. M., Reckien, D., Reyer, C. P. O., Marcus, R., Le Masson, V., Jones, L., … & Serdeczny, O. (2017).Social Vulnerability to climate change: a review of concepts and evidence. *Regional Environmental Change 17*: 1651-1662.

Pandey, A. C., Singh, S. K., & Nathawat, M. S. (2010). Waterlogging and flood hazards vulnerability and risk assessment in Indo Gangetic plain. *Natural Hazards, 55*(2): 273-289.

Paramasivan, C. & Pasupathi, R. (2016). An Overview of Cauvery Delta Zone in Tamil Nadu. *International Journal of Trend in Research and Development 3*(5): 399-403.

Parthasarathy, G., & Pothana, V. (1983). Capitalism in Agriculture and Peasant Farming: Case of Godavari Delta. *Economic and Political Weekly 18*(39): A93-A97.

Pelling, M. (1999). The political ecology of flood hazards in urban Guyana. *Geoforum 30*(3): 249-261.

Pelling, M. (2001). Natural disasters? In: N. Castree, B. Braun (Eds). Social Nature: Theory, Practice, and Politics (pp. 170-188). Blackwell Publishers: Oxford.

Pennington, B. T., Bunbury, J., & Hovius, N. (2016). Emergence of civilisation, changes in fluvio-deltaic style, and nutrient redistribution forced by Holocene sea-level rise. *Geoarchaeology 31*(1): 194-210.

Prasad, N. P. (2015). Agrarian Class and Caste Relations in 'United' Andhra Pradesh, 1956-2014. *Economic and Political Weekly 50*(16): 77-83.

Preston, B. L., Yuen, E. J. & Westaway, R. M. (2011). Putting vulnerability to climate change on the map: a review of approaches, benefits, and risks. *Sustainability Science 6*(2): 177-202.

Rabby, Y. W., Hossain, M. B., & Hasan, M. U. (2019). Social vulnerability in the coastal region of Bangladesh: An investigation of social vulnerability index and scalar change effects. *International Journal of Disaster Risk Reduction 41*: 101329.

Rahman, M. S. (2013). Climate change, disaster and gender vulnerability: A study on two divisions of Bangladesh. *American Journal of Human Ecology 2*(2): 72-82.

Rao, G. N. (1988). Canal irrigation and agrarian change in colonial Andhra: a study of Godavari district, c. 1850-1890. *The India Economic & Social History Review 25*(1): 25-60.

Rao, K. N., Saito, Y., Nagakumar, K. C. V., Demudu, G., Basavaiah, N., Rajawat, A. S., Tokanai, F. … & Nakashima, R. (2012). Holocene environmental changes of the Godavari Delta, east coast of India, inferred from sediment core analyses and AMS14C dating. *Geomorphology 175-176*: 163-175.

Rao. K. N., Saito, Y., Nagakumar, K. C. V., Demudu, G., Rajawat, A. S., Kuba, S. & Li, Z. (2015). Palaeogeography and evolution of the Godavari delta, east coast of India during the Holocene: An example of wave-dominated and fan-delta settings. *Palaeogeography, Palaeoclimatology, Palaeoecology 440*: 213-233.

Ravichandran, N. (2020). As Tamil Nadu Braces for Cyclone Nivar, Memories of Gaja Drive Farmers, Fisherfolk Sleepless. Retrieved from: https://thewire.in/environment/as-tamil-nadu-braces-for-cyclone-nivar-memories-of-gaja-drive-farmers-fisherfolk-sleepless

Ribot, J. (2014). Cause and response: vulnerability and climate in the Anthropocene. *The Journal of Peasant Studies 41*(5): 667-705.

Rodríguez, H., Donner, W. & Trainor, J. E. (2018). *Handbook of Disaster Research (second edition)*. Springer: Cham

Roelen, K. & Camfield, L. (2015). Mixed Methods Research in Poverty and Vulnerability. Palgrave Macmilan: London

Roy, T. (2012). Natural Disasters and Indian History: Oxford India Short Introductions. *OUP Catalogue*.

Rufat, S., Tate, E., Emrich, C. T., & Antolini, F. (2019). How Valid Are Social Vulnerability Models? *Annals of the American Association of Geographers 109*(4): 1131-1153.

Sebesvari, Z., Foufoula-Georgiou, E., Harrison, I., Brondizio, E. S., Bucx, T., Dearing, J. A. … Wilson, C. A. (2016a). *Imperatives for sustainable delta futures: brief for GSDR – 2016 update.* Available from https://sustainabledevelopment.un.org/content/documents/972032_Sebesvari_Imperatives%20for%20sustainable%20delta%20futures.pdf

Sen, A. (1981). Poverty and Famines: an Essay on Entitlement and Deprivation. Oxford University Press: Oxford

Shaji, J. (2021). Evaluating social vulnerability of people inhabiting a tropical coast in Kerala, south west coast of India. *International Journal of Disaster Risk Reduction 56*: 102130.

Singh, C., Deshpande, T., & Basu, R. (2017). How do we assess vulnerability to climate change in India? A systematic review of literature. Regional Environmental Change, 17(2), 527-538.

Singh, P., Yadava, M. G., Ahmad, M. Z., Mohapatra, . P., Laskar, A. H., Doradla, S. … & Kumanan, C. J. (2015). Fertile farmlands in Cauvery delta: evolution through LGM. *Current Science 108*(2): 218-225.

Smit, B. & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change 16*(3): 282-292.

Spielman, S. E., Tuccillo, J., Folch, D. C., Schweikert, A., Davies, R., Wood, N., & Tate, E. (2020). Evaluating social vulnerability indicators: criteria and their application to the Social Vulnerability Index. *Natural Hazards 100*(1): 417-436.

Srinivasan, V. (2019, May 7). Looking into the crystal ball: Anticipating and influencing change in Asian Deltas. Inaugural address as Professor to the Prince Claus Chair in Development and Equity 2018/2020). Utrecht.

Stacey, D. B., & Visweswaran, V. R. (2013). Water resources development in the Cauvery river basin, India. *Engineering History and Heritage 166*(2): 106-118.

Stoddart, B. (2010). Water, land, language and politics in coastal Andhra, 1850-1925. *South Asian History and Culture* 1(3): 341-356.

Syvitski, J. P. M., Kettner, A. J., Overeem, I., Hutton, E. W. H., Hannon, M, T., Brakenridge, R. … & Nicholls, R. J. (2009). Sinking deltas due to human activities. *Nature Geoscience 2*(10): 681-686.

Tate, E. (2012). Social vulnerability indices: a comparative assessment using uncertainty and sensitivity analysis. *Natural Hazards 63*(2): 325-347.

Taylor, M. (2013). Climate change, relational vulnerability and human security: rethinking sustainable adaptation in agrarian environments. *Climate and Development 5*(4): 318-327.

Tessler, Z. D., Vörösmarty, C. J., Grossberg, M., Gladkova, I., Aizenman, H., Syvitski, J. P. M. & Foufoula-Georgiou, E. (2015). Profiling risk and sustainability in coastal deltas of the world. *Science 349*(6248): 638-643

The Hindu (2019, 5 August). Flood situation in Godavari delta still grim. Retrieved from: https://www.thehindu.com/news/national/andhra-pradesh/flood-situation-in-godavari-delta-still-grim/article28816309.ece

Tobler, W. R. (1970). A Computer Movie Simulating Urban Growth in the Detroit Region. *Economic Geography 46*(1): 234-240.

