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A Crowdsensing Method for Water Resource Monitoring in Smart Communities

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DECLARATION

I, Clara Mloza Banda, hereby declare that the dissertation for the degree, Master of Science in Computer Science and Information Systems, is my own work and that it has not previously been submitted for assessment of completion of any postgraduate qualification to another university or for another qualification.

Clara Mloza-Banda.

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ABSTRACT

Crowdsensing aims to empower a large group of individuals to collect large amounts of data using their mobile devices, with the goal of sharing the collected data. Existing crowdsensing studies do not consider all the activities and methods of the crowdsensing process and the key success factors related to the process. Nor do they investigate the profile and behaviour of potential participants. The aim of this study was to design a crowdsensing method for water resource monitoring in smart communities. This study opted for an exploratory study using the Engaged Scholarship approach, which allows the study of complex real-world problems based on the different perspectives of key stakeholders.

The proposed Crowdsensing Method considers the social, technical and programme design components. The study proposes a programme design for the Crowdsensing Method which is a Crowdsensing Reference Framework that includes a Crowdsensing Process with key success factors and guidelines that should be considered in each phase of the process. The method also uses the Theory of Planned Behaviour (TPB) to investigate citizens' intention to participate in crowdsensing for water resource monitoring and explores their attitudes, norms and perceived behavioural control on these intentions. Understanding the profiles of potential participants can assist with designing crowdsensing systems with appropriate incentive mechanisms to achieve adequate user participation and good service quality. A survey was conducted to validate the theoretical TPB model in a real-world context. Regression and correlation analyses demonstrated that the attitudes, norms and perceived behavioural control can be used to predict participants' intention to participate in crowdsensing for water resource monitoring.

The survey results assisted with the development of an Incentive Mechanism as part of the Crowdsensing Method. This mechanism incorporates recruitment and incentive policies, as well as guidelines derived from the literature review and extant system analysis. The policies, called the OverSense policies, provide guidance for recruitment and rewarding of participants using the popular Stackelberg technique. The policies were evaluated using simulation experiments with a data set provided by the case study, the Nelson Mandela Bay Municipality. The results of the simulation experiments illustrated that the OverSense recruitment policy can reduce the computing resources required for the recruitment of participants and that the recruitment policy performs better than random or naïve recruitment policies.

The proposed Crowdsensing Method was evaluated using an ecosystem of success factors for mobile-based interventions identified in literature and the Crowdsensing Method adhered to a majority (90%) of the success factors. This study also contributes to information systems design theory by proposing several sets of guidelines for crowdsensing projects and the development of crowdsensing systems. This study fulfils an identified need to study the applicability of crowdsensing for water resource monitoring and explores how a crowdsensing method can create a smart community.

Keywords: Crowdsensing; Water resource monitoring; Smart communities; Theory of Planned Behaviour; Data collection protocols

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LIST OF ACRONYMS

GPS	Global Positioning System
ICT	Information and Communication Technology
IT	Information Technology
NMBM	Nelson Mandela Bay Municipality
SMS	Short Message Service
STP	Social, Technical and Programme designs
TPB	Theory of Planned Behaviour
USSD	Unstructured Supplementary Service Data
UX	User eXperience
WASH	Water, Sanitation and Hygiene

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1 INTRODUCTION

1.1 Background

In 2015, the United Nations Sustainable Development Goals (SDGs) set targets to be adopted by all nations to tackle climate change and address important areas of human development (United Nations, 2017). One of the 17 SDGs, Goal 6, is to "*ensure availability and sustainable management of water and sanitation for all*". This goal sets several targets including reducing water pollution, increasing the efficiency of water use and implementing integrated water resource management (UNICEF & WHO, 2017). One of the targets focuses on the importance of supporting and strengthening local communities to participate in water, sanitation and hygiene (WASH) projects to ensure the success and sustainability of the implementations of these projects (Hall *et al.*, 2016).

There are various players in the provision of water and sanitation services that rely on good data to make informed decisions. Examples of such players are local governments who manage the infrastructure of water resources, and water authorities who provide water services within their municipalities or districts. Accurate and consistent information is the key to providing sound water supply and sanitation services (Champanis *et al.*, 2013). Mobile technologies offer affordability and sustainability in the dissemination of information, monitoring of interventions, as well as communication between communities and their service providers (Breslin, 2013; Hellström & Jacobson, 2014).

The ubiquity of mobile devices has influenced many creative thinkers to use mobile technologies as solutions to issues in the WASH sector, including water resource monitoring. Water resource monitoring is the collection of data that reflects the current situation of water resources at certain points and time intervals (The Office of the Compliance Advisor/Ombudsman, 2008). Due to the advent of mobile devices, citizens can act as sensors and actively participate in collecting data used to improve the actions of the organisation responsible for water sanitation (Yadav *et al.*, 2013). Communities that leverage technology (such as mobile devices) to improve the quality of life, make better choices and drive innovation are referred to as smart communities (Jin *et al.*, 2014).

Researchers are realising the potential of leveraging millions of personal mobile devices to sense, collect and analyse large amounts of data as an alternative to deploying thousands of static sensors in a community (Yang *et al.*, 2015a). This paradigm is commonly referred to as crowdsensing. Crowdsensing, also known as participatory sensing, aims to empower citizens to use their mobile phones to collect and share sensed data from their surrounding environments (Kanhere, 2011). Figure 1-1 illustrates a typical architecture of crowdsensing as described by He, Chan and Guizani (2015). Crowdsensing allows mobile devices to function as sophisticated sensors (He, Chan & Guizani, 2015). With crowdsensing, citizens can use the camera as a video and/or image sensor, GPS receivers can provide location information and microphones can be used as an acoustic sensor (Kanhere, 2011; Nel, Booysen & Van Der Merwe, 2014). The collected data can then be stored in a central database server where it can be accessed directly or processed further to create information useful to the relevant stakeholders (He, Chan & Guizani, 2015).

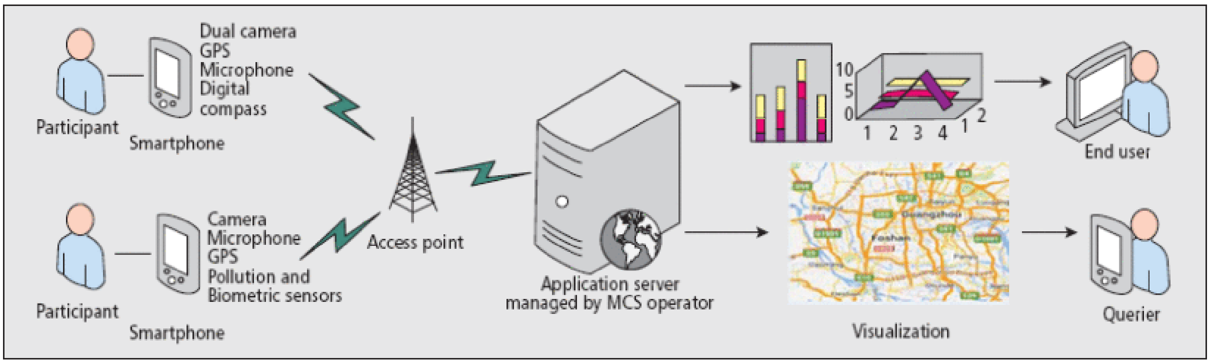


Figure 1-1: Typical Architecture of Crowdsensing (He, Chan & Guizani, 2015).

1.2 Problem Description

Hydrological science underpins most decision-making on water resources and serves as the basis for assessment of risks related to water such as floods and droughts (Hannah *et al.*, 2011). However, this area of science is characterised by an acute scarcity of data in both the spatial and temporal domains. Many developed countries have deployed sensing infrastructure to collect spatial and temporal data about city events but it is costly and ineffective to use hardware sensors for monitoring in developing regions (Buytaert *et al.*, 2014). Several African countries are implementing management models to keep water sources functional (Jiménez & Pérez-Foguet, 2010; Glotzbach *et al.*, 2013). However, there is still a lack of significant improvement in service delivery due to a lack of shared and relevant information between communities and service providers. Even though a third of water sources in rural areas are non-functional and require servicing (Jiménez & Pérez-Foguet, 2010; Glotzbach *et al.*, 2013), cities often receive better service than rural areas. Rural communities are unable to access affordable knowledge services due to their state of poverty (Champanis *et al.*, 2013). Other researchers (Hutchings *et al.*, 2012; Breslin, 2013; Hellström & Jacobson, 2014) report that there is also a lack of responsiveness by service providers to use generated information to inform their decisions or planning in the WASH sector. Crowdsensing can alleviate the costs of water resource monitoring by using citizen's mobile devices as sensors.

Mobile devices provide an enhanced means of collecting information from consumers and service providers, and are being used for various management and monitoring tasks including enhanced water usage feedback to water users, automated meter reading and remote leakage detection (Nel, Booysen & Van Der Merwe, 2014; Ssozi-Mugarura, Blake & Rivett, 2016). The use of mobile devices in the WASH sector can make communities smarter by using technology to improve the provision of services. However, a common characteristic of technology interventions in developing countries is that they are externally conceived and address an assumed need with little or no buy-in from the citizens (Dodson, Sterling & Bennett, 2013). The risk with such an approach is that instead of empowering communities through technology, the interactions result in short-term and imposed implementations plagued with uncertain sustainability when the implementer leaves the community. The use of crowdsensing to address the challenges of water resource monitoring needs to be researched.

Therefore, the problem statement for this research is as follows:

> *There are several problems with the sharing of relevant information between communities and water service providers. The main problems relate to the deployment of sensing infrastructure, the lack of responsiveness by the service providers to the generated information, the lack of access to the information and the sustainability of the technology solutions.*

1.3 Research Aim

The main aim of this research is therefore:

> *To design an effective crowdsensing method for water resource monitoring in smart communities.*

Weber (2010) defines a method as an information technology (IT) artefact comprising a set of steps to solve a defined problem. The main contribution of this study is to propose a theoretical crowdsensing method that provides processes, frameworks, theories and guidelines to solve the problems defined in Section 1.2.

1.4 Research Questions

The **main research question (M-RQ)** will be used to guide this research study:

> *How can crowdsensing be used for effective water resource monitoring in smart communities?*

The following secondary research questions will act as guides to obtain sufficient information to answer the primary research question:

> **RQ1:** What are the problems faced by citizens and water service providers regarding crowdsensing and water resource monitoring as identified by literature and within a real-world context?
>
> **RQ2:** What are the common activities and key success factors for crowdsensing projects?
>
> **RQ3:** What sociotechnical design can be used for a crowdsensing system that recruits and incentivises participants to collect data continuously for water resource monitoring?
>
> **RQ4:** What design guidelines can be used for crowdsensing for water resource monitoring to create a smart community?

1.5 Relevance and Envisaged Contributions

Identifying and documenting the essential features of technology solutions is crucial in designing IT artefacts. According to Hutchings *et al*. (2012), there are three useful aspects to consider in designing a mobile-based solution, specifically the social, technical and programme (STP) design aspects. The STP aspects can be applied to crowdsensing due to the nature of crowdsensing of relying on mobile devices as the data collection tool for the system platform. Therefore, the crowdsensing method for water resource monitoring in smart communities (hereafter referred to as the Crowdsensing Method) will consider all these three aspects of design as discussed in this section.

1.5.1 Social Design

The social design of a data collection tool such as a crowdsensing system is as important, or even more important, than the technical design (Hutchings *et al.*, 2012). Developing a robust social design of a crowdsensing system may be seen as more important than the technical design because the performance and usefulness of a crowdsensing system are highly dependent on citizens' willingness to participate in the data collection process (Jaimes, Vergara-Laurens & Raij, 2015). The number of participants to guarantee coverage and data quality determines the success or failure of a crowdsensing project. Hutchings *et al*. (2012) urge researchers to gain an understanding of the social system around their technical solutions because every user has special requirements for what they want the system to address. Hutchings *et al*. (2012) propose four social design considerations:

- User perceptions to explore the social system around the solution, as the social context has a direct influence on users' intentions to use the technical solution.
- Incentives and barriers for participation.
- Privacy of users' personal information.
- Verification to ensure credibility and usefulness of the collected data.

1.5.2 Technical Design

The technical design of a solution covers the customisation and enhancement of mobile devices, as well as the evolving of features and platforms to meet the specific needs of the project (Hutchings *et al.*, 2012). Common technical design options that are used for data collection in the WASH sector are smartphone applications, short message service (SMS), interactive voice response and geolocation features. Common technical design options for data dissemination and analytics are web-based dashboards and mapping, bulk SMSs and other reports and data formats such as spreadsheets, videos and interactive graphs.

1.5.3 Programme Design

The programme design is the management structure of the solution which ensures the longevity and sustainability of the developed system (Hutchings *et al.*, 2012). The programme design highlights the plan for implementation and ongoing sustainability of the system.

1.5.4 Envisaged Contribution

The sociotechnical theory emphasises that technology and the people that use the technology are interdependent and that people's behaviour and technology affect each other (Klein, 2014). Klein (2014) states that it is imperative that researchers clarify how technology and people's behaviour affect each other. The envisaged main contribution of this study is a Crowdsensing Method that has three components, each of which is also a contribution to the research community: a social, technical and programme design of crowdsensing for water resource monitoring. However, since the technical and social designs overlap and have a significant effect on each other, this study combines the social and technical designs into one sociotechnical design (Figure 1-2).

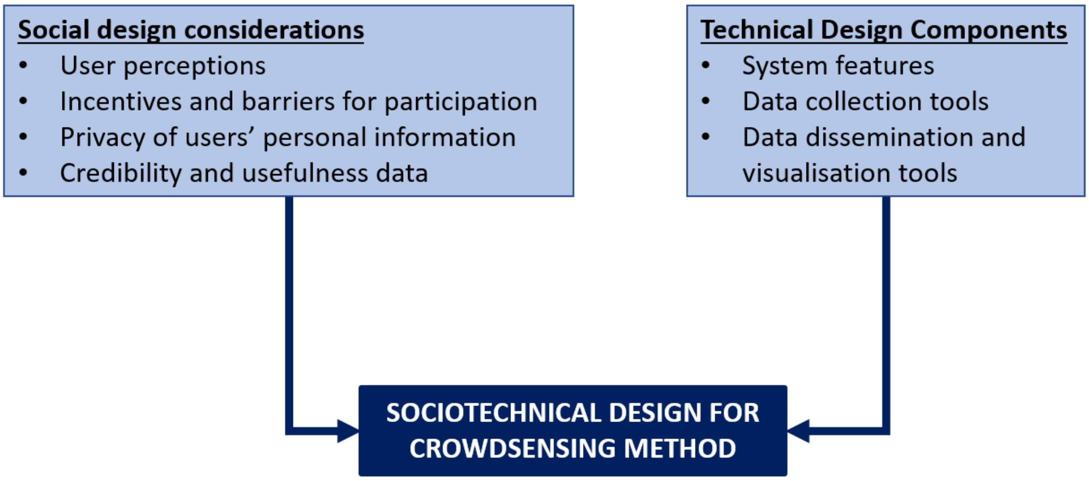


Figure 1-2: Sociotechnical Design for Crowdsensing Method (Author's Own Construct).

Therefore, the proposed Crowdsensing Method has two main components, a sociotechnical design and a programme design (Figure 1-3).

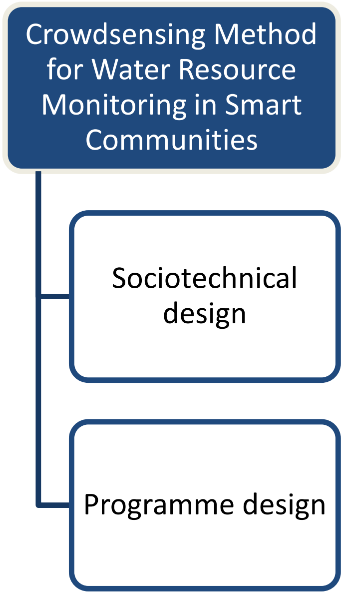


Figure 1-3: Proposed Crowdsensing Method considering STP Design (Author's Own Construct).

1.6 Scope and Constraints

The main topic of this research is citizen engagement in water resource monitoring, with a focus on crowdsensing. The field of citizen science will be investigated to highlight how crowdsensing can optimise water resource monitoring efforts in developing countries. In addition, the research study will explore how to motivate citizens to participate in crowdsensing, what information to collect and how to incorporate social design aspects in crowdsensing systems. Due to time constraints, this study will not cover the implementation and evaluation of the technical solution but rather focus on developing a robust sociotechnical design for a crowdsensing system for water resource monitoring. In addition, the service providers' behaviour in response to information generated from crowdsensing is out of the scope of this study.

1.7 Research Methodology and Dissertation Structure

Van de Ven (2007) proposes the engaged scholarship methodology as a research methodology to enhance the rigour and relevance in research. Engaged scholarship is a form of participatory research that studies complex real-world problems based on the different perspectives of key stakeholders. Engaged scholarship is concerned with bridging the theory-practice gap by involving stakeholders, such as practitioners, users, sponsors, clients and researchers, to simultaneously develop new theoretical insights and contribute to practice problem solving (Van de Ven, 2007; Mathiassen, 2017). The defining characteristic of engaged scholarship is that it strives to solve problems in a real-world situation (Mathiassen, 2017), thus making engaged scholarship a suitable methodology to address the main research question of this study. The four research activities of engaged scholarship are as follows (Van de Ven, 2007):

1. Problem formulation.
2. Theory building.
3. Research design.
4. Problem solving.

This study will use the design and evaluation form of engaged scholarship to allow the researcher to direct all activities as an external observer in attempting to solve the practical problem that exists in water resource monitoring. The researcher will engage with stakeholders through a citizen science approach, so the stakeholders can influence the study designs that may affect them, as well as give consent where required. In citizen science, the public plays a role in data collection across broad geographic regions, usually to address questions raised by researchers (Bonney *et al.*, 2009b; Cavalier & Kennedy, 2016). More details about citizen science can be found in Chapter 2. Engaged scholarship, along with citizen science, will influence the execution of the research activities in this study. The engaged scholarship methodology and a description of how it will be applied are also discussed in more detail in Chapter 2. Figure 1-4 illustrates the structure of this dissertation.

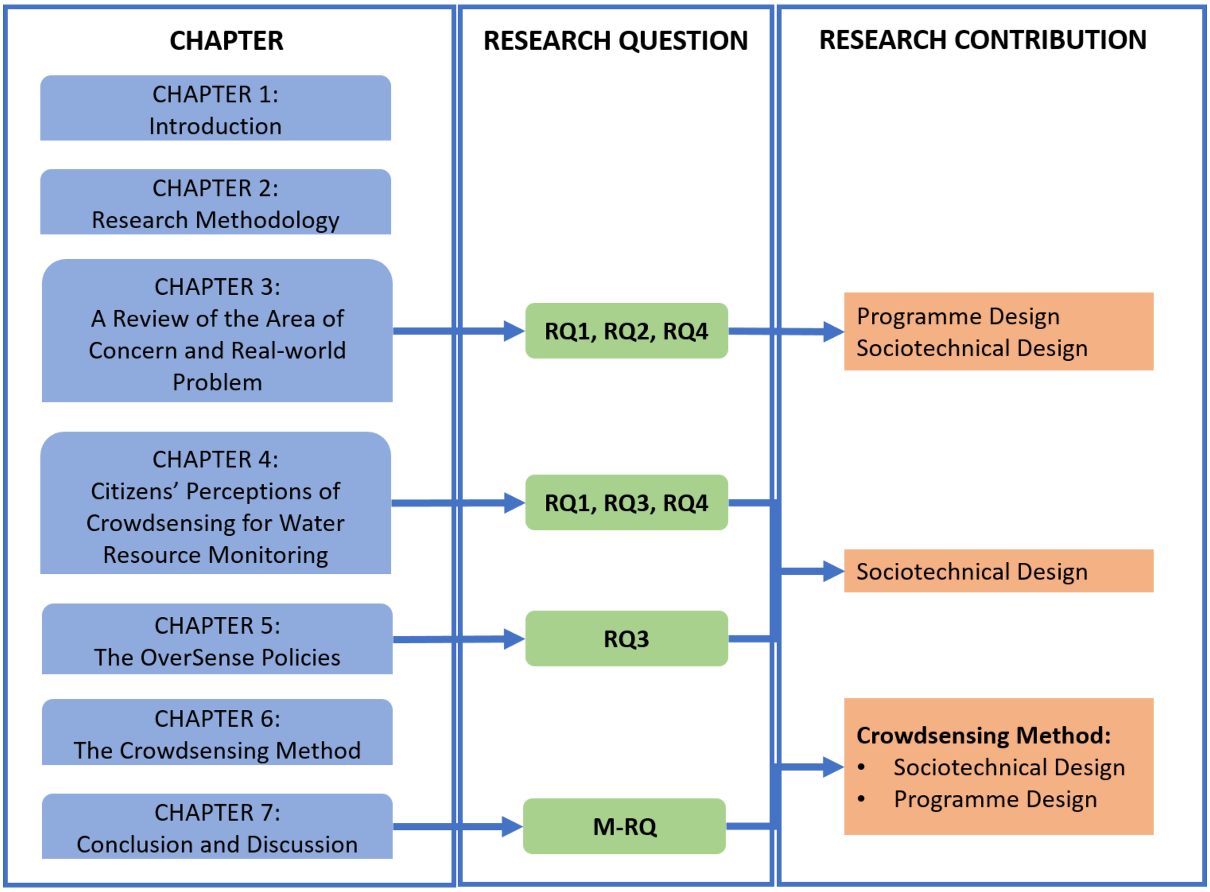


Figure 1-4: Dissertation Structure.

