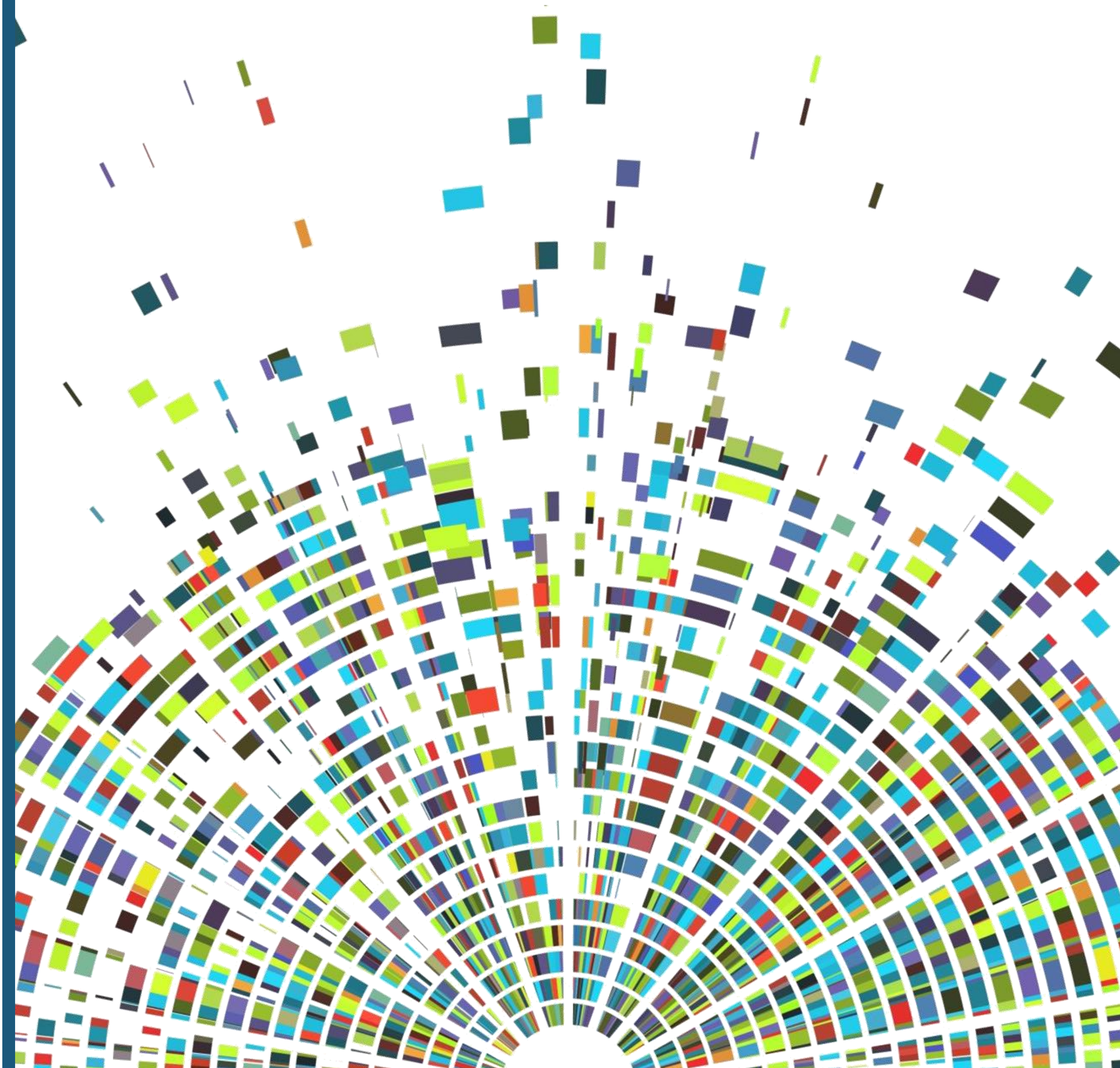
Groundwater Monitoring Feasibility Study for Kumasi, Ghana

Using value sensitive design methods to synergize diverse stakeholder perspectives to develop groundwater management and monitoring strategies



TU Delft

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Groundwater Monitoring Feasibility Study for Kumasi, Ghana

Using value sensitive design methods to synergize diverse stakeholder perspectives to develop groundwater management and monitoring strategies

Master Thesis Report

By

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at the Delft University of Technology

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Contents

Preface

Water resources challenges are not solely technical; they are also heavily influenced by and with social factors. After completing my bachelor's degree in environmental engineering, this was something I was interested in, but that an engineering degree did not provide. And thus was my reason for moving to Delft to study Communication Design for Innovation (CDI) with a technical focus in water management.

My goal in determining a thesis topic was to learn more about the intersection of water resources and communication challenges. In this vein, I was introduced to the African Water Corridor (AWC), whose mission is to "develop - with partners - one or more African Water Corridors, carriers for sustainable development through co-creation of innovative, open-source technologies and sustainable implementation strategies" (TU Delft, 2022).

This project would not have been possible without help, support, and encouragement of countless people. First, I need to thank all the individuals in Ghana who contributed to my project. This includes the interview respondents who generously shared their time and knowledge with me as these discussions are the foundation of the findings presented in this report. Importantly, I want to thank Clement Okyere Darko whose expertise and guidance was incredibly valuable as a translator and interview companion. Additionally, I want to thank Dr. Isaac Monney who provided introductions for multiple interviews and ensured my travel went smoothly.

This project was made possible by the support and guidance of Didier de Villiers and the African Water Corridor research team. I want to thank them for their collaborative partnership, funding and providing an environment which allowed me to fully integrate my interests in water resources and communication science. Additionally, my supervisors Dr. Éva Kalmar, Dr.ir. Steven Flipse and Dr.ir. Edo Abraham were instrumental in the completion of this project. I want to thank them for their time, enthusiasm, and guidance over the last several months.

I could not have completed this degree without my family who supported and encouraged me from across the ocean over the last 2.5 years of my studies in Delft. Lastly, I want to thank my friends both in the United States and the Netherlands. Thanks especially to my peers in the *afstudeerhok* for their camaraderie throughout writing this report.

I am thankful for the opportunity to complete this thesis in collaboration with CDI and the AWC, the results of which I hope generates further study in the Kumasi water sector.

K.E. Thorp

November 2022

Summary

Like many cities in sub-Saharan Africa, Kumasi, Ghana is facing greater groundwater demands in part due to rapid urbanization. However, currently Ghana does not systematically monitor groundwater, which poses a challenge in management and implementation of science-based policy. Additionally, coordination among stakeholders in Ghana's water sector has been described as inadequate by the National Water Policy which results in greater obstacles in water resource management. In order to simultaneously address these issues, value sensitive design is implemented to synergize diverse stakeholder perspectives to develop groundwater management and monitoring strategies. Value sensitive design provides a theoretical basis for explicitly incorporating values into innovations. In order to address the goal of the study, 46 semi-structured interviews with stakeholders in the Kumasi water sector were conducted as well as literature and policy reviews.

The first research question aims to identify key stakeholders and their role in groundwater management. The results identifed over 40 stakeholder groups in the Kumasi water sector. However, the most well-known groups are Ghana Water Company Limited (GWCL) and the Water Resources Commission (WRC). In addition to these government organizations, technical experts, specifically affiliated with Kwame Nkrumah University of Science and Technology (KNUST), were cited as necessary to involve in the development of a groundwater monitoring technology.

The second research question seeks to identify practical considerations for groundwater monitoring. Here, there was a general negative view of groundwater management with challenges including limited regulation, lack of awareness for groundwater issues, and limited collaboration among groundwater stakeholders. To address these challenges, the most cited design requirement mentioned during the interviews was the need for mass education on water related concerns. Lastly, there were significant concerns among many of the interviewees about borehole drilling and the importance of informal communication between drillers and neighbors to ensure safe and sustainable access to groundwater.

The third research question uses value sensitive design protocols to create value profiles for each of the stakeholder groups. The values incorporated in this study are economic efficiency, environmental sustainability, safety, social equity, participation, reliability, and trust. Respondents were asked, through a token allocation activity, to indicate what values are important for groundwater monitoring. Although the value profiles between stakeholder groups were not statistically different, the anecdotal evidence from interviews suggests that participation is connected to other values. This indicates that participation contributes to achieving other values in the implementation of a groundwater monitoring program.

The last research question sought to identify communication tools to incorporate considerations derived from the research questions, case studies, Ghanaian water policy, and a theoretical framework based on participatory design. This resulted in the recommendation of three parallel strategies: a) multi-stakeholder involvement, b) technology development and c) a water education campaign. The programs are designed to operate in a cyclic manner based on a social learning model specific to water management. This will enable a groundwater monitoring technology to be developed (b) alongside a water education campaign (c) in the community where water will be monitored. Implementation of a multistakeholder advisory board to coordinate these efforts and facilitate collaboration will ensure a participatory process. The next steps are to disseminate findings to key stakeholders in the Ghana water sector and continuously adapt the action plans as new information is identified.

Acronyms

Abbreviation	Name
AAMUSTED	Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development
AWC	African Water Corridor
CBO	Community Based Organization
CC	Commercial Consumer
CIDA	Canadian International Development Agency
COM	Community Ownership & Management
CSIR	Council for Scientific and Industrial Research
CWSA	Community Water and Sanitation Agency
DA	District Assembly
DANIDA	Danish International Development Agency
DC	Domestic Consumer
DP	Development Partner
DWST	District Water and Sanitation Team
ECOWAS	Economic Community of West African States
EHSD	Environmental Health and Sanitation Directorate
EPA	Environmental Protection Agency
EU	European Union
FC	Forestry Commission
GAEC	Ghana Atomic Energy Commission
GDP	Gross Domestic Product
GGSA	Ghana Geological Survey Authority
GIDA	Ghana Irrigation Development Authority
GoG	Government of Ghana
GSS	Ghana Statistical Services
GWCL	Ghana Water Company Limited
GWSC	Ghana Water and Sewerage Corporation
KNUST	Kwame Nkrumah University of Science and Technology
M&E	Monitoring and Evaluation
MDG	Millennium Development Goal
MESTI	Ministry of Environment, Science, Technology and Innovation
MoE	Ministry of Education
MoEn	Ministry of Energy
MoF	Ministry of Finance
MoFA	Ministry of Food and Agriculture
MoH	Ministry of Health

MOM	Monitoring Operation and Maintenance
MSWR	Ministry of Sanitation and Water Resources
MWH	Ministry of Works and Housing
MWRWH	Ministry of Water Resources, Works and Housing
NCWSP	National Community Water and Sanitation Program
NDPC	National Development and Planning Commission
O&M	Operation and Maintenance
PURC	Public Utilities Regulatory Commission
RBB	River Basin Board
RCC	Regional Coordinating Council
Re	Regulator
SDG	Sustainable Development Goals
SP	Service Providers
TR	Training and Research
TU Delft	Delft University of Technology
UN	United Nations
VSD	Value Sensitive Design
WASH	Water, sanitation and hygiene
WASTAN	Water and Sanitation Committee
WHO	World Health Organization
WRC	Water Resources Commission
WRI	Water Research Institute
WRM	Water Resource Management
WSDB	Water Supply and Sanitation Development Board
WSMT	Water and Sanitation Management Team
WSS	Water Supply and Sanitation
WSSDP	Water Sector Strategic Development Plan

Chapter 1 Introduction

1.1 Introduction

The sixth United Nations sustainable development goal is titled "Clean Water and Sanitation" which seeks to "ensure availability and sustainable management of water and sanitation for all" (United Nations Department of Economic and Social Affairs, 2022). The UN aims to achieve these goals by 2030. As of 2022, the Sub-Saharan African country of Ghana is making moderate improvements to achieve this goal, although, major challenges still remain (appendix A.1).

Threats to water scarcity and lower quality in Ghana include population growth, urbanization and rapidly growing and diversifying water demands (Ministry of Water Resources, Works and Housing, 2007). Kumasi is the country's largest city by population which is rapidly urbanizing with a growth rate of 5.3% between 2000 and 2018, while Ghana as a whole is growing annually at 2.3% between 2000-2021 (United Nations, 2018) (Ghana Statistical Service, 2021). The Ghana National Water Policy cited that the rate of urbanization outstrips current levels of increase in urban water supply (Ministry of Water Resources, Works and Housing, 2007). These concerns are elevated when considering that Kumasi is a climate sensitive region with increasing rainfall variability and more pronounced dry seasons (Ministry of Water Resources, Works and Housing, 2007).

1.1.1 Problem Definitions

Groundwater is used for both domestic and industrial purposes, however, groundwater resources management has been hampered by limited data and information (Water Resources Commission, 2012). Groundwater is neither completely renewable nor completely nonrenewable- meaning that while groundwater can be replenished through rainfall and thus be renewed, the rate of consumption can make the utilization unsustainable and thus nonrenewable to its original water table level. This contributes to the desire to determine the extent to which groundwater pumping is sustainable (Maxwekk, Geophrey, & Abudu Kasei, 2012).

A literature review on Scopus science using the search terms "groundwater" and "Ghana" and "monitor" yields only three results (appendix E.17). Without access to data on groundwater levels, management strategies are severely limited. A report studying the sustainable management of Ghana's natural resources recommends that surface and groundwater systems should be monitored frequently especially for emerging contaminants, their sources and possible public health and ecological implications. (Ebo Yahans Amuah, Afia Boadu, & Solomon, 2022). Ghana does not have a formal national groundwater monitoring program, and management without data means it is challenging if not impossible to make science-based policy decisions.

Problem Statement 1: Rapid urbanization puts increasing pressure on Kumasi's water resources, and with minimal groundwater data available, sustainable management of these resources is challenging to achieve.

Technical challenges in water management are exacerbated by a lack of coordination and dialogue among relevant agencies and institutions (Ministry of Water Resources, Works and Housing, 2007). Ghanian governance water sector is divided into three main fields: policy and planning, facilitation and regulation, and local service delivery (Oduro-Kwarteng, Monney, & Braimah, 2015). However, stakeholders in the Pra River Basin, in which Kumasi is located, have identified weak institutional capacity as a significant problem in managing water resources. Contributions to this include limited capacity of institutions, fragmented responsibilities, inadequate coordination of stakeholders, and inadequate stakeholder participation (Water Resources Commission, 2012).

Problem Statement 2: There is an inadequate level of coordination among stakeholders in Kumasi's groundwater management sector, which is an obstacle in achieving effective water resource management.

1.1.2 Communication Approach

In sustainable development, many complex challenges arise in which there is a need to align diverse stakeholder expectations (Kruger, Gusmao, Braga França, & Gonçalves Quelhas, 2018). While there are many models for collaborative action in innovation design, the scope of this study will utilize value sensitive design. Value sensitive design is a design technique which puts user values at the forefront of the design process. Typically, the capabilities of a product limits how people behave with it. However, value sensitive design seeks to proactively design technology by explicitly incorporating user values in the design process so that users can preemptively determine how they will interact with the product (Friedman, Kahn, & Borning, 2006). Designing for values and incorporating diverse perspectives in this case study is appropriate given water's universal necessity and the role it plays in everyday life. This indicates that incorporating values in socio-hydrological research is both import and relevant (Mostert, 2018). This relevance of "human values involved in water" is discussed in literature and will be expanded upon in this thesis (Ravesteijn & Kroesen, 2015).

Given the context of incorporating values in design, the **approach** of the study is to be problem driven not solution focused. Solution focused design begins with a solution and then proceeds to check if it works within the larger puzzle. However, *problem driven design* aims to understand the larger puzzle first and find a solution which fits in the broader context. This comes down to, rather than forcing a piece into a puzzle which is might not belong (solution focused), taking time to assess the full puzzle to find a piece which fits. In the scope of values in water management, this broader context includes relevant information on socio-hydrological constructs, their interactions, and "how they influence and are influenced by the prevalent social values and management institutions" (Mostert, 2018).

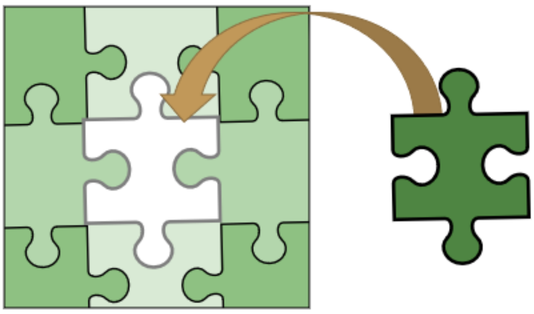


Figure 1. Problem Focused Approach

1.1.3 Research Goal

This study was commissioned by the African Water Corridor research group with the Delft University of Technology to study the feasibility implementing a groundwater monitoring system in Kumasi. Therefore, the **goal** of this study will be to use value sensitive design methods to synergize diverse stakeholder perspectives in order to develop groundwater management and monitoring strategies for Kumasi, Ghana.

1.2 Research Questions

In order to address the problem statements and fulfill the goal of this study, there are four research questions. First, because the study is led by a values approach which takes multistakeholder perspectives into account, the key stakeholders, their roles, and interactions are assessed. This will be accomplished by answering the first research question:

RQ1: Who are the key stakeholders in the development of groundwater monitoring in Kumasi, Ghana and what are their roles?

Identification of stakeholders will aid in understanding practical groundwater management in Kumasi. The second research question seeks to determine the practical groundwater management considerations and the key stakeholders' place in it. This is accomplished by answering the second research question:

RQ2: What are important considerations in the groundwater management setting in Kumasi, Ghana?

The first two research questions provide greater context to the groundwater management landscape in Kumasi by understanding the stakeholders and their engagement in the water sector. The third research question will utilize a value sensitive design approach to build value profiles for each stakeholder group and determine the motivations for such values.

RQ3: What are the values of key stakeholders in the development of a groundwater monitoring system in Kumasi, Ghana?

Lastly, the results from the research questions, theoretical framework, case studies and Ghanaian policy will be utilized to determine design requirements and a recommendation for next steps in the development of a groundwater monitoring system in Kumasi.

RQ4: How can value sensitive design be used to identify strategy for groundwater monitoring?

A full outline for the procedure of answering these research questions and an outline of the paper is described on the next page.

1.3 Outline Reading Guide

Chapter 2: Context			
Ghanian Governance and Water Policy	Integrated Water Resource Management	Kumasi Groundwater Management	Water Management Case Studies

Chapter 3: Theoretical Framework			
Value Sensitive Design Approach	Identity Analysis	Multistakeholder Engagement	Holistic Theoretical Framework

Chapter 4: Methods			
VSD Operationalization	Semi-Structured Interview	Coding and Data Analysis	Literature and Policy Review

Chapter 5: RQ1 Identifying Stakeholders			
Stakeholder Roles	Collaboration	Communities of Practice	Identification of Key Stakeholders

Chapter 6: RQ2 Groundwater Management Practical Considerations			
Groundwater management views	Practical management	Management Challenges	Goals for management

Chapter 7: RQ3 Stakeholder Values			
Value profiles per actor	Connections between values	Value consensus and importance	Value Interpretations

Chapter 8: RQ4 Recommendations			
Theoretical Approach	Design Requirements	Recommendation	Evaluation of Design

Chapter 9: Conclusions		
Discussion	Synthesis	Next Steps

Chapter 2 Context

2.1 Introduction

Front Material			Body Research Questions			Conclusions	
Context	Theory	Methods	RQ1	RQ2	RQ3	RQ4	Conclusion

The first section of the report provides context for the case study and establishes the setting for the remainder of the report. This is achieved through a review of content related to Ghana's governance, water policies, goals and current groundwater information in Kumasi. Then, the global context of integrated water resource management and other groundwater management systems are described.

Objectives	
	Review Ghanian governance structures and related water policy
	Define integrated water resources management and its application in Ghana
	Assess groundwater management and use in Kumasi
	Analyze water management case studies for comparable scenarios

2.2 Ghana Water Governance

2.2.1 Governance Overview

The setting of the project is in Kumasi, Ghana. Ghana is a coastal nation in sub-Saharan Africa and member of the Economic Community of West African States (ECOWAS). Ghana's government structure is decentralized, through both national and regional jurisdictions. There are 16 regions in Ghana, but the focus of this study is on the Ashanti region where Kumasi is the regional capital (Ghana Statistical Service, 2021). Within the regions, the government is further decentralized into Metropolitan, Municipal and District Assemblies (MMDAs) where the type of assembly is determined by the population as seen in table 1. There are 27 assemblies in the Ashanti region, with the Kumasi Metropolitan being the most heavily populated and surrounded by municipal assemblies.

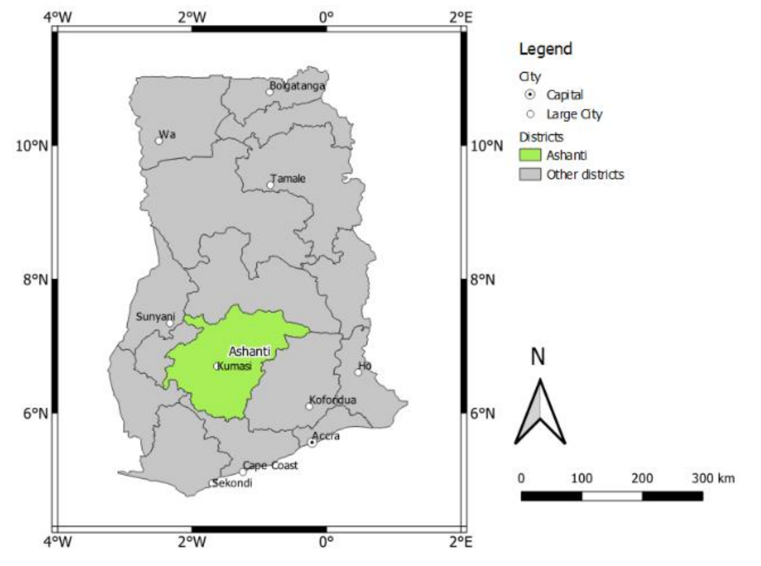


Figure 2. Ashanti region in Ghana

Table 1. MMDAs in Ghana

Type	Number assemblies	Represents	Population
Metropolitan	6	Urban areas	>250,000
Municipal	56	Single towns	>95,000
District	154	Rural and small towns	<95,000

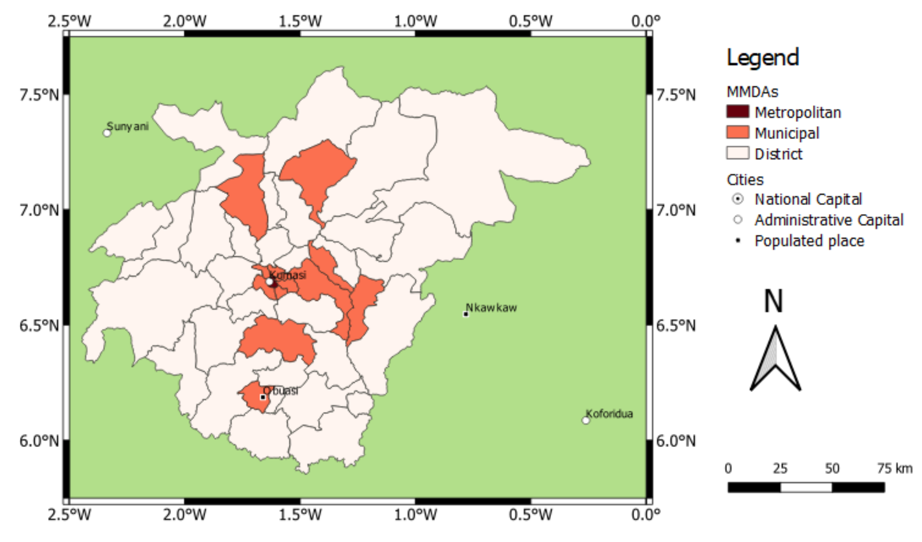


Figure 3. Ashanti region and MMDAs

2.2.2 Ghana Water Policy

Prior to the 20th century, water resources management was based on traditional laws made obligatory by fetish priests and priestess (Monney & Antwi-Agyei, 2018). With independence from British colonization in 1957, Ghana was able to make autonomous decisions and statutory laws in water resource management (Monney & Antwi-Agyei, 2018). This began with the creation of the Ghana Water and Sewage Corporation (GWSC) in 1965 which was tasked with water supply throughout the country. However, rural communities were having difficulty gaining access to water so the rural water department was created within the GWSC to target these communities.

In the 1990s, Ghana's water sector saw rapid expansion starting with the constitution in 1992 which vested ownership of the nation's water to the President of Ghana. The Water Resources Commission was instituted in 1996 and was placed in charge of the country's national water resources. There is no private ownership of water in Ghana as the WRC Act of 1996 states that "The property in and control of all water resources is vested in the President on behalf of, and in trust for the people of the Republic" (Parliament of Ghana, 1996).

With a combination of acts in 1998 and 1999, the Ghana water supply sector was reformed. The GWSC was dissolved and in its place, there were two agencies: the Community Water and Sanitation Agency (CWSA) and Ghana Water Company Limited (GWCL) (Monney & Antwi-Agyei, 2018). The two agencies are both responsible for water supply, but the CWSA is solely responsible for rural communities while GWCL is responsible for urban areas. The goal for the establishment of the CWSA was to provide an "institutional base for the implementation of the national community water and sanitation program" (Obosi, 2020).

The 2000s saw additional regulation for groundwater drilling and management strategies through the WRC. The WRC requires corporations to register for a permit to use groundwater. According to the Water Use Regulations L.I. 1692, all "freshwaters such as stream, rivers, and lakes, and springs, and underground water" require a permit (Water Resources Commission, 2001). However, if the use is for "households for domestic purposes and irrigation on farmlands less than a hectare" a permit is not necessary, but registration is required for no fee (Water Resources Commission, 2001).

Prior to 2017, water resources were managed at the federal level through the Ministry of Water Resources, Works and Housing and the Ministry of Local Government and Rural Development. However, in 2017 the Ministry of Water Resources, Works and Housing was replaced by the Ministry of Sanitation and Water Resources. This ministry manages the WRC, GWCL and CWSA through the Water Directorate to coordinate policies, programs and projects on water resource management (Ministry of Sanitation and Water Resources, 2018).

Additionally, there were international commitments and reports which Ghana was involved which include the Africa Water Vision 2025, Sharm El Sheikh Declaration and Commitments, and the African Agenda 2063 (African Union, 2004), (The Assembly, 2008), (African Union Commission, 2015). All of these agreements propose goals and action plans to improve of the water sector in Africa.

2.2.3 Ghana Groundwater Monitoring Status

Ghana currently does not have a nationalized groundwater monitoring program. A nationalized groundwater monitoring program, for this study, is classified as a database of groundwater levels managed by a government agency where groundwater is measured on regular time. After thorough review of groundwater monitoring projects in Ghana, four government sanctioned monitoring programs were identified. However, information on these projects is extremely limited.

The WRC delegates groundwater data collection to the Groundwater Division of the Council for Scientific and Industrial Research – Water Research Institute (CSIR-WRI). The long-term objective of this division is to "generate, process and disseminate information on the availability of groundwater, quantity of water to be abstracted for various uses as well as the reliability and sustainability of its recharge" Council for Scientific and Industrial Research, 2020). Additionally, the division "undertakes groundwater monitoring and assessment studies as well as groundwater database management", however, the database could not be located in this investigation (Council for Scientific and Industrial Research, 2020). In the past, the CSIR-WRI monitored groundwater in the Accra Plains, but this project was discontinued in the late nineties due to urbanization and land disputes which rendered most of the well locations inaccessible (IGRAC, 2020). In 2020, the WRI reported the installation of hydro-meteorological equipment including 60 meteorological, 13 hydrological and 22 groundwater equipment in the Pra and Densu river basins (Council for Scientific and Industrial Research, 2020).

The Ghana Atomic Energy Commission (GAEC) also plays a role in groundwater monitoring, but it is not in their mandate. Their involvement in groundwater monitoring is specific to a groundwater isotopic study for the northern region of Ghana with the Water Resources Commission (Water Resources Commission, 2011).

The most accessible information is from the Canadian International Development Agency (CIDA) funded project in Northern Ghana. This is the Hydrogeological Assessment Project of the Northern Regions of Ghana which established a groundwater monitoring network (figure 4). The latest public information from this study is from 2011.

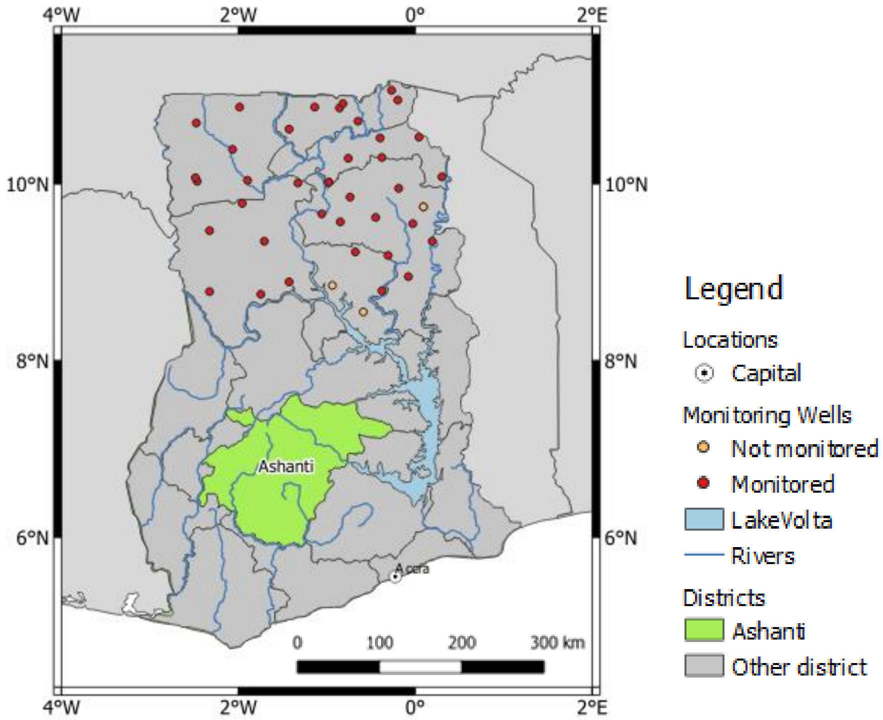


Figure 4. Locations of monitoring wells in the WRC network (WRC, 2011)

2.2.4 Ghana Water Policy Framework

2.2.4.1 Ghana National Water Policy (2007)

A key piece of legislation which provides a framework for the sustainable management of water resources is The Ghana National Water Policy. It was published in June 2007 by the Ministry of Water Resources, Works and Housing in response to the National Development Framework which is put forth by the National Development Planning Commission. The document emphasizes throughout that a key concern is the lack of an effective integration and harmonization in the activities of key stakeholder institutions (Ministry of Water Resources, Works and Housing, 2007).

The document highlights three issues: water resource management, urban water supply and community water and sanitation. For each of these issues, there are focus areas which address principles and challenges, policy objectives and policy measures/actions (see appendix A.2). The key policy actions in the scope of this research are the *communication* and *data* categories. For communication, there is an emphasis on participatory decision making to "encourage interdisciplinary and participatory research that recognizes the need for a link between technology and communities" (Ministry of Water Resources, Works and Housing, 2007). The data category focuses on the availability of data, information sharing and promotion of technical research.

2.2.4.2 Water Sector Strategic Development Plan (2012-2025)

The Water Sector Strategic Development Plan was published in March 2014 by the Ministry of Water Resources, Works and Housing in response to the Ghana National Water Policy. The main vision for the plan is to achieve "sustainable water and basic sanitation for all by 2025" (Ministry of Water Resources, Works and Housing, 2014). The plan includes three service packages and four cross cutting issues (see appendix A.2). For each package, there are policy objectives, strategies and indicators described to address it.

The plan mentions that a key issue is the "inadequacy of data on water quality and groundwater resources resulting from a weak capacity for collecting reliable hydrologic, meteorological and water quality data" (Ministry of Water Resources, Works and Housing, 2014). Specifically, under Water Resource management, the policy objective of "improv(ing) access to water resource knowledge base to facilitate water resources planning and decision making" involves three strategies relevant to this study below.

(1) Improve hydrological and meteorological data and information management
(2) Implement a developed Groundwater Management strategy to increase access to accurate groundwater resource information
(3) Strengthen water quality monitoring and data assessment

2.2.5 African Policy Agenda and Framework

In addition to the Ghanian context, the African Union has also established a series of plans to transform the water sector. These include the Africa Water Vision 2025, the Sharm El-Sheikh Commitments and Africa Agenda 2063.

2.2.5.1 Africa Water Vision 2025

The Africa Water Vision 2025 was established in 2000 by the World Water council in order to "to lead to a future where the full potential of Africa's water resources can be readily unleashed to stimulate and sustain growth in the region's economic development and social well-being" (African Union, 2004). There are ten vision statements the report aims to achieve. The focus of this report is on the seventh which is stated below. One of the drivers for accomplishing the goal is technology. Specifically seeking to address "the existence of critical gaps in data (specifically the) ground and surface water information and knowledge in the water sector" (African Union, 2004).

> "There is an effective and financially sustainable system for data collection, assessment and dissemination for national and trans-boundary water basins" (African Union, 2004)

2.2.5.2 2008 Sharm El-Sheikh Commitments

In 2008, the member states of the African Union, gathered to recognize the "importance of water and sanitation for social, economic and environmental development of our countries and Continent" (The Assembly, 2008). The report addresses multiple sectors of water and sanitation including regulatory, technology, involvement and finances. In respect to technology, the commitments aim to invest in "information, knowledge and monitoring and institutional development as well capacity building" (The Assembly, 2008). Regarding participation, the document aims to:

> "Promote effective engagement of African civil society and public participation in water and sanitation activities and programs" (The Assembly, 2008)

2.2.5.3 Africa Agenda 2063

In 2015, the African Union Commission published the Africa Agenda 2063 which describes seven aspirations for transforming Africa for "unity, self-determination, freedom, progress and collective prosperity" (African Union Commission, 2015). Water security is primarily mentioned in the first aspiration which is "a prosperous Africa based on inclusive growth and sustainable development" (African Union Commission, 2015). With respect to water, this aspiration aims to ensure people have access to water and that investments in science and technology are made to ensure sustainable development. The 18th point broadly aims for Africa to:

> "have equitable and sustainable use and management of water resources for socio-economic development, regional cooperation and the environment" (African Union Commission, 2015)

2.3 Integrated Water Resources Management

2.3.1 Global Framework

Global challenges in the water field include economy, social inequity, governance, climate, technology adaptation, security, food production, ecosystem threats, population rise, pollution and water conflict (Global Water Partnership Technical Advisory Committee, 2000). To address these concerns, the Global Water Partnership created a framework for which water management can be achieved. This concept is known as integrated water resources management, or IWRM. The GWP implemented the definition of IWRM as stipulated below.

"IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."
(Global Water Partnership Technical Advisory Committee, 2000)

There are four principles known as the Dublin Principles which are commonly accepted in the international community and used for implementation in water resource management (Global Water Partnership Technical Advisory Committee, 2000). These principles (below) are context dependent and should be adapted based on the circumstances of the case.

Table 2. Dublin Principles (Global Water Partnership Technical Advisory Committee, 2000)

I	**Fresh water is a finite and vulnerable resource,** essential to sustain life, development and the environment.
II	Water development and management should be based on a **participatory approach**, involving users, planners and policymakers at all levels.
III	**Women play a central part** in the provision, management and safeguarding of water.
IV	**Water has an economic value** in all its competing uses and should be recognized as an economic good.

Additionally, there are three overriding criteria of IWRM which take social, economic and natural conditions into account.

1. *Economic efficiency in water use*- attempt to maximize the economic and social welfare derived not only from the water resources base but also from investments in water service provision.
2. *Equity*- in the allocation of scarce water resources and services across different economic and social groups.
3. *Environmental and ecological sustainability*- as the water resources base and associated ecosystems are finite

Implementation of the Dublin principles, the definition of IWRM and the overriding criteria can be achieved in a three-sector approach: the enabling environment, institutional roles, and management instruments.

Table 3. IWRM sector approach

Management instruments	Enabling environment	Institutional roles
Allocation Regulations Economic tools	Policies Legislation Financing	Organizational framework Institutional capacity building

2.3.2 Ghanian Approach to IWRM

In addition to the global report on IWRM, there are operationalized plans for IWRM implementation in Ghana. There are two relevant policy documents which focus on the national level and the Pra River Basin level. Both documents are composed by the Water Resources Commission.

2.3.2.1 National Integrated Water Resources Management Plan: December 2012

In accordance with global and ECOWAS (Economic Community of West African States) recommendations, Ghana developed and IWRM plan which built upon years of continuous institutional development in the water planning sector (as referenced in section 2.2). Despite intense growth of the water sector, the national IWRM plan identifies problems including uncontrolled catchment degradation, pressure due to climate change and climate variability and increasing population growth and urbanization (Water Resources Commission, 2012). As it relates to the scope of this paper, there are significant concerns in weak enforcement of regulations and permits, lack of data and information on surface and groundwater quantity and quality, and inadequate skilled human resources for IWRM (Water Resources Commission, 2012).

In order to address these issues, the WRC created policy objectives, strategic outcomes and actions (appendix A.2). The comprehensive report touches on several vital components for a successful IWRM plan. For the scope of this study, the focus will be on outcome 3.1 which states "improve data and information management". Below are two of the supporting actions to reach this outcome:

- Support the set-up, rehabilitation, and upgrade the hydrometeorological monitoring networks as well as introduce new technologies for data collection and analysis.
- Strengthen human and technical capacities of institutions for data analysis and archiving

2.3.2.2 Pra River Basin: Integrated Water Resources Management Plan: June 2012

The Global Water Partnership states that "subsidiarity in water resources management is essential so that different tasks are undertaken at the lowest appropriate level" (Global Water Partnership Technical Advisory Committee, 2000). To fulfill this, the WRC created IWRM plans for each of its river basins. Kumasi is located in the north of the Pra River Basin (figure 5). The Pra River Basin Integrated Water Resources Management Plan was created by coordinating members of the Pra Basin Board (PBB) which includes representatives from government, consumer groups and civil society. The Pra Basin Board determined the top five problem areas for the basin to address:

1. Inadequate water supply to meet demand for domestic, commercial, agricultural, and industrial purposes (including mining)
2. Land degradation from deforestation, agriculture, mining settlements, etc.
3. Water quality deterioration from household, commercial, industrial (including mining) and agricultural wastes
4. Insufficient response to climate variability and change
5. **Weak institutional capacity in terms of human, financial, logistic, data, information, etc**.

2.4 Current Groundwater Situation in Kumasi

As previously discussed, the Pra River Basin is an example of Ghana's decentralized water governance structure and these basins are managed by the Water Resources Commission (WRC). Kumasi is located in the northern section of the Pra River Basin- specifically, in the Offin sub basin (Water Resources Commission, 2012). There are three sub basins within the Pra: the Birim, Main Pra and Offin. All three are managed out of the WRC office in Kumasi.

The Pra River Basin WRC is responsible for managing water resources within this jurisdiction. Water resources challenges in Kumasi are related to population increase, unsustainable application of fertilizers and pesticides, and unregulated mining activities (Ebo Yahans Amuah, Afia Boadu, & Solomon, 2022). Additionally, Ghana is characterized as having a moderate to high vulnerability to both floods and droughts (BGR, 2022).

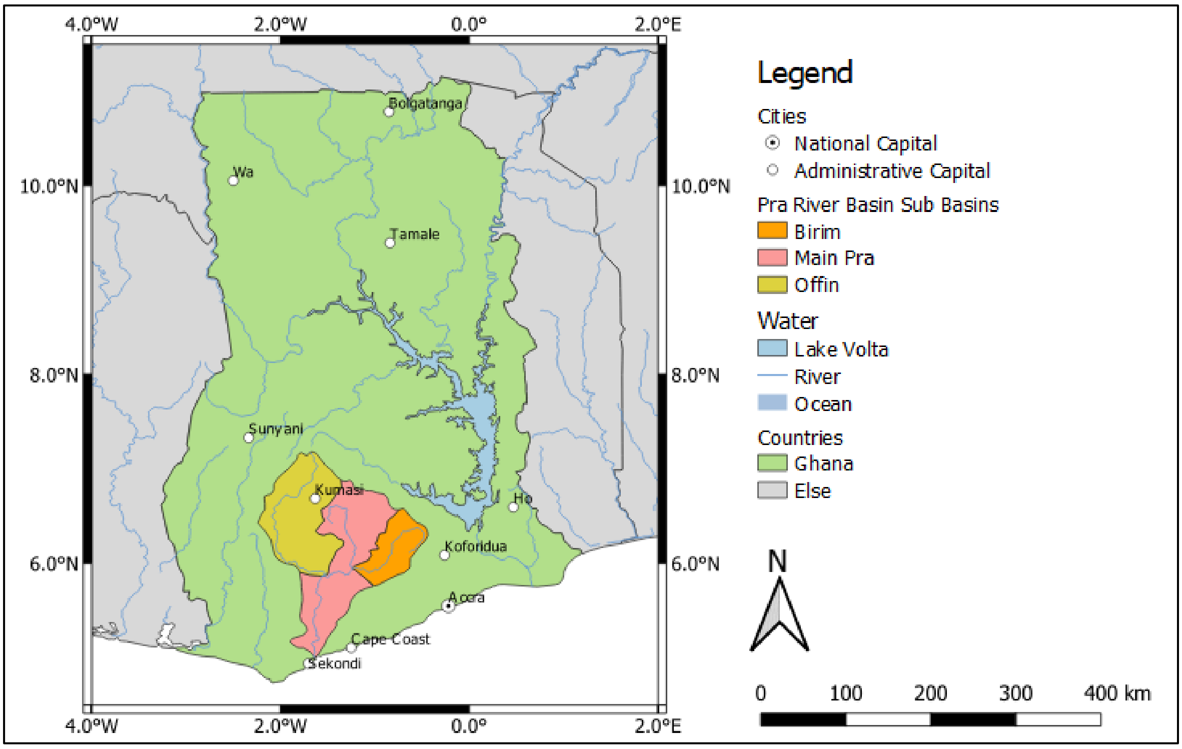


Figure 5. Pra River Basin

2.4.1 Preliminary Study: Groundwater Source and Distribution

In June of 2022, a team of surveyors affiliated with TU Delft and the African Water Corridor research groups conducted a large-scale survey in the greater Kumasi area to gain insight and understanding on domestic water use. A total of 496 households were interviewed and locations were selected from the grid system seen in appendix A.5. Questions about water source and motivations for using such sources were asked. The findings of this study provide a baseline set of information for this thesis.

2.4.1.1 Sources of domestic water consumption

There are nine sources of water for domestic purposes: private pipe, public pipe, private borehole, public borehole, wells, rainwater or sachet. See appendix A.5 for water source utilization distribution.

2.4.1.1.1 Piped Water

Piped water indicates that the water is distributed through the piped water network which is overseen by the Ghana Water Company Limited (GWCL). GWCL abstracts this water primarily through surface sources then treats it before distribution. Private piped water is delivered directly into homes. This source of water has two limitations to access. First, there is a fee associated with it that must be paid to GWCL. This limits access to those who can afford it. Secondly, the distribution network is not homogenous throughout the country (figure 9). Therefore, for individuals outside of the GWCL service area, alternative sources of water are necessary.

An alternative form of piped water is a **public tap**. This water is distributed in the same way through the GWCL. However, instead of direct access in homes, the pipe exists in a public area for consumers to collect by paying a fee.

2.4.1.1.2 Direct Groundwater Connection

The next source is a **borehole**. A borehole is a long stretch of pipe which is drilled into the earth to reach the aquifer. There are two types of pumping for a borehole to retrieve water from the aquifer: mechanized or manual. In a *mechanized* borehole, a pump is used abstract water from the aquifer to a storage tank (polytank), where it is stored until it is needed. In a *manual* borehole, there is a lever used which is manually lifted with a hand pump to retrieve water. These hand pumps are drilled in more shallow aquifers than mechanized options because the force required to manually procure water should be lower. Naturally, a mechanized borehole is more expensive than a manual borehole. As part of Government of Ghana's policy objectives to achieve the Millennium Development Goals (MDG), the government has embarked on water supply in rural communities by providing mostly, boreholes fitted with hand pumps (Maxwekk, Geophrey, & Abudu Kasei, 2012).