Tran, H., Nguyen, Q. & Kervyn, M. (2017). Household social vulnerability to natural hazards in the coastal Tran Van Thoi District, Ca Mau Province, Mekong Delta, Vietnam. *Journal of Coastal Conservation 21*: 489-503.

Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L. … & Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *PNAS 100*(14): 8074-8079.

United Nations (2015). Transforming our world: the 2030 agenda for sustainable development. Retrieved from https://sdgs.un.org/

United Nations (2019). Population Division: World Population Prospects 2019. Retrieved from: https://population.un.org/wpp/

United Nations Development Programme (UNDP) (2020). Human Development Report 2020. The Next Frontier: Human Development and the Anthropocene. UNDP: New York.

United Nations Office for Disaster Risk Reduction (UNISDR) (2015). Making Development Sustainable: The Future of Disaster Risk Management: Global Assessment Report on Disaster Risk Reduction. United Nations: Geneva

Upadhya, C. B. (1988). The Farmer-Capitalists of Coastal Andhra Pradesh. Economic and Political Weekly 23(28): 1433-1442.

Van Bavel, B., Curtis, D. R., Dijkman, J., Hannaford, M., de Keyzer, M., van Onacker, E., & Soens, T. (2020). Disasters and History: The Vulnerability and Resilience of Past Societies. Cambridge University Press: Cambridge

Vanham, D., Weingartner, R. & Rauch, W. (2011). The Cauvery river basin in Southern India: major challenges and possible solutions in the 21st century. *Water Science & Technology 64*(1): 122-131.

Van Schendel, W. (1991). Three Deltas: Accumulation and Poverty in Rural Burma, Bengal and South India. Sage Publications: New Delhi

Vieira, R. M. D. S. P., Sestini, M. F., Tomasella, J., Marchezini, V., Pereira, G. R., Barbosa, A. A., ... & Ometto, J. P. H. B. (2020). Characterizing spatio-temporal patterns of social vulnerability to droughts, degradation and desertification in the Brazilian northeast. *Environmental and Sustainability Indicators 5*: 100016.

Warr, P., & Aung, L. L. (2019). Poverty and inequality impact of a natural disaster: Myanmar's 2008 cyclone Nargis. *World Development 122*: 446-461.

Watts, M. J. & Bohle, H. G. (1993). The space of vulnerability: the causal structure of hunger and famine. *Progress in Human Geography 17*, 43-67.

Winchester, P. J. & Penning-Rowsell, E. (2001). *Socio-economy of the Coastal Areas & Cyclone Vulnerability: Technical Report No. 3 of the Andhra Pradesh Cyclone Hazard Mitigation Project*. Delft Hydraulics: Delft / Hyderabad.

Wisner, B., Blaikie, P., Cannon, T. & Davis, I. (2004). *At Risk: Natural Hazards, People's Vulnerability and Disasters*. Routledge: London, New York.

Wisner, B. & Gaillard, J. (2009). An introduction to neglected disasters. *JAMBA: Journal of Disaster Risk Studies 2*(3): 151-158.

Wisner, B., Gaillard, J.C. & Kelman, I. (2012). The Routledge Handbook of Hazards and Disaster Risk Reduction. London and New York: Routledge

Wolters, M. L. & Kuenzer, C. (2015). Vulnerability assessment of coastal river deltas – categorisation and review. *Journal of Coastal Conservation 19*(6): 345-368.

Wood, E., Sanders, M., & Frazier, T. (2021). The practical use of social vulnerability indicators in disaster management. *International Journal of Disaster Risk Reduction 63*: 102464.

Woodruff, J. D., Irish, J. L. & Camargo, S. J. (2013). Coastal flooding by tropical cyclones and sea-level rise. *Nature 504*(7478): 44-52.

Yamunan, S. (2017). In the Cauvery delta region of Tamil Nadu, farmers no longer consider the summer crop to be viable. Retrieved from: https://scroll.in/article/841909/in-the-cauvery-delta-region-of-tamil-nadu-farmers-no-longer-consider-the-summer-crop-to-be-viable

Zhou, Y., Li, N., Wu, W. & Shi, P. (2014). Local Spatial and Temporal Factors Influencing Population and Societal Vulnerability to Natural Disasters. *Risk Analysis 34*(4): 614-639.

Zoomers, A. & van Westen, G. (2011). Introduction: translocal development, development corridors and development chains. *International Development Planning Review 33*(4): 377-388.

APPENDIX

Appendix 1 Multicollinearity of IDVI

The multicollinearity of all variables and indicators of the IDVI were assessed using the Spearman's correlation, a non-parametric correlation coefficient that can be used assess and test correlation between variables, with r > 0.8 indicating highly collinear datasets (Hagenlocher *et al.* 2018). Statistical significance was tested using a two-tailed approach in SPSS software. No high multicollinearity was found in the datasets (table A1-A2).