Chapter 1 has introduced the real-world problem and an area of concern in literature. The motivation and relevance of this study have been discussed and the methodology that will be used to carry out this study was identified. **Chapter 2** describes and argues for the engaged scholarship research methodology to be adopted for this study. The second chapter also introduces the conceptual framing to support and structure the data collection and analysis, and methods of inquiry that allow the researcher to answer the research questions.

Chapter 3 presents a systematic review of the literature on the area of concern, which is the adoption of crowdsensing for water resource monitoring in smart communities. The evaluation of what is known, or not known, about the area of concern will substantiate the relevance of the study and the choice of the research questions. The chapter starts by describing water resource monitoring and how the ubiquity of mobile devices have revolutionised the water sector. Smart communities are defined and crowdsensing is proposed as a means of building a smart community. The findings of the literature review enable the proposal of a Crowdsensing Reference Framework, which is a part of the programme design of the Crowdsensing Method.

Chapter 4 initiates the crowdsensing process proposed in the previous chapter by focusing on the first phase of the crowdsensing process, the Project Initiation phase. A global survey was conducted to inquire about citizens' motivations for participating in water resource monitoring using crowdsensing. **Chapter 5** uses a literature review and the results of the survey to develop recruitment and incentive policies for the sociotechnical design for the Crowdsensing Method. The policies are evaluated using simulation experiments on a real-world dataset.

Chapter 6 presents an evaluation of the entire Crowdsensing Method against criteria identified in literature. **Chapter 7**, the final chapter of this dissertation, reports on the contributions to the real-world problematic situation and the area of concern as a response to the main research question. Finally, recommendations for future work are provided.

2 RESEARCH METHODOLOGY

2.1 Introduction

The preceding chapter introduces the research by describing the problem the study is trying to address, as well as the identified research aim and questions. Engaged scholarship is motivated as a suitable choice for this research study (Section 2.2). The engaged scholarship research methodology provides a research design that has several components including a conceptual framing to guide data collection (Section 2.3) and methods of inquiry for the data collection (Section 2.4). There are several ethical considerations of the study (Section 2.5).

2.2 The Engaged Scholarship Research Methodology

Iivari, Hirschheim and Klein (1998, p.173) describe information systems (IS) as "technical systems with social implications" or "social systems that are technically implemented". Iivari, Hirschheim and Klein (1998, p.173) go on to describe an IS as a social system that can be characterised as an "embodiment of interpretive schemas, facilities for coordination and organisational/social norms". IS research has shifted focus from technological challenges to process, organisational and social challenges. Thus, there is an ongoing requirement to use a suitable research methodology that guides researchers to understand and interpret the social process in order to develop an IT artefact.

The engaged scholarship methodology is ideal for IS research because an engaged scholarship study exposes researchers to social systems of practice and science to develop real knowledge aimed at solving real problems (Van de Ven, 2007). Mackinnon (2010) describes a scholarship that is engaged as a scholarship of action, which focuses on doing instead of talking about doing. Instead of focusing on the lifeworld of scholars, engaged scholarship is primarily concerned with the lifeworld in the community (Van de Ven, 2007). Thus, the impact of engaged scholarship centres more directly on the concerns of the community, while still being of reciprocal benefit to science. Van de Ven (2007) proposed engaged scholarship to enable scholars to expand their capabilities by studying complex problems and generating knowledge that advances both science and practice. Engaged scholarship has the ability to produce knowledge that is more insightful and penetrating as compared to research generated by solitary scholars or practitioners because engaged scholarship leverages different kinds of knowledge retrieved from involving others in the study (Van de Ven, 2007). Engaged scholarship views organisations, groups and individuals as learning workplaces where scholars and practitioners can jointly produce knowledge by running alternative tests and investigating different views of a common problem (Boyer, 1996). Engaged scholarship is based on the following key components of critical realism (Van de Ven, 2007):

- People have a limited individual understanding of the real world that exists outside themselves.
- All data, facts and observations are theory-laden, whether explicitly or implicitly.
- Understanding complex real-world problems require multiple perspectives.
- Methods of inquiry can never be value-free and impartial; some methods are better suited to examining a phenomenon than others.
- An evolutionary growth of knowledge can be generated by selecting models that fit the intended problem.
- Theoretical and methodological triangulation (the use of many methods, models and sources of information in a study) produces robust knowledge.

This study is based on an assumption that a particular object of IS research may have three different perspectives (the STP design), thus requiring a mixed-method strategy. Engaged scholarship is based on critical realism which, unlike other IS research models, recognises that knowledge can be physical, social and theoretical (Mingers, Mutch & Willcocks, 2013). Engaged scholarship takes a critical realist perspective that takes a subjective epistemology and objective ontomology, thus, it supports triangulation to access the different types of knowledge (Van de Ven, 2007).

2.2.1 Engaged Scholarship Diamond Model

Engaged scholarship as a methodology allows the researcher to step outside themselves to obtain and be informed by the understanding of others in each activity of the research process (Van de Ven, 2007). The four activities of an engaged scholarship study are:

> **ACTIVITY 1: Problem formulation:** Situate, ground and diagnose the research problem and question in its real-world context. This activity requires engaging with the people who experience and know the problem, as well as conducting a review of relevant literature.
>
> **ACTIVITY 2: Theory building:** Build a conceptual model by developing and adapting plausible alternative theories to address the research question as it exists in its context. Theory building requires a continuation of the review of relevant literature from the problem formulation. This activity continues the review of relevant literature from the Problem Formulation activity in addition to reviewing existing theories and research. This activity also required engaging with knowledge experts from relevant disciplines and functions that have addressed the problem.

ACTIVITY 3: Research design: Design and conduct research to evaluate how well the alternative theory applies to the case by comparing plausible alternative models that address the research problem. This activity requires engaging with research methodology experts, as well as the people in the communities giving consent to the study and access to data.

ACTIVITY 4: Problem solving: Communicate, interpret, and apply the research findings to the solution that better answers the research question to address the problem. This activity requires engaging with the intended audience to interpret the findings.

The engaged scholarship methodology requires multiple iterations and revisions of the four research activities to refine the developed models and theories (Figure 2-1). This study follows the engaged scholarship research activities beginning with formulating a problem and searching for relevant theories, then using the theories to develop a model which is then evaluated to deliver a solution that is then applied to a real-world context. The research methodology may deliver several subsidiary problems that need to be addressed as an interdependent set, resulting in a coherent pattern when the study is complete (Van de Ven, 2007).

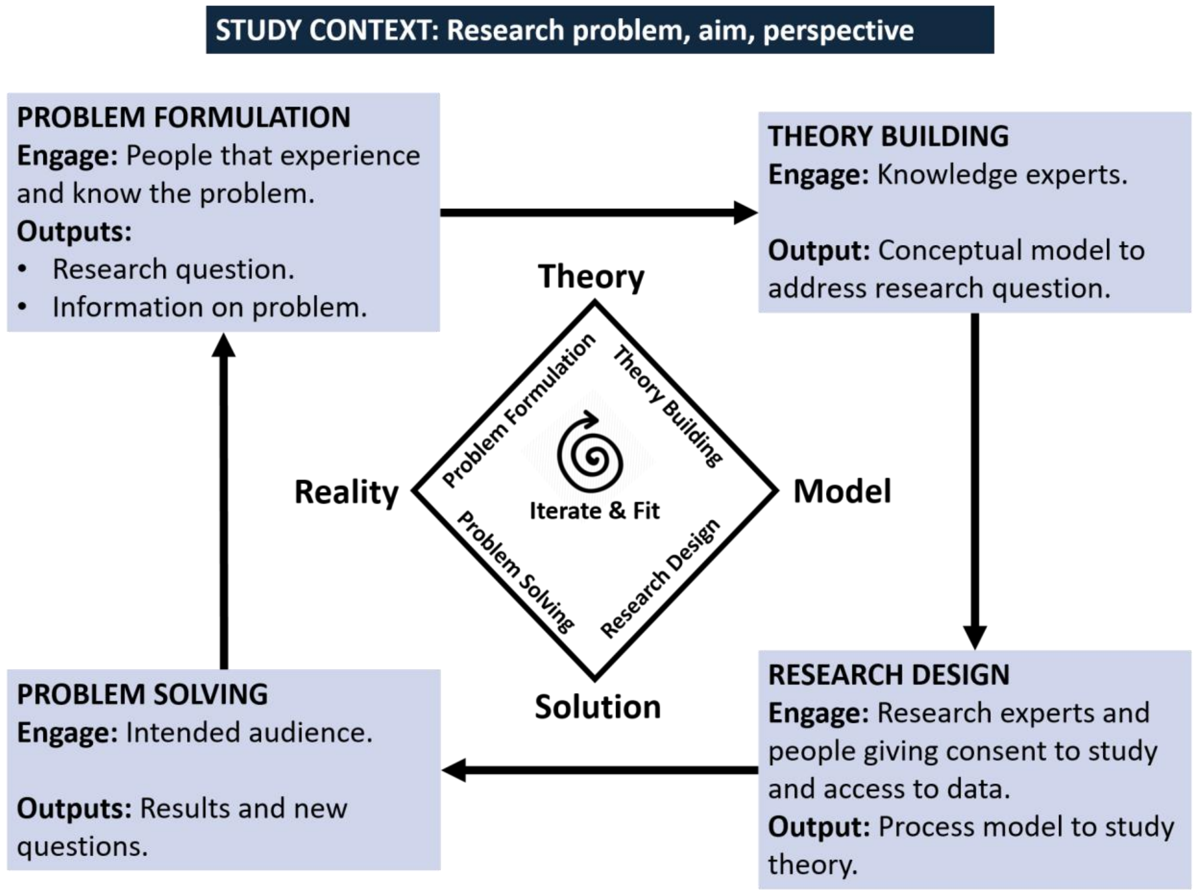


Figure 2-1: Engaged Scholarship Methodology [Adapted from Van de Ven (2007)].

2.2.2 Forms of Engaged Scholarship

The implementation of engaged scholarship can be practised in four forms in attempting to address the research questions (Van de Ven, 2007):

- **Informed basic research:** focuses on understanding a social phenomenon by obtaining the perspectives and advice of relevant stakeholders on a research question.
- **Collaborative research:** focuses on the collaboration and co-production of knowledge with stakeholders.
- **Design and evaluation research:** focuses on the design and evaluation of artefacts to support stakeholders in addressing practical problems.
- **Action/intervention research:** focuses on changing practices by applying interventions to the specific needs of a client through problem-solving while developing theoretical insights to contribute to academic knowledge.

Informed basic research, and design and evaluation research require the researcher to be an external observer of the social system under examination (Van de Ven, 2007). It is necessary for the researcher to take an outsider role to enable the production of impartial and legitimate results. The researcher remains in control of all research activities while the stakeholders take an advisory role. On the other hand, the collaborative and action/intervention forms of research require a balance of power and activities between the researcher and the stakeholders. The researcher takes on the role of an internal participant in the client's social setting to aid in the understanding of the problem. Table 2-1 presents the four forms of engaged scholarship and how they relate to the research question and perspective.

		Research Question	
		To describe/explain	**To design/control**
Research Perspective	**External observer**	Informed basic research	Design and evaluation research
	Internal participant	Collaborative research	Action/intervention research

Table 2-1: Forms of Engaged Scholarship [based on Van de Ven (2007)].

Based on the main research question of this study (Section 1.4), the design and evaluation form of engaged scholarship will be adopted. This form of research allows the researcher to go beyond describing the research problem to attempt to obtain knowledge of the efficacy of alternative solutions that can be applied to the problems (Van de Ven, 2007). In addition, design and evaluation research fits into the study's goal to design and evaluate a method for solving a practical problem within a certain area of context.

2.2.3 Structure of an Engaged Scholarship Study

Mathiassen (2017) proposes a generic structure of an engaged scholarship study with the following components and relationships:

- A research question (RQ) is raised based on a real-world problematic situation (P) and an area of concern in the literature (A).
- The researcher collects and analyses empirical data drawing on a conceptual framework (F) and a method of inquiry (M).
- Eventually, the research leads to contributions to P (C_P) and A (C_A), and possibly to F (C_F) and M (C_M).

Table 2-2 presents the descriptions of each of the components of engaged scholarship while Figure 2-2 illustrates the relationships between the components.

Component	Description
Title	The title expresses the essence of your research design with an emphasis on C.
P	People's concerns in a real-world problem setting.
A	An area of concern in some specific body of knowledge within the literature that relates to P.
F	The conceptual framing guides data collection and is the foundation for data analyses to answer RQ.
M	The adopted methods of empirical inquiry to guide the engaged scholarship research that allow the research to draw available data from P and answer the RQ.
RQ	The research question relates to P and allows for research into A. All relationships must focus on the central role of the RQ to ensure the research design is coherent and consistent.
C	The contributions to P and A and possibly to F and M

Table 2-2: Components of the Structure of an Engaged Scholarship Study.

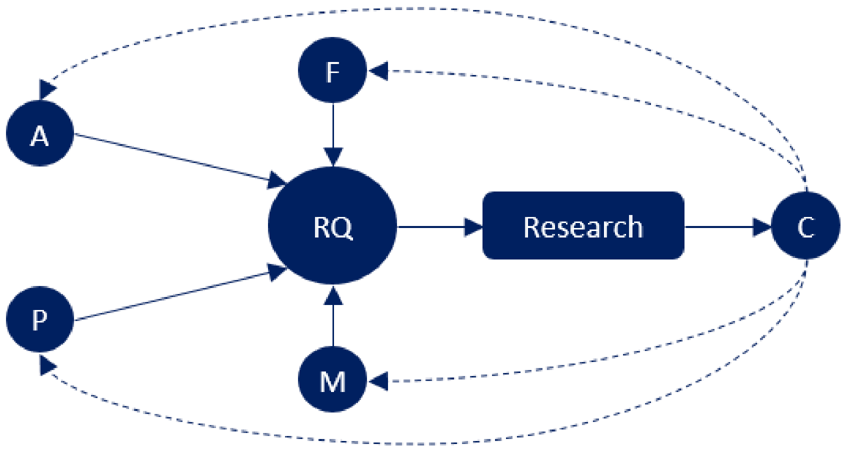


Figure 2-2: Generic Structure of Engaged Scholarship Study (Mathiassen, 2017).

2.2.4 Motivation for Engaged Scholarship as a Research Methodology

Engaged scholarship was selected as a suitable research methodology based on the following principles (Mathiassen, 2017):

- Engagement scholarship is defined and driven by engagement with the problem setting, which is achieved by drawing on the perspectives of key stakeholders in a real-world problematic situation.
- Engaged scholarship aims to develop knowledge that may help address the practical problem, as well as contribute new knowledge to extant literature in the area of concern.
- Engaged scholarship distinguishes the area of concern bound by literature from the real-world problem resulting in the dual goal of contributing to practice and academic literature.
- Engaged scholarship places the research question at the core of the research design and ensures that the main research question relates both to the problem in the real world and literature.
- By engaging researchers or practitioners in the problem and area of concern, engaged scholarship helps bring the issues to light and part of a conversation.
- The iterative methodology allows the researcher to refine the contributions to ensure satisfactory contributions to theory and practice.
- Engagement of people from diverse perspectives and backgrounds allow the triangulation of the complex problem to access different kinds of knowledge the study will provide.

2.3 Conceptual Framing (F)

In the engaged scholarship methodology, the conceptual framing helps guide the data collection and analysis (Mathiassen, 2017). The choice and articulation of conceptual framing are important because the conceptual framing drives the researcher in answering the main research question to develop the research contributions. Options for conceptual framing can be drawn on concepts from the literature gathered on A (F_A) and concepts independent of A (F_I). This study draws on several theories and models as the conceptual framing that guides data collection specifically:

- F_A: Citizen science as a model for citizen participation in science research (Section 2.3.1).
- F_A: Incentive Theory for Participatory Crowdsourcing (Section 4.2.2.2).
- F_I: Theory of Planned Behaviour (Section 4.2.1).

2.3.1 Defining Citizen Science

Citizen science is a term with multiple origins (Riesch & Potter, 2014). Alan Irwin first introduced citizen science as a more democratic form of participatory science in which science addresses, and seeks to meet, the concerns and needs of citizens (Irwin, 1995; Cavalier & Kennedy, 2016). In addition, Irwin's idea of a more democratic science looks towards citizens to take charge of the production of reliable scientific knowledge. Unaware of Irwin's work, Rick Bonney used citizen science as a term that describes projects where non-scientists contribute scientific data (Bonney *et al.*, 2009b; Cavalier & Kennedy, 2016). Bonney's definition limits the role of the citizen to participating in data collection, however, citizen science has expanded to engage the public in other aspects such as formulating research questions and data interpretation (Cavalier & Kennedy, 2016).

Citizen science differs from other collaborative approaches to public participation in scientific research because it is founded on the active engagement of non-scientists in the generation of scientific knowledge (Wiggins & Crowston, 2011). Citizen science is appropriate to guide the data collection and analysis as citizen science engages a dispersed network of volunteers to assist in professional research using methodologies that have been developed by or in collaboration with professional researchers (Cooper *et al.*, 2007). Citizen science has become a popular approach for engaging communities in scientific research to increase the chances of technology acceptance and sustainability in communities (Pocock *et al.*, 2014).

The digital revolution has made citizen science a widespread phenomenon across various environmental disciplines (Wiggins & Crowston, 2011). Citizen scientists can use the Internet, smartphones and other network connections to submit their observations anywhere and at any time. Examples of the application of citizen science in water resource monitoring include:

- Starkey *et al*. (2017) describe the value of using citizen science for catchment modelling and characterisation in the United Kingdom. Citizens' flood, rainfall and river level observation were used to build a catchment model to support the characterisation and management of catchment response.
- Wanda *et al*. (2017) describe how citizen science was used to collect water samples and personal observations to determine WASH-related risks in Malawi.
- In 1998, GroundTruth, an environmental consulting organisation, collaborated with the Wildlife and Environment Society of South Africa (WESSA) to develop miniSASS (Graham, Dickens & Taylor, 2004). MiniSASS allows citizens to identify if certain animals are present in the water as an indicator of river health.

Wiggins and Crowston (2011) argue that the active involvement of non-scientists in the research may deliver benefits to the non-scientists, either intrinsically or extrinsically. Researchers have identified several benefits of citizen science such as increasing the amount of scientific data, building social capital by enrolling communities toward environmental goals, driving policy change as well as challenging authority to support social justice struggles (Kimura & Kinchy, 2016).

2.3.2 A Typology of Citizen Science based on Citizen Involvement

The role of the citizen in citizen science is different from volunteering to participate in a research study such as giving an interview, joining a focus group or responding to a survey. Citizen science is about the process of citizens collecting and coding data about the world they observe around them. The citizens are the observers. Haklay (2013) presents a framework for classifying the engagement and participation of citizens in citizen science activities (Figure 2-3). The four levels of citizen science in Haklay's framework are crowdsourcing, distributed intelligence, participatory science and extreme citizen science.

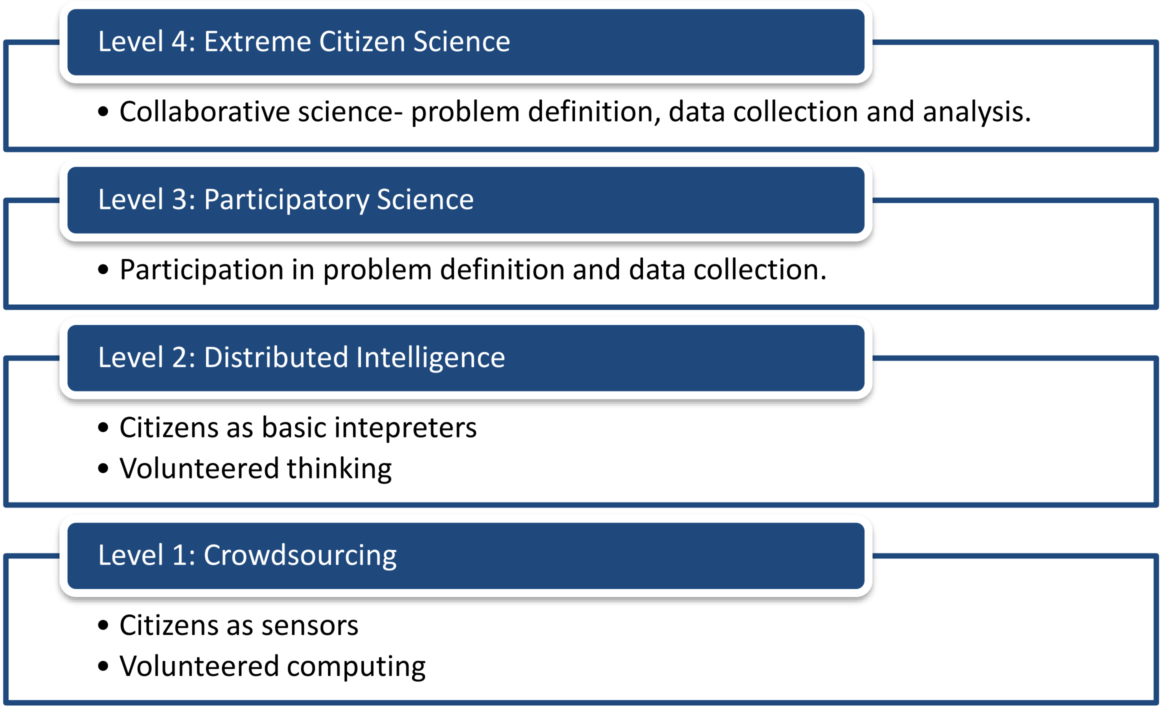


Figure 2-3: Framework for Classifying Citizen Engagement and Participation in Citizen Science (Haklay, 2013).