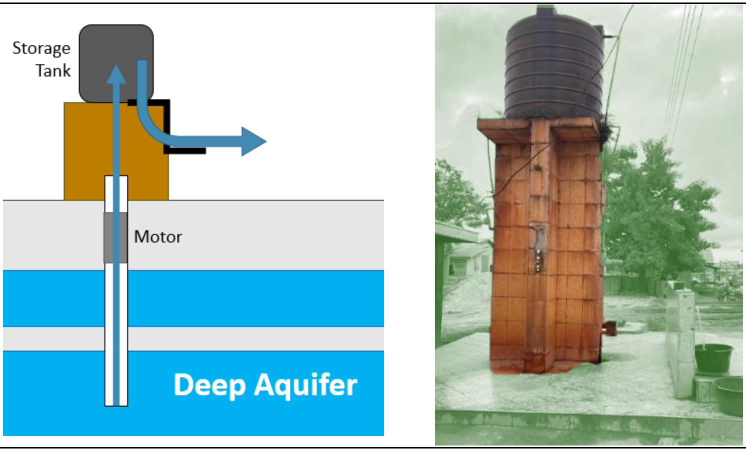


Figure 6. mechanized borehole

Simplified model of mechanized borehole which is drilled deeper in the aquifer, uses a motor to collect the water and a storage tank to store it.
**not to scale*
Photo credit: (Thorp, 2022)

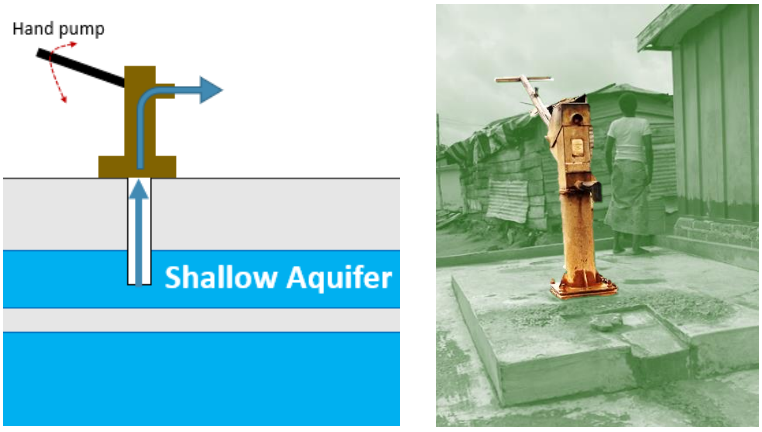


Figure 7. Manual Borehole

Simplified model of manual borehole, which is drilled shallow in the aquifer, uses a hand pump to collect the water and water is immediately collected.
**not to scale*
Photo credit: (Thorp, 2022)

Boreholes can be either public or private. A *public borehole* is created by the government by request of the community and placed in the hands of a caretaker. The caretaker collects payment from the consumer and then returns the payment to the assembly who oversees the borehole operation. When collecting water, individuals may bring large bowls, containers or other receptacles to store the water and bring it back to their homes. A *private borehole* is installed by a drilling company on the property of the owner. Before drilling, a qualified hydrogeologist must survey the area, conduct tests on the aquifer and report the information back to the WRC. The main limitation to private boreholes is the cost, as drilling is an expensive service. Domestic boreholes do not require a permit, but they must be registered, without a fee, by the Water Resource Commission, however, this is not commonly done for fear of incurring a cost (Oduro-Kwarteng, Monney, & Braimah, 2015). Conversely, commercial use boreholes require use permits from the WRC, which involves a fee (Water Resources Commission, 2022).

The next type of water source is a **well**. A well is a structure created by excavating to the aquifer via drilling or digging. Wells have a wide diameter sufficient for a water collection device such as a bucket or container. Similar, to boreholes, wells can be public or private. They can also be manual or mechanized. In a manual well, a rope is connected to the collection device and sent down to the water level, filled up and then returned to the surface through hoisting the rope manually, turning a rope coil or through a mechanized system with retrieves water with a motor. Often, wells are covered to prevent debris from entering or unauthorized individuals from utilizing the source.

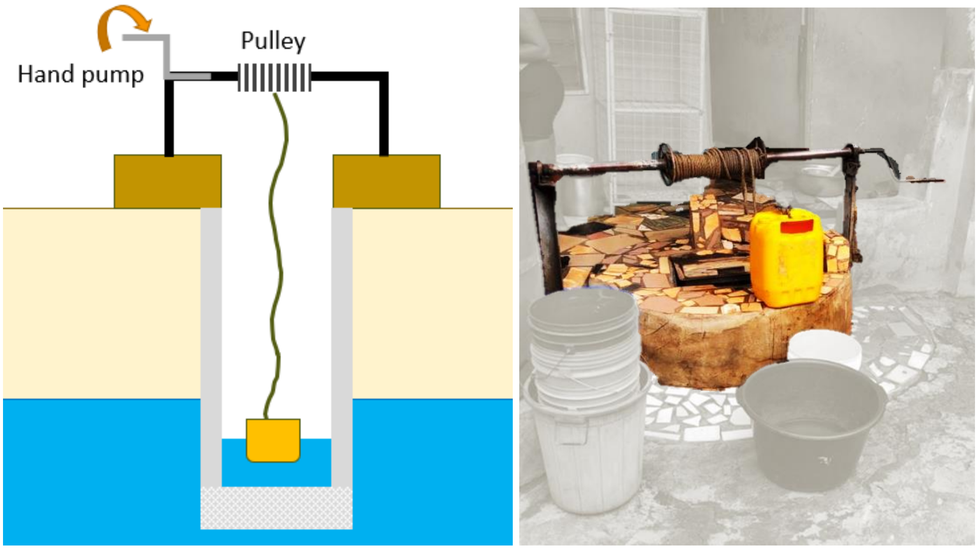


Figure 8. Well Diagram

2.4.1.1.3 Alternatives

A new and underutilized source of water, according to the study results is **rainwater**. Rainwater is harvested from roofs and deposited into a storage basin for later use.

Lastly, there is **sachet** water which is drinkable water that is distributed in small plastic bags. The tip of the bag can be torn off and water consumed directly in this way. Sachet producers utilize groundwater as their source before packaging it and shipping to consumers and distributors.

2.4.1.2 Trends and Takeaways

When analyzing the results of the survey spatially, it shows that the areas with highest groundwater use (boreholes and wells) are on the periphery of the Kumasi Metropolitan area. This is because the GWCL pipeline does not service these areas and thus groundwater is the only available source. As seen in the map below, the darker red squares indicate a greater use of groundwater, and the black lines show the GWCL piped network.

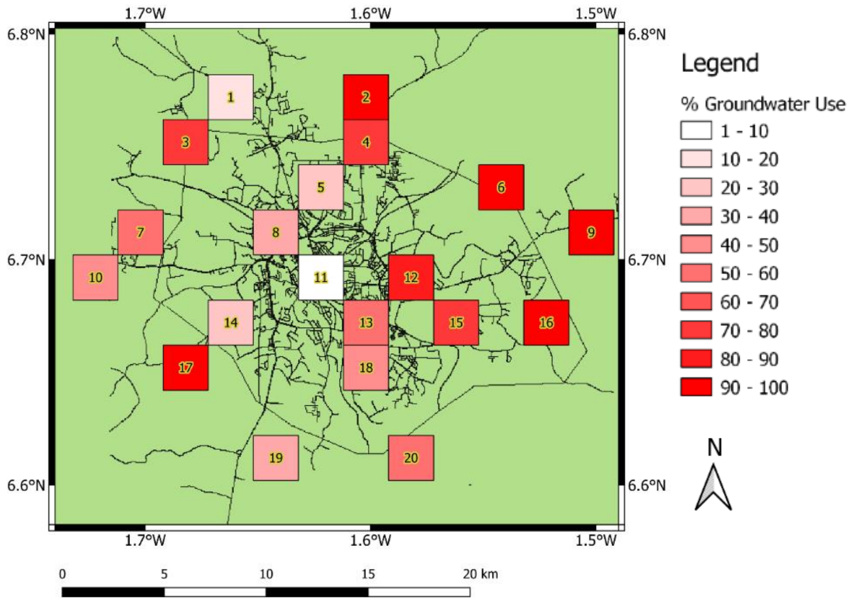


Figure 9. Map of study region with squares representing percent groundwater use

A trend was found by assessing water source utilization by monthly income level. At the time of the study, one US Dollar was about 7.5 Ghanian Cedis (GH₵) (Bank of Ghana, 2022). As seen in figure 10, as income increases, utilization of private boreholes increases from 0% to 40%. This supports the claim that income is a barrier to utilization of private boreholes because when people earn more money, they install a borehole. Inversely, as income increases, utilization of public boreholes decreases from about 60% to less than 20%. This decrease is likely due to the switch from public to private use. Sachet water use also increases as income increases from about 70% to 90%. Sachet water is about 50 pesewas (0.50 GH₵) for a 500mL single serving. This illustrates that when water access is limited, users must seek alternative sources.

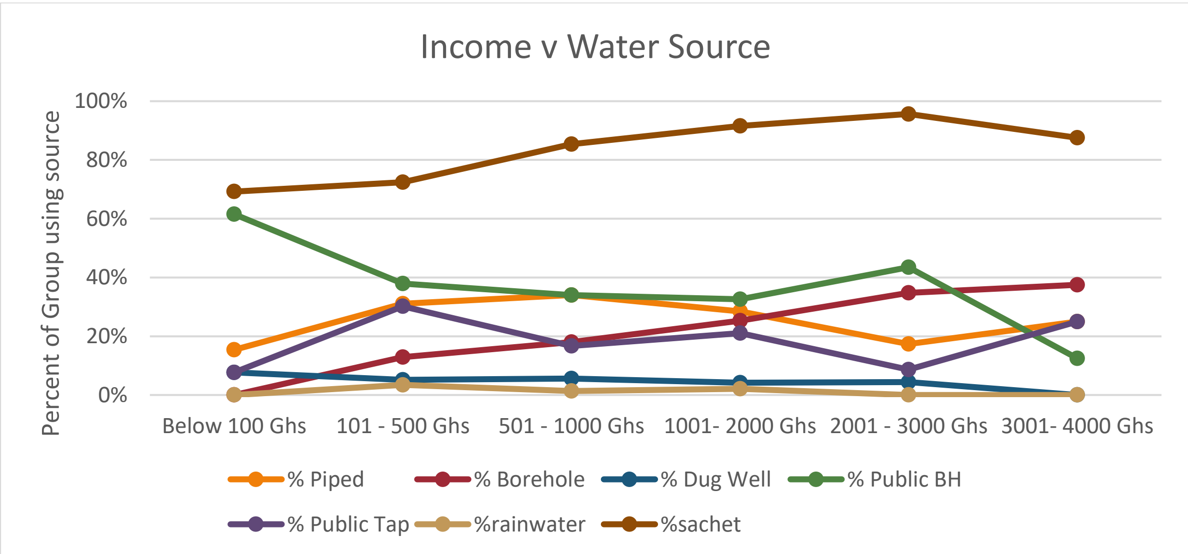


Figure 10. Household income v water source

Another key takeaway from the data is determination of groups which the households identify as responsible for groundwater. The most common responses were individuals, government and owners. The results show a lack of understanding of relevant government agencies in groundwater management.

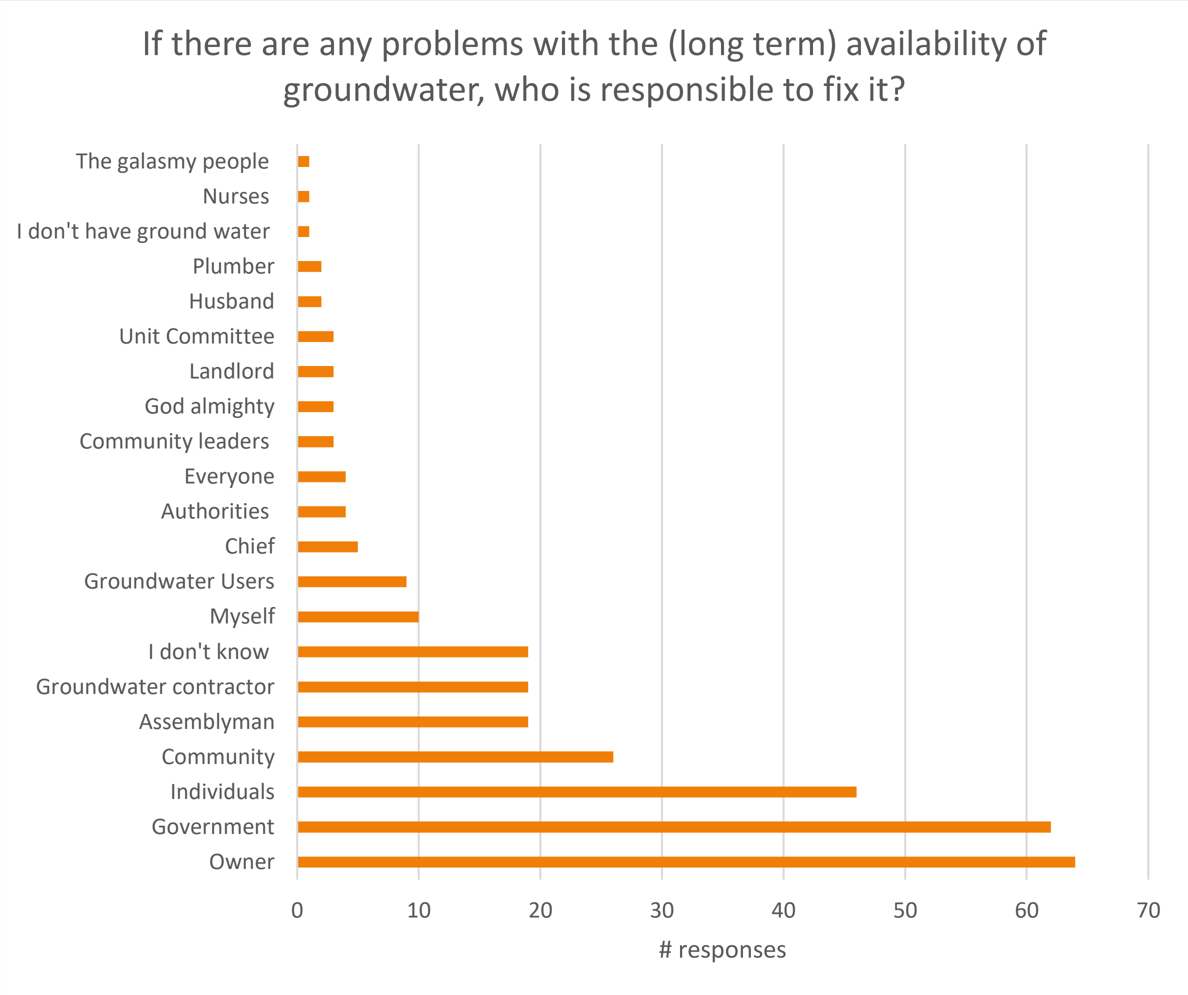


Figure 11. Domestic household responses for group responsible for groundwater availability

2.5 Groundwater Management Case Studies

Timely and cost-effective groundwater monitoring is a global challenge in countries of all economic backgrounds (Colchester, Marais, Thompson, Hope, & Clifton, 2017). This section reviews current groundwater models, case studies on groundwater management in African states, as well as a section on community water management practices. In this context, groundwater monitoring refers to measuring groundwater levels, abstraction, spring discharge or water quality (Kukuric & vav Vliet).

2.5.1 Global Information Systems

In order to assess existing groundwater monitoring in Ghana, African states and Africa as a whole, online databases were searched to collect a summary of available data on groundwater resources in the study region (SADC, 2020). The full search results can be found in appendix A.3. If a database was useful in understanding monitoring efforts in Ghana, it is further investigated in this section. The review of current data supports the claims in literature that there is limited information on groundwater in Africa (Adelana, 2009). It is evident by the review that a significant portion of the data handling and management has been led by international organizations from the United Kingdom, the Netherlands, Germany, Switzerland and others.

2.5.1.1 International Groundwater Resources Assessment Center (IGRAC)

IGRAC is an organization which promotes "international sharing of information and knowledge required for sustainable groundwater resources development and management worldwide" (UNESCO- IHE Delft, 2022). The organization is partnered with UNESCO, the World Meteorological Organization (WMO), and the government of the Netherlands. They offer multiple datasets, projects and information on worldwide groundwater. IGRAC powers the Global Groundwater Monitoring Network (GGWM). The GGWM is pictured below and shows the spatial distribution of its' data sets. The map highlights the density of information in North America, Europe and Australia. The data available in Africa is minimal and concentrated in southern Africa. There is no data for Ghana available on this platform.

Figure 12. GGMN data distribution (IGRAC, 2022)

2.5.1.2 British Geological Survey: Africa Groundwater Atlas

The British geological survey provides an online portal for access to a literature database and GIS (global information system) layers for Africa's groundwater resources. In the literature portal, there are 8710 articles in the archive and 327 with relevance to Ghana, but only 2 with reference to Kumasi in the title (BGS, 2022). The data provided comes in forms of hydrological and geological maps, datasets and supplemental information.

2.5.1.3 Water Point Data Exchange

The last database for groundwater information is through the Water Point Data Exchange (WPdx) which is operated by the Global Water Challenge, a coalition of organizations with expertise in the WASH (Water Sanitation and Hygiene) sector working to provide safe water to global communities. The database has over 406,566 records from 54 countries. Through downloading data from the webpage, the map below was created to indicate locations of boreholes throughout Ghana. This is the most significant data found on Ghana's groundwater resources from the review. The map shows the distribution of boreholes and the organization which deployed them. There were 1000 data points for all of Ghana. The information downloaded includes source of water, source of data, type of water access, affiliated technology, location, and installation year. In the scope of this project, it is helpful to see the distribution of water access points based on organization deployment. As visualized here, there is a severe data gap in the Ashanti region with only 3 data points in Kumasi. There is a high distribution of boreholes in the south predominantly installed by the Community Water and Sanitation Agency, while the remaining sources come from NGOs. The map visualizes challenges of the severe decentralization of water resource management as it is has "affected data collection and ultimately that which is usable for groundwater management" (Adelana, 2009).

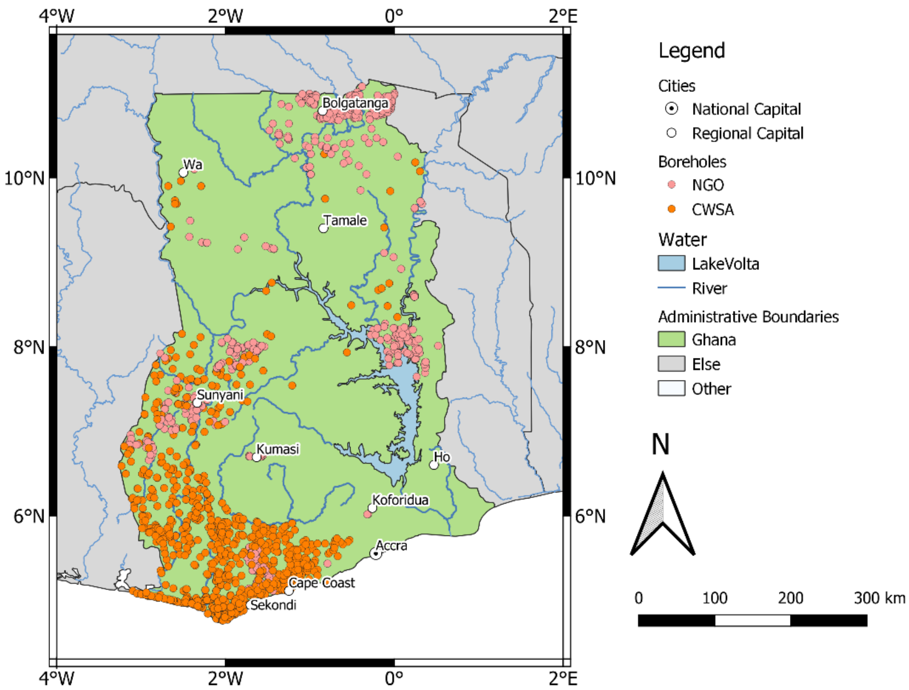


Figure 13. Borehole distribution per WDpx database (GWC, 2020)

2.5.1.4 GRACE Water Storage

An alternative method for groundwater monitoring is to use remote sensing. Remote sensing poses the benefit of not going physically to a site to conduct measurements; however, this type of monitoring requires data validation with in-situ wells. The German Research Center for Geosciences uses remote sensing through gravity information service, or GRAVIS, to measure groundwater storage (GFZ, 2022). The technology used behind this data is run by NASA's GRACE (Gravity Recovery and Climate Experiment) program which utilizes satellites to monitor large-scale groundwater changes. Although GRACE is an extremely powerful tool, it is limited in "simulating realistic groundwater variations in regions with intensive groundwater abstraction" (Li, et al., 2019). Groundwater storage is a function of the water level, the size of the aquifer and the porosity of the aquifer. Storage does not provide information on water level which is the parameter sought after in this study.

2.5.2 African Context

Groundwater management practices vary within the continent of Africa with differing results (Adelana, 2009). The table below shows an array of monitoring programs in Africa. Two programs were selected for further study. The first is South Africa which represents a high GDP nation in the south with a detailed monitoring program. The other is Nigeria which represents a GDP nation like that of Ghana in Sub Saharan Africa.

Table 4. Selected case studies for groundwater monitoring in African cities

Location	GDP/ capita USD[2]	Region	Water level data (well)	GW Information	Model approach
Addis Ababa, Ethiopia[1]	944	East	Fairly good but no database	Full survey data	-
Abidjan, Cote D'Ivoire[1]	2578.8	West	Shallow, not well documented	Useful summary document	Groundwater flows modelling to quantify the groundwater resources
Cape Town, South Africa[1]	6994.2	South	Fairly good record since 1967 but lots of gaps	Full survey data	Modelling groundwater behavior
Dakar, Senegal[1]	1606.5	West	Record since 1975 with missing gaps	Useful summary document	Investigate impact of withdrawal and seawater advancement**
Lagis, Nigeria[1]	2085	West	Shallow, no consistent data	Useful summary document	Numerical groundwater flow modelling
Lusaka, Zambia[1]	1120.6	South-Central	Shallow, fragmented data	General background only	-

[1] (Adelana, 2009); [2] GDP in USD for 2021 (World Bank, 2022)

2.5.2.1 Case Study: Republic of South Africa

The literature on water governance and specifically, water monitoring in Africa points to South Africa as the leading example. The South African National Water Act of 1998 stipulates that "groundwater abstraction and quality be monitored" (Adelana, 2009). Additionally, there are compulsory standards which dictate that all water service authorities have a program to monitor the quality of the water they supply.

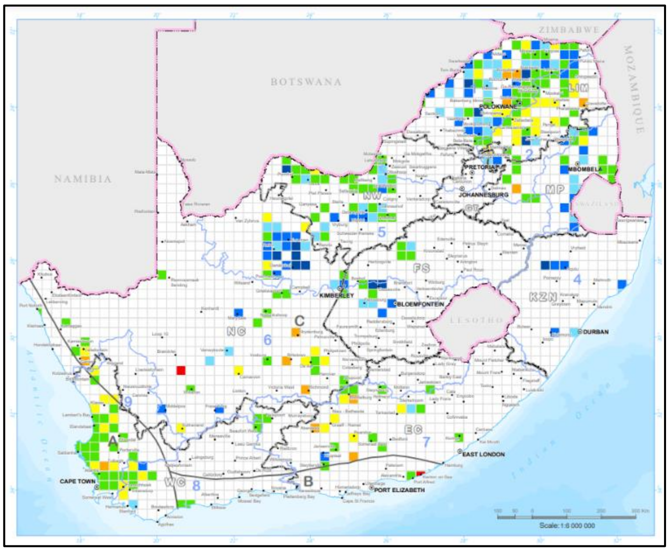


Figure 14. Groundwater data coverage in South Africa (DWS, 2021)

The Department of Water Affairs and Forestry (DWA) is the institution in charge of groundwater management and delegates monitoring tasks to the regional offices. The objective of the program is to identify spatial and temporal trends, to understand causes and effects of groundwater changes and to monitor for both quantity and quality. There are approximately 1800 monitoring points which are monitored monthly on a manual basis with water level dippers (IGRAC, 2020). The data is collected by a groundwater monitoring field committee. The DWA produces maps which are available to the public, while other more specific data is stored in the National Groundwater Archive. This is a centralized web database for those with an interest to register for data access (DWA, 2021).

As seen in table 4, South Africa's GDP per capita is far higher than that of the other nations with less formal groundwater management systems. Lower GDP countries lack the resources and/or capacity to follow suit (Adelana, 2009). In addition to groundwater monitoring, South Africa implements community managed systems under direct control of local governments (Obosi, 2020).

2.5.2.2 Case Study: Nigeria

Nigeria is located to the east of Ghana in Sub Saharan Africa. Here, the Federal Ministry of Water Resources formulates the National Water Resources policies and coordinates their implementation. This ministry delegates assessment of national water resources to the Nigeria Hydrological Services Agency (NIHSA) who monitors water resources quantity, quality, availability and distribution. NIHSA is responsible for groundwater monitoring in Nigeria with an established network of 43 monitoring points, 32 of which are equipped with data loggers which measure groundwater at least daily (IGRAC, 2020). The results of these data are stored at NIHSA headquarters in Abuja. These data can be access by request to the agency (NHSA, 2022).

2.5.3 Community Management and Participation

The concepts of community management and participation often arise in literature of groundwater management in Africa. Community management is a widely accepted technique in rural water supply systems in sub–Saharan Africa and has been rising in popularity since the 1980s (Obosi, 2020). These systems are characterized by the formation of a community water committee responsible for operating the system, setting and collecting water tariffs, and managing maintenance and repair activities (Harvey & Reed, 2006). Typically, there is some form of community-based organization (CBO) which brings people together to facilitate technical and financial resources to manage water resources (Obosi, 2020). A brief overview of community managed systems in sub-Saharan Africa is in appendix A.6.

One of the main criticisms on this style of management relates to the absence of a strategic approach to implementation. Failure rates of these systems range from 30-60% due to a series of factors including: limited demand, lack of acceptability, perceived lack of ownership, limited community education and limited community management structure (Harvey & Reed, 2006).

These factors come together in one idea: an oversimplification of water management in low-income countries. External organizations tend to create the CBO and hand off operations to the community and therefore abdicate responsibility for the outcome- hence a lack of strategic planning. There is also the idea of external foreign groups judging these nations with “simplistic cultural differences rather than judge them by our own standards and values” (Harvey & Reed, 2006). While there are appropriate moments for acceptance, understanding and application of cultural differences, this idea creates a double standard for GDP diverse countries: “rural water systems in high-income countries are not generally managed successfully by communities, so why should there be an automatic expectation that they can be in low-income countries?” (Harvey & Reed, 2006).

However, there is a difference between community management and community participation. While management focuses on statutory, formalized settings, participation is “designed to establish communities as effective decision-making entities” (Harvey & Reed, 2006).

2.5.3.1 Participatory Case Studies

A key component to successful participatory community models is institutional support from government and/or NGOs as evidenced by case studies in sub-Saharan Africa (see appendix A.6). A weakness of these systems is a lack of a long-term plan. Components contributing to long term deterioration include lack of or minimal: incentives for volunteers, replacement mechanism for participants, trust, contact with local government and resources to fix or replace mechanisms (Harvey & Reed, 2006). Similarly, short term participation was also noted as a weakness in citizen science applications where citizen participants became disengaged with the research process over time (Weng, 2015). Strategies to counteract long term disillusionment with participatory programs can be summarized in three categories: involvement through incentives and consultation, establishment of legal frameworks and training activities (Harvey & Reed, 2006).

Case studies in Africa found that regular check-ins by the overseeing organization are key to long term sustainability. In one area of Ghana, where a local NGO made quarterly visits to communities to provide this support, 86% of all rural water systems (44 surveyed) were functioning (Harvey & Reed, 2006). Similarly, districts in Zambia with strong district water and sanitation teams (consisting of government and NGO personnel), which met and monitored communities regularly, demonstrated significantly higher sustainability levels than those of districts with weaker institutional set-ups (Harvey & Reed, 2006).

Embedded in these strategies is collaboration between communities. This was highlighted in a case study in Turkey where the researchers found that the most effective applications of technical solutions in water management were done when the administrators and technical personnel were working in a strategically collaborative manner (Ekmekçi & Günay, 1997). This strategy is visualized in the adapted graphic below which indicates that solutions are most effective when administrators and technical personnel collaborate so that neither field dominates. In this project, they found that the technical side of the solution was not lacking, but rather public awareness was weak because “people generally tend to not regard an event as a problem unless they personally suffer seriously from it” (Ekmekçi & Günay, 1997). This indicates a need for public understanding of water resources concerns in order to implement an effective solution.

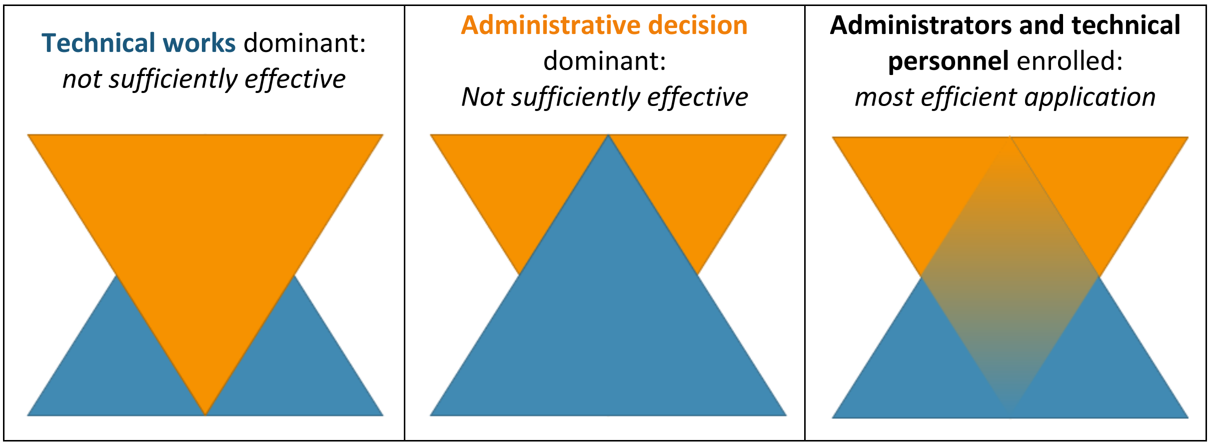


Figure 15. Technical and Administrative Integration

2.6 Summary

The context section of the report included content on Ghana's governance, water policy and current standing with water monitoring. Additionally, it covered case studies for groundwater management, monitoring and community participation in other countries. There are some key takeaways from this chapter which will be utilized for the design portion of the report as indicated below. The numbered cells in each summary section refer to design requirements utilized in the recommendation section of the report. They are not in chronological order, which is expanded on in chapter 8.

2.6.1 Ghana Water Governance

Since the 1990s, Ghana's water sector has been expanding with greater roles and capacity. The Ghana National Water Policy marks a framework of goals in Ghana's water sector which relate to technical expansion, human resource capacity, funding and application of integrated water resource management. One of these goals is to monitor groundwater nationally, however efforts to do this have been short lived. Based on the review of Ghana's water governance and groundwater monitoring systems, the table below was constructed to explicitly state design requirements to apply in the design component of this report.

13	The first takeaway is the importance of the principles of **integrated water resources management** including: fulfilling the subsidiary principle, enabling environment, institutional roles, and management instruments.
14	Next is the importance of Ghana's **monitoring in the northern region**. As the most developed groundwater monitoring system in the country, it is important to take note for how it was implemented in the past to create a more enduring system in the future.
15	Ghanian water policy aims to expand **technology for water management**. These goals are related to expanding data availability, strengthening water monitoring, supporting research projects and ensuring sustainable management.
16	Lastly, Ghanian water policy emphasizes **participation**. Participatory components include building capacity, promoting partnerships, ensuring public awareness, education, and interdisciplinary research

2.6.2 Case Studies

In addition to takeaways from Ghana water policy, there are also takeaways from case studies from other nations, primarily in Africa, in technology development and community organization.

17	In order for participants in a community water organization to remain involved, there needs to be **incentivizes for participants**.
18	There is a need to **retain participants and engage new members** over time.
19	Similar to the point above, there needs to be a **training scheme for new members** which is an organized method followed routinely for new members.
20	The case study in Zambia showed the need to **include local government** in community-based projects.
21	The case study in Ghana showed the need to **have regular meetings with the stakeholder groups involved in the project** to discuss progress and challenges.
22	South Africa has a highly developed groundwater monitoring system with data available to the public- data should be publicly **available by request**.
23	Lastly, the case study in Turkey identified the need to integrate fields in water management by ensuring that the **technical and administrative sides do not overpower the other**.

Chapter 3 Theoretical Framework

3.1 Motivation

Front Material			Body Research Questions			Conclusions	
Context	**Theory**	Methods	RQ1	RQ2	RQ3	RQ4	Conclusion

This chapter will establish the theoretical lens of the study. The section is organized first through establishing value sensitive design as the frame which to answer the research questions. This will then be supported by theories and models in the scope of values, identity, and multi-stakeholder engagement. Finally, a holistic theoretical framework is presented.

Objectives	
	Define value sensitive design and the values approach to the study
	Explain identity theories in relation to value sensitive design
	Describe multistakeholder engagement theories in relation to value sensitive design
	Synthesize a holistic theoretical framework implementing each of the three components

3.2 Overview

The two key problems in the research project are a lack of groundwater data and lack of coordination among groundwater stakeholders in Kumasi. To address these problems, value sensitive design (VSD) is the focal point for the theoretical framework. Value sensitive design embodies three areas which are relevant to the problem statements: values, identity and multistakeholder engagement.

The figure below shows the sequence in which the theories are explained in this section of the report. The framework begins with *value sensitive design* 1 as the center of the study. Here, an overview of value sensitive design and the motive for its application is explained.

The analysis of **values** is necessary to support the application of value sensitive design. The models in this section elaborate on how values can be translated to design requirements which is key for answering all research questions. The *Values Hierarchy* 2 and *Model of Reasoning* 3 are applied to formulate a clear method to operationalize VSD. At the transition point is the *Levels of Mental Programming* 4 which shows how values are related to identity.

The first two research questions are focused on both individual role and identity within a group. Therefore, the **identity** portion of the framework identifies the individual acting as a member of a larger group with theories that support both the group and individual level. Specifically, *social cognitive theory* 5 and *social identity theory* 6 are applied. At the transition between identity and multistakeholder engagement is *communities of practice* 7 which demonstrates identities of groups and their interactions.

The last group of values is for **multistakeholder engagement**. The importance of this is evident in the case context material and is applied throughout the research questions. Here, *collaboration models* 8 are applied to identify types of collaboration. Lastly, *cocreation* 9 is implemented at the intersection of multistakeholder engagement and values because cocreation focuses on integrating values of stakeholders into design.

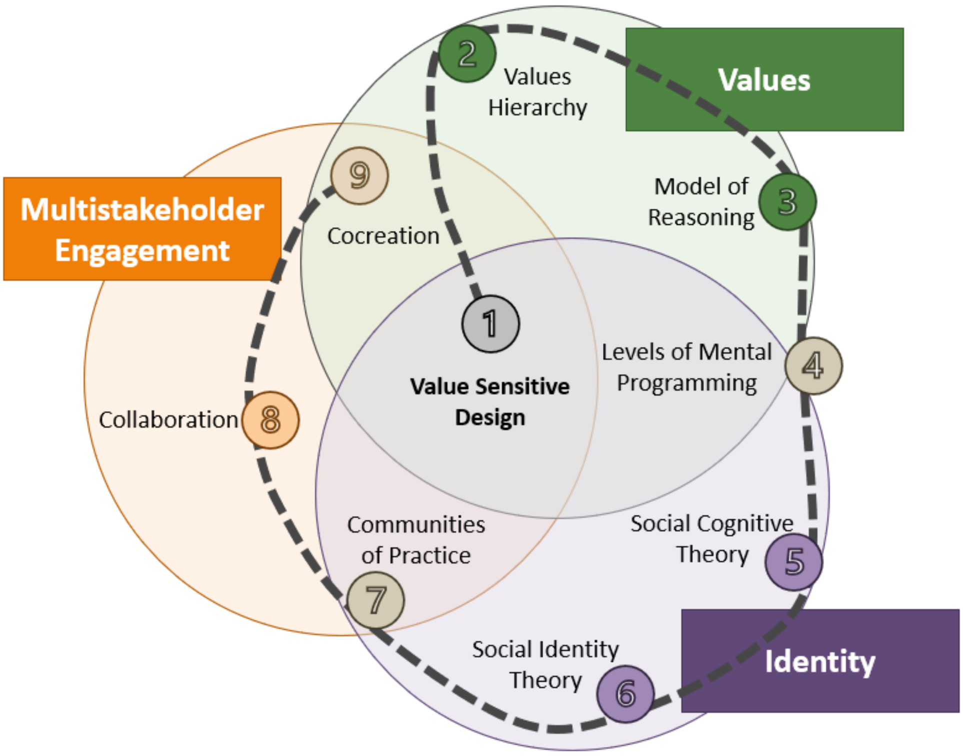


Figure 16. Theoretical Framework Map

3.3 Values Approach to Design

Understanding the values of stakeholders can aid in the design for a product or service. This understanding will be accomplished through a *value sensitive design* protocol and supported with the *model of reasoning* and *values hierarchy*. Associating values with groups will be explained in the *levels of mental programming* section.

3.3.1 Value Sensitive Design

There are many interpretations and definitions for value. The Oxford English dictionary defines value as “the principles or standards of a person or society; the personal or societal judgement of what is valuable and important in life” (Oxford Languages, 2022). Friedman, one of the pioneers of value sensitive design, describes value to mean “what a person or group of people consider important in life” (Friedman, Kahn, & Borning, Value Sensitive Design and Information Systems, 2006). In this way, values depend on the likeness of individuals within a culture.

The basis of value sensitive design (VSD) involves integrating moral values in a “principled and comprehensive manner throughout the design process” (Friedman, Peter H., & Borning, 2001). Value sensitive design seeks to be proactive in order to influence the design process as Friedman notes “people and social systems affect technological development, and new technologies shape (but do not rigidly determine) individual behavior and social systems” (Friedman, Peter H., & Borning, 2001). This is to say that the way people act is shaped by technologies they use- people are limited in the way they act in the digital space by the capabilities of the digital technology. However, people are also able to shape the capabilities of technology and thus be proactive about the way they might act with it.

There are three iterative components of value sensitive design methodology: conceptual, empirical and technical (Friedman, Kahn, & Borning, 2006). *Conceptual investigation* is the analysis of constructs in the case such as affected stakeholders and values involved. This is used to formulate relevant values and tradeoffs. *Empirical investigation* places the value(s) in the context of the case and seeks to understand stakeholders and their values. The last is *technical investigation* which is the embodiment of values in a technology. Although these three components are essential for value sensitive design, there is no one method for application of the concept. The operationalization of VSD depends on the goals of the case and the context in which it is occurring.

3.3.1.1 Values in Water Management

Designing with values is beneficial in the water sector. As water is a fundamental resource for all parts of life, integrating values into the design process is appropriate. In water engineering and management, there are four key interests and values: functional, transboundary, social, and sociopolitical (Ravesteijn & Kroesen, 2015). Functional interests relate to multipurpose character of water systems. Transboundary items relate to divisions in territory. Social components involved conditions under which water systems operate. Lastly, sociopolitical values involve how the government is involved. Ravesteijn and Kroesen recommend an eight-step protocol for designing for values in integrated water resource management as outlined in the table below (Ravesteijn & Kroesen, 2015).

Table 5. IWRM approach to value sensitive design (Ravesteijn & Kroesen, 2015)

#	Step	Description
1	Identify problem and goals	Determining problem statements and goals for the case study
2	Stakeholder analysis	Map relevant parties and associated values
3	Conceptual analysis	Analyze the diversity of perspectives
4	List of solutions	Based on 1-3, create a list of solutions
5	Integrated impact assessment	Impact assessment for moral and technical alternatives considering basic perceptions, values, and perspectives of the stakeholders
6	Impact assessment	Repeat step 5 for implementation strategies
7	Select solution	In consultation with stakeholders
8	Implement	In cooperation with stakeholders

3.3.1.2 Motivation for VSD application

Traditionally, technology is developed with values implicit, with designers creating systems which have values embedded in the product, but values are not explicitly stated at the beginning of the design process. VSD places values at the forefront of the deign process by explicitly stating them and designing to achieve them. Given complex challenges in the water sector and water's relation with people, the environment and economy, value sensitive design provides an opportunity to embody these advanced challenges through designing with values in mind. This procedure can allow for actors to deal "with divergent values through negotiation and dialogue about value priorities, institutional design, and social experimentation in order to find the right way forward" (Ravesteijn & Kroesen, 2015).

The goal of the project is to allow a diverse arrangement of perspectives to participate in the shaping of a groundwater management strategy. VSD provides a pathway to integrate various perspectives in the design process by utilizing a common language: values. Human values are something that can be universally spoken about by diverse stakeholder groups because it does not require specialized expertise but focuses on the way things should be. As such is the motivation for applying value sensitive design in this case study: VSD will allow for diverse stakeholder perspectives to be taken into account in the design of a system which could potentially influence stakeholder interactions with water. VSD promotes the idea that technology should not influence human behavior, but humans can influence technology to be proactive about the liberties the technology will provide them. With a resource as valuable as water, this proactive attitude is essential in technology development.

3.3.2 Model of Reasoning by Designers

Roozenburg and Eekels describe a model which has potential to operationalize value sensitive design from values of the target group to design requirements (Roozenburg & Eekels, 1998). The model of reasoning (below) links values (which the users experience) to the product (which the designer creates). Furthermore, it illustrates that values, needs, functions, priorities and form are all related. *Form* describes the way an item is presented and includes factors like color, material, texture, size and decoration. *Properties* follow from the form and describe the "expected behavior of a product under certain circumstances" (van Boeijen & Zijlstrsa, 2020). Examples of properties include weight, strength, and comfort. *Functions* describe what users can do with it and depends on the context for which the item is being used. The use of an item in one environment might have different connotations and implications in another. *Needs* are derived from the target consumer group. What do the users need for the item to accomplish? Finally, *values* are derived from how people perceive the product's added value and is influenced from cultural context of morality and a basic understanding of contextual right and wrongs (van Boeijen & Zijlstrsa, 2020).

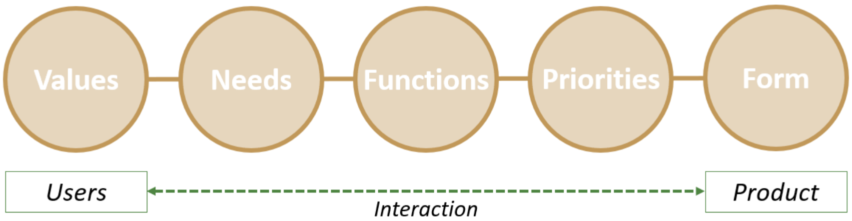


Figure 17. Model of Reasoning by Designers

3.3.3 Values Hierarchy

Another model which operationalizes the idea of value sensitive design and the relationship between values and product is van de Poel's Values Hierarchy (van de Poel, Translating Values into Design Requirements, 2013). The pyramid hierarchy structure has a base of *design requirements*, a mid-section for *norms* and places *values* at the top layer. For this model, van de Poel subscribes to Moore's definition of value which is intrinsic, and states that "a kind of value is 'intrinsic' means merely that the question whether a thing possess it, and in what degree it possesses it, depends solely on the intrinsic nature of the thing in question" (Moore, 1992).

The *conceptualization* of values clarifies the meaning and applicability of a value. The middle layer are norms which are "all kinds of prescriptions for, and restrictions on, action" (van de Poel, 2013). Norms are composed of objectives, goals and constraints which are generally references to an end to be achieved such as a state or affairs, capability or activity. The base of the pyramid are design requirements.

The pyramid can be used for *specification*- or relating higher elements (values) to lower elements (design requirements). There is asymmetry in the model because design requirements are implemented for the sake of values and/or norms but not the other way around. This is because values and norms are far more general and can be applied to design requirements.

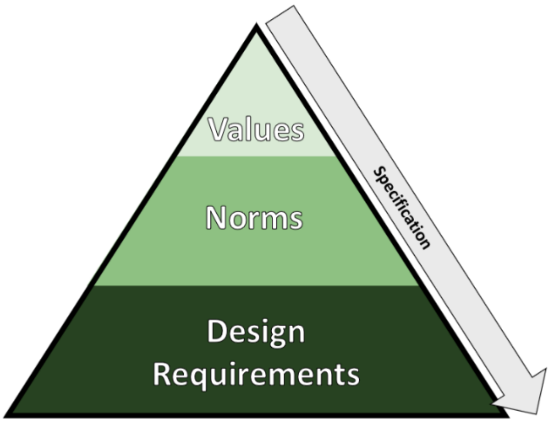


Figure 18.Values Hierarchy

3.3.4 Three Levels of Mental Programming

Values can be specific to various levels of identity: personal, cultural or universal (van Boeijen & Zijlstrsa, 2020). With each of these levels, values are acquired either through learning or through inheriting. For example, at the human nature, or universal level, values are inherited because humans assimilate from childhood to recognize core values. Hofstede likens this to the human ability to "feel fear, anger, love joy, sadness and shame" (Hofstede, Hofstede, & Minkov, 2010). Whereas cultural values are group oriented and learned from membership to different communities. In this context, culture is defined as "the collective programming of the mind that distinguishes the members of one group or category of people from others" (Hofstede, Hofstede, & Minkov, 2010). In this sense, culture is learned and not innate. The top of the pyramid is the personality or individual level. Here, traits are partly inherited and learned. The learning comes as influence from cultural input (the previous level) as well as a combination of unique personal experiences. In this way, the individual is unique from the group, but is heavily influenced by it.

Hofstede continues by explaining that values are the "core of culture" and acquired early on in life where humans absorb necessary information from their environment (van Boeijen & Zijlstrsa, 2020). Hofstede defines values as "broad tendencies to prefer certain states of affairs over others" (van Boeijen & Zijlstrsa, 2020). Values manifest in practices; however the meaning of such practices are only known to in-group members and may be interpreted incorrectly by outsiders. Specifically, values are represented visibly in institutions such as rules and laws. When designing a product, typically the center of the pyramid is focused on as a group can be targeted for the placement of a product (van Boeijen & Zijlstrsa, 2020).