Table A1: Correlation matrix Cauvery Delta

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18	V19	V20	V21	V22	V23	V24	V25
V1	1.000	,175**	-,178**	-,056*	-0.012	-,155**	-,273**	-,111**	-,203**	-,475**	-,472**	-,316**	-,271**	,371**	0.020	-,165**	0.034	-,141**	-,239**	-,229**	-,092**	-,143**	-,406**	-,061*	,121**
V2	,175**	1.000	-,472**	-,087**	-,180**	-,087**	,091**	-0.014	-,139**	,053*	-,182**	-0.043	-,240**	,142**	-,127**	-,141**	-,087**	0.021	-,094**	-0.026	-,216**	-,224**	-,071**	-,061*	-,060*
V3	-,178**	-,472**	1.000	,103**	-,066**	,342**	-0.026	0.002	,088**	,209**	,318**	,097**	,259**	-,211**	,142**	,330**	,130**	-,162**	,252**	,206**	,318**	,323**	,241**	,312**	,159**
V4	-,056*	-,087**	,103**	1.000	-0.008	0.026	0.008	-0.040	,089**	0.043	,105**	0.024	,132**	-0.034	,052*	,107**	,072**	-,210**	,066**	,080**	,168**	0.027	-,061*	,133**	,083**
V5	-0.012	-,180**	-,066**	-0.008	1.000	-,072**	,088**	0.003	,133**	-,097**	-0.049	0.027	-0.008	,103**	0.011	-,115**	-0.021	,182**	-,064*	-,057*	-,073**	0.025	-,142**	-,192**	-0.021
V6	-,155**	-,087**	,342**	0.026	-,072**	1.000	,172**	-,061*	,054*	,303**	,280**	,164**	,219**	-,232**	-0.002	,294**	0.004	-,127**	,174**	,246**	,217**	,214**	,325**	,265**	,309**
V7	-,273**	,091**	-0.026	0.008	,088**	,172**	1.000	,054*	,314**	,441**	,345**	,388**	,293**	-,314**	-,051*	,194**	-,064*	,176**	,236**	,311**	,165**	,195**	,405**	0.006	-,068**
V8	-,111**	-0.014	0.002	-0.040	0.003	-,061*	,054*	1.000	,130**	,054*	,084**	,089**	,063*	-0.028	0.004	-0.023	-0.047	,147**	,103**	0.039	-0.030	,068**	,077**	-,108**	-,071**
V9	-,203**	-,139**	,088**	,089**	,133**	,054*	,314**	,130**	1.000	,265**	,343**	,270**	,333**	-,217**	,055*	,063*	0.025	,228**	,142**	,193**	,155**	,172**	,226**	-,089**	-,088**
V10	-,475**	,053*	,209**	0.043	-,097**	,303**	,441**	,054*	,265**	1.000	,713**	,500**	,474**	-,490**	0.015	,434**	-0.020	,092**	,341**	,487**	,325**	,265**	,640**	,238**	-,112**
V11	-,472**	-,182**	,318**	,105**	-0.049	,280**	,345**	,084**	,343**	,713**	1.000	,494**	,549**	-,469**	0.043	,439**	,066*	,051*	,375**	,433**	,401**	,331**	,610**	,228**	-,072**
V12	-,316**	-0.043	,097**	0.024	0.027	,164**	,388**	,089**	,270**	,500**	,494**	1.000	,424**	-,340**	-0.022	,232**	-0.039	,199**	,262**	,316**	,223**	,248**	,492**	-0.036	-,154**
V13	-,271**	-,240**	,259**	,132**	-0.008	,219**	,293**	,063*	,333**	,474**	,549**	,424**	1.000	-,377**	,117**	,480**	,072**	-,116**	,327**	,401**	,467**	,410**	,494**	,263**	0.023
V14	,371**	,142**	-,211**	-0.034	,103**	-,232**	-,314**	-0.028	-,217**	-,490**	-,469**	-,340**	-,377**	1.000	-,078**	-,426**	-0.037	-0.029	-,273**	-,311**	-,319**	-,295**	-,486**	-,228**	,055*
V15	0.020	-,127**	,142**	,052*	0.011	-0.002	-,051*	0.004	,055*	0.015	0.043	-0.022	,117**	-,078**	1.000	,086**	,056*	-,126**	0.047	,086**	,164**	,095**	0.041	,141**	,090**
V16	-,165**	-,141**	,330**	,107**	-,115**	,294**	,194**	-0.023	,063*	,434**	,439**	,232**	,480**	-,426**	,086**	1.000	,130**	-,263**	,354**	,381**	,483**	,348**	,456**	,522**	,076**
V17	0.034	-,087**	,130**	,072**	-0.021	0.004	-,064*	-0.047	0.025	-0.020	,066*	-0.039	,072**	-0.037	,056*	,130**	1.000	-,198**	,149**	0.012	,162**	,086**	,095**	,166**	,057*
V18	-,141**	0.021	-,162**	-,210**	,182**	-,127**	,176**	,147**	,228**	,092**	,051*	,199**	-,116**	-0.029	-,126**	-,263**	-,198**	1.000	-,060*	-0.034	-,301**	-,068**	0.025	-,459**	-,292**
V19	-,239**	-,094**	,252**	,066**	-,064*	,174**	,236**	,103**	,142**	,341**	,375**	,262**	,327**	-,273**	0.047	,354**	,149**	-,060*	1.000	,258**	,267**	,410**	,481**	,202**	-0.003
V20	-,229**	-0.026	,206**	,080**	-,057*	,246**	,311**	0.039	,193**	,487**	,433**	,316**	,401**	-,311**	,086**	,381**	0.012	-0.034	,258**	1.000	,447**	,247**	,403**	,264**	-0.040
V21	-,092**	-,216**	,318**	,168**	-,073**	,217**	,165**	-0.030	,155**	,325**	,401**	,223**	,467**	-,319**	,164**	,483**	,162**	-,301**	,267**	,447**	1.000	,366**	,352**	,491**	,155**
V22	-,143**	-,224**	,323**	0.027	0.025	,214**	,195**	,068**	,172**	,265**	,331**	,248**	,410**	-,295**	,095**	,348**	,086**	-,068**	,410**	,247**	,366**	1.000	,458**	,271**	,092**
V23	-,406**	-,071**	,241**	-,061*	-,142**	,325**	,405**	,077**	,226**	,640**	,610**	,492**	,494**	-,486**	0.041	,456**	,095**	0.025	,481**	,403**	,352**	,458**	1.000	,249**	-,065*
V24	-,061*	-,061*	,312**	,133**	-,192**	,265**	0.006	-,108**	-,089**	,238**	,228**	-0.036	,263**	-,228**	,141**	,522**	,166**	-,459**	,202**	,264**	,491**	,271**	,249**	1.000	,269**
V25	,121**	-,060*	,159**	,083**	-0.021	,309**	-,068**	-,071**	-,088**	-,112**	-,072**	-,154**	0.023	,055*	,090**	,076**	,057*	-,292**	-0.003	-0.040	,155**	,092**	-,065*	,269**	1.000

	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8
ID1	1.000	-,080**	-,130**	-,184**	,146**	-,061*	-0.018	,224**
ID2	-,080**	1.000	,191**	,185**	-,071**	,116**	,179**	,149**
ID3	-,130**	,191**	1.000	,436**	-,270**	,200**	,338**	-0.027
ID4	-,184**	,185**	,436**	1.000	-,252**	,368**	,579**	-0.006
ID5	,146**	-,071**	-,270**	-,252**	1.000	-,210**	-,211**	0.042
ID6	-,061*	,116**	,200**	,368**	-,210**	1.000	,385**	,072**
ID7	-0.018	,179**	,338**	,579**	-,211**	,385**	1.000	,314**
ID8	,224**	,149**	-0.027	-0.006	0.042	,072**	,314**	1.000

*. Correlation is significant at the 0.05 level (2-tailed) **. Correlation is significant at the 0.01 level (2-tailed)

Variables

V1: Population density
V2: Household size
V3: No age 16-59
V4:Disabled population
V5: Female population
V6: Gender literacy gap
V7: Illiteracy rate
V8: Unsafe drinking water
V9: No electricity
V10: No sanitation
V11: No bathroom
V12: No modern cooking fuels
V13: Kutcha housing
V14: Non-workers
V15: Marginal workers
V16: Agricultural labourers
V17: No mechanised wheelers
V18: Marginal landholdings
V19: Under Rs. 5000
V20: No banking services
V21: No mobile telephones
V22: No motorised vehicles
V23: No refrigerator
V24: Caste population
V25: Caste literacy gap

Indicators

ID1: Demography
ID2: Gender
ID3: Education
ID4: Standard of living
ID5: Economic productivity
ID6: Agriculture
ID7: Income and assets
ID8: Caste

