ACCESS TO WATER: ADVANCEMENT OF MULTIDIMENSIONAL, MULTISCALAR, AND PARTICIPATORY METHODS OF MEASUREMENT IN THE GLOBAL SOUTH

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Abstract

This project deploys a modified Water Poverty Index (WPI) in villages reconstructed after the 2004 tsunami in southeastern India. While previous measurements of access to water have advanced understandings of waterscape complexities, this modified WPI improves past efforts and deconstructs some of the previous misunderstandings and notions regarding access to water. The traditional WPI is multidimensional and seeks to measure water access in a holistic fashion; the WPI presented here employs this approach, but is adapted to include new place-based indicators (e.g., Secondary Sources). Furthermore, unlike previous iterations of the WPI, our modified index incorporates water quality testing, three weight schemes, and operates at several scales. Ultimately, the construction and arrangement of our modified WPI enables statistical analyses, geospatial analyses, and water poverty mapping—which are absent in most prior studies—while still remaining easy to populate and descriptively analyze among laypersons. Statistical tests of original household data from a total of 24 villages in Nagapattinam District, Tamil Nadu, and Karaikal District, Puducherry, indicate significant differences between the two districts in indicator scores as well as total WPI scores. Additionally, the urban and rural areas within each district were found to be significantly different in level of water poverty, and trends were similar across the three weight schemes. Multiple linear regressions show correlation of independent socioeconomic variables (i.e., Income, Education, and Assets-Networks) with the dependent indicator of Capacity, but not with the other indicators or total WPI scores. Global Moran’s I tests indicate positive spatial autocorrelation, demonstrating that indicator and WPI scores tend to cluster in space. Overall, the results match what was anticipated, yet serve to challenge commonly held assumptions on urban-rural hierarchies and the role of socioeconomic variables in determining water poverty. The construction, deployment, and analytical potential of this modified WPI can be used by scholars to improve existing conceptualizations and measurements of access to water, while the results can be used by local governments and nonprofits to improve resource allocation and inform spatially-targeted interventions.

ACCESS TO WATER: ADVANCEMENT OF MULTIDIMENSIONAL, MULTISCALAR, AND PARTICIPATORY METHODS OF MEASUREMENT IN THE GLOBAL SOUTH

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General Audience Abstract

This study uses a modified, participant-based Water Poverty Index (WPI) to measure access to water among 24 reconstructed villages in Karaikal and Nagapattinam Districts in South India. While following the traditional WPI framework, this WPI modifies previous indicators and includes new indicators such as Secondary Sources, Quality, and Quantity. The modified WPI also supports statistical analyses as well as geospatial analyses and water poverty mapping. Further differentiation of this WPI is that it applies three separate weight schemes to interpret findings. The first weight scheme is the traditional application of equal weights; the second uses best management practices, the engineering and public health literatures, and grounded observations and fieldwork to develop an 'expert' weight scheme; and the third 'survey' weight scheme adheres to participants' rankings in terms of which WPI indicators they perceive as most important when dealing with water issues. After indicator and WPI scores were calculated, independent sample t-tests, Wilcoxon Signed Rank tests, and stepwise multiple linear regressions were conducted on all scores. The tests were also conducted at several scales and across the three weight schemes. Results show that Karaikal District significantly outperformed Nagapattinam District, urban Karaikal significantly outperformed rural Karaikal, and rural Nagapattinam significantly outperformed urban Nagapattinam (which defies previous notions of urban-rural hierarchies). The regressions failed to return high R^2 values, indicating that factors such as income and education are not correlated with WPI scores. The results from this tool can be used to aid in interventions by local governments and nonprofits to improve overall resource management.

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Chapter I: Introduction

1.1 Introduction

An estimated 663 million people lack access to an improved source of drinking water globally (UN-Water, 2015: 29), and 80% of that number live in slums or rural areas (WHO/UNICEF, 2013). Unfortunately, this number increases when access includes additional factors outside of the widely used improved-unimproved paradigm, such as distance traveled, financial capability, quantity, and water quality (which is often not tested). The inclusion of these indicators generates a more holistic portrayal of water tribulations experienced compared to the binary metric of access to either an improved or unimproved sources that has been employed by the World Health Organization, United Nations, and other domestic and supranational organizations. Another issue that arises by only measuring if one has improved access to water resources is the assumption that water from improved sources is actually safe, which in many cases is not true (Bain et al., 2014; Shaheed et al., 2014; Martínez-Santos, 2017). Therefore, there needs to be an alternative framework to understand if access to drinking water is actually safe and appropriate instead of solely focusing on the infrastructure. It is important to acknowledge that peoples across the world collect water in different methods. In developed countries water is supplied in mainly piped to premise but in developing countries collection has a greater variation. Some populations fill buckets or jugs from surface water and may have to travel great distances to fulfill this task (Rajagopal, Wichman, & Brands, 2017).

The term ‘water crisis’ has been an increased concern among scholars and non-scholars alike in the recent decades. Our relationship with water will only become more tenuous as climate change progresses and increased stress on environmental and water resources ensues. According to the United Nations, over 40% of the world lives in areas that categorized as water scarce, and that number is expected to increase if interventions, both environmental and social, are to happen. Water scarcity refers to the physical lack of water in an area and can be caused by various reasons (Falkenmark, 2009, 2011). Examples include climatic causes such as drought, anthropogenic causes such as over pumping and damming, and temporal and spatial inequities based on the geographic and geologic make up of a region. Water resources are unevenly distributed across space. The main catalyst of such deprivation is caused by precipitation that falls unevenly across the year; providing either too much or too little at a given time.

In terms of access to water, the issue is not always a lack of the resource, but often the capability of the unserved to have the capital to make the resource available to themselves (Rijsberman, 2004). This brings us to a concept that is central to this research project: water poverty. As defined by Oxford dictionary, water poverty is defined as "The condition of not having access to sufficient water, or water of an adequate quality, to meet one's basic needs." and, "The condition of being unable to afford to pay one's water bills."

Thus, the 'water poverty cycle' takes root since one may spend a majority of their day focusing on accessing water. In turn, since such efforts are spent focusing on handling water, employment, educational, and leisure opportunities are missed due to managing water or illness from consuming unsafe water. Such individuals lack water security and become ensconced in a water poverty trap since they lack both the economic means and water resources required to elevate themselves out of the suppressed state. As argued by Sullivan et al. (2003), "To redress any kind of poverty, access to these capital types must be redistributed more equitably" (Sullivan et al., 2003: 193). Water is essential for all life, and without it, any attempt for poverty alleviation is futile (Sullivan, 2002).

When discussing access to water one must acknowledge the multidimensional nature of water and the various spheres in which it is used. As defined by Molle and Molinga (2003), [Water] can be divided into five major categories. These include: drinking water, domestic water, food security needs, economic production, and environmental needs (Molle & Mollinga, 2003: 530).

The first, and the most crucial category of water is, drinking water. This is undeniably the most vital use of water; and since 2010 has been declared a basic human right. The basic need of consumption for fluid replacement is estimated at approximately three liters in a temperate climate and region. This number increases when other climates and regions are taken into consideration (Gleick, 1996: 84). The second, Domestic Water, represents the domestic uses of water required for hygiene, cleaning, and cooking. The amount required to be an adequate amount for these uses can be and are naturally diverse for different areas of the world. The third, Food Security Needs, is the need for water to farm and secure the necessary means to produce food. In many places in the developing world, especially in rural settings, this is the main source of food and income. The fourth use known as Economic Production acknowledges the use of water in the production of goods. The fifth use of water recognizes the overall environmental needs, and water's purpose in nature. As humans, we make up part of the hydrological cycle and Earth's ecosystems. This use acknowledges that water is needed to allow for natural systems to operate. Examples include, remediation for hypoxic events, biodiversity stability, and aquatic ecosystems.

As stated, these are the main five categories in which water use is divided into, but it does not acknowledge water use in other dimensions of human life. For many, water is used as a part of practice in religions, recreation, transportation, and the arts. In all scenarios of use, any type of water scarcity would affect some, if not all, dimensions of use.

1.2 Problem statement

According to estimates of the Joint Monitoring Programme (JMP), 97% of India's urban population has improved access to water while 93% of India's rural population enjoys access to some form of improved source. While those numbers appear high, such measures do not take into account other factors that govern water access, water poverty, and water security.

For this project, coastal southeast India was chosen because there is scarce research on drinking water after the 2004 Indian Ocean Tsunami ravaged the area. Disasters alter natural, built, and cultural landscapes, and research needs to be conducted to investigate how reconstruction handled these issues and how the values of local populations were (or were not) incorporated in a way that aligns with social, cultural, and livelihood needs. In a region such as South India, which is vulnerable to multiple types of natural hazards, it is important that there be a unique approach to rebuilding and evaluating the waterscapes of communities (Juran, 2015). In South India, Nagapattinam District (in the state of Tamil Nadu) and Karaikal District (which lies in the Union Territory of Puducherry) were selected for analyses based on the opportunity to analyze major post-disaster reconstruction of their water sectors. Within the districts, 24 study sites (12 from each district, six urban and six rural) were randomly selected for data collection at the household scale. The decision to use community level, or village, was chosen because it could be considered a micro sociological system whose well-being depends on the availability of water resources nested within a larger multilevel institutional and hydrological environment are managed (Jonsson & Wilk, 2014).

The two districts, Karaikal and Nagapattinam, are essentially identical in their socio-physical characteristics. Socio-demographically speaking, both of these districts are characterized by the same culture, language, religion, and similar economic situations. Though politically speaking their governments are very different. Karaikal is a much wealthier district when compared to Nagapattinam. After the tsunami, the two districts had to reconstruct the buildings from the ground up, and the districts overhauled water-society constructs to different levels given their different capacities.

Lying in the same geography, the two districts also experience the same temperature and climatic conditions. The two districts are characterized by a tropical maritime climate with various rainfall patterns throughout the year. The district of Karaikal experiences approximately 120 cm of rain a year, with approximately 70% of that accumulating between October and December due to the southwest monsoon. Yearly monsoons, months of drought, and continentality disrupt the functionality of having equitable access throughout the year.

In terms of the physical topography, these districts are virtually identical. Given the study sites' location on the coast and situation in the Cauvery River Basin, this area is rich in water resources; but when referring to the geology of this region, the deltaic nature of this area creates poor soil for drainage and disrupts the natural function of riparian zones causing poor filtration for ground water and is prone to frequent flooding events.

The Cauvery River is one of the most important rivers in Southern India, and its importance has been compared to the Mississippi River in the United States of America. However, due to pollution, population pressures, and the irregularity of the monsoon season, it is hard for residents to safely access water from the river and its tributaries throughout the year. This causes residents to rely on untreated groundwater and surface water to supplement their needs. While this might not pose as an initial issue, these water resources are over-appropriated and highly polluted. In fact, the basin that contains all study sites (i.e., Cauvery River Basin) has a past that is heavily influenced by water conflicts and scarcity. To be specific, based on the Falkenmark Index, the study area exhibits a "severe shortage of water" and has environmental flows that are "over appropriated" (Falkenmark, 2009: 73). Thus, the study area demonstrates empirical physical scarcity, and the water quality is degraded by economic activities, agricultural runoff, and a lack of wastewater treatment upstream.

Chapter II: Literature Review

2.1 Access to water

In 2010, the United Nations General Assembly declared water as a human right. The UN argued that water and sanitation should be accessible to all persons in all places at all times, and that access to water is a prerequisite for meeting other fundamental human rights. This declaration was part of the UN's Millennial Development Goals (MDGs), which have since been replaced with a newer set of achievable targets known as the Sustainable Development Goals (SDGs). The MDGs were able to fulfill many of their targets and have contributed vastly to global development in the recent decades. MDG Target 7C of the broader "Ensure Environmental Sustainability" goal set out to halve the proportion of the world's population without access to an improved source of water. In 2010, the goal of 2.4 billion people with access to an improved source was met five years ahead of time. Unfortunately, while global numbers reflect this level of access, many countries fail to maintain their side of the promise, and are not ensuring fair and equitable access of water to their citizens. In such cases, the number reported for access to water masks the true condition and amount of people maintaining access to water.

After the completion of the MDGs in 2015, the UN created another set of goals, the SDGs, which aim to continue and augment many of their predecessors' intentions. Other significant changes that have been made since the MDGs to SDGs is the acknowledgement that access to proper water and sanitation needs to be its own goal. Therefore, Goal 6 was created, which aims to, "by 2030, achieve universal and equitable access to safe and affordable drinking water for all" (UN, 2016). Thus, access water and concomitant issues of water poverty and water security were provided their own goal and were set to be eliminated rather than only halved.

Another significant change made for the SDGs is the recognition that the previous metric employed by the JMP to monitor progress towards the goal is not adequate, especially in regard to the actual water quality of so-called ‘improved’ sources. Currently, the JMP is the agency tasked with monitoring the success of the previous MDG goal 7C and the current SDG goal 6. The JMP’s metric for measuring access to water employs a unidimensional, binary metric of improved versus unimproved source. It is worth stressing that access to an improved source does not equate to access to water that is biologically, chemically, and physically safe. Not to mention that such sources may not provide adequate quantities, may be located too far from households, and may not be operable 24 hours per day or throughout the calendar year. Thus, this project seeks to measure water in a way that is more holistic, multidimensional, and representative of the waterscapes in which humans actually reside.

To address the issue, the JMP is currently piloting a cost-effective method for measuring water quality and has deployed it in five countries as of now (WHO, 2015). Note that the recognition of an appropriate and vetted measurement of access to water must include quality; which is incorporated in this study, as are other measurements such as water quantity, distance, pressure, availability, and other factors that necessarily affect access.

As populations increase, the consumption of natural resources generally increases. Depletion and degradation of any resource, especially water, is already a pressing global concern. Water scarcity will worsen in both acuteness and spatial extent without advances in technology *and* place-based applications in critical areas of water resource management, efficiency, and allocation. There is plenty of literature that discusses how the lesser developed world—particularly marginalized populations similar to the study populations in South India—will be most affected by these issues (Gleick, 1996; Sullivan, 2002; Sullivan et al., 2003;

Falkenmark, 2009; Falkenmark, 2011). Thus, this study seeks to inform place-based approaches to water resource management and capital allocation via a participatory, multiscalar index that supports both statistical and geospatial analyses. The results of the index can be used for diagnostic, prescriptive, and evaluative purposes for entities such as local governments, humanitarian organizations, managers, and policy and decision makers.