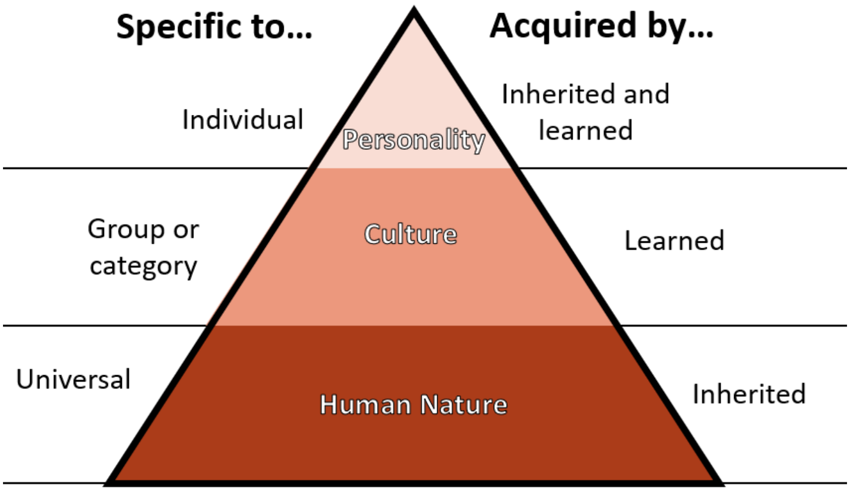


Figure 19. Levels of mental programming (Hofstede, Hofstede, & Minkov, 2010)

3.4 Identity

Following the values approach, the next category of the theoretical framework is identity. This is utilized because the study assesses stakeholder groups and establishing an understanding of both group identity and identity of individuals within a group is relevant in the understanding of stakeholder involvement. *Social cognitive theory* is used to show how external factors can influence behavior and *social identity theory* is used to show a group identity can cause individuals to embody group values.

3.4.1 Social Cognitive Theory

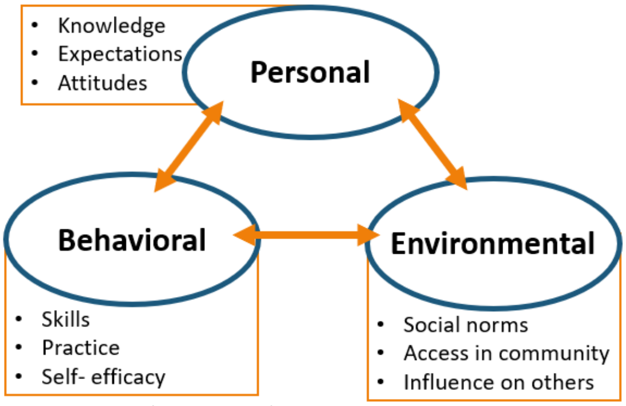


Figure 20. Social Cognitive Theory

Social cognitive theory was first published by Bandura in 1986 and establishes a connection for learning which occurs in an interaction between the person, environment and behavior (Bandura, 1986). In this way, there is a balance between external (environment) and internal (personal) characteristics to acquire, or learn, behavior. The personal, or sometimes referred to as cognitive, level refers to knowledge, expectations and attitudes an individual may have. The environment is the setting in which the individual is placed and includes components like social norms, access to others, and influence on others. Lastly, the behavioral group encompasses the skills, practice and self-efficacy demonstrated by an individual. This study is related to group identity and this theory is related to people's behavior within an environment. A person's environment and the social norms they are accustomed to will influence the behaviors made. In this case, an environment can include other individuals or a group.

3.4.2 Social Identity Theory

Another theory rooted in identity and external influences on the self is social identity theory. Social identity theory was first introduced to describe the phenomenon that a person's sense of self is based on membership to a group (Tajfel & Turner, 2004). These groups can be social class, familial, sport team, discipline, or many others (social categorization). The theory goes on to say that the group with which people associate themselves provides an important source of pride and a sense of belonging. Social identity theory has significant influence on support or opposition for environmental issues as support can hinge on the group with which the individual identifies (Fielding & Hornsey, 2016). Once a group affiliation is determined, members tend to assimilate norms to the group in a way that many beliefs and ideas become homogenized within the group (social identification).

An important distinction to make is that social identity theory relates to intergroup relations- that is to say the relation occurring between two or more groups. While oppositely, self-categorization theory demonstrates the intragroup relation- meaning the relation within the singular group itself (Hornsey, 2008). Both theories share the same assumptions and meta-theoretical propositions. Combined, the theories illustrate that the self is composed of both a personal identity and a social identity which relates to groups in which individuals belong.

Individuals can have multiple identities for various groups for which they belong. While it is possible for an individual to be a part of various groups, membership into one group may prohibit membership to another. For example, being a member of one political party prohibits an individual from being a member of another opposing party. Therefore, the positions of one group may contradict the positions of another.

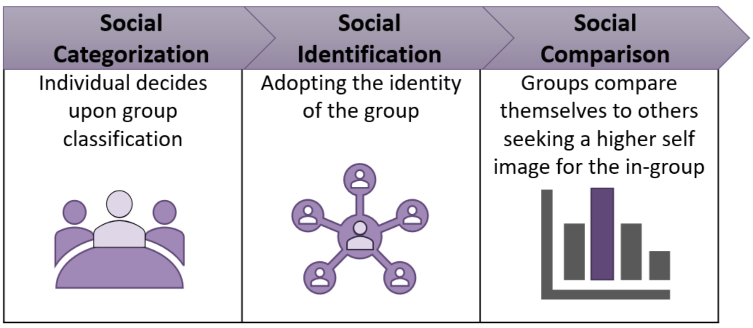


Figure 21. Social Identity Theory

3.5 Multistakeholder Engagement

The final category is for multistakeholder engagement. First, *communities of practice* are described to introduce the idea of communities exhibiting varying disciplines associated with their group identity. Next, *cocreation* is described to establish an applied method of communities of practice collaborating to create a product. Lastly, *collaboration* by means of transdisciplinarity is described to elaborate on how these communities of practice can work together.

3.5.1 Communities of Practice

Application of information to practice is a complex process as it involves both explicit and implicit knowledge sharing by individuals and groups from varying backgrounds. A challenge with science collaboration is that there is a lack of formal structure for expectations to be established among participating groups (Kalmár & Stenfert, 2020). Wenger introduced the idea of communities of practice in 1991 to describe "groups of people who share a concern or passion for something they do and learn how to do it better as they interact regularly" (Wenger-Trayner & Wenger-Trayner, 2015). The three characteristics of a community of practice are the domain, the community and the practice. The *domain* specifies the area of interest in which all members share. The *community* relates to the relationship which the members have and how they engage to share information. Lastly, the *practice* is the shared repertoire of resources which may include experiences or tools. The concept of a community of practice can apply to organizations, governments, education, the social sector, and other kinds of groups.

The formation of communities of practice in the scientific community contributes to quantity and quality of knowledge production (Mauser, et al., 2013). However, segmented groups with clear and hard boundaries between them can be a challenge as differences in perspectives can lead to conflicts in projects between partners. This conflict is evidence of why it is important to have communications for a shared understanding.

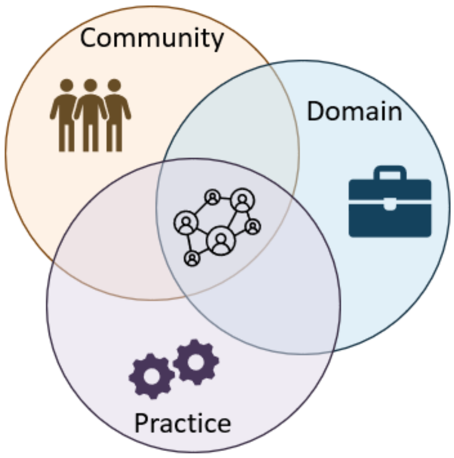


Figure 22.a Communities of Practice Components

3.5.2 Collaboration Types

When working with multiple communities of practice, there can be different types of collaboration depending on the needs of the project and background of the collaborators. Integrated water resource management calls for multidisciplinary and participatory approaches, while new literature points to transdisciplinarity as a goal for integration of nonacademic and academic actors in research (Mauser, et al., 2013).

The classification of collaboration depends on the level of integration and the types of collaborators involved as visualized in figure 23. The x axis represents the degree of integration between communities and the y axis represents types of stakeholders involved. The model shows that transdisciplinary collaboration involves both high integration and diverse actor involvement. Low integration indicates groups working in parallel towards a common goal as opposed to integrated work efforts.

Because transdisciplinary teams involve non-traditional stakeholders from other sectors of society in the collaboration, there is a greater potential to solve "complex or wicked problems" due to participants having a greater deal of understanding of the problem and a diverse set of perspectives

(Kalmár & Stenfert, 2020). While integration of knowledge is key, it is also valuable to clarify the differences between knowledge from various sectors. Transdisciplinarity is a reflexive principle which aims “at the solution or transition of societal problems. . .by differentiating and integrating knowledge from various scientific and societal bodies of knowledge” (Mauser, et al., 2013).

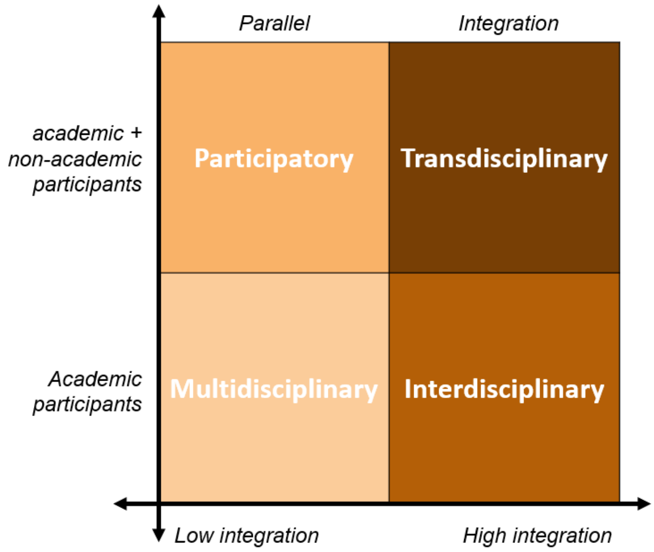
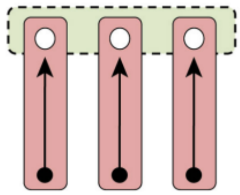
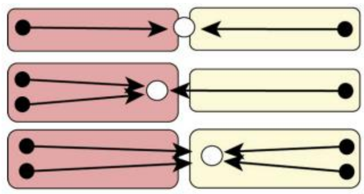
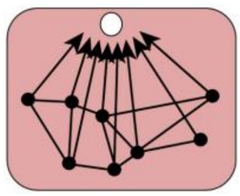
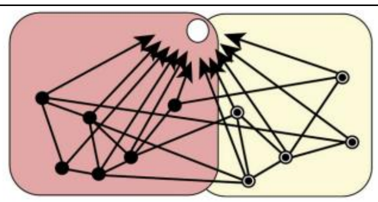
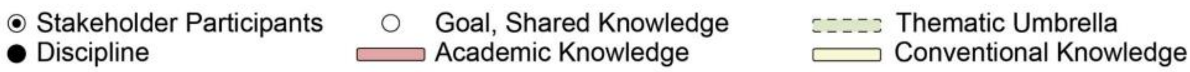


Figure 23. Degrees of involvement (Tress, Tress, & Fry, 2004)

Table 6. Collaboration classifications (Tress, Tress, & Fry, 2004) and (Morton, Martin, & Eigenbrode, 2015)

Name	Classified by…	Icon
Multidisciplinary	Multiple disciplines working independently (parallel) under one thematic area.	
Participatory	Academic and nonacademic participants exchanging knowledge without integration	
Interdisciplinary	Crossing disciplinary boundaries (integration) with common goal setting. Integrated knowledge	
Transdisciplinary	Crossing disciplinary boundaries, common goal setting, involvement of various partners and development of integrated knowledge.	



3.5.3 Cocreation

To bring the framework full circle, at the intersection of multistakeholder engagement and values is cocreation which "changes the perspective of organization-based production processes to (value) 'chain-based' production processes" (Kruger, Gusmao, Braga França, & Gonçalves Quelhas, 2018). Cocreation first emerged as a way for businesses to create mutual value for the company and its consumers by involving the consumers in the development of a product (Galvagno & Dalli, 2014). Cocreation is a process where there is "joint, collaborative, concurrent, peer-like production of new value, both materially and symbolically" (Galvagno & Dalli, 2014). Cocreation occurs either sponsored or autonomously. *Sponsored cocreation* is a cocreating activity which is conducted by consumer communities on behalf of an organization, while *autonomous cocreation* occurs with consumers voluntarily (Zwass, 2010).

In the work of sustainable development, there is a need for integrated thinking and action for collaboration which can be addressed through cocreation. The Delft Global Initiative defines their application of cocreation as "close cooperation between TU Delft scientists and local partners in Sub Saharan Africa and Southeast Asia (local universities, companies, governments, NGOs, startups) to jointly find concrete solutions to global societal challenges" (TU Delft, 2019). Cocreation is an iterative process which can be used as a strategy to achieve sustainable development by integrating social equity, environmental sustainability and economic efficiency while considering multiple stakeholders (Kruger, Gusmao, Braga França, & Gonçalves Quelhas, 2018).

Cocreation is not a method, but rather a concept for creating new solutions (Radulescu, Leedertse, & Arts, 2020). However, models have been created to operationalize ideas behind cocreation. The figure below illustrates the Kruger model for value cocreation towards sustainability. This thesis will focus on the preparation, significance and solution components. The preparation phase is when a problem or opportunity is identified, which is similar to the inspiration phase of design thinking. The significance phase focuses on providing information impacting stakeholders. In the solution phase, the product is a plan to respond to the problem identified in the preparation phase.

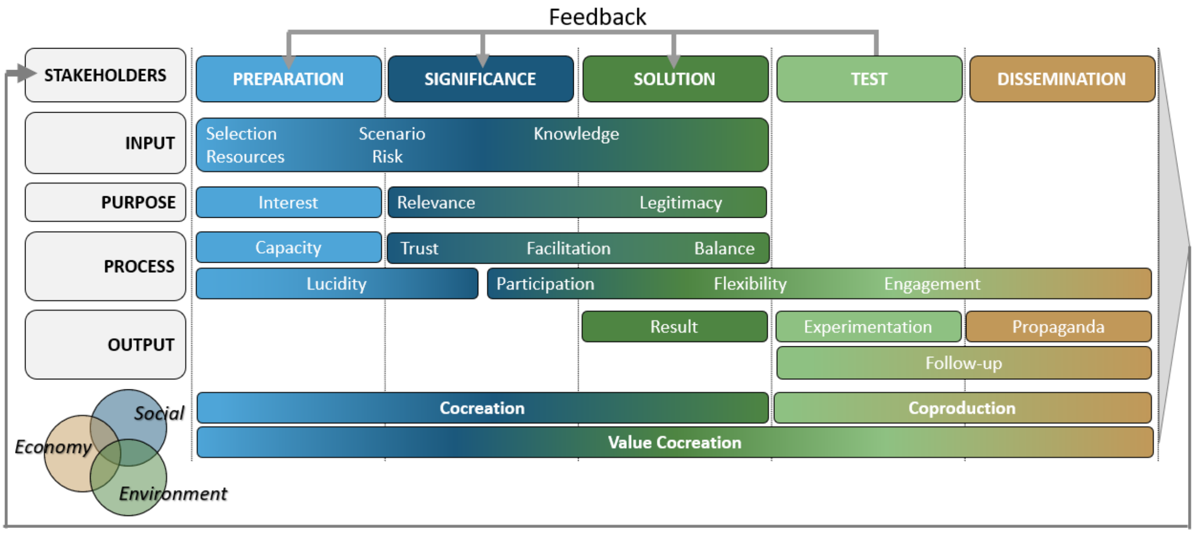


Figure 24. Kruger Model of cocreation (Kruger, Gusmao, Braga França, & Gonçalves Quelhas, 2018)

3.6 Framework

The theoretical framework for this study utilized **value sensitive design** as the focal point. As represented in the figure below, each theory and model applied is related to value sensitive design because of its focus on values, identity and/or multistakeholder engagement. Value sensitive design was applied at the center because it fulfills the needs of the project by identifying a method to integrate perspectives of diverse stakeholder groups to design a technology that suits the values of the users interacting with it.

The theories classified under **values** provide a connection between values, design requirements and specifically link values to the group level of analysis. This contributes to operationalization of value sensitive design. In the **identity** category, identity models, and contributors to individual and group identity are established. In connection with value theories, individual, group and universal identities are differentiated which contributes to stakeholder analysis through the identity lens. Lastly, the **multistakeholder engagement** group provides examples and models for how various stakeholders can collaborate for a common goal.

On a comprehensive level, the theories, cumulatively, provide a method for determining design requirements and stakeholder goals for the case study of groundwater monitoring in Kumasi. Starting with the individual identity, *social cognitive theory* ❺ demonstrates how environment and cognition influence behavior and thus behavior can be learned. Contributing to this is *social identity theory* ❻ that demonstrates once an identity is assumed, individuals may consume the traits of the group. This is relevant to *communities of practice* ❼ because communities of practice operate as a group. Communities work with different degrees of integration between them with the highest level of integration at the *transdisciplinary* ❽ level. Finally*, cocreation* ❾ models support the idea of limited boundaries between communities of practice and a transdisciplinary working style to create value for and with consumers at all levels. This then circles back to *value sensitive design* ❶ because, as indicated on the *levels of mental programming* ❹, values are group specific and can be learned- as is supported by social cognitive and social identity theories. This provides the legitimacy for studying value profiles at the group level. The *values hierarchy* ❷ and the *model of reasoning* ❸ provide models for determining design requirements from values as will be expanded upon in the methods section.

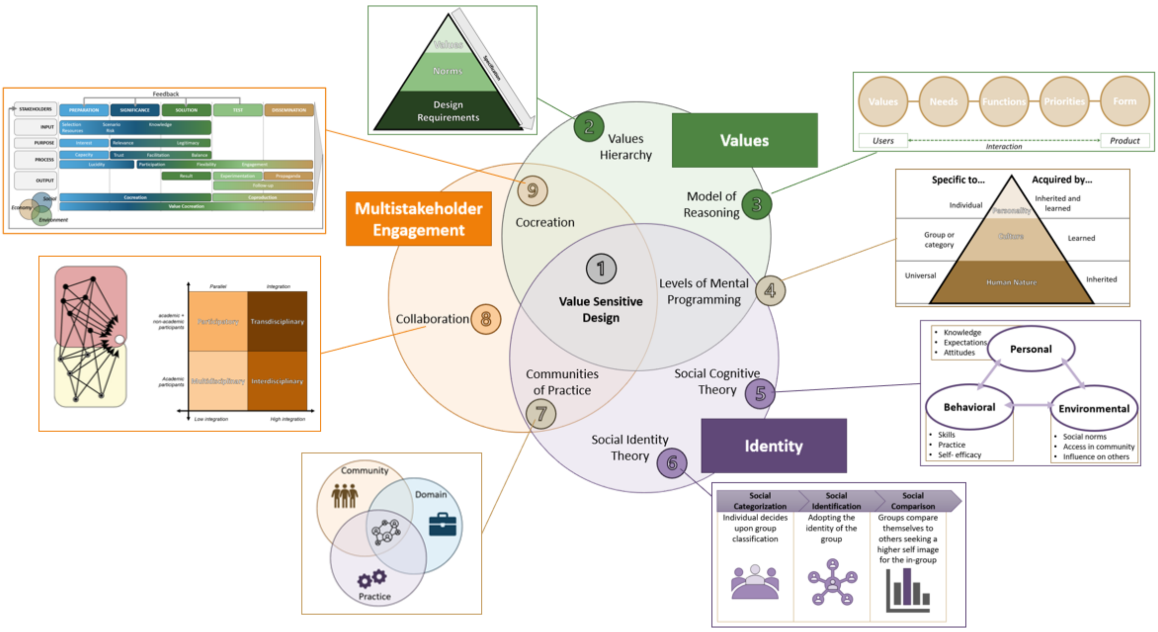


Figure 25. Theoretical Framework with models

Chapter 4 Methods

4.1 Introduction

The methods for answering the research questions are based on the context of the case study (chapter 2) and the theoretical framework (chapter 3). First, the theoretical backbone for the comprehensive report is explained based on the framework from the previous chapter. Next, development of the value sensitive design strategy is illustrated in relation to theoretical models. Then the interview protocol and sampling method are explained. Lastly, supplemental methods for the remaining research questions are defined. The table below shows a summary of the methods used to answer each research question.

Table 7. Methods Overview

Research Question	Methods	Output(s)
RQ 1: Identifying stakeholders	• Literature review • Semi- structured interview	• List of key stakeholders and their relevance to groundwater management
RQ 2: Practical considerations	• Semi- structured interview	• Practical management systems • Design requirements and challenges
RQ 3: Stakeholder value profiles	• Semi- structured interview • Values Activity	• Value profiles per stakeholder group • Interpretations of values
RQ 4: Recommendations	• Semi- structured interview • Ghana policy review • Case studies • Theoretical framework	• List of design requirements • List of recommendations

Objectives
Operationalize value sensitive design into an activity with quantified outcomes
Create semi-structured interview protocol based on theory and project goals
Develop protocol for coding interview transcripts and analyzing data
Specify procedure for literature and policy review

4.2 From Theory to Method: Overview

Several of the theories and models from the theoretical framework propose procedures for a cohesive, participatory and values-centric design process. The methods for this thesis will utilize three complementary models: the Kruger model of cocreation (Kruger, Gusmao, Braga França, & Gonçalves Quelhas, 2018), integrated water resource management design (Ravesteijn & Kroesen, 2015), and value sensitive design (Friedman, Peter H., & Borning, 2001). The figure below shows how the three models relate to each other and how this report structure has integrated the approaches.

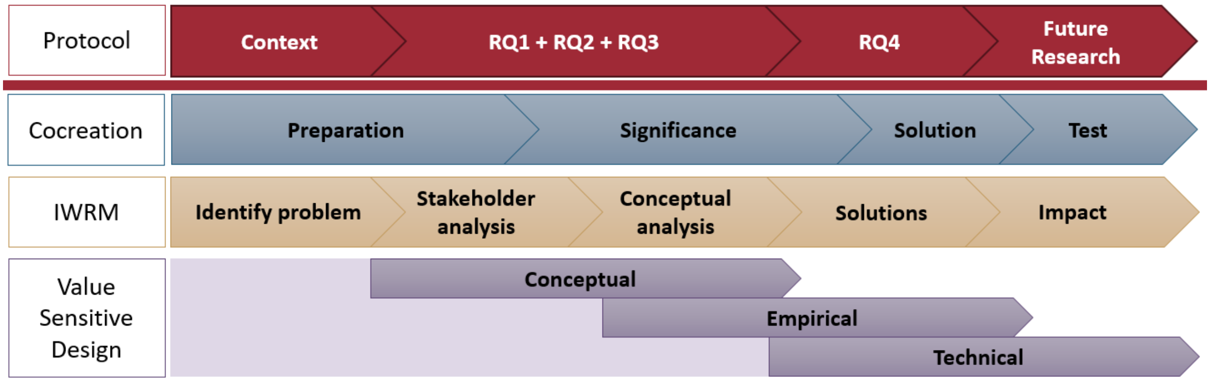


Figure 26. Comprehensive Theoretical based report structure (Kruger, Gusmao, Braga França, & Gonçalves Quelhas, 2018), (Ravesteijn & Kroesen, 2015), (Friedman, Peter H., & Borning, 2001)

The **context** section of the report involves both *preparation* components derived from cocreation, and *problem identification* utilized in integrated water resource management design (IWRM). These components were completed by defining groundwater management institutions, governance and case studies.

The next component of the protocol is answering **research questions 1, 2 and 3**. These are aimed at identifying stakeholders, determining practical considerations, and creating value profiles for stakeholders. The three questions are implemented in figure 26 in one phase because the models contribute to each of the research questions. In determining the *significance* of the case study, dentification of scenario details and risks involved are assessed in RQ1 and RQ2 by gathering information about stakeholders and practical management considerations. Components of IWRM including *stakeholder* and *conceptual analysis* overlap with the *conceptual level* of value sensitive design. These steps involve mapping relevant parties with their associated values and analyzing diversity of perspectives. The *empirical level* of value sensitive design is also applied because it seeks to greater understand the context of the case. This is achieved in all research questions, but specifically in greater detail with RQ2 given its relevance to practical management considerations.

The **fourth research question** involves composing recommendations based on the results of the previous sections. Here, the *solution* phase of cocreation is applied which includes creating flexibility in the result. The solution incorporates both *empirical* and *technical* components of value sensitive design. These complement each other in the fourth research question because the results of the empirical analysis are applied to incorporate values into a technical recommendation.

The last phase of the report relates to **future research**. Here, according to cocreation and IWRM models, there needs to be *testing* on the recommendations to assess *impacts*. This portion of the report is specifically aligned with *technical* investigation for value sensitive design because the testing will show if and how the technology embodies values.

4.3 Operationalizing Value Sensitive Design

4.3.1 Overview

The focal point of the study is value sensitive design, which can be operationalized in a variety of ways. In this section, key values associated with water management are identified through literature review. Then a design protocol for value sensitive design is developed.

4.3.2 Determine values

4.3.2.1 Literature review

The first step of designing for values is to determine the values involved in the case study. Determination of values in water management can be determined by surveys, interviewing, Q-methodology, discourse analysis of cultural texts, or focus groups interviewing experts (Mostert, 2018). However, for this study, a literature review was done to build on existing research. The goal of the literature review was to obtain a list of values and definitions relevant in water management.

To ensure specificity of values related to water, the literature review included three searches in the SCOPUS science platform (see appendix B.7 for search terms and results). The first search was specific for value sensitive design and groundwater, but there were no results. The second search aimed to achieve more general results by simply searching for water instead of groundwater which yielded five results, and one of these papers (B) included a list of values involved in water management. Finally, to find more results, the third search was conducted to find value sensitive design articles which contained water. This resulted in finding one final additional article (C) because the article found in the second search was also a result in the third search. The last search was completed to locate articles with values in reference to integrates water management and one of these papers included stakeholder values (D).

The sources resulting from the literature review are listed below (A-D). The first source (A) was not found in the literature review but was incorporated because integrated water management is a globally agreed upon approach for water management which incorporates values into its principles (chapter 2.4). The second source (B) was utilized for its relevance to value sensitive design for groundwater management. The third study (C) found values involved in smart metering. The fourth study (D) was utilized because it determined values based on interviews with water professionals. To supplement the literature-based sources, values of Ghanian government stakeholders as provided on their official webpage, were inspected and the repeated values were incorporated (see appendix B.8 for complete list). These sources found specific values utilized for value sensitive design in a water management context.

A. Integrated Water Resource Management: Principles and Definition (Global Water Partnership Technical Advisory Committee, 2000)
B. Handbook of Ethics, Values, and Technological Design: Design for Values in Water Management (Ravesteijn & Kroesen, 2015)
C. How to Weigh Values in Value Sensitive Design: A Best Worst Method Approach for the Case of Smart Metering (van de Kaa, Rezaei, Taebi, van de Poel, & Kizhakenath, 2020)
D. Stakeholder Value Orientations in Water Management (Vugteveen, et al., 2010)
E. Ghanian government websites (appendix B.8)

The table shows a summary of the sources used (A-E), the search number where the source was found, and the values listed in the source. From here, a list of 23 unique values were generated. To simplify the list while encompassing the 23 values, clusters were created as noted in the gray column. The clusters were created by comparing definitions and values and grouping the similar and overlapping concepts. Sustainability was categorized in multiple clusters, but this is because the particular definition of sustainability varied between sources.

This procedure ensured *mutual exclusivity,* or ensuring no cross-over between values, by analyzing definitions and ensuring each was unique. This list was also *collectively exhaustive* (ensuring values were not missing) because the values duplicate themselves as denoted with an asterisk(*) and the values found easily cluster into seven overarching values as shown below.

Table 8. Values generated from literature review

	Source				
Cluster	**A**	**B**	**C**	**D**	**E**
Search no.	(n/a)	(2/3)	(3)	(4)	n/a
Economic efficiency	1. Economic efficiency		2. Cost-effectiveness	3. Cost	
Environmental sustainability	4. Environmental sustainability*		5. Environmental sustainability*	6. Environmental sustainability*	
Participation	7. Coordination	8. Democratic participation	9. Procedural justice	10. Communication 11. Responsibility	12. Teamwork
Reliability		13. Sustainability	14. Reliability		15. Excellence/ Quality
Safety		16. Safety* 17. Security *	18. Safety* 19. Security*	20. Safety*	
Social Equity	21. Social equity	22. Distributive justice* 23. Social sustainability	24. Distributive justice*		
Trust			25. Disclosure 26. Privacy 27. Trust		28. Transparency 29. Integrity

4.3.2.2 Values Definitions

Table 9. Values for Interview

Value	Definition	Source
Economic Efficiency	The attempt to maximize the economic and social welfare derived from water resources and investments in water service provision	(Water Resources Commission, 2012)
Environmental Sustainability	The present use of the resource should be managed in a way that does not undermine the life-support system thereby compromising use by future generations of the same resource	(Global Water Partnership Technical Advisory Committee, 2000)
Participation	The involvement of users, planners and policymakers at all levels in water development and management	(Global Water Partnership Technical Advisory Committee, 2000)
Reliability	The ability of a product to perform its function adequately over a period of time without failing	(van de Poel, Design for Values in Engineering, 2015)
Safety	The reduction of risks to a reasonably feasible and desirable extent	(van de Poel, Design for Values in Engineering, 2015)
Social Equity	The basic right for all people to have access to water of adequate quantity and quality for the sustenance of human wellbeing	(Global Water Partnership Technical Advisory Committee, 2000)
Trust	The establishment of human reliance that is willing, voluntary and carried out under conditions of uncertainty and vulnerability	(Nickel, 2015)

4.3.3 Interview Session Design

This section goes through the design process for creating a method to assess values of stakeholders in this case study. There were four primary iterations as outlined below as well as the reason for discarding the design and implementing another method.

Table 10. Values Activity Iterations

Version	Description	Reason for discarding
1. Q- Sort	Cards with statements on them are scored on a grid of most to least preferred	Grid could be intimidating and time consuming to explain during interview
2. Values grid	Worksheet where values are scored using chips as weights	Could be biased with preconceived position of values on a worksheet
3. Value cards and chips	Combination of methods allows for respondents to review values and place them on sheet to remove bias	Cards were written in only English
4. Bilingual value cards and chips	Same iteration as (3), but value cards are written in both Twi and English	Final version

4.3.3.1 Version 1: Q- sort

The first iteration of a value sensitive design method was Q-methodology. The method involves a Q-sort grid, as depicted in figure 27, and accompanying objective statements. The grid is given to the respondent as a worksheet and the statements are written on cards which can fit in the cells of the worksheet. The respondent is instructed to place the objective statements on the Q-sort grid in the cells which represent statements in which they most and least agree. The results allow for the researcher to determine value orientations based on their agreement or disagreement with these statements.

Such an application is utilized in water resource management analyses. A report from (Minkman, van der Sanden, & Rutten, 2017) used this method to study practitioners' viewpoints on citizen science in water management.

Despite its proliferated use in the water management, there are concerns about the Q-method's timely explanation process. Although effective and widespread in application, the protocol may seem overwhelming to work with and requires a large number of objective statements to sort. The next iteration should be a simple model which requires little explanation time for the interviewer.

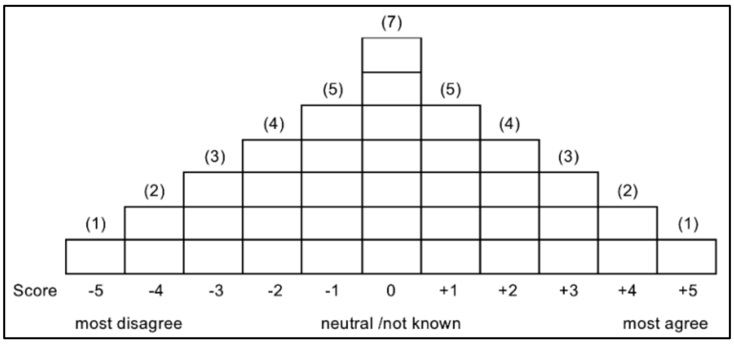


Figure 27. Q-Sort Matrix (Yoshizawa, Iwase, Okumoto, Tahara, & Takahashi, 2016)

4.3.3.2 Version 2: Values Grid

Another approach for determining value profiles per actor is using a values grid with tokens. In the method proposed by Flipse and Puylaert, there were eight values with definitions placed on a board as pictured in figure 28 (Flipse & Puylaert, 2018). The interviewee was provided with 80 tokens which they were instructed to place on top of the values according to which values were most important in the development of an autonomous vehicle. The more tokens a respondent places on top of a value, the more important that value is for the respondent.

The respondent was instructed to use all 80 tokens which introduces the constant sum dilemma. This means that by allocating more tokens to one value, there are less tokens to distribute to the other values. This puts the respondent in a position to make a choice between values.

This method, while simpler and more user friendly than the Q-sort, has positional bias because the position of the values on the board are pre-determined by the researcher's decision. There is potential for values positioned at the top of the board to receive more tokens simply because they are on top. Additionally, providing 10 tokens per value for a total of 80 tokens may be time consuming and overwhelming in the interview procedure.

Figure 28. Values Grid (Flipse & Puylaert, 2018)

4.3.3.3 Version 3: Value Cards and Tokens

The final concept combines components from both the Q-sort and the Values Grid. The design follows the values grid with two key changes. First, the number of tokens was changed from 10 per value to 3 per value for simplification. This was to minimize time needed to complete the activity while still providing the constant sum dilemma. The other alteration was that instead of having the values pre-arranged on a board, the values would be cards which the interviewee can place freely to avoid interviewer bias. This technique was derived from the Q-sort method.

This version of the protocol was pilot tested with eight individuals. Three of which are water sector professionals, two are water students and two are master students outside of the water field and two are not in the water field. Three of the mock interviews were in person and the rest were held online using an online whiteboard (Miro) version of the activity and video calling. In total, there were four drafts of this activity created. For images of the drafts, see the appendix B.9.

4.3.3.3.1 Draft 1: Ranking and Tokens

For the digital trials, Miro was used as an accessible online version. Additionally, it would not require the physical creation of the cardboard game activity to minimize time and resources. The first version used a double ranking system. First, the values were ranked from 1 to 7 with 1 being the most important and 7 being the least important. To do this, the respondent would first place the values in position 1 through 7. The second ranking involved the placement of tokens next to each of the values.

However, there were flaws uncovered during pilot studies. First, the cards lack definitions which at first was intentional so that the respondents could freely interpret values on their own. However, the pilot subjects had difficulty completing the activity without definitions. Secondly, the double ranking system proved to be an unnecessary complication as using the tokens would rank the values anyway and ranking the values from 1-7 in combination with the tokens caused confusion for the interviewees.

4.3.3.3.2 Draft 2: Tokens and Definitions

The next draft implemented cards with definitions and a blank work area so the interviewee could place the cards anywhere they deemed appropriate. This removes bias from the researcher and simplifies the activity into one ranking system. The question was also written at the top so that interviewees could refer to the task assignment. During this pilot session, follow up questions and prompting statements were added to the interview protocol in anticipation of questions during the interview.

4.3.3.3.3 Draft 3: Physical Version 1

After the online trials, a physical board and complementary "Value Cards" were made. A board was created because in some of the interview locations, there would not be access to a table or surface which respondents could place cards. Black foam core was used as the base and Velcro was adhered to both the board as well as the back of the Value Cards so that the cards would stick to their assigned position on the board. The value cards were written with the name of the value in bold at the top and the definition at the bottom. The respondents would then be able to place the cards in their desired position on the board.

4.3.3.3.4 Draft 4: Physical Version 2

Upon arrival to the interview site, there was a concern of language translation as many of the respondents only spoke Twi, while the values cards were written in English. It was clear the cards could not be translated in the moment as the translations could be forgotten and would need to be asked repeatedly throughout the interview. With the aid of a bilingual (Twi and English) Ghanian colleague and interviewing partner, the definitions were translated to Twi through writing on a sticky-note and adhering it to the front of the Value Cards (appendix B.9). This enabled users to flip back and forth between Twi and English if they desired (appendix B.10).

To ensure that the goal of the activity was achieved and gather design requirements, follow-up questions were asked. These questions were designed based on the mock interviews and literature of similar studies (Flipse & Puylaert, 2018) (Vugteveen, et al., 2010). The follow up questions were designed to learn about the motivation behind token allotment of the top and bottom ranked values. Additionally, interpretations of the values were asked in relation to groundwater management.

4.4 Semi-Structured Interview

4.4.1 Sample Selection

4.4.1.1 Practical Matters

When determining the stakeholders to interview, individuals were contacted and chosen based on pre-established contacts, availability, and access. They were sent emails and/or WhatsApp messages to schedule an appointment in person. Based on these limitations, the following groups were interviewed:

Consumers	Organizations
• Domestic households • Car Washes • Public Water Caretakers	• Borehole Companies • Ghana Water Company Limited • Community Water and Sanitation Agency • Assembly Men • Committee Members • Hydrogeologists • Kumasi Metropolitan Assembly • Water Resources Commission • TU Delft- African Water Corridor • Kwame Nkrumah University of Science and Technology (KNUST)

There are two key differences in the practical interviewing methods between organizations and consumers. First, for consumers, there was a multilingual Ghanian translator who aided the researcher in door-to-door interviewing. The role of the translator was to approach the respondents, introduce the study and carry out the interview protocol in Twi, then repeat the answers of the respondent in English. When a respondent had a question, the translator served as a mediator between the researcher and the respondent. Secondly, the consumer interviews were conducted in a door- to door sampling method. Whereas the organization interviews were planned in advance and held in the office of the organization.

4.4.1.2 Consumers

To interview consumers, door-to-door sampling was conducted. In order to determine locations, data from the African Water Corridor study described in chapter 2.5 was utilized. The goal was to sample groundwater consumers, therefore, the location for interviews was established by identifying regions of high groundwater use. First, the neighborhoods were summarized by determining the total sample size, number of private boreholes, public boreholes and dug wells. These are the three sources of groundwater use in the area. Next, a calculation was done to determine the percent of respondents which use any of the groundwater sources.

The data is organized first in numbered zone (grid), and second in neighborhoods within the zone. From this data, sample zones were identified with three filters. The first filter was to identify the neighborhoods with over 90% respondent groundwater use. This resulted in altering the list from 48 to 21 neighborhoods. Next, the sample size needed to be sufficient to justify going to the site. Therefore, samples were limited to neighborhoods with over 10 total surveys in the area. This resulted in 6 neighborhoods.

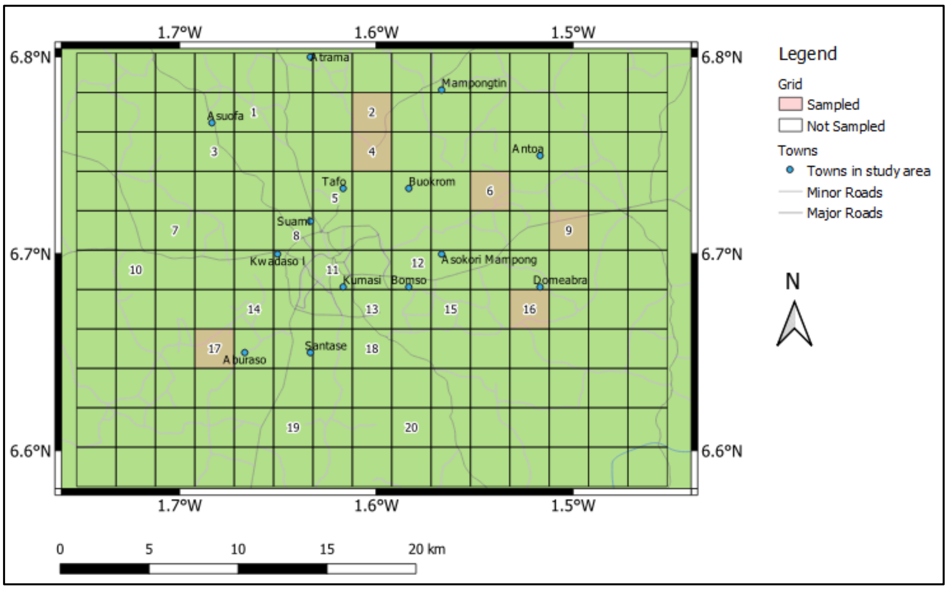


Figure 29. Mapped locations of domestic groundwater users

In order to ensure an income-diverse sample, the average income of each neighborhood and income brackets (percent of the maximum income zone) were calculated. The result was six neighborhoods with income ranging from 39%- 100% of the highest sampled income. A graphic result of the identified locations is in figure 29 above.

Table 11. Domestic groundwater consumer sample locations

Zone	Neighborhood	Sample Size	Borehole	Dug Well	Public Borehole	% GW Users	Income %
2	Taaboum	13	9	4	2	100%	84%
4	Ahwiaa	21	11	2	6	90%	62%
6	Asabi	16	12	0	4	100%	39%
9	Ejisu	25	5	0	20	100%	58%
16	Domeabra	25	3	0	22	100%	48%
17	Akyeremade	25	9	0	15	96%	100%

4.4.2 Protocol

Two different interview protocols were developed for the consumer and organization groups with some overlap in content as summarized in the table below. This is because for consumers, and specifically households, interviews need to be brief so as to not take too much of the participant's time. The interview was semi structured with prescribed questions, but the interviewer also engaged in follow up questioning to learn about a particular response if warranted. Both interviews included the same basic structure: an introduction of the interviewee, perceptions of groundwater management, and a values activity. For the full interview protocol, see appendix C.

Table 12. Interview Protocol Overview

Organization	**Consumer**
Introduction: Group role • Group identification • Group's role • Views on water management	Introduction: Groundwater use • Type of groundwater • Satisfaction with groundwater • Tracking of groundwater
**Introduction of problem* Groundwater Management • Knowledge of groundwater monitoring Collaboration • Collaboration in groundwater management Design • Goals, opportunities and challenges • Group contribution	**Introduction of problem* Groundwater Management • Who should be in charge • Involvement in monitoring
Values Activity • Ranking importance of values	Values Activity • Ranking importance of values
Specification • Values to design requirements	Specification • Values to design requirements

4.4.2.1 Theoretical Backbone

The interview is structured after a combination of methods, theories and models. The procedure follows the illustration in figure 30 which combines the Model or Reasoning and Values Hierarchy (Roozenburg & Eekels, 1998) (van de Poel, 2013) . These are combined because as van de Poel states, design requirements encompass “properties, attributes or capabilities” of a product (van de Poel, 2013). The interview starts with the introduction, then climbs the pyramid in the groundwater management section to determine baselines functions and needs. Then, through the values activity, the prioritized values of the stakeholders are determined. In the last step of specification, the pyramid is descended to translate values to design requirements.

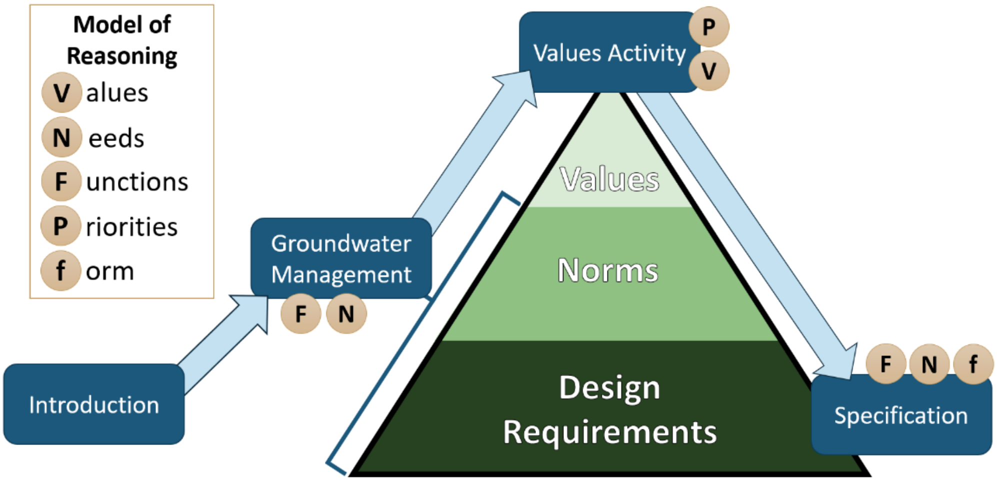


Figure 30. Theory based method

4.4.2.2 Introduction

The first part of the interview focuses on the stakeholder group, their role, and views on groundwater management in Kumasi. The first question the respondent is asked is to identify the name of the organization for which they are employed. After self-identifying, they are prompted to respond in the remainder of the interview as a member of that organization. This was done to apply social identity theory because, as discussed in the theoretical framework, values are more culturally relevant than the individual level. Additionally, the scope of the research is to gather more information on the stakeholders as groups and not individuals. This approach is focused on the organizational unit of analysis (Babbie, 2010).

For the consumer protocol, the introductory material involved the consumer identifying the source of groundwater for which they use: either a borehole or a well. They were also asked to remark on their experience as a groundwater consumer with regards to quality, quantity and overall satisfaction.

4.4.2.3 Groundwater Management

After this introductory data is collected and the interviewer is primed with discussions of groundwater management in Kumasi, the design section of the interview askes the respondent for design requirements in a groundwater monitoring system. These questions are kept open so that the respondent can answer in a manner which fits to their design needs and away from the interviewer’s predisposition of what a groundwater monitoring system should be or do. For example, instead of asking “How would you like to measure groundwater levels in Kumasi?”, questions like “What does ideal groundwater monitoring look like to you?” are asked. In this step, the *needs* and *functions* of an appropriate groundwater monitoring technology are determined without the influence of values.