Table A2: Correlation matrix Godavari Delta

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18	V19	V20	V21	V22	V23	V24	V25
V1	1.000	0.053	-,078*	0.060	,074*	0.013	,287**	0.009	-,159**	-,169**	-,189**	-,236**	-,287**	-,369**	-0.037	-,295**	-0.022	,420**	0.050	-0.020	-0.044	-,078*	-,139**	-,119**	0.008
V2	0.053	1.000	-,562**	-0.001	-,131**	-,228**	0.029	,093**	,134**	,161**	,122**	,129**	,148**	-,120**	-,066*	-,110**	0.003	0.031	0.014	-0.062	-,258**	-,131**	0.029	,090**	-,089**
V3	-,078*	-,562**	1.000	,079*	0.023	,417**	0.011	-0.023	0.018	0.050	,080*	0.026	0.015	,079*	,143**	,158**	,078*	,097**	,200**	0.050	,243**	,382**	,155**	-0.009	,102**
V4	0.060	-0.001	,079*	1.000	-0.007	,144**	,135**	,101**	-0.054	0.050	0.023	-0.028	,063*	0.010	0.044	0.011	-,163**	,158**	,081**	-0.016	-0.042	-0.019	-,151**	0.006	-0.037
V5	,074*	-,131**	0.023	-0.007	1.000	-,105**	0.047	-0.050	-,116**	-,238**	-,191**	-,229**	-,067*	-0.008	-0.027	-,109**	-0.028	-,069*	-,074*	-,096**	-0.014	-0.025	-,207**	-0.043	-0.024
V6	0.013	-,228**	,417**	,144**	-,105**	1.000	-,155**	,081*	-0.003	,157**	,140**	,179**	-0.039	-0.038	,098**	,124**	-0.043	,099**	,232**	,192**	,198**	,192**	,161**	-,088**	,156**
V7	,287**	0.029	0.011	,135**	0.047	-,155**	1.000	-0.061	-,128**	-,238**	-,270**	-,379**	0.060	-0.054	0.012	-,271**	0.009	,406**	-,099**	-,383**	-,251**	-,233**	-,327**	,245**	-,123**
V8	0.009	,093**	-0.023	,101**	-0.050	,081*	-0.061	1.000	,191**	,279**	,252**	,255**	0.026	-0.047	,103**	0.027	-,094**	,131**	,118**	,125**	0.015	0.008	,094**	,131**	,068*
V9	-,159**	,134**	0.018	-0.054	-,116**	-0.003	-,128**	,191**	1.000	,544**	,547**	,498**	,393**	,171**	,193**	,176**	-0.023	-0.009	,112**	,097**	0.049	0.039	,223**	,181**	-0.046
V10	-,169**	,161**	0.050	0.050	-,238**	,157**	-,238**	,279**	,544**	1.000	,802**	,624**	,329**	,136**	,225**	,319**	0.013	,104**	,241**	,260**	,154**	,175**	,419**	,094**	-0.040
V11	-,189**	,122**	,080*	0.023	-,191**	,140**	-,270**	,252**	,547**	,802**	1.000	,635**	,303**	,185**	,188**	,325**	0.030	0.048	,224**	,263**	,195**	,167**	,379**	,128**	-0.053
V12	-,236**	,129**	0.026	-0.028	-,229**	,179**	-,379**	,255**	,498**	,624**	,635**	1.000	,267**	,102**	,102**	,287**	-0.036	-0.041	,208**	,264**	,182**	,077*	,405**	,126**	0.004
V13	-,287**	,148**	0.015	,063*	-,067*	-0.039	0.060	0.026	,393**	,329**	,303**	,267**	1.000	,392**	,105**	,179**	0.000	-,115**	-0.030	-,128**	-,076*	-0.023	,073*	,122**	-,135**
V14	-,369**	-,120**	,079*	0.010	-0.008	-0.038	-0.054	-0.047	,171**	,136**	,185**	,102**	,392**	1.000	,161**	,263**	0.017	-,233**	0.013	-,123**	-0.035	,089**	,097**	,212**	-0.026
V15	-0.037	-,066*	,143**	0.044	-0.027	,098**	0.012	,103**	,193**	,225**	,188**	,102**	,105**	,161**	1.000	0.023	-0.029	,130**	,115**	0.039	-,069*	0.045	0.022	-,093**	0.011
V16	-,295**	-,110**	,158**	0.011	-,109**	,124**	-,271**	0.027	,176**	,319**	,325**	,287**	,179**	,263**	0.023	1.000	,064*	-,184**	,064*	,200**	,266**	,231**	,280**	,148**	0.011
V17	-0.022	0.003	,078*	-,163**	-0.028	-0.043	0.009	-,094**	-0.023	0.013	0.030	-0.036	0.000	0.017	-0.029	,064*	1.000	-0.029	,207**	0.040	-0.008	,281**	,278**	0.008	-0.045
V18	,420**	0.031	,097**	,158**	-,069*	,099**	,406**	,131**	-0.009	,104**	0.048	-0.041	-,115**	-,233**	,130**	-,184**	-0.029	1.000	,242**	0.036	-,090**	-0.005	0.003	,117**	-,112**
V19	0.050	0.014	,200**	,081**	-,074*	,232**	-,099**	,118**	,112**	,241**	,224**	,208**	-0.030	0.013	,115**	,064*	,207**	,242**	1.000	,160**	,064*	,391**	,350**	0.022	0.016
V20	-0.020	-0.062	0.050	-0.016	-,096**	,192**	-,383**	,125**	,097**	,260**	,263**	,264**	-,128**	-,123**	0.039	,200**	0.040	0.036	,160**	1.000	,305**	,126**	,236**	-,088**	,069*
V21	-0.044	-,258**	,243**	-0.042	-0.014	,198**	-,251**	0.015	0.049	,154**	,195**	,182**	-,076*	-0.035	-,069*	,266**	-0.008	-,090**	,064*	,305**	1.000	,219**	,236**	-0.033	,148**
V22	-,078*	-,131**	,382**	-0.019	-0.025	,192**	-,233**	0.008	0.039	,175**	,167**	,077*	-0.023	,089**	0.045	,231**	,281**	-0.005	,391**	,126**	,219**	1.000	,482**	-0.001	0.012
V23	-,139**	0.029	,155**	-,151**	-,207**	,161**	-,327**	,094**	,223**	,419**	,379**	,405**	,073*	,097**	0.022	,280**	,278**	0.003	,350**	,236**	,236**	,482**	1.000	0.026	-0.007
V24	-,119**	,090**	-0.009	0.006	-0.043	-,088**	,245**	,131**	,181**	,094**	,128**	,126**	,122**	,212**	-,093**	,148**	0.008	,117**	0.022	-,088**	-0.033	-0.001	0.026	1.000	0.029
V25	0.008	-,089**	,102**	-0.037	-0.024	,156**	-,123**	,068*	-0.046	-0.040	-0.053	0.004	-,135**	-0.026	0.011	0.011	-0.045	-,112**	0.016	,069*	,148**	0.012	-0.007	0.029	1.000

	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8
ID1	1.000	,121**	,233**	0.011	-,128**	,136**	0.046	-0.059
ID2	,121**	1.000	-,084**	-0.054	-0.002	0.022	,140**	-0.013
ID3	,233**	-,084**	1.000	-,256**	-0.041	,104**	-,393**	,077*
ID4	0.011	-0.054	-,256**	1.000	,291**	,157**	,312**	,104**
ID5	-,128**	-0.002	-0.041	,291**	1.000	0.045	0.023	,081*
ID6	,136**	0.022	,104**	,157**	0.045	1.000	,379**	0.052
ID7	0.046	,140**	-,393**	,312**	0.023	,379**	1.000	0.037
ID8	-0.059	-0.013	,077*	,104**	,081*	0.052	0.037	1.000