Level 1 - Crowdsourcing: Haklay's framework describes the most basic level of citizen science as crowdsourcing (Haklay, 2013). Crowdsourcing focuses on obtaining the needed services or content by soliciting contributions from people (Guo *et al.*, 2014). Crowdsourcing is an activity that engages people to perform tasks that automated sensors cannot accomplish (Hochachka *et al.*, 2012). An example of crowdsourcing is Wikipedia, where thousands of contributors across the world have collectively created the world's largest encyclopaedia. Crowdsensing is a form of crowdsourcing that collects sensor data from mobile devices (Haklay, 2013; Yang *et al.*, 2015a). Citizens participate by providing the resources necessary for automatic data collection using sensors (volunteered computing) or by being sensors themselves (human sensors). Figure 2-4 illustrates the relationship amongst citizen science, crowdsourcing and crowdsensing.

Level 2 - Distributed Intelligence: The drawback of the basic level of engagement is that the participants' cognitive abilities are wasted (Haklay, 2013). The second level utilises the cognitive ability of the participants by requiring the participants to undertake some basic training, observe and collect data and/or carry out a simple interpretation activity.

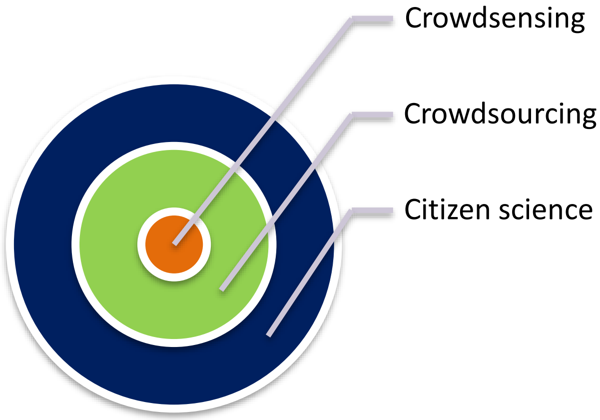


Figure 2-4: Citizen Science vs Crowdsourcing vs Crowdsensing (Author's Own Construct).

Level 3 - Participatory Science: Citizens define the problem, and devise a data collection method in consultation with scientists and experts (Haklay, 2013). The citizens are also engaged in the data collection but require the assistance of the scientists in the analysis and interpretation of the data.

Level 4 - Extreme Citizen Science: Extreme Citizen Science is an advanced level of citizen science that involves the complete integration of problem determination, data collection and other research activities (Haklay, 2013). The participants may choose not to take part in the analysis and interpretation of results. This form of citizen science requires the scientists to act as facilitators and not just experts.

A citizen science project may be classified into more than one category. For example, in computing projects, most participants may just provide computing power as crowdsensing. Participants committed to the project could develop their skills to be able to help other participants with technical problems. Highly committed participants could move to a higher level and get in touch with the project coordinator (scientist) to discuss results and suggest new research directions (Haklay, 2013).

2.3.3 A Typology of Citizen Science Participation in Scientific Research

Bonney *et al.* (2009a) state that there are ten steps of citizen involvement in scientific research. Firstly, a research question for the study is defined. The next step is to gather information and resources required to address the research question. Several hypotheses are formulated to explain the phenomenon, followed by the design of data collection methodologies to test the hypotheses. The next steps are to collect data, then analyse the samples. Any data that is collected and data that comes from the analysis of the collected samples are analysed and interpreted to draw raw conclusions. Lastly, the results are disseminated to the intended audience to be discussed and formulate new research questions.

There are three types of citizen science research projects; contributory, collaborative and co-created projects (Bonney *et al.*, 2009a). Contributory projects are generally driven by researchers and the citizens are mainly involved in the data collection (Bonney *et al.*, 2009a). Collaborative projects are similar to contributory projects where citizens contribute to the project by collecting data to answer the research questions posed by scientists. However, citizens participating in collaborative projects are actively involved in analysing the data and can take part in the design of data collection protocols, data interpretation, as well as dissemination of results. In co-created projects, citizens are involved in all ten research steps and may even come up with the research question. Bonney *et al.* (2009a) devised a typology of citizen involvement in citizen science research projects highlighting citizen involvement in the steps of scientific research (Table 2-3).

RESEARCH STEPS	CONTRIBUTORY PROJECTS	COLLABORATIVE PROJECTS	CO-CREATED PROJECTS
Define question			✓
Gather information and resources			✓
Develop hypotheses			✓
Design data collection methodologies		(✓)	✓
Data collection	✓	✓	✓
Analyse samples		✓	✓
Analyse data	(✓)	✓	✓
Interpret data and raw conclusions		(✓)	✓
Disseminate results	(✓)	(✓)	✓
Discuss results and ask new questions			✓
✓ = Citizens involved in step; (✓) = Citizens sometimes involved in step			

Table 2-3: Typology and Steps of Citizen Participation in Scientific Research (Bonney *et al.*, 2009a).

2.3.4 Citizen Science and Engaged Scholarship

This research study proposes using the citizen science method proposed by Bonney *et al.* (2009a) to guide citizen engagement and participation in the study. In citizen science research, the public plays a role in data collection across broad geographic regions, usually to address questions raised by researchers (Wiggins & Crowston, 2011), thus, making it suitable to be the conceptual framing to support the engaged scholarship methodology. In this regard, the researcher proposes incorporating the ten research steps of citizen science within the four activities of engaged scholarship to provide the researcher with a process and guidelines to follow throughout this research (Figure 2-5).

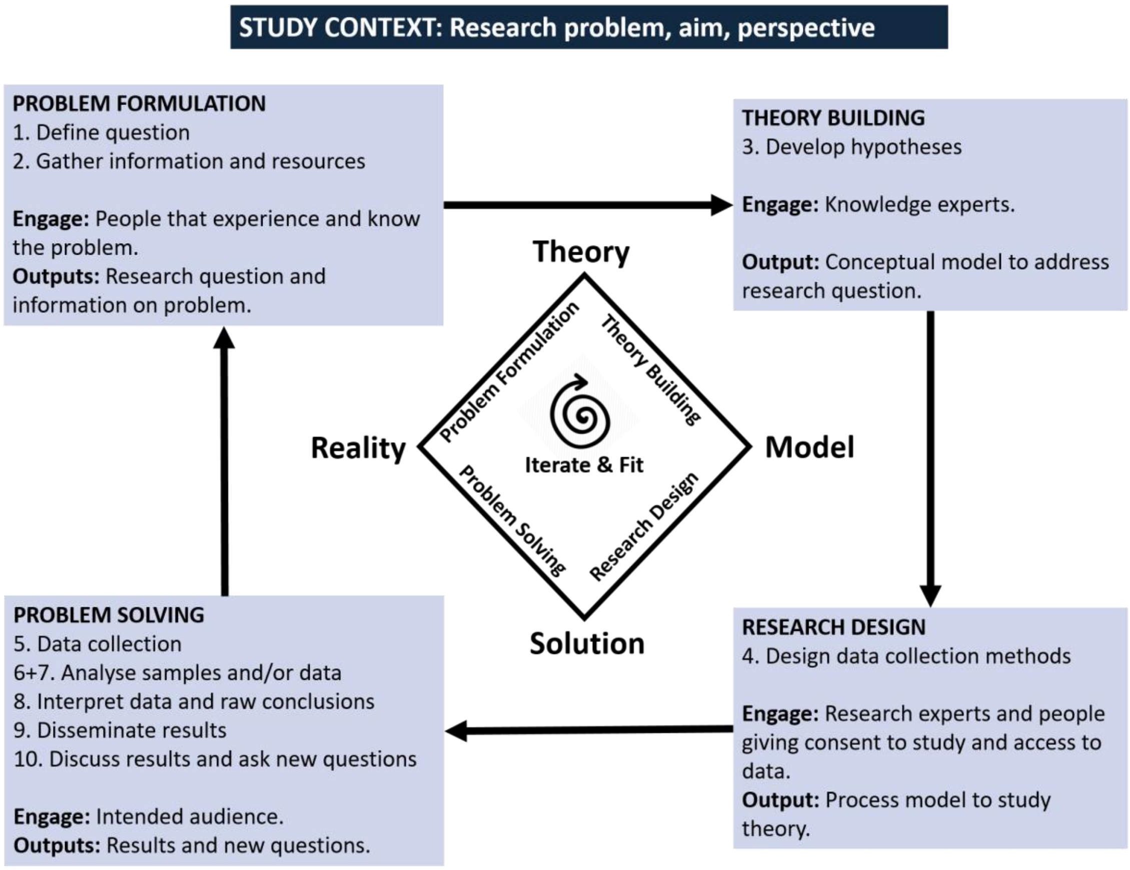


Figure 2-5: Mapping of Citizen Science Steps to Engaged Scholarship Diamond Model (Author's Own Construct Adapted from Figure 2-1).

2.4 Adopted Methods of Inquiry (M)

As stated earlier, researchers practising engaged scholarship can use a wide portfolio of qualitative and quantitative methods to obtain an understanding and perspectives from key stakeholders in a real-world problematic situation (Van de Ven, 2007). Mixed methods research is research that combines components of quantitative and qualitative research approaches for purposes such as improving data accuracy, expanding the range of inquiry and combining information from complementary data sources to produce a more complete picture of the research context (Johnson, Onwuegbuzie & Turner, 2007; Denscombe, 2008). A mixed methods approach to this research study design was selected to support engaged scholarship because it allows the consideration of the primary research question from different angles and allows the researcher to choose the best research method to answer each secondary research question (Bryman, 2012). In addition, using mixed methods provides a better understanding than qualitative or quantitative methods alone (Denscombe, 2008).

Researchers using the engaged scholarship methodology can use extant theory and empirical findings to address the research problem (Van de Ven, 2007).

2.4.1 Critical Literature Review

This study uses a literature review to answer several research questions. The review fuels both the Problem Formulation and Theory Building research activities to gather information and resources about the area of concern and the conceptual framing that guides the data collection in the Research Design activity. Three inclusion criteria were defined to assess studies' relevance and validity. The selected studies had to 1) originate from a quality conference paper, peer-reviewed article, or reputable website, organisation, book publisher or university, 2) date after 2011 and 3) be conference papers, scientific articles, books, theses, websites and reports. Three fields of research were identified as starting points for the search:

- Crowdsensing as the main area.
- WASH as the specific field of the studies.
- Smartphones as the target devices.

Google Scholar and Google Search were selected to perform the search for the literature. Although Google Scholar offers the advantage of an automated full-text search, Google Search allowed the researcher to acquire relevant data from crowdsensing websites that have not published articles on their work. Table 2-4 shows the specific search terms to be used in the literature search.

FIELD	STRING
Crowdsensing	("crowdsensing" OR "crowd sensing" OR "citizen science" OR "human sensors" OR "mobile crowdsensing" OR "crowdsourcing" OR "crowd sourcing" OR "citizen participation")
WASH	("water" OR "WASH" OR "water resource monitoring" OR "water monitoring" OR "environment" OR "environmental monitoring" OR "water resources")
Mobile Context	("mobile application" OR "mobile app" OR "app" OR "smartphone" OR "mobile device" OR "mobile phone" OR "mobile device sensors")

Table 2-4: Search Strings for Literature Review.

The search was carried out several times depending on the research objective. In addition to the search engines, literature was also obtained via references in the selected articles. The analysis of the studies was based on subject analysis by going through the abstract to decide whether the document should be entirely read.

2.4.2 Empirical Research Methods

As stated earlier, IS research is not only about technical solutions, but human behaviour, project management and organisational issues. Empirical methods are crucial for disciplines like Web and software engineering as they allow researchers to incorporate human behaviour into the research approach that they choose. Empirical research is a means of deriving knowledge from actual experiences or observations rather than theories or belief, thus, it allows for informed and well-grounded decisions, by making it possible to evaluate and validate results scientifically (Wohlin, Höst & Henningsson, 2006). There are two types of approaches to empirical studies; qualitative and quantitative research. The main methods used in empirical research are surveys, experiments, case studies and observational methods (Kitchenham *et al.*, 2002).

2.4.2.1 Qualitative and Quantitative Research

This study uses both quantitative and qualitative empirical methods in a mixed methods approach to allow for the theoretical and methodological triangulation of the research problem. Qualitative research focuses on understanding phenomena in their natural setting (Wohlin, Höst & Henningsson, 2006). Qualitative research involves using explanations the subjects of the study brings to the researcher to interpret a phenomenon and understand the subjects' view of the problem. On the other hand, quantitative research focuses on identifying a cause and effect relationship. Many researchers conducting quantitative research set up experiments or collect data through surveys or case studies. Quantitative methods require a hypothesis and the researcher exists as an objective, impartial observer. However, quantitative methods do not allow the exploration of subjects in depth and may force people into categories. In this regard, it is common to use quantitative and qualitative research approaches to investigate the same topic but answer different research questions. A researcher can conduct quantitative research to test the effect of some manipulation and then use qualitative research to understand the results of the quantitative investigation.

2.4.2.2 Survey

Surveys involve collecting a large amount of qualitative or quantitative data from a large number of people in the target population, primarily through questionnaires and interviews (Wohlin, Höst & Henningsson, 2006). In this study, the researcher distributed a **questionnaire** to citizens to understand factors that would affect their motivation to participate in crowdsensing for water resource monitoring. This method was used in the Problem Formulation and Problem Solving activity of engaged scholarship to engage with the citizens and collect data relevant to the development of the solution. The researcher engaged with knowledge experts in the relevant disciplines, as well as people from case study organisations who provided access to the citizens and information. Engaging with the knowledge experts is performed in the Theory Building activity of engaged scholarship to develop a conceptual model to address the research question. The results of the surveys are analysed to derive descriptive and explanatory conclusions and then generalised to the sampled population.

2.4.2.3 Experiment

An experiment typically begins with a research question that requires testing through experimentation (Kitchenham *et al.*, 2002). Usually, a researcher has a certain theory which they use to propose and test a hypothesis in order to derive predictions about specific events. The objective of an experiment is to manipulate one or more variables and measure the effect of the manipulations (Wohlin, Höst & Henningsson, 2006). An experiment ends with the interpretation of the data and formulation of a theory. The results of the experiment are presented as the most reasonable explanation for the phenomenon. Experiments also relate to the Problem Solving activity of engaged scholarship where the study runs confirmatory experiments to test hypotheses derived in the Theory Building activity as rigorously as possible.

2.4.2.4 Case Study

Yin (2014) defines a case study approach to research as a form of empirical inquiry. A case study is an intensive systematic investigation of a person, group of people, community or a unit in which the researcher examines complex phenomena in the natural setting to increase the understanding of the phenomena (Yin, 2014). In research, case studies allow the researcher to investigate a complex issue, within its real-life context and to gain an understanding of the issue from the participant's perspective. The engaged scholarship methodology often relies on a case study to represent the real-world problematic situation in a research study (Mackinnon, 2010). Case studies can be used to study a real project by examining in-depth data relating to several variables, with the aim of generalising over several units (Gustafsson, 2017).

This study uses the case study approach in conjunction with engaged scholarship, to test the sociotechnical design. Most municipalities or cities in Africa do not have an open communication line between citizens and their service providers. Furthermore, data sourced from citizens may not be available and/or may not be given to research institutions or universities to be used in research. The Nelson Mandela Bay Municipality (NMBM) was approached to serve as a case study for this research since they have similar problems to the problems identified in literature (Section 1.2). Agreement was obtained to use their dataset with records of complaints made by citizens for the purposes of this research study.

The NMBM is a metropolitan municipality in South Africa, located in the Eastern Cape Province. NMBM comprises the city of Port Elizabeth, the towns of Uitenhage and Despatch, and the surrounding rural areas (Figure 2-6). Nelson Mandela Bay Municipality (2016) reports that 100% of the households in NMBM have access to water and informal areas receive water through standpipes within a 200m radius. However, NMBM is still facing challenges of water losses and scarcity threatening sustainable water supply for the residence. NMBM continually invests in infrastructure that can address water scarcity in the municipality. One of NMBM's initiatives to address the water crisis is the provision of a hotline for citizens to report water issues such as blockages, leaks and abuse.

Figure 2-6: Nelson Mandela Bay Municipality.

2.5 Research Methods and Dissertation Structure

This study follows Van de Ven's (2007) engaged scholarship methodology to inform the activities of the study. The study uses citizen science as the conceptual framing to guide the data collection and analysis, while the mixed methods approach is used for empirical inquiry. A significant aspect of engaged scholarship is to ground the research in theory and the real-world problem. The real-world problem in this study revolves around the problems with the sharing of relevant information between communities and water service providers. Figure 2-7 illustrates how the methodology was adopted, how the iterations were implemented to address the RQs and how each chapter reports on each of these aspects.

Chapters 1 and 3 provide a deep understanding of the area of concern and the real-world problem using a critical literature review and the case study approach respectively. RQ2 is fully addressed in Chapter 3 while RQ1 and RQ4 are addressed in Chapters 3 and 4. RQ3 is addressed in Chapters 4 and 5.

The engaged scholarship methodology is iterative in nature and this study performs three iterations of the four research activities (Problem Formulation, Theory Building, Research Design and Problem Solving). Two iterations are reported on in Chapter 4; these iterations were conducted to understand the real-world problem from the citizens' perspective. A survey was conducted to provide detailed insight into the real-world problem regarding citizens' perceptions of crowdsensing for water resource monitoring and the relationship between theory and the real-world problematic situation. The third iteration, covered in Chapter 5, contributed to the development of the sociotechnical design of the Crowdsensing Method. The sociotechnical design is a significant contribution to both the area of concern and the real-world problematic situation as it proposes recruitment and incentive policies that can be used to recruit and motivate citizens to contribute data to a crowdsensing system continuously. The sociotechnical design is evaluated through a set of experiments and the results of the experiments showed that the recruitment policy performs better than random or naïve recruitment policies.

Several research contributions to the area of concern and real-world problem are made from Chapters 3 to 5. These contributions all form part of the Crowdsensing Method, which is iteratively developed and improved upon. The Crowdsensing Method is evaluated in Chapter 6 using success factors for mobile-based solution design as proposed by Hutchings *et al.* (2012). To conclude this research, the final chapter, Chapter 7, reports on the key findings of this study and how the main research question is addressed and provides recommendations for future research.

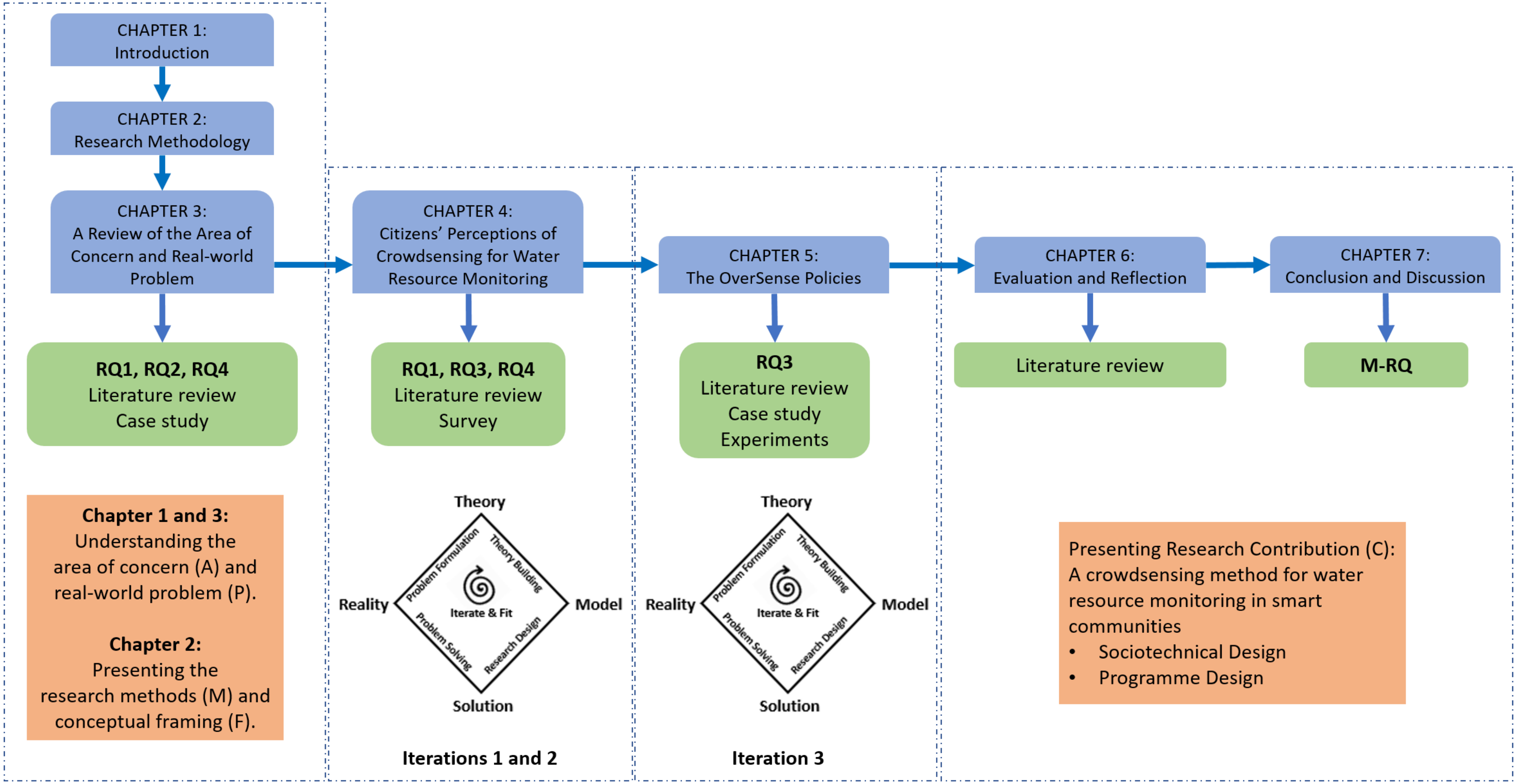


Figure 2-7: High-Level Process Flow Diagram of this Research Study.