4.4.2.4 Values Activity

In the second step, the interviewees completed a values activity to determine the prioritization of values related to groundwater monitoring. The respondents were first given an explanation of the activity and told they would rank the importance of a set of values according to the question "What values are most important for an ideal groundwater monitoring system in Kumasi?". Next, they were given the deck of value cards, seven in total, each of which have the name of the value and literature-based definition in both English and Twi (see appendix B.10). They were instructed to go through the values to become familiar with them, and then place each of the cards on the activity board. Next, respondents are asked to allocate 21 tokens to the seven values in order to answer the assigned question. They did this by placing the tokens on top of the value cards. They were told they can allocate them in any way they would like, but they must use all the tokens. The result is a quantified metric of the importance of each value to the respondent. This step takes place at the top of the values hierarchy pyramid where the values are *prioritized* in relation to the others by using the tokens.

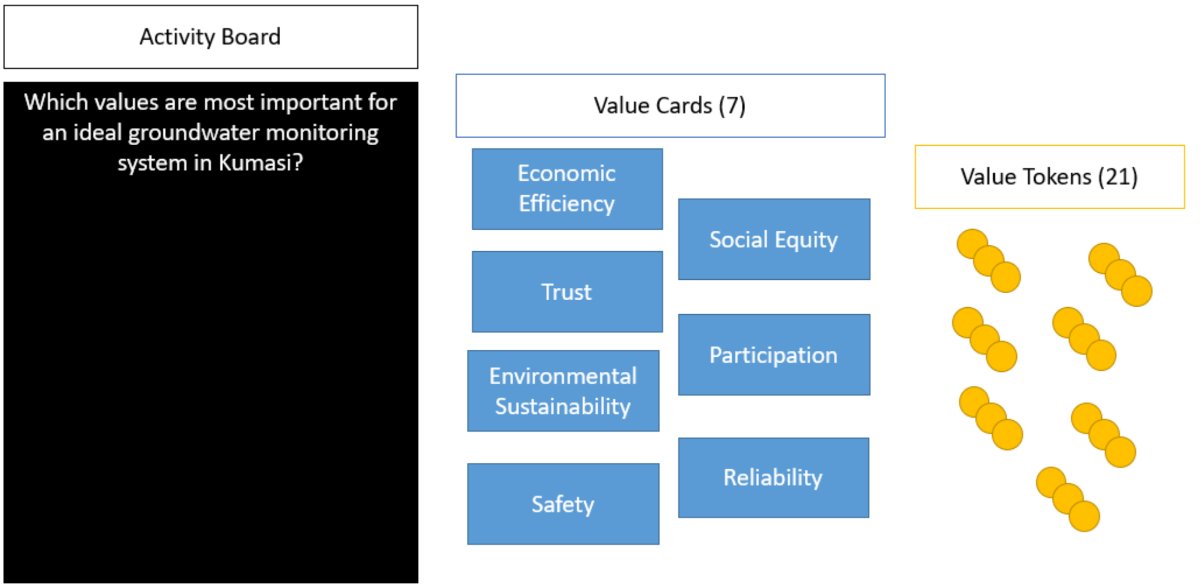


Figure 31. Values activity materials

4.4.2.5 Specification

The final part of the interview will be a *specification* session whereby the topmost and bottommost ranked values are further discussed to determine what the respondent believes the *needs* and *functions* of a groundwater monitoring technology would have in the context of that value. For example, if a respondent ranked trust as the highest value, the interviewer would say "You ranked trust the highest out of all the values. What would a groundwater monitoring technology trustworthy?". In this way, the specification moves down the pyramid by starting with a value and ending with a design requirement.

4.4.3 Interview Analysis

Interviews were recorded with an audio recording device and manually transcribed. Once transcribed, the interviews were analyzed through coding in ATLAS.ti and Microsoft Excel. The goal of the codes is to answer the research questions, so the code groups vary per research question. Codes were assigned to all transcripts according to the coding groups and definitions in appendix D. After assigning codes to the interviews, the coding is checked again to ensure there are no mistakes or biases. The coding approach was thematic because the coding framework resulted from both literature and the data itself (Urquhart, 2013). The code protocol was adapted during the coding as codes were restructured to ensure a consistent and concise analysis approach.

4.4.4 Ethics

Prior to conducting the interviews, ethical considerations were taken into account through completing a human research ethics committee (HREC) approval through the Delft University of Technology. The design of the protocol was such that it fulfilled the requirements as outlined in Babbie: voluntary participation, respondents sign informed consent form, no harm to subjects, confidentiality (through pseudo anonymizing data), and avoiding deception through a prebriefed and debrief (Babbie, 2010). Interviews are pseudo anonymized when transcribing. In the data materials, the respondent is identified as their group affiliation and a unique random number.

4.5 RQ1: Methods

The first research question seeks to determine key stakeholders and their roles in groundwater management in Kumasi. In order to do this, four steps were completed as summarized in table 13 below.

Table 13. Procedure to identify key stakeholders

Step	Activity	Result
1	Literature and policy review	- List of stakeholders - Relationships between stakeholders- statutory - Roles of institutions
2	Interview	- Relevant stakeholders as mentioned in interviews - Relationships between stakeholders- practical
3	Analyze	- Assess steps 1-2 to determine key actors

4.5.1 Literature and Policy Review

4.5.1.1 1a. Systematic Literature Review

In order to determine the key stakeholders involved in groundwater management in Kumasi, a systematic literature review was undertaken. First, to gain baseline information about groundwater monitoring conditions, keyword searches were conducted in Scopus science with search yields shown in table 14 below. For full details on search terms, see appendix E.17.

Table 14. RQ1 Literature Review

#	Keywords	Search Yield	Considered for review	Analyzed	Chosen
1	Ghana; groundwater; monitor	3	1	1	1
2	Ghana; groundwater; Kumasi	14	2	1	1
3	Ghana; groundwater	45	5	3	2
4	Kumasi; water	149	8	8	7
	Total	*211*	*16*	*13*	*11*

There were key criteria which the articles must meet in order to be analyzed. First, the article must be accessible without a fee through public access, TU Delft membership or through direct author exchange. Secondly, the article must be focused on the country of Ghana to ensure local relevance. There is limited information for Kumasi specific information, so the scope was broadened to encompass Ghana. Third, the abstract must mention institutions, stakeholders, or recommendations for groundwater management. Fourth, there was a strong preference for articles published from Ghanian institutions. Fifth, the articles must have been published after 1998, because this is the critical year in which water management infrastructure was fundamentally changed after several reforms as mentioned in chapter 2. Lastly, because the first search using "monitor" only developed three results, the terms were broadened to either "groundwater" or "water". In the fourth search, the keywords were altered to find articles related to "Kumasi" and "water" with the limitation of the abstract including a reference to water governance, regulation, social interactions or groundwater. This was done to increase the search yield (by using "water" instead of "groundwater") and to focus on Kumasi (by using "Kumasi" instead of "Ghana"). After this procedure, 11 articles were chosen. During the assessment, baseline information about the groundwater management situation in Ghana was obtained and all stakeholders mentioned in the articles were recorded.

4.5.1.2 1b. Policy Review

During the literature review, key Ghanian water policies were recorded for a second policy focused review as outlined in the table below. This resulted in the defined statutory roles and definitions for each stakeholder group. Components of these documents are explained in chapter 2. After completing reviews 1a and 1b, the result was an exhaustive list of stakeholders as seen in table 16 of the results section of chapter 5.

Table 15. Analyzed policy documents

#	Policy Document	Publishing Organization (year)
1	Ghana National Water Policy	Ministry of Works and Housing (2007)
2	State of Groundwater Resources	Water Resources Commission (2011)
3	Groundwater Management Strategy	Water Resources Commission (2011)
4	National Integrated Water Resources Management Plan	Water Resources Commission (2012)
5	Pra River Basin Integrated Water Resource Management Plan	Water Resources Commission (2012)
6	Water Sector Strategic Development Plan (2012-2025)	Ministry of Works and Housing (2014)

4.5.2 Semi-Structured Interviews

As mentioned in chapter 4.4, semi-structured interviews were utilized to answer all research questions. The interview procedure and sequential coding of the interviews for this research question can be found in section 4.4.

4.5.3 Selection of Stakeholders

In order to be selected as a key stakeholder, the actor must meet at least one of the qualifiers described below.

1. **Member of the Pra River Basin Management Board**- This board has historically overseen developments of water management specific to the Pra River Basin. Members of this group have already been determined by local institutions as important for water management in Kumasi.
2. **Defined as a "principal sector agency" in the Ghana National Water Policy**- These institutions are defined as those that "deal with direct facilitation and implementation" of water resources (Ministry of Water Resources, Works and Housing, 2007). Similar to membership of the Pra River Basin Management Board, these stakeholders are defined as valuable in the nationalized water policy.
3. **Has technical capacity for implementing monitoring**- Technical and/or academic groups may have been excluded from the government-based suggestions (1-2 above). Incorporating technical specialists in development of a water innovation is key to its success.
4. **Mentioned with high frequency in interviews**- Literature and policy review can aid in defining stakeholders, but practical stakeholders may differ from those policy suggests. Therefore, stakeholders mentioned with high frequency during interviews were included.

4.6 RQ4: Recommendation

Formulating recommendations incorporated the conclusions from four sectors of the report as visualized below. At the end of each chapter, there are numbered summary points listed. In chapter 8 of the report, these are accumulated to form a list of considerations and sensitivities for groundwater management, otherwise noted as design requirements.

First, the **research question** conclusions were integrated to determine what the data suggests can and should be done to address the problem statements. Next the results of the research questions were compared to **Ghana water policy** documents to determine if the results of the research questions complemented or contradicted official policies and/or goals. After this, a general recommendation concept was deduced and **case studies** from compatible scenarios were assessed to determine what solutions have been applied in similar situations. Lasty, to align the recommendation with social science theory, a **theoretical framework** was adopted to support recommendations.

The four components of design resulted in a list of 30 requirements. Based on these considerations, **three recommendation categories** (denoted below as A, B and C), and a series of complementary action programs were formulated. The figure below illustrates that the design requirements provided barriers and opportunities for which the recommendations could be created and that the recommendations are based on the foundation set forth by the design process.

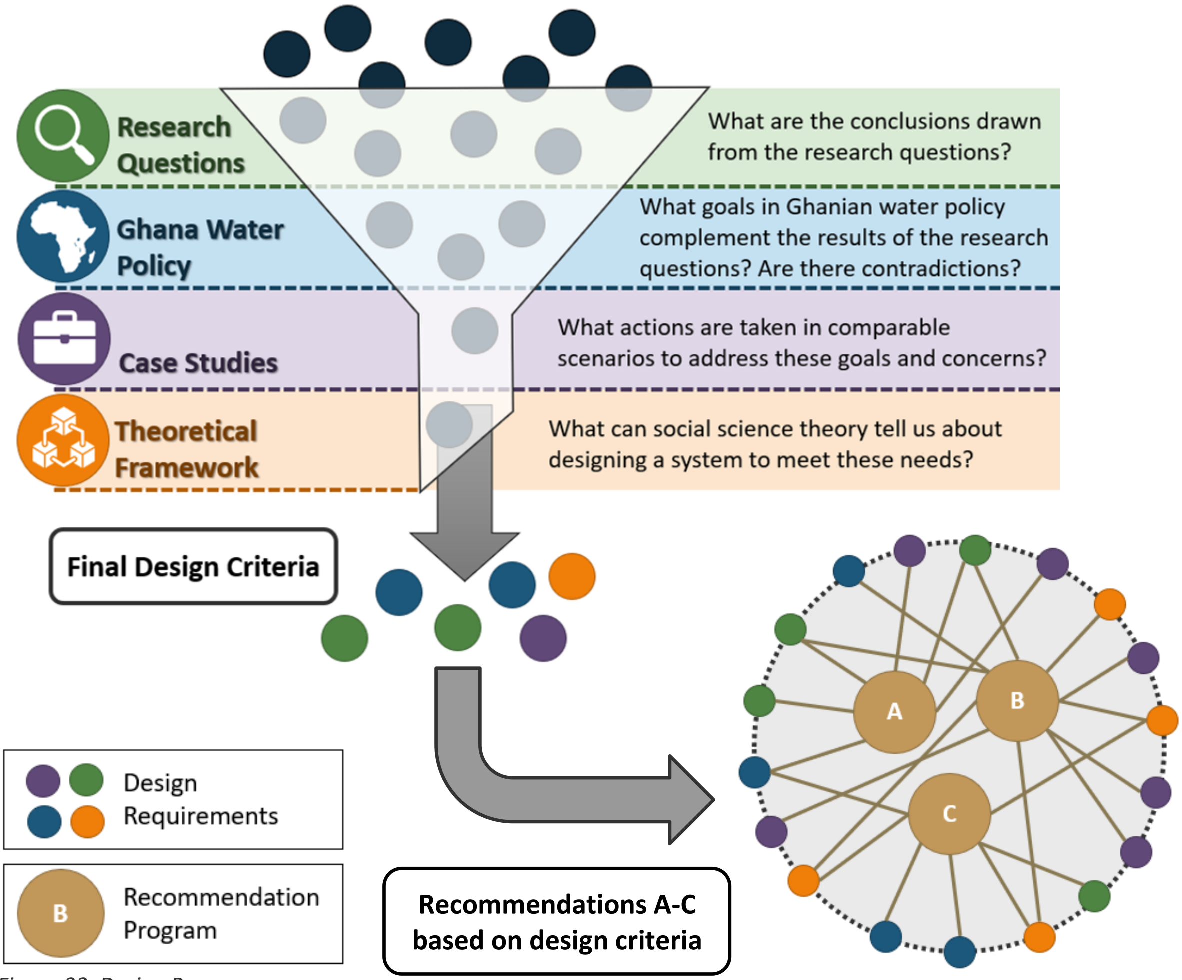


Figure 32. Design Process

4.7 Methods Review

4.7.1 Measurement Quality

There are four concepts which describe the quality of a method and measurements. They are precision, accuracy, validity and reliability.

Precision "concerns the fineness of distinctions made between the attributes that compose a variable" (Babbie, 2010). Some questions in the interview protocol were purposefully kept vague and imprecise so that the interviewee could freely respond without limitations. However, because of the semi-structured nature of the interview, the interviewer could ask follow-up questions for greater precision.

Accuracy indicates the closeness of the measured value to the correct value. To check results to ensure correctness and accuracy, the results were fact checked with existing policy and literature to determine if the results contradicted current knowledge.

A *valid* measure is one that accurately reflects the concept it is intended to measure (Babbie, 2010). To create valid protocol which ensured the research questions were answered, mock interviews were carried out. Mock interviews were conducted with individuals of varying backgrounds as discussed in the previous section. The individuals were instructed to stress test the protocol to ensure that the procedure was effective prior to the experiment and anticipate points of concern in the interview.

Lastly, *reliability* is the degree to which data can be repeated in other studies of the same phenomenon (Babbie, 2010). To address *reliability*, the interview procedure and values activity were based on established methods as previously discussed.

Chapter 5 Identifying the Stakeholders

5.1 Motivation and Goals

Front Material			Body Research Questions			Conclusions	
Context	Theory	Methods	**RQ1**	RQ2	RQ3	RQ4	Conclusion

RQ1: Who are the key stakeholders in the development of groundwater monitoring in Kumasi, Ghana and what are their roles?

The first research question is focused on identifying stakeholders in Kumasi's groundwater management sector. In order to do this, literature and Ghanian policy were reviewed, and interviews were conducted. The objectives for this section are:

Objectives
Identify actors and their roles in the groundwater management sector in Kumasi, Ghana
Create network graphic to illustrate relationships between actors
Classify key stakeholders into communities of practice
Classify the current groundwater management collaboration model

5.2 Results

5.2.1 Stakeholder Roles

The first result is a comprehensive table of stakeholders involved in the Ghanian water sector specific to Kumasi and a brief description of their role in groundwater management. The table is based on the cumulative methods for this research question including literature and policy reviews, and interviews. To be included in this table, the stakeholder must be mentioned with a description in one of the five policy documents from chapter 2. The stakeholders are organized by function and position in government including: national government, ministries, facilitation and regulation, service delivery, consumers, and academic.

There are three symbols in the table to indicate membership to a particular classification derived from Ghanian water governance documents. The Pra Basin Integrated Water Resources Management Plan dictates institutions which serve on the Pra River Basin Management Board (Water Resources Commission, 2012). The Ghana National Water Policy classifies organizations into either principal water sector institutions (dealing with direct facilitation and implementation) or allied institutions (playing supportive roles including regulation and oversight) (Ministry of Water Resources, Works and Housing, 2007). Labeling these classification aids in identifying key stakeholders.

Legend

Ⓟ Pra River Basin Management Board	Δ Principal water sector institution	◯ Allied institutions

Table 16. Stakeholders in Kumasi, Ghana groundwater sector

Stakeholder	Description
National Government	
1. Ghana Central Government	The republic of Ghana is a constitutional democracy. Laws are written by parliament and passed by the President[1] ◯
2. Development Partners	Diverse group of supporters who provide financial and/or technical support[1]
3. National Development and Planning Commission (NDPC)	Create development framework to be carried out by the ministries[1]
Ministries	
4. Ministry of Sanitation and Water Resources (MSWR)	Key ministry formulating policy, coordination and operations in the water sector. The Water Directorate leads water resource management and oversees reporting agencies[2] Δ
5. Ministry of Works and Housing (MWH)	Initiates and formulates policies in the Works and Housing sector[2] Δ
6. Ministry of Local Government and Rural Development (MLGRD)	Oversees development at local administrative levels in the metropolitan, municipal and district assemblies across the country[3] Δ
7. Ministry of Environment, Science, Technology and Innovation (MESTI)	Develops policies and plans regarding environmental protection[3]
8. Ministry of Finance and Economic Planning (MFEP)	Prepares national budget to inform annual expenditures[3] ◯
9. Ministry of Health (MoH)	Responsible for policy formulation and implementation through the Ghana Health Service[1] Δ

10. Ministry of Food and Agriculture (MOFA)	Oversee water related uses in irrigation for agriculture[1]
11. Ministry of Fisheries	Responsible for fishing activity both in land and marine[1]
12. Ministry of Harbors and Railways	Responsible for water transportation and navigation both inland and coastal territory of Ghana [1]
13. Ministry of Energy	Responsible for water based energy and regulates hydropower[1]
14. Ministry of Women and Children	Lead agency for implementing National Gender and Children's policy[1]
Facilitation and Regulation	
15. Environmental Protection Agency (EPA)	Protection of water resources and regulation activities within catchment areas[1]
16. Regional coordinating council (RCC)	Regional government below federal level. For Kumasi, this is the Ashanti Coordinating Council[1]
17. Metropolitan, Municipal and District Assemblies (MMDA)	Local governments for districts tasked with service delivery and implementation of policy[1]
18. Water Resources Commission (WRC)	Key institution for coordinating between water resources actors and implementing regulation and management of water resources policy[1]
19. Community Water and Sanitation Agency (CWSA)	Facilitates rural water supply through providing drinking water and sanitation[1]
20. Public Utilities Regulatory Commission (PURC)	Regulates standard services such as drinking water quality and tariffs for urban water supply[1]
21. Environmental Health and Sanitation Directorate (EHSD)	Operates under the MLGRD and are responsible for overall sanitation service delivery[4]
22. District Water and Sanitation Team (DWST)	Coordinates with MMDAs to implement WASH (water, sanitation and health) services[4]
23. River Basin Boards	Subsidiary of the WRC and oversees development in river basin to ensure protection of water resources[4]
24. Forestry Commission	Implement strategies to improve land management[5]
25. Minerals Commission	Regulates and manages mineral resources in Ghana and coordinates policies[1]
26. Lands Commission	Provides services in geographic information, guaranteed tenure, property valuation, surveying[1]
27. Ashanti Regional House of Chiefs	Regional chiefs of the Ashanti region and a subsidiary of the National House of Chiefs[5]
28. Ghana Atomic Energy Commission (GAEC)	Responsible for peaceful uses of atomic energy. Involved in groundwater monitoring for isotopic studies[6]
29. Ghana Geological Survey Authority (GGSA)	advise, promote and research on geoscientific issues (ex. groundwater) [6]
Service Delivery	
30. Private Borehole companies	Hired by consumers to drill boreholes into aquifer for groundwater access[3]
31. Non-Governmental Organizations (NGOs)	Provide funding for development projects[1]
32. Ghana Water Company Limited (GWCL)	Responsible for overall planning, managing and implementation of urban water supply[1]
33. Waste and Sanitation Committees (WATSAN)	Established within assembly to assist communities in management of *rural* water supply [7]

34. Water Supply and Sanitation Development Board (WSDB)	Established within assembly to assist communities in management of *small-town* water supply[7]
35. Ghana Irrigation Development Authority (GIDA)	Under the MOFA and focuses on water conservation and irrigation in the agriculture field[1]
36. Private Tankers	Deliver water in tanks to rural communities and overseen by PURC [3]
Consumers	
37. Domestic consumers	Groundwater consumers are those who consume water from boreholes or wells at the household level
38. Commercial consumers	Large consumers of groundwater such as car washes, hotels, sachet water producers and bottled water producers.
39. Minorities	Target groups of women and indigenous peoples[1]
Academic	
40. Delft University of Technology (TU Delft)	Academic institution in the Netherlands with research groups in technical fields including civil engineering and water management[6]
41. African Water Corridor (AWC)	Works on projects for sustainable development of water resources in sub–Saharan Africa[6]
42. Council for Scientific and Industrial Research- Water Research Institute (CSIR-WRI)	Water resources information service under WRC. Mandates for water resources data collection and processing[1]
43. Hydrological Services Department (HSD)	Water resources information service under WRC[1]
44. Kwame Nkrumah University of Science and Technology (KNUST)	Academic technical university with research expertise in civil and geological engineering

[1] (Ministry of Water Resources, Works and Housing, 2007); [2] (USAID, 2021); [3] (Monney & Antwi-Agyei, 2018) [4] (Ministry of Water Resources, Works and Housing, 2014); [5] (Water Resources Commission, 2012); [6] (TU Delft, 2022); [6] (Water Resources Commission, 2011) [7] (Water Resources Commission, 2012)

5.2.2 Interview Results

5.2.2.1 Sample

The interviewees were categorized in three levels. The first is the *role* which designates the interviewee's organization or consumer type. The *group* is one level above *role* and describes the roles by their function. Finally, the *category* separates the consumers and the organizations. Due to time constraints among the consumers, not all interviewees were able to complete the values activity, therefore, these sample sizes are separated. The result was 46 interviews with individuals from various consumer groups and organizations in the Kumasi water sector.

Table 17. Sample size per group

Category	Group	Role	Activity	No Activity	Total
Consumer	Domestic	Households	6	17	23
		Public Water Caretaker	0	5	5
	Commercial	Car Wash	3	0	3
Organization	Academic	TU Delft	1	0	1
		KNUST- Geological Engineering	2	0	2
		KNUST- Civil Engineering	1	0	1
	Service Provider	Borehole Company	1	0	1
		Hydrogeologist	2	0	2
		Ghana Water Company Limited	2	0	2
		Community Water and Sanitation Agency	1	0	1
	Regulation	Water Resources Commission	1	0	1
		Assembly Man	2	0	2
		Committee Members	1	0	1
		Kumasi Metropolitan Assembly	1	0	1

For the remainder of this thesis, data will primarily be assessed at the *group* and *category* levels. Additionally, the sample size between each group is highly skewed. Therefore, to minimize bias towards one group who may have been disproportionately represented, data is scaled to ensure each group is equally represented. To do this, weighted averages were calculated according to equation 1 below. Because there are five groups (i), each one is weighted by 20%. This calculation was done for simplicity, however, in reality, stakeholders have varying degrees of power and influence. In the equation, *i* indicates one of the five groups and *x* indicates a particular response within that group.

Equation 1. Weighted average general equation

$$weighted\ average = \sum_{i=1}^{5} \left(\frac{response\ x\ by\ group\ i}{total\ group\ i\ sample\ size} \right) \times 0.2$$

The interview was conducted in a mixture of English (the native language of the author) and Twi (the dominant language in Ashanti region). The graph below shows the interview language distribution based on category. For the interview to be accessible, it is imperative to have an interview protocol which is independent of language proficiency or else results will be skewed toward English proficient speakers.

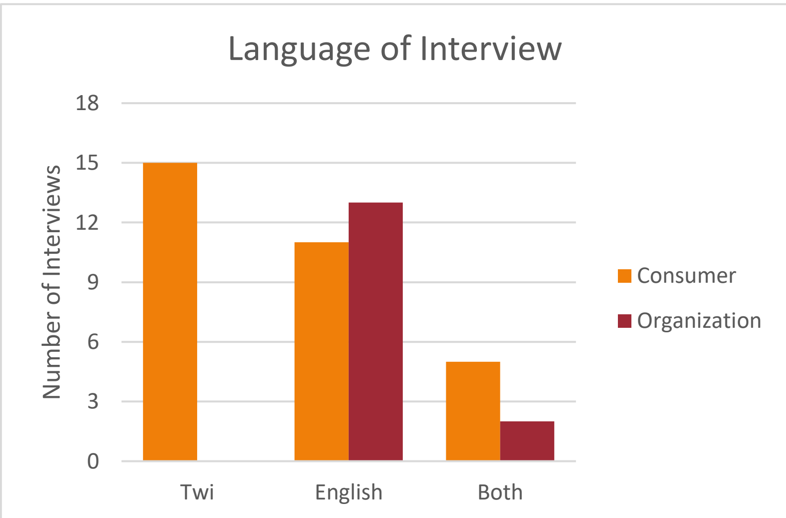


Figure 33. Interview language distribution

5.2.2.2 Organization Frequency

5.2.2.2.1 Occurrence of stakeholders in discussion

Interviews were coded for organizations and stakeholder groups mentioned. Frequency of mentions is corrected so that a stakeholder group was only counted one time if it was mentioned multiple times in one interview. There is a total of 29 stakeholders named in interviews with only one respondent not being able to name one. The results were weighted per group as demonstrated in equation 1.

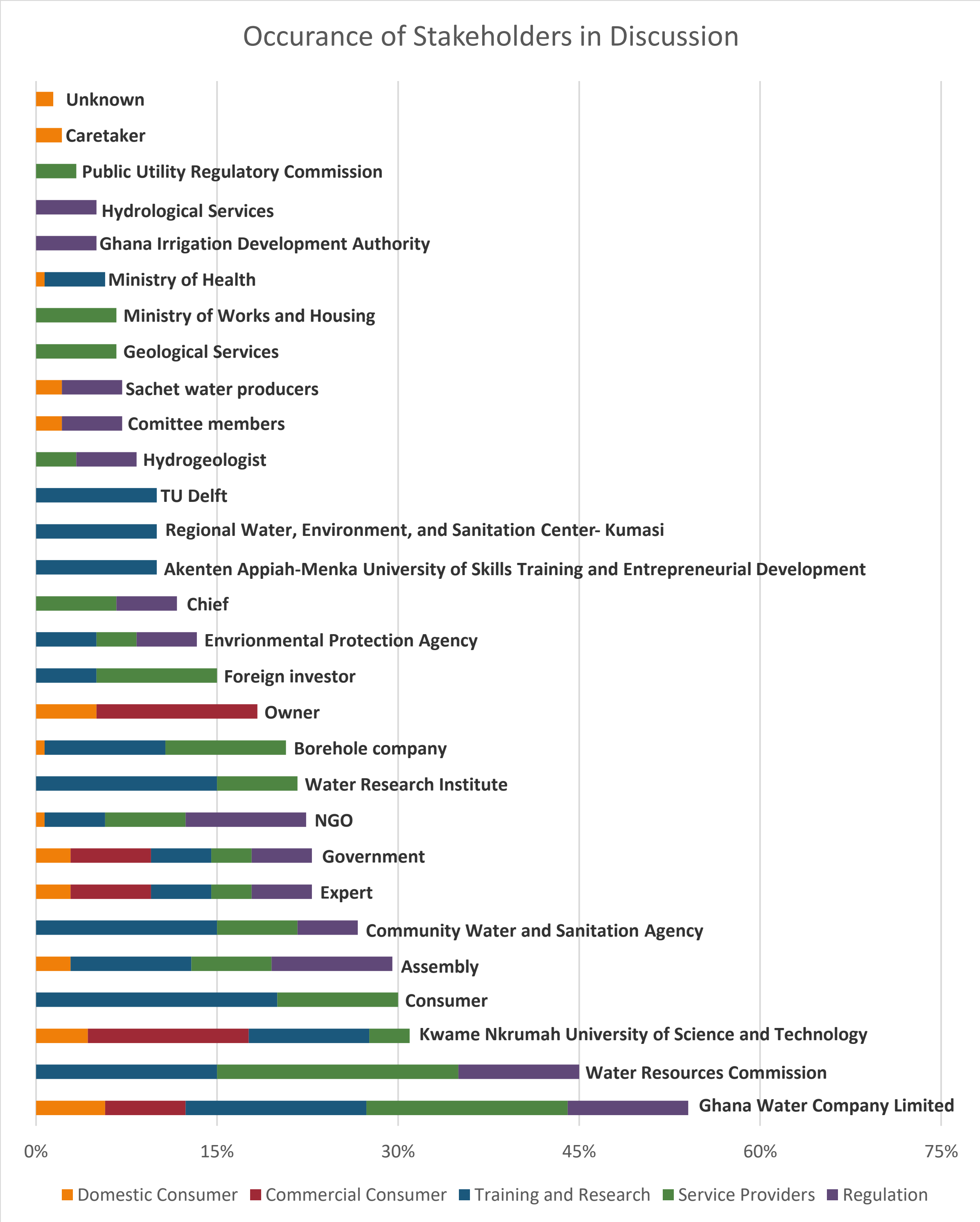


Figure 34. weighted average of occurrence of stakeholder groups during interviews

5.2.2.2.2 Discussed organizations

Additionally, data was collected to determine how groups were discussing other stakeholders. To do this, figure 35 was created where the y-axis is the sum of equations 2 and 3 as described below. The x-axis indicates the responding stakeholder group (group i), and the colored bars indicate the stakeholders the respondents are discussing (type x).

Equation 2 (light colored bars) resembles the spread of knowledge. A low value indicates that knowledge is concentrated in few individuals while a high value indicates that more respondents in the group had the same answers. Numerically, it measures the percent of the respondent group to mention another stakeholder group. For example, 100% of the training and research group surveyed referenced a service provider.

Equation 2

$$\%\, mention = \frac{number\ of\ group\ i\ to\ reference\ stakeholder\ type\ x}{Total\ number\ respondents\ in\ group\ i}$$

Equation 3 (darker bars) resembles the number of stakeholders a respondent group mentioned. A high value indicates that the respondent group named all potential stakeholders within that group, while a low value indicates that they named few. In the same example as earlier, the training and research group named 40% of the total service providers. The calculation is a percent of the total stakeholders named in all the interviews as categorized in figure 36. The denominator in equation 3 is the value of n in figure 36. The numerator is the number of stakeholders within the group which were referenced by the respondent group.

Equation 3

$$\%\, total = \frac{number\ of\ \ type\ x\ groups\ mentioned\ by\ group\ i}{Total\ number\ of\ type\ x\ groups\ (n)}$$

The results show that each stakeholder group, with the exception of commercial consumers and service providers, know the most about their own group. This is demonstrated by high bars when a respondent is referencing themselves. For example, the cumulative blue bar is the highest for the regulation group, indicating they have broad knowledge about their practice. Additionally, the only group to mention commercial consumers were the *training and research group*. On this note, training and researchers and service providers have the most knowledge of stakeholder groups in groundwater management. This is demonstrated by higher values for most of the bars. *Service providers* are the main group talking about external groups, likely because they are working with them to provide services. Lastly, *consumers* spoke mostly about themselves and service providers with limited information on other groups.

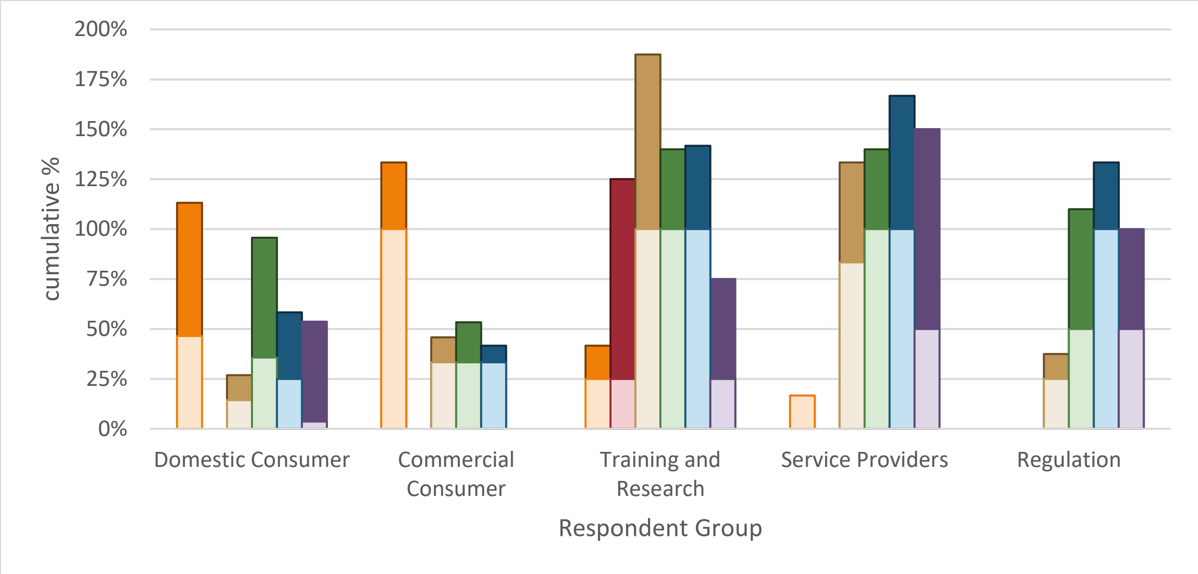


Figure 35. Organization Discussion

	Referenced groups					
	Domestic Consumer	**Commercial Consumer**	**Training and Research**	**Service Providers**	**Regulation**	**External**
% spread						
% total						

Figure 36. mentions of stakeholder group based on the interview group

Referenced Group	Identified stakeholders	
Domestic consumer (n= 6)	• Caretaker • Household • Husband	• Interviewee • Landlord • Owner
Commercial consumer (n= 1)	• Hostel	
Academic (n= 8)	• AAMUSTED • Academic • Expert • TU Delft	• KNUST • KNUST students • Regional Water Environment Sanitation Center- Kumasi • Water Research Institute
Service Providers (n= 5)	• Community Water and Sanitation Agency • Borehole companies	• Sachet water producers • Ghana Water Company Limited • Hydrogeologists
Regulation (n= 11)	• Assembly • Geological services • Environmental Protection Agency • Hydrological services • Ministry of health • Chiefs	• Ghana Irrigation Development Authority • Ministry of Works and Housing • Government • Public Utility Regulatory Commission • Water Resources Commission
External (n= 2)	• Foreign investor	• NGO
Unknown (n= 1)	• I don't know	

5.2.2.2.3 Organizations v Consumers

The table below shows the difference between stakeholder groups mentioned by organizations, consumers and both. Organizations mentioned twice the number of stakeholders as the consumers. Consumers responses were more generalized and with a closer relationship to the consumer in the chain of supply. This illustrates a familiarity with close contact stakeholders but a lack of awareness for the broader institutional groundwater management system. Whereas organizations named a far more diverse set of stakeholders and were more specific in their responses. For example, while consumers would reference "experts", organizations would reference specific academic institutions.

Table 18. names of stakeholders mentioned by organizations and consumers

Organizations	**Both**	**Consumers**
Sample size=15	*Sample size=46*	*Sample size= 31*
Total stakeholders= 26	*Total stakeholders= 10*	*Total stakeholders= 13*
1. Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED) 2. Chiefs 3. Council for Scientific and Industrial Research (CSIR)-Water Research Institute (WRI) 4. Community Water and Sanitation Agency 5. Environmental Protection Agency 6. Foreign investor 7. Geological Services 8. Ghana Irrigation Development Authority 9. Hydrogeologist 10. Hydrological Services Department 11. Kwame Nkrumah University of Science and Technology (KNUST) 12. Public Utilities Regulatory Commission (PURC) 13. Regional Water and Environmental Sanitation Centre, Kumasi (RWESCK) 14. Delft University of Technology 15. Ministry of Works and Housing 16. Water Resource Commission	1. Assembly 2. Borehole company 3. Committee members 4. Consumers 5. Expert 6. Government 7. Ghana Water Company Limited 8. Ministry of Health 9. Non-governmental organization (NGO) 10. Sachet water producer	1. Public Water Caretaker 2. Owner 3. Unknown

5.2.2.3 Contribution

Another dimension incorporated in interviews was the interviewee's willingness to be involved and/or contribute to a groundwater monitoring system in Kumasi. The responses were coded into task categories and paired to the stakeholder group which reported it. This data was analyzed to determine the percent of the stakeholder group which reported contributing the task. The results are shown in table 19. The table shows that there is a high percentage of involvement from all stakeholder groups with agreement to work on all tasks. However, it is worth noting that Ghana Water Company Limited is split with their involvement. This is because it is highly dependent on where the monitoring occurs- if the monitoring is within their jurisdiction or they are being paid through a client, there is greater interest involvement.

> "Most of the boreholes in Obuasi, we drilled 80-90%. So at least we have some small data that we can share and collaborate with them. If we could do that for the districts that could be quite huge."
>
> - Community Water and Sanitation 45

Determining the contribution of consumers to groundwater monitoring was altered in comparison to organizations. When asking consumers if they would be involved in groundwater monitoring, respondents said either *yes (Y)* or yes under a *condition* (C) (figure 37). One of the main conditions involved was wanting a service to accompany the monitoring such as quality testing, maintenance repair or data sharing. Another condition was ensuring the respondent had the time to participate. In explaining these answers, respondents also mentioned that they would want to participate to prevent waterborne illness, and hence the condition for services accompanying the monitoring.

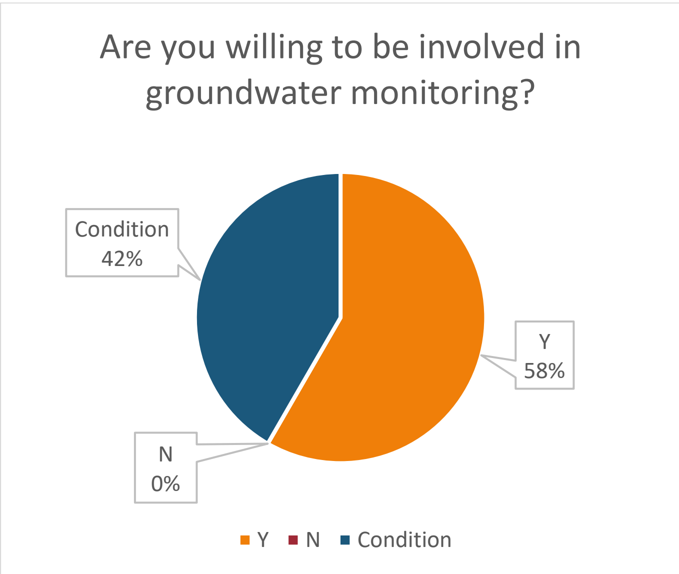


Figure 37. Consumer involvement in groundwater monitoring

> "I don't have much knowledge, but I want more knowledge of what to do if there is cracks or dirt. If there is assistance, I will be encouraged and would be happy if there were support"
>
> - Domestic Consumer 28

Table 19. Tasks agreed to by stakeholder groups

	Task							
	Advise policy	**Data collection**	**Lead**	**Partner**	**Research**	**Technology development**	**Tools**	**Community Participation**
Households								78%
Public Water Caretaker								80%
Car Wash								67%
TU Delft- AWC				100%	100%	100%		
KNUST- Geological Engineering					100%			
KNUST- Civil Engineering	100%				100%	100%		
Borehole Company		100%		100%			100%	
Ghana Water Company Limited		50%		50%			50%	
Community Water and Sanitation Agency		100%		100%	100%			
Hydrogeologist		50%						
Kumasi Metropolitan Assembly				100%				
Assembly Man				100%	100%			
Committee Members				100%				
Water Resources Commission			100%					

5.2.3 Stakeholder Network

After assessing all stakeholders through completing a literature and policy review and conducting interviews, a network was illustrated. Only those groups that were mentioned in interviews, in literature and determined as relevant in groundwater monitoring are included. The network is organized in the manner which was presented in most of the existing literature. Arrows represent a reporting hierarchical structure.

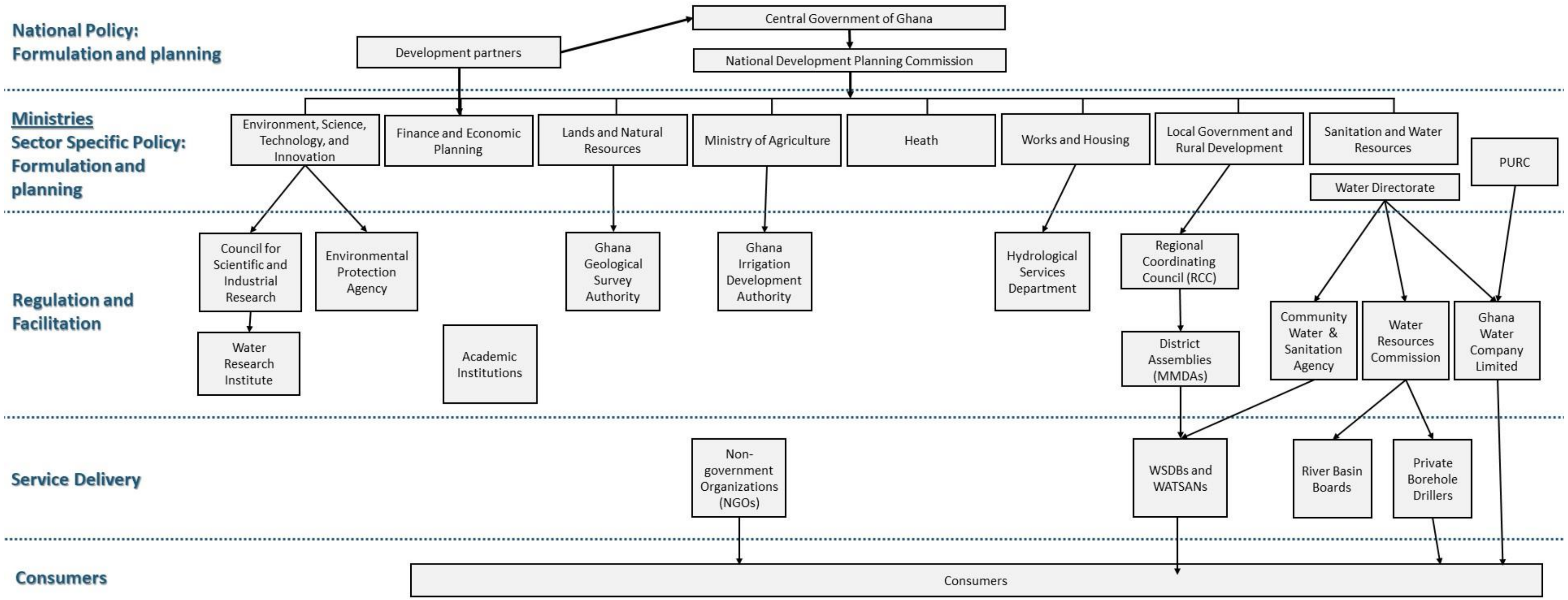


Figure 38. Stakeholder network graphic…. (Water Resources Commission, 2012), (Oduro-Kwarteng, Monney, & Braimah, 2015), (Monney & Antwi-Agyei, 2018), (Ministry of Water Resources, Works and Housing, 2014), (Water Resources Commission, 2012)

PURC: Public Utilities Regulatory Commission; WSDB: Water and Sanitation Development Board; WATSAN: Water and Sanitation Committee

5.2.4 Collaboration Identification

The interviewed stakeholders belong to certain groups with particular areas of expertise or common interests, otherwise known as communities of practice. For this study, three communities of practice are identified to categorize stakeholders. The three areas are: social, institutional, and technical. These were derived from van der Kooij's study. where the three concepts simultaneously influence each other in the setting of water irrigation technology (van der Kooij, Zwarteveen, & Kuper, 2015). This, therefore, is an apt comparison: introducing a technology for water resources. To define the terms, the social is described as people-to-people relationships, technology is related to innovation and institutional is related to government action.

To visually represent the communities of practice, a triangle with blending colors is depicted below with each point representing a community of practice. The structure of this graphic was inspired from Ekmekçi & Günay where triangles were used to illustrate interaction between technical works and administrative decision (Ekmekçi & Günay, 1997). However, for this application, one triangle was used, and a third element added (the social).

The merging of colors represents the blending of communities. This indicates that the middle of the triangle is the blend of all three. The closer the name of the organization is to the point, the more the organization fits into that single community. The stakeholders included in the diagram are only those that were interviewed as there is insufficient information to include organizations which only relied on literature.