2.2 Stakeholder perspective and place-based approaches

Participatory methods or place-based approaches have been used in research to understand the true condition of study site. While there is some concern that other research methods tend to put words into the mouths of participants, participatory methods tend to minimize that problem and allow participants to speak their truth (Dayal et al., 2000; Mayoux & Chambers, 2005). In this project, responses from participants about what they favored more among the five indicators help provide a base in which we were able to create a meaningful and measurable way to understand some of the issues that are faced in their waterscape. Additionally, by using participant driven methods we were able to develop weight scheme that was grounded in their truths of their relationship with the waterscape.

In the case of a village, it can be considered a micro-sociological system whose well-being depends on the availability of water resources nested within a larger multilevel institutional and hydrological environment are managed. Therefore, it is important to study this unique socioeconomic situation, not only for this particular area but also potentially the area at large and compare the similar geographies. Unique tools of measurement need to be developed and executed to understand the local conditions and concerns of those populations affected by such dilemmas.

When assessing access to water, it is important to incorporate the stakeholders' relationship, involvement, and lived experiences with the waterscape. Individuals who inhabit a waterscape are most knowledgeable of its scenario for access, quantity, quality, etc. and are therefore excellent resources in identifying local water supply/infrastructure issues. This knowledge can in turn be harnessed to identify indicators for measurement and analysis, which can ultimately be used for comparative, evaluative, and planning purposes.

There is no shortage of literature that discusses the importance studying the stakeholder perspective when developing and maintaining waterscapes. Aslam et al. (2016) stresses the need to consider the local stakeholders' needs and views of their waterscape in order to ensure a sustainable system. Stakeholder knowledge is critical because despite how well the waterscape is engineered, the system may fail if it is not in line with the local population's needs, values, culture, and economy. Aslam et al. found that among the stakeholders of community-based drinking water systems, they cared most about: "clean drinking water sources, properly maintained infrastructure protecting the water quality, and socially aware consumer communities are vital for a sustainable community based drinking water system" (Aslam et al., 2016). There is much research on stakeholder involvement in water supply systems. Aslam et al.'s (2016) research focused on Northern Pakistan, while Roark et al. (1989) focused on Africa and Juran (2015) conducted longitudinal research in the study area of South India.

2.3 Methodologies and approaches to measure access to water

There is a desperate need for policy and resource allocation to ensure that infrastructure development (i.e., improved sources of water) are accessible, sustainable, and free of all pathogens and chemical contaminants. However, before that can occur there must be a more rigorous and definitive method to measure water access so that evidence-based policy making, decision making, and infrastructure development can take place. One way to measure access to water is using the improved-unimproved metric that was developed by the UN and JMP. As outlined by the JMP, an improved water source is defined as "piped water into the dwelling, piped water to plot or water, public tap or standpipe, tubewell or borehole, protected well or spring and rainwater" (WHO/UNICEF JMP, 2008). While these examples may be 'improved' based on the mode of infrastructure and delivery, JMP does not measure actual water quality. Further, the water may be untreated, the access point may not be available at certain times of the day or across the seasons, it may be located too far from households, and it may not supply enough quantities to fulfill all household needs. All of these issues render the improved-unimproved metric as an inadequate measure that exaggerates access to water, and the issues themselves lead households to rely on unimproved sources (e.g., surface water, tanker lorry water, and untreated groundwater).

The literature suggests that there exist more rigorous and multidimensional approaches to measuring human-water relationships. One method is to use indicators and indices to measure access because, unlike the JMP's approach, indices are able to incorporate multiple factors that affect human access and the water resources itself (Gleick, 1996; Sullivan, 2002; Sullivan et al., 2003; Falkenmark, 2009; Juran et al., 2017). Though, if an index is not employed properly, per se not using the proper indicator or uses data sets that are of small resolution, the index may will fail to properly convey true conditions of the population studied. Therefore, to make indices more meaningful, it is pertinent to explore the extent of how such indices can reflect local settings (Jonsson & Wilk, 2014).

One of the most widely used indices to measure waterscapes is the Falkenmark Index (**Table 2.1**), which measures the balance of total amount of runoff and human appropriations of water. Falkenmark contends that if there is 1,000 cubic meters of water per person, then the area is characterized as being in water stress, and anything below that is considered water scarce or depleted and not sufficient for further appropriation. See table below for further clarification of levels of scarcity

Table 2.1: Thresholds for Falkenmark Index

Falkenmark Indicator **(m^3/capita/year)**	**Water Stress Implications**
<1700	Water Stress
<1000	Chronic Water Scarcity
<500	Beyond the Water Barrier

Table adapted from Falkenmark, M. (2009). Water and the next generation – towards a more consistent approach. In A. K. Biswas, C. Tortajada, & R. Izquierdo (Eds.), *Water management in 2020 and beyond* (pp. 65-88). Heidelberg: Springer

A second index, the Basic Human Water Requirements Index developed by Peter Gleick, observes the minimum quantity of water a person needs to survive each day (Gleick, 1996). According to Gleick (1996), humans require at least 50 liters per day for domestic purposes (i.e., not including water for income generation, growing food, etc.). The index considers the following categories: water for consumption, water for personal sanitation, water for household sanitation, and water for food preparation. While the four indicators are critical, the index does not incorporate water used in other spheres of people's lives, and it does not consider the source or quality of water.

Another index for measuring access to water is the Water Poverty Index (WPI), which was developed by Caroline Sullivan in 2002. The WPI acknowledges the multidimensionality of waterscapes and human-water relationships better than most indices, but still needs to be improved. Sullivan developed the WPI based on the concept of 'water poverty,' which argues that poverty and access to water are self-reinforcing. Without access to water of adequate quality and quantity, individuals must allocate resources/time securing and managing water and also fall ill more often; such a context leads to a loss of productivity and income, and the cycle continues (Sullivan, 2002: 1195). Sullivan's first WPI had indicators that measured the following: accessibility of a source based on consumption; domestic and agriculture needs; total population with access to water and sanitation; and time and effort to retrieve water for the household. While this initial index began to address the complexities of access to water, Sullivan found that when calculating the WPI there needed to be more indicators to create a better representation of an area. Sullivan (2003) revised her WPI and included more indicators to analyze the community level scale in Tanzania, Sri Lanka, and South Africa. See **Table 2.2.** This refined, composite index employed indicators that measured: resource, access to resource, capacity, use, and environment (Sullivan et al., 2003). By using more indicators, Sullivan found the revised WPI better represented the true condition of the hydro-social cycle. An issue that arises when calculating a WPI is the misinterpretation of local populations since the majority of data are secondary and at a larger scale (e.g., data from censuses or the UN) (Van der Vyver, 2012). While these data are valuable, such representations allow for generalizations and treat local levels superficially—the issues are better or worse depending on who you are and where you are located.

Other applications of the WPI have been applied to irrigation (Cho et al., 2010), aggregated indices such as the WASH PI (Garriga & Foguet, 2013); and various scales such as community, basin, and district scale (Garriga & Foguet, 2013; Manandhar et al. 2013; Sullivan et al., 2003).

Table 2.2: Community scale WPI

WPI Component	**Subcomponents or variables used**
Resources (R)	• Assessment of availability of surface and groundwater • Quantitative and Qualitative evaluation of reliability and variability resources • Quantitative and qualitative assessment of water quality
Access (A)	• Percentage of households with clean water and a piped water supply • Recorded conflicts pertaining to water use • Percentage of population of access to sanitation • Percent of water carried by women • Time spent collecting water • Access to irrigation coverage (dependent on climate characteristics)
Capacity (C)	• Wealth dependent on ownership of items • Under five mortality rate • Education level • Membership among water user association • % of households receiving a pension or wage • % households of reporting WASH related illness
Use (U)	• Domestic water consumption rate • Agriculture water use • Livestock water use • Industrial water use

Environment (E)	• People's use of natural resources • Recorded loss of crops during the past five years • % of households reporting erosion on their property

Adapted from: Sullivan, C. A., Meigh, J. R., & Giacomello, A. M. (2003). The Water Poverty Index: Development and application at the community scale. Natural Resources Forum, 27(3), 189–199. https://doi.org/10.1111/1477-8947.00054

Most WPIs are developed using Sullivan's five indicators weighted equally. However, the index does not have to be static, so depending on the goal and scale a researcher can add and/or change indicators. Another ability of the WPI is to weight indicators based on their significance in the study area or in line with local goals or expectations. Unfortunately, many studies do not alter indicator weights. While this may be acceptable for basic comparison, not all places are homogeneous and even neighboring areas can have very different waterscapes. Thus, it is important to understand local values, expectations, and lived experiences in order to add in, modify, and weight indicators in a way that mirrors those ideologies. By not adapting the indicators and weights, the WPI might not accurately represent the true condition of the waterscape. Conversely, a more participatory and place-based index better represents the water scenario and provides more robust data for statistical and geospatial analyses as well as information for policy making, decision making, and resource allocation.

Another modified Water Poverty Index, developed by Salameh (2002), measures the availability of water for domestic and food production within a defined population. Unlike other WPIs, this WPI does not account for where the water is retrieved from, whether someone has the ability to attain it, and many other factors. Not to be confused with Sullivan's Water Poverty Index, this WPI is less complex than Sullivan's version and better represents one sub-indicator than an aggregated index.

If compared to Sullivan's version of the WPI, one may compare it to the Environment indicator that measures the groundwater and surface water available in the region under analysis. Furthermore, unlike other WPIs this redefined WPI takes into account water used not only for irrigation or agriculture purposes, but more specifically for food production. It acknowledges that some results may be a little misleading at times and clarification should be made of that score may misinterpret because if a country under production and receiving less than 150 mm/year that it is not at its highest production capacity and should be acknowledged when comparisons and decisions are to be made (Salameh, 2000).

Thus far in this review of water-related indices, the WASH Poverty Index developed by Garriga and Foguet (2013), approaches understanding water and the surrounding dimensions in the most holistic manner. The WASH Poverty index is an aggregation of three separate sub-indices: Water Poverty Index (WPI), Sanitation Poverty Index (SPI), and Hygiene Poverty Index (HPI). The WPI component, which represents the water-related index, is derived from Sullivan (2002) and Sullivan et al. (2003) original and community scale WPI. This sub-index represents the physical and socio-economic extent in which access to water is affected. The second sub-index, the Sanitation Poverty Index (SPI), represents the percentage of those that have access to improved sanitation based on the United Nations standards. (United Nations General Assembly, 2009). An interesting aspect of this index is that it not only measures if there is a facility, but if those using facility have the capability to construct and repair the latrine when needed; as well as measures factors of hygiene that contribute to the continual use of the facility. The third sub-index, The Hygiene Poverty Index (HPI), aggregates four components, representing the four transmission routes that can cause oral fecal contamination (Webb et al. 2006). These components include: food, drinking-water, personal hygiene, and domestic household hygiene.

The WASH PI identifies WASH deprivation at the household level because the authors acknowledge that at this scale is the most appropriate to measure poverty. The authors also acknowledge that if scale is increased, proper representation of data would be skewed due the inability of proper statistical representation. An increase of scale could mean be lost of valuable resolution and the results might underrepresent and mask regional disparities (Sullivan & Meigh, 2007) The implementation of the technique is an adaptation of a methodology developed for an estimation of WPI by Garriga and Foguet (2010) but has been adapted to support the WASH PI structure. The framework for this analysis is more complex than previous Water related Poverty Indices because it also incorporates and Multivariate analysis at the sub-index level and the weighting is then built on the importance of the index's composition to determine the principle factors. Unlike previous water related indices it acknowledges the necessity of using a household level approach in scale. Also, incorporate statistical analysis, and also incorporates mapping component for visual interpretation. Like other indices it is useful for policy makers and capture a more comprehensive approach to understand constraints and challenges experienced within access to WASH services. As of yet, this index is the most holistic in its attempt to measure WASH related circumstances since it combines multiple, better indices and includes not only water but hygiene and sanitation as well.

Similar to the WPI the Water Prosperity Index Plus (WPI^+) measures access to water in a similar framework to that of the WPI but instead of using the measurement of Capacity, the WPI^+ Capacity aims to provide an assessment of "the ability of society to manage water resources" (Sullivan & Meigh, 2007:114; Jonsson & Wilk, 2014:04). The Capacity component typically incorporates financial assets, education attainment, and health; but it also incorporates a community's to effectively manage, lobby for improvements, and the overall presence and effectiveness of water users associations themselves (Sullivan & Meigh, 2003; 2005; 2007). "However, the capacity indicators used in the WPI (i.e., literacy rates, under-five mortality rate, income levels, ownership of durable items, percent of households with one person employed, and membership in water users associations) only partly reflect these dimensions" (Jonsson & Wilk, 2014: 266). The five components were taken from Sullivan et al. (2003) community scale components, but some indicators were added or replaced to reflect values that are more representative of the community values and priorities of the local population's water situation.

Therefore, the WPI^+ aims to understand how the water situation is lacking but to also measure the potential for success and sustainability of equitable access. Different from the Water Poverty Index, the Water Prosperity Index aims to measure the sustainability of water management. The Capacity component in this index aims to provide an assessment of "the ability of society to manage water resources" instead of the traditional method of available capacity, this indicator may be harder to measure it requires a more ethnographic approach to understanding the water situation, and many cases of time and resources. Institutions may not have the ability to provide the resources needed to accurately measure this indicator.

2.4 Research questions

This thesis research project begins by critiquing current methodologies and approaches to measure access to water. The goal is to identify multidimensional, multiscalar, and participatory measurements of water access that can be incorporated into a modified WPI for southern India. Next, using a modified WPI and original data from 24 villages in India, the following basic and applied research questions are investigated:

RQ 1: What is the level of water poverty across the study villages?

- *Obj. 1.1*: Calculate water poverty at the household level.
- *Obj. 1.2*: Determine statistically significant differences among WPI and indicator scores (i.e., Quality, Quantity, Access, Secondary Sources, and Capacity) at different scales and across several weight schemes.
- *Obj. 1.3*: Determine statistically significant patterns among WPI and indicator scores across space.
- *Obj. 1.4*: Determine relationships between socioeconomic status (i.e., income, education, and assets-networks) and WPI and indicator scores.

RQ 2: What recommendations can be made to address water poverty in the study villages?

- *Obj. 2.1*: Identify range of and general issues surrounding water poverty in the study villages.
- *Obj. 2.2*: Identify which spatial locations and which water poverty components are in most need of assistance.