2.6 Ethical Considerations

Myers and Venable (2014) state that researchers must use the ethical principles adopted by research institutions when conducting IS research due to reasons such as the dual potential of IT to enhance or destroy human dignity. One of the main concerns is the risk of violating a research subject's privacy; revealing a person's information to others and subjecting them to disastrous consequences. In this regard, there is an increased focus on the adherence to ethical principles by higher education institutions and research institution boards. The Nelson Mandela University requires any researchers seeking to involve human participants in their study to seek ethical approval from the university's research ethics committee board. Since this study engages with stakeholders at every step of the research, it was pertinent that the researcher seeks the ethics approval from the committee. The approval was granted and the ethics clearance number for this study is H17-SCI-CSS-008 (Appendix A).

Following ethical guidelines, the stakeholders involved in this study were required to sign a consent form to confirm their voluntary participation in this study. All stakeholders were treated fairly and with honesty and the data they provided was kept safe and secure. The data was only used for the purposes of this study.

2.7 Summary

This chapter discussed the research methods to be used in this study. Van de Ven (2007) proposes four activities that form an engaged scholarship study - Problem Formulation, Theory Building, Research Design and Problem Solving. These activities, in conjunction with the contributory citizen science model (Bonney *et al.*, 2009a), will be used to govern this research study. Mathiassen (2017) provides a template to support the process of research design for an engaged scholarship study. The template is adapted to this research study based on information from previous sections (Table 2-5).

Component	Description	Application in this Research Study
Title	The title expresses the essence of your research design with an emphasis on C.	A crowdsensing method for water resource monitoring in smart communities
P	People's concerns in a real-world problem setting.	There are several problems with the sharing of relevant information between communities and water service providers. The main problems relate to the deployment of sensing infrastructure, the lack of responsiveness by the service providers to the generated information, the lack of access to the information and the sustainability of the technology solutions.
A	An area of concern in some specific body of knowledge within the literature that relates to P.	Adoption of crowdsensing for water resource monitoring in smart communities.
RQ	The research question relates to P and opens for research into A. All relationships must focus on the central role of the RQ to ensure the research design is coherent and consistent.	How can crowdsensing be used for effective water resource monitoring in smart communities?
F	The conceptual framing guides data collection and is the foundation for data analyses to answer RQ. F_A draws on concepts from A, while F_I draws on concepts independent of A.	F_A: Citizen Science. F_A: Incentive Theory for Participatory Crowdsourcing. F_I: Theory of Planned Behaviour.
M	The adopted methods of empirical inquiry to guide the engaged scholarship research that allows the research to draw available data from P and answer the RQ.	• Literature review. • Case study. • Survey. • Experiments.
C	The contributions to P and A and possibly to F and M.	Crowdsensing method for water resource monitoring in smart communities with sociotechnical and programme designs.

Table 2-5: Research Design based on Engaged Scholarship (Adapted from Table 2-2).

3 A REVIEW OF THE AREA OF CONCERN AND REAL-WORLD PROBLEM

3.1 Introduction

The previous chapter presented engaged scholarship as the selected research methodology to be used in this study and highlighted the research methods, models and theories to be used. Any engaged scholarship study must be grounded in the problematic situation and the area of concern to ensure the research question relates to both the area of concern (A) and problematic situation (P). These are:

> **A:** Adoption of crowdsensing for water resource monitoring in smart communities.
>
> **P:** There are several problems with the sharing of relevant information between communities and water service providers. The main problems relate to the deployment of sensing infrastructure, the lack of responsiveness by the service providers to the generated information, the lack of access to the information and the sustainability of the technology solutions.

The first research method used in this study is an extensive literature review of P and A to ensure the study is grounded in theory and the research problem (Section 2.2) before starting the first iteration of research activities. This chapter will therefore address the following research questions (Section 1.4):

> **RQ1:** What are the problems faced by citizens and water service providers regarding crowdsensing and water resource monitoring as identified by literature and within a real-world context?
>
> **RQ2:** What are the common activities and key success factors for crowdsensing projects?
>
> **RQ4:** What design guidelines can be used for crowdsensing for water resource monitoring to create a smart community?

The main problems faced by citizens regarding crowdsensing and water resource monitoring relate to issues with regards to a lack of citizen participation and the development of smart communities to use technology to support and strengthen local communities (Section 3.2). Crowdsensing has been used in various disciplines to collect data from citizens to produce scientific knowledge and/or respond to citizens' needs and concerns (Section 3.3). A review of literature resulted the development of a Crowdsensing Reference Framework (Section 3.4).

Several crowdsensing systems have been developed for water resource monitoring including a mobile application deployed by NMBM (Section 3.5). After reviewing the literature and the NMBM mobile application, several conclusions are made (Section 3.6).

This chapter presents several deliverables that are theoretical and practical contributions to P and A:

- Problems in Smart Communities (Section 3.2.2).
- Challenge Framework for Crowdsensing (Figure 3-5).
- A Crowdsensing Reference Framework that includes:
  - A Crowdsensing Process (Figure 3-4).
  - Key Success Factors and Guidelines for Crowdsensing Projects (Table 3-3).
- Design Guidelines for Crowdsensing Systems (Table 3-4).
- A Crowdsensing Method for Water Resource Monitoring in Smart Communities Version 1 (Figure 3-9).

The full chapter structure is illustrated in Figure 3-1.

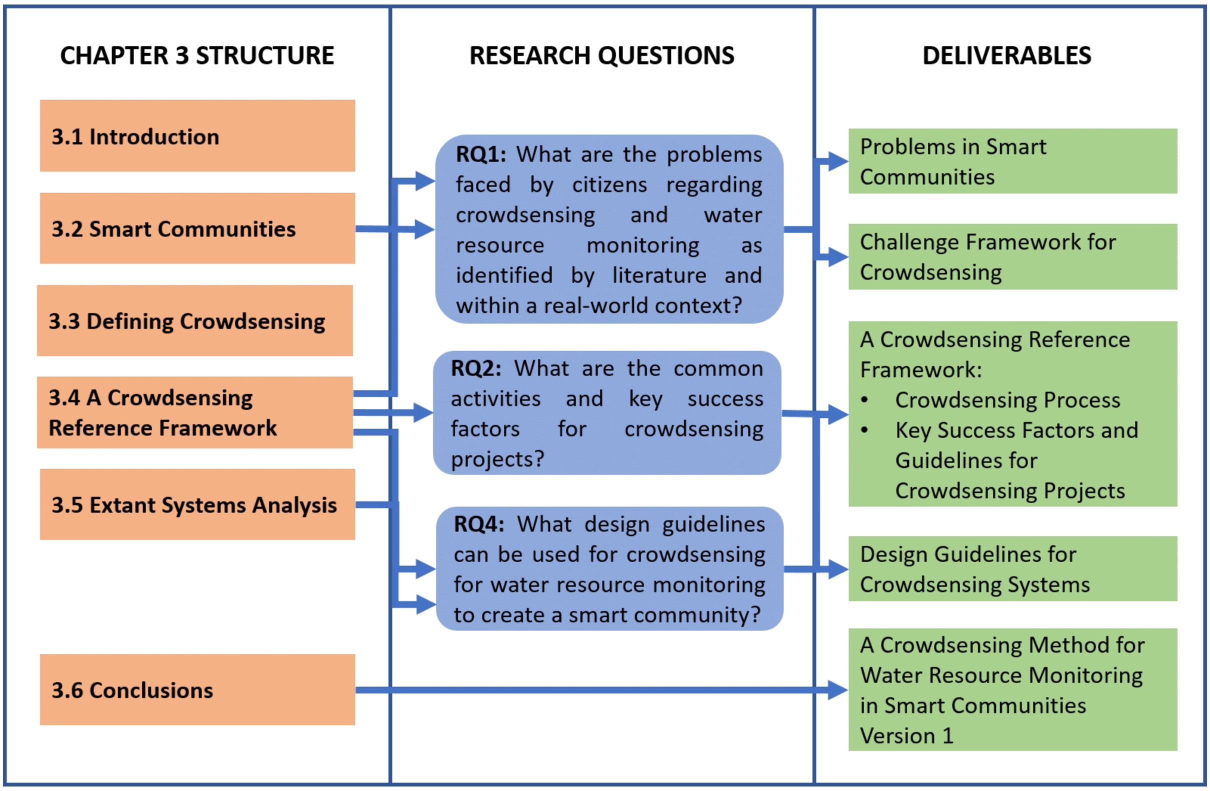


Figure 3-1: Structure of Chapter 3.

3.2 Smart Communities

Since data collection exercises are often costly and difficult to replicate, smart technologies are being used to collect the required data, analyse the data and provide feedback, all in real time. Thus, there is an increased demand on cities to incorporate smart technologies to gather and analyse data in real time to extract information and convert it into usable knowledge (Jin *et al.*, 2014).

3.2.1 The Smart Community Concept

The concept of a smart city has become increasingly popular with local governments, with the assistance of other stakeholders, striving to manage their resources smarter (Washburn & Sindhu, 2010; Nam & Pardo, 2011). Washburn and Sindhu (2010, p.2) define a smart city as "*the use of Smart Computing technologies to make the critical infrastructure components and services of a city — which include city administration, education, healthcare, public safety, real estate, transportation, and utilities — more intelligent, interconnected, and efficient*". However, there are claims that the term "smart city" is a marketing ploy (Caragliu, del Bo & Nijkamp, 2011), that smart cities value business over people (Greenfield, 2013) and widen the gap between who can generate and access information (David, Justice & Mc Nutt, 2015). The critics of smart cities have been a significant motivating force behind the development of smart communities. Sun *et al*. (2016) recommend that smart cities develop into smart communities to benefit more people by including small towns and rural areas.

The Smart Communities Guidebook (Wilson, 1997), as cited by Lindskog (2004, p. 1), describes a smart community as *a geographical area ranging in size from neighbourhood to a country whose residents, organisations and governing institutions are using IT to transform their region in significant ways*. More recently, Gurstein (2014) argues that a smart community must focus on social inclusion, as well as the needs of a community and its citizens using information and communication technologies (ICTs) as a facilitator. Xia and Ma (2011) state that a key property of a smart community is to handle the hybrid group of people, as social objects, and physical objects to integrate the cyber, physical and social worlds for the delivery of smart services. Xia and Ma (2011) identified several key properties of a smart community:

- A smart community is a system that is both physically and socially aware.
- The number of members, as well as the lifecycle of a smart community varies depending on the application it supports.
- A smart community does not need to be connected to the Internet; it may function in a local environment.
- A smart community must have good scalability as the size might change over time.

The various definitions of a smart community have one aspect in common: the emphasis on the proactive participation of the people living in the territory to improve their quality of life (Traverso, 2015). The participation collaboration of various community stakeholders is pivotal for smart communities, in addition to the technology that enables monitoring and providing feedback (Petrushyna, Klamma & Jarke, 2014). ICT infrastructure and applications are important but without the citizens' engagement and willingness to collaborate and cooperate with external stakeholders, there is no smart community (Wilson, 1997).

Considering the definitions identified in literature and highlighted in this section, this study takes on the holistic view of a smart community as *a community in which the community members, organisations and governing institutions leverage IT to transform the community in significant and positive ways, regardless of which technologies are utilised.*

3.2.2 Problems in Smart Communities

Smart communities provide the benefit of facilitating citizen participation in policy and decision-making by giving the citizens a platform to connect with the government (Lindskog, 2004). However, a number of studies have highlighted both social and technology acceptance problems that arose from the installation of a smart community infrastructure in countries such as USA and Japan, which are both developed countries (Karlin, 2012; Granier & Kudo, 2016).

3.2.2.1 Technology Learning Curve

Smart communities are characterised by employing a set of sophisticated sensing, processing and communicating digital technologies (Kranz & Picot, 2011). The deployment and integration of these technologies present significant knowledge challenges to the community, since their complexity imposes a substantial burden on the users in terms of the knowledge needed to use them effectively (Zheng & Dedrick, 2012).

3.2.2.2 Cost of Intelligence

With smart communities comes a major need to install sensors that operate in difficult environmental conditions and are affordable to deploy and maintain over long periods of time (Nahrstedt *et al.*, 2016). Costs of implementing and maintaining a smart community include energy consumption, costs of connecting to the Internet (mobile data, Wi-Fi) and the cost of each individual device.

3.2.2.3 Scalability

In relation to the cost of smart technologies, scalability is a challenge to smart communities. Smart community initiatives often start small, but grow fast, and scale big. Therefore, the IT infrastructure must consider the massive take-up of sensor devices and applications, as well as a massive growth in data and network traffic (Khatoun & Zeadally, 2016).

These three problems can be addressed by allocating a huge financial investment to the deployment and maintenance of the smart community. Such an investment may not be feasible for developing countries, especially to scale the "smartness" throughout the country. The paradigm of crowdsensing is a burgeoning sociotechnical concept that can allow a smart community to leverage the ubiquity and sensing power of mobile devices to capture and map phenomena of common interest (Ogie, 2016).

3.3 Defining Crowdsensing

The aim of smart communities is to use technology in order to connect citizens and positively transform communities by means of ICT (Gurstein, 2014; Traverso, 2015; Lendák, 2016). There has been a significant increase in the means of collecting data from various sensors and devices, and mobile phones have become pertinent in accessing real-time data from citizens (Fan & Bifet, 2013) leading to the increasing popularity of crowdsensing (Cilliers, Flowerday & Mclean, 2016; Lendák, 2016). Guo *et al.* (2014, p.593) defines crowdsensing as "*the ability to acquire local knowledge through sensor-enhanced mobile devices – e.g., location, personal and surrounding context, noise level, traffic conditions, and in the future more specialized information such as pollution – and the possibility to share this knowledge within the social sphere, healthcare providers, and utility providers.*"

Crowdsensing is based on the crowdsourcing concept of engaging a crowd to solve a complex problem through an open forum (Brabham 2008). The motivation behind crowd-powered problem-solving is the belief in the "Wisdom of the Crowd" (hereafter referred to as crowd wisdom). Crowd wisdom is based on the assumption that aggregating information in groups results in better decisions than those based on an individual (Surowiecki, 2004). Crowdsensing allows researchers and organisations the opportunity to solicit the crowd wisdom of mobile device users and for crowd-powered data collection and analysis over large geographical areas by connecting to a large number of people at once (Guo *et al.*, 2014; Gong & Shroff, 2017). In this regard, Yang *et al.* (2015a) describe crowdsensing as crowdsourcing with smartphones (Figure 3-2).

Crowdsensing involves the participation of citizens in the collection of both user-contributed data (human intelligence) and sensed data from mobile devices (machine intelligence) using their mobile devices to contribute to a common purpose (Yadav *et al.*, 2013; Guo *et al.*, 2014). Crowdsensing aims to empower citizens of a smart community to use their mobile phones to collect and share sensed data from their surrounding environments (Kanhere, 2011). Mobile networks in developing countries are making progress and the adoption of mobile phones keeps increasing, offering the possibility to use the data users provide to improve the quality of life (Fan & Bifet, 2013).

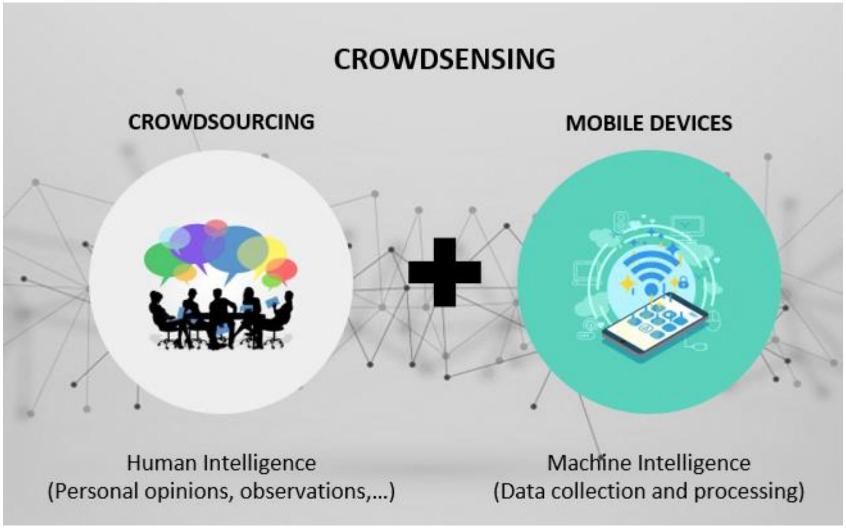


Figure 3-2: A Comparison of Crowdsensing and Crowdsourcing [Adapted from Guo *et al.* (2014)].

In a crowdsensing network (Figure 3-3), sensing tasks are distributed by a crowdsensing platform coordinated by administrators of the crowdsensing project (Zhang *et al.*, 2016). The administrators use rewards to motivate mobile device users to collect sensing data from the areas that must be monitored, namely Points of Interest (PoIs). The data is then transmitted to the crowdsensing platform for aggregation and processing into a suitable form for interested parties (Louta *et al.*, 2016; Zhang *et al.*, 2016).

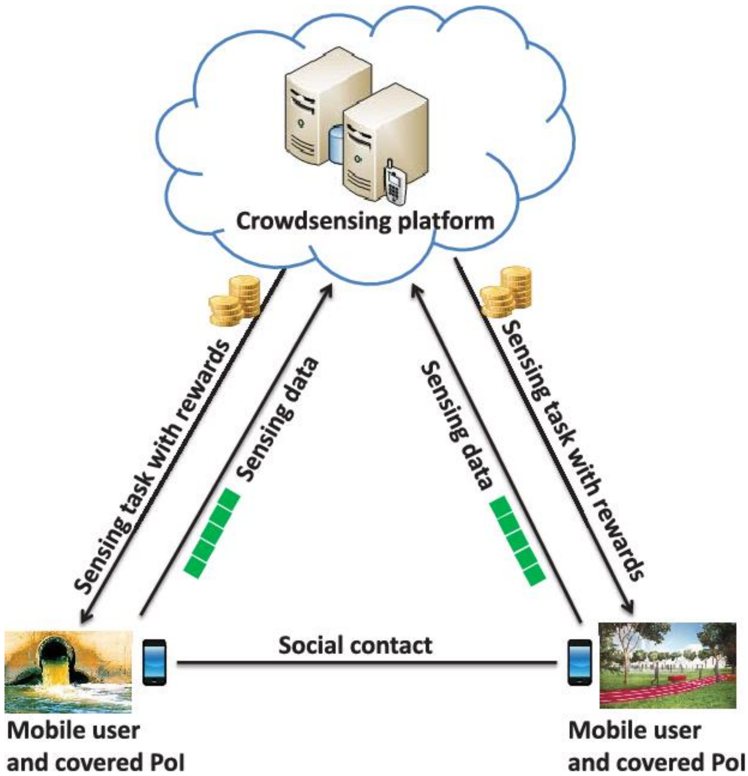


Figure 3-3: An Example of a Crowdsensing Network (Zhang *et al.*, 2016).

In typical crowdsensing architecture, a mobile phone acts as a sensor, collecting, processing and distributing data. Today's high-end mobile phones have general purpose sensors like a camera and a microphone, as well as specialised sensors including GPS, digital compass, proximity sensor, ambient light sensor and accelerometer (Yang *et al.*, 2015a). The affixing of a sensory device to a mobile phone provides the opportunity to track dynamic information about humans and the environment and understand their patterns. In addition to the mobile device sensors, crowdsensing allows citizens to act as sensors and actively participate in collecting data (Yadav *et al.*, 2013). Citizens can sense their surroundings and provide information about their interpretation through text, voice, video, location and other means of communication.