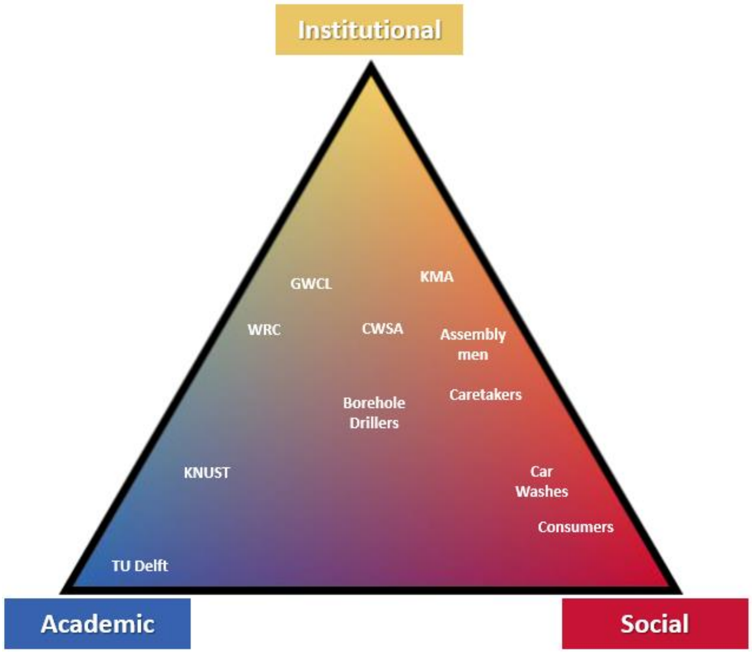


Figure 39. Communities of Practice

There are few groups which only belong to one community. TU Delft is located on the academic extreme because they are an external group with no government position and is not located in Ghana. They mentioned only being interested in the project as a knowledge partner and therefore they would fall here at this corner.

Other groups are multifaceted and located in more blurred regions. For example, the assembly men are at the intersection of social and institutional. This is because the assembly men are local leaders but have a high degree of integration with the community. The same goes for caretakers because they have a role to play in maintaining the public water source, however, their role itself involves being a fixture in the community. Caretakers also find themselves at the intersection between social, institutional and academic because of their oversight of a borehole.

The Ghana Water Company Limited and Water Resources Commission are located on the other side with a blend of both institution and academic. This is because although they are primarily government organizations, they both employ technical staff. In some cases, these staff may have been graduates of KNUST. KNUST falls more on the academic side with some integration in the institutional and social sectors.

At the center of the triangle are private borehole drilling companies. This is because they interact with and are a part of each end of the triangle. These companies are required to register with the WRC and abide by drilling regulations. Additionally, drillers contract certified hydrogeologists in their survey procedure and are therefore involved in the academic corner. Lastly, they are involved as a social group because they are embedded in communities when drilling.

Based on this analysis, the collaboration can be classified as multi-disciplinary. Although there is a blended field of work for some of the groups, there is minimal collaboration between them. However, each group is not a monolith of a community, meaning that most of the groups have members which specialize in a variety of things. This can make a higher form of collaboration easier to achieve.

5.2.5 Key Stakeholders

Based on the analysis in this chapter, seven stakeholder groups were identified as key to involve in the development of a groundwater monitoring system. As mentioned in the methods section, there were four components which determined if a stakeholder would be categorized as key. To reiterate, they are a member of the Pra River Basin Board, are identified as a principal water sector organization by the Ghana National Water policy, have technical capacity to develop groundwater monitoring services and are frequently mentioned as an important stakeholder in the interviews. Of the 29 groups mentioned in the interviews, the top 12 are incorporated as key stakeholders in this report. Additionally, table 19 was consulted to ensure that all contribution fields were fulfilled in the inclusion of the key stakeholders identified. This section contains and a brief summary of each organization and an explanation for its relevance as a key stakeholder for the development of groundwater monitoring.

Table 20. Key Stakeholder Determination

	Pra Basin Board Member[1]	Principal Water Sector[1]	Technical Capacity[2]	Rank[3]
Water Resources Commission (WRC)	×	×		2
Community Water and Sanitation Agency (CWSA)	×	×		6
Assembly	×	×		5, 8
Borehole Drilling Companies			×	11
Consumers	×			3, 12
Academic groups			×	4, 7, 10, 16
Ghana Water Company Limited (GWCL)	×	×		1

[1] table 16; [2] table 19; [3] see figure 34 for the frequency of mentions for a stakeholder

5.2.5.1 Water Resources Commission (WRC)

The mandate of the WRC is to "regulate and manage the utilization of water resources, and co-ordinate relevant government policies in relation to them" (Parliament of Ghana, 1996). The WRC is overseen by the Ministry for Sanitation and Water Resources, and specifically, the Water Directorate. However, this ministry operates at the federal level in Accra, whereas the WRC is decentralized with a local office for the Pra River Basin in Kumasi. Additionally, the previous groundwater monitoring program in northern Ghana was led by the WRC. If there were to be a groundwater monitoring system in Kumasi, it would be the WRC to oversee the program as mentioned by the interviewee representing the WRC:

> "It is within our mandate. We will go all out if we have the resources. … We want a system that is not as a reactive measure, but proactive. How do we check so that we also guide policies and town planning … We need data to push the agenda for people to really understand it."
>
> - Water Resources Commission 32

Given that the WRC would lead a potential groundwater monitoring program in Kumasi, it is also important to consider the groups which they cited as needing to work with. These include the Hydrological Services Department, Community Water and Sanitation Agency (CWSA) and the Ghana Irrigation Development Authority (GIDA). The hydrological services department is an agency with the Ministry of Works and Housing while GIDA is affiliated with the ministry of agriculture. The WRC was the only interviewee to mention GIDA, and this is because of GIDA's jurisdiction over monitoring in agrarian regions.

The WRC was the second most frequently mentioned organization in the interviews, behind the Ghana Water Company Limited. This shows they are well known among organizations, but it is worthy to note that no consumers mentioned the WRC. This indicates a knowledge gap in awareness of organizations by consumers.

Ultimately, the WRC was determined to be a key stakeholder because it is their mandate, the interviews with stakeholders prove that the respondents want the WRC to be involved, and, significantly, the WRC interviewee was the only respondent to indicate that their organization would lead a groundwater monitoring campaign.

5.2.5.2 Community Water and Sanitation Agency (CWSA)

Ghanian water distribution is delegated to two groups with different jurisdictions. Ghana Water Company Limited oversees *urban water supply* which utilizes piped water sourced from surface water and dams. Conversely, *rural water supply* is overseen by the Community Water and Sanitation Agency (CWSA). The CWSA relies on groundwater to supply their constituents. The CWSA's mandate is to "facilitate the provision of safe drinking water and related sanitation services to Rural Communities and Small Towns in Ghana" (CWSA, 2020). Therefore, the CWSA is not necessarily involved in monitoring, but because their service primarily concerns groundwater, they are an important stakeholder to consider for this case study.

The CWSA's water provision structure is decentralized as demonstrated in figure 40 The Ministry of Local Government and Rural Development in collaboration with the Ministry of Sanitation and Water Resources are the federal ministries which oversee rural water distribution. The key actions are overseen by the CWSA. Allocation of community water sources is distributed first to the regional level through Regional Water and Sanitation Teams (RWST) who stem from the regional coordinating councils (RCCs). Kumasi is located under the jurisdiction of the Ashanti RCC. At the next subsidiary level, district assemblies, through the District Water and Sanitation Teams (DWSTs) create a prioritized list of communities in need of water resources. This list is approved by the RWST. The approved communities are provided with boreholes for public access to groundwater.

Small towns and communities are defined to have a population range from 75 people to 50,000 people (Ministry of Water Resources, Works and Housing, 2010). Water delivery is divided between Water and Sanitation Development Boards (WSDBs) for small towns, and Water and Sanitation Committees (WATSAN) for rural areas. Both WSDBs and WATSANs are composed of a community formed membership and responsible for the overall management of water supply for the community.

Both are composed of volunteer community members who come together to make decisions on their water source. In each system, there is a mechanic and water caretaker. The mechanic works on large repairs of the community's public borehole while the caretaker oversees the operation of the borehole through small repairs and collection of fees from consumers who come to collect water.

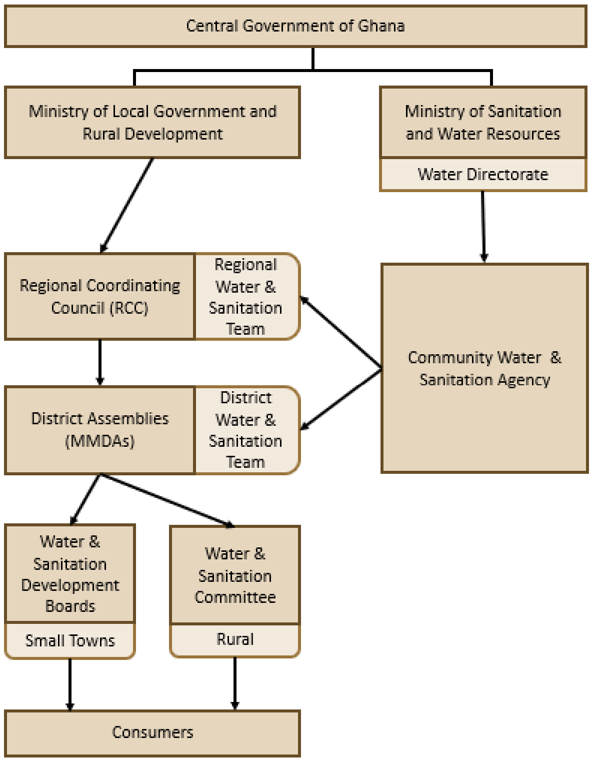


Figure 40. CWSA decentralized government

Despite this decentralized community water management system, four of these groups were not mentioned in the interviews: RWST, DWST, WATSAN and WSDBs. This could be because this management system is not implemented in practice, respondents are unaware of the groups, or they do not play as significant of a role as the policy documents suggest. However, public borehole caretakers were mentioned in the interviews. These individuals are a key operational fixture in the community as access to water through the public borehole relies on the caretakers.

The CWSA is one of the three agencies under the Water Directorate of the Ministry for Sanitation and Water Resources which therefore makes it relevant for the study. Additionally, as a large government organization, the CWSA has multifaceted employees including government officials and technical staff which makes them well equipped to take part in a multidisciplinary project like groundwater monitoring. As the overseeing agency for the community distribution of groundwater, their involvement would include the access to both the human resources and the borehole infrastructure. The CWSA would benefit from a groundwater monitoring system because the information would aid in their borehole drilling efforts. It is imperative, however, that for the CWSA to be involved, the project should be within their jurisdiction of small towns and rural areas.

> "If the lead agency decides to collaborate with us, we can give the technical expertise depending on availability. That is what we can contribute, but in terms of funding, we do not have the resources because it is not our mandate. We are not the lead agency"
>
> - Community Water and Sanitation Agency 45

5.2.5.3 Assemblies

In connection with the CWSA, local governments should be involved. First are the **assemblies (MMDAs)** which can be metropolitan, municipal or district depending on population size. A groundwater monitoring project would most likely focus on municipal or district areas because these are the areas with high borehole use. The main departments within the assembly to be involved in a groundwater monitoring project are the **environmental health departments** and **works (engineers) departments.** Both departments were mentioned in interviews as groups who could contribute to and promote the application of groundwater monitoring within their jurisdictions.

The individuals in a community are familiar with their local **assemblyman** representative as well as the **committee members**. As mentioned in the interviews, if a large water monitoring program occurred in a community without the knowledge of the assemblymen, this would create an environment with low trust. Having the support of local government can create a smoother transition for monitoring to take place within communities.

Local government was included as a key stakeholder group to fulfill a decentralized model of water management. The local leaders have more intimate knowledge and relationships with the communities and their support is key for successful local programming. Additionally, the expertise of the assemblies would be valuable as their existing structures may lend itself to utilizing groundwater monitoring.

> "We don't have groundwater management because we don't have funding. We need people to come in and train us so that we can handle it ourselves."
>
> - Assembly Man 08

5.2.5.4 Borehole companies

The next stakeholder involved are **private borehole companies**. These groups are essential to the groundwater landscape in Kumasi. They are the link between consumers and the groundwater as they are the surveyors, hydrogeologists, and physical drillers. The organizations maintain data for all the boreholes drilled and share it with others upon request. Borehole companies are mandated to register with the WRC and share data with them.

Private borehole companies are included as a key stakeholder because of their multifaceted involvement in the groundwater sector of Kumasi as noted in the collaboration model (figure 39). They are in the academic group because of their technical expertise, the social group because of their interaction with private individuals for drilling, and the institutional group because of their registration with the WRC. In this way, borehole companies provide a useful link between the communities of practice which can applied in a groundwater monitoring program.

> "With groundwater we have an ally to regulate the use of groundwater. The idea was to register all individuals who use boreholes who use their water from underground and use groundwater as the main source. But we have not been able to achieve that. But we have achieved it for commercial purposes. We have to first register you and then give you a permit, and we need to make sure you follow the guidelines. The third wing is borehole drillers. We register them. We have a training for them, so they have a good result for their client, and they give us good data. They give us data for where they drill boreholes."
>
> - Water Resources Commission 32

5.2.5.5 Consumers

Depending on how groundwater monitoring is implemented, **consumers and owners of wells and boreholes** should be involved. Should groundwater monitoring utilize public or private groundwater access points, then the consumer and owners of those sources must be consulted with in a participatory manner. Additionally, there is great interest from community members to participate in such a system as mentioned in table 19. As consumers are the end users, their participation should be ensured. This approach aims to be participatory: not top-down or bottom-up, but a system in which the groups are contributing to each other from all sides.

"We all come together to make water clean and have faith to involve ourselves in a voluntary way we can protect and monitor our groundwater well."

- Domestic Consumer 15

5.2.5.6 Academic Institutions

The next stakeholder is identified as a collection of groups: academic institutions. First, **KNUST** is the premier technical university in Ghana and has departments with technical experts in groundwater, hydrogeology, big data and have the necessary experience and familiarity with groundwater management in the region. When interviewed, the KNUST individuals were enthusiastic about being involved in a groundwater tracking project.

"If there were to be a water monitoring program here in Kumasi, we will be happy to be involved but right from the beginning. For instance, if you are developing a database platform we want to be involved because it is such that, if a program ends, we can continue. When choosing a platform, we want to be involved so we work with the university here. We have the IT services so they understand the code and the platform, so when there is no coding, we can support it."

- KNUST 43

Another key academic group is the **Council for Scientific and Industrial Research- Water Research Institute (CSIR-WRI)**. This is a government facilitated research group with headquarters in Accra. The group has seven areas of research focus, and one of them is groundwater research. This research division's long-term objective "is to generate, process and disseminate information on the availability of groundwater, quantity of water to be abstracted for various uses as well as the reliability and sustainability of its recharge" (Council for Scientific and Industrial Research, 2020). The division, as of 2020, has taken up groundwater monitoring, assessment, and database management as key tasks. Specifically, there are projects which establish groundwater monitoring networks in the Pra Basin as mentioned in chapter 2. However, despite this major development, there is a lack of knowledge about the program as it was not mentioned in any of the interviews. In collaboration with the WRI, is the **Ghana Atomic Energy Corporation**, as they partner with the WRI to monitor groundwater for isotopes and have funding to support the project.

The next academic group to be involved in the project is the Delft University of Technology's research groups the **African Water Corridor** and the **Delft Global Initiative**. The TU Delft Global Initiative seeks to cocreate with "all relevant stakeholders" (TU Delft, 2019). This research group seeks to serve as a knowledge partner to aid in water resource management in Sub-Saharan Africa. The group has existing partnerships in the Kumasi water sector and has current projects relating to groundwater aquifer recharge for domestic wells. Therefore, they have the capacity and partnerships to integrate into the academic side of a groundwater monitoring solution.

> "What our role really is here, is to just to quantify the problem and then really drive an education awareness campaign around what that problem is- then it's clear and what solution options there are."
>
> - TU Delft 46

These three groups (KNUST, CSIR-WRI, TU Delft) were identified in the interviews, however the scope of involvement from academic groups should not be limited. There are several other academic, research and training institutions in Ghana which could contribute to this project in a meaningful way. This includes but is not limited to Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED), Sunyani Technical University and University of Energy and Natural Resources (UENR).

5.2.5.7 Ghana Water Company Limited (GWCL)

Ghana Water Company Limited is the third agency under the Water Directorate of the Ministry of Sanitation and Water Resources. Their primary objective is water delivery through piped systems in urban areas. In this case study, the urban area is the metropolitan of Kumasi and some of the surrounding regions where the piped network reaches. The company also has a drilling unit which offers borehole drilling services for private use. GWCL is consequential as a stakeholder in water resources management in Ghana as evidenced by it as the most frequently mentioned organization during interviews.

However, if GWCL were to be involved in groundwater monitoring, it would need to be of use to them- meaning the data would need to be in their service area where they are hired to drill private boreholes, or in an area where they utilize groundwater. Most of GWCL's water supply is derived from surface water, but they also supplement that with groundwater. Despite the fine line of interest, GWCL is valuable because of their prominence in the Ghana water sector and technical assets.

> "From where I sit, it will be useful for Ghana water, but we will not take initiative. Ghana water can partner with others to take initiative on monitoring water"
>
> - Ghana Water Company Limited 34

5.3 Discussion

The discussion section for this research question reviews the data in a critical lens to compare the outcomes with expectations. Additionally, the quality of the results are discussed regarding limitations, potential sources of bias and representative metrics.

5.3.1 Results Discussion

5.3.1.1 Consumers

There was a gap in knowledge of water sector organizations between consumers and organizations. Significantly, consumers frequently mention the Ghana Water Company Limited as an important stakeholder for groundwater management, despite the fact that GWCL does not provide groundwater for public access. The Community Water and Sanitation Agency provides infrastructure for public groundwater access and private borehole drillers provide private groundwater access under regulation of the Water Resources Commission. Therefore, there is a false attribution for GWCL to oversee groundwater when, in reality, it is the CWSA, WRC and private borehole drillers who are the primary providers of groundwater. This is likely a visibility concern as the GWCL is well known and established, whereas the CWSA is lesser known. Although consumers did not mention the CWSA, they did mention the public water caretaker who operates within the service of the CWSA. This indicates a lack of understanding of the broader governance structure.

In connection to this result, a contributing result is that consumers are most familiar with stakeholders closest to them in service delivery. This means that consumers are more likely to mention a stakeholder who operates at a local level such as the caretaker, assembly, and committee members. Additionally, consumers mentioned general stakeholders as opposed to specific organizations. For example, consumers would cite the need for “experts” rather than “KNUST researchers”. This further illustrates the consumers’ a lack of understanding of key players in the water sector.

Lack of awareness is not a unique trait in Kumasi. An Organization for Economic Co-operation and Development report on water governance states that many other countries experience a “lack of citizen concern about water policy and low involvement of water users’ associations” (OECD, 2011). This includes Chile, Italy, Korea, Mexico and even the “international example” of water resource management, the Netherlands (OECD, 2011). However, it is worth considering if consumers particularly need to know of these government institutions. Does their knowledge of institutions or lack thereof impede groundwater management? This could be a topic for future study. However, if consumers are going to be involved in a participatory groundwater management strategy, then they should be aware of the stakeholders with whom they are working.

5.3.1.2 Local Water Governance

Despite the CWSA’s decentralized model for water governance in communities and small towns, these groups, specifically WATSANs and WSDBs, were not mentioned in the interviews. Anecdotally, during an interview with an assembly man, he mentioned the need to have a committee to fulfill the purpose of WATSANs and WSDBs. This could illustrate that these groups are not fully operational or known in some areas.

[we need to] “establish a committee that will enable to help groundwater to do their work successfully in the community”

- Assembly Man 31

5.3.1.3 Division of tasks in the water sector

There are three agencies under the Water Directorate of the Ministry of Sanitation and Water Resources: the Water Resources Commission, the Ghana Water Company Limited, and the Community and Water Sanitation Agency. The GWCL and CWSA belong to the service provision sector whereas the WRC belongs to the regulation sector. While the GWCL is mandated to oversee water provision in urban areas through piped water distribution, the CWSA oversees water distribution in rural areas through provision of public wells and boreholes to communities.

Each of the three organizations seeks to achieve the subsidiary principle of integrated water resource management. The subsidiary principle aims to manage water resources at the lowest practical level. The WRC establishes river basin management districts. The CWSA achieves this through establishing regional and district water sanitation teams and even through community level management.

However, as service providers, the GWCL and CWSA's service areas do not align with the same bounds as the WRC's. The GWCL oversees strictly urban areas and the CWSA oversees strictly rural areas. The interviewees with these groups insisted on the separation between the two groups. However, the WRC's jurisdiction does not relate to populations in urban or rural areas, but by watershed as recommended by integrated water resource management guidelines. There are clear pros and cons of this management style. For the WRC independently, this is ideal and follows the principles outlined by the Global Water Partnership for successful water management. However, because there is limited interaction between the three groups, management can be challenging as evidenced by misalignment for responsibility among other stakeholder groups.

5.3.1.4 Communities of Practice

As demonstrated in section 5.2.4, stakeholders in the Kumasi water sector have intersecting communities of practice. For example, many groups have academic components, even when the organization is not strictly an academic institution. This points to the idea that not only can these organizations belong to multiple communities of practice, but also that boundaries within communities of practice are limited.

The figure below illustrates that each academic group (green square) has a groundwater community of practice within it (brown circle), but there are boundaries toward entering the community because of a lack of awareness of the group's projects (a). However, if groups are given access to each other and awareness of projects, there can be innovative knowledge exchange to prevent groups from becoming "self-contained, defensive and oriented towards its own focus" (Verouden, 2016). The idea of limited boundaries in communities of practice is an idea that Wenger emphasizes in his publications on communities of practice (Wenger-Trayner & Wenger-Trayner, 2015). This is illustrated in figure 40b because if there are limited boundaries (dashed lines) for similar communities, then goals (brown circles) can be shared, and groups can work more effectively.

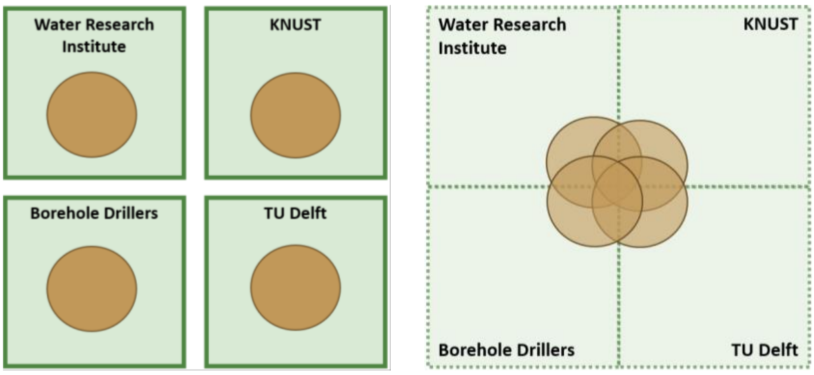


Figure 41a. Communities with boundaries 40b. communities with minimal boundaries

5.3.2 Data Quality

5.3.2.1 Bias

A key bias of this portion of the study that could only be determined after the interviews is acquiescence bias in the context of asking individuals what they would want to contribute to a groundwater monitoring project. This type of bias occurs when an interviewee responds in a manner which they anticipate will please the interviewer. The results showed a high percentage of involvement in a groundwater monitoring system from all stakeholder groups. However, this could be biased because they could have responded “yes” to involvement because they wanted to please the interviewer.

5.3.2.2 Limitations

The overarching limitation for the study is the sample size. Due to limited time and resources, there was a low sample size per group, with four groups sample size ranging from 3-6 while there were 28 domestic consumers sampled. However, a larger sample size, in some cases, would not be possible. Some of the organizations have a low number of staff and therefore the maximum number of participants is limited.

In addition to a low sample, there were other groups which were not interviewed. Specifically, it would have been valuable to interview *bottled and sachet water companies* who abstract massive quantities of water for commercial distribution. Additionally, *nongovernment organizations* play a significant role in funding drinking water projects in Kumasi. The *Council for Scientific and Industrial Research- Water Research Institute* would have been incredibly valuable as an interview given their research capacity, mandate, and current efforts to monitor groundwater. However, they do not have an office in Kumasi, and were unable to be contacted through other means.

5.3.2.3 Metrics of Quality

Precision: The main result of the section was the list of key stakeholders in groundwater management. This result was precise given the specific of the organizations defined and the distinct nature of the different groups.

Accuracy: The results are accurate because the identification of key stakeholders was cross checked with Ghanian policy documents as well as existing literature.

Validity: The output of this section is valid because the goal was to identify key stakeholders in the groundwater management field. The outputs were a list of organizations and their roles.

5.4 Summary

RQ1: Who are the key stakeholders in the development of groundwater monitoring in Kumasi, Ghana and what are their roles?

The first research question seeks to analyze stakeholders, their roles and relevance to groundwater monitoring. This was achieved through literature and policy review to have an overview of stakeholders and conducting interviews with individuals in Kumasi involved in the water sector. The results of the study were a complete overview of groups with significant involvement in the Ghanaian groundwater sector, their roles, and a network graphic to illustrate their involvement structure. Based on the methods, the key stakeholders and several other takeaways were derived from this research question to be incorporated further in the report.

1	*Collaboration*: Ghana's water governance is based on a hierarchal structure with decentralized components for groundwater distribution; the collaboration within this structure can be classified as multidisciplinary due to the many disciplines involved but limited integration of those communities of practice.
2	*Consumers*: interviewed consumers are familiar with organizations close to domestic supply; consumers also remarked that there is a lack of awareness for groundwater management practices
3	*Readiness*: Most interviewees responded with a readiness attitude towards involvement in groundwater monitoring. This includes respondents who would be involved for all identified tasks.
4	*Key stakeholders*: Over 40 groups were identified with a role in groundwater management in Ghana and Kumasi; there were seven actor groups identified at key which are listed below

Table 21. Key stakeholders and role

Stakeholder	**Relevance to groundwater monitoring**
Water Resources Commission	Key facilitator in the implementation of groundwater policy and mandated to do so.
Community Water and Sanitation Agency	Facilitator of water distribution in rural areas where groundwater use is high.
Assemblies	Local government will provide knowledge of area and aid in implementation
Private borehole companies	Borehole companies enable consumer access to groundwater and are the intersection of institutional/ academic and social sectors.
Consumers	Depending on the scope of groundwater monitoring, households are the end user for monitoring.
Academic institutions	Technical experts can contribute the assets and feedback for a successful groundwater monitoring system.
Ghana Water Company Limited	Facilitator in water distribution in urban areas.

Chapter 6 Groundwater Management Practical Considerations

6.1 Motivation and Goals

Front Material			Body Research Questions			Conclusions	
Context	Theory	Methods	RQ1	**RQ2**	RQ3	RQ4	Conclusion

RQ2: What are important considerations in the groundwater management setting in Kumasi, Ghana?

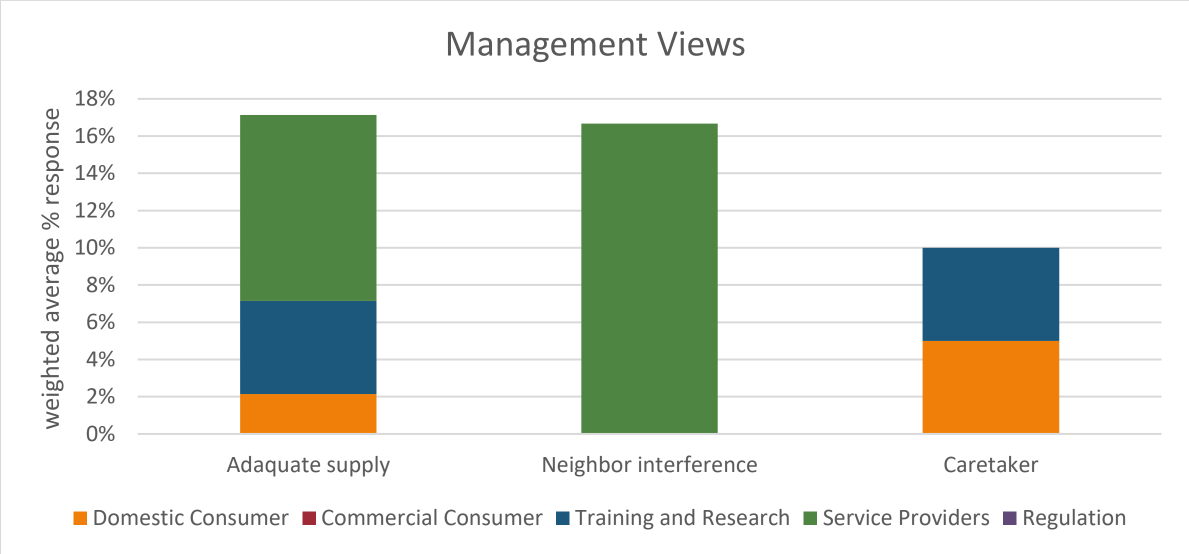
In addition to Ghanaian water policy, it is also valuable to understand groundwater management in practice. This section of the report focuses on how stakeholders interact with groundwater and what they would like to see in a management system. The goals of this section are:

Objectives	
	Identify views on and satisfaction with current groundwater management
	Identify practices involved in borehole drilling
	Determine challenges in groundwater management
	Determine design requirements for a groundwater monitoring system

6.2 Results

6.2.1 Groundwater Management

The first result corresponds to views on current groundwater management in Kumasi. As was done in chapter 5, the results in this section are weighted averages and calculated with equation1.



Only 2 of the 46 respondents had a *positive* comment to leave about groundwater management. Both responses were from service providers and the comment was about being pleased that communities have access to groundwater. However, the most common response was that there was *no management*. This response came from four of the five groups. These responses would say that there is no management or that is does not exist as in the example below.

> "So honestly, the laws of groundwater management in Ghana are not existing. We don't have it. Unlike maybe when you go to Nigeria."
>
> - Hydrogeologist 40

6.2.2 Groundwater consumption

6.2.2.1 Groundwater access types

When interviewing groundwater users, their type of access was asked. The results show that most of the sampled consumers use mechanized boreholes through public access. When discussing reasons why the individuals used groundwater, most responded that it was the only source available to them. This further illustrates the concepts discussed in the context section where the Ghana Water Company Limited pipelines do not reach rural areas outside of the Kumasi metropolitan area.

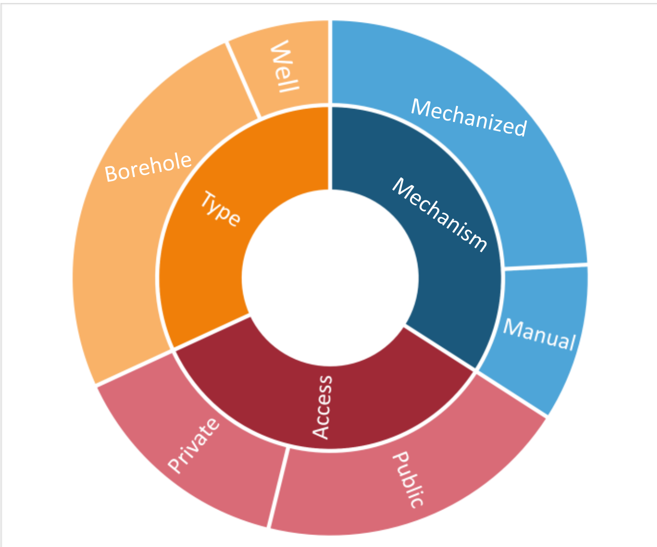


Figure 42. Groundwater Access

6.2.2.2 Groundwater Satisfaction

The next result is for groundwater satisfaction by consumers specific to quantity, quality and overall satisfaction. A response of "OK" indicates that the respondent simply said that their satisfaction is "okay". Conditional satisfaction was coded when a respondent indicated they were satisfied given other conditions.

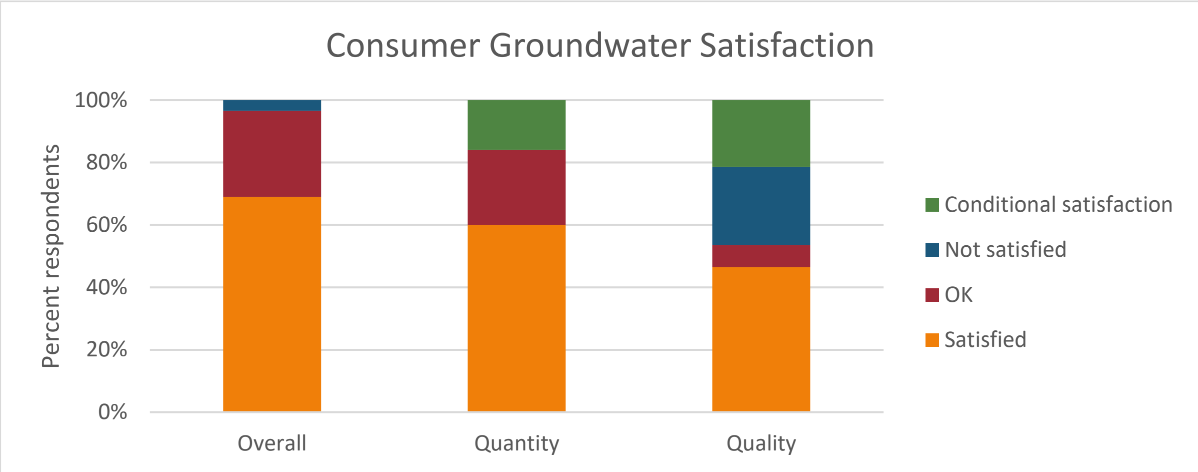


Figure 43. Groundwater consumer satisfaction

The results show that most respondents were overall satisfied with their groundwater and its quantity. The primary conditional response for quantity satisfaction is that they were satisfied most of the time, but it is challenging in the dry season.

The response for quality is spread with more conditional and unsatisfied responses than for overall and quantity satisfaction. Most of the conditional statements for quality were related to treating the water either with chemicals or a filter, or that they have the water tested for quality. When a respondent indicated that were not satisfied, this was mostly due to taste issues, saltiness or that they do not use it to drink or cook.

"Sometimes there are some worms in the water which is not advisable. It causes sickness but they don't know the reason they are getting sick. So, if there is monitoring, it will help with this sort of problem"

- Domestic Consumer 16

6.2.3 Borehole Drilling

An essential component of groundwater management in Kumasi is borehole drilling. This is because boreholes are a mechanism which provides groundwater to consumers. In discussions of groundwater monitoring and management, there were four key areas which were discussed in detail with interviewees. First, is the limitation of piped water access. Second is the borehole drilling procedure and the regulations participants are supposed to abide by in the process. Third, concerns regarding neighboring interferences are discussed. Lastly, concerns regarding poor borehole construction are explained.

6.2.3.1 Access to Water

Starting with the consumer, communities on the outskirts of urban areas frequently lie outside the distribution network for piped water provided by the Ghana Water Company Limited (GWCL). The consumption of piped water is metered, and bills are paid to GWCL. Supply of piped water is often inconsistent as mentioned by respondents. For this reason, individuals without access to piped water or who want a backup source to piped water supply, will utilize groundwater.

> "If they rely on Ghana water, the water will be cut off. But they work every day, so they need the water to work"
>
> - Car Wash 36

There are multiple groundwater access options, and the selection is often determined in part by income. Those who can afford it might install a private borehole on their property. Although it is private, if the owner wants, they can choose to allow neighbors to utilize their private borehole. Installation of private boreholes is a complex and, according to respondents, many borehole drillers do not abide by the regulations. Because of this, it was cited in 11 interviews that there was no regulation on groundwater. Many respondents said that if one has financial resources, there is little standing in the way of installing a borehole on their private property.

> "In areas where the [piped] system doesn't extend to, people have decided to drill their own boreholes within their own houses. The law says that if you want to drill a borehole in your house, you must seek approval from the Water Resource Commission. Over time, people who drill boreholes don't seek approval. So, it is very difficult to manage that. So, the management of groundwater level, as far as the city is concerned, is very difficult. Because anyone at all can decide to drill a borehole. They call anyone at any time to drill a borehole for them, so it has made the management of boreholes and groundwater very very difficult because the regulations are there, but people are not following it."
>
> - Community Water and Sanitation Agency 45

6.2.3.2 Drilling Procedure

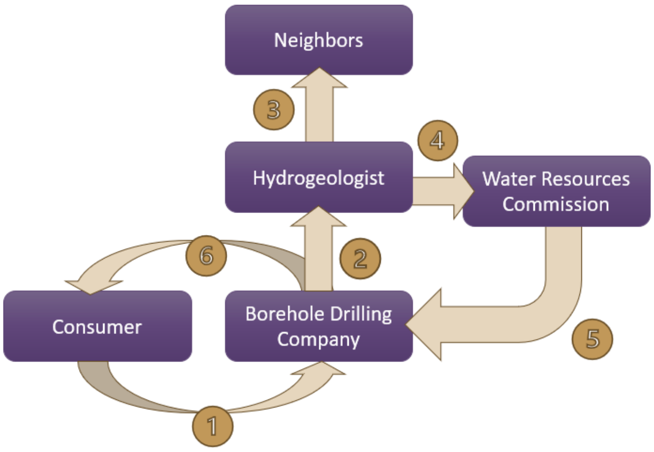


Figure 44. Borehole drilling procedure

The figure to the right illustrates the procedure for drilling private boreholes for domestic use. First 1, the consumer hires a borehole drilling company to provide groundwater access through drilling. The drilling company hires a certified hydrogeologist 2 who, with a team, conducts a geological survey of the area proposed for a borehole. In this survey multiple criteria need to be evaluated both through technical survey protocols and seeking information from neighboring areas (see next section for details). The survey team will consult neighbors 3 for information on locations of nearby septic tanks, boreholes and drilling records of nearby boreholes. The neighbors might have hard copies of the drilling reports given to them by the hydrogeologist who drilled their borehole. These reports can be shared with new drillers, so they are well informed on the local groundwater situation. Upon completion of the survey, the drilling team and hydrogeologist report back to the WRC 4 to register the borehole 5. Once this process of surveying and registration is complete, then the borehole drillers 6 can drill for the consumer.

This demonstrates the procedure recommended by experts during interviews, but as the next section demonstrates, this procedure is not always followed.

"I feel that abstraction of groundwater should be regulated. Why? The private drillers who drill to get groundwater for individuals, they only look at your 30x30 meter size of plot and then they find a place to go drill not thinking about the quality of water they are going to get or what your neighbor is doing. The education is not there, the information is not there, and the data is not there to educate us, so everyone is just doing what they want to do. They are abstracting and then they are finding cracks in their buildings, and it is settling. In Ghana they don't have a sanitary waste system. Most people have a septic tank in their premises. They might have a septic tank and so they drill far from it on their property, but that might be closer to your neighbor's septic tank. So, there is contamination going on."

- Ghana Water Company Limited 34

6.2.3.3 Neighboring Interferences and Concerns

Surveying nearby properties is critical for the stability of the aquifer and the safety of the resulting groundwater. Figure 45 illustrates an arial view of a community where each cell represents a walled property, and the dark green cell represents the client who wants a borehole drilled on their property. First, determining locations of septic tanks is critical, because if a borehole is drilled too close, this can be dangerous for quality concerns. The figure illustrates that if a survey is not conducted, a driller could unknowingly drill a borehole right next to a septic tank. It is important to determine locations of nearby boreholes, as drilling too many boreholes within an area can destabilize the aquifer. Obtaining the drilling reports of nearby boreholes is important because understanding the depths of neighboring boreholes will influence the design of future boreholes. This is because the depth of one borehole can impact the yield of new boreholes.

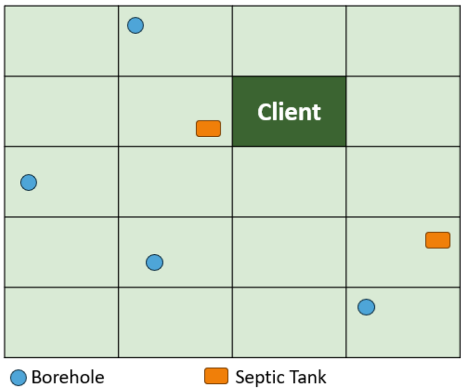


Figure 45. Arial view of community

> "Wherever we work, we make sure we keep records ... I have a soft copy for myself and one for the client. So that the client can show it to the drilling team of your neighbor [and tell them] 'When they drilled for me, they drilled 10 years ago, this is the report they gave to me…'"
>
> - Hydrogeologist 39

As illustrated below, when a competing borehole is drilled, it will take longer for both wells to abstract a volume of water. This change is illustrated by the change in drawdown level in the red arrow. The dashed lines indicate the cone of depression for the first yield (dashed) and the second yield after the other borehole is drilled (solid line).

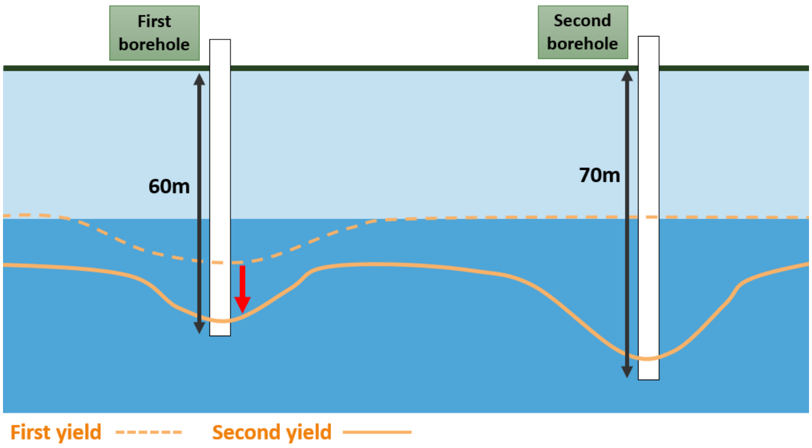


Figure 46. Neighboring borehole interference

> "Let's say [your borehole is] 60 m and your neighbor drills 70m. Automatically if before you were pumping 20 minutes for 2500 [liters] … it will [now] take more hours before it can get full"
>
> – Hydrogeologist 39

6.2.3.3.1 Anecdote

The excerpt and illustration below tell an anecdotal story of an individual (neighbor A, hydrogeologist 40) seeing his neighbor (neighbor B) drill from behind a wall. This provides a narrative of the importance of communication in the borehole drilling sector.

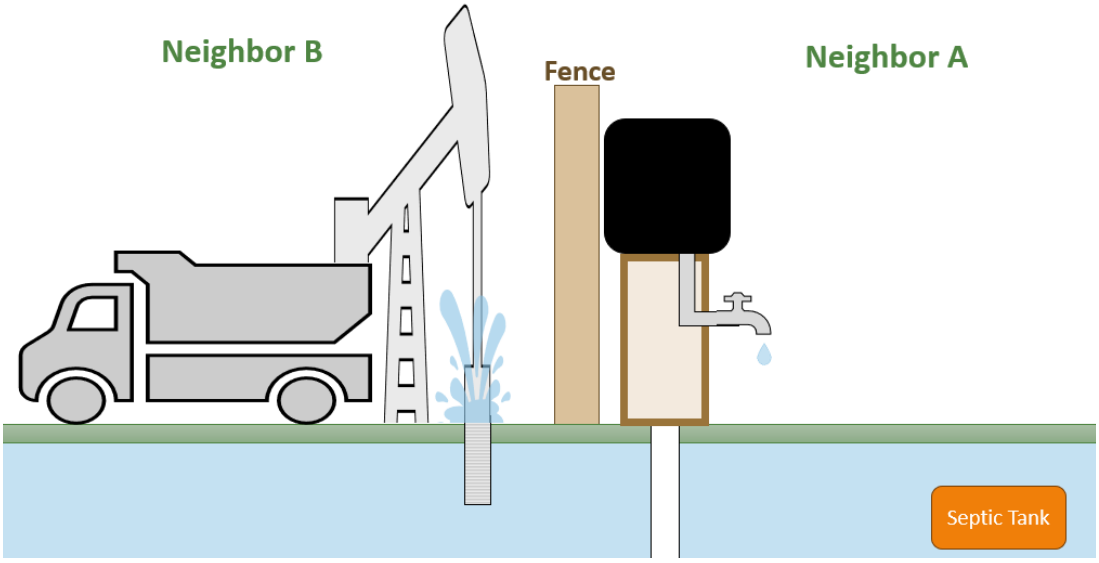


Figure 47. Illustration of anecdote

> "Well, you see here our laws in government of groundwater are so relaxed. You can just wake up and say, "I want to drill a borehole". And then a house here can also drill a borehole. Initially, I [**neighbor A**] am sharing the first one with him [**neighbor B**], so his borehole was closer to mine, but because of the fence, he was not seeing it. So, when I saw the machine and I went over and I said, 'I have drilled here, so if you drill your borehole here there could be issue of interference'. Because he felt the land belongs to him, he never understood what I was saying. Then I told him I have my septic tank here too as well, so it could get contaminated. So, it wasn't until then that he understood and shifted it"
>
> - Hydrogeologist 40

This story complements the details shared by other interviewees and illustrates the informal communication which goes on in the borehole drilling sector. If neighbor A did not have the technical background and intuition to go speak with his neighbor (B), then the borehole could have been drilled and cause interference between both systems.

6.2.3.4 Poor Construction

Many of the interviewees were concerned that appropriate drilling procedures are not followed and that this endangers the aquifer and the water itself. The hydrogeologists interviewed share the concern that many drilling companies do not dig sufficiently deep enough into the aquifer, do not use appropriate materials, and do not conduct a survey before drilling.