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

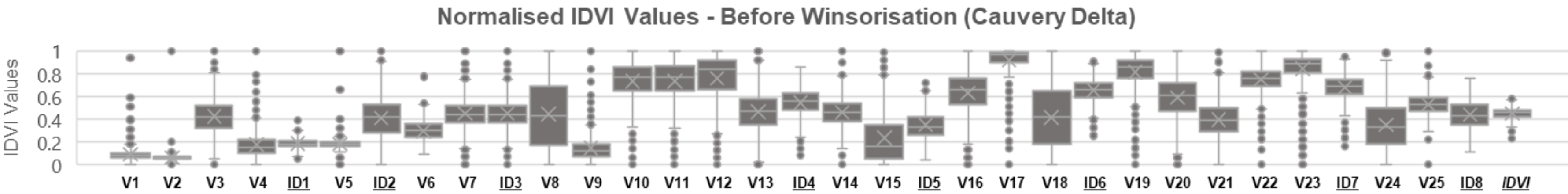
Variables

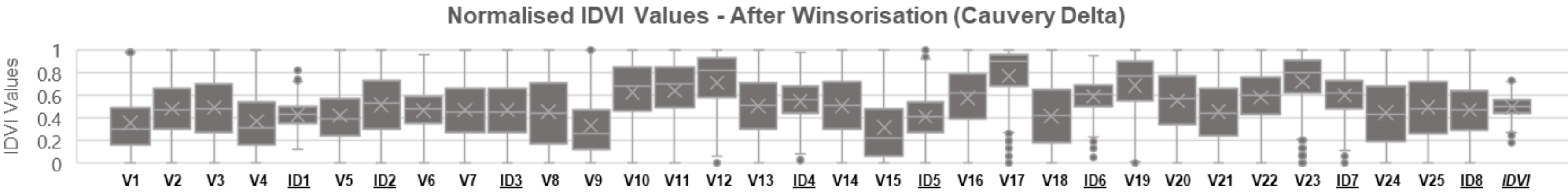
V1: Population density
V2: Household size
V3: No age 16-59
V4:Disabled population
V5: Female population
V6: Gender literacy gap
V7: Illiteracy rate
V8: Unsafe drinking water
V9: No electricity
V10: No sanitation
V11: No bathroom
V12: No modern cooking fuels
V13: Kutcha housing
V14: Non-workers
V15: Marginal workers
V16: Agricultural labourers
V17: No mechanised wheelers
V18: Marginal landholdings
V19: Under Rs. 5000
V20: No banking services
V21: No mobile telephones
V22: No motorised vehicles
V23: No refrigerator
V24: Caste population
V25: Caste literacy gap

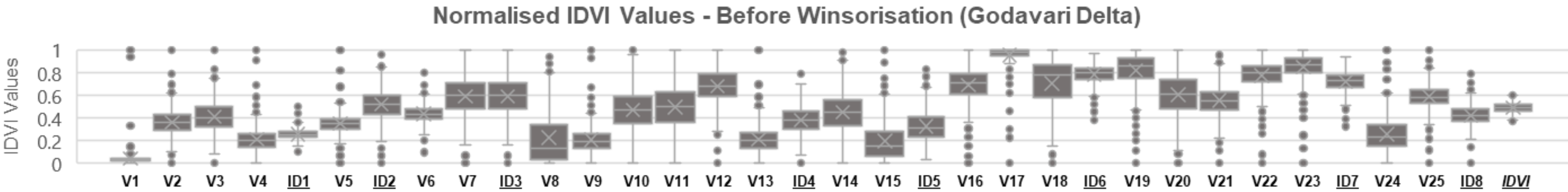
Indicators

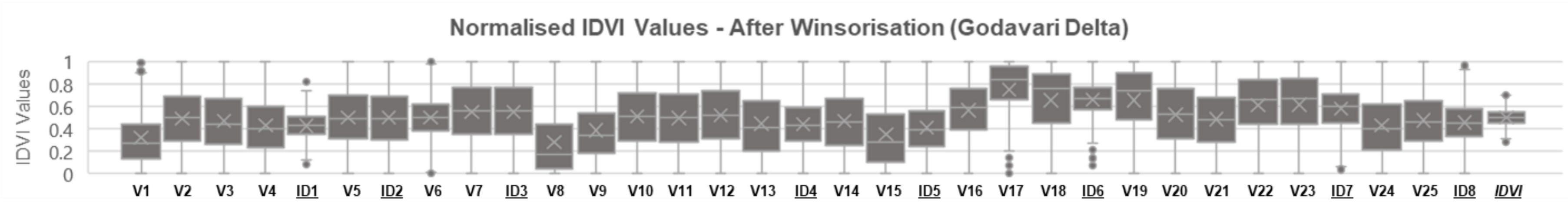
ID1: Demography
ID2: Gender
ID3: Education
ID4: Standard of living
ID5: Economic productivity
ID6: Agriculture
ID7: Income and assets
ID8: Caste

Appendix 2 Winsorisation Distribution









Variables								**Indicators**	
V1: Population density	V5: Female population	V9: No electricity	V13: Kutcha housing	V17: No mechanised wheelers	V21: No mobile telephones	V25: Caste literacy gap		ID1: Demography	ID5: Econ. productivity
V2: Household size	V6: Gender literacy gap	V10: No sanitation	V14: Non-workers	V18: Marginal landholdings	V22: No motorised vehicles			ID2: Gender	ID6: Agriculture
V3: No age 15-59	V7: Illiteracy rate	V11: No bathroom	V15: Marginal workers	V19: Under Rs.5000	V23: No refrigerator			ID3: Education	ID7: Income and assets
V4: Disabled population	V8: Unsafe drinking water	V12: No modern cooking fuels	V16: Agricultural labourers	V20: No banking services	V24: Caste population			ID4: Standard of living	ID8: Caste