For crowdsensing projects to be successful, researchers and practitioners need to reflect on the lessons learned from other similar studies. There is evidence of a lot of research in the field of crowdsourcing and crowdsensing, possibly due to the rapid development of new technologies and the growing popularity of this field. However, few studies have proposed comprehensive processes or frameworks that provide guidance with regards to these projects, particularly for smart communities where the people factor is a strong consideration. Whilst traditional system development frameworks and methodologies are available, there are several differences between these systems and crowdsensing systems and projects. Therefore, it cannot be assumed that these frameworks will be effective.

3.4 A Crowdsensing Reference Framework

As part of this research, the author of this study proposes a comprehensive Crowdsensing Reference Framework as a contribution to both researchers and practitioners to get a clear understanding of the nature and scope of crowdsensing projects. Using a critical review of literature (Section 2.4.1), primary data was collected, analysed and systematically consolidated to build the initial framework.

3.4.1.1 The Crowdsensing Process

The literature review identified five studies (Tilak, 2013; Christin, 2016; Liu, Shen & Zhang, 2016; Alsheikh *et al.*, 2017; Guo *et al.*, 2014) that propose different steps that researchers followed to develop their crowdsensing systems. Alsheikh *et al*. (2017) identified two main phases of the crowdsensing process, namely: 1) **Data Sensing and Gathering**; and 2) **Data Analytics**. However, Alsheikh *et al*. (2017) do not provide significant detail of the activities, challenges or success factors involved in these phases. In addition, Alsheikh *et al*. (2017) does not highlight activities involved in initiating the project. However, other studies (Tilak, 2013; Christin, 2016; Alsheikh *et al.*, 2017) recommend three significant activities related to the initiation of a crowdsensing project. Christin (2016) proposes ***Tasking*** as a significant activity of crowdsensing as it involves determining the tasks that the participants will execute. Tilak (2013) identifies ***Recruitment and Coordination*** as a crucial activity as it involves recruiting participants and ensuring they have the needed tools and guidance to perform the tasks. None of the five studies analysed identified the activities required in ***System development and evaluation*** of the crowdsensing system. System development and evaluation is a strict requirement for mobile projects (Nascimento *et al.*, 2016), before deploying any mobile application to users. The term **Project Initiation** is proposed to describe the first phase of crowdsensing and the three activities identified above are included in the Project Initiation phase.

The resulting three main phases of crowdsensing projects recommended in this study are therefore:

- Project Initiation (Author's Own Construct).
- Data Sensing and Gathering (Alsheikh *et al.*, 2017).
- Data Analytics (Alsheikh *et al.*, 2017).

Whilst Alsheikh *et al.* (2017) does not provide detailed activities for crowdsensing, several other researchers classify the crowdsensing phases into more detail, based on the activities performed. The most extensive classification of activities is provided by Tilak (2013) and Christin (2016). Table 3-1 provides a comparison of the various activities proposed by the four investigated studies. The cells shaded in grey illustrate the gaps identified in the approaches to the crowdsensing process as proposed by the authors. Other authors use different terms for the same activity; as such, each row in the table represents similar activities.

<table>
<tr><th>PHASES</th><th>ACTIVITIES</th><th>Tilak (2013)</th><th>Guo et al. (2014)</th><th>Christin (2016)</th><th>Liu et al. (2016)</th></tr>
<tr><td rowspan="3">Project Initiation</td><td>Tasking</td><td></td><td></td><td>Tasking</td><td></td></tr>
<tr><td>System development and evaluation</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Recruitment and coordination</td><td>Recruitment and coordination</td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Data sensing and gathering</td><td>Data collection</td><td>Sensor data acquisition</td><td>Crowdsensing</td><td>Sensing</td><td>Data collection</td></tr>
<tr><td>Local processing and storage</td><td></td><td></td><td>Local processing and storage</td><td></td></tr>
<tr><td>Data transfer</td><td>Data transfer</td><td>Data transmission</td><td>Reporting</td><td></td></tr>
<tr><td rowspan="4">Data analytics</td><td rowspan="2">Central processing and storage</td><td rowspan="2">Data management and storage</td><td>Data collection infrastructure</td><td rowspan="2">Central processing and storage</td><td rowspan="2">Data storage</td></tr>
<tr><td>Crowd data processing</td></tr>
<tr><td rowspan="2">Presentation</td><td>Data analysis and visualisation</td><td rowspan="2">Applications</td><td rowspan="2">Presentation</td><td rowspan="2">Data upload</td></tr>
<tr><td>Feedback</td></tr>
</table>

Table 3-1: Comparison of Various Approaches to the Crowdsensing Process.

Figure 3-4 illustrates a summary of the process to be followed for crowdsensing projects as proposed in this study. The proposed process was derived from the literature reviewed and reported in this section and has three main phases, with several activities (identified in Table 3-1) and outputs involved in each phase.

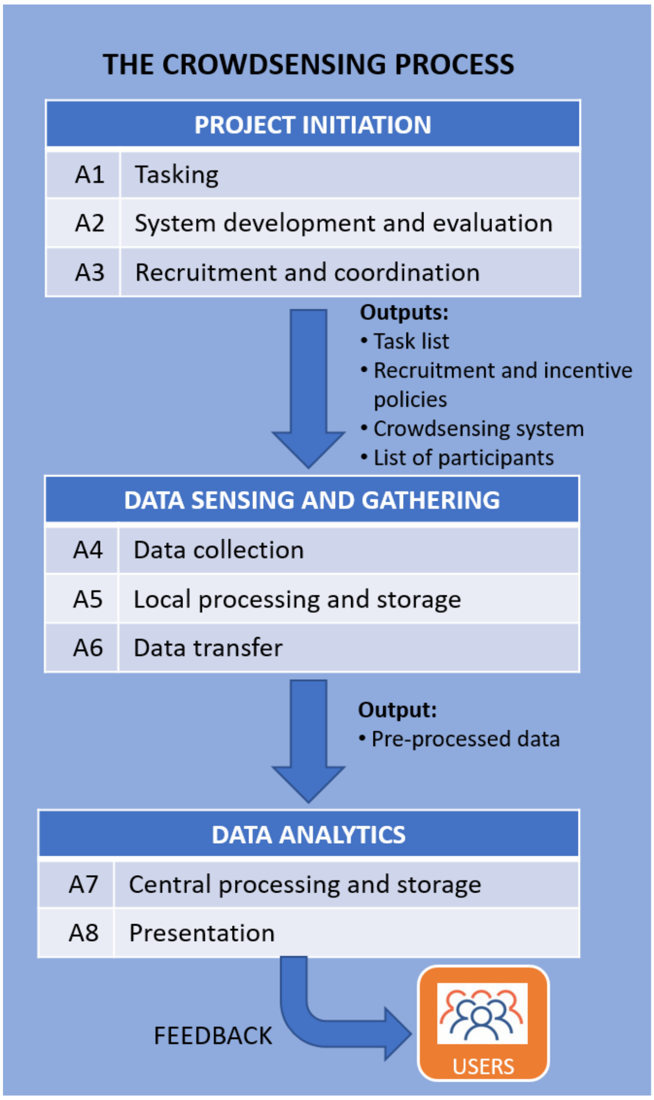


Figure 3-4: The Crowdsensing Process (Author's Own Construct).

A. Project Initiation

The first activity in a crowdsensing project is Tasking, whereby project coordinators need to determine the tasks of crowdsensing to be executed (Christin, 2016). In addition to determining the tasks, the Tasking activity involves developing the design of the crowdsensing system from the system requirements elicited by the project coordinators. Two essential requirements for a crowdsensing system are the recruitment and incentive policies for the recruitment and coordination of the crowdsensing project. Reddy, Estrin and Srivastava (2010) define a recruitment policy as a policy that considers the crowdsensing project requirements and recommends participants that should be selected to collect data (Reddy, Estrin & Srivastava, 2010). When participants are selected to perform certain crowdsensing tasks using the recruitment policy, the crowdsensing system offers incentives to the selected participants based on the budget of the crowdsensing project. The crowdsensing project must manage the budget efficiently to yield as much payoff from the participants as possible (Angelopoulos *et al.*, 2014). The crowdsensing project can manage the budget using an incentive policy. Therefore, the outputs of the Tasking activity are the tasks, a list of system requirements and the recruitment and incentive policies.

The second activity of the Project Initiation phase involves the development and evaluation of the crowdsensing system (Nascimento *et al.*, 2016). The development of the system requires the consideration of the tasks, system requirements and policies resulting from the Tasking activity. The developed system must go through a usability and user experience (UX) evaluation before deployment, since usability and UX are key criteria for evaluating mobile applications and the development of crowdsensing systems and ultimately projects (Nascimento *et al.*, 2016). UX involves a person's emotions about using a product, system or service and comprises all aspects of a users' interaction with a product (Norman & Nielsen, 2018). On the other hand, usability is defined by the ISO 9241 standard (ISO 9241-210, 2010) as: "*the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*." Evaluating the usability and UX of the system is important to increase the quality in use of the developed system (Nascimento *et al.*, 2016).

The next activity in this phase is Recruitment and Coordination. In this phase, participants are identified and briefed on the usage of the mobile data collection tool, as well as on the policies on data access, security and privacy (Tilak, 2013). Since these policies must be explained, it can be deduced that the policies must first be identified. The consent of the participants is required before moving forward. The tasks are then distributed to the participants' mobile devices through mobile applications (Christin, 2016).

B. Data Sensing and Gathering

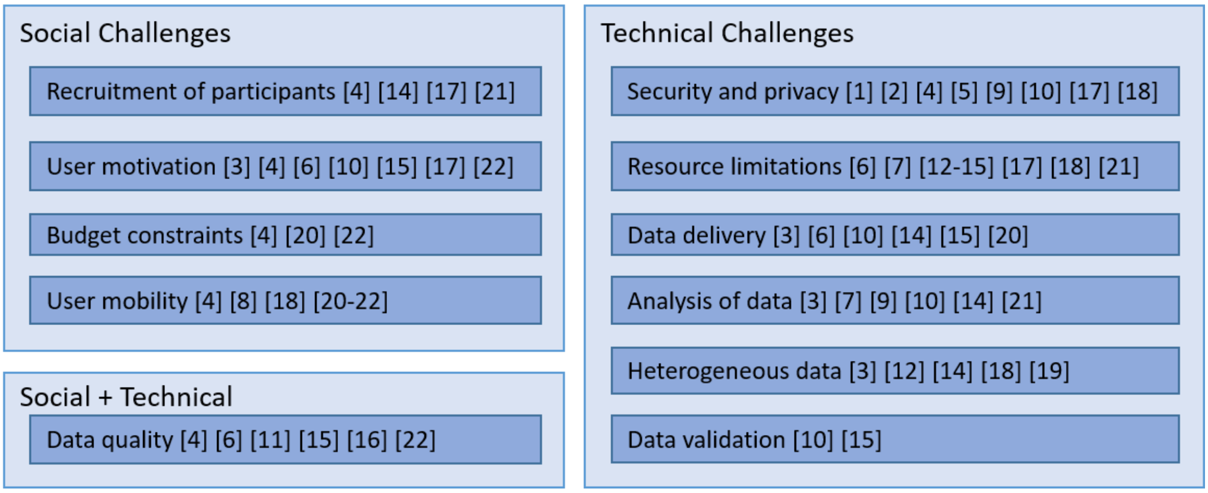
In the second phase, Data Sensing and Gathering, crowdsensing participants sense and collect data using mobile devices according to the defined sensing tasks identified in the Project Initiation phase. The sensory data can be annotated with subjective observations and reports such as the user's emotions and their accounts on the events surrounding them (Alsheikh *et al.*, 2017). The collected data may be locally processed on the device then stored temporarily before transmission to a server (Christin, 2016). The last activity in this phase involves transferring the data to an application server for further analysis through networks such as mobile and Wi-Fi networks (Tilak, 2013).

C. Data Analytics

In the third phase, the Data Analytics phase, the collected data is stored in a central database, awaiting processing (Christin, 2016; Liu, Shen & Zhang, 2016). The raw data is analysed using data analytics such as machine learning methods (Guo *et al.*, 2014; Alsheikh *et al.*, 2017). The last activity is the Presentation activity where stakeholders extract useful information from the analysed data and make effective predictions (Christin, 2016). In the Presentation activity, data visualisation tools, report generation services and other platforms can be used to share outcomes with other stakeholders and provide feedback (Tilak, 2013; Guo *et al.*, 2014).

3.4.1.2 Challenges of Crowdsensing

Crowdsensing seems like a great solution to collecting data over large geographical areas. However, there are some challenges that can be encountered while engaging in these projects. The author of this study performed a literature review that developed a Challenge Framework for Crowdsensing (Figure 3-5). The framework is further divided into two dimensions of challenges, **social** and **technical** challenges. These two dimensions are considered significantly relevant to the study as they distinguish between challenges related to the social and technical designs individually. The framework can be used in developing crowdsensing projects in research and practice.



Authors

[1] Alsheikh *et al.* (2017)
[2] Copos *et al.* (2016)
[3] Guo *et al.* (2014)
[4] Jaimes, Vergara-Laurens and Raij, (2015)
[5] Kapadia, Kotz and Triandopoulos (2009)
[6] Liu, Shen and Zhang (2016)
[7] Louta *et al.* (2016)
[8] Mendez and Labrador (2012)
[9] Nahrstedt *et al.* (2016)
[10] Noureen and Asif (2017)
[11] Reddy *et al.* (2007)
[12] Sun *et al.* (2016)
[13] Vergara-Laurens and Labrador (2011)
[14] Xiao *et al.* (2013)
[15] Yadav *et al.* (2013)
[16] Yang, Zhang and Roe (2013)
[17] Yang *et al.* (2015a)
[18] Yang *et al.* (2015b)
[19] Yerva *et al.* (2012)
[20] Zhang *et al.* (2016)
[21] Zheng *et al.* (2014)
[22] Zheng *et al.* (2017)

*Data quality is regarded as both a social and technical as it is an issue that can be based on the quality of the data submitted by the participant or the ability of the crowdsensing system to impose data quality mechanisms.

Figure 3-5: Challenge Framework for Crowdsensing (Author's Own Construct).

The challenges were also classified according to the phase of crowdsensing they pertain to, namely: **Project Initiation**; **Data Sensing and Gathering**; and **Data Analytics** (Table 3-2).

Phase	Challenge
Project Initiation	Budget constraints
	Recruitment of participants
	User motivation
	User mobility
Data Sensing and Gathering	Data quality
	Data delivery
	Security and privacy
	Resource limitations
Data Analytics	Analysis of data
	Heterogeneous data
	Data validation

Table 3-2: Linking Crowdsensing Challenges to Phases of the Crowdsensing Process.

A. Project Initiation Phase

The four commonly cited challenges in the Project Initiation phase of crowdsensing are:

- Budget constraints.
- Recruitment of participants.
- User motivation.
- User mobility.

Budget Constraints

Crowdsensing does not guarantee citizen participation because citizens must volunteer information willingly (Bosha, 2015). Citizens require incentives in return for volunteering information which may cause budget constraints. Guo *et al.* (2014) identify the development of a solid economic model as a significant step in formulating a crowdsensing project. Many projects have found success in using monetary payments as rewards (Rogstadius *et al.*, 2011). However, due to budget constraints, many projects often find other rewards for participation (Hochachka *et al.*, 2012).

Recruitment of Participants

A significant challenge of crowdsensing projects is the difficulty in recruiting and coordinating citizens as participants for the project (Jaimes, Vergara-Laurens & Raij, 2015). It is important in crowdsensing to maintain a minimum number of participants to keep the system functional. To determine the necessary number of participants, there is a need to analyse variables such as the target area size, frequency of contributions, nature of the phenomenon under analysis and the sensing demands.

Erickson and Kellogg (2000) recommend social translucence as a system design approach to stimulate social interaction and increase participation through visibility, awareness, and accountability (Erickson & Kellogg, 2000). A socially translucent system allows participants to be aware of their participation, as well as create awareness of the activities of others. For example, some researchers (Zhou *et al.*, 2013; Yang *et al.*, 2017) use social interaction incentives alongside explicit mechanisms to maximise user participation. Yang *et al*. (2017) propose the social incentive mechanism that leverages the social ties among participants to promote cooperation in crowdsensing. The social incentive mechanism provides incentives depending on the behaviour of the participant's friends, thus, influencing the participant to motivate their friends to contribute to gain higher rewards. The CrowdAnswer system is a question-answering system that uses micro-blogs to exploit their huge user base (Zhou *et al.*, 2013). CrowdAnswer also uses explicit mechanisms to avoid confining participants to a single social cluster. Each user receives a pool of *n* free credits that increase or decrease when a user makes or replies to a query.

User Motivation

In addition to recruiting participants, crowdsensing poses a challenge of ensuring the collection of large quantities of data from a large number of participants (Guo *et al.*, 2014). Motivation and engagement are crucial in the successful completion of a task (Huang & Soman, 2013). Participating in crowdsensing may expose participants to privacy leaks, data costs or energy consumption; thus, deploying crowdsensing in the real world can be challenging and citizens require incentives to motivate them to participate and collect high-quality data (Jaimes, Vergara-Laurens & Raij, 2015). Many researchers state that the success of crowdsensing projects relies on providing appropriate rewards to participants to recruit, engage, and retain human participants, as well as to ensure that there is a stream of data continuously coming into the application (Ganti, Ye & Lei, 2011; Hochachka *et al.*, 2012; Louta *et al.*, 2016). Participants may drop out if the return on investment does not meet their expectations (Guo *et al.*, 2014). It is necessary to ensure the crowdsensing system actually assists the participants in improving their understanding of their surroundings and derive benefits from the information sharing (Liu, Shen & Zhang, 2016).

Several crowdsensing systems have found success in using game concepts to recruit, engage, and retain participants (Davis & Coskie, 2008; Tuite, Snavely & Tabing, 2011; Anderson *et al.*, 2013; Kawajiri, Shimosaka & Kahima, 2014). The use of game design elements in real-world or productive activities to influence, engage and motivate individuals in performing tasks is referred to as gamification (Beier, 2014; Huang & Soman, 2013). The goal of gamifying an existing system is to increase motivation by combining game mechanics with game dynamics to the system to make it more fun, interesting and engaging. Rewards such as points and badges are the main game dynamics utilised in gamification. Receiving something of value for performing a task motivates individuals with the intention to perform the behaviour again (Beza, 2011). In addition, points and badges act as a form of feedback to display their achievement of tasks and incentivise participants to progress through more levels of the tasks to access more rewards, locked content and other items that are scarce to attain.

User Mobility

Another key challenge in crowdsensing is user mobility, specifically the determination of locations and the assessment of variability of interest in different regions to enable the accurate representation of regions with a low number of participants (Mendez & Labrador, 2012; Jaimes, Vergara-Laurens & Raij, 2015). Mendez and Labrador (2012) suggest using density maps to show which areas are being neglected and to develop incentive mechanisms to encourage the participation of users located in those specific areas. The crowdsensing system can generate a map based on the origin of the data contributed. The system can award points based on the mobility of a user, as well as data collection in sparse locations to incentivise the participants to be mobile. The need for achievement, the accomplishment of difficult challenges or goals and success motivates many people (Beza, 2011). Recognition of their achievements serves as a satisfying reward.

B. Data Sensing and Gathering Phase

The four commonly cited challenges in the Data Sensing and Gathering phase of crowdsensing are:

- Data quality.
- Data delivery.
- Security and privacy.
- Resource limitations.

Data Quality

Citizens might submit data that is not relevant to the intended purpose of the crowdsensing project (Jaimes, Vergara-Laurens & Raij, 2015). The risk of crowdsensing is users sharing, low-quality, incorrect or fake data (Guo *et al.*, 2014). In addition, the data contributions may be inconsistent or redundant, and sensors may sense the same even under different conditions. An important design issue of crowdsensing incentive mechanisms is to consider how to encourage participants to contribute data of high quality. High data quality is an essential component of a crowdsensing project (Hochachka *et al.*, 2012). The design and implementation of a crowdsensing system must strive to limit incorrect data entry, as well as incorporate robust data selection techniques to improve data quality (Hochachka *et al.*, 2012; Guo *et al.*, 2014). Hochachka *et al.* (2012) suggest using quality control filters to ensure accurate data entry. Some researchers use reputation schemes computed from peer assessment and/or past performance to address the problem of data quality (Yerva *et al.*, 2012; Yang, Zhang & Roe, 2013; Liu, Shen & Zhang, 2016).

Security and Privacy

Crowdsensing presents a major need for security and privacy during the collection of data as crowdsensing devices send the user's personal and potentially sensitive information to a third-party (Copos *et al.*, 2016). The data being relayed may be exposed to various entities that could intercept the traffic and infer the user's information (Nahrstedt *et al.*, 2016). Crowdsensing poses a privacy threat to users in contributing data with location tags (Yang *et al.*, 2015a). Sensed data may inadvertently reveal a user's location or frequently travelled routes (Jaimes, Vergara-Laurens & Raij, 2015). Privacy-preserving mechanisms attempt to disassociate a user's data from their identity, which conflicts with collecting data of high quality (Kapadia, Kotz & Triandopoulos, 2009; Jaimes, Vergara-Laurens & Raij, 2015). Louta *et al.* (2016) suggest having a generic security/privacy framework in place that is independent of the crowdsensing system or the nature of the data to address user-specific privacy issues. Privacy schemes and techniques must efficiently address how users' willingness to share data in spite of the privacy risks varies (Louta *et al.*, 2016). In addition, crowdsensing systems must adopt a fully decentralised privacy-preserving architecture which gives users the control to protect their own personal data (Giannetsos, Gisdakis & Papadimitratos, 2014; Louta *et al.*, 2016). Guo *et al.* (2014) stress the importance of allowing users to decide what data they want to share and to whom.