Chapter III: Water Access in Coastal South India: Measurements and Links among Water Poverty, Socioeconomic Status, and Space

3.1 Introduction

In 2010, the UN declared Resolution A/RES/64/292—the human right to water and sanitation. As argued by Gadgil (1998: 234), "improved longevity, reduced infant mortality, health, productivity, and material well-being are generally recognized as fruits of development," with water representing a prerequisite for all of these outcomes. However, spatial, temporal, and socioeconomic issues have rendered the human right difficult to bestow. Thus, the UN's SDGs—a follow-up on their previous MDGs—also address water and sanitation by seeking to 'ensure availability and sustainable management of water and sanitation' (Goal 6.1) for all by 2030. This goal, which is linked to and complemented by Goals 1 (no poverty), 3 (good health), and 11 (sustainable cities and communities), is measured through various metrics, such as Indicator 6.1.1, which measures the proportion of the global population using safely managed drinking water services. Indicator 6.1.1 uses country data compiled through the WHO and UNICEF's Joint Monitoring Programme (JMP).

The first issue that arises with the JMP's tracking method is fuzziness of accuracy given that data derive from the country level. Using low resolution data can lead to misrepresented and masked information, thereby serving to obfuscate lower political (e.g., rural vs. urban) and socioeconomic (e.g., income, education, demographics) scales. The second issue is that the UN seeks to ensure safe water free of contaminants and other pollutions, but that objective is not actually measured (i.e., water quality is not measured, but automatically assumed to be 'safe' and 'better' when improved sources are accessible). Furthermore, providing clean water is another objective (Target 6.3), but monitoring focuses on pollution outputs and surface water bodies.

Therefore, the target does not directly focusing on safe drinking water that is managed and delivered to end consumers.

Current methods fail to accurately measure the true level of access to water among those on the ground. Common modes of measurement, combined with representation of the data (e.g., scale), tend to oversimplify and conceal major issues in study areas questioned. For example, some methodologies simply measure the physical amount of water available, others simply measure whether an 'improved' source exists, while still others attempt to use a more holistic approach by taking several factors into consideration, such as distance traveled, water available, and the quality of the water source. A movement towards the latter approach is methodologically and pragmatically more useful.

3.2 Literature review

Indices have long been used to convey complex information to various audiences in a manner that can be easily understood in a meaningful way. Indices can be used to measure social, economic, and environmental scenarios. For example, the Happy Planet Index (Abdallah & Marks, 2014) measures the overall sustainability and happiness of a place; the Social Vulnerability index measures vulnerability to hazards (Cutter et al., 2003); and the Water Quality Index measures the quality of groundwater (Ramakrishnaiah et al., 2009). Furthermore, indices can be harnessed to facilitate policy and decision making and are widely viewed as powerful tool to span the gap from scientists to practitioners, politicians, stakeholders, and other agents of change. However, not all indices are created equal in terms of their ability to accurately measure scenarios and provide nuanced information for real-world applications. Thus, there exists value in critiquing existing indices and incorporating elements and approaches that advance the areas of holistic measurement, accurate representation, and practical applications to diverse stakeholders.

In terms of interactions between water resources and society, the Falkenmark Index and the Basic Human Water Needs Index are two of the most widely used indices. The Falkenmark Index measures the physical amount of water available to the population of a region, but does not consider access to such water nor the quality (Falkenmark, 2009). As for the Basic Human Water Needs Index, it only declares the minimum amount of water required to support human consumption, daily activities, hygiene, and sanitation, but does not provide knowledge or insight on how to meet such demands (Gleick, 1996). Rather, it merely measures how many liters one attains and relates it to the volume required to carry out a minimum domestic life, rendering the index unidimensional in nature. Second, the Basic Human Water Needs Index is static and does not acknowledge that with different geographies the amount of water consumed also changes, not to mention that it fails to account for personal gardens, income generation, and other water uses. Overall, neither index measures how individuals are access water, the quality of the water, or an array of social, political, and economic attributes that dictate the water scenario. While the Basic Human Water Needs Index touches on these issues in its conceptualization, the index is not actually adapted to contexts in which it is deployed. Compared to the modified WPI presented here, these measurements of water access are inferior due to being less dynamic and primarily unidimensional in their measurements.

Caroline Sullivan (2002) developed a widely used metric, the WPI, with the intent of creating a novel metric that acknowledges the multidimensional nature of water access in a place. The original WPI aimed to be simple to operate while simultaneously able to harness data that is easily attainable (e.g., census and UN data). The WPI considers five indicators, which are summed to arrive at a total WPI score: Use, Resource, Access, Environment, and Capacity. The WPI, when compared to indices such as the Falkenmark Index, Basic Human Water Needs Index, and other existing indices, begins to measure waterscapes and their residents in a more holistic way—yet there remains much room for improvement (see Sullivan et al., 2003). For example, the reliance on large scale, often national level data, is still lacking.

While we adopted many of the original WPI's components, our modified WPI does not use the Environment and Use indicators since (1) (accurate) data does not exist at the study site and/or watershed scales and (2) the study sites all lie in the same geography and thus exhibit a similar culture, livelihoods, and natural resource availabilities. Thus, there would be no net gain since all study sites would have the same scores for Environment and Use. For these reasons we chose to focus on other place-based factors that amalgamate to fashion heterogeneity in water poverty and access. Similarly, the Resources indicator was not used since we lacked the ability to measure total annual renewable surface and groundwater features. While data are available, we were not comfortable with the trustworthiness of the data, and the data are at a scale that would again reserve the same score for all of the study sites (i.e., they all lie in the same basin). While Sullivan's WPI takes local differences into consideration, it is still applied as a 'one size fits all' measurement and therefore our WPI seeks to improve upon past iterations by curating contextualized, place-based indicators that are both representative of the study region and applicable to the people who manage, live in, and cope with the waterscapes of question.

A recent WASH PI, developed by Garriga and Foguet (2013) offers a more nuanced approach to understanding the water scenario in an area, and we have adopted several of these enhanced approaches. The WASH PI acknowledges the need for the lower scales of analysis by using household level data as opposed to larger scale national or district level data. The index is also multidimensional, allowing for more holistic measurements and interpretations. However, a limitation is that the WASH PI still uses the five indicators proposed in the traditional WPI rather than introducing contextualized and smaller scale indicators to better suit the physical, social, and built environments being investigated. A further critique is that the WASH PI is not easy for laypersons to deploy, and it has many sub-indicators that render data collection time consuming.

The WPI deployed in this study takes note of the many critiques and limitations of other water indices, particularly in terms of: scale; context; weighting; statistical and geospatial applications; leveraging input from study participants and stakeholders; and constructing a tool that can be employed and understood by non-academics. For example, this study utilizes household level data, which is rare with the exception of pilot studies in Sri Lanka, Tanzania, South Africa (Sullivan et al., 2003); district level comparisons in Kenya (Garriga & Foguet, 2010); a basin level study in Nepal (Manandhar et al., 2012); and 14 villages studied in India that formed the backbone for this project (Juran et al., 2017). These studies, this study included, explicitly acknowledge that misrepresentation of data and variability are often overlooked at larger scales, resulting in a homogenous view of inherently diverse social and physical landscapes (Longley et al., 2010, Sullivan et al., 2006; Sullivan et al., 2003).

Methods of weighting are often arbitrary and rarely defined or defended (Garriga & Foguet, 2010; Juran et al. 2017). Therefore, many users of the WPI elect to use an equal weight scheme that necessarily interprets all indicators as equally important to the individual or communities managing water. Alternatively, we argue that this method necessarily oversimplifies the relative importance of indicators, which is not representative of the data or people. Rather, the employment of several weight schemes allows for various iterations of what experts, respondents, and water practitioners believe are important, with the equal weight scheme still present as a generic, controlled, or sterile measure. Finally, while our WPI is assembled in a way that facilitates statistical and geospatial analyses (which are not often conducted in similar studies), it is still manageable and able to be implemented by individuals who lack a background in research study design and data analytics.

Given this background, this paper explores the following research questions:

RQ 1: What is the level of water poverty across the study villages?

- *Obj. 1.1*: Calculate water poverty at the household level.
- *Obj. 1.2*: Determine statistically significant differences among WPI and indicator scores (i.e., Quality, Quantity, Access, Secondary Sources, and Capacity) at different scales and across several weight schemes.
- *Obj. 1.3*: Determine statistically significant patterns among WPI and indicator scores across space.
- *Obj. 1.4*: Determine relationships between socioeconomic status (i.e., income, education, and assets-networks) and WPI and indicator scores.

RQ 2: What recommendations can be made to address water poverty in the study villages?

- *Obj. 2.1*: Identify range of and general issues surrounding water poverty in the study villages.
- *Obj. 2.2*: Identify which spatial locations and which water poverty components are in most need of assistance.

3.3 Study Area and Methods

3.3.1 Study area

This project deploys a modified, place-based WPI in Nagapattinam District, Tamil Nadu, and Karaikal District, Puducherry. Nagapattinam and Karaikal are similar in terms of geology, physiography, climate, demographics, and water issues, all of which support comparative analyses. Further, the study area and study sites are similar in their physical location near the coast as well as experiences with post-disaster reconstruction. When comparing the two districts Nagapattinam exceeds Karaikal not only in size, but also population. Nagapattinam is the only discontinuous district in the country of India. The two parts of the district are separated by Karaikal, an enclave of the Union Territory of Puducherry that is surrounded by Nagapattinam. According to the most recent census, Nagapattinam's population is approximately 1.6 million with the majority living in rural areas (Directorate of Census Operations, Tamil Nadu, 2012). Tamil is the most widely spoken language spoken with some English among professionals and the college educated. The region is majority Hindu with small pockets of Muslim and Christian Populations (Directorate of Census Operations, Tamil Nadu, 2001).

Smaller than Nagapattinam, Karaikal's population is approximately 200,000 with almost an equal amount of people residing in urban (49%) and rural areas (51%) (Government of India, 2012*)*. Similar to Nagapattinam, Tamil is spoken among the majority of the population, as well as some English and French among professionals. Regarding religion, the majority is Hindu with some Muslims and Christians (Office of the Registrar General & Census Commissioner, 2001). This study area of Nagapattinam and Karaikal experiences a tropical climate with yearly monsoon seasons. Due to seasonality, the warmer months are April-June with an average temperature of 37° C, and the relatively cooler months are November-February with an average of 21° C. On average this area receives approximately 1,014 mm of precipitation, which mainly occurs during the wet monsoon season. This yearly occurrence can create problems for local populations, including water quality issues and difficulties accessing water due to flooding. On the other extreme, in the drier season surface water storage and access to groundwater are critical for the region. Thus, local populations confront issues of water stress and physical water scarcity on top of issues of pollution, water contamination, and erosion.

Both districts were impacted by the 2004 Indian Ocean tsunami and forced to reconstruct entire villages from the ground-up, including water infrastructure. Each government, along with nonprofit assistance, rebuilt and extended water services to dozens of newly constructed villages after the tsunami. In terms of water, reconstructed houses were provided improved sources, but lack piped to premise water supply and are must walk to communal public taps supplied by the government. All households in the study sites have access to 'improved' water sources as defined by the SDGs and MDGs, but more holistic metrics that account for field observations, ethnographic inquiries, water quality tests, and quantitative analyses (i.e., our modified WPI), tell a different story. Thus, while inhabitants of the study villages are 100% covered by improved sources according to the binary improved-unimproved method utilized by the UN and other organizations, we argue that an improved metric is required to unmask the true condition of such complex waterscapes.

After visiting 37 reconstructed villages across Nagapattinam and Karaikal Districts, 24 were randomly selected as study sites (**Fig. 3.1**). The 24 study sites (12 in each district comprised of 6 rural and 6 urban based on official political boundaries of *panchayat* vs. municipal government) have been inhabited since roughly 2008 and typically have about 200 houses (**Figs.**

3.2-3.3). The 24 settlements were investigated through the lens of water, with common issues relating to quality and access depicted in **Figs. 3.4-3.6**.

***Fig. 3.1**: Study area map portraying the 24 randomly selected study sites in Nagapattinam District, Tamil Nadu, and Karaikal District, Puducherry*

Fig. 3.2*: A typical study site (Andana Pettai, rural Nagapattinam District)*

Fig. 3.3*: A typical study site (Vettakaramedu, Karaikal Municipality)*

Fig. 3.4*: Collecting water from 'improved' public water sources at the study sites*

Fig. 3.5*: Some water access points have an extreme density of households that must be served (Akkaraipettai, rural Nagapattinam District)*

Fig. 3.6: *Drainage is either absent or defunct at most study sites, which serves to complicate water retrieval and water quality (Vaddakku Vanjore, rural Karaikal District)*

3.3.2 The modified WPI and data collection

This study expands upon and advances a study by Juran et al. (2017), who developed a similar modified WPI for Nagapattinam and Karaikal Districts. This initial study investigated 14 study sites (seven in each district) by gathering data on water and socioeconomic attributes across 300 households and 75 public taps that serve the households. Juran et al.'s (2017) WPI encompasses five place-based indicators (namely Quality, Quantity, Access, Secondary Sources, and Capacity), which were identified in a participatory manner by conducting 14 focus group discussions (one at each study site) and 76 qualitative interviews (4-7 at each site depending on population).

The following equation is used to calculate the WPI developed by Juran et al. (2017), and the same equation is used in this WPI. Several weight schemes will be also employed, as denoted by the *weightx* subscript and further explained later in **Table 3.3**.

$$WPI = Q_{weightx} + L_{weightx} + A_{weightx} + S_{weightx} + C_{weightx}$$

Appendix 1 provides the open-ended household interview instrument that helped to identify the five place-based indicators, and **Appendix 2** details how each indicator is calculated. In reference to pushing forward the study by Juran et al. (2017), contributions of this study are to: (1) expand the dataset from to 300 to 507 households, 75 to 125 public taps, and 14 to 24 study sites (**Table 1**); (2) balance the composition of rural and urban study sites in each district (now balanced with six rural and six urban sites in each district); and (3) update the participant-dictated weight scheme with an additional 207 surveyed households. Furthermore, more extensive analyses will be conducted. This paper utilizes new comparative statistical tests; tests more indicators and scales; tests the predictive ability of socioeconomic indicators on water access; and introduces geospatial analyses to test for clustering of indicator and WPI scores.