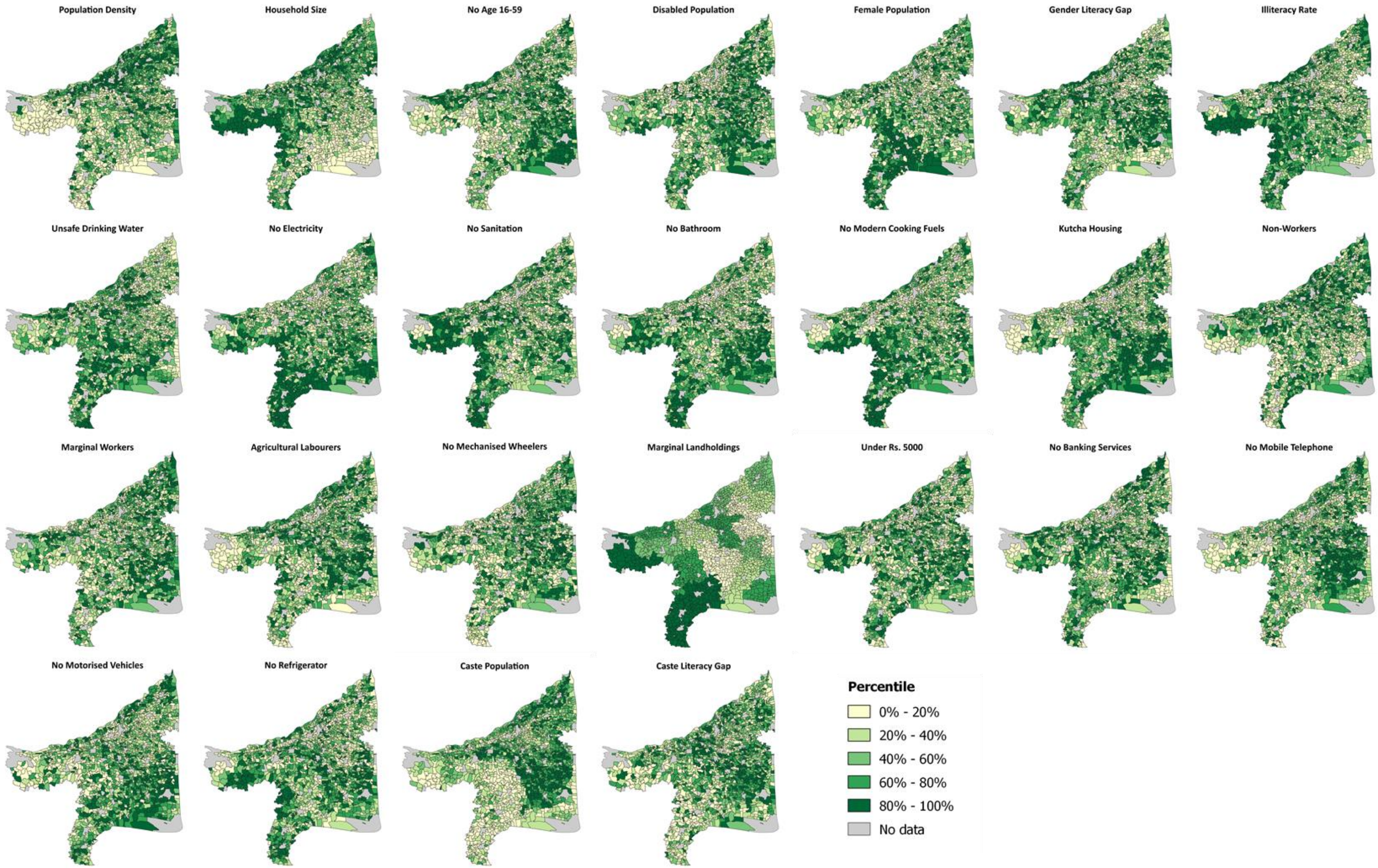
Appendix 3 IDVI Statistics – Non-Normalised (after Winsorisation)

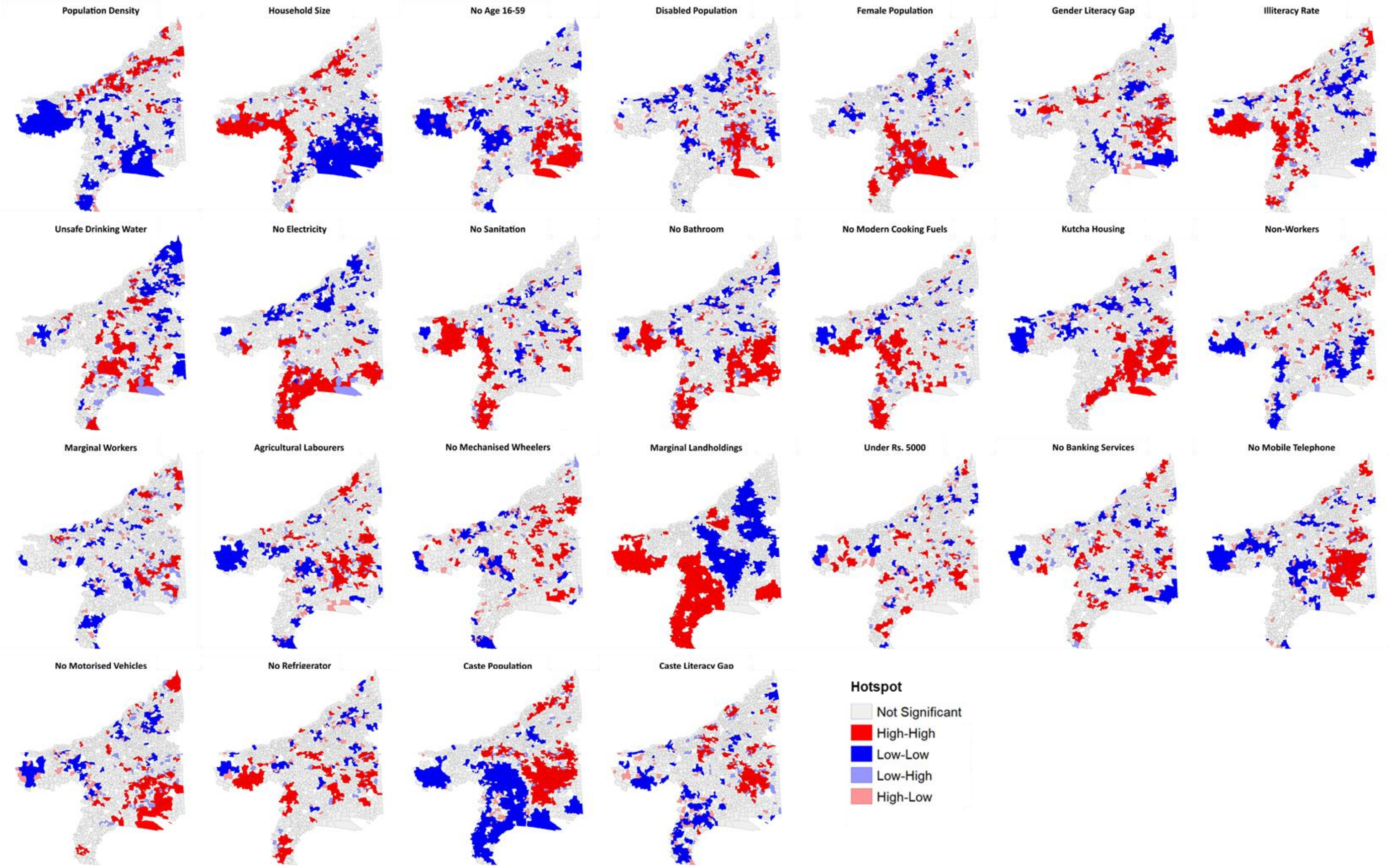
		Cauvery Delta (n = 1514)						Godavari Delta (n = 1010)					
Indicator	**Variable**	**Min**	**Max**	**Mean**	**Median**	**St. Dev**	**Skewness**	**Min**	**Max**	**Mean**	**Median**	**St. Dev**	**Skewness**
Demography	Population Density	2.09	11.12	5.31	4.82	2.39	0.90	2.53	17.61	7.38	6.58	3.91	1.07
	Household Size	3.54	4.31	3.91	3.90	0.20	0.11	3.21	3.86	3.53	3.53	0.18	0.01
	No age 15-59	2.97	9.66	6.24	6.20	1.86	0.06	5.24	13.84	9.26	9.03	2.39	0.19
	Disabled Population	1.11	9.09	4.08	3.61	2.19	0.73	1.43	8.42	4.43	4.23	1.87	0.40
	INDICATOR	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***
Gender	Female Population	48.46	53.14	50.50	50.39	1.22	0.41	48.26	51.15	49.73	49.72	0.78	-0.05
	Female Literacy Gap	6.64	17.69	12.30	12.26	3.02	-0.05	11.00	35.45	23.17	22.99	6.73	0.05
	INDICATOR	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***
Education	Illiteracy Rate	19.77	37.28	27.99	27.70	4.80	0.18	24.45	47.97	35.11	34.76	6.43	0.22
	INDICATOR	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***
Standard of living	Unsafe Drinking Water	0.70	97.94	44.67	43.11	31.14	0.18	0.30	77.32	21.90	13.60	22.41	1.11
	No Electricity	2.05	19.63	7.86	6.60	4.84	1.00	2.10	12.07	5.93	5.46	2.70	0.66
	No Sanitation	40.57	94.27	74.08	77.04	14.93	-0.72	25.49	82.85	53.77	53.65	16.01	0.04
	No Bathroom	38.13	95.70	74.85	78.10	15.96	-0.79	16.18	68.21	42.03	42.10	14.52	0.04
	No Modern Cooking Fuels	23.47	97.94	76.25	84.00	21.39	-1.18	43.45	91.00	68.19	68.00	13.29	-0.09