There are several challenges to design an incentive mechanism for crowdsensing that guarantees some level of data quality, as well as ensures the privacy of participants and the security of the data. Incentive mechanisms must be designed and operated in a privacy-preserving manner (Giannetsos, Gisdakis & Papadimitratos, 2014). Techniques to protect user privacy, such as anonymity, must be explored to encourage users to make data contributions (Gustarini, Wac & Dey, 2016; Guo *et al.*, 2014). Researchers must develop trust preservation and abnormal detection technologies to maintain the integrity and quality of the data (Liu, Shen & Zhang, 2016).

Resource Limitations

The resource consumption for users involved in crowdsensing, which may include cellular data, battery and memory, may expose them to security and privacy threats, as well as increase costs to the participants (Yang *et al.*, 2015b). Crowdsensing poses a power consumption issue to the users' devices in regards to sensing and transmitting data to data storage (Vergara-Laurens & Labrador, 2011). In some cases, crowdsensing requires performing some local analytics on the sensing device to reduce the backend processing load (Ganti, Ye & Lei, 2011; Louta *et al.*, 2016). In addition to the reduction of backend processing, local analytics allows primitive processing of the raw data to produce intermediate results, necessitating lesser energy consumption and bandwidth for data transmission (Ganti, Ye & Lei, 2011; Louta *et al.*, 2016). Local analytics also reduces the time spent in transmitting raw sensor data, which may be significant to delay-sensitive applications (Ganti, Ye & Lei, 2011). However, local analytics poses a challenge in the identification of heuristics and the design of algorithms to perform the functions.

Liu *et al*. (2016) identified data deduplication as an essential method of cost reduction of crowdsensing implementation as it strives to eliminate data redundancy. Data deduplication filters and compresses raw data (such as images) collected by the mobile device to eliminate redundant data and reduce storage overhead, traffic load, as well as the cost of transmission (e.g. energy and bandwidth costs).

Data Delivery

The delivery of data from distributed participants to the centralised server poses a challenge with regards to network and connectivity issues such as low bandwidth or unavailability of network access (Noureen & Asif, 2017). Guo *et al.* (2014) emphasise the importance of ensuring crowdsensing systems are tolerant of network interruptions. An issue that is important with dealing with both the challenges of data delivery and protecting the user's privacy is ensuring that the data uploads are transparent and do not run without notifying the user (Guo *et al.*, 2014).

C. Data Analytics Phase

The three commonly cited challenges in the Data Analytics phase of crowdsensing are:

- Analysis of data.
- Heterogeneous data.
- Data validation.

Analysis of Data

Analysis of crowdsensing data spans multiple challenges related to data management, processing and mining, as well as machine learning challenges (Yang *et al.*, 2015b; Kapadia, Kotz & Triandopoulos, 2009). Most crowdsensing systems require instant answers, thus, there is a need for fast and efficient systems to provide access to retrieval of and processing of the data (Nahrstedt *et al.*, 2016). Such systems will enable decision makers to react fast either to inform the public about upcoming events and/or organise major actions to protect the citizens. In addition, there is a need to aggregate robust machine learning algorithms and decision algorithms into a computing framework that can analyse large data sets to find meaningful domain-specific insights from the data and make the right decision when analysis shows certain behaviours and findings (Zheng *et al.*, 2014; Nahrstedt *et al.*, 2016).

Heterogeneous Data

In addition, Yerva *et al.* (2012) report the challenge of integrating data from different source types such as images, audio, text and GPS coordinates. Multiple data sources may contribute conflicting information about the same object. Truth discovery is a method that can tackle this challenge by aggregating noisy data to estimate the reliability of each source (Quoc Viet Hung *et al.* 2013; Gao *et al.* 2015), and has been successfully used to solve various issues such as data integration and truth detection (Gao *et al.* 2015).

Data Validation

Bosha (2015) further highlights a problem of data validation required for the sensing data, which may have a negative impact due to the time required to process the invalid entries. Crowdsensing systems must be robust and adaptive to identify inaccurate, redundant, inconsistent and/or obsolete data collection, as well as inadequate user participation (Chen *et al.* 2015). Zhang *et al.* (2016) state that sensing data must fulfil the "4A" requirements which are: accuracy, adequacy, availability and affordability.

3.4.1.3 Key Success Factors and Guidelines for Crowdsensing Projects

The challenges identified in crowdsensing projects by previous studies (Figure 3-5) should be considered for a project to be successful. Therefore, this study adopts the view that these challenges can be considered as key success factors in the process for crowdsensing projects. The literature review also identified recommendations on how to address each challenge from various researchers (Section 3.4.1.2). Since the challenges are considered as key success factors, the recommendations on how to address each challenge must be considered as guidelines for crowdsensing projects.

Table 3-3 maps each phase of the crowdsensing process to its related key success factor and guidelines made by researchers originating from various project types, view angles, and contexts. As part of a research study on citizen science in water quality monitoring, Minkman (2015) performed a systematic literature review to develop a framework for key success factors of citizen science. Only three of the success factors were specific to mobile crowdsensing (referred to in this study as crowdsensing). These three factors can also be seen as guidelines in Table 3-3 highlighted by an asterisk.

PHASE	ACTIVITY	KEY SUCCESS FACTOR		GUIDELINES		AUTHORS
Project Initiation	A1, A2	K1	Budget constraints	G1	Development of a solid economic model	Jaimes, Vergara-Laurens and Raij (2015); Ogie (2016)
				G2	Identify non-monetary rewards	Hochachka *et al.* (2012)
	A1, A2, A3	K2	Recruitment of participants	G3	Maintain minimum number of participants	Jaimes, Vergara-Laurens and Raij (2015)
				G4	Analyse variables such as target area size and frequency of contributions	Jaimes, Vergara-Laurens and Raij (2015)
				G5	Use social translucence as design approach	Erickson & Kellogg (2000)
		K3	User motivation	G6	Keep target audience capacity in mind*	Minkman (2015)
				G7	Communicate benefits to prospective participants	Liu, Shen and Zhang (2016)
				G8	Investigate and provide appropriate rewards	Ganti, Ye and Lei (2011); Hochachka *et al.* (2012); Louta *et al.* (2016)
				G9	Incentive mechanisms must be adaptable to increasing demands	Jaimes, Vergara-Laurens and Raij (2015)
				G10	Reduce the complexity of the data collection protocols	Bonney *et al.* (2009b)
		K4	User mobility	G11	Assess variability of interest in different regions	Mendez and Labrador (2012); Jaimes, Vergara-Laurens and Raij (2015)
				G12	Generate density map	Mendez and Labrador (2012)
Data Sensing and Gathering	A4	K5	Data quality	G13	Limit incorrect data entry	Hochachka *et al.* (2012); Guo *et al.* (2014)
				G14	Use quality control filters	Hochachka *et al.* (2012)
				G15	Incorporate robust data selection techniques	Hochachka *et al.* (2012); Guo *et al.* (2014)
				G16	Use reputation schemes	Yerva *et al.* (2012); Yang, Zhang and Roe (2013); Liu, Shen and Zhang (2016)
		K6	Security and privacy	G17	Implement a generic security/privacy framework	Louta *et al.* (2016)
				G18	Adopt a fully decentralised privacy-preserving architecture	Giannetsos, Gisdakis and Papadimitratos (2014)
				G19	Balance privacy and data trustworthiness*	Minkman (2015)
				G20	Use privacy-preserving mechanisms	Kapadia, Kotz and Triandopoulos (2009); Jaimes, Vergara-Laurens and Raij (2015)
				G21	Develop trust preservation and abnormal detection technologies	Liu, Shen and Zhang (2016)
	A5	K7	Resource limitations	G22	Keep general device capacity in mind*	Minkman (2015)
				G23	Provide local analytics	Ganti, Ye and Lei (2011); Louta *et al.* (2016)
				G24	Use data deduplication	Liu, Shen and Zhang (2016)
	A6	K8	Data delivery	G25	Ensure system is tolerant of network interruptions	Guo *et al.* (2014)
				G26	Ensure data uploads are transparent	Guo *et al.* (2014)
Data Analytics	A7	K9	Analysis of data	G27	Systems must be fast and efficient	Nahrstedt *et al.* (2016)
				G28	Develop data analysis framework	Zheng *et al.* (2014); Nahrstedt *et al.* (2016)
		K10	Heterogeneous data	G29	Use truth discovery	Quoc Viet Hung *et al.* (2013); Gao *et al.* (2015)
	A7, A8	K11	Data validation	G30	The system must be robust and adaptive	Chen *et al.* (2015)
				G31	Ensure data is accurate, adequate, available and affordable.	Zhang *et al.* (2016)

Table 3-3: Key Success Factors and Guidelines for Crowdsensing Projects.

3.4.1.4 A Crowdsensing Reference Framework

Figure 3-6 illustrates a Crowdsensing Reference Framework that provides a classification of activities, key success factors to be considered for crowdsensing projects and the phase of the crowdsensing process they should be considered. Specifically, the reference framework comprises of:

- Crowdsensing Process with the activities labelled from A1 to A8 (Figure 3-4).
- Key Success Factors for Crowdsensing Projects labelled from K1 to K11 (Table 3-3).
- Guidelines for Crowdsensing Projects labelled from G1 to G31 (Table 3-3).

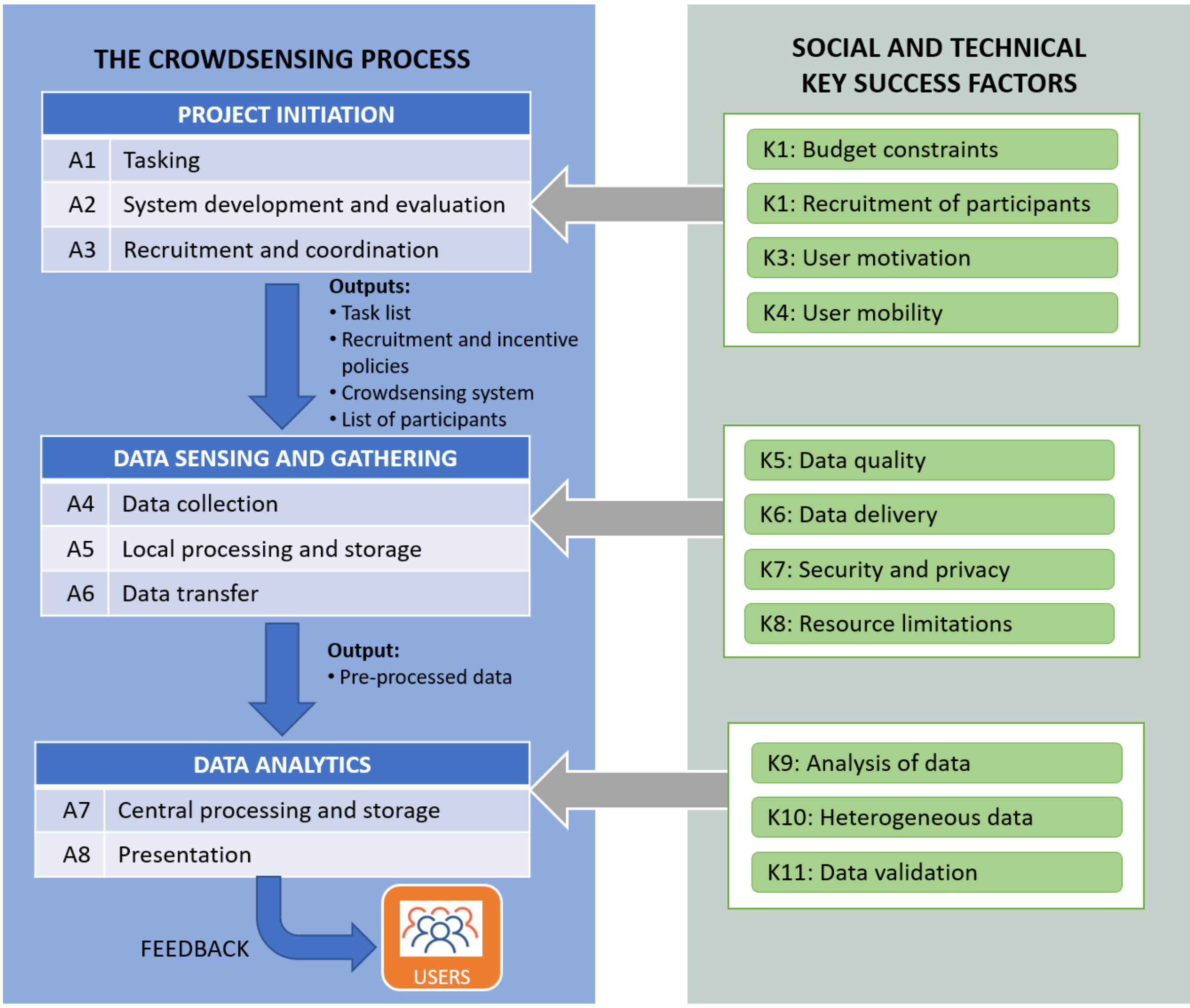


Figure 3-6: A Crowdsensing Reference Framework (Author's Own Construct).

There are several crowdsensing projects that use crowdsensing to improve lives, for example, the Mahali Project for space weather monitoring (Pankratius *et al.*, 2014), a location tracker for elderly citizens in a smart city (Shien & Singh, 2017), as well as a disease surveillance project (Haddawy, 2015). From these examples, it can be deduced that crowdsensing satisfies the key elements of a smart community since it is technology-centric, provides engagement with the citizens and transforms the community in positive ways. Experiences across all industries have shown how IT solves the problem of increasing information needs, and certain areas in the water sector already benefit from the use of ICTs, such as the use of mobile devices for data collection.

3.5 Extant Systems Analysis

Over the past decade, the coverage of the Global System for Mobile Communications (GSM) has outgrown the spread of access to water services and affordable and reliable electricity, providing millions of people with access to modern infrastructure services (Nique & Opala, 2014). For example, approximately 130 million people in sub-Saharan Africa do not have access to a safe water source but are covered by mobile networks. The mobile industry has had a tremendous impact on global development across the domains of education, health, agriculture and finance (Perrier, DeRenzi & Anderson, 2015).The trend of using pervasive and ubiquitous technologies such as mobile device applications for information dissemination has started gaining momentum in the water sector (Nel, Booysen & Van Der Merwe, 2014). There are a vast number of water-related crowdsensing systems that have been deployed, however, only a few applications relevant to this study were described below.

3.5.1 E-government Crowdsensing Systems

Many mobile applications aim to facilitate citizen engagement and allow local governments to interact with urban data to have a comprehensive view of city processes. These applications measure phenomena in a range of services including the environment and infrastructure. An example of such an application is uRep, a mobile application that citizens can use to report hazardous situations in their community, such as electricity cuts, burst pipes and congested roads (Goncalves, Silva & Morreale, 2014). Utility companies can update their progress in rectifying the issues and the users can view the progress through the application. Afreen *et al.* (2017) introduced SpeakUp, an application they believe has more advanced features than uRep. SpeakUp goes beyond reporting only hazardous situations but implores users to report all their daily issues so that appropriate action can be taken by recovery teams. SpeakUp also provides tagging and group discussion features to spread awareness among people in nearby locations. SpeakUp also goes beyond uRep in using GPS for location-based services, in addition to the visual (photos and videos) and textual data submissions. In the same direction, Lanfranchi *et al.* (2014) present WeSenseIt which also allows geo-located neighbourhood discussions about areas of interest or hazardous/threatening situations, as well as water-related issues in the area. In addition, WeSenseIt allows authorities or citizens to communicate crowdsourcing tasks to other citizens or staff members. Lanfranchi *et al.* (2014) stresses the importance of assessing the quality and reliability of data contributions.

Pistolato and Brandão (2016) require citizens to register before reporting city incidents to the ConnectCity e-government application as a way of increasing the reliability of the reports. ConnectCity also allows other users to explore an incident report and add additional information.

Another application that allows residents to report on problems in the city's systems is the San Francisco SF311 mobile application (SF311, 2018b). The SF311 application allows residents of San Francisco to report water quality issues such as dirty, discoloured, oily or sandy water, or if the water tastes or smells different (SF311, 2018a). In addition, residents are encouraged to report water waste in the neighbourhood or other parts of the city. The app requires additional information such as images and location data. Yadav *et al.* (2013) deployed a crowdsensing testbed to collect data about city events across India through an android application, SMS messages and social media feeds. The data inputted by the user included the event type, message/text, event tags, textual location, and image and audio, while the time stamp, cell information and longitude and latitude were picked up by the device automatically. However, the textual data contributions posed a challenge that most of the contributions contained noisy data, as would be expected in data entry through mobile applications.

3.5.2 Water-Specific Crowdsensing Systems

FirstPost (2014) reports on the deployment of a mobile application by the Delhi Jal Board (DJB) to register civic complaints related to water supply and sewage. The DJB application collects complaints and suggestions accompanied by a photograph, audio and location data. The Discharge mobile application (Discharge, 2018) was deployed in Tanzania to measure the velocity, levels and discharge of rivers and channels using the video camera in the smartphone. Kim *et al.* (2011) identified standard measures for water quality to be used in Creek Watch, an iPhone application and website (creekwatch.org) to be used to report information on waterways. The measures were defined based on the needs of water monitoring organisations and are to be accompanied with a photo of the PoI, timestamp and GPS location as per request of the organisations. Users with testing kits may also record chemical properties such as turbidity, pH level, dissolved oxygen and temperature. Rapousis and Papadopouli (2016) report on QoWater, a crowdsensing water quality assessment system. QoWater uses user feedback and sensed data to detect changes in water quality based on odour, colour, taste and chemical properties, and alerts the user of contamination events detected close to their location. After a user registers to QoWater, the user can query water quality in a specific location and time period. A user can take on either of two roles: (1) the role of a customer who can submit their evaluation based on odour, colour, taste, pressure and appearance (2) the role of a scientist (or expert) which queries for colour, appearance, pressure, and chemical and biological measurements. QoWater also automatically detects the current location of the device and timestamp. Rapousis and Papadopouli (2016) report that the challenge of such monitoring systems is timely and reliable contamination event detection and the system's ability to validate data contributions.

3.5.3 Design Guidelines for Crowdsensing Systems

The extant system analysis (Sections 3.5.1 and 3.5.2) identified eight design guidelines for crowdsensing systems, which are a contribution to the sociotechnical design of the Crowdsensing Method (Table 3-4). The eight design guidelines are generic to all crowdsensing systems and as such, are applicable to crowdsensing systems for water resource monitoring.

DESIGN GUIDELINES		REFERENCES
D1	Defined measures for phenomena accompanied by an image, textual data and location of PoI. Audio and video are optional.	Kim *et al.* (2011); Yadav *et al.* (2013); Rapousis and Papadopouli (2016); Afreen *et al.* (2017)
D2	An expert role for users to make more complex measurements.	Rapousis and Papadopouli (2016)
D3	Progress updates available for users.	Goncalves, Silva and Morreale (2014)
D4	Tagging for users to communicate tasks to other users.	Lanfranchi *et al.* (2014)
D5	Allow users to explore reports and add information.	Pistolato and Brandão (2016)
D6	Timely and reliable alerts for issues close to the user's location.	Rapousis and Papadopouli (2016)
D7	Geo-located group discussion features for awareness.	Lanfranchi *et al.* (2014); Afreen *et al.* (2017)
D8	Compulsory user registration to increase the reliability of the reports.	Pistolato and Brandão (2016)

Table 3-4: Design Guidelines for Crowdsensing Systems.

3.5.4 Evaluation of the Case Study Data Collection Process

NMBM, the case study (Section 2.4.2.4), implore its citizens to report incidents related to service delivery using two methods: a hotline and mobile application. Similarly to uRep (Goncalves, Silva & Morreale, 2014), the hotline and mobile app can be used by citizens to report any incidents related to service delivery such as burst pipes, potholes, electricity cuts and water leaks using the NMBM mobile application. The process of reporting an incident is as follows.

> First the citizen must make a phone call to their hotline number or submit an incident report through the municipality's e-government mobile application. Call centre agents are available to take calls from citizens from 06h00 and 22h00 on weekdays. Citizens can make reports in the South African language of their choice and the agents are responsible for transcribing the information into English. Incidents related to service delivery under the governance of NMBM are logged onto an automated information system and the citizen is provided with a reference number for their complaint.

Citizens can use the reference number to contact the call centre and check the progress of the issue resolution.

All departments responsible for reported incidents have live access to the call logging and reporting system and have permission to review their assigned incidents and record the outcomes of the investigation and incident resolution against each incident. The assigned department is tasked with the responsibility of contacting the citizen who made the complaint with regular updates of the incident resolution. If there are further issues, a closed incident can be reopened for further attention.