To populate the index, a proportionally representative number of households (*n*=277 in Nagapattinam District, *n*=230 in Karaikal District) were randomly selected from the 24 study sites (**Table 3.1**). Households were surveyed using a quantitative instrument (see **Appendix 3**), and these data points were used as variables to calculate sub-indicator, indicator, and total WPI scores for each household. The survey also asked each household to rank indicators in terms of relative importance to the household (which is used to calculate a 'survey weight scheme'), and it included water quality testing both in the household and at the public taps from where the households retrieve water (**Fig. 3.7-3.8**). Samples at public taps (minimum of five at each village) were randomly selected but stratified to satisfy the condition that they must serve a sampled household (Longley et al., 2010). Quality was tested using sterilized H_2S strip tests according to standards of the WHO (Sobsey & Pfaender, 2002). This field-based method was optimal given that study sites are located one full day from a lab, rendering alternative methods logistically infeasible.

Table 3.1: Study sites and sampling

Jurisdiction	**Household surveys and water quality tests**	**Water quality tests at taps**
Nagapattinam District – Urban		
Amritananda Mayi-Rotary Nagar	20	5
Mahalakshmi Nagar	22	5
Melavanjore	23	5
New Nambiyar Nagar	37	9
Samanthanpettai	26	6
Saveriyarkovil	26	6
Nagapattinam District – Rural		
Akkaraipettai	21	5
Andana Pettai	21	5
New Kallar	23	5
Sellur	20	5
Theti	23	5
Uzhuvar Nagar	15	4
Karaikal District – Urban		
Amman Kovil Pathu	19	5
Kilinjilmedu	24	5
Kizhakasakudimedu	21	5
MGR Nagar	19	5
Paravaipettai	15	5
Vettakaramedu	16	5
Karaikal District – Rural		
Akkam Pettai	18	5
Kallikuppam	20	5
Kottucherrymedu	20	5
Mandapathur	18	5
Pattinacherry South	22	5

Vaddakku Vanjore	18	5
TOTAL	*507*	*125*

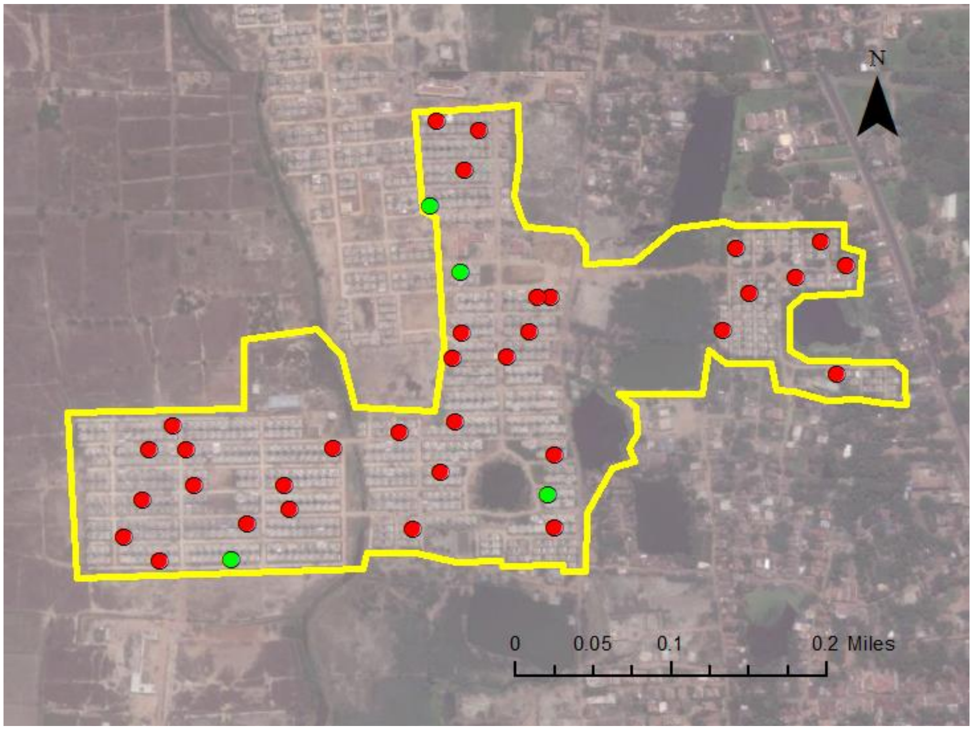

Fig. 3.7: *Household surveys and household water quality samples at a typical site; red is positive for fecal coliform, green is negative (New Nambiyar Nagar, Nagapattinam Municipality)*

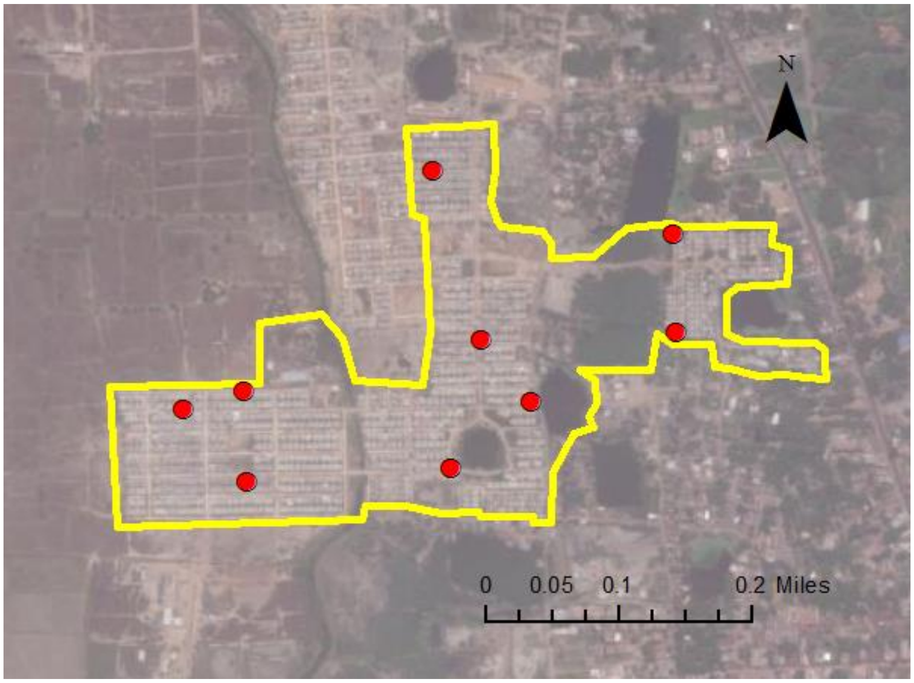

Fig. 3.8: *Water quality sampling of taps (i.e., water sources) at a typical site; red is positive for fecal coliform, green is negative (New Nambiyar Nagar, Nagapattinam Municipality)*

3.3.3 Data analysis

3.3.3.1 Statistical analysis

Data were analyzed using JMP 13.0 Statistical Software. First, independent sample t-tests were conducted to compare the differences of household means of three indicators (Access, Capacity, and Quantity) between Nagapattbettinam and Karaikal Districts and between the urban and rural villages within each district. These tests were also conducted for total WPI scores and across several weight schemes. A second test, Wilcoxon signed-ranked tests, was used to analyze the means of the other two indicators (Secondary Sources and Quality) due to the nonparametric nature of the data and their non-normal distribution. Previous studies have used chi-square to analyze these two indicators, but we felt the Wilcoxon tests better suit the data. Next, tests were conducted to examine the ability of three independent variables (Education, Income, and Assets-

Networks) to predict factors of water access. Thus, Stepwise Regressions, a form Multiple Linear Regression (MLR), were employed to better understand correlations among the three independent variables with indicator and index scores; each of the five indicators were tested and total WPI scores were also tested across three weight schemes. The objective was to gain insight on how socioeconomic status influences water poverty, with the assumption that higher levels of educational attainment, income, and assets and networks indicate that one also has an increased ability to access water.

3.3.3.2 Water poverty mapping and Global Moran's I

Mapping can be used for research and as a tool to cross cultures and surmount linguistic barriers by portraying information in a way that is easily understood. For example, the cartographic and geospatial abilities of Geographic Information Systems (GIS) have been used extensively for data analysis, visualization, and to deliver information from experts to politicians and other stakeholders. Previous studies have used these capabilities to map water poor areas and identify *de jure* territories in need of additional resources (Bigman & Fofack, 2000; Cullis & O'Regan, 2004; Garriga & Foguet, 2013). Thus, this project similarly uses GIS for purposes of analysis and stakeholder engagement by identifying spatial concentrations of waterscape features and helping to understand geographic connections that exist in space.

A Global Moran's I test was conducted in ArcGIS Desktop 10.4 to analyze spatial relationships of the vector data. Global Moran's I checks for correlations among attributes and their spatial distribution. If the Global Moran's I test returns a statistically significant p-value, then it indicates the data are clustered in space, while a non-significant p-value (depending on the index score) is interpreted as dispersed or random. Positive index scores mean that data values are similar as a factor of nearness whereas negative index scores signify dispersal and repelling of data values in space. The tool is an inferential statistic and is to be interpreted in the context of its null hypothesis, which operates under the assumption that any given data set is random in space. Thus, our analyses tested whether correlations exist between all indicator and total WPI scores (for three weight schemes) across space. Global Moran's I equation listed below.

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2}$$

Where z_i is the deviation of an attribute or feature *i* from its mean $(x_i - X)$, $w_{i,j}$ is the spatial weight between feature *i* and *j*, *n* is equal to the total number of features, and S_0 is the aggregate of all spatial weights.

3.4 Results

3.4.1 Indicator and WPI scores

Results of independent sample t-tests and Wilcoxon signed-ranked tests are provided in **Table 3.2**. In terms of district comparisons, Karaikal significantly outperformed Nagapattinam across all five indicators and total WPI score. Nagapattinam District scored lower in every indicator and hence in total WPI, suggesting there are significant differences in waterscapes and their residents between the two districts. Within Karaikal, statistical tests do not reveal significant differences in total WPI score between the rural and urban study sites, although urban Karaikal significantly outperformed in Quantity while rural Karaikal significantly outperformed in Capacity. These findings suggest that waterscape conditions are relatively similar among study sites within Karaikal District. However, the findings differ in Nagapattinam District. Rural study sites in Nagapattinam significantly outperformed their urban counterparts in Quality and Secondary Sources (and all indicator scores were greater except for Capacity), ultimately helping lead to a significantly higher total WPI score for rural Nagapattinam. These findings indicate that waterscape conditions are relatively better in rural parts of Nagapattinam District. Beyond **Table 3.2**, the distribution of indicator scores across these scales can be observed in radar diagrams below.

Table 3.2: Comparison of indicator and total WPI scores

	District Comparison			*Urban vs. Rural Nagapattinam*			*Urban vs. Rural Karaikal*		
	Nagapattinam	**Karaikal**	**p-value**	**Urban**	**Rural**	**p-value**	**Urban**	**Rural**	**p-value**
Quality (Q)	25.3†	40.7†	<0.0001*	17.4†	35.0†	<0.0001*	43.2†	38.3†	0.2389
Quantity (L)	60.8†	77.9†	<0.0001*	59.3†	62.6†	0.2839	85.4†	70.5†	<0.0001*
Access (A)	53.6†	64.4†	<0.0001*	53.0†	54.4†	0.1726	64.6†	64.2†	0.7511
Secondary Sources (S)	28.3†	34.6†	.0041*	20.3†	38.2†	<0.0001*	43.2†	38.3†	0.7272
Capacity (C)	59.2†	62.8†	.0364*	59.4†	59.0†	.8545	55.2†	70.3†	<0.0001*
Total WPI	45.4†	56.1†	<0.0001*	41.9†	49.8†	<0.0001*	56.8†	55.4†	.3003

*†Household mean; *Significance at 95%*

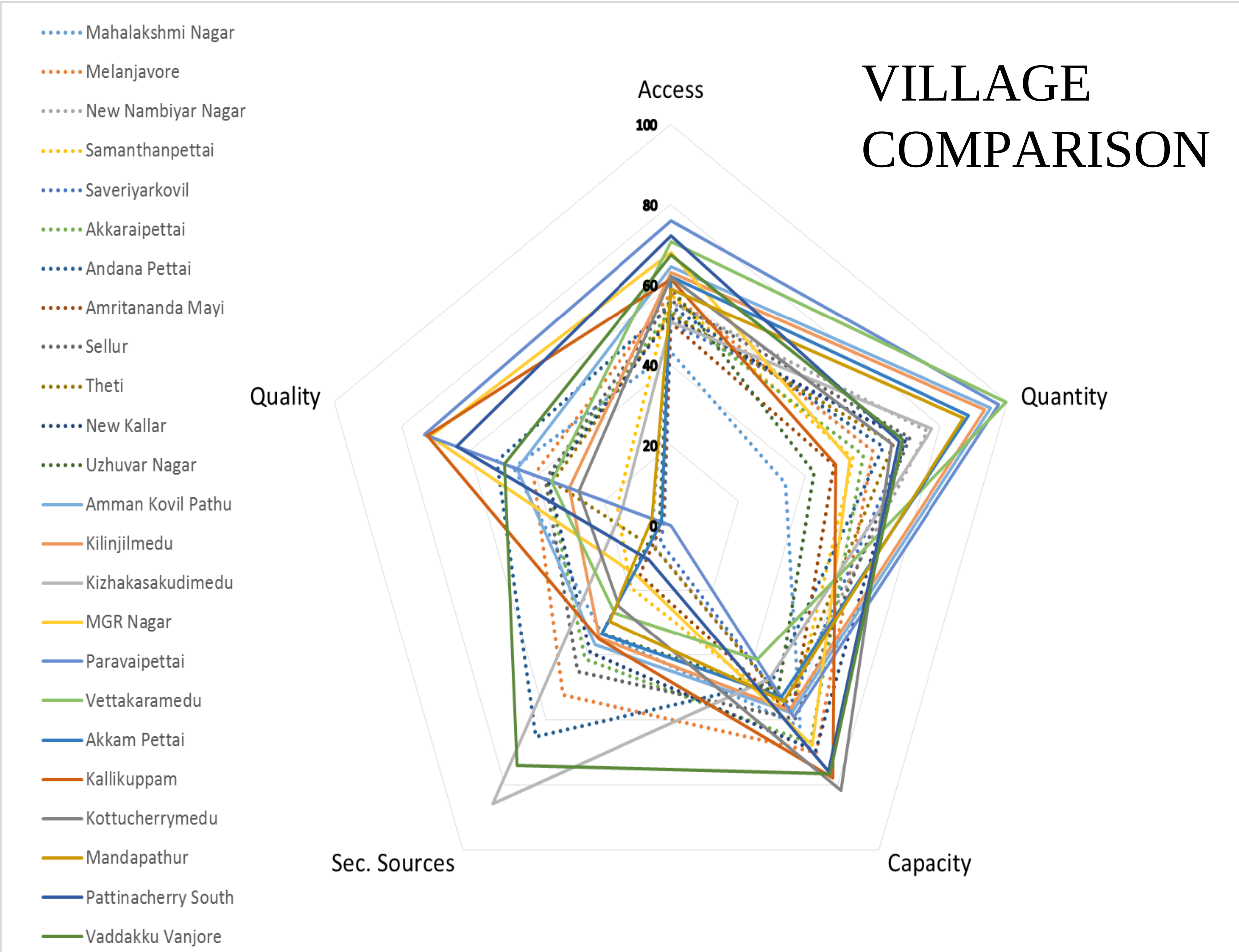

Fig. 3.9: Radar diagram displaying averaged household indicator scores for the 24 study sites

Fig. 3.9 illustrates the distance between the indicator scores of all 24 villages. While valuable to illustrate comparisons at the village level, overall the figure is noisy and perhaps better complemented by comparisons at the district level. **Fig. 3.10** illustrates distances in indicator scores between the districts of Nagapattinam and Karaikal, which reaffirms data in **Table 3.2** in which Karaikal outperformed Nagapattinam in all facets of water poverty. This is not surprising because Karaikal is a special government territory which results in it having a higher level of governmental means.