> "They're approaching to the drilling activity is little bit- I would say is questionable. They are looking at profit margin. So sometimes the quality of the construction is compromised. You know, with the borehole drilling it is not just about the punching of the hole."
>
> - Ghana Water Company Limited 33

The reason for this poor construction and not following the regulations is due to cost, according to the interviews. The longer it takes to drill, conduct a survey, or drill deeper involves more money to complete the tasks. And if a client does not have the means to pay for those services, the borehole driller may skip the portions that the client does not pay for. Drilling shallow wells was a large concern because in the dry season, the borehole may struggle to achieve desired water quality standards. This is depicted in the figure and complementing quote below which shows that in the dry season, the quality may suffer in a shallow well, as denoted by a turbid water droplet.

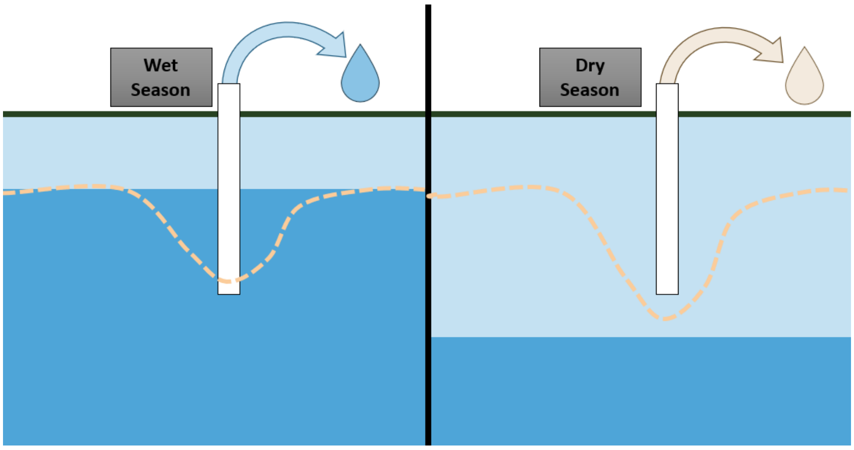


Figure 48. wet season versus dry season water yield

> "Some people will not give you the amount of money you asked. …. Although you will get water, because of the amount that you give to a person [borehole driller], you will not have enough pipe to get to the water. So, you get surface water. We cannot buy more pipes to get to the water. So that is the problem with the dry season you cannot get that much water. If you pump to the tank, you will see it is dirty. So, it will be a good position for the owner of the borehole or the landlord to give you money to buy the materials."
>
> - Borehole driller 38

6.2.4 Data Sources

Another key component of understanding practical groundwater management in Kumasi is taking note of organizations which monitor groundwater in any capacity. These results arose in the interviews when asking about groundwater monitoring and any knowledge the interviewee had on existing groundwater monitoring infrastructure. The result was seven organizations which have some form of groundwater data either currently or in the past. Table 22 shows the organization which possesses the data, the source(s) who identified the data collecting organization, and how the data is managed.

Table 22. Organizations in possession of groundwater data

Organization	Sources	Data management
Borehole drillers	TU Delft WRC Borehole Companies Hydrogeologist	Varies per company. They are required to provide survey data to the WRC for boreholes drilled.
Community Water and Sanitation Agency	CWSA Hydrogeologist	Some data on boreholes through the Ashanti region; some hard copies not digitized
Foreign Organizations	Hydrogeologist	Internalized information and not available
Ghana Water Company Limited	GWCL	Drilling reports, most of which do not have GPS coordinates; hard copies
KNUST	KNUST	Used for studies; no master database
Mines	KNUST WRC Hydrogeologist	Have monitoring wells in regulated mining regions
Water Resources Commission	WRC	Data derived from borehole drilling reports
Ghana Irrigation Development Authority	WRC	Groundwater data for agriculture

As borehole drillers are a key component of groundwater infrastructure, it is worth pointing out that there is no data exchange after drilling. The drillers conduct the survey, drill and report to the WRC, but after that, there is no more data collection as mentioned by the WRC:

> "What we do with the borehole drillers is a partnership. We don't have resources to collect information. So as a part of the permit conditions, they have to submit information on every borehole they drill for us. It is only with the drilling. We don't follow up with the using. They do the pumping test, but what happens after the client is using the water- there is a gap. That is where, as a commission, we need a strategy for getting it."
>
> - Water Resources Commission 32

6.2.5 Groundwater Management Challenges

When discussing challenges in managing groundwater, there were seven phenomena which reoccurred throughout the interviews. The two most cited challenges are collaboration and lack of awareness which both fall under communication challenges. Collaboration and funding were cited with almost unanimous agreement from the organizations and only few mentions from the domestic stakeholders. Lack of awareness was mentioned as a challenge for all stakeholder groups, but mostly with consumers.

The graph shows that the main groups citing challenges were the organizations, with consumers mostly commenting on capacity concerns and lack of awareness. This can lead to the conclusion that consumers are insufficiency informed on groundwater management and therefore are unable to identify challenges.

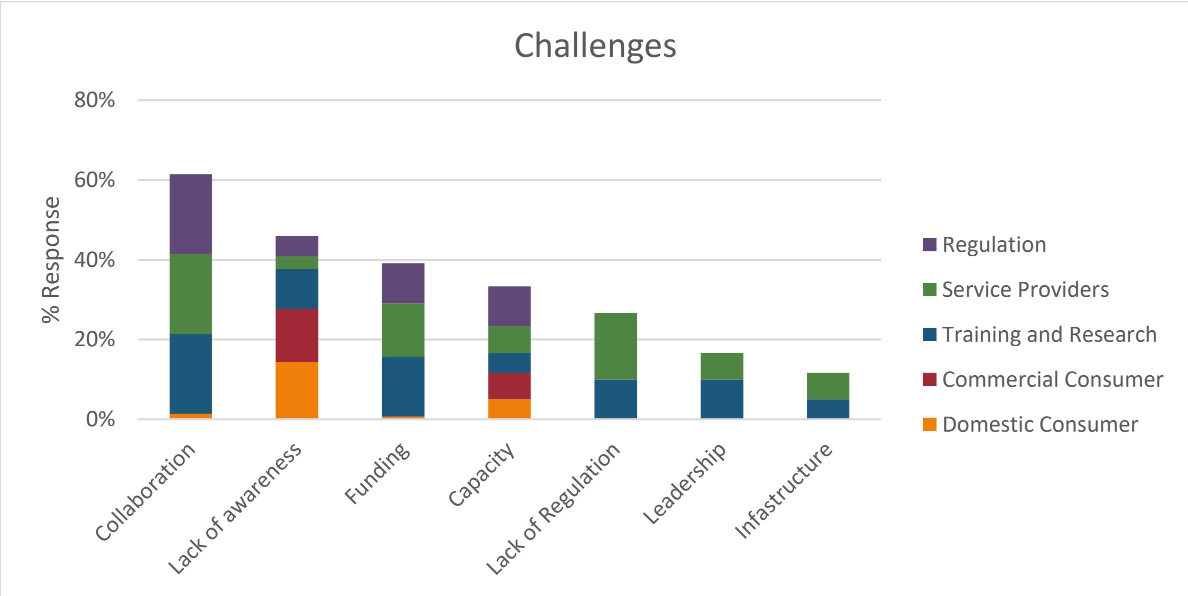


Figure 49. Challenges in groundwater management

6.2.6 Groundwater Monitoring Design Requirements

In coding the interviews for design requirements, three categories resulted: collaboration, function and technology. *Collaboration* was coded as any design requirement or activity that would involve information exchange. *Functions* were coded to indicate how the monitoring should work. *Technology* indicates a specific technological device or program to be applied in a system.

There were 22 total design requirements identified. When assessing each stakeholder group, the training and research group identified the most in every category. This illustrates the need to incorporate technical experts in the development of a groundwater monitoring system.

Table 23. types of design requirements by group

	Domestic Consumer	Commercial Consumer	Training and Research	Service Providers	Regulation
Collaboration	2	1	4	3	3
Function	4	3	8	6	7
Technology	1	0	7	3	4
Total Design	7	4	19	12	14

6.2.6.1 Collaboration

One of the challenges respondents referenced most is the need for collaboration in the water sector. When discussing design requirements in the collaboration category, education was the most reported response mentioned by all stakeholder groups.

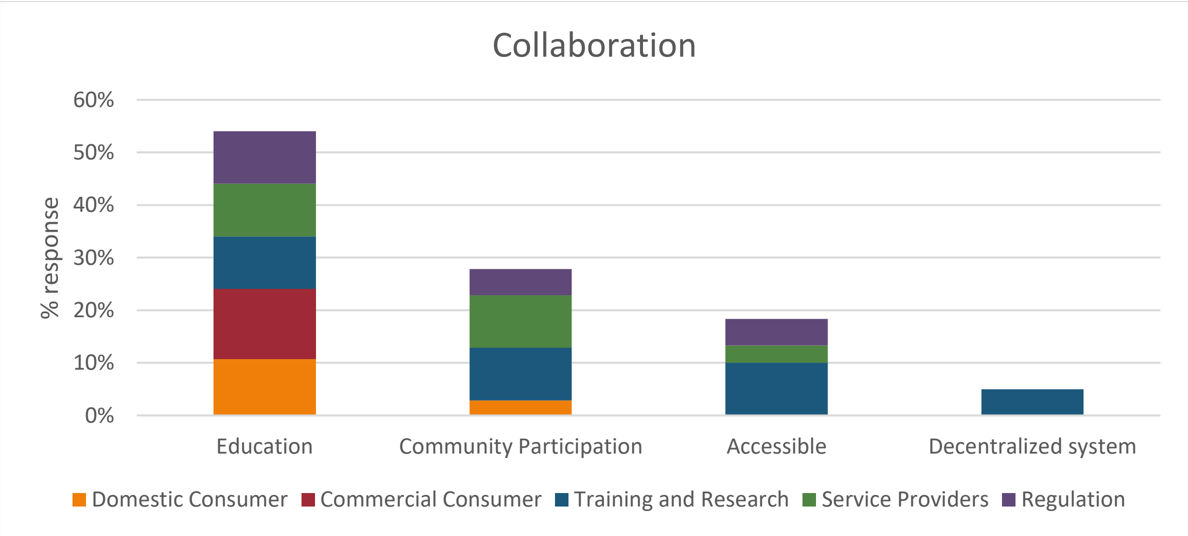


Figure 50. interviewee design requirements relating to collaboration

6.2.6.2 Functions and Technologies

In discussing the functions of a groundwater monitoring technology, ten functions were identified. The most cited function is for the system to have a **large scale of data** to account for the heterogeneous nature of the aquifer in Kumasi. This is connected to **spatially targeting particular areas** to target vulnerable areas or high groundwater use regions.

> "Ideal monitoring system in Kumasi should have well distributed monitoring points, data accessible remotely, an easy to maintain system which without sustainable support should still be able to run with a lot of local involvement"
>
> - KNUST 43

There are two functions that were notably mentioned by consumers. First, consumers want to know their **water consumption levels**. This would indicate a personal groundwater monitoring system. However, the regulating agencies did not ask to monitor domestic groundwater use. This points to the earlier findings that there is a readiness in consumers to participate and gain more knowledge about their water use. Consumers also identified the desire for a monitoring system to offer a **service**. Examples given in interviews include water treatment or maintenance on their borehole. Lastly, many respondents cite the need for **more regulation** in the water sector. This supports the view of water management as either nonexistent or poor in section 6.2.1.

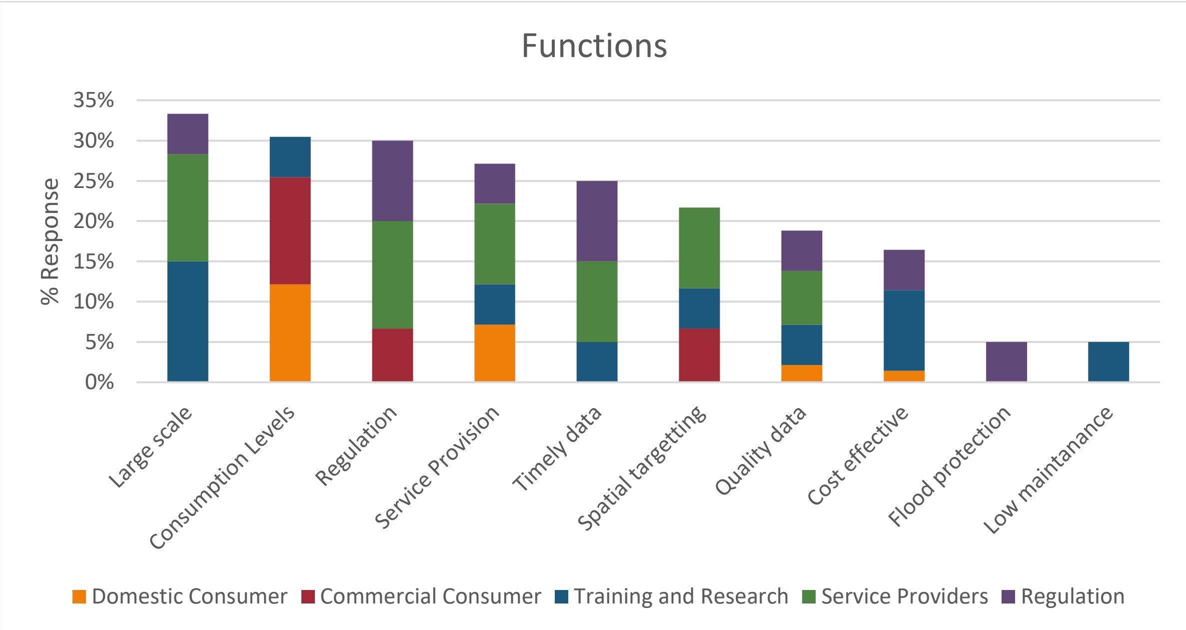


Figure 51. Interviewee design requirements relating to functions of a groundwater monitoring system

The findings on technology were limited and not specific, the main ideas presented in the findings were derived from academic groups with additional contribution from regulators and service providers. These concepts include:

- Data repository
- Device
- Models
- Telemetry
- Aquifer recharge
- Mobile technology
- Open data
- Pilot test

6.3 Discussion

6.3.1 Methods Discussion

When discussing groundwater monitoring, during the interview, the concept of monitoring was kept vague in the interview script. The reason for this was to provide the respondents with freedom to describe their interpretation of groundwater monitoring and specify their desires for a system without interviewer bias. For example, if the interviewer had described a groundwater *level* monitoring system, this would limit responses to only *water level-based ideas* when there may have been other concepts the respondent wanted to discuss. Therefore, because of the vague description of monitoring, there were many interpretations. Some of these interpretations included monitoring for quality, quantity, individual consumption, or abstraction rates as described below. However, some also interpreted monitoring as tracking the number of boreholes in Kumasi and the distribution of such boreholes. This was a valuable takeaway as it informed the study that there is minimal recording of boreholes drilled and that it is a desired characteristic for groundwater monitoring.

> “There is no regulation on that- that is what I am talking about. So, we can monitor the water to know the data but there are things we need to look out for. Yes, there is a lot of volume there we need to pump for our waste, and we need to regulate each other so we don’t run the aquifer dry or deplete. We need a monitoring system with other things.”
>
> - Ghana Water Company Limited 34

Another varying interpretation in the interview was about the “biggest opportunity” for groundwater monitoring. The goal behind asking the question “*What do you see as the biggest opportunity in establishing groundwater monitoring?”* was to determine existing infrastructure which is already in place so that groundwater monitoring could be applied into the pre-existing framework. Instead, many respondents would speak about the benefits of groundwater access and the opportunities water provides for consumers.

Another concern in the method, again, is sample size. The response percentage is quite low for most of the data. This can be attributed, among other things, the low sample size of commercial consumers and their minimal input into the interview results.

6.3.2 Results Discussion

6.3.2.1 Challenges and design

One of the missions of this thesis report was to compose a list of technical design requirements and specific technologies which could be applied in a groundwater monitoring program in Kumasi. This was attempted by asking probing questions about needs, desires, functions and priorities as referenced in the model of design. However, the results were quite limited and not as specific as the original aim of the study sought to achieve. Despite this limitation, the results provide a useful starting point for future dialogues about what might make a successful and mutually beneficial groundwater monitoring program.

One of the challenges cited in the design of a groundwater monitoring system is funding. This addresses a weakness covered in the previous section because it was often discussed that non-government organizations and foreign groups provide funding for boreholes and water resources projects. Non-government organizations were not interviewed in this project but would be a key group to involve in order to address funding concerns.

In relation to groundwater quality, pollution concerns were prevalent. Specifically, there are concerns about the mining industry and the runoff from the cleaning process. Although the mining companies monitor groundwater, there are still concerns about the quality of water itself. Because of this concern, among others, monitoring for quality was a highly desired trait in the design of a monitoring system.

6.3.2.2 Data

Despite the literature review showing limited data on groundwater resources, the interviews proved useful in identifying groups which possess the information. However, there is a lack or organization and digitization when it comes to this information as there is no central server for groundwater data. This is a common occurrence in Africa and "there is an urgent need to arrest the loss of data and to recover the amassed information" (Adelana, 2009).

Additionally, the data available in online databases as cited in chapter 2, is proven to be incomplete based on observation and interviews. As one KNUST researcher mentioned, a student reported a minimum of 112 boreholes on the KNUST campus alone, whereas the online databases show only 3 in all of Kumasi.

A data source shared with the interviewer was a catalogue of all boreholes in the eastern region of Ghana. This report was conducted by the CWSA and involved a long process of field visits to log all boreholes with locations. Unfortunately, the effort was short lived as new boreholes drilled were not added to the system.

6.3.3 Data Quality

Precision: The measurement for precision in this section is challenging to achieve. The questions asked were vague and open ended, therefore it was more likely that imprecise responses would be received. This is not necessarily a poor outcome, as there were concepts which overlapped and were mentioned multiple times. This allowed for a clearer narrative to be reached.

Accuracy: The results in this section are accurate to the experiences of the respondents. When studying how systems operate in practice, it is best to have multiple accounts to substantiate a narrative. This was achieved because multiple interviewees overlapped in their description of the informal borehole drilling sector. Additionally, information in the interviews was substantiated by existing literature.

Validity: The goal of this section was to gather practical information on the groundwater management landscape in Kumasi. The method was valid because the respondents provided ample anecdotal evidence of concerns and practices in the groundwater sector.

Bias: One of the more significant findings is that collaboration was cited as a design requirement. This could potentially be a biased response because the interviewer was introduced as a communications student. Therefore, respondents may have been primed to discuss communication style problems.

6.4 Summary

RQ2: What are important considerations in the groundwater management setting in Kumasi, Ghana?

This research question focused on the landscape of practical groundwater management considerations in Kumasi. The method to answer the research question was through interviews with stakeholders in the Ghanian groundwater sector. There were four key takeaways:

5	*Management:* The most common response is that **groundwater management** is either poor or not in place; According to interview driven data, a lack of **regulation compliance** with borehole drilling is a challenge for the sector; Drilling a borehole is the main way for domestic consumers to get access to groundwater and income is limiting factor to do so
6	*Challenges:* The most mentioned **challenges** for the implementation of a groundwater monitoring system are collaboration, lack of awareness and funding
7	*Design Requirements*: The most common collaboration **deign requirement** was education; The three most cited functions for a groundwater monitoring system are large scale data, regulation and determining consumption levels; The academic groups identified the most design requirements and the most specific examples
8	*Existing infrastructure*: There is an **informal network for data sharing** among borehole drillers and an existing physical infrastructure of boreholes which could be utilized for a groundwater monitoring program

=

Chapter 7 Stakeholder Values

7.1 Motivation and Goals

Front Material			Body Research Questions			Conclusions	
Context	Theory	Methods	RQ1	RQ2	**RQ3**	RQ4	Conclusion

RQ3: What are the values of key stakeholders in the development of a groundwater monitoring system in Kumasi, Ghana?

This research question is the focal point of the design portion of the study. The approach of using value sensitive design is used to put the values of those involved in the groundwater monitoring sector at the forefront of the design process. This section includes the results of the values activity completed in the interviews and interpretations of the values. Lastly, the results are discussed in relation to literature and theory.

Objectives	
	Compile value profiles for each stakeholder group
	Conduct statistical analysis to determine significance of value distribution
	Evaluate consensus of value importance within stakeholder groups
	Determine interpretations of values in relation to groundwater monitoring

7.2 Results

7.2.1 Value Profiles

The first results show the mean value distribution based on stakeholder group. The bars show that the values sum to 21 in each of the groups. This demonstrates the constant sum dilemma which is the foundation for using the token-based value sensitive design method. The results show the benefits of using tokens because it provides the ability for nuance and understanding. If the system were linear rank based (1-7), then the spread of importance per value could not be assessed.

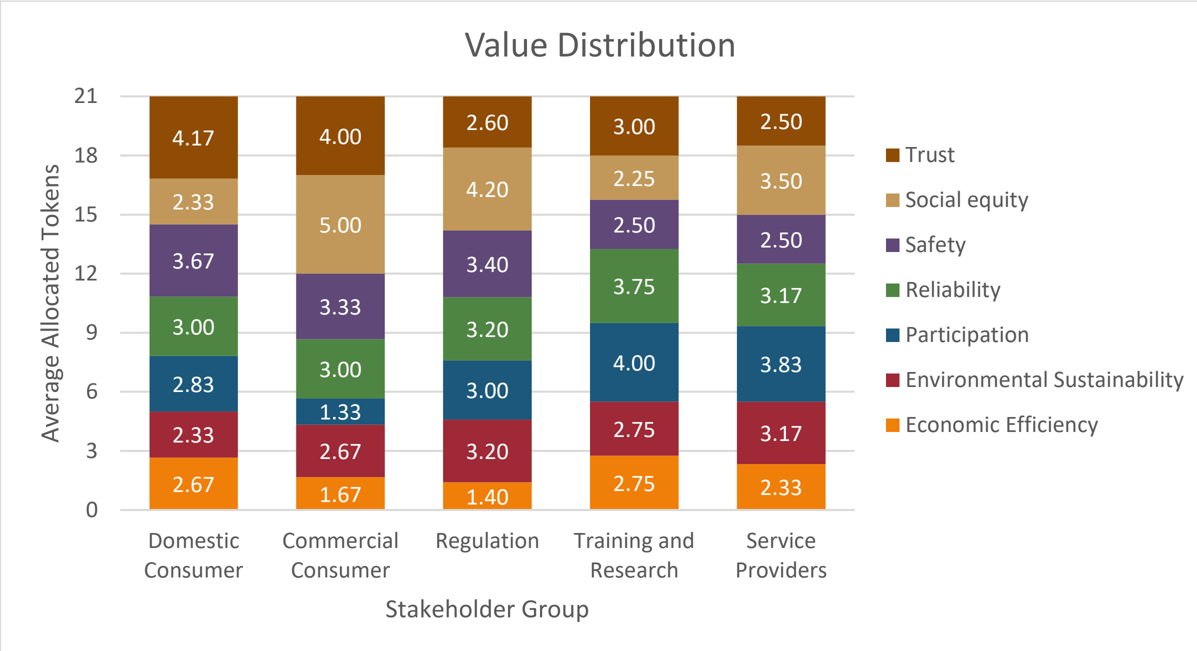


Figure 52. Value distribution per stakeholder group

Domestic consumers weighed *trust* and *safety* as the most important values with greater than 3 tokens allocated for each. The remaining values were more equally distributed between 2.33-3.00.

Commercial consumers weighed *trust* and *social* equity as the most important values. There were only 3 data points which resulted in under 2 tokens for the whole set, and two of those are in the commercial consumer group for *participation* and *economic efficiency*. Participation received 1.33 on average in this group, which is the lowest token allocation for any of the stakeholder groups. Commercial consumers also ranked *economic efficiency* quite low at 1.67. These low rankings were likely a tradeoff decision because of the high ranking allocated to *social equity* and *trust*.

Regulators ranked *social equity* as the most important value. Similarly, to the commercial consumers, regulators also allocated a small amount to *economic efficiency* with 1.40 on average. This is over 1 token less than the next highest value within this group. This extremely low value could be a trade off because of the high value of *social equity*.

Training and researchers marked *participation* and *reliability* as the most important values. Because of this, the remaining values are all allocated 3.00 or less. The lowest allocated value for this group is *social equity*.

Service providers have a similar value distribution to training and research. The highest allocation is *participation*, but with a small margin of about 0.6.

7.2.1.1 *Descriptive Statistics*

7.2.1.1.1 Standard Deviation

Table below shows the standard deviations associated with the graph in figure 52. Standard deviation is a measure of the variance from the mean of a sample. A higher value indicates a wide spread in the responses, while a lower standard deviation indicates that the group was in agreement on the number of tokens to place on for the indicated value. Agreement, or low standard deviations are colored blue while higher deviations are marked in orange.

The table shows that deviations from the mean were higher with *domestic consumers, commercial consumers*, and *regulators*. This is likely due to the diversity of individuals interviewed in these groups. Oppositely, the *training and research* and *service provider* groups had the most agreement on the tokens assigned to values. This is likely because there is more organization among these groups than the consumer groups and therefore, they have clearer values associated with their group.

	Commercial Consumer	**Domestic Consumer**	**Regulation**	**Service Providers**	**Training and Research**
Economic Efficiency	1.53	1.86	1.14	0.82	1.26
Environmental Sustainability	3.06	2.07	0.84	1.72	0.96
Participation	1.15	2.23	1.58	1.72	0.82
Reliability	3.00	1.79	1.79	0.75	0.50
Safety	2.31	2.34	2.97	1.05	1.00
Social equity	2.65	1.86	2.95	0.55	1.89
Trust	2.65	1.94	1.52	1.52	1.41

7.2.1.1.2 One-Way ANOVA Test

In addition to the means and standard deviations per value, statistical significance tests were performed to determine if there is a significant difference between the values. For this, one-way ANOVA tests were performed to determine whether there are any statistically significant differences between the means of the groups. In this test, *the null hypothesis (Ho) is that there is not a difference between the means*. If the calculated p value is less than the alpha value used in the calculation (α= 0.05), then the null hypothesis is rejected. A rejected null hypothesis indicates that there is a significant difference between means. This test was selected because of the low sample size among groups (from n= 3 to n=6). In addition to the ANOVA test, the range was also calculated by finding the difference between the highest and lowest values for the given sample.

There are two categories of data which are calculated. First, in table 24, there is the difference *within a group for values*. The "within" indicates if the number of tokens allotted per value within a stakeholder group are significantly different. It determines if the distribution within a group is significant. In table 24, n refers to the number of interviewees for each group. The table shows that the p value for is greater than the alpha value of 0.05 for all tests and therefore, the null hypothesis is accepted and **there is not a significant difference in means within groups**. The lowest range is for service providers which indicates that that the distribution for the values was the most even. The highest range is for commercial consumers at 3.67 which indicates a more extreme token allocation.

Table 24. Values within group

Group	n	p value	Range
Commercial Consumer	3	0.57	3.67
Domestic Consumer	6	0.66	1.83
Regulation	5	0.49	2.80
Service Providers	5	0.49	1.50
Training and Research	4	0.36	1.75

The second table, table 25, shows the difference *between groups* for particular values. The "between" indicates if groups responded significantly different for a specific value. The tables shows, similar to the test above, that the p values are all greater than the alpha value of 0.05 and therefore, the null hypothesis is accepted and there is not a significant difference in means between groups. The lowest range is for reliability which indicates that there was most agreement between groups for this value's token allocation. The highest ranges are for participation (2.67) and social equity (2.75). This indicates that the groups had greater disagreement on the allocation for these values.

Table 25. Values between groups

Value	p value	Range
Economic Efficiency	0.48	1.35
Environmental Sustainability	0.92	0.87
Participation	0.26	2.67
Reliability	0.96	0.75
Safety	0.84	1.17
Social equity	0.27	2.75
Trust	0.44	1.67

7.2.2 Value Connections

When discussing the distribution of tokens, many respondents explained their value placement in relation to other values. A common tactic to explain value distributions was to say something to the effect of "once [parent value] is achieved, then [contributing value] will also be achieved". The table below shows the number of times a contributing value (rows) were cited in reference to a parent value (columns). It was also common for this attribution to influence token allotment. It was more common for contributing values to be allocated lower amounts because the tokens were attributed to the parent value. Often the explanation would be something like "I gave low tokens to [contributing value] because once you have [parent value], then [contributing value] will be achieved". The last row indicates the total number of times a value was referenced as either a parent or contributing value. It is important to note that there was not an interview question which asked about what values contribute to each other- this was a coincidence that occurred throughout the interviews. The table shows that participation, as both a parent and contributing value, has the most connections with other values. The shades of green demonstrate higher number of connections. The gradient shows that there is a high density of connection for four values: participation, trust, reliability and safety.

Table 26. Connections between values

		Parent Value						
		Participation	Trust	Reliability	Safety	Environmental Sustainability	Social Equity	Economic Efficiency
Contributing Value	Participation		3	1	0	0	1	0
	Trust	3		2	0	0	0	0
	Reliability	3	1		0	1	0	0
	Safety	4	3	2		0	0	0
	Environmental Sustainability	2	1	0	1		0	0
	Social equity	2	1	0	0	0		0
	Economic Efficiency	3	0	0	0	0	0	
Total		22	14	10	10	5	4	3

7.2.2.1 Value Network

To illustrate the connections between values from the previous page, figure 53 was created. The lines represent a connection between the two values as either a parent or contributing value. The thickness of the line is directly proportional to the number of times the values were connected to each other in the interviews. The green lines indicate a connection involving participation. This is to highlight the prevalence of this value being linked to other values. The figure shows that participation was linked to all values at least once, while trust was linked to all values except for economic efficiency.

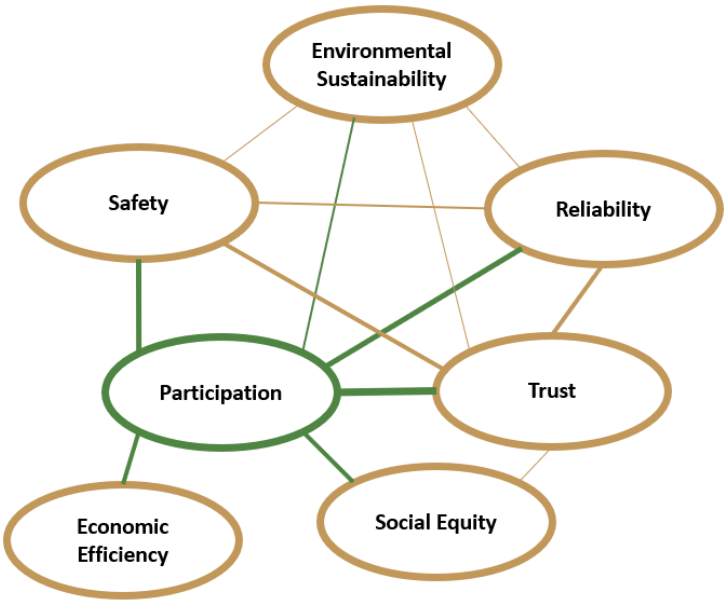


Figure 53. value connection network

The following section explains each value's connection to other values. The heading lists the name of the value, the number of respondents who linked it to another value and the fraction of other values it was attributed to.

Participation	**22 connections**	**6/6 Values**

Participation had the most connections to other values by a margin of 8, with the next highest being trust with 14 connections. This is demonstrated in the quote below which attributes participation with multiple other values and diminishes the tokens allocated to contributing values (social equity and environmental sustainability) in the name of applying them to the parent values (participation, trust and reliability).

> "I saw social equity and environmental sustainability as very important. But I didn't give them that many tokens and the reason for that is I just thought that if you have good participation and trust between users and we have a reliable system, then I think social equity and environmental sustainability will hopefully be outcomes."
>
> - TU Delft 46

These connections support the literature because community participation is cited as a prerequisite for sustainability, which can aid in achievement of efficiency, effectiveness, equity, and replicability (Harvey & Reed, 2006). Participation is also a foundation in cocreation which aids in development in sustainable innovation while supported by an "innovative, transparent, adaptive and participatory environment" (Kruger, Gusmao, Braga França, & Gonçalves Quelhas, 2018).

Trust	14 connections	5/6 Values

Trust was the second most referenced value in connection with others. There was a clear link, as mentioned above, between trust and participation. The Kruger model of cocreation states that “trust is fundamental for participation and balance” in the cocreation process for sustainable development (Kruger, Gusmao, Braga França, & Gonçalves Quelhas, 2018). Furthermore, literature mentions that highly participatory collaborations, such as transdisciplinarity, require respect, trust and shared understanding between collaborating partners (Kalmár & Stenfert, 2020).

> “Whatever data is being taken is for the purpose of it being taken- not for selfish interest. That is why I also took the trust. Because participation and trust are linked. You have me, I should trust whatever you are bringing, I trust you for the reason you are here.”
>
> - Ghana Water Company Limited 33

The importance of trust is stressed by authors in the field of water management as well because a relationship based on trust between scientists and citizens is a motivating factor for citizens to contribute to citizen science (Minkman, van der Sanden, & Rutten, 2017).

Reliability	10 connections	4/6 Values

Reliability had 10 connections to other values, evenly split between parent values and contributing values. The greatest number of connections for reliability was with participation. Other connections to reliability are environmental sustainability, safety and trust.

> “The reason why I put only one here [on reliability], when you have trust, safety and participation, this will come. If you don’t have trust, they won’t participate. If you have trust and participation, then the rest [reliability] will come.
>
> - Assembly Man 08

Safety	10 connections	4/6 Values

Safety was mentioned most often as a prerequisite for other values as modeled by 9 contributing value connections and only 1 parent value connection. The tendency for safety to be classified as a contributing value over a parent value is because safety was defined as a qualifier for individuals to participate and trust in a system. Safety was linked to four values: participation, trust, reliability, and environmental sustainability.

> “I believe once you are talking about safety, you are talking about environmental health and with environmental sustainability”
>
> - Kumasi Metropolitan Assembly 44

Environmental Sustainability	**5 connections**	**4/6 Values**

Environmental sustainability had 5 total respondents attribute it to another value. However, most of the links are only supported by one person. Environmental sustainability was specifically defined as separate from the more global and broad term of sustainability. *Environmental* sustainability is more focused on the environment, whereas sustainability is known to have three components: economy, social and environment (Global Water Partnership Technical Advisory Committee, 2000).

Social Equity	**4 connections**	**2/6 Values**

Social equity received few connections, and they were only for trust and participation. When mentioning the connection during the interview, they were not strong or emphasized.

> "When you have participation, that's social equity"
> - Water Resources Commission 32

Economic Efficiency	**3 connections**	**1/6 Values**

Economic efficiency was mentioned the least in relation to other values and was only linked to participation. When it was mentioned as a connection, it was also grouped with other values and not singled out on its own. This contributes to the consistent low token allocation to economic efficiency as referred in section x.

> "When there is economic efficiency, reliability and education, and safety, people will mobilize themselves"
> - Domestic consumer 30

7.2.3 Importance

For the analysis, a threshold of four tokens determines if the value is important. This was selected because if the respondent allocated all tokens equally, there would be 3 tokens per value. Therefore, a value is considered important if there were more than 3 tokens allocated and unimportant if there are less than 3 allocated. An allocation of 3 tokens is considered moderate.

In order to simplify the results, a calculation was performed to determine if a value was marked as simply "important" or "not important". This was done because although agreement on exact number of tokens was not achieved, it could be that respondents still agree that a value is worth more than 3. To calculate the percent of a stakeholder group marking a value as important, equation 4 was implemented. If all respondents in a group allocated more than 3 tokens to a particular value, this result would be 100%, thus indicating 100% agreement on the value being important.

Equation 4. Agreement on importance

$$\%\ agreement\ on\ importance = \frac{\#important}{total\ respondents\ in\ the\ stakeholder\ group}$$

important= number of respondents in group who allocated more than 3 tokens to the value

To visualize the results, a scatter plot was created in figure 55 to illustrate importance of a value versus the stakeholder groups' agreement on the value's importance (equation 4). Figure 54 below shows how the quadrants represent this idea.

The x-axis shows the percent of the stakeholder group which marked the value as "important" (result of equation 4). Both extremes of the x-axis indicate agreement. The right side indicates agreement within the stakeholder group of the value's importance (red), while the left side indicates agreement within the stakeholder group of the value's *lack of importance* (yellow). In other words, a value of 0% on the x-axis indicates that no respondents in the stakeholder group marked the value as important, thus indicating that they agree the value is not important. Points in the middle of the x-axis indicate disagreement within the group on the value's importance.

The numerals in the corners provide an identification for the quadrants while the percentages in the center of each quadrant indicate the portion of data falling in each zone. The results show that most of the data (72%) was marked as agreement of unimportance, while there were few data points (17%) indicating agreement on importance. About 11% of data falls on the y axis and was not assigned to a quadrant because conclusions cannot be drawn.

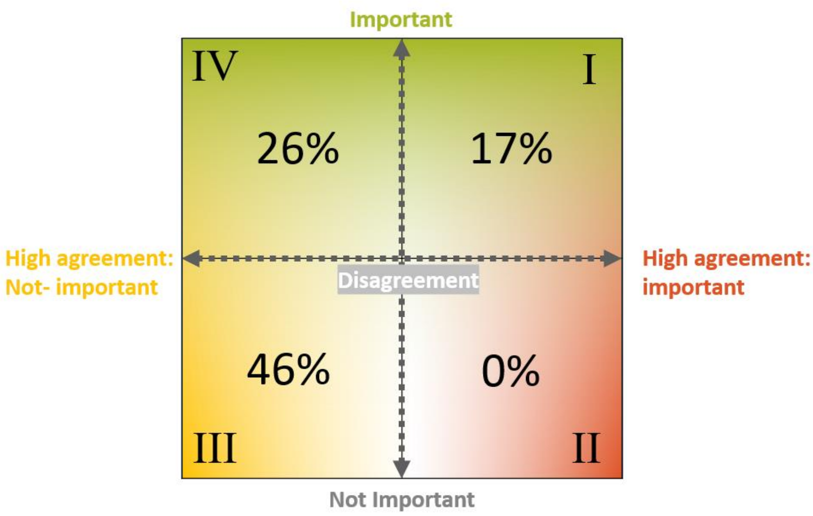


Figure 54. importance v agreement

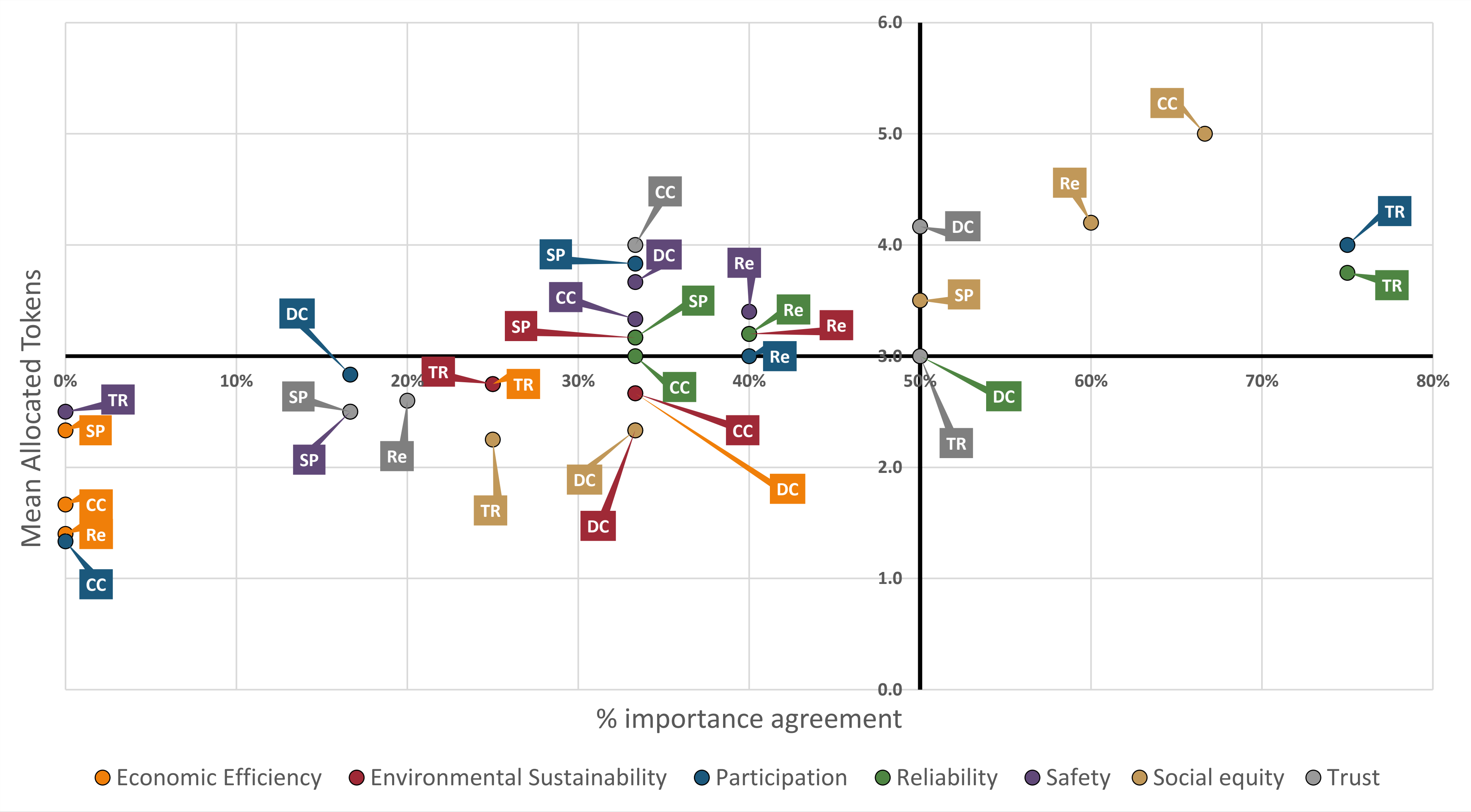


Figure 55. Token Allotment v Agreement

Data label indicates stakeholder: Commercial Consumer (CC); Domestic Consumer (DC); Regulation (Re); Service Provider (SP); Training and Research (TR)

Y-axis represents the mean token distribution per value for the indicated stakeholder group

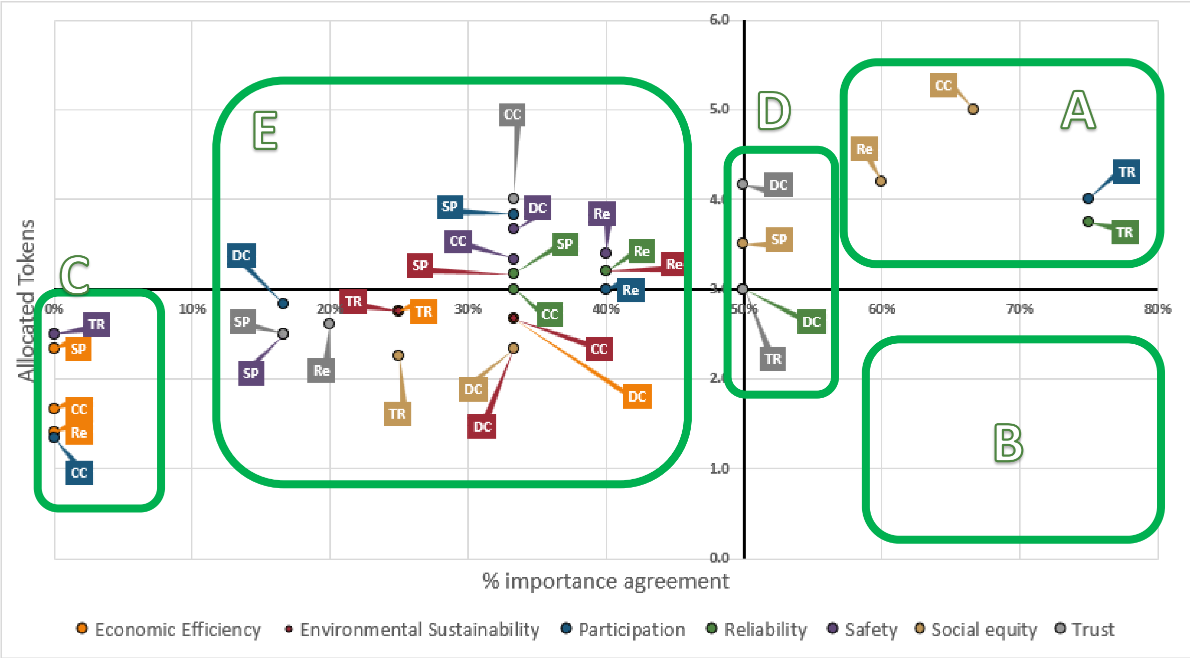


Figure 56. Importance v Agreement zones

To go through the results of this analysis, the results are discussed in terms of location. First, in **section A**, there are four values within the quadrant which denotes 60-80% agreement among the indicated stakeholder group that the colored value is important. For example, it is noted that about 66% (x-axis) of commercial consumers (CC) agree that social equity (tan) is important with an average token allocation of 5.0 (y-axis). The two highest agreed upon values for importance come from those in training and research (TR) in reliability (green) and participation (blue).

Second B is noticeably blank. This is because the cell is for the intersection of agreement on importance (X) and unimportant values (Y). These incompatible variables result in a blank quadrant.

Section C is located on the extreme end of quadrant 3 and focuses of 5 results where the x value for % agreement on importance is equal to 0.0%. Conversely, 0% agreement on importance is the same thing as 100% agreement (unanimous) on unimportance. Three of these values are for economic efficiency and placed there by service providers, commercial consumers, and regulators. The other two are for participation (from commercial consumers) and for safety (from training and research).