	Kutcha Housing	15.41	60.47	38.10	38.53	12.28	-0.06	6.01	35.39	19.08	18.17	8.53	0.31
	INDICATOR	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***
Economic productivity	Non-Workers	43.24	65.85	54.69	54.77	6.33	-0.06	46.04	64.15	55.66	55.78	5.10	-0.16
	Marginal Workers	0.89	68.35	22.08	16.01	20.01	0.93	0.90	47.98	17.28	13.93	13.56	0.78
	INDICATOR	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***
Agriculture	Agricultural Labourers	27.92	83.89	60.16	62.46	15.62	-0.44	45.25	85.95	68.26	69.25	10.91	-0.40
	No Mechanised Wheeler	76.45	99.57	94.19	97.11	6.49	-1.54	97.92	100.00	99.48	99.67	0.57	-1.39
	Marginal Landholdings	63.66	89.19	76.59	76.05	7.56	0.00	67.06	90.17	82.42	84.77	6.60	-0.80
	INDICATOR	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***
Income and assets	Less than 5000 Rs.	50.57	96.81	82.09	86.28	13.05	-1.04	52.88	97.58	82.14	85.96	13.02	-0.84
	No Banking Services	25.57	83.74	57.58	58.93	16.57	-0.29	34.28	88.00	62.48	62.80	15.53	-0.13
	No Mobile Telephone	22.24	64.93	41.63	40.82	11.74	0.25	40.80	71.98	55.88	55.90	8.54	0.09
	No Motorised Vehicles	51.98	92.34	75.42	76.32	10.23	-0.51	64.54	93.30	82.08	83.58	8.15	-0.64
	No Refrigerator	70.68	98.27	90.52	92.64	7.19	-1.39	85.82	99.02	93.95	94.65	3.79	-0.66
	INDICATOR	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***
Caste	Caste Population	6.10	70.36	34.72	33.40	19.33	0.25	5.13	48.75	23.89	22.53	12.13	0.39
	Caste Literacy Gap	-4.99	23.94	9.35	8.84	8.19	0.08	-10.33	29.44	8.56	7.89	10.37	0.18
	INDICATOR	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***
IDVI	*IDVI*	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***	***n.a.***