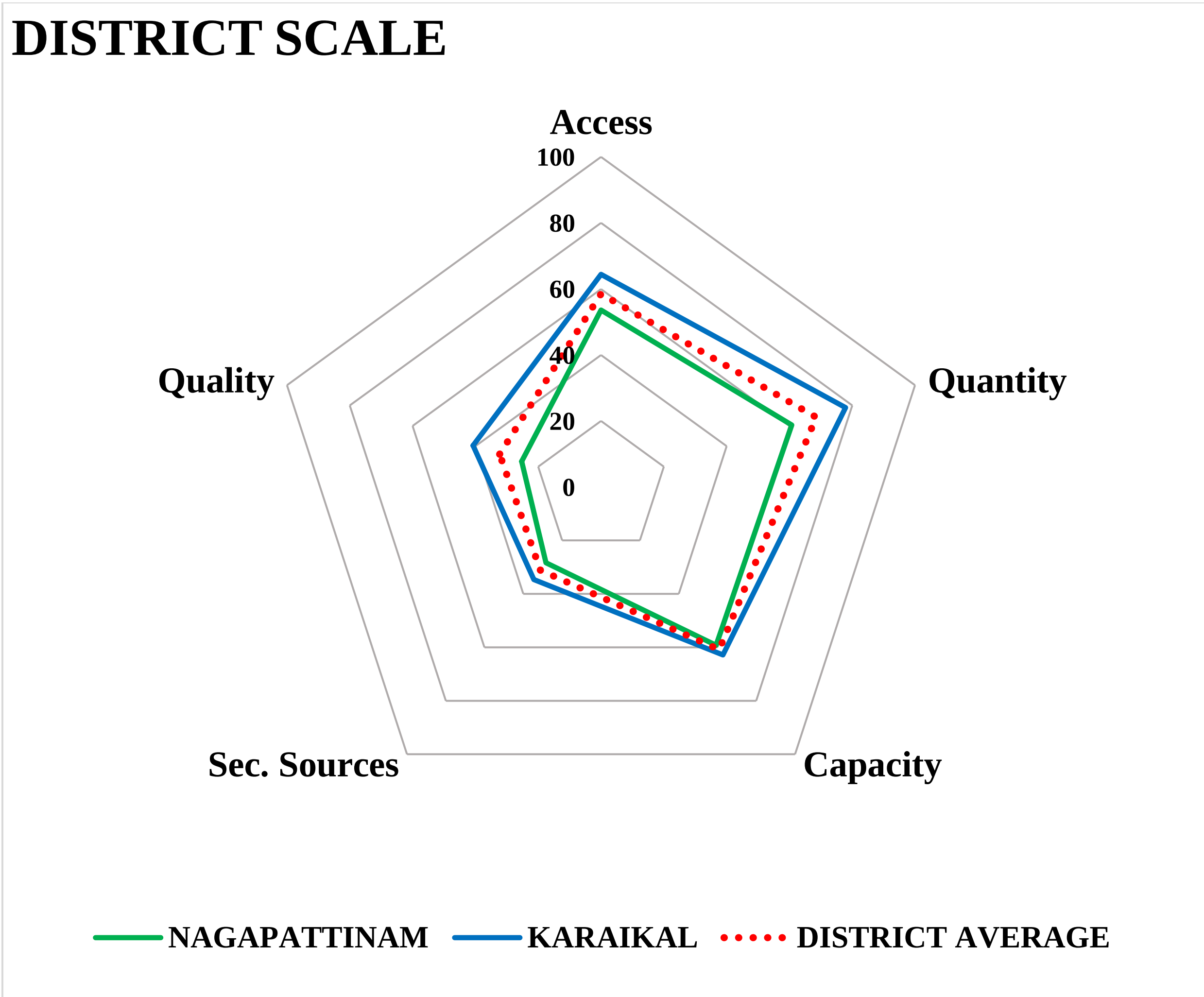

Fig. 3.10: Radar diagram displaying averaged household indicator scores of the two districts

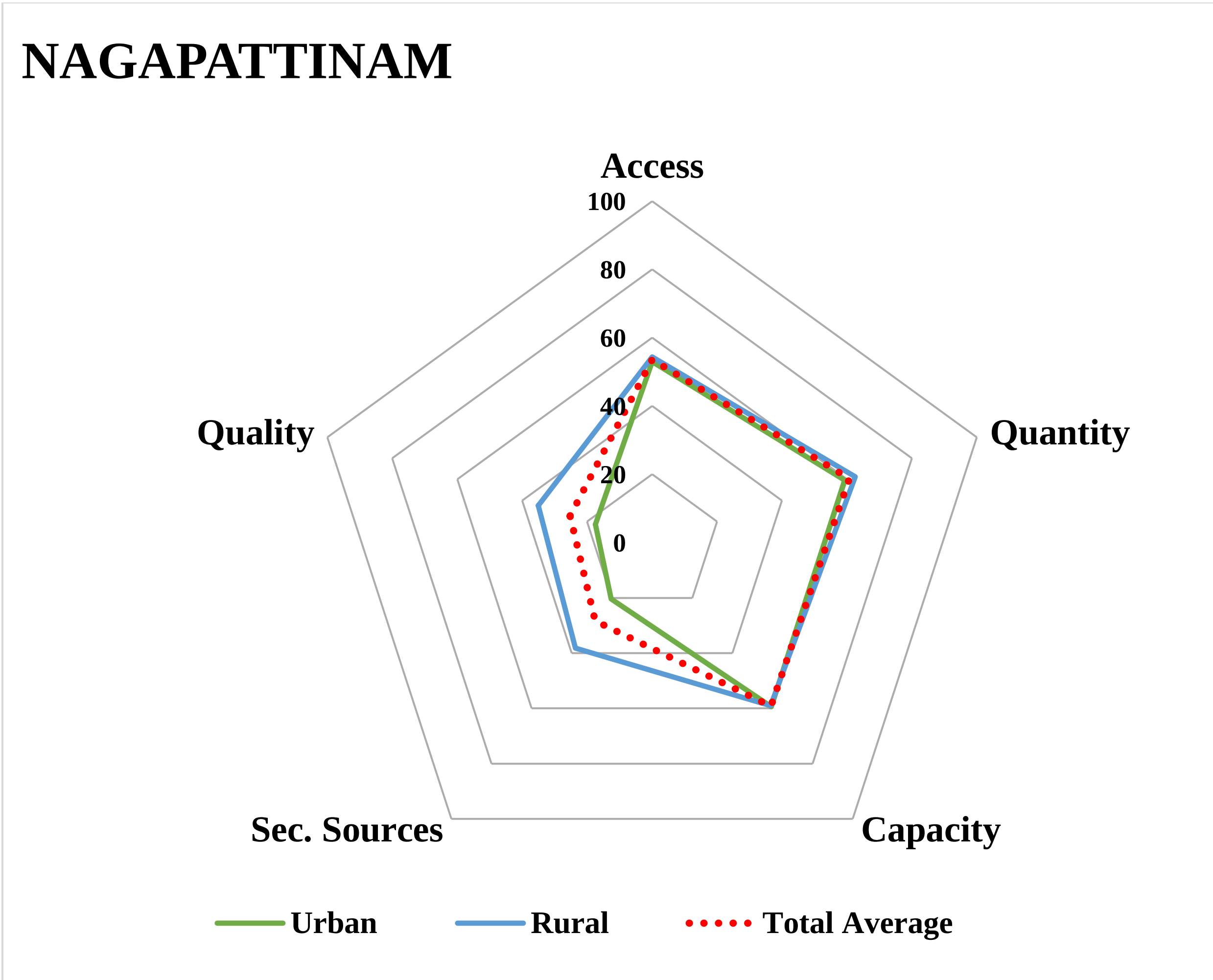

Fig. 3.11: Radar diagram displaying averaged household indicator scores in rural and urban Nagapattinam

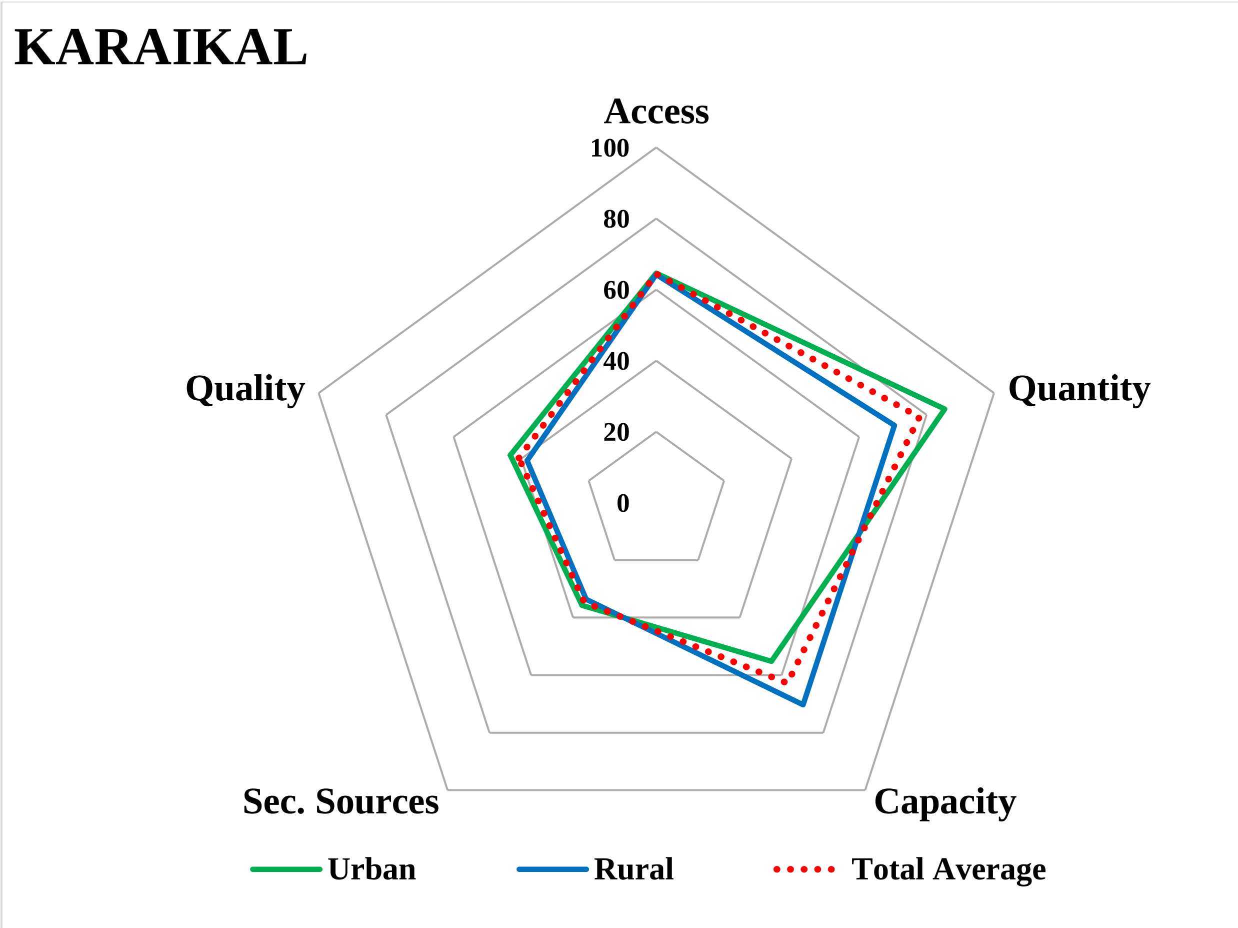

Fig. 3.12: Radar diagram displaying averaged household indicator scores in rural and urban Karaikal

Fig. 3.11 illustrates the distance between indicator scores in rural and urban Nagapattinam. As supported by **Table 3.2**, rural Nagapattinam outperforms its urban counterpart area in all but one indicator (Capacity). Finally, **Fig. 3.12** illustrates the same Karaikal district, where the urban setting outperformed the rural setting in all but one indicator (Capacity). Comparing **Fig. 3.11** and **Fig. 3.12**, it can be seen that the rural and urban areas in Karaikal both outperform performance in Nagapattinam.

3.4.2 WPI scores across the weight schemes

In addition to the classic equal weight scheme, two additional schemes—survey weight and expert weight—were applied to total WPI scores (**Table 3.3**). Results of independent sample t-tests reveal similar trends among the three weight schemes (**Table 3.4**). Karaikal District significantly outperformed Nagapattinam District across all three weight schemes, and rural study sites within Nagapattinam District significantly outperformed their urban cohorts across all weight schemes. Thus, the two alternative weights maintain that waterscape conditions are markedly different between the districts and within Nagapattinam. Interestingly, while the equal weight scheme determined no significant differences within Karaikal District, the two alternative schemes determined that urban Karaikal District significantly outperforms rural Karaikal. These discrepancies highlight the intricacies and impacts of weighting (i.e., through *whose* eyes matters) and will be discussed further.