Section D focuses on four values which are disagreed upon within the stakeholder group for importance. Two are for trust (domestic consumers and training/research), one is for participation (service providers), and the last is for reliability (domestic consumers). The numeric average for the importance of these values ranges from 3 to about 4. Finally, **section E** is where the majority of the data lies: importance agreement ranging from 15-40% and token allotment ranging from 2.2- 4.0.

7.2.4 Value Explanations

In addition to quantitative data through the allocation of tokens, there was also qualitative data collected. After the respondent placed the tokens, they were asked to explain their choices. This section provides explanations and interpretations of values to make sense of the data. The section is organized by value. Each value's explanation page is provided with 1) the name and definition as provided in the activity, 2) the importance versus agreement chart highlighting the value of interest, 3) explanation and summary of interpretations by the respondents and 4) supporting quotes from interviews.

7.2.4.1 Economic Efficiency

"The attempt to maximize the economic and social welfare derived from water resources and investments in water service provision"
(Water Resources Commission, 2012)

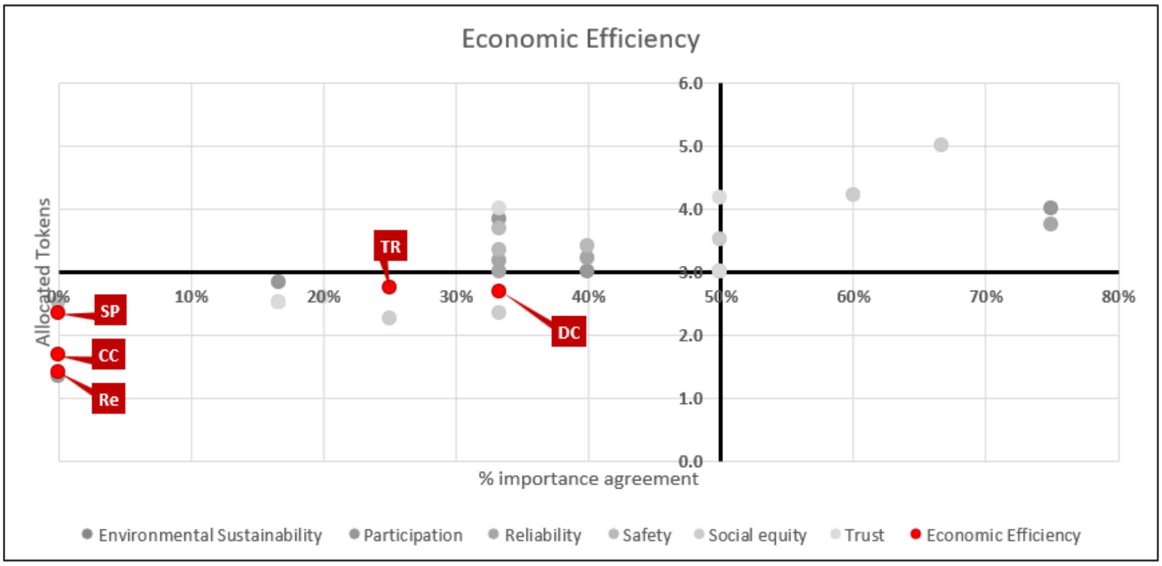


Figure 57. Importance v Agreement: Economic Efficiency

As demonstrated in the figure above, all points fall in quadrant III. All groups rated economic efficiency as unimportant with three groups (service providers, commercial consumers, and regulators) even unanimously agreeing that it is unimportant. The denotation of unimportance is symbolized by the points falling below the threshold of importance (3.0).

The explanation for this low valuation of economic efficiency can be explained by interpretations of the definition during the interviews. Some respondents mentioned that water should not be used for economic gain- and thus that economic efficiency should not be prioritized. So instead of connecting economic efficiency with a groundwater monitoring system, these respondents thought economic efficiency was applied to make money from water- an idea with which they disagreed.

Others, namely domestic consumers, mentioned that access to piped water is expensive, and therefore that there is currently not economic efficiency. Additionally, some responses were not specific with their reasoning as the respondents would restate or rephrase the definition itself in explaining their token allocation. The more specific and design-instructive responses were given by academic groups. As mentioned below, economic efficiency is tied to funding, which is a key challenge to overcome in this project.

"…because if it is not economically efficient, no one is interested in sustaining it- especially in the developing world where funding is difficult. If it is economically efficient, it is easy to be continued because everybody will understand that you maximize economic and social welfare from water resources so it very very important. The decision, it is one of the things that you embark on before you start the project. If it is not efficient, no one will embark on it."

- KNUST 43

7.2.4.2 Environmental Sustainability

> *"The present use of the resource should be managed in a way that does not undermine the life-support system thereby compromising use by future generations of the same resource"*
> (Global Water Partnership Technical Advisory Committee, 2000)

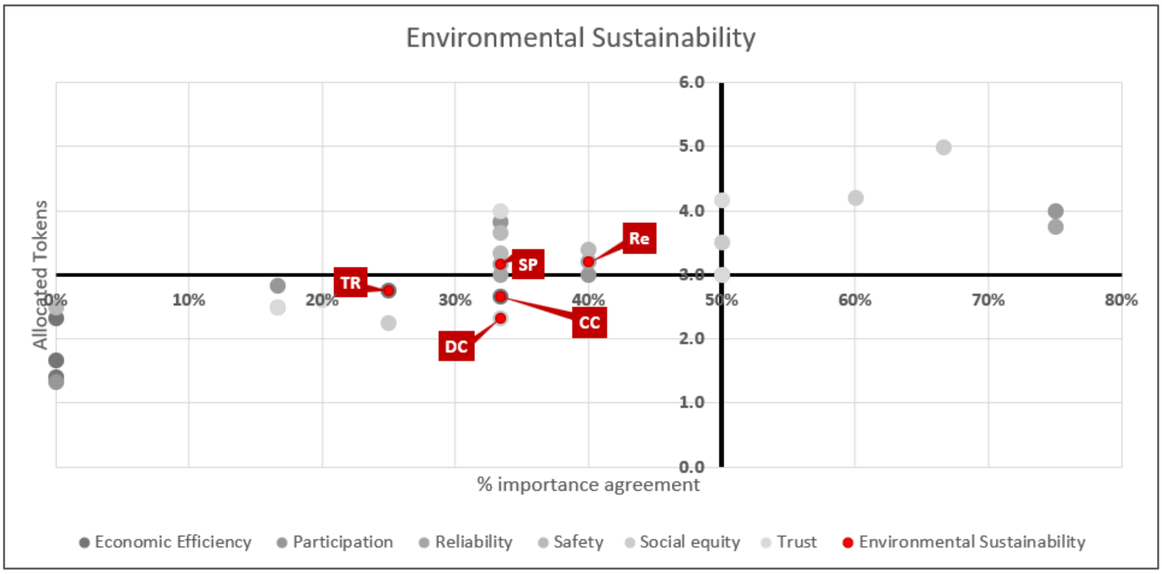


Figure 58. Importance v Agreement: Environmental Sustainability

Responses for environmental sustainability fall within the same region of the graph (section E as discussed earlier). This signifies that the groups marked it at moderate to unimportant (2.2- 3.0 tokens) with consensus on importance ranging from 25-40%. With this finding, there are no strong opinions on environmental sustainability being more or less important than the others.

In the discussions of this value, many respondents used the definition to explain their ranking. Specifically, respondents would emphasize the importance of future generations and how water and health go together. This explanation was not applied to the monitoring of water, but more so on the water itself.

> "Water needs to be protected for young individuals so that in the future, water will be available to them and not cause health issues."
>
> - Domestic Consumer 03

Discussions which aided in design resulted from academic groups. In this case, environmental sustainability was likened to sustainability of the monitoring equipment which then translates to sustainability of the water itself. In this way, environmental sustainability was an output of the system and not an input.

> "It needs to be sustainable so that the information we get can be used to ensure that the source of the water is also sustainable."
>
> - KNUST 42

7.2.4.3 Participation

"The involvement of users, planners and policymakers at all levels in water development and management"
(Global Water Partnership Technical Advisory Committee, 2000)

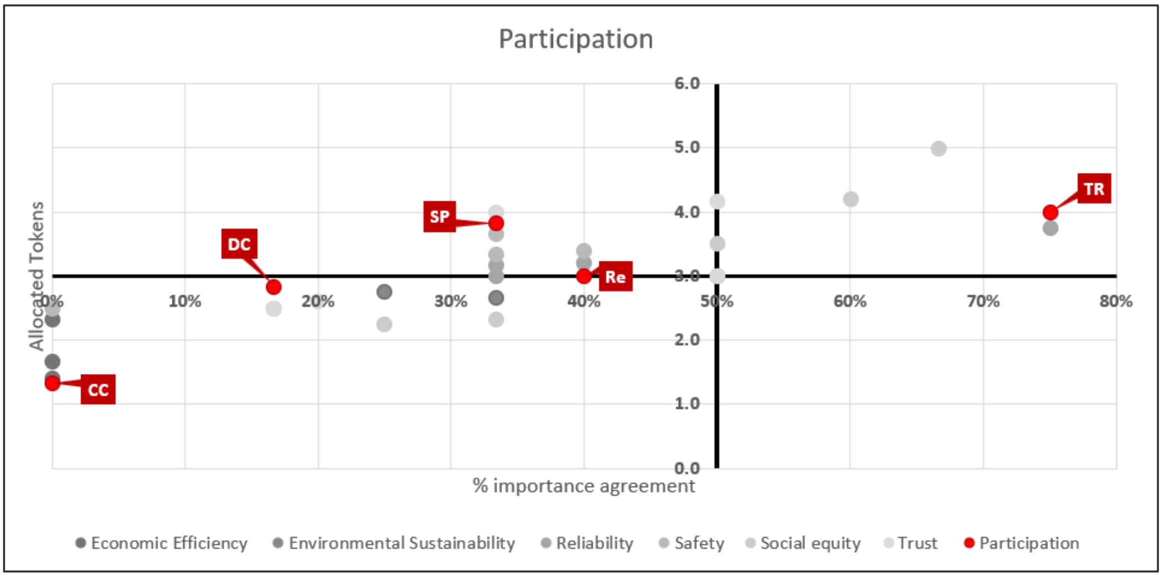


Figure 59. Importance v Agreement: Participation

The next value is participation. As demonstrated above, the agreement on importance of this value greatly shifts depending on the stakeholder group. Both commercial and domestic consumers marked the value as unimportant (located in quadrant III). While training and researchers have 75% agreement of the value's importance, 100% of the commercial consumers agree on the value's unimportance.

Discussion of participation as a value resulted in two primary topics. First, the idea of awareness among stakeholders for groundwater, management and utilization was discussed. Second, the organizational groups mentioned the large number of stakeholders involved in the water sector and the need to bring them together.

> "For water projects, you are trying to bring about, there should be community buy in. There should be participation… for those who should benefit from it, they should be aware as to how you set things up, how you can make economic gains out of it."
>
> - Kumasi Metropolitan Assembly 44

However, the figure above does not tell the full story of this value's contribution to the study as mentioned in the previous sections. Even if participation was ranked low, it might have been done because the respondent absorbed participation into another higher-ranking value.

> "Because of the multi sector interest in land, groundwater is in the land, it is multifaceted. The institutions that manage the land are many, so we need to bring them all on board. It hasn't traditionally been that way institutional-wise."
>
> - Water Resources Commission 32

7.2.4.4 Reliability

"The ability of a product to perform its function adequately over a period of time without failing"
(van de Poel, Design for Values in Engineering, 2015)

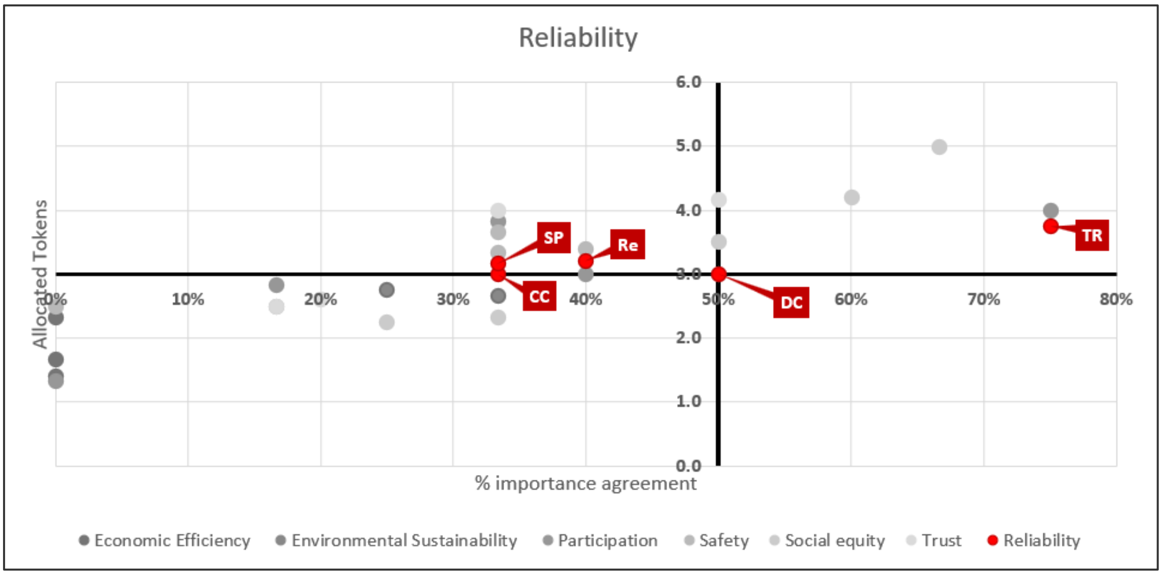


Figure 60. Importance v Agreement: Reliability

There was only one group which had agreement on reliability's importance as a value- the training and researcher group. Meanwhile, the remainder allotted an average of about 3 tokens for this value indicating moderate importance.

Similarly, to other values, many respondents used the definition itself in explaining reliability. The emphasis was on the importance for the product to function for a duration of time. However, like other interpretations, this was interpreted often as reliability of the water itself- not the monitoring system. Specifically, respondents would say the water needs to be reliable and available at all times.

Stemming from this, the importance of reliable electricity was determined because electricity should be available for the monitoring to function. Other definitions or explanations include the need for accurate data, lack of failure and ensuring that the water is safe and can be relied on for consumption. Technical interpretations of this value were derived from academics in terms of techniques to achieve reliability.

"For it to be reliable you need adequate monitoring stations. If you only have two monitoring stations, it will not be reliable because there is a lot of heterogeneity in groundwater. So one, you need a dense network so that it gives you enough coverage so that confidence is high. Two, for it to be reliable, the science should be good especially on local conditions. So if there is not a lot of science based on local conditions, you projections will not be very good. Then three if you are hosting the system if some of the services are hosted online so that the products are online. People need to be able to get the information."

- KNUST 43

7.2.4.5 Safety

"The reduction of risks to a reasonably feasible and desirable extent"
(van de Poel, Design for Values in Engineering, 2015)

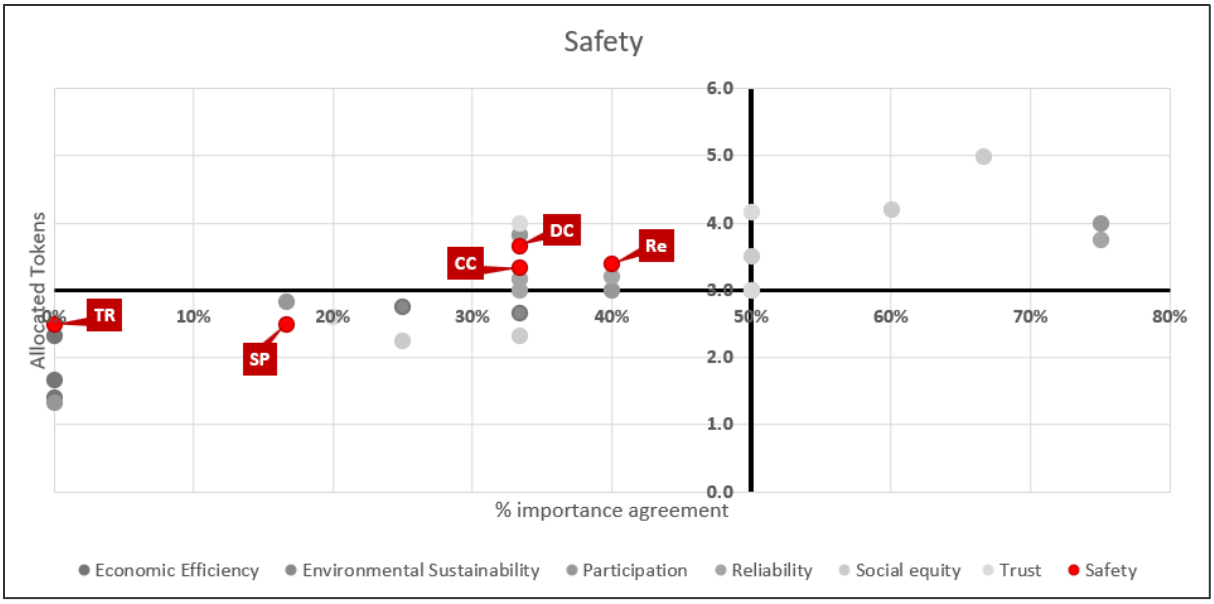


Figure 61. Importance v Agreement Safety

All of the data points for safety lie in the left half (quadrants III and IV) of the graph which demonstrates a general attitude towards safety's lack of importance. In discussions regarding safety, most respondents talk about the safety and quality of the water itself as opposed to the safety of a monitoring system. This resulted in a discussion of operationalizing this through monitoring. Respondents mentioned that monitoring for water quality could ensure safety.

"We need to be collecting samples intermittently, maybe every two weeks or month so that we monitor the quality of the water- if it is getting bad or interventions need to take place, we can detect that with regular sample collection"

- Kumasi Metropolitan Assembly 44

Technical groups unanimously agree that safety is unimportant. This is because they were associating safety with the monitoring of groundwater and the risk for human health in developing a groundwater monitoring system is low. Therefore, there are few concerns that would need to be approached.

The different scores were therefore represented by how the group interpreted the value. If the value was interpreted as safety of the water itself, it was more important, but if it was about the monitoring system, it was less important.

7.2.4.6 Social equity

"The basic right for all people to have access to water of adequate quantity and quality for the sustenance of human wellbeing"
(Global Water Partnership Technical Advisory Committee, 2000)

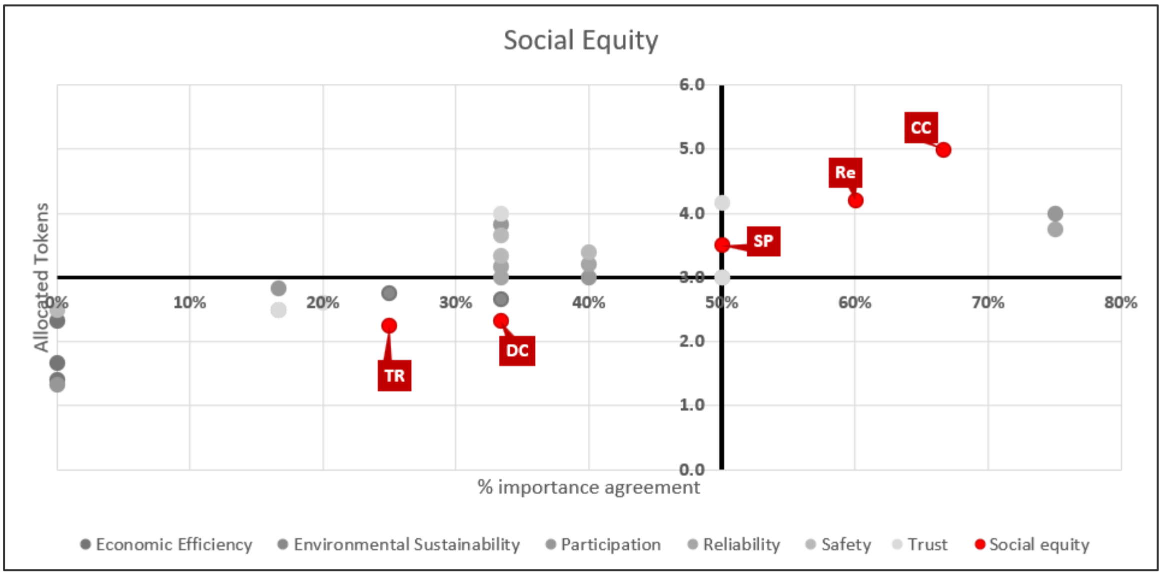


Figure 62. Importance v Agreement: Social Equity

As seen in the figure, there is a significant spread of data for social equity. While both regulators and commercial consumers have over 60% agreement of its importance with an average value over 4.0, academics and domestic consumers rate it as unimportant with about 65-75% agreement.

Respondents who ranked social equity as important emphasized that social or economic standing should not prevent water access and that all communities deserve water access. Within this value, the phrase "water is life" was mentioned on multiple occasions.

Those in training and research marked the value as unimportant with 75% agreement. This is explained in the separation of three factors: the water itself, the design of the system, and allocation of the data. All three of these had different answers. In respect to water itself, respondents emphasize the importance of fair and equal distribution and access to water. In design of the system, the academics argue that social equity is not relevant. However, in the allocation of data, social equity is a component to ensure everyone has access to information.

"If we are looking at the greater Kumasi, we define a boundary and ask how we can monitor the whole place effectively. We will not include a layer on income levels, ethnicity or anything like that. Science is blind so social levels. That is why I ranked it low."

"Once it comes to utilization of the data, then social equity is important because the rich are easily served so you need to bring in the layer of the social and the income level and other things in to make sure those who are marginalized and those who perhaps don't have access to a laptop or phone will have access to information. You shouldn't only have it in English- you make the other systems available."

- KNUST 43

7.2.4.7 Trust

"The establishment of human reliance that is willing, voluntary and carried out under conditions of uncertainty and vulnerability"
(Nickel, 2015)

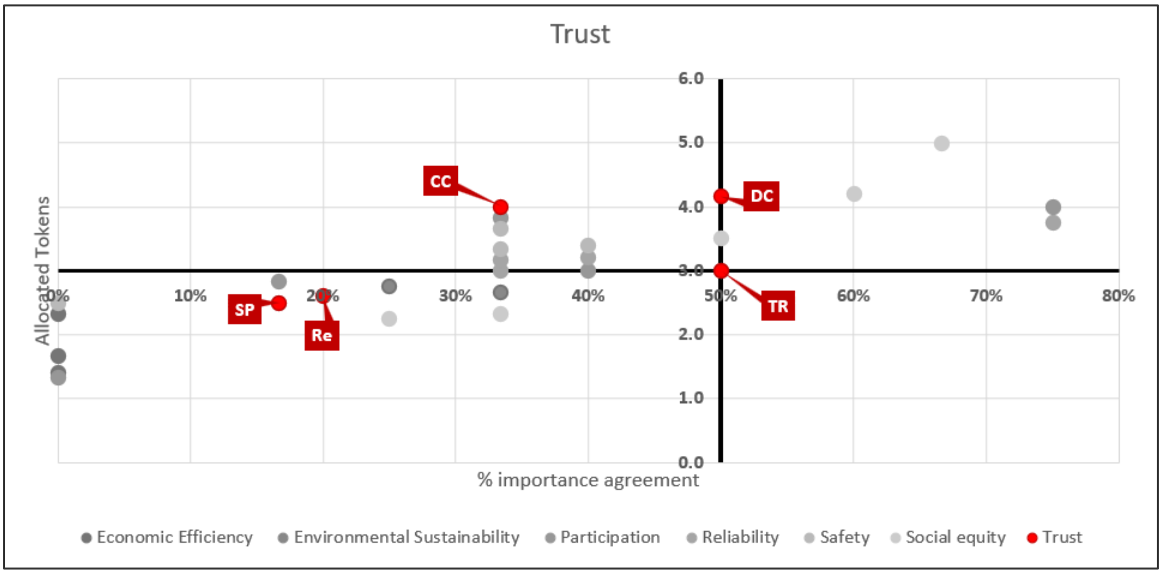


Figure 63. Importance v Agreement: Trust

Similarly, to other values, the view of trust as an important value depends on the group affiliation. While service providers and regulators agree by about 80% that it is unimportant, the others view it as moderately important with some disagreement. There could be disagreement on the value of trust because as mentioned earlier, trust was associated as a parent and contributing value 14 times. Therefore, trust could be more important than this data shows.

The respondents spoke about trust in different applications. There is trust in the water itself, the monitoring system, the people working on the project, the data, and the communities where it is functioning. Noticeably, both domestic and commercial consumers rate trust as more important than the other groups by about 1 token. This is because the consumers associated trust with the water itself. In other words, the consumers need to trust the water they are drinking to use it.

The training and research group's view of trust falls exactly in the middle of the graph showing that the view on trust as an important value is disputed and that the average token allocation was about 3.0.

"If they don't trust you, they may think you are using it for something else and then your system will fail. Trust is important because if people don't trust the information coming out of your groundwater monitoring system, then they won't use it because they don't trust. So, data collection, installation, sustaining the system, utilization- you need to get trust from all the stakeholders and the other stakeholders' willingness to participate is also based on trust."

- KNUST 43

7.3 Discussion

7.3.1 Methods Discussion

7.3.1.1 Language

The interview was conducted in a mixture of English and Twi, the dominant local language of the interviewees. When conducted in Twi, a bilingual Ghanaian translator asked the interview questions in Twi, then translated the answers to English. For the activity, the values were written on the cards in both English and Twi. All interviews with organizations were conducted in English and only a portion of interviews with consumers which were conducted in Twi (see chapter 5).

Despite the translator and the translated values activity, there were still concerns about how language played a role in the results. First, some respondents were illiterate in both languages. This resulted in the challenge of reminding the respondent what each of the cards meant. There is a challenge here with unintentional bias. Illiterate respondents may feel pressure to respond and place tokens quickly and perhaps not ask questions for the worry of feeling insecure for their lack of literacy, despite both the researcher and translator attempting to create a comfortable environment. It would have been more streamlined to only interview English literate individuals, but this would have led to a significant bias in data towards a more privileged population.

Another weakness in the protocol is that the translator neglected to ask some of the questions because they were either forgotten or skipped. In addition to this, some responses in Twi were not translated exactly back to English so some of the responses were summarized instead of restated.

Lastly, the values in Twi were handwritten on the cards by the translator. Because they were done on site and last-minute, there was not an opportunity to do a literature review on translating the intended definition from English to Twi. However, the local knowledge from the translator was appropriate to describe the value as the translator would be able to verbally articulate the intended value in English.

7.3.1.2 Interview

The interview itself introduced unintentional variables between settings. Of the 46 interviews, one was conducted over video call out of necessity. For this, the values board was created in Miro and the activity was carried out in the same way as the mock interviews.

In the interview environment itself, there were external stimuli that caused challenges. First, in the domestic consumer interviews, most of the respondents did not have enough time for the values activity and thus only provided responses for the first part of the interview. This resulted in a bias of the values activity being completed by individuals with more spare time. Another challenge is that the interview was designed to be done individually, but because of time constraints, there were four interviews were multiple people (2-3) would participate in the interview at once. This allowed for a greater number of participants in the study, but also introduced the problem of having one main speaker and then one or two speakers who would only add short details when necessary. Although the interview was designed for individuals, this method also worked and allowed for more diversity of perspectives.

Another concern with the interviews is that in some cases, individuals would be busy with other tasks but would still take part in the interview. These individuals wanted to participate in the interview while working on their other tasks such as reading emails, writing or cleaning. Although not ideal, its impact on the results were likely negligible. The last source of interference is the other stimuli occurring within the area. Some interviews were held in offices where there were few distractions, while others were held outside where there were children, water spills, neighbors stopping to talk or other phone calls coming in. This caused interruptions in the interview process which hurt the flow of the interview.

7.3.1.3 Activity

In the values activity, there were challenges and potential sources of bias. First, in placing tokens on values, respondents are in a vulnerable position by telling the interviewer what values are most important. First, the interviewee may feel time pressure to respond quickly and thus not take time to answer the questions thoughtfully. Additionally, they might feel pressure to respond in a certain way if the interviewer shows a strong attachment to any of the values. Specifically, participation was frequently mentioned in relation to other values. This could be a biased response because the interviewer was introduced as a communications student. Therefore, the respondent may have been biased to discuss communication style concepts more than they otherwise would.

A common piece of feedback from the interviewees was a commentary on the definitions of the cards. It was pointed out that some of the value definitions were more focused on the effects of monitoring as opposed to the monitoring itself. Additionally, some of the definitions were more focused on the water itself than monitoring. This caused individuals to respond differently depending on how heavily the definition was relied on to answer the question. Influences of this can be found in the value connections section where values are related to each other in the explanations.

7.3.2 Results Discussion

7.3.2.1 Value Profile Significance

The statistics show that there was no significant difference between the groups or within the groups for the token allotment towards values. This was a surprising finding and believed to be due to the low number of tokens. There were 21 total tokens for seven values. This would mean that if all tokens were allocated evenly, there would be three each- which makes even distributing one token significant. Therefore, there were not sufficient tokens to illicit significant differences between means. For example, in (Flipse & Puylaert, 2018), they used 10 tokens per value for a total of 80 tokens (8 values). This would lead to practical challenges as handing a respondent a large number of tokens to place on a board could be overwhelming. Some of the respondents exhibited signs of being overwhelmed with 21 tokens, so increasing it by more than triple could lead to practical obstacles. Therefore, the number of tokens was decreased to 3 each.

7.3.2.2 Value Agreement

In order to see more differences, the data was separated between important and unimportant as seen in section 7.2.3. This led to more significant findings and trends when looking at the data in a binary way. The results showed that only 4 of the values were agreed upon as important. Two of these data points were for training and research groups. This group also had lower standard deviation values on their placement of values. This speaks to the idea of the social identity of training and researchers to be more closely tied to their group, as there is the lowest variance from the mean for their allocation of values.

Both domestic and commercial consumers on the other hand have greater standard deviations. This illustrates a lack of a social identity. This could be because the identity of consumer is not strong enough of an identity, so the consumers were responding from their individual identity.

7.3.2.3 Explanations

When the respondents were asked to clarify their value choices and explain, the responses varied. Many respondents would simply use the provided definition in the explanation which was not helpful in obtaining unique interpretations. The main group that was able to be more specific with design criteria were those in academia. This demonstrates the contribution the training and research group can make towards a groundwater monitoring project. Although the training and research group was the most specific and detailed with their responses, this does not discount the contributions of other stakeholders because this method was designed to be inclusive and involve individuals from diverse communities.

Respondents explained their token allocation differently based two sets of binary interpretations. First there was confusion on the value relating to water monitoring for the water itself. This concern was also found in the pilot studies. In order to address it there were two actions taken. First, the assigned activity question was adhered to the value activity board so the respondent could reference it. Second, the interview protocol emphasized the study's focus on monitoring. Despite these efforts, for some participants, it was challenging to separate monitoring and the water itself. The data gathered is valuable in understanding the values and importance of the groundwater, but the intention of the protocol was to gather data related to groundwater monitoring, not the water itself.

> "That is where my problem is. Designing the system and the water itself. If you are looking them as separate issues, then maybe I don't know what to say about designing sustainably."
>
> - KNUST 42

The second binary interpretation of values is the view of a value as an input or output of monitoring. Many respondents would say that the value cannot be designed because it is an outcome of monitoring groundwater and would therefore find the token allocation challenging.

Another concept of interpretation were the values themselves. It was clear from the transcripts that the token allocation depended on how the respondent was interpreting the value. In this case, the takeaway is not necessarily the quantitative value from each stakeholder group, but the reasoning behind its valuation.

7.3.3 Data Quality

Precision: The data gathered had wide ranges and standard deviations within sample groups. Therefore, the results are quantitatively imprecise. Additionally, interpretations varied depending on a variety of factors as discussed in this chapter, which furthers imprecision. However, the study benefited from imprecise results as it allowed for a broader range of information to be collected.

Accuracy: There is no existing data to check for accuracy of value profiles between actors in this setting. However, these results contribute to the existing literature that these values play a role in groundwater management.

Validity: The reason why the results of this research question are not valid is because the definitions were interpreted differently by different stakeholders. Therefore, the measurement was inconsistent. But at the same time, values, in general, mean different things to different people which is why it was used as a tool in this study. The goal of this section was to uncover interpretations of values, and in this way, there was validity.

Reliability: Again, because of the different interpretations, the protocol for quantifying values is not reliable. However, the portion of the method which seeks to uncover design requirements and meaning behind values is a reliable method and can be applied for other studies.

7.3.4 Contribution to Field

This study contributes to design for values in water management in multiple ways. First, the definition of core values and their relevance to groundwater monitoring is clearly stated. The values as discussed in the interviews were a complete list because when asked if there were values relating to groundwater management which were not listed, all respondents said the list was complete and that they could not think of other values relating to groundwater management. The findings of this paper therefore dictate relevant values related to the design of a groundwater monitoring system in Kumasi, Ghana and contribute to literature on this matter where there is a significant data gap.

> "I did enjoy the interview actually. It made me think in mays that I haven't- so that is useful."
>
> - TU Delft 46

The study also contributes valuable insight for a method to determine design requirements from values. Many interviewees remarked that the interview was a positive experience as it prompted them to think about groundwater monitoring in ways they have not before. Therefore, one of the more important outputs of the research is the conversation generated the protocol.

7.4 Summary

RQ3: What are the values of key stakeholders in the development of a groundwater monitoring system in Kumasi, Ghana?

The third research question was focused on values of the stakeholders in the water sector of Kumasi, Ghana. The procedure involved conducting an interview with a token-based activity to place weight onto values to determine which values were key in the creation of a groundwater monitoring system. The results came in forms of 1) quantitative data for tokens placed on each value profiled by stakeholder group, 2) the consensus among the stakeholder group on the value's importance and 3) reflections and interpretations of the values. From these data there are four key findings which will be carried through to the design and recommendation phase.

9	*No significant difference*: there was no statistic significant between or within groups for value profiles of stakeholder groups. This shows that the profiles are statistically similar. However, the motivations behind the values were different.
10	*Importance v agreement*: Only 4/35 data points were both important and agreed upon. Oppositely, 5/35 data points were 100% agreed upon that they were unimportant.
11	*Technical experts*: Technical experts provided the most design requirements and specific suggestions. This group also had the most agreement on value importance.
12	*Values:* the results provide seven values involved in groundwater monitoring. Economic efficiency was regarded with low importance, while participation most frequently cited as connected to other values.

Chapter 8 Recommendations

8.1 Motivation and Objectives

Front Material			Body Research Questions			Conclusions	
Context	Theory	Methods	RQ1	RQ2	RQ3	**RQ4**	Conclusion

RQ4: How can value sensitive design be used to identify strategy for groundwater monitoring?

This chapter marks the culmination of the content covered in this paper up to this point. Here, with the final research question, results from the previous research questions are synthesized and integrated with theoretical background and case study evidence to provide a series of recommendations for next steps in the creation of a groundwater monitoring system in Kumasi, Ghana. The four objectives of this section will contribute to answering the research question.

Objectives	
	Assemble a theoretical approach to apply to the recommendation design
	Cumulate design requirements into a list from the comprehensive report
	Implement design for recommendation based on design requirements
	Analyze potential impacts in the design recommendation and reflect

8.2 Theoretical Approach

The key finding from the previous chapter is the prevalence of participation as a key value in the implementation of a groundwater monitoring system. Because of this finding, the approach to the solution will be that of **participatory design**. Contributing to participatory design practices are two learning models which can aid in the operation of a participatory practice. First, a **social learning model** as applied in water management is utilized. Second, a **two-way learning model** is applied to introduce concepts of information exchange. Together, the three of these theories complement the initial theoretical framework proposed in chapter 3 to establish a theory-based recommendation for a groundwater monitoring system in Kumasi.

8.2.1 Participatory Design

Public participation with science and technology is a widely accepted approach in science communication (Kalmár & Stenfert, 2020). Participation supports the idea that science communication should be a collaborative effort from communities involving social sciences and engineering professionals. The motive behind participatory design highlights the need for multi-perspective, multi-sector, and multidisciplinary teams in design for a better understanding of complex problems. A cornerstone of participatory design is that “citizens have the right to influence the world they are living in [and] the technologies they are going to use to solve societal problems they are part of” (Kalmár & Stenfert, 2020). This is something that both participatory design and *value sensitive* design have in common. They both seek to provide a proactive approach to design where the user can influence the product in the design stage so they can shape how they use the product in the future.

There is a continuum of user participation in participatory design projects as seen in figure 64 which ranges from *no involvement* to *strong user control*. *Symbolic involvement* is where advice is asked and ignored, *user advice* is when advice is solicited from users, and *users in the design team* indicates that the user is a part of the team.

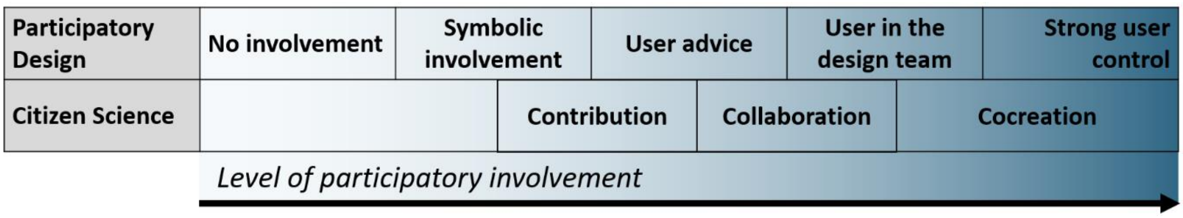


Figure 64. Participatory design and citizen science spectrum

An application of a participatory approach in water management is citizen science, which is an activity where “members of the general public, typically as part of a collaborative project with professional scientists” contribute to data collection or analysis relating to the natural world (Oxford Languages, 2022). Citizens might participate in citizen science because it is fun, the topic interests them, or the topic matters to them (Minkman, van der Sanden, & Rutten, 2017). Similarly, to the gradient of participatory design, Bonney claims there are three potential levels of involvement for citizens to participate: contribution, collaboration, and co-creation (Bonney, et al., 2009). The relevance of the two models is compared in figure 64. In the *contribution* level, citizens collect data and design is done by scientists. In *collaborative* settings, citizens are involved in analysis and sometimes design. While in *cocreation*, citizens are involved in all steps and may even initiate. A drawback of citizen science projects is that it lacks reciprocity in learning exchange- that is to say, that while citizens are expected to learn, scientists are not promised the same benefit of knowledge (Kalmár & Stenfert, 2020).

Based on this continuum, there exists three broad categories of participatory design approaches: design for, with or by users. In *design for users*, professionals design products on behalf of users while the users only have a slight influence on design. In *design with users*, designers and users partake in a codesign process. In this context, the roles and responsibilities are distinct, but users have strong input. Lastly is *design by users* which involves “the users design and develop parts of the idea of the product, supported by the designers and various toolkits” (Kalmár & Stenfert, 2020).

8.2.2 Social Learning

A key issue with the public engagement and communication model is that it puts a high degree of pressure on the science communicators themselves as they must do the research and communication portions (Kalmár & Stenfert, 2020). A solution for this concern is the concept of *social learning* which can aid in the change in participant understanding. Change in understanding can include recall of new information or change in attitude- this can be both affective and cognitive: head and heart.

Social learning theory was published originally in 1977 to describe the phenomenon whereby individuals learn in a social environment through observation and imitation of others (Bandura, Social Learning Theory, 1977). This theory is a cognitive level concept which occurs within an individual and therefore does not consider a group’s shared meanings.

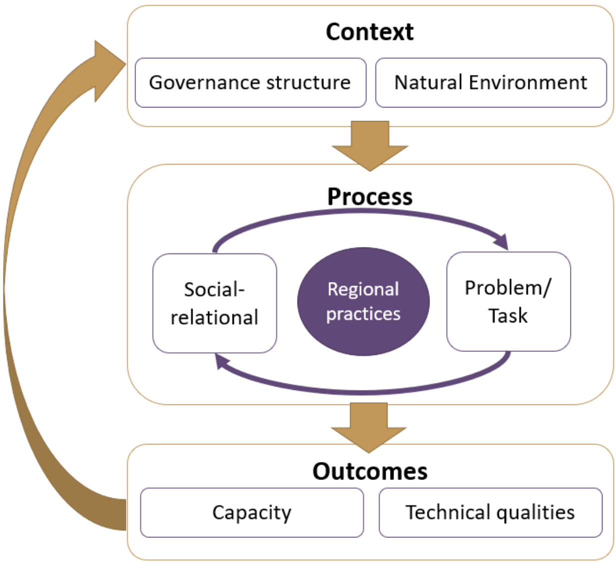


Figure 65. Social Learning Model (Pahl-Wostl, et al., 2007)

To describe a conceptual framework for multilevel social learning in river basin management, the Harmonizing Collaborative Planning project created the model in figure 65 (Pahl-Wostl, et al., 2007). It describes learning in the *context* of water management through multiparty collaboration. Within the context, both the *governance structure* and *natural environment* of the river basin are considered.

Through the context, *processing* of information involves solving management problems which manifest as *problem/ task* management or *social-relational* issues. The integration of task management and social relational issues is facilitated by *relational practices* such as task-oriented actions, relational qualities of reciprocity, and reflexivity. Examples of such practices can include joint field visits or common training sessions. Qualities which are of importance for the success of these practices include: quality of interaction, shared ownership of a task, openness and reflexivity.

The *outcomes* of these processes include both 1) *technical qualities* which serve as measures to address environmental problems and 2) *capacity* of stakeholder groups to deal with the problem. The concept of procedural rationality contributes to the idea that high quality processes which utilize multidisciplinary cooperation leads to higher technical quality outcomes. Additionally, active involvement and sense of ownership lead to a higher willingness to reach agreements and commitment to the outcome.

The overall social learning process described here can be applied to groups or networks which contributes to the concept of communities of practice as discussed in chapter 3 (Wenger-Trayner & Wenger-Trayner, 2015). The model in figure 66 resembles a ***micro level*** system for a singular multiparty collaboration process, however, there are also meso and macro level processes. The ***meso level*** looks at the full water management landscape, while the ***macro level*** addresses the entirety of government and societal conditions.

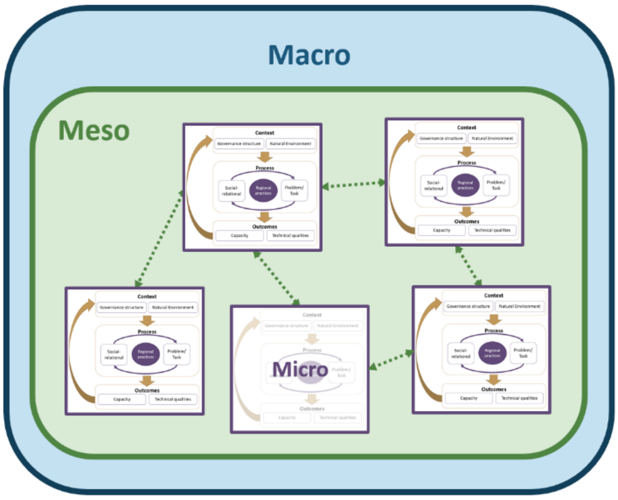


Figure 66. Social Learning Model Levels

Level 3: Macro
The governance and societal structural conditions that are characterized by cultural values, governance regime, or power structures

Level 2: Meso
The actors in the water management regime who may partly engage in bilateral interactions

Level 1: Micro
multiparty collaboration process in which representatives from different stakeholder groups interact

Although this evidence suggests clear benefits of social learning, there are also impediments which can cause challenges in its implementation. Some of these include centralized political and economic systems, privatization, commercialization of the environment, rigid bureaucratic systems, and political secrecy (Pahl-Wostl, et al., 2007). The impediments illustrate strong boundaries in a community of practice model, as boundaries between communities prevent collaboration.

8.2.3 Two Way Learning Model

Participatory design ideals reject the idea of one-way communication, or the deficit model of learning. This style of education views the student as an empty box with a deficit of knowledge for which the teacher is supposed to fill. In this way, learning goes one way: from the teacher to the student. However, there are inherent flaws in this style. First, it views the student as an individual with no or limited knowledge- which is not necessarily true. Secondly, the teacher does not gain knowledge out of this transfer: hence one-way. The alternative to this model is two-way communication, whereby both teacher and student learn from each other. Participatory design argues that “scientists should actively reach out to society and engage people in discussions or even in participate in scientific activities” (Kalmár & Stenfert, 2020).

In a literature review on Scopus science, two-way learning models are commonly used in the health sector, agricultural extension, and with indigenous communities. In order to achieve this mutual learning, all parties need to be prepared to learn from each other (Staley & Barron, 2019). Despite a consistent field of application, there is not a consistent method for involvement because by its very nature, voluntary involvement cannot be controlled. Therefore, any project involving mutual learning needs to be flexible in design, responsive to the context of the case, and negotiated and agreed upon by the individuals involved (Staley & Barron, 2019). It is important to note that while there are no universal methods for involvement, there are standards for ethical approaches when doing projects involving human participants.

A case study which looked at rice farmers in Ghana and two-way learning with researchers, extension agents and farmers found that there was a learning and acceptance gap between the groups (Bentley, Van Mele, & A, 2010). While farmers were accepting of ideas, there was a greater need for researchers to be more involved. In another study which assessed social learning in an agriculture setting, they found that “social learning projects that include socially differentiated groups and create conditions for substantive two-way learning enhance the relevance and legitimacy of knowledge and governance outcomes, increasing the potential for accelerating sustainable development outcomes” (Shaw & Kristjanson, 2014).