The process of reporting issues through the hotline is similar to the mobile application. However, instead of the manual entry by call centre agents, citizens enter all the details using the NMBM mobile application. Figure 3-7 shows the process of reporting or querying incidents in the NMBM application, while Figure 3-8 shows screenshots of the NMBM mobile application. The home screen of the NMBM app prompts the citizen to make a choice between reporting an incident or querying an incident that they reported before. If the citizen chooses to report an incident, they are asked to provide the details of the incident. The citizen then uses their GPS to submit the location of the incident and adds details about the location on the street and suburb name. The citizen then concludes the report by providing their phone number and email address. After the citizen submits the report, they receive a reference number they can use to query the progress of incident resolution.

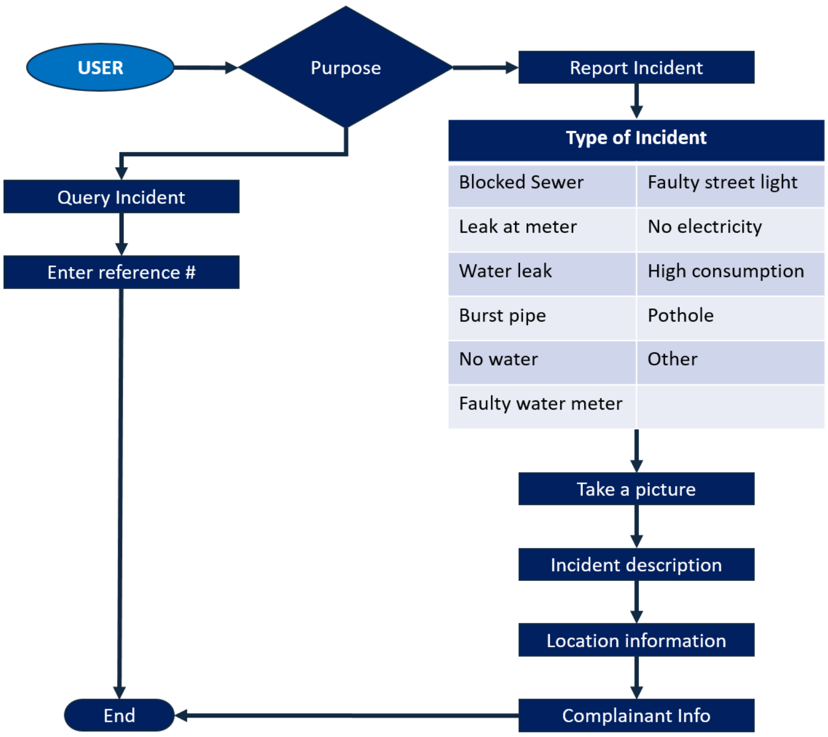


Figure 3-7: Data Collection Process in NMBM Mobile Application.

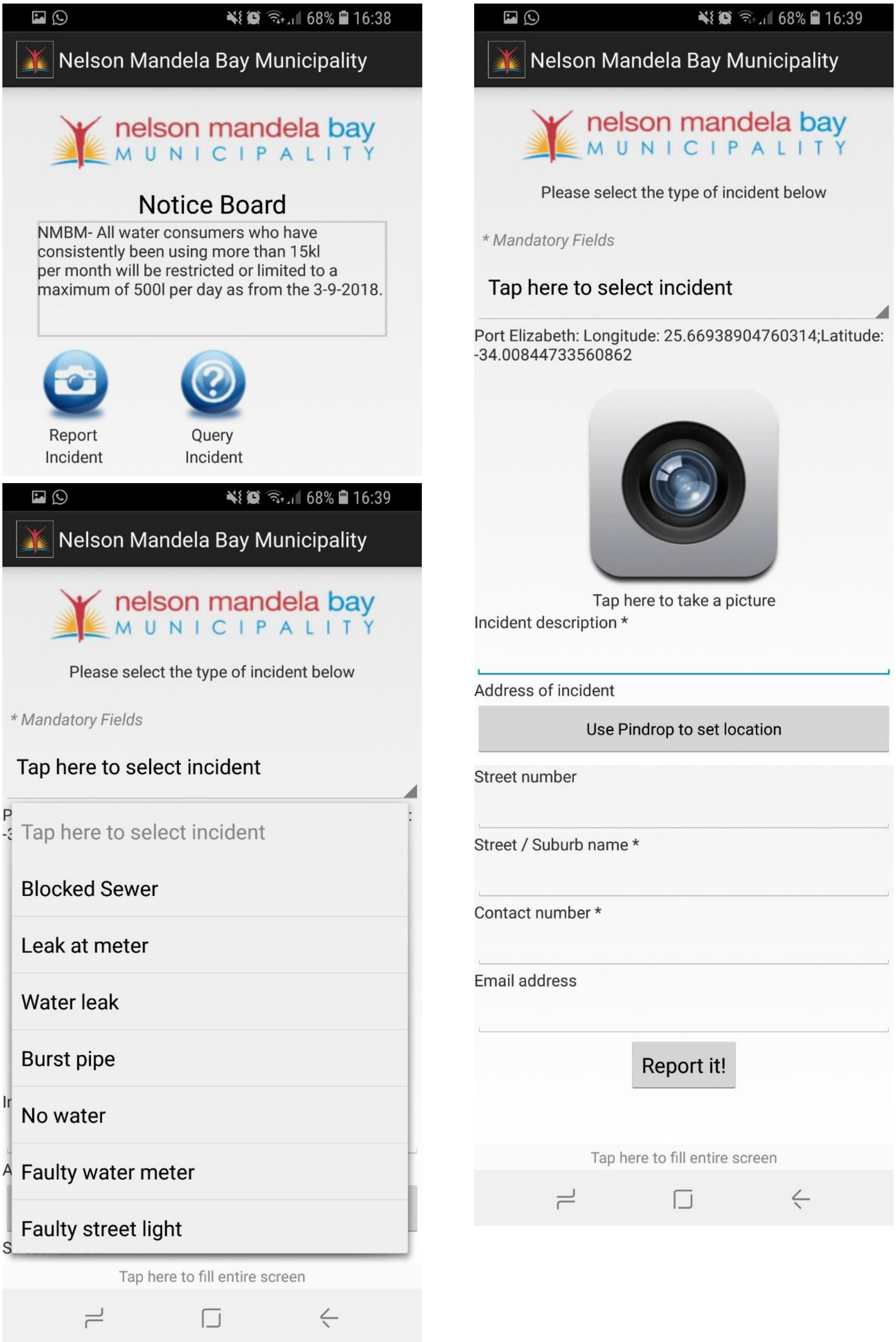


Figure 3-8: Screenshots of the NMBM Mobile Application.

The evaluation of extant crowdsensing systems for water resource monitoring revealed eight design guidelines (Table 3-4) that provide guidance for developing a crowdsensing system. The NMBM mobile application was evaluated as an extant crowdsensing system using two sets of criteria. Firstly, in terms of the designed guidelines from other crowdsensing systems for service delivery (Table 3-5) and secondly according to its adherence to the Key Success Factors and Guidelines for Crowdsensing Projects (Table 3-3).

The results of the evaluation of design guidelines (Table 3-5) revealed that the NMBM app only has three of the eight guidelines (R1, R3 and R8). The results of the evaluation show that the NMBM app has several shortcomings in allowing the user to interact with other users, view and add to other reports, as well as take on more complex tasks.

DESIGN GUIDELINES		NMBM APP
D1	Defined measures for phenomena accompanied by an image, textual data and location of PoI.	✓
D2	An expert role for users to make more complex measurements.	
D3	Progress updates available for users.	✓
D4	Tagging for users to communicate tasks to other users.	
D5	Allow users to explore reports and add information.	
D6	Timely and reliable alerts for issues close to the user's location.	
D7	Geo-located group discussion features for awareness.	
D8	Compulsory user registration to increase the reliability of the reports.	✓

Table 3-5: Evaluation of NMBM App using Design Guidelines for Crowdsensing Systems.

The second evaluation of the key success factors and guidelines was done according to the phases of a crowdsensing process (Table 3-6). However, this section only reports on the factors and guidelines in the Project Initiation phase. The evaluation based on the Data Sensing and Gathering and Data Analysis phases are reported on in Chapter 5.

KEY SUCCESS FACTOR		GUIDELINES		NMBM APP
K1	Budget constraints	G1	Development of a solid economic model	✓
		G2	Identify non-monetary rewards	
K2	User motivation	G3	Keep target audience capacity in mind	✓
		G4	Communicate benefits to prospective participants	✓
		G5	Provide appropriate rewards	
		G6	Incentive mechanisms must be adaptable to increasing demands	
		G7	Reduce the complexity of the data collection protocols	✓
K3	Recruitment of participants	G8	Maintain the minimum number of participants	
		G9	Analyse variables	
K4	User mobility	G10	Assess variability of interest in different regions	✓
		G11	Generate density map	✓

Table 3-6: Evaluation of NMBM App against Guidelines in the Project Initiation Phase.

The hotline is funded by NMBM and all the staff that work on the project are NMBM staff. The project does not use any form of rewards to incentivise citizens to submit water issues thus the citizens are expected to make data submissions for the citizen's own benefit and the benefit of their community. The NMBM has simple data collection protocols that do not require the citizen to input a lot of data to the mobile application. However, the NMBM app is a native app that requires the citizen to have the app to be installed on their mobile device in order to make data submissions which may be considered a nuisance by citizens. The NMBM staff responsible for the data can generate density maps to assess the variability of interest in different regions but the citizens are not privy to any information on data submissions excluding their own.

3.6 Conclusions

Crowdsensing contains several key elements of a smart community, since it involves both technology and engagement of people, and can be used to improve the quality of living for the people in a community. Crowdsensing can alleviate the three identified barriers to smart communities (technology learning curve, scalability and cost of intelligence) by using citizens' mobile devices as the technology required to transform their lives. There are several challenges that project coordinators face in crowdsensing projects such as the motivation of users, managing heterogeneous data and providing data analytics for the large amounts of data coming into the crowdsensing platform. The literature review on the challenges of crowdsensing led to the development of a Challenge Framework for Crowdsensing. Therefore, the first research question ***RQ1:*** *What are the problems faced by citizens and water service providers regarding crowdsensing and water resource monitoring as identified by literature and within a real-world context?* has been partially answered based on the literature review and development of the Challenge Framework for Crowdsensing.

Three phases of the crowdsensing process were identified in literature that can assist coordinators of crowdsensing projects in structuring the projects. The three phases are 1) Project initiation; 2) Data sensing and gathering and; 3) Data analytics (Section 3.4.1.1). The outputs to the Project Initiation phase are a task list, recruitment and incentive policies, crowdsensing system and list of participants. Pre-processed data is the only output from the Data Sensing and Gathering stage while the output of the Data Analysis phase is the feedback that is given to the users of the crowdsensing system. There are eight key success factors that should be considered in each phase of the crowdsensing process according to literature (Section 3.4.1.4). The key success factors and the phase they pertain to are:

- Project Initiation – recruitment of participants, user motivation, budget constraints and user mobility.
- Data Sensing and Gathering – data quality, data delivery, security and privacy and resource limitations.

- Data Analytics – analysis of data, heterogeneous data and data validation.

The following research question has therefore been answered in this chapter from a theoretical perspective:

> **RQ2:** What are the common activities and key success factors for crowdsensing projects?

In answering RQ2, a Crowdsensing Reference Framework was proposed (Figure 3-5). The reference framework consists of the crowdsensing process and its related key success factors and Guidelines for Crowdsensing Projects (Table 3-3). During the project initiation phase, specifically the tasking activity, the project coordinators must elicit requirements of the crowdsensing system based on the tasks that the users of the system are expected to perform (Section 3.4.1.4). The Design Guidelines for Crowdsensing Systems (Table 3-4) should be used to inform the design of a crowdsensing system. Thus, the fourth research question ***RQ4:*** *What design guidelines can be used for crowdsensing for water resource monitoring to create a smart community?* has been partially answered in this chapter. Figure 3-9 illustrates the first version of the main contribution of this study, a Crowdsensing Method for Water Resource Monitoring in Smart Communities (also referred to as the Crowdsensing Method).

The extant system analysis (Section 3.5) revealed that project coordinators mainly focus on developing a technical solution that allows citizens to report water issues. The studies identified through the system analysis make no mention of the social or program components of their crowdsensing design. The results of the review show that the coordinators of crowdsensing projects do not adequately investigate the social design considerations identified in Section 1.5.1. The success of crowdsensing, and therefore the development of a smart community, lie in the continuous engagement of citizens and the citizens' willingness to collaborate and cooperate with the project coordinators. Failure in understanding the social systems that exist around the area of context and real-world problem, poses a risk to the success of the project and can lead to the failure to meet the minimum number of participants to keep the crowdsensing system functional. The next chapter reports on an investigation into citizens' perceptions of crowdsensing for water resource monitoring in order to develop an understanding of the social systems around crowdsensing for water resource monitoring.

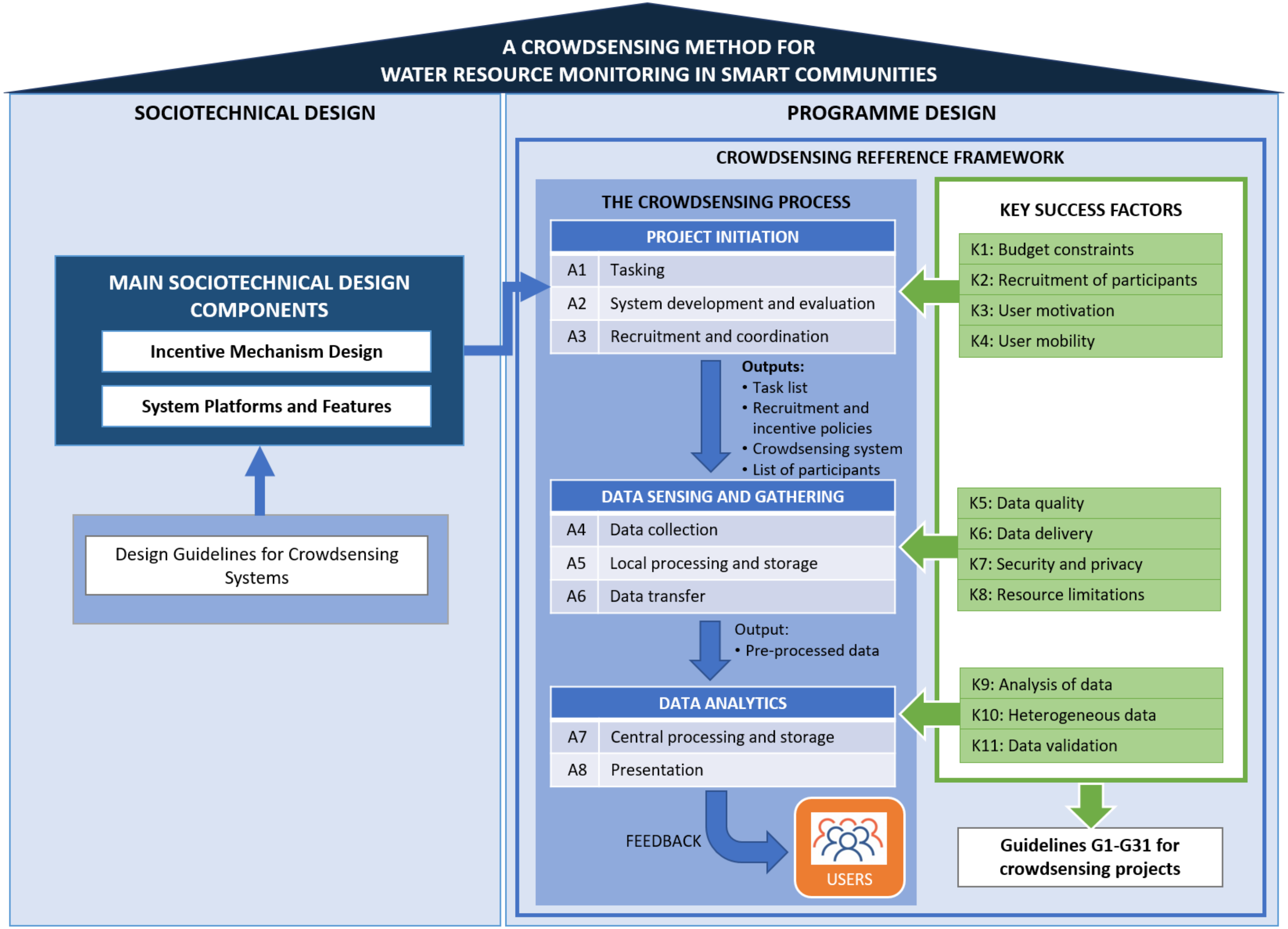


Figure 3-9: A Crowdsensing Method for Water Resource Monitoring in Smart Communities Version 1 (Author's Own Construct).

4 CITIZENS' PERCEPTIONS OF CROWDSENSING FOR WATER RESOURCE MONITORING[1]

4.1 Introduction

The previous chapter examined literature on the domain to expand the understanding of the problem. Chapters 1 and 3 provided an understanding of the real-world problematic situation and the area of concern while Chapter 2 explored the conceptual framing (F) and methods of inquiry (M) of the research study. This chapter reports on the research activities of engaged scholarship by investigating the citizens' perceptions of P and A to make contributions to P and A. This chapter will thus address the following research questions (Section 1.4):

> **RQ1:** What are the problems faced by citizens and water service providers regarding crowdsensing and water resource monitoring as identified by literature and within a real-world context?
>
> **RQ3:** What sociotechnical design can be used for a crowdsensing system that recruits and incentivises participants to collect data continuously for water resource monitoring?
>
> **RQ4:** What design guidelines can be used for crowdsensing for water resource monitoring to create a smart community?

The main problems in crowdsensing projects relate to the recruitment and motivation of participants (Section 4.2). A survey was therefore conducted to elicit the perceptions of citizens toward crowdsensing and water resource monitoring (Section 4.3). After analysing the results of the survey several guidelines are proposed for citizen participation in crowdsensing for water resource monitoring (Section 4.4). These guidelines are added to the Crowdsensing Method and an updated version (Version 2) is proposed and several conclusions are made (Section 4.5).

---

[1] The literature and survey results discussed in this chapter were published as a full double-blind peer-reviewed conference paper at the 2018 Annual Conference of the South African Institute of Computer Scientists and Information Technologists (SAICSIT). Clara Mloza-Banda and Brenda Scholtz. 2018. Crowdsensing for Successful Water Resource Monitoring: An Analysis of Citizens' Intentions and Motivations. In SAICSIT '18, Port Elizabeth, South Africa, September 26-28, 2018. (**Appendix C**).

This chapter presents several deliverables that are theoretical and practical contributions to P and A:

- Conceptual Model for Submission of Water Data using TPB (Figure 4-15).
- Framework of Motivational Factors for Crowdsensing (Figure 4-14).
- Guidelines for Citizen Participation in Crowdsensing for Water Resource Monitoring (Section 4.4.4).
- A Crowdsensing Method for Water Resource Monitoring in Smart Communities Version 2 (Figure 4-17).

The full chapter structure is illustrated in Figure 4-1.

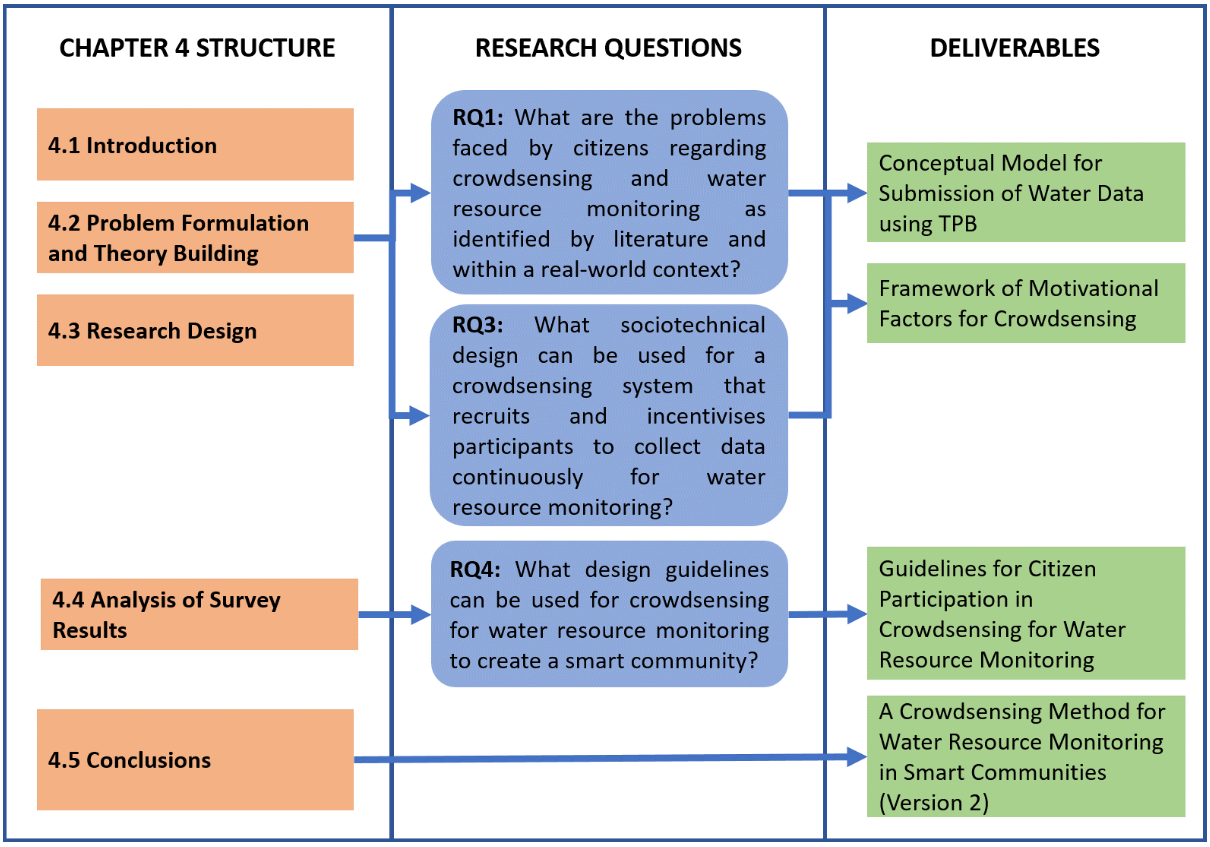


Figure 4-1: Structure and Deliverables for Chapter 4.