Appendix 4 IDVI Statistics – Normalised

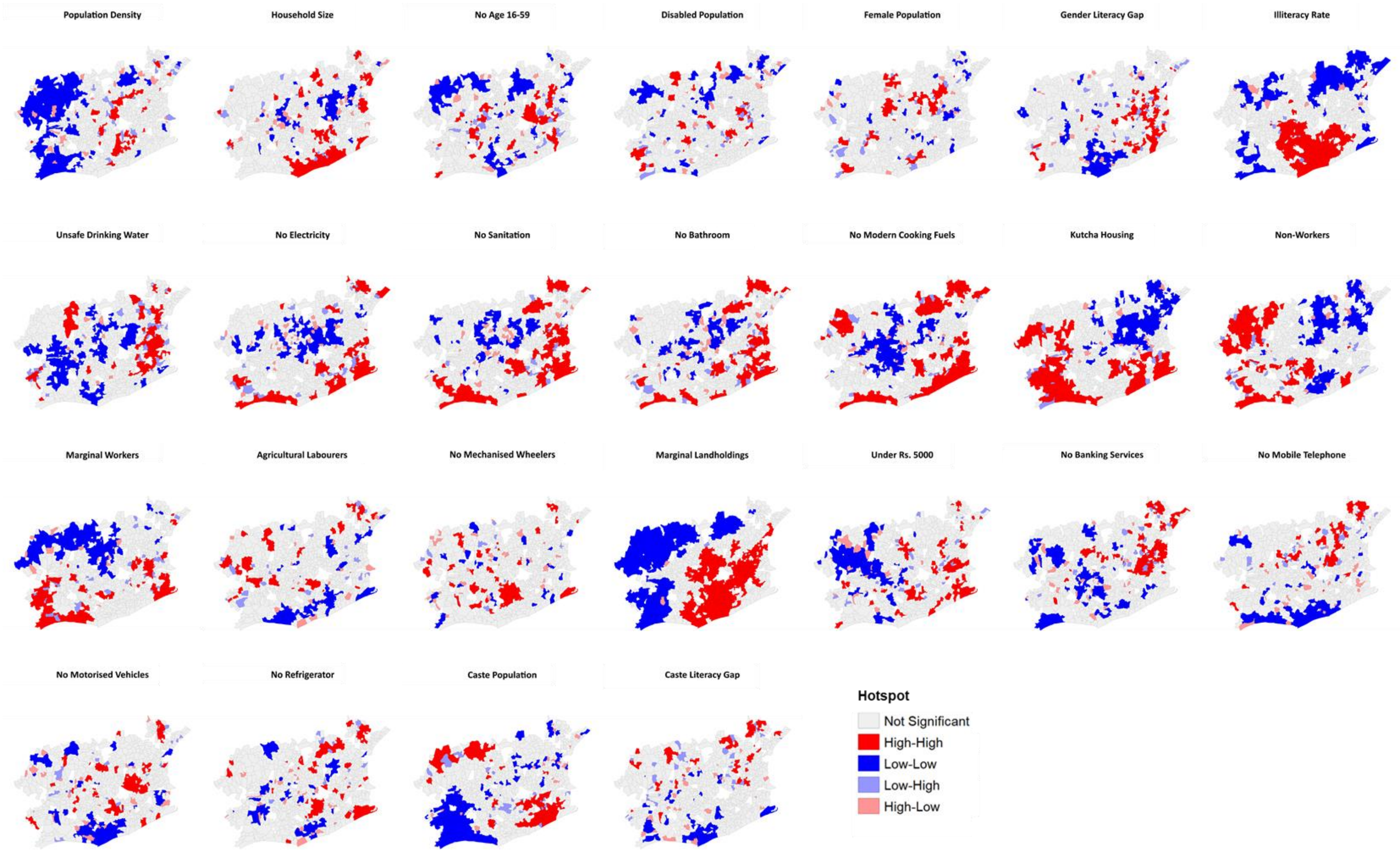
		Cauvery Delta (n = 1514)						Godavari Delta (n = 1010)					
Indicator	**Variable**	**Mean**	**Median**	**St. Dev**	**Moran's I**	**HH (%)**	**LL (%)**	**Mean**	**Median**	**St. Dev**	**Moran's I**	**HH (%)**	**LL (%)**
Demography	Population Density	**0.357**	0.302	0.265	**0.361**	10.52	14.98	**0.322**	0.269	0.259	**0.269**	7.52	15.45
	Household Size	**0.480**	0.474	0.262	**0.466**	11.52	16.91	**0.491**	0.496	0.274	**0.269**	10.30	8.81
	No age 15-59	**0.489**	0.484	0.277	**0.300**	11.25	9.72	**0.468**	0.441	0.278	**0.299**	9.70	10.10
	Disabled Population	**0.372**	0.312	0.274	**0.204**	8.59	10.05	**0.428**	0.401	0.268	**0.184**	5.64	7.33
	INDICATOR	**0.424**	0.427	0.113	**0.291**	8.12	11.71	**0.427**	0.428	0.114	**0.285**	10.30	10.69
Gender	Female Population	**0.419**	0.390	0.260	**0.279**	9.65	7.12	**0.499**	0.492	0.271	**0.139**	7.43	4.85
	Female Literacy Gap	**0.513**	0.531	0.281	**0.252**	9.59	9.25	**0.498**	0.491	0.275	**0.228**	7.72	9.01
	INDICATOR	**0.466**	0.477	0.182	**0.231**	7.65	8.32	**0.498**	0.503	0.183	**0.172**	6.63	6.93
Education	Illiteracy Rate	**0.469**	0.453	0.274	**0.309**	10.38	10.58	**0.547**	0.562	0.274	**0.612**	22.67	15.45
	INDICATOR	**0.469**	0.453	0.272	**0.309**	10.38	10.58	**0.574**	0.562	0.274	**0.612**	22.67	15.45
Standard of living	Unsafe Drinking Water	**0.452**	0.436	0.320	**0.305**	11.85	12.58	**0.280**	0.173	0.291	**0.381**	12.57	16.34
	No Electricity	**0.331**	0.259	0.276	**0.369**	11.72	11.98	**0.384**	0.337	0.271	**0.304**	9.90	11.78
	No Sanitation	**0.624**	0.679	0.278	**0.297**	10.39	7.99	**0.507**	0.509	0.279	**0.377**	16.24	9.80
	No Bathroom	**0.638**	0.694	0.277	**0.326**	14.85	9.32	**0.497**	0.498	0.279	**0.319**	12.48	10.40
	No Modern Cooking Fuels	**0.709**	0.813	0.287	**0.218**	10.32	5.53	**0.520**	0.516	0.279	**0.526**	17.72	16.83
	Kutcha Housing	**0.504**	0.513	0.272	**0.397**	13.72	10.12	**0.445**	0.414	0.290	**0.584**	20.00	18.91
	INDICATOR	**0.543**	0.562	0.185	**0.410**	15.58	11.19	**0.439**	0.433	0.198	**0.478**	17.72	15.15
Economic productivity	Non-Workers	**0.507**	0.510	0.280	**0.251**	7.46	9.92	**0.468**	0.462	0.281	**0.407**	11.88	17.13
	Marginal Workers	**0.314**	0.224	0.297	**0.172**	6.26	7.12	**0.384**	0.277	0.288	**0.309**	11.29	14.16
	INDICATOR	**0.410**	0.411	0.191	**0.180**	6.39	6.86	**0.408**	0.387	0.220	**0.381**	11.78	16.14
Agriculture	Agricultural Labourers	**0.576**	0.617	0.279	**0.300**	11.85	8.72	**0.565**	0.590	0.268	**0.248**	7.92	8.81
	No Mechanised Wheeler	**0.767**	0.893	0.281	**0.210**	10.05	6.92	**0.748**	0.840	0.276	**0.115**	8.32	4.06
	Marginal Landholdings	**0.417**	0.416	0.247	**0.891**	22.90	26.96	**0.655**	0.762	0.290	**0.904**	29.41	21.78
	INDICATOR	**0.587**	0.607	0.139	**0.257**	9.65	7.46	**0.656**	0.670	0.154	**0.386**	10.50	12.38
Income and assets	Less than 5000 Rs.	**0.682**	0.772	0.282	**0.202**	8.06	5.66	**0.655**	0.740	0.291	**0.329**	9.50	11.39
	No Banking Services	**0.550**	0.574	0.285	**0.229**	9.32	7.46	**0.525**	0.531	0.289	**0.374**	11.98	11.78
	No Mobile Telephone	**0.454**	0.435	0.275	**0.353**	13.18	10.99	**0.484**	0.484	0.274	**0.193**	7.13	8.91
	No Motorised Vehicles	**0.581**	0.603	0.253	**0.261**	10.52	7.79	**0.610**	0.662	0.283	**0.262**	10.30	9.50
	No Refrigerator	**0.719**	0.796	0.261	**0.292**	12.12	7.06	**0.616**	0.669	0.287	**0.231**	7.92	851
	INDICATOR	**0.597**	0.620	0.192	**0.338**	12.45	8.06	**0.578**	0.594	0.180	**0.361**	11.78	11.58
Caste	Caste Population	**0.445**	0.425	0.301	**0.574**	19.71	20.37	**0.430**	0.399	0.278	**0.359**	11.39	13.86
	Caste Literacy Gap	**0.496**	0.478	0.283	**0.266**	10.92	10.05	**0.475**	0.458	0.261	**0.126**	6.63	5.35
	INDICATOR	**0.471**	0.472	0.232	**0.564**	19.04	18.97	**0.453**	0.449	0.193	**0.247**	8.02	7.82
IDVI	*IDVI*	**0.495**	0.501	0.089	**0.319**	7.72	7.06	**0.501**	0.498	0.076	**0.465**	15.35	14.06

Appendix 5 Social Vulnerability Variables – Cauvery Delta




Population Density
Household Size
No Age 16-59
Disabled Population
Female Population
Gender Literacy Gap
Illiteracy Rate
Unsafe Drinking Water
No Electricity
No Sanitation
No Bathroom
No Modern Cooking Fuels
Kutcha Housing
Non-Workers
Marginal Workers
Agricultural Labourers
No Mechanised Wheelers
Marginal Landholdings
Under Rs. 5000
No Banking Services
No Mobile Telephone
No Motorised Vehicles
No Refrigerator
Caste Population
Caste Literacy Gap
Hotspot
Not Significant
High-High
Low-Low
Low-High
High-Low

Appendix 6 Social Vulnerability Variables – Godavari Delta


Population Density
Household Size
No Age 16-59
Disabled Population
Female Population
Gender Literacy Gap
Illiteracy Rate
Unsafe Drinking Water
No Electricity
No Sanitation
No Bathroom
No Modern Cooking Fuels
Kutcha Housing
Non-Workers
Marginal Workers
Agricultural Labourers
No Mechanised Wheelers
Marginal Landholdings
Under Rs. 5000
No Banking Services
No Mobile Telephone
No Motorised Vehicles
No Refrigerator
Caste Population
Caste Literacy Gap
Hotspot
Not Significant
High-High
Low-Low
Low-High
High-Low