Table 3.3: Breakdown of weight schemes

	EQUAL WEIGHT	**SURVEY WEIGHT[1]**	**EXPERT WEIGHT[2]**
QUALITY (Q)	0.200	0.331	0.250
QUANTITY (L)	0.200	0.263	0.250
ACCESS (A)	0.200	0.285	0.200
SEC. SOURCES (S)	0.200	0.111	0.125
CAPACITY (C)	0.200	0.010	0.175
SUM	1.000	1.000	1.000

[1] Weights conform to indicator rankings as reported by 507 surveyed households

[2] Weights independently determined after consulting the literature, best management practices, knowledge and observations gained from fieldwork, and key informant interviews

Table 3.4: Comparison of total WPI scores across weight schemes

	District Comparison			***Urban vs. Rural Nagapattinam***			***Urban vs. Rural Karaikal***		
	Nagapattinam	**Karaikal**	**p-value**	**Urban**	**Rural**	**p-value**	**Urban**	**Rural**	**p-value**
Equal	45.4†	56.1†	<0.0001*	41.9†	49.8†	<0.0001*	56.8†	55.4†	.3003
Survey	43.4†	56.8†	<0.0001*	39.3†	48.4†	<0.0001*	59.7†	53.9†	.0005*
Expert	46.1†	57.9†	<0.0001*	49.7†	53.4†	.001*	59.2†	56.5†	.001*

*†Household mean; *Significance at 95%*

3.4.3 Predictive ability of socioeconomic variables

Using Stepwise Regression, the predictive ability of three socioeconomic variables (Education, Income, and Assets-Networks) were found to be poor. Results (R^2 values) revealed that, in almost all scenarios, the independent variables showed a relatively strong correlation to Capacity and little correlation with the remaining indicators and total WPI scores across the weight schemes. That is not to say there were no correlations among the independent variables, but overall the R^2 values are overwhelmingly too small to identify any meaningful correlations. See **Appendix 4** for a full report on MLR results.

3.4.4 Spatiality of water poverty

Significant positive spatial autocorrelation exists across all indicator (**Table 3.5**) and all total WPI scores across the weight schemes (**Table 3.6**). These findings suggest that levels of water poverty are not randomly distributed but instead spatially clustered. Rationale to explain the spatial clustering will be discussed later.

Table 3.5: Global Moran's I results of WPI indicators

Indicator	*Global Moran's I Index*	*p-value*
Quality (Q)	0.619526	<0.0001*
Quantity (L)	0.402495	<0.0001*
Access (A)	0.684797	<0.0001*
Secondary Sources (S)	0.375837	<0.0001*
Capacity (C)	0.250029	<0.0001*

**Significance at 95%*

Table 3.6: Global Moran's I results of total WPI scores across the weight schemes

Weight Scheme	*Global Moran's I Index*	*p-value*
Total WPI - Equal	0.466908	<0.0001*
Total WPI - Survey	0.618156	<0.0001*
Total WPI - Expert	0.548899	<0.0001*

**Significance at 95%*

3.5 Discussion

Based on popular belief, the perception exists that if people have a greater income, level of education, assets, and (formal and informal) networks that one will also have greater access to water. Various papers have argued that these socioeconomic variables largely determine who enjoys relatively higher levels of water access, and that low levels of these variables lead to poorer water access (Ahmad, 2003; Johnson & Wilk, 2014). On the other hand, it is argued that access to adequate quantities and quality of water resources better facilitates attaining an education, generation of economic growth, and fewer missed days of work and school. However, scholars have begun to question whether socioeconomic indicators have strong correlations with water access and water quality (Shah & Van Koppen, 2006; Juran et al. 2017). Still, the accepted belief is that along with high levels of socioeconomic conditions comes knowledge on health and hygiene, disease transmission, importance of treating water at the point-of-use, and the monetary resources and capital to act upon such knowledge and purchase water supplies that are perceived as higher quality. However, in the case of Nagapattinam and Karaiakal, the data do not show a strong correlation.

In the case of Nagapattinam and Karaikal, an analysis of socioeconomic variables found little correlation with waterscape conditions. The measured variables of Income (total household monthly income), Education (highest level of education completed in the household), and Assets-Networks (household capital and resources as well as kinship and membership in self-help, civil society, cooperative, and other formal and informal institutions) revealed little correlation to the five indicators and three total WPI scores. The only dependent variable to show significance was the Capacity indicator. This was completely expected given that the Capacity indicator is comprised by summing the Income, Education, and Assets-Networks variables. What was not expected, however, was that the other four indicators (Quality, Quantity, Access, and Secondary Sources) and three total WPI scores would exhibit such low predictive value. Our hypothesis (and conventional academic wisdom), was that relatively easy access to good quality water at an adequate quantity is a function of capacity (defined here as Income, Education, and Assets-Networks). However, results returned from the Stepwise Regression models indicate that socioeconomic variables, in the case of Nagapatinam and Karaikal, do not have as much influence on water access as is assumed. It could be that, in a complex scenario such as this, waterscapes are involved in constant feedback loops that are mostly outside the control of waterscape residents. Outside actors and forces such as state/territory governments, local governments, resource managers, and climate may impinge residents' abilities to surmount negative features and capitalize on positive features of the waterscapes (Shah & Van Koppen, 2006; Juran et al. 2017). The result problematizes conventional beliefs higher levels of income, education, assets, and networks to draw upon necessarily lead to the outcome of increased water access for the study sites.

In the household survey, participants were asked which of the five indicators they feel mostly affect their access to water, ranked from one to five, with one being the most important. Study participants rarely selected Capacity in their top three, let alone showed much importance at all. Overall, the top three indicators were ranked as: (1) Quality, (2) Quantity, and (3) Access. We question whether this is due to socioeconomic status perceptions among participants that they have little control over improving water supplies, therefore, leading their concerns be more tangible issues such as quality, quantity, and access. We believe that in this case, processes of local governments and nonprofits superimposing reconstruction over preexisting water supply and water availability conditions caused this scenario. These failures in post-disaster aid have been conceptualized 'disasters after disaster' (Juran, Forthcoming). While the goal was to reconstruct in a way that facilitates rehabilitation and allows for life to become 'normal' again, the process failed to acknowledge underlying issues that also required mitigation and intervention. If not properly handled, these 'disasters after the disaster' can create a larger catastrophe than the initial disaster that prompted remedial actions in the first place. In regions of the world such as India, where there are concentrations of low-income, marginalized populations, there is often little ability to improve the infrastructure and water resource management operations to which they are subjected. As argued in this paper and in concepts of ‘water poverty’ and ‘water slavery,’ a continual poverty trap will remain until equitable access to adequate quantities of safe water is guaranteed.

Results also challenge accepted notions of urban-rural dichotomies in which urban areas are assumed to possess relatively ‘better’ waterscapes than their rural counterparts. However, our findings indicate this to only be true in Karaikal District. In Nagapattinam District, we found that that the rural study setting outperforms in all but one indicator, with two indicators being significant and total WPI scores significant across all three weight schemes. Urban sites in Nagapattinam outperformed marginally and insignificantly in Capacity (59.4 vs. 59.0), and underperformed in all other measures. Based on decisions made by these two governments, we see much better water quality in rural Nagapattinam because additional treatment (chlorination) is implemented in local water towers due to the water ‘having to traveled so far’ to get there. In urban Nagapattina, water supplies are only treated at the source node and are not secondarily treated in local water towers. Furthermore, there is greater access to Secondary Sources in rural areas. While urban residents must rely primarily on public taps, rural residents have greater access to surface water bodies (e.., rivers, canals, ponds) and there is greater ability to construct a well given greater access to open space. The end result, in this case, is that traditional urban-rural hierarchies are challenged.

In terms of positive spatial autocorrelation, we contend that clustering is a relic of human organization and not ‘natural’ features upon the landscape. We argue that natural attributes such as water resource availability, climate, and soil type are not principal determinants of clustering—in fact, such attributes are similar given that the study sites are all situated in the same physical geography. Rather, proximate villages demonstrate more similar WPI scores than relatively distant villages due to social dynamics and features of human origin, such as administrative delineations and the engineered environment. These human and built systems interact with hydrologic systems to fabricate a human ecology of water. Therefore, trends are not an etiology of natural hydrology (i.e., determined by forces of gravity and physics), but of social hydrology (i.e., how water moves through and is managed by socially-constructed systems). At play is a version of the hydro-social cycle (Swyngedouw, 2009; Linton & Budds, 2014) in which WPI scores are sensitive to political space and existing infrastructure. For example, significant differences between and within districts (i.e., Karaikal vs. Nagapattinam and rural vs. municipal administration) reveal the influence of political space. Additionally, the presence of infrastructure, or lack thereof, is telling. Some study sites were provided individual taps while others must tolerate public taps. Some sites have access to multiple wells while others have few or none. Some sites are provided higher quality while that of other sites is poor. And, some sites are positioned closer to their local water tower and consequently enjoy greater flow rates and quantities from the ability to 'steal' water from 'downstream' sites—a recognized design limitation of serial and branched piped networks in the study area (Bhave & Gupta, 2006; Chinn, 2009). Observed collectively, we argue that clustering is a spatial phenomenon determined primarily by human organization, administrative dynamics, and built environment attributes upon the landscape, not by naturally occurring features.

Findings can be leveraged to assist in more efficient and geographically-targeted water resource management as well as to identify where water sector interventions would be most impactful. For example, results could be used to guide policy making, inform more equitable allocation of water resources, and to plan future urban planning projects. Academically, our modified WPI represents a novel approach that builds on past attempts to measure access to water in a multidimensional, multiscalar, and more participatory fashion. An inclusion of more parameters that influence water access is which ultimately needed to better capture the dynamics that govern such processes. Finally, the modified WPI can be adapted by scholars and practitioners in other locations by adding, eliminating, and adjusting indicators and subindicators to suit the local context.

3.6 Conclusion

Current methods of measuring access to water are inadequate, especially the improved-unimproved metric currently utilized by the UN, WHO, and to measure progress for the SDGs. Inaccurate representations and interpretations of waterscapes have the potential to swing policies and resources in the wrong directions. What is needed, therefore, is a measurement that is multidimensional and multiscalar. Additionally, an approach that incorporates waterscape residents, is flexible (e.g., can add or delete indicators, employ competing weight schemes, etc.) and simple to operationalize (e.g., can be calculated with addition, multiplication, and division) is needed to empower local governments and nonprofits with knowledge to develop evidence-based interventions. The approach, data collection, and methods employed here were created with the intention that those who lack experience in analytics can still use the tool successfully.

The modified WPI presented in this project supports all of these avenues, not to mention that it also supports more rigorous statistical and spatial analyses for researchers and practitioners who have the knowledge and resources to perform such analyses. This is the first WPI to engage both statistical and geospatial analyses (most engage neither) while also being participatory (e.g., indicators chosen by subjects and a survey weight scheme created by subjects) and deployable by local actors who may lack knowledge of statistics and spatial statistics. Furthermore, while previous scholars have employed geospatial analysis to analyze water resources (e.g., to measure contaminants in bodies of water, predict potential areas for groundwater access, and for purposes of visualization), few have used GIScience to analyze the relationship between space and access to water (Rashid, 2012; Purushotham et al., 2013). While our WPI is similar in concept and construction to the original WPI, it was made appropriate for India and the post-tsunami context, which makes its comparisons more robust and meaningful. The same approach can be used to develop modified WPIs for other complex scenarios.

Chapter IV: Conclusion

Indices have been employed to better quantify and interpret an array of situations. Indices present complicated and multidimensional information in a straightforward method (with an equation that normalizes products across an easily understood scale) that can reach and be comprehended by various audiences. The development of this modified WPI is unique because it moves towards these ends while also taking advantage of other advances and approaches in index development. Our modified WPI was created based on originally sourced data at the household level and was vetted over the course of eight years of fieldwork and discussions with a local water managers, engineers, sociologist, and nonprofits in the region. Further, beyond field observations and expert input, the facet of participant involvement allowed for the curation of geographically relevant indicators that better represent the obstacles confronted by local populations. Thus, the WPI includes elements of the infrastructure while also incorporating other social and political factors that impact access to water. This approach sheds light on the true situation of a waterscape. While infrastructure is an extremely important component of water access water, there are external factors that also hinder or enable access to water, such as capacity. Though we acknowledge that there are other indicators that may be applicable in this case of Nagapattinam and Karaikal, we felt it was important to listen to and understand conditions from the perspective of those that reside in the waterscapes. In comparison to other WPIs, this is something that is woefully underrepresented. While a ‘one size fits all’ solution is necessary and useful, the rigidity and static nature of the index should adapted to fit local contexts. While water issues may be similar in two places, the method for identifying, understanding, and solving the problems should be dictated by local geographies.

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Appendix 1: Water and sanitation household interview

Exploration of Water and Sanitation Elements of Post-Tsunami Reconstruction

Location: Nagapattinam, Tamil Nadu, and Karaikal, Puducherry

Verbal consent was obtained: Yes ____ No ____

BACKGROUND

1. Name:____ (male / female)

2. Age: _______

3. Name of settlement:____

4. Pre-tsunami location:_________________________Distance from pre-tsunami location: _______ What ties does your household maintain with the pre-tsunami location (e.g., still maintain a house there, visits to damaged house, visit family or friends still residing there)?

5. Which entity constructed the houses:____

6. Total number of houses constructed by relief agency:__________

7. When were the houses finished: ________ When did you occupy your house: _________

8. Individual houses OR blocks of flats (circle).

9. Is there a head of the settlement:_________If so, how was that person chosen?

10. Prevailing employment characteristics of the settlement:___________________________

11. Number of persons working in your household (paid and unpaid):_______What is their occupation(s)?

WATER

12. Who is the provider for treated water:_______________________________ Are they maintaining the infrastructure? Explain.

13. Is there a person in charge of water for your settlement or for the *panchayat*? If so, how was that person(s) chosen?

14. Do availability windows conflict with the household's daily schedule (e.g., constrict mobility, education, and employment opportunities)? Explain.

15. Has a queuing system been established:_____ If so, how was it developed and how does it work?

16. For what purposes are the different sources of water used?

17. Do you boil the water or use any other treatment mechanisms? If so, what types of water do you boil or treat and for what purposes?