On this note, development style projects have a tendency to promote elite social institutions with different agendas as “the social scientists wanted to promote ‘participation’ not quite realizing at the time that the other actors on the project were already busy trying to ‘participate’ by putting forward their own goals” (Bentley, Van Mele, & A, 2010). Two-way learning works to address power and hierarchical dynamics as the facilitator’s attitude, skills and capacities must work to moderate these knowledge hierarchies. This was achieved in Shaw’s study through trust building: creating incentives, moderating power imbalance, attending to cultural norms and attenuating knowledge hierarchies (Shaw & Kristjanson, 2014). Attenuating the knowledge hierarchy was done by encouraging researchers to move into learner roles. External facilitation of the education can “help minimize the knowledge hierarchy implicit when researchers manage and facilitate learning processes” (Shaw & Kristjanson, 2014).

8.2.4 Framework

As demonstrated in the figure, participatory design joins value sensitive design at the center of the theoretical framework Venn diagram. This is because they both seek to achieve proactive design of a product by users so that users can influence their capabilities with the product. It is value-laden in nature because its implementation is based in the value of participation. Participation also urges the integration of diverse stakeholders affiliated with different identities. As referenced by Bonney, participatory design can also be cocreative in nature (Bonney, et al., 2009).

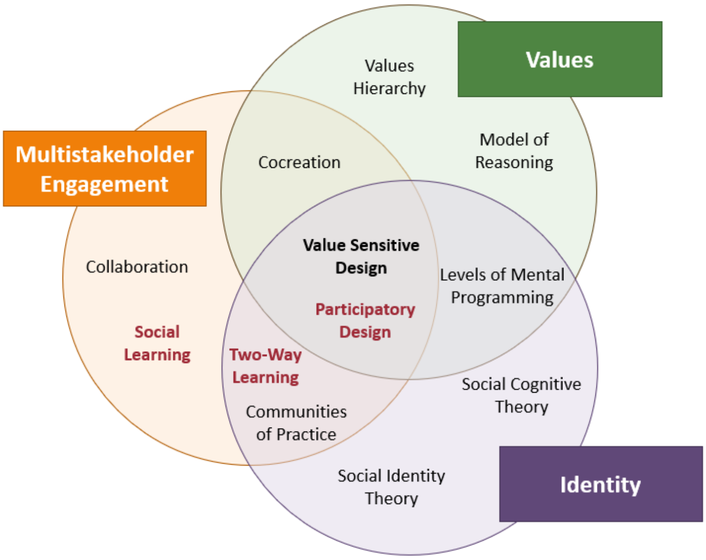


Figure 67. Cumulative Theoretical Framework

Social learning theory was added to the multistakeholder engagement bubble because of its emphasis on learning in an environment of others. Here there is a clear link from social learning to collaboration models as social learning occurs best with limited boundaries as is also encouraged in transdisciplinary studies.

Lastly, two-way learning was added at the intersection of identity and multistakeholder engagement. This is because two-way learning inherently identifies two identities of a teacher and a student and seeks to encourage both to collaborate and engage.

8.2.5 Summary

The theoretical framework implemented for this design complements the framework provided at the outset. The key takeaways from this section involve concepts from the theoretical framework for the project as well as the theoretical framework applied for implementation. The overall theme of the theories is the idea of participatory design and limited boundaries between communities to encourage learning between members. The theoretical based design requirements are listed here.

Participatory Design	**24**	*Citizen involvement*: citizens play a role in effective design for a "design by users" approach
Social Learning	**25**	*Peer learning*: individuals learn from other in-group members
	26	*Social Learning model*: learning occurs in a loop like cycle between context, process and outcome.
Two Way Learning	**27**	*External facilitator*: external representative should design education to minimize power dynamics
	28	*Openness*: participants of all levels should be open to sharing and receiving knowledge
Transdisciplinary	**29**	*Participant diversity:* it is important to include diverse groups in collaboration
Social identity	**30**	*In- group messenger:* a member of the in-group should be responsible for sharing information to an audience

8.3 Recommendation

8.3.1 Recommendation Summary

In order to make a data-driven, science based and appropriate recommendation, the results from the comprehensive paper are taken into account. A total of 32 design requirements were determined. Table 17 summarizes them according to the source of information.

After determining the design requirements, a proposed recommendation was created. Table 28 summarizes the main components of the design The three recommendation programs are multistakeholder involvement (A), technology development (B) and an educational campaign (C).

8.3.1.1 Cumulative Design Requirements

Table 27. cumulative design requirements

Source		#	Description
Research Questions	*RQ1*	1	*Collaboration*: multi-disciplinary water sector operates with a decentralized hierarchal governance structure
		2	*Consumers*: consumers are most familiar with local stakeholders
		3	*Readiness*: all interviewees responded with high readiness to be involved in groundwater monitoring for various tasks
		4	*Key stakeholders*: over 40 groups play a role in groundwater management; Key stakeholders identified
	RQ2	5	*Management:* there is a poor view of groundwater management from respondents; limited regulation on borehole drilling
		6	*Challenges*: collaboration, lack of awareness and funding
		7	*Design requirements*: academic groups are key in determining requirements; education desired by all groups
		8	*Existing infrastructure*: informal network for data sharing among borehole drillers; existing physical infrastructure of boreholes
	RQ3	9	*Value profiles*: value profiles for actors are statistically similar
		10	*Importance v agreement:* low consensus on agreement for importance of values
		11	*Technical experts*: key design requirements came from technical experts; high consensus among academic groups
		12	*Values*: participation most frequently cited as connected to other values; economic efficiency regarded with low importance
Ghana Policy	*IWRM*	13	*IWRM concepts*: subsidiary principle, enabling environment, institutional roles, and management instruments
	Monitoring	14	*Monitoring*: lessons learned from previous attempts to monitor groundwater in Ghana
	Technology	15	*Technology*: develop technology in accordance with Ghanaian policy
	Participation	16	*Participation*: involve stakeholders in accordance with Ghanaian policy
Case Studies	*Development studies*	17	*Incentives:* participants need to be incentivized to stay involved
		18	*Replacement:* structure to replace participants over time
		19	*Training scheme:* organized method to train participants
	Zambia	20	*Local government:* local government must be involved
	Ghana	21	*Regular meetings*: stakeholder groups should meet with regularity to maintain involvement
	South Africa	22	*Public data*: data should be available to the public by request
	Turkey	23	*Field integration*: technical and administrative groups need to balance each other in collaboration
Theory	*Transdisciplinary*	24	*Citizen involvement*: citizens play a role in effective design
	Participatory	25	*Peer learning*: individuals learn from other group members
	Social Identity	26	*Social Learning*: cyclic structure of water management structure between context, process and outcome
	Social learning	27	*External facilitator*: external social scientist should design collaboration
		28	*Openness*: both participants and educators should be open to learning
	Two-way learning	29	*Participant diversity:* include diverse groups in collaboration
		30	*In- group messenger:* a member of the in-group should be responsible for sharing information to an audience

8.3.1.2 Design Summary

The table below shows the cumulative design summary. To see how the design requirements are fulfilled by each of the recommendations, see appendix H.

Table 28. Summarized Recommendation with affiliated motivation

	Multistakeholder Involvement (A)	Technology Development (B)	Education Campaign (C)
Overview	**A.1** Establish periodic meetings for stakeholders to voluntary participate in a groundwater monitoring program	**B.1** Involve groundwater experts to develop groundwater monitoring technology	**C.1** Implement a water education program for consumers in regions with high groundwater use
Stakeholders	**A.2** Delegate leadership of the advisory board to the WRC in collaboration with members of the Pra River Basin Management Board	**B.2** Engage experts from institutions such as KNUST, WRI and GAEC in collaboration with TU Delft	**C.2** Facilitate education campaign with KNUST graduate students speaking at gatherings of water users
Activities	**A.3** Utilize informal networks of pre-established relationships between stakeholders to share organization activities	**B.3** Create groundwater models and pilot studies before integration of a monitoring system into a community	**C.3** Integrate grade schools in environmental education program
	A.4 Outsource collaboration oversight to external social scientist or communication specialist	**B.4** Utilize existing data sources and borehole infrastructure	**C.4** Schedule regular community meetings with groundwater consumers to discuss water use and offer technical advice for water related concerns
Collaboration activities	**A.5** Provide round table discussion on developments in monitoring and education	**B.5** Set up mechanism for technical working group to share results, updates and needs from monitoring development at collaboration meetings	**C.5** Integrate assembly men and committee members as leaders to establish relationship with community
Integration	**O.1** Integrate the three programs when a groundwater monitoring program is ready to be applied		

8.3.1.3 Responsibility Delegation and Overview

The approach for the recommendation is to address coordination among the many water sector stakeholder in Kumasi. To illustrate the recommendation and provide an overview of the three programs working together, the figure and table below were constructed.

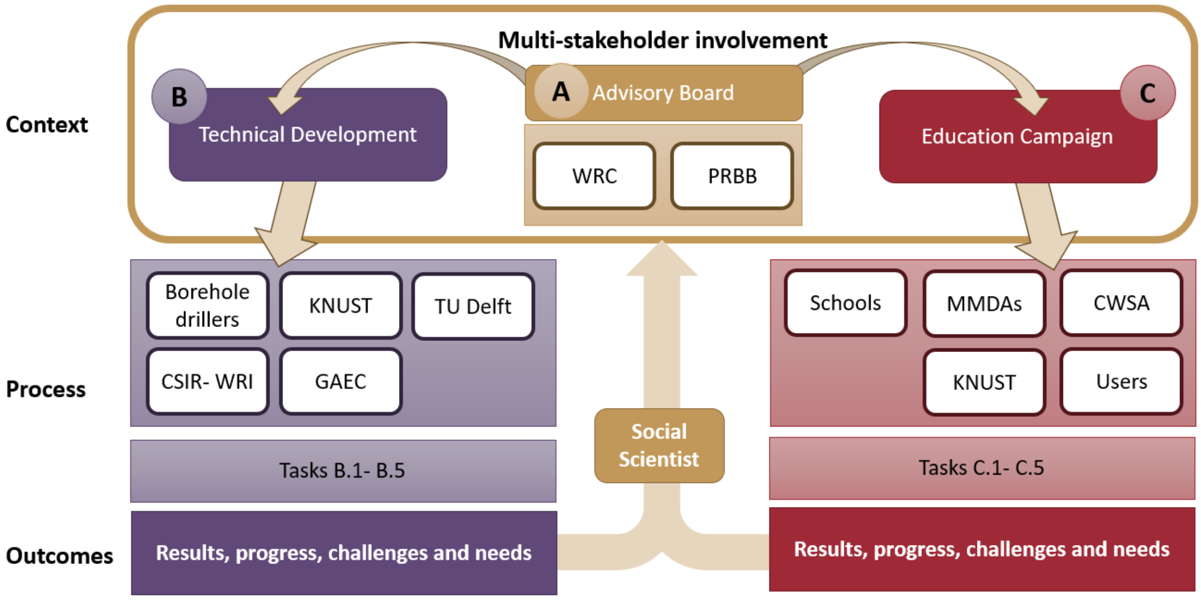


Figure 68. Responsibility and Task overview

The figure is reflective of Paul-Wostl's social learning model (Pahl-Wostl, et al., 2007). It begins with the *context* of the multistakeholder involvement group (blue), and then proceeds downward into two parallel *process* groups for both the technical development (green) and education campaign (orange). The end results of these parallel programs serve as *outcomes*. Then the three programs are integrated, and facilitation is done by a social scientist to ensure efficient design discussions and minimize power dynamics. In the integration phase, the programs come together to exchange information and then repeat the cycle in an iterative loop. This cyclic process enables development to be shaped by an iterative process and evolve as new information is uncovered.

8.3.2 Recommendation

This section goes over each recommendation by category starting with the integration of the recommendation. Then recommendations A, B and C are described in detail.

8.3.2.1 Integration

The proposed recommendation involves three programs: a multistakeholder advisory group, a technology development project, and a water education campaign. The program starts with the initialization of the advisory group, and as the group becomes established and goals are clarified, the two working groups on technology development and education can be launched in parallel. The integration of the three of these components come together when a groundwater monitoring technology is ready to be applied to a community as indicated on figure 69.

O.1	Integrate the three programs when a groundwater monitoring program is ready to be applied

The graphic to the right is a simplified version of the figure on the previous page and shows that the three programs occur in tandem and that the working groups come together periodically to collaborate on the projects. The first program is **multistakeholder engagement (A)** which involves utilizing the existing network to organize key stakeholders. The involvement of these groups is in alignment with the Ghana National Water Policy as it states that it is essential to "promote partnerships between the public and private sectors for the protection and conservation of water resources through the use of cleaner and efficient technologies, effective waste management and sound land management and agricultural practices" (Ministry of Water Resources, Works and Housing, 2007).

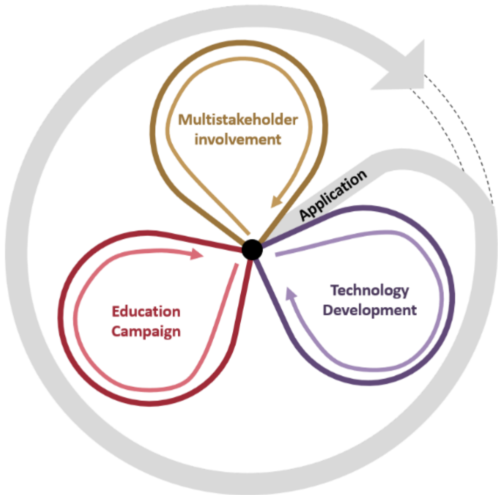


Figure 69. Simplified loop process

After the key collaborators are gathered, the launch of the two contributing programs can be initiated: **technology development (B)** and an **education campaign (C)**. The figure shows that the three projects are run in parallel and operate independently but come back together on a periodic basis for collaboration to adapt to the project developments. This will enable open discussion, social learning and a design which includes multiple viewpoints. This will also give other stakeholders to be more involved in the programs to encourage a higher degree of involvement as demonstrated in transdisciplinary style collaborations.

The gray circle of the diagram resembles **program integration** for application of groundwater monitoring. The goal of this step is to fulfill the Ghana National Water Policy's effort to encourage interdisciplinary and participatory research that recognizes the need for a link between technology and communities.

This means that when there is a groundwater monitoring technology prepared for a community level pilot test, the location of the pilot test is where the education campaign was held. This is because community participation from early on in a water supply project enhances the future sense of ownership (Harvey & Reed, 2006). Encouraging ownership of the system is imperative because if communities do not regard the system as theirs, the system is more likely to fail. (Adelana, 2009)

8.3.2.2 A: Multistakeholder Involvement

The first recommendation is for multistakeholder involvement through an advisory group. For this portion, there are five recommendations. To create a coordinated effort, the development of this program is inclusive to diverse stakeholder groups but organized in a systematic manner.

A.1	Establish periodic meetings for stakeholders to voluntary participate in a groundwater monitoring program

The first strategy calls for the organization stakeholders who wish to be involved in a groundwater monitoring program. This can be thought of as a **stakeholder advisory group**. There is already a group established for similar purposes: the Pra River Basin Management Board. This board is composed of stakeholders in the water sector who previously collaborated to develop the WRC's Integrated Water Resource Management Plan. Because of these pre-established connections, there is higher confidence in the program's success and participation level. In addition to this board, consumers, engineers and social scientists can be involved to ensure diverse communities of practice thus fulfilling a component of participatory design. These meetings can occur on a regular basis on a time frame which meets the constraints of those involved.

"Well, if your system relies on data points from citizens that you know, by definition it has to be participatory or it won't work. And I think the other key reason to make a groundwater system participatory is... the reason that you would want to monitor groundwater is to ensure sustainable usage of the resource. And if you don't have participation at all levels, then you don't have awareness of what the challenges are. And I think particularly in Kumasi, the challenge of groundwater sustainability is something that I don't think will be solved in the centralized manner, I think it needs buy-in from all parties. So, participation on the monitoring side of things leads to awareness and education which hopefully leads to participation and a solution."

- TU Delft 46

A.2	Delegate leadership of the advisory board to the WRC in collaboration with members of the Pra River Basin Management Board

To establish the advisory board, the Water Resources Commission can take the lead, as it is their mandate to oversee projects like this. The WRC's involvement is paramount in coordination with other government authorities because leadership by "NGOs and non-government authorities … has led to disorganized programming" (Adelana, 2009).

However, because the WRC is strained for resources, it can outsource its needs to other branches of the advisory board. The WRC seeks "broad stakeholder engagement of central, regional, and local governance institutions" (Water Resources Commission, 2011). In order to achieve this, there should be "inter-sectoral collaboration and co-ordination committees at District level" (Water Resources Commission, 2012).

A.3	Utilize informal networks of pre-established relationships between stakeholders to share organization activities

In order to establish involvement and interest in the programs, the current informal networks within the Kumasi water sector can be utilized. Because of these pre-existing relationships, organizations may be more willing to be involved. Many of these relationships are within the borehole drilling community because the drillers are connected with the consumers and share borehole information with each other. Additional pre-established relationships are with academic groups as there are other collaborations in the past between TU Delft and KNUST as well as alumni of KNUST who work at the Water Research Institute. Capitalizing on these relationships will strengthen the involvement in the program from the start.

Additionally, collaboration with the CWSA is necessary because they oversee water distribution in rural areas. The CWSA operates in a decentralized fashion and has established relationships with communities because of this. One of these CWSA-affiliated individuals at the community level is the public water caretaker. These individuals oversee the public water access points and are thus key community members in the water distribution network. By integrating the caretakers in the education program, the education facilitators can learn more about local water circumstances. Therefore, the CWSA's involvement will be vital for any rural community-oriented projects like monitoring and education campaigns.

> "One key thing is lots of local involvement because usually if there is a system being designed and the local is less than 50%, it dies down. But if the local involvement, they buy into it more, it is more sustainable, and they will keep it."
>
> - KNUST 43

A.4 Outsource collaboration oversight to external social scientist or communication specialist

To minimize undesirable power dynamics in the collaboration and facilitate peer learning, the collaboration should be facilitated by a social scientist familiar with the case. Coordination among these institutions will prevent overlapping of responsibilities as well as the development of policies with greater coherence. This will aid in the sustainable and effective utilization of both financial and human resources (Ebo Yahans Amuah, Afia Boadu, & Solomon, 2022). It should be noted that sometimes involving a social scientist introduces the obstacle of them influencing their own agenda onto the case. This should be balanced such that the facilitator is familiar with the case and balanced by other social scientists to minimize one individual's influence. Specifically, the facilitator(s) can act by "creating incentives, moderating power imbalance, attending to cultural norms and attenuating knowledge hierarchies" (Shaw & Kristjanson, 2014).

A.5 Provide round table discussion on developments in monitoring and education

During the stakeholder integration meetings, the stakeholders can provide progress on each of the projects. These progress updates can include insights, current models, project needs and contributions. The WRC specifically seeks "well established procedures… where plans and programs are elaborated and vetted following a participatory approach allowing for thorough public discussions, often in workshop settings" (Water Resources Commission, 2012). These discussions will aid in creating and sustaining awareness to "sensitize stakeholders on water resource management problems, issues and solutions" (Water Resources Commission, 2012). As a logistic detail, the time and place of the meeting should be accessible for all those involved, as ability to access meetings should not prohibit participation.

8.3.2.3 B: Technical Development

The second component of the recommendation is to involve experts in the working group for technical development of a groundwater monitoring system in Kumasi. Here, there are five components which utilize each of the four design requirement sources.

B.1 Involve groundwater experts to develop groundwater monitoring technology

A key finding of the interviews is that respondents want to involve experts in this groundwater monitoring project and the interviewed academics are mutually interested in being involved. This supports the WRC's groundwater management strategy which, among other goals, aims to (Water Resources Commission, 2011):

1. Support the data collection agencies to provide data and information on land use and water resources"
2. Support the standardization of methods of data collection, archiving, processing and dissemination, both at national and regional levels, for use by all riparian countries

The overarching goal of this recommendation is to incorporate experts in developing a groundwater monitoring system. The group statutorily required to monitor groundwater is the Council for Scientific and Industrial Research- Water Research Institute (CSIR-WRI), who has developed components of a groundwater monitoring system, but there is limited available information on it. The Ghana Atomic Energy Corporation (GAEC) has been delegated this responsibility as well, but specifically for monitoring of isotopes in groundwater. With the WRI and GAEC working together and integrating local universities, there are greater capabilities for developing such a technology.

Universities which may be interested in working on this project include but are not limited to Kwame Nkrumah University of Science and Technology (KNUST), Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED) and the University of Energy and Natural Resources-Sunyani. However, technical experts are not limited to universities, as is mentioned in section chapter 5. Technical experts are embedded in government affiliated groups such as the Ghana Water Company Limited and Community Water and Sanitation Agency.

B.2 Engage experts from institutions such as KNUST, WRI and GAEC in collaboration with TU Delft

As previously mentioned, experts were a key source of technical information and sought out for involvement by other stakeholder groups. The key groups involved for oversight of the project are KNUST, the Water Research Institute, and the Ghana Atomic Energy Corporation.

Additional groups which may seek to be highly involved in the development are TU Delft, technical experts embedded in government organizations and graduate students at KNUST. TU Delft, and specifically, the African Water Corridor research group, strives to be a knowledge partner for this project. Additionally, graduate students at KNUST should be given the opportunity to be actively involved in the project, perhaps by integrating the concepts into thesis work, as it was mentioned during interviews is a common practice. This action item for program B differs from the first because this encourages not only participation of technical experts, but collaboration for them to work together on a shared goal.

B.3 Create groundwater models and pilot studies before integrating a monitoring system into a community

The initial output of the groundwater technical working group would be to conduct a pilot study before applying it to a community. An ideal base for this working group to conduct research out of is the Regional Water, Sanitation and Environment Center- Kumasi (RWSECK). RWSECK is affiliated with KNUST and is the main water research hub in Kumasi. The center is host to researchers, students and staff with instrumentation on site to be an appropriate location for study. After identifying a technology there should be an initial pilot study at the RWESK. The research center has a borehole on site which is specifically used for educational purposes. The Integrated Water Resources Management Plan for the Pra Basin outlines several technology steps which support the basis for this recommendation (Water Resources Commission, 2012):

1. Intensify education and training at all levels
2. Develop GIS-driven data and information databases on the ecosystems, socio-culture, economics, water cycle, water supply systems, etc.
3. Carry out research into technology development, adaptation, Etc.

B.4 Utilize existing data sources and borehole infrastructure

As a result of conducting interviews, it was found that there is pre-existing infrastructure in the form of data and physical boreholes. These fixtures will provide useful starting points for the water monitoring system. As mentioned in chapter 6, there are several groups which possess groundwater data in the form of drilling reports, student research or short-term monitoring. By involving the borehole drilling companies and assessing their data reports, this can aid in the production of groundwater models.

Another key piece of infrastructure are the boreholes themselves. Technical experts cited that there is no need to drill additional boreholes to monitor groundwater. This would significantly add to the cost of an already constrained budget and further disrupt the aquifer by drilling. There is already a well-established collection of boreholes drilled throughout the country.

There are two recommendations for boreholes to utilize for monitoring, and both are of public interest. The first option is a public borehole operated under the jurisdiction of the Community Water and Sanitation Agency. These are overseen daily by a caretaker and the function of the borehole is of interest to the community because it is a public source of water. The second option is boreholes located at public schools. These boreholes are also of public interest as they serve water for the community and students. Similar monitoring efforts in Kumasi have been successful by placing weather monitoring stations "near schools, where they will be integrated in the curriculum" (van de Giesen, Hut, & Selker, 2014). Both of these options could be an appropriate solution as these are overseen by community members and thus have joint interest. This application can also pair with the water education campaign as mentioned in C.3.

"If we are able to share information because at least that will be able to help you. For the wellbeing of Ghanaians- that is our mandate. Because water is life. If all agencies have the data, at least we will know how to use that data to help Ghanaians."

- Community Water and Sanitation Agency 45

B.5	Set up mechanism for technical working group to share results, updates and needs from monitoring development at collaboration meetings

When the working groups meet for the multistakeholder advisory group, the technical working group will present updates to the group and seek input. This concept is representative of a participatory design process whereby the users are brought in to become members of the design team. It also allows for open communication where sharing needs and struggles on a project, when another group might have a solution for it or resources available to solve the concern. This is supported by the Ghana National Water Policy as they aim to "encourage interdisciplinary and participatory research that recognizes the need for a link between technology and communities" (Ministry of Water Resources, Works and Housing, 2007).

8.3.2.4 C: Education Campaign

The last section of recommendations is forming a water education campaign for the communities that would receive groundwater monitoring. There are five recommendations in total.

C.1	Implement a water education program for consumers in regions with high groundwater use

The central component of the last recommendation is the implementation of a water education program for consumers, ideally in regions where groundwater use is higher than average or where the Ghana Water Company pipeline does not serve. The curriculum of such a program would focus on groundwater use, safety, and methods of water conservation and would be facilitated by water professionals. This is supported by the interview results as education by experts was a common desire among all stakeholders. This design choice is supported by The Ghana National Water Policy's encouragement of the application of Integrated Water Resource Management in all levels of education.

The first campaign should be introduced and supported by the local assembly man and committee members. This task will be delegated from the advisory group to the local leaders because of the close connection the assembly man has with his constituents. Regular meetings with the water education program will lead to trust between the groups. The education program will provide a network for social learning of water concerns.

> "When we educate ourselves about the importance of water, people will know how to economize using the water. When we educate ourselves, we will know how to protect it for future generations"
>
> - Domestic Consumer 30

C.2	Facilitate education campaign with KNUST graduate students speaking at gatherings of water users

The facilitation of the group could be through KNUST graduate students who enrolled in the civil or geosciences engineering program who specialize in groundwater. These individuals can lead the group, field questions from participants and offer advice. Utilizing students for these tasks is common in Kumasi and therefore will have less friction to implement.

Provision of expertise by a technical group like KNUST is essential to "ameliorate complex technical problems that are beyond the management and financial capabilities of the community" (Harvey & Reed, 2006). Additionally, by instituting Ghanaian graduate students as knowledge brokers, information will be transferred by an in-group member as opposed to an external group such as TU Delft or a non-government organization (Fielding & Hornsey, 2016). The program should meet regularly to ensure consistent continuation of the program.

> "We need experts for water who are highly educated. There should be mass education. Those who are in charge should regularly monitor groundwater so they can also educate them on what to do."
>
> - Car Wash 19

C.3	Integrate grade schools in environmental education program

In addition to consumer based regular education units, special trips should be made to grade schools, as it is important to educate all levels of water users for long term planning. This strategy will ensure that there is a plan for continuation of the community education program when the adult participants dissipate from the program. If introduced to the program at a young age, the students might be more likely to join as adults as they are more familiar with the program.

Additionally, the grade school component is crucial for the integration phase of the project. This is because, as mentioned in the overview, the boreholes at schools will be the targets for the monitoring equipment to be placed. This is similar to the Trans-African Hydro-Meteorological Observatory (TAHMO) project which integrated weather monitoring with an education curriculum (van de Giesen, Hut, & Selker, 2014). By involving the schools directly in the program from an early stage, there will be higher likelihood for integration.

> "The children who are coming are the future generations, so if they are protected, there will be economic development. They should be healthy enough so they can help build the nation."
>
> - Car Wash 36

C.4	Schedule regular community meetings with groundwater consumers to discuss water use and offer technical advice for water related concerns

The interview results showed that consumers desire education for their groundwater consumption. By creating a community wide water education program, this can be achieved. Examples of this can be in the form of short seminars, courses, panels or discussion groups (Ekmekçi & Günay, 1997). It has been demonstrated in water related citizen science that individuals viewing citizen science for education and sharing local knowledge value "trust in citizens motivations and commitments"

(Minkman, van der Sanden, & Rutten, 2017). This demonstrates the need for participants to trust in the education program. In addition to this, the meetings need to occur regularly to ensure consistent engagement in the communities and incentivize participants.

These meetings should not be designed for one-way, or deficit model learning. Instead, the goal for education would be for mutual, two-way learning between the educator and the consumers. To achieve this, first, the educators need to be open to the idea that they will also be learning when they make these visits. Second, consumers need to feel comfortable to share their knowledge with the educator. In this way, both groups can gain in their shared experiences to have a better understanding of interaction between groundwater and its users.

A key incentive for consumers to be involved is the practical advice they will receive from involvement in the group. This can grow from an array of sources. First, the educator can share techniques and suggestions for water use. However, another mechanism is by social learning. The benefit of having these groups in a local region is to open the dialogue about water use and better understand problems affecting consumers in the area. By one consumer sharing a concern, another individual might have also encountered the same problem and found a solution. By sharing these experiences and collecting the knowledge base of the consumers, the community can benefit through collective knowledge.

> "Once it is in the form of a societal club, those who are members can go out and educate people on it. Because once it is a fun club, it is in a participatory format. When they meet and they discuss current issues with others, they can share the information with others."
>
> - Domestic Consumer 03

C.5	Integrate assembly men and committee members as leaders to establish relationship with community

In all four sources of design requirements, it is cited that involvement of local government is imperative. The assemblymen and committee members are readily accessible to community members and therefore, would be an ideal collaborator for the education program. Involving the assemblymen and obtaining their endorsement is necessary to create a program which is trusted by the community. The assemblies also have departments such as engineering and environmental health that could contribute to both the education and technical development programs.

> [the assembly could contribute] … "officers who have some level of knowledge and level of training specifically in that area. They will be able to support what is being rolled out."
>
> - Kumasi Metropolitan Assembly 44

8.4 Discussion

8.4.1 Results discussion

8.4.1.1 Scale

The scale required to monitor groundwater for a region is something that would require years of planning, regulation, budgeting, research and implementation to enact. Because of this, the proposed recommendation focuses on the proactive steps to ensure a participatory design process. The results of the data did not offer conclusive information to determine a technical groundwater monitoring method. However, the conclusions from research questions 1-3 aid in a useful starting point for a future project.

Contributing to the concept of scale is the social learning model describing the macro, meso and micro levels of application (Pahl-Wostl, et al., 2007). The recommendation focuses on the macro level because this level describes “the actors in the water management regime consisting of organized stakeholder groups, who may partly engage in bilateral interactions” (Pahl-Wostl, et al., 2007). This complements the theoretical framework described in chapter 3 because the level of analysis was designated at the group level of identity. However, components from the macro level were taken into account as the macro level is described to be “the governance and societal structural conditions that are characterized by cultural values, governance regime, or power structures” (Pahl-Wostl, et al., 2007). The analysis was not completed fully at the macro level because the sample size was too low to accomplish macro-level analysis and it was out of this project’s scope to analyze at this level. However, by integrating the values assessment (chapter 7), studying stakeholders (chapter 5), and governance structures (chapter 2), this contributes to macro-level components.

8.4.1.2 Adaptivity and Reflexivity

Inclusion of adaptivity in the planning scheme is imperative in any large-scale project, but especially in a climate sensitive region. Therefore, a cyclic structure was implemented in the proposal. These loops encourage adaptivity and reflexivity as looping back for integration allows for participants to examine their actions and reflect on decision making. This reflection can prompt adaptation in the collaboration and course-correct when challenges are encountered.

8.4.1.3 Hierarchy

Another aspect the design attempts to address is hierarchy. Sometimes hierarchical collaborations are desired by team members while other times they are not- whether for personal, cultural or ethical reasons. Forms of hierarchy which could occur in the recommendation are institutional, educational and class.

Institutional hierarchy can occur when a government leader is presiding over those in a lower or no government role. These types of hierarchies are, in the case of Ghanian governance, purposefully designed in order to have a clear reporting structure. However, there are other hierarchies which are undesirable.

The *education hierarchy* may occur in the education campaign as those in the "teacher” role may be seen with a higher status because of their formal educational background. This could create a power differential for the participants in the program as some forms of knowledge, like university studies, may be valued over other forms. Therefore, it is valuable to collaborate the diverse areas of knowledge irrespective of status in order to create a more comprehensive social learning experience. The education campaign was designed to limit this potential hierarchy through the implementation of two-way learning.

Another potential is *class hierarchy*. As demonstrated in chapter 2, as income increases, so does the frequency of private borehole ownership. It was clear in the interviews that perhaps the only limiting factor for an individual to drill a private borehole is income. Therefore, when adopting a community learning group, while everyone might identify as a groundwater user, there are clear class-income hierarchies which will exist within that group. This should be addressed in the design so that these communities are targeted to ensure their inclusion in the program and that socio-economic status is not a barrier for participation.

8.4.1.4 Power Dynamics

Relating to hierarchies is the notion of power in collaborations. Specifically, there should be attention drawn to the inclusion of KNUST graduate students as intermediaries for both the education campaign and for the adoption of groundwater monitoring. It was mentioned in multiple interviews that graduate students from various technical universities are utilized for small studies. However, this introduces the ethical dilemma of graduate student exploitation for their free labor. To combat this risk, the concern should be raised at the outset of the project and involve the graduate students in establishing tasks which are in and out of their scope of work.

8.4.1.5 Kruger Model

To reflect back on the theoretical framework, the scope of this thesis was to work on the preparation, significance and solution portions of cocreation as described by the Kruger Model (below). The next step for this case study is the *testing phase* which would be an experiment and evaluation of the recommendation proposed in this chapter. As demonstrated in the figure below, the testing phase involves feedback on the preparation, significance and solution phases which is accounted for in the loop-like feedback structure of the recommendation.

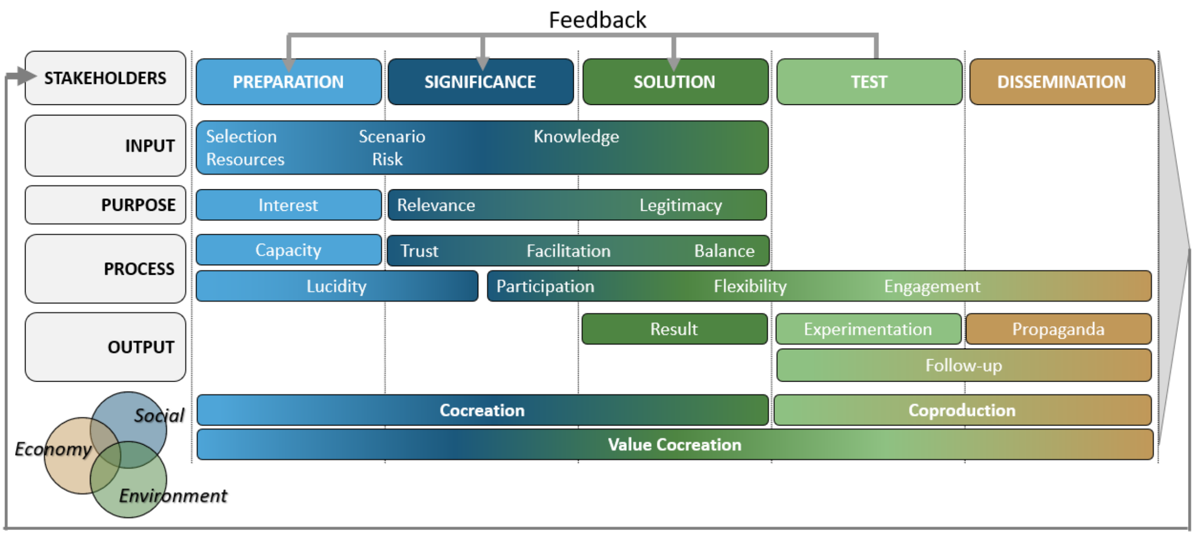


Figure 70. Kruger Model of cocreation (Kruger, Gusmao, Braga França, & Gonçalves Quelhas, 2018)

8.4.2 Further Study

8.4.2.1 Indigenous Knowledge

Throughout the paper it was noted that indigenous communities were not interviewed, and traditional knowledge was not accounted for in the study because it was out of scope. Indigenous communities in the Ashanti region have close, sophisticated relationships and knowledge relating to water, its use and management (Water Resources Commission, 2012). Incorporating these stakeholders into the study would have, therefore, been quite valuable. The WRC states that "through the participation of traditional authority and fusing indigenous and scientific knowledge…harmonious basin management can be restored" (Water Resources Commission, 2012). In future studies, the chiefs and members of the Asante should be included in the design of the groundwater monitoring system to ensure an inclusive design process.

8.4.2.2 Technical Development and Regulations

This report provides useful information to launch a groundwater monitoring project, but specific action items need to be specified for both technical accomplishments and regulations. Recommending regulations was out of scope of the project but was named as an area for improvement by the interviewees. This is a task which could be worked on in the advisory group and in additional studies which have a heavier focus on policy.

8.5 Summary

RQ4: How can value sensitive design be used to identify strategy for groundwater monitoring?

The final research question investigated a series of design requirements and recommendations for a groundwater monitoring program in Kumasi. The scope of these recommendations was limited to items which could be logically concluded from the study. There were two final products which synthesized the results.

First was the **design requirement summary** as noted in table 27. This summarized findings from the research questions, supporting theoretical framework, Ghanaian water policy and comparative case studies. Secondly, and complementary to the design requirement summary is the **recommendation grid**. This grid specifies the three main areas for recommendation strategies based on the design requirements: multi-stakeholder engagement, technical development and education. The appendix contains the final deliverable derived from this chapter which pairs these components together, to explain the requirements the design needs to meet, the recommended design, and how the recommendation meets the design requirements.

Chapter 9 Conclusions

9.1 Introduction

Front Material			Body Research Questions			Conclusions	
Context	Theory	Methods	RQ1	RQ2	RQ3	RQ4	**Conclusion**

The final section of the report aims to synthesize findings from all sections of the report. There are three sections of this chapter as outlined below.

Objectives	
	Discussion and reflection on the key findings of the report
	Synthesis of the conclusions for each research question
	Next steps for the case study in relation to the recommendations

9.2 Discussion Overall

The goal of the study was to use value sensitive design methods to synergize diverse stakeholder perspectives to develop groundwater management and monitoring strategies for Kumasi, Ghana. This resulted in an array of findings which illustrate a practical, comprehensive, literature and interview-based understanding of the groundwater monitoring landscape in Kumasi. This was achieved through involving a broad group of interviewees to encompass a diverse array of perspectives and sources of information. However, the key limitation of the study is the inability to interview all stakeholder groups due to limited time and resources. A more comprehensive study would need to be launched to include other groups not represented in this paper.

A weakness of the report is that there were not sufficient technical design criteria to determine a specific technology to monitor groundwater. Conclusions could not be made based on the data collected and therefore, it would not be appropriate to make a recommendation based on this limited information. However, the recommendation identifies a path to determine a technology in a participatory format. This path has potential to lead to an enduring groundwater monitoring technology because it incorporates the key stakeholders (chapter 5), is designed around values of interviewees (chapter 7) and incorporates relevant information on social science theory as it relates to participatory design.

The results of this study provide a framework, not only for Kumasi, but for similar projects involving the integration of natural resources and technology. Specifically, countries with comparable implementation challenges who are at similar design stages for groundwater monitoring projects (as mentioned in chapter 2.6). The cyclic recommendation structure is designed to integrate stakeholders in the design team and ensure multiple points of feedback for adaptivity. This framework can be applied for scenarios where there is a need for technology within society where diverse stakeholder participation is desired.

The processes of cocreation, integrated water resource management and value sensitive design were implemented into the structure of the report. Kruger conducted a literature review to determine methods of operationalizing cocreation but did not identify value sensitive design (Kruger, Gusmao, Braga França, & Gonçalves Quelhas, 2018). Therefore, this thesis expands on existing literature to demonstrate how value sensitive design can be applied to cocreation. At the future research stage, the impact of the solution is analyzed and should be reiterated upon for continuous adaptation.

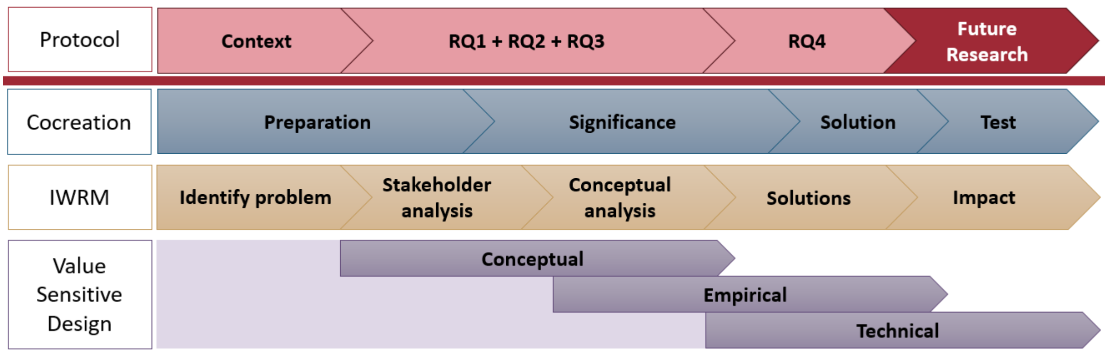


Figure 71. Overview of theoretical foundation for the report structure with a focus on future research

9.3 Conclusions Overall

There were four research questions which this thesis attempted to answer. Each research question built on the previous in a manner that enabled the recommendation to naturally result from the data.

RQ1: Who are the key stakeholders in the development of groundwater monitoring in Kumasi, Ghana and what are their roles?

The first research question focused on understanding the key stakeholders in the water sector in Kumasi. This was done to build an appropriate strategy around the framework of stakeholders. The result was that the key stakeholders primarily operate at the local level in Kumasi. Ghana's water governance structure is decentralized and identifying key stakeholders at the local level of governance is valuable in creating a localized groundwater management strategy. Including stakeholders from academic circles as well as regulatory and consumer groups will ensure that a program is built to encompass social, technical, and institutional qualities and thus ensure a participatory approach to water management.

RQ2: What are important considerations in the groundwater management setting in Kumasi, Ghana?

After determining the key stakeholders, insights on the practical insights and considerations of groundwater management were determined to complement the statutory understanding of management. This resulted in key considerations to account for when designing a groundwater monitoring system. Some of these include negative views on groundwater management from most interviewees, complexities of drilling boreholes, and design requirements for a groundwater monitoring system.

RQ3: What are the values of key stakeholders in the development of a groundwater monitoring system in Kumasi, Ghana?

The study was approached through value sensitive design therefore, the third research question sought to determine value profiles for each stakeholder group. The results found that there were seven values involved in groundwater monitoring: economic efficiency, environmental sustainability, participation, reliability, safety, social equity, and trust. There was no statistical difference between these values for any of the stakeholders. However, interpretations of the values demonstrate that interviewees associate participation with all other values.

RQ4: How can value sensitive design be used to identify strategy for groundwater monitoring?

The goal of the last research question was to implement a recommendation which synthesized the findings of research questions 1-3, a theoretical framework of participatory design, Ghanaian water policy, and case studies. The recommendation proposed three components: a multistakeholder advisory group, technical groundwater monitoring development, and a water education campaign. These three programs can work together to establish an effective, enduring water monitoring system through an organizational structure that works in a cyclic manner to ensure adaptivity.

9.4 Next steps

The design recommendation is to implement a threefold system of a multistakeholder advisory group, education campaign and technical groundwater monitoring development. As pictured, these three systems will work together for an integrated process which adapts in a cyclic process. For the process to begin, a stakeholder with the capacity and drive must take initiative to start the program. This is where the African Water Corridor can participate. Their approach is to implement cocreation through participatory action in the water sector and therefore, their involvement can start this process for an integrated approach to design a groundwater monitoring system. This study focused on preparation, significance and solution of the Kruger cocreation model, and the next step is to test the proposal. After testing, the result can be reevaluated and iterated upon. Adaptation is critical to the operation of this project to adopt new information and integration of key stakeholders in the design process beyond symbolic participation and into the realm of cocreation.

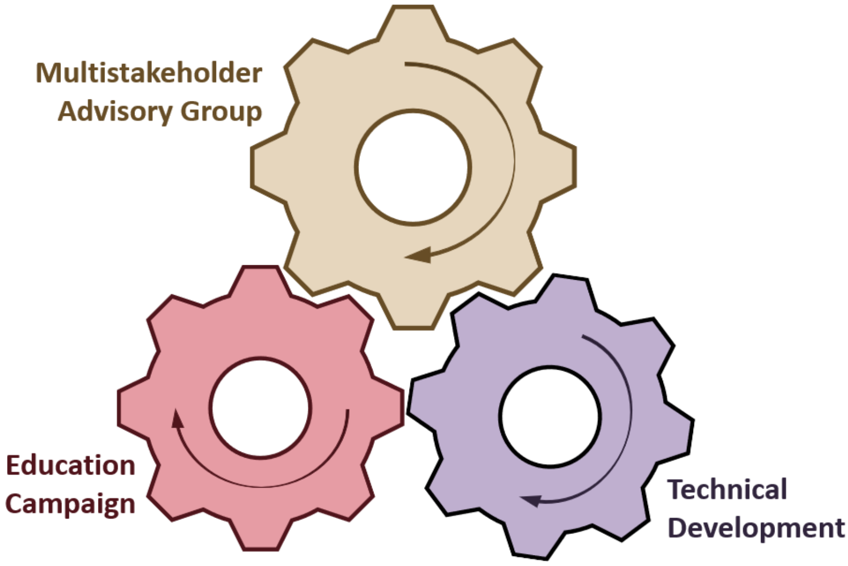


Figure 72. Summary of recommendation components

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