18. Issues of water quality (e.g., taste, color, odor)? Have there been any outbreaks of disease or skin ailments that have been linked to water quality?

19. Is there a volumetric cost or initial or recurring connection fee for water? If so, explain.

20. Issues of water pressure? If so, explain.

21. Is the water obtained enough to meet daily household needs? Explain.

22. What methods have been employed to cope with or modify water scarcity, access, pressure, or fees (e.g., storage, limit usage, queuing system, holes dug, intercepting the pipes, protests, complaints)?

23. Is there a difference in volume of water obtained during the wet and dry seasons? Likewise, do pressure and other attributes of water vary?

24. Besides community taps, what other infrastructure was provided (e.g., in-house pipes, overhead tanks, wells)? Are they operable and are/were they utilized? Explain.

25. Have any complaints about water been filed? If so, in what manner, to which entity, and what was the result?

26. Rate your satisfaction with the water scenario between 0-10 (where 0 is lowest and 10 is highest: _______ . Explain.

27. Describe the water source, quality, quantity, and access at the pre-tsunami settlement?

28. What are the differences between the pre- and post-tsunami settlements (both good and bad)?

29. Do you feel that the current water situation is an improvement compared to the pre-tsunami context? Explain.

30. Additional comments on water not probed thus far?

SEWAGE

31. Do you have a: septic tank (individual, joint, or community); leach pit; OR municipal sewage connection (circle).

    a. If a septic tank or leach pit, has it been filled or blocked: _________If so, how many months did it take to fill/block: ________

    b. If a septic tank, have you had it pumped:________ If so, who pumped it and what was the cost?

    c. If a leach pit, do you wait for the filled portion to dry and then empty it: _______ How long between the cycles: _________

    d. If a municipal connection, is the system operable, is/was it utilized, and is it adequately maintained by the governing body? Explain.

32. Are the bathroom and toilet one room or two separate rooms?

33. Is, or has there been, any visible seepage/leaking of the sewage infrastructure? Does the infrastructure get inundated during the monsoon season? Explain.

34. Does the bathroom have a water access point: ______ If so, does it function: _______

35. Does your household currently use the toilet regularly: yes / no (circle). Do all people in the household use the toilet? Is it used all year round (i.e., during dry and monsoon seasons)?

    a. If yes, what water is used to flush the toilet: _______________________

    b. If not, was it used initially and why did the household cease usage?

c. If not used regularly, is it used in emergencies, during sickness, or when privacy is required (especially by women in the household)?

d. If not, is lack of water a hindrance?

e. If not, is adequacy or quality of infrastructure a hindrance? Explain.

f. If not, where does the household 'go to the bathroom'? Has this led to any problems (e.g., privacy, security, disputes with landowners, during the monsoon)?

g. Are there other hindrances to usage (e.g., tank/pit is full, facilities inoperable, issues of culture or purity, location of infrastructure)?

h. If not, what would need to be altered in order for you to use the infrastructure?

i. If not, what is the bathroom used for (e.g., storage, *puja* room): _______________

36. How do issues related to sewage infrastructure differ during the wet and dry seasons?

37. Who is responsible for maintaining the sewage infrastructure? Is it being maintained? Explain.

38. Have any complaints about sewage infrastructure been filed? If so, in what manner, to which entity, and what was the result?
39. Rate your satisfaction with the sewage scenario between 0-10 (where 0 is lowest and 10 is highest): ________ . Explain.

40. Describe the toilet and sewage situation at the pre-tsunami settlement?

41. What are the differences between the pre- and post-tsunami settlements (both good and bad)?

42. Do you feel that the current sewage situation is an improvement compared to the pre-tsunami context? Explain.

43. Additional comments on sewage issues not probed thus far?

DRAINAGE

44. What is the method of drainage: none; dug ditches; concrete ditches (circle).

45. Who is responsible for maintaining the drainage infrastructure? Have they cleaned it and how often? Have the residents or outside volunteers ever cleaned it?

46. Are there problems draining domestic water (i.e., bathroom, sink, and laundry water)?

47. Are there problems draining rainwater? Does your roof leak?

48. Are there anthropogenic causes for drainage blockage (e.g., garbage, plastic refuse, and intentional blockage with sand or cement)? If intentional blockage, why?

49. How do issues related to drainage differ during the wet and dry seasons?

50. Is flooding common:______

    a. If yes, how often and how much rain is needed to cause flooding?

    b. If yes, how high has the water reached (use physical marker)?

    c. If yes, has water surrounded the house requiring you to walk through the water for entry?

    d. If yes, has water entered the house:_________ If yes, how many times: ________

    e. If yes, have you ever been forced to temporarily relocate: ______How many times: _____ For how long and where did you stay?

    f. If yes, how has flooding affected daily household tasks, mobility, and education and employment opportunities?

    g. If yes, what has the government done to mitigate and/or respond to flooding?

h. If yes, what have you and/or the residents done to mitigate and/or cope with flooding?

51. Drainage is clogged: never; sometimes; often; almost always (circle).

52. Is stagnation a problem in ‘normal’ times and/or during floods? If so, are there problems of: stench; mosquitoes; outbreaks of disease; other (if other, explain) (circle).

53. How has drainage or flooding affected water access and quality? Which of these problems exist: waterlogged access points; forced closing of access points; contaminated water; other (if other, explain) (circle).

54. How has drainage or flooding affected sewage amenities? Which of these problems exist: seepage; flooded septic tank or leach pit; flooded toilet pan; other (if other, explain) (circle).

55. Have any complaints about drainage been filed? If so, in what manner, to which entity, and what was the result?

56. Rate your satisfaction with the drainage scenario between 0-10 (where 0 is lowest and 10 is highest):________. Explain.

57. Describe the drainage situation at the pre-tsunami settlement (i.e., was there drainage infrastructure)? Was flooding common?

58. What are the differences between the pre- and post-tsunami settlements (both good and bad)?

59. Do you feel that the current drainage situation is an improvement compared to the pre-tsunami context?

60. Additional comments on drainage issues not probed thus far?

WRAPUP

61. Do you feel safer from hazards (e.g., floods, cyclones, tsunamis, outbreaks of disease) in the post-tsunami settlement compared to the pre-tsunami settlement? Explain. Would you rather live at the previous settlement or the current settlement and why?

62. Out of the all topics probed (water, sewage, and drainage), is there anything else you would like to add?

63. Issues related to water, sewage, and drainage have been probed. Rank the three issues from most problematic to least problematic. Explain why you chose that ranking.

1.

2.

3.

64. What participation/inputs were you sanctioned in the resettlement and reconstruction processes? Likewise, in terms of water, sewage, and drainage?

65. If you were given more participation/input power, what would you have suggested or demanded during the resettlement and reconstruction processes? Likewise, in terms of water, sewage, and drainage

Appendix 2: Details on index construction

INDICATORS	FORMULAE	VARIABLES, STANDARDS, AND UNITS	RATIONALE	SUPPORTING LITERATURE
Quality (*Q*)	$Q = [(qh + (qt_n / qt_t)) / 2] \times 100$	quality in household (*qh*) and quality at public taps (*qt*, wherein qt_n = no. of negative tests and qt_t = total no. of tests) determined by H_2S tests as either positive (recorded as 0) or negative (recorded as 1); all tests (both *qh* and *qt*) positive earns 0 and all tests negative earns 100	Quality is linked to health, human rights, and development; quality is poor in the study area and post-point contamination is a major issue given transportation, storage, and serving processes	Fewtrell and Bartram, 2001; Sobsey & Pfaender, 2002; Clasen & Bastable, 2003; Ashbolt, 2004; Gundry et al., 2004; Bain et al., 2014; Juran & MacDonald, 2014; Liu et al., 2014; Shaheed et al., 2014
Quantity (*L*)	$L = [(l / hp) / 50] \times 100$	*l* is total liters of tap water secured by household on day of survey and *hp* is total household population on day of survey; 0 liters earns 0 and 50 liters (accepted standard) or more per person earns 100	Quantity is inked to health, human rights, and development; government supplies are scarce in the study area and limited quantities impact livelihoods and the ability to satisfy cultural functions	Gleick, 1996, 1998; CPHEEO, 1999; Sullivan & Meigh, 2003; Sullivan et al., 2003; Rijsberman, 2006; Falkenmark, 2009; MoUD, 2011; Sphere

				Project, 2011; Sultana & Loftus, 2012
Access (*A*)	*A* = (*Di* + *H* + *W* + *De* + *F* + *Co*) / 6 whereas: Distance (*Di*) = [(200.01 - *di*) / 200.01] x 100 Hours (*H*) = (*h* / 24) x 100 Windows (*W*) = [(*w* - *w*min) / (*w*max - *w*min)] x 100	*di* (distance to tap) measured from doorstep to tap in meters (recorded as 0 if tap is on premises); a distance >200 meters (accepted standard) earns 0 and a distance of 0 earns 100 total hours water is available per day (*h*) is measured in minutes and converted to hours; 0 hours earns 0 and 24 hours (standard of continuous supply) earns 100 *w* is total no. of availability windows per day; *w*min (0, lowest recorded value)	Distance is critical because most households walk to public taps, rendering shorter distances relatively convenient; shorter distances also enable more trips, less physical burdens, and fewer opportunity costs associated with water retrieval Greater hours of availability provide extended opportunities for water retrieval, and uninterrupted supplies provide public health benefits, economic/livelihood benefits, and convenience A single window of availability anchors individuals to the home and represents a major opportunity cost,	Shiva, 1991; CPHEEO, 1999; Crow & Sultana, 2002; Sneddon et al., 2002; Bapat & Agarwal, 2003; Bhave, 2003; Sullivan et al., 2003; Bhave & Gupta, 2006; UNHCR, 2007; Chinn, 2009; McKenzie & Ray, 2009; MoUD, 2011; Sphere Project, 2011; Juran, 2015

		earns 0 and values ≥*w*max (3, highest recorded value) earns 100	whereas additional windows enable more opportunities to retrieve water, greater flexibility in daily schedules, greater mobility, more freedom to leave home for work/school, and less reliance on household water storage	
	Density (*De*) = [(31- *de*) / 30] x 100	*de* is no. of households served per tap; a density ≥31 households (accepted standard is 30) earns 0 and a density of 1 earns 100	Density per tap measures the stress level of limited infrastructure and resources; allocation across many households impacts quantity, queueing time, and conflicts	
	Flow Rate (*F*) = [1 - (*f* - *f*min) / (*f*max - *f*min)] x 100	*f* is seconds for tap to dispense 30 liters (converted to l/s); *f*min (33 s., lowest recorded value) earns 100 and values ≥*f*max (271 s., accepted standard) earn 0	Flow rate (surrogate for pressure) impacts quantity and queueing time as well as quality since low pressure permits the entrance of external agents	
	Conflicts (*Co*) = [1 - (*co* / 12)] x 100	*co* (defined as heated arguments up to and including physical	Conflicts affect mental and physical health; their absence indicates a	

		confrontations) were counted over the past year; 12 or more earns 0 and 0 earns 100	more pleasant waterscape while their presence indicates a more contentious and burdensome waterscape	
Secondary Sources (*S*)	*S* = [(*as* + *se* + *tr*) / 3] x 100	*as* (is there access to secondary source), *se* (is source ≥30.5 m. from sewerage infrastructure), and *tr* (is source treated) are each measured as 'no' earns 0 and 'yes' earns 1	Access to a supplemental source beyond public taps is a coping mechanism; further, it is better if the source does not interact with sewerage infrastructure and better yet if the source is treated/'improved'	Chaplin, 1999; Ahmad, 2003; Reynolds & Barrett, 2003; Lee & Schwab, 2005; Chinn, 2009; Woodson, 2010; Bain et al., 2014
Capacity (*C*)	*C* = (*I* + *E* + *R*) / 3 whereas: Income (*I*) = [(*i* - *i*min) / (*i*max - *i*min)] x 100 Education (*E*) = (*e* / 12) x 100	*i* is total monthly household income; *i*min (₹850, lowest recorded value) earns 0 and values ≥*i*max (₹10,000, contextualized standard) earn 100 *e* is highest grade completed in household; 0 grades completed earns 0 and ≥12 grades (contextualized standard) earns 100	Income is associated with vulnerability, capacity, resiliency, and ability to cope with emergency situations—particularly when confronting water-related issues Education is a component of adaptive capacity, vulnerability reduction, and managing stresses upon human systems; it also bestows knowledge on	Belcher, 1972; Bolin, 1976; Peacock, et al., 1987; Sullivan, 2002; Ahmad, 2003; Brooks, 2003; Cutter et al., 2003; Sullivan & Meigh, 2003; Adger et al., 2004; Nakagawa & Shaw, 2004; Birkman & Fernando, 2007; Munasinghe,

	Resources (*R*) = [(*a* + *v* + *k* + *n* + *t*) / 25] x 100)	assets (*a*, max 12), investments (*v*, max 4), kinship (*k*, max 5), social networks (*n*, max 3), and time in residence (*t*, max 1) represent resources significant to the context; resources were identified and categorized via interviews with subjects, sociologists, and nonprofits; a total of 0 resources earns 0 and 25 resources (max possible) earns 100	germ theory, water quality, hygiene and sanitation, waterborne diseases, etc. The five components comprise a basket of resources that can be leveraged to manage or improve waterscapes, seek assistance during crises, and converted to cash; time in residence provides knowledge on what to expect in seasonal availability of water, frequency and magnitude of precipitation, level of government and nonprofit involvement, and impacts the ability to adapt to and modify the waterscape	2007; Sharma & Patwardhan, 2008; Falkenmark, 2009; Lewis & Kelman, 2010; Mehta, 2011; Hall & Borgomeo, 2013

Final WPI equation (*weightx* applied according to weight schemes provided in Table 3.3):

$$WPI = Q_{weightx} + L_{weightx} + A_{weightx} + S_{weightx} + C_{weightx}$$

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Appendix 3: Water Poverty Index household survey

Exploration of Water and Sanitation Elements of Post-Tsunami Reconstruction

Location: Nagapattinam, Tamil Nadu, and Karaikal, Puducherry

Verbal consent was obtained: Yes ____ No ____

Village: ____

Survey #: ________

Verbal consent was obtained: Yes ____ No _____

Logged GPS point of house location: Yes ____ No _____

1. Times of water availability:

-Window 1: _____________________

-Window 2: _____________________

-Window 3: _____________________

-*Total hours*: ____________________

2. How many households share the access point from where you retrieve water: _______ houses

3. Total quantity of water obtained for household today: ___________ liters

4. Today's total household population: _________ persons

5. a. Has your household ever been involved in any conflicts over water: Yes ___ No ___

b. If yes, how many conflicts in the last year: _______ conflicts

6. Total monthly household income: Rs. _____________

7. Highest level of education completed in the household: __________ grades/degree

8. a. Which of the following are owned by or part of the household (circle):
   Electrical connection; TV; Phone (mobile or landline); Motorcycle; Vehicle; Livestock; Boat/cart/work implements/petty shop; Pattirum/patta or home insurance; Gas connection; Radio/cassette/CD/DVD player; Refrigerator; Air conditioner; Other (e.g., rice grinder, sewing machine, invertor, computer)

   b. Has your household (circle):

   Added on to house (concrete or masonry); Built fence/overhang/shed (concrete or thatch); Installed borewell/handpump OR pump OR Syntex tank OR in-house pipes; Planted trees/garden/flowers; Other (explain)

   c. Is anyone in the household a member of a civic, trade, religious, or cooperative organization (e.g., union, SIFFS, SHG, Rotary, microcredit, cooperative)? - _______ organizations

   d. How many relatives (household scale) live within 1 km: _______ relatives

   e. How many months have you lived in the house: <6; 6-12; 12-18; 18-24; >24 [circle]

9. Are there supplemental sources of water (e.g., well, pond, tanker lorry, packaged water)?

Yes ____ No _____

-If yes, is the source treated: Yes ____ No _____

-If yes, measure distance from sewage infrastructure: __________ ft

10. Measure distance of tap from household: ________ m

-Logged GPS point of tap location: Yes ____ No _____

11. Measure time taken to dispense 30 liters: __________ seconds

__________ seconds

__________ *total seconds*

12. Presence of fecal indicator bacteria: + ______ - ______

13. Rank the most important for your household (rank 1-3, with 1 most important):

-Access to water _____

-Household socioeconomic capacity _____

-Water quality _____

-Quantity of water _____

-Availability of supplemental sources of water _____

Appendix 4: Results of Multiple Linear Regression

4.1 All Household MLR Results

Table 4.1.1 Quality Model - All Households

Quality Model - All Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.04	0.04	29.4	4883.77

Table 4.1.2 Quantity Model - All Households

Quantity Model - All households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0	0	27.58	4813.96

Table 4.1.3 Access Model - All Households

Access Model - All Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.03	0.03	10.38	3827.69

Table 4.1.4 Secondary Source Model - All Households

Secondary Source Model - All Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.02	0.02	32.96	4971.67

Table 4.1.5 Capacity Model - All Households

Capacity Model - All Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.84	0.84	7.4907	3507.79

Table 4.1.6 WPI Equal Weight Model - All Households

WPI EQUAL Weight Model - All Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.2	0.2	11.03	3900.1

Table 4.1.7 WPI Survey Weight Model – All Households

WPI SURVEY Weight Model - All Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.04	0.04	13.87	4122.21

Table 4.1.8 WPI Expert Model – All Households

WPI EXPERT Weight Model - All Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.15	0.15	11.65	3950.26

4.2 All Nagapattinam Households Stepwise Regression Results

Table 4.2.1. Quality Model – All Nagapattinam Households

Quality Model - All Nagapattinam			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0	0	25.339	2587.063

Table 4.2.2. Quantity Model – All Nagapattinam Households

Quantity Model - All Nagapattinam			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0	0	25.37	2587.804

Table 4.2.3. Access Model – All Nagapattinam Households

Access Model - All Nagapattinam			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0	0	8.77	1999.409

Table 4.2.4. Secondary Source Model – All Nagapattinam Households

Secondary Sources Model - All Nagapattinam			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.0294	0.259	32.03	2721.518

Table 4.2.5. Capacity Model – All Nagapattinam

Capacity Model - All Nagapattinam			
R- squared	Adjusted R-squared	RMSE	BIC
0.89	0.89	5.15	1755.95

Table 4.2.6.WPI Equal Weight Model – All Nagapattinam

WPI Equal Weight Model - All Nagapattinam			
R- squared	Adjusted R-squared	RMSE	BIC
0.15	0.14	10.6645	2116.848

Table 4.2.6 WPI Survey Weight Model – All Nagapattinam

WPI Survey Weight Model - All Nagapattinam			
R- squared	Adjusted R-squared	RMSE	BIC
0	0	12.207	2182.473

Table 4.2.5 WPI Expert Survey Model – All Nagapattinam

WPI Expert Weight Model - All Nagapattinam			
R- squared	Adjusted R-squared	RMSE	BIC
0.12	0.11	10.49	2104.86

4.3 All Karaikal Households Stepwise Regression Results

Table 4.3.1 Quality Model – All Karaikal Households

Quality Model - All Karaikal			
R- squared	Adjusted R-squared	RMSE	BIC
0.06	0.05	32.09	2262.51

Table 4.3.2 Quantity Model - All Karaikal Households

Quantity Model - All Karaikal			
R- squared	Adjusted R-squared	RMSE	BIC
0.06	0.05	26.55	2175.44

Table 4.3.3 Access Model - All Karaikal Households

Access Model - All Karaikal			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.025	0.02	9.26	1690.93

Table 4.3.4 Secondary Source Model - All Karaikal Households

Secondary Source Model - All Karaikal			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0	0	32.12	2258.56

4.3.5 Capacity Model - All Karaikal Households

Capacity Model - All Karaikal			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.82	0.82	9.07	1690.27

Table 4.3.6. WPI Equal Weight Model – All Karaikal Households

WPI EQUAL Weight Model - All Karaikal			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.2	0.19	9.45	1704.54

Table 4.3.7 WPI Survey Weight Model - All Karaikal Households

WPI SURVEY Weight Model - All Karaikal			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.02	0.02	12.6	1832.55

Table 4.3.8 WPI Expert Survey Model – All Karaikal Households

WPI EXPERT Weight Model - All Karaikal			
R- squared	Adjusted R-squared	RMSE	BIC
0.15	0.14	10.37	1747.56

4.4 All Urban Households Stepwise Regression Results

Table 4.4.1 Quality Model – All Urban Households

Quality Model - All Urban Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.03	0.03	29.62	2591.549

Table 4.4.2 Quantity Model - All Urban Households

Quantity Model - All Urban Households			
R- squared	Adjusted R-squared	RMSE	BIC
0	0	28.43	2093.14

Table 4.4.3 Access Model - All Urban Households

Access Model - All Urban Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.02	0.02	11.67	2093.14

Table 4.4.4 Secondary Source Model – All Urban Households

Secondary Source Model - All Urban Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.08	0.08	30.89	2618.63

Table 4.4.5 Capacity Model – All Urban Households

Capacity Model - All Urban Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.91	0.91	5.21	1669.38

Table 4.4.6 WPI Equal Weight Model – All Urban Households

WPI EQUAL Weight Model - All Urban Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.17	0.16	11.43	2085.73

Table 4.4.7 WPI Survey Weight Model - All Urban Households

WPI SURVEY Weight Model - All Urban Households

R- squared	Adjusted R-squared	RMSE	BIC
0.04	0.04	15.1	2230.56

Table 4.4.8 WPI Expert Weight Model - All Urban Households

WPI EXPERT Weight Model - All Urban Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.11	0.1	12.57	2132.14

4.5 All Rural Households Stepwise Regression Results

4.5.1 Quality Model – All Rural Households

Quality Model - All Rural Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.04	0.04	28.88	2300.32

Table 4.5.2 Quantity Model – All Rural Households

Quantity Model - All Rural Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.02	0.02	26.23	2254.26

Table 4.5.3 Access Model – All Rural Households

Access Model - All Rural Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.05	0.04	8.66	1724.63

Table 4.5.4 Secondary Sources Model – All Rural Households

Secondary Source Model - All Rural Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.07	0.07	31.06	2335.07

Table 4.5.5 Capacity Model – All Rural Households

Capacity Model - All Rural Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.81	0.8	8.85	1744.09

Table 4.5.6 WPI Equal Weight Model – All Rural Households

WPI EQUAL Weight Model - All Rural Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.23	0.21	10.32	1817.07

Table 4.5.7 WPI Survey Weight Model – All Rural Households

WPI SURVEY Weight Model - All Rural Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.03	0.03	12.2	1888.55

Table 4.5.8 WPI Expert Weight Model – All Rural Households

WPI EXPERT Weight Model - All Rural Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.18	0.17	10.53	1826.82

4.6 All Rural Nagapattinam Households Stepwise Regression Results

Table 4.6.1 Quality Model – All Rural Nagapattinam Households

Quality Model - All Rural Naggapatinam Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0	0	23.93	1138.78

Table 4.6.2 Quantity Model – All Rural Nagapattinam Households

Quantity Model - All Rural Nagapattinam Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.05	0.04	23.53	1138.37

Table 4.6.3 Access Model – All Rural Nagapattinam Households

Access Model - All Rural Nagapattinam Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0	0	6.89	832.49

Table 4.6.4 Secondary Source Model – All Rural Nagapattinam Households

Secondary Source Model - All Rural Nagapattinam Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.04	0.03	32.39	1217.06

Table 4.6.5 Capacity Model – All Rural Nagapattinam Households

Capacity Model - All Rural Nagapattinam Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.89	0.89	5.79	801.2

Table 4.6.6 WPI Equal Weight Model – All Rural Nagapattinam Households

WPI EQUAL Weight Model - All Rural Nagapattinam Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.11	0.1	9.92	926

Table 4.6.7 WPI Survey Weight Model – All Rural Nagapattinam Households

WPI SURVEY Weight Model - All Rural Nagapattinam Households			
R- squared	Adjusted R-squared	RMSE	BIC
0	0	10.91	945.52

Table 4.6.8 WPI Expert Weight Model – All Rural Nagapattinam Households

WPI EXPERT Weight Model - All Rural Nagapattinam Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.06	0.06	9.68	919.97

4.7 All Rural Karaikal Households Stepwise Regression Results

Table 4.7.1 Quality Model – All Rural Karaikal Households

Quality Model - All Rural Karaikal Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.09	0.09	32.92	1152.06

Table 4.7.2 Quantity Model – All Rural Karaikal Households

Quantity Model - All Rural Karaikal Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.06	0.05	27.73	1112.25

Table 4.7.3 Access Model – All Rural Karaikal Households

Access Model - All Rural Karaikal Households			
R- squared	Adjusted R-squared	RMSE	BIC
0	0	7.84	815.29

Table 4.7.4 Secondary Sources Model – All Rural Karaikal Households

Secondary Sources Model - All Rural Karaikal Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.11	0.1	29.64	1127.74

Table 4.7.5 Capacity Model – All Rural Karaikal Households

Capacity Model - All Rural Karaikal Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.73	0.72	11.14	9080.04

Table 4.7.6 WPI Equal Weight Model – All Rural Karaikal Households

WPI EQUAL Weight Model - All Rural Karaikal Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.2	0.2	10.65	12.6

Table 4.7.7 WPI Survey Weight Model – All Rural Karaikal Households

WPI SURVEY Weight Model - All Rural Karaikal Households			
R- squared	Adjusted R-squared	RMSE	BIC
0	0	13.20	936.38

Table 4.7.8 WPI Expert Weight Model – All Rural Karaikal Households

WPI Expert Weight Model – All Rural Karaikal Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.16	0.15	12	907.69

4.8 All Urban Nagapattinam Households Stepwise Regression Results

Table 4.8.1 Quality Model – All Urban Nagapattinam Households

Quality Model - All Urban Nagapattinam Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.13	0.11	22.38	1415.52

Table 4.8.2 Quantity Model – All Urban Nagapattinam Households

Quantity Model - All Urban Nagapattinam Households			
R- squared	Adjusted R-squared	RMSE	BIC
0	0	26.39	1454.2

Table 4.8.3 Access Model – All Urban Nagapattinam Households

Access Model - All Urban Nagapattinam Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.05	0.05	9.77	1152.19

Table 4.8.4 Secondary Sources Model – All Urban Nagapattinam Households

Secondary Sources Model - All Urban Nagapattinam Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.08	0.07	28.79	1484.99

Table 4.8.5 Capacity Model – All Urban Nagapattinam Households

Capacity Model - All Urban Nagapattinam Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.92	0.92	4.43	916.29

Table 4.8.6 WPI Equal Weight Model – All Urban Nagapattinam Households

WPI EQUAL Weight Model - All Urban Nagapattinam Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.23	0.25	9.67	1153.14

Table 4.8.7 WPI Survey Weight Model - All Urban Nagapattinam Households

WPI SURVEY Weight Model - All Urban Nagapattinam Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.09	0.08	11.24	1195.34

Table 4.8.8 WPI Expert Weight Model - All Urban Nagapattinam Households

WPI EXPERT Weight Model - All Urban Nagapattinam Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.21	0.2	9.77	1156.1

4.9. All Urban Karaikal Household Stepwise Regression Results

Table 4.9.1 Quality Model – All Urban Karaikal Households

Quality Model - All Urban Karaikal Households			
R- squared	Adjusted R-squared	RMSE	BIC
0.06	0.05	30.58	1115.58

Table 4.9.2 Quantity Model – All Urban Karaikal Households

Quantity Model - All Urban Karaikal Households			
R- squared	Adjusted R-squared	RMSE	BIC
0	0	23.92	1055.77

Table 4.9.3 Access Model – All Urban Karaikal Households

Access Model - All Urban Karaikal Households			
R- squared	Adjusted R-squared	RMSE	BIC
0	0	10.72	872.9

Table 4.9.4 Secondary Source Model – All Urban Karaikal Households

Secondary Sources Model - All Urban Karaikal Households			
R- squared	Adjusted R-squared	RMSE	BIC
0	0	33.1	1129.9

Table 4.9.5 Capacity Model – All Urban Karaikal Households

Capacity Model - All Urban Karaikal Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.92	0.92	5.34	725.08

Table 4.9.6 WPI Equal Weight Model – All Urban Karaikal Households

WPI EQUAL Weight Model - All Urban Karaikal Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.23	0.22	7.5	798.83

Table 4.9.7 WPI Survey Weight Model – All Urban Karaikal Households

WPI SURVEY Weight Model - All Urban Karaikal Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.04	0.03	11.37	890

Table 4.9.8 WPI Weight Model – All Urban Karaikal Households

WPI Expert Weight Model - All Urban Karaikal Households			
R- squared	**Adjusted R-squared**	**RMSE**	**BIC**
0.22	0.2	8.84	836.26