4.2 Problem Formulation and Theory Building

Jaimes *et al*. (2015) emphasise that the success or failure of a crowdsensing scheme depends on the number of citizens willing to participate in the data collection process to guarantee coverage and data quality. However, very few researchers investigate the potential profile of participants for their crowdsensing projects and the social systems around the crowdsensing systems. It is pertinent that project coordinators understand potential participant profiles to design crowdsensing systems of good service quality that use appropriate incentive mechanisms to achieve adequate user participation. The knowledge and understanding of the profile of potential participants of a crowdsensing system can provide guidance and recommendations for project coordination and data collection protocols, which can in turn improve the success of crowdsensing. While Chapter 3 identified crowdsensing problems in literature (Figure 3-5), this chapter identifies problems faced by citizens in a real-world context.

The main problems identified are (Section 3.4.1.2):

- Difficulty in the recruitment of adequate participants to keep a crowdsensing system functional.
- Motivating a large number of citizens to provide large quantities of data.

In line with the Problem Formulation activity of the Engaged Scholarship methodology (Figure 4-2), and in order to further understand the problems identified above, the researcher defined two supplementary research questions related to **RQ1:** *"What are the problems faced by citizens and water service providers regarding crowdsensing and water resource monitoring as identified by literature and within a real-world context?"*. These two additional questions are:

> **RQ1.1:** How do past behaviour, behavioural attitude, subjective norms and perceived behavioural control influence the intention to participate in crowdsensing for water resource monitoring?
>
> **RQ1.2**: What are the factors that affect the citizens' motivation to participate in crowdsensing for water resource monitoring?

4.2.1 Crowdsensing as a Behaviour

This study is designed as an intervention to integrate water resource monitoring as the norm in smart communities. Crowdsensing requires continuous data collection to be successful, and the continuous submission of data by participants can be defined as a behaviour. For this reason, this study uses the TPB to investigate and understand the continuous submission of water data (as participants' behaviour).

TPB is a commonly used theory first developed by Icek Ajzen (Ajzen, 1991). The TPB states that "behavioural intention is the key predictor of behaviour, with *attitudes*, *norms* and *perceived behavioural control* as the most important antecedents of a person's intention to perform the behaviour" (Fishbein & Ajzen, 2010; Ajzen, 1991). TPB also acknowledges actual behavioural control as mediating the effect of intention on behaviour (Francis *et al*. 2004; Fishbein & Ajzen 2010). There are three primary social psychological constructs associated with the TPB namely: behavioural attitude, subjective norms and behavioural control (Figure 4-3).

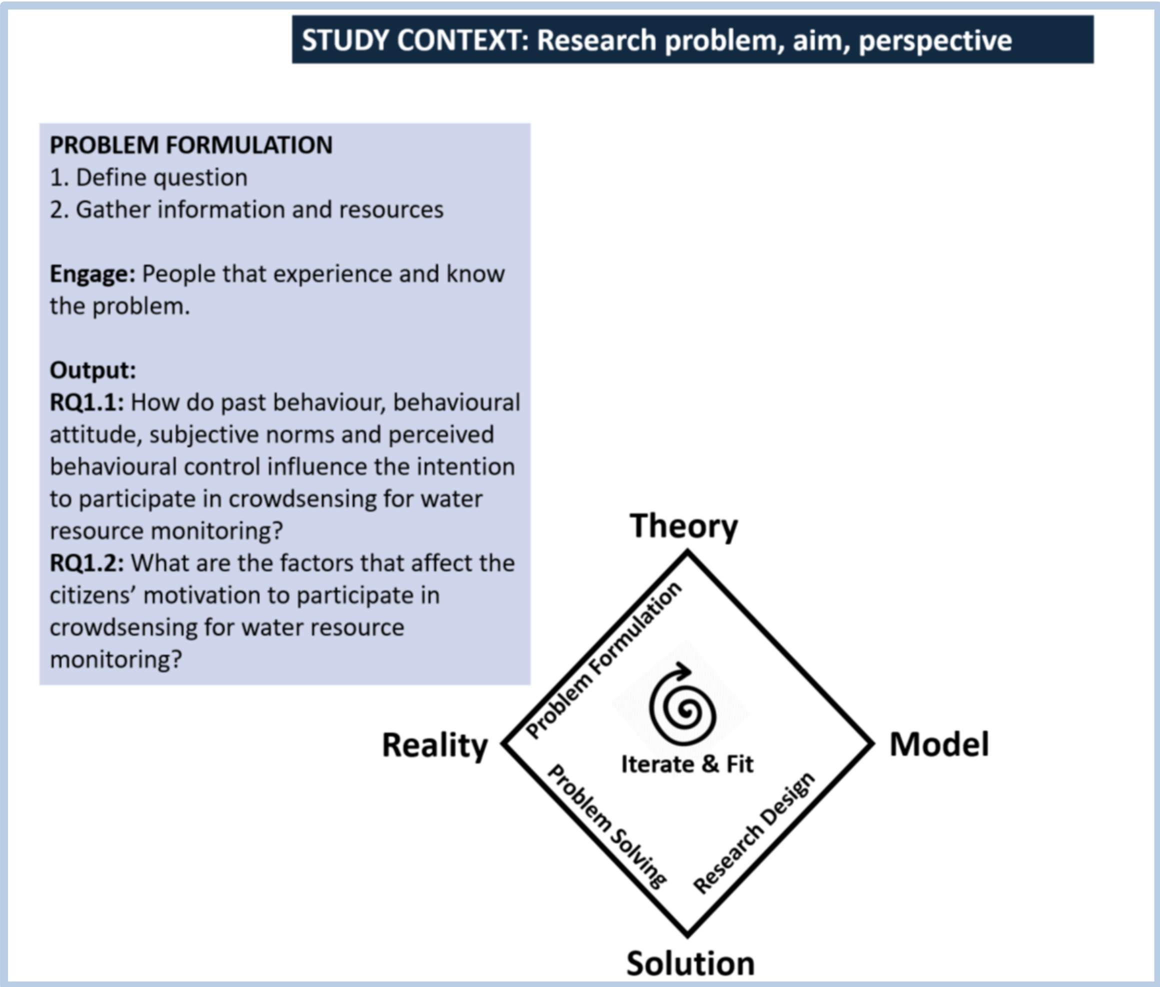


Figure 4-2: Problem Formulation of Citizens' Perceptions of Crowdsensing for Water Resource Monitoring (Iterations 1 and 2).

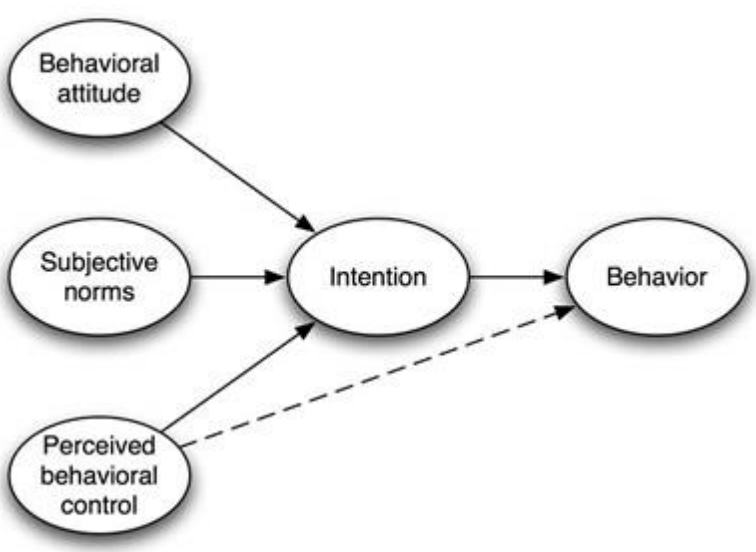


Figure 4-3:Theory of Planned Behaviour (Fishbein & Ajzen, 2010).

4.2.1.1 Behavioural Attitude

An attitude is a certain way of thinking or feeling about something (Francis *et al*. 2004; Fishbein & Ajzen 2010). Behavioural attitude refers to a person's evaluation of the behaviour which includes beliefs about the consequences, as well as their positive and negative judgements about performing the behaviour (Francis *et al*. 2004; Fishbein & Ajzen 2010). Typically, the more positive an individual's attitude is toward a certain behaviour, the higher the chance they will engage in the behaviour (Fishbein & Ajzen, 2010).

4.2.1.2 Subjective Norms

Subjective norms refer to a person's estimation of the social pressure to perform the target behaviour or not (Francis *et al*. 2004; Fishbein & Ajzen 2010). Subjective norms are the beliefs about how other people expect the person to behave and how the person feels about their expectation (Francis *et al.*, 2004). Subjective norms can be through what an individual sees or thinks others are doing (descriptive norms), or through pressure brought on by the expectations of others (injunctive norms).

4.2.1.3 Behavioural Control

Perceived behavioural control explores how much control a person has over their own behaviour and their confidence in being able to perform the behaviour (Francis *et al*. 2004; Fishbein & Ajzen 2010). This construct allows an exploration into the internal and situational factors that can facilitate or inhibit performing the behaviour (Francis *et al.*, 2004). Investigating perceived behavioural control can assess the person's self-efficacy by asking how difficult they would find it to perform the behaviour and the confidence that they would be able to accomplish it. On the other hand, actual behavioural control is whether an individual can actually perform the behaviour (Francis *et al*. 2004; Fishbein & Ajzen 2010). Actual behavioural control is determined by an individual's abilities, skills and external factors that can act as barriers to the indulgence of the behaviour (Fishbein & Ajzen, 2010).

4.2.1.4 Application of TPB

TPB can assist in developing the sociotechnical design for the Crowdsensing Method in the following ways:

- Studies into the **behavioural attitudes** towards a certain behaviour can allow the researcher to discover citizens' perceptions into how they feel about the crowdsensing project.
- Studies into the **subjective norms** can develop insights into how social norms can contribute to the sociotechnical design for the Crowdsensing Method.

- Studies into **behavioural control** can help highlight the *motivations* that could lead to citizens' continuous participation. Furthermore, studies into behavioural control can lead to the discovery of *barriers and opportunities* that exist in the crowdsensing process.

TPB is used in the study to investigate citizens' intentions to participate in water resource monitoring and to determine the influence of their attitudes, norms and perceived behavioural control on their intentions. Past behaviour is added as a fourth construct to investigate the effect of past behaviour on current intention and future behaviour. The following hypotheses were proposed in the model (Figure 4-4):

$\boldsymbol{H_{1.1}}$: *An individual's intention to continuously submit water data is influenced by their past behaviour.*

$\boldsymbol{H_{1.2}}$: *An individual's intention to continuously submit water data is influenced by their behavioural attitude.*

$\boldsymbol{H_{1.3}}$: *An individual's intention to continuously submit water data is influenced by their subjective norms towards the behaviour.*

$\boldsymbol{H_{1.4}}$: *An individual's intention to continuously submit water data is influenced by their perceived behavioural control over the behaviour.*

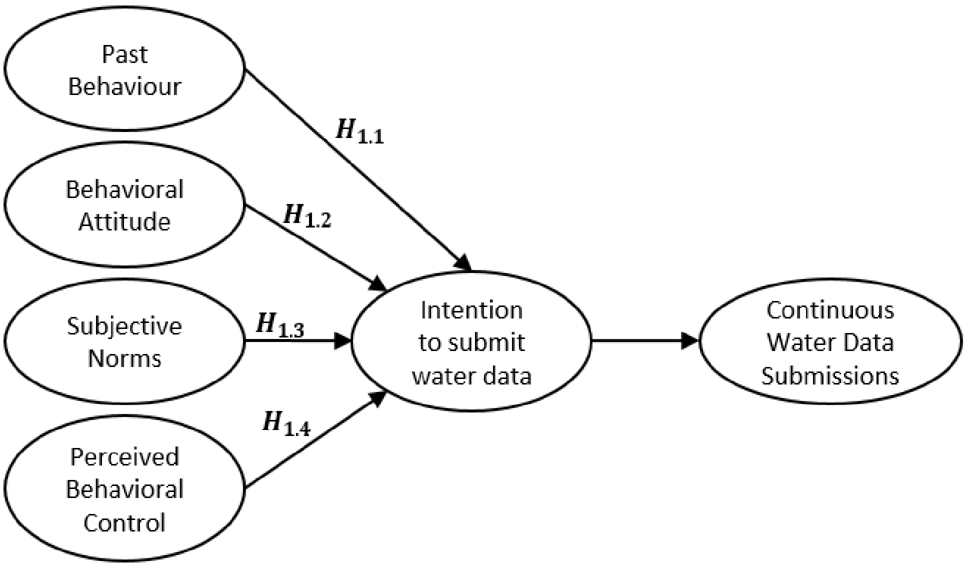


Figure 4-4: Conceptual Model for Submissions of Water Data using TPB (Author's Own Construct).

The appropriate application of TPB has shown to predict the intention to perform a behaviour (Martin *et al.*, 2017). However, having an intention does not confirm the engagement of a behaviour. A researcher seeking behaviour change needs to discover what emotional, social or cognitive forces activate the behaviour (Joachim *et al.*, 2015). Those forces, whether internal or external, must be able to induce an individual's motivation and stimulate their desire and energy to be continually interested and committed to performing a given behaviour.

4.2.2 Motivational Factors and Incentives for Crowdsensing

A significant key success factor for crowdsensing projects is ensuring user motivation and considering the design of incentive mechanisms (Table 3-3). Guidelines G10 and G13 advise on identifying appropriate rewards, preferably non-monetary for long-term sustainability of the project. Citizens participating in crowdsensing consume their own resources such as computing and battery power (Yang *et al.*, 2015a). In addition, the citizens expose themselves to potential privacy threats by sharing their sensed data with location tags. Yang *et al.* (2015a, p.1733) state *a user would not be interested in participating in crowdsensing, unless it receives a satisfying reward to compensate its resource consumption and potential privacy breach.* Thus, it is important to develop robust incentive mechanisms as crowdsensing systems rely on adequate user participation to achieve good service quality (Jaimes, Vergara-Laurens & Raij, 2015).

The development of a crowdsensing system requires the investigation of citizen's motivations to design incentive mechanisms that allow the continuous collection of data (Figure 4-5). Brewer, Hollingsworth and Campbell (1995) describe an incentive as a reward, reinforcement or external stimulus that motivates an individual to perform a behaviour. The *Merriam-Webster Online dictionary* (2018) defines a mechanism as a "*technique for achieving a result*". In this regard, an incentive mechanism can be described as a technique for providing incentives to motivate behaviour. An example of an incentive mechanism is using gamification to reward a crowdsensing participant for completing a task.

4.2.2.1 Motivational Factors for Citizen Participation in Citizen Science

The recruitment, motivation and retention of participants is always a significant challenge for any citizen science project (Rotman *et al.*, 2014; Minkman, 2015). Minkman (2015) provides a theoretical framework of motivational factors and barriers affecting citizen intention to participate in a citizen science project. The framework describes over 40 citizen motivations and barriers to participating in citizen science, which is relevant to crowdsensing as crowdsensing is a form of citizen science (Section 2.3). Table 4-1 shows a summarised version of the framework that Minkman (2015) uses to survey the motivations and barriers in the context of a specific citizen science project.

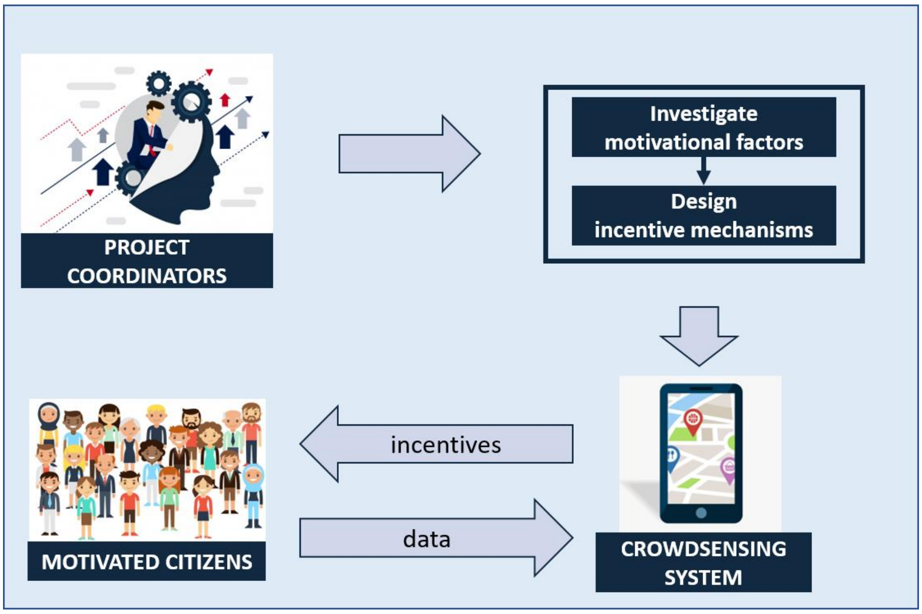


Figure 4-5: Relationship between Motivational Factors and Incentives in Crowdsensing (Author's Own Construct).

INITIAL MOTIVATIONAL FACTORS FOR PARTICIPATION IN CITIZEN SCIENCE		
• Financial compensation	• Learn new skills	• Being able to act independently
• Direct feedback	• Combine existing skills	• It is fun
• Increase of chance on a job	• Learn new things	• To kill time
• Increase my capacity	• Discover things	• I like this project
• Teach others	• Do scientific research	• Beautiful environment
• Help others	• Gain new social contacts	• It matches my hobbies
• Do something with friends	• Being part of a community	• I feel responsible to do so
• Contribute to science	• Contribute to conservation	• Improve my reputation

DE-MOTIVATIONAL FACTORS TO PARTICIPATE IN CITIZEN SCIENCE	
• Data not being used	• Insufficient time
• Not willing to collect for policy needs	• Volunteer physically unable
• Lack of confidence.	• Unappealing recording process
• Power gap between volunteer and coordinators	

Table 4-1: Summarised Framework of Motivational Factors for Participation in Citizen Science (Minkman, 2015).

Minkman (2015) describes motivational factors that motivate citizens to make the first step toward participation in citizen science. However, crowdsensing requires continuous data collection to be successful. The success of crowdsensing, and citizen science, relies on the long-term participation of the volunteers (Rotman *et al.*, 2014). Rotman *et al.* (2014) suggest five motivational factors to encourage long-term participation:

- **Acknowledgement and Attribution:** Volunteers would like to be recognised and attributed to the work they perform and see that the work brings value to the area of concern.
- **Policy and Activism:** Volunteers would want to see the impact of their work on the government, institutions or community depending on the project objectives.
- **Mentorship:** Other volunteers may seek deeper involvement in the project and to move up the citizen science pyramid (Section 2.3.2).
- **Common goals:** A volunteer may remain in a project long-term because it aligns with their common goals.
- **Trust:** A volunteer may maintain trust in the process, the usage of their data, value, leadership roles.

4.2.2.2 Incentive Theory for Participatory Crowdsourcing

Citizens may participate in crowdsensing for various reasons ranging from internal desires and a wish to gain external rewards. Bosha, Cilliers and Flowerday (2017) propose an incentive theory for a participatory crowdsourcing project in a developing country. The theory extends the Incentive Theory which is a motivational theory that states that motivation to perform tasks is dependent on both extrinsic and intrinsic incentives (Cherry, 2018). **Intrinsic incentives** provide the internal feeling that comes with accomplishing an activity or task (Massung *et al.*, 2013). Intrinsic incentives include satisfaction, enjoyment and interest. Monetary and tangible non-monetary incentives can serve as **extrinsic incentives** to motivate citizens to contribute data (Brewer, Hollingsworth & Campbell, 1995; Bosha, Cilliers & Flowerday, 2017). Bosha, Cilliers and Flowerday (2017) extend the Incentive Theory by adding an extra type of incentive, **internalised-extrinsic incentives** to encourage the continuous collection of data. Internalised-extrinsic incentives motivate citizens to make data contributions to gain or improve their standing in their community, then teach and influence other members of the community (Gassenheimer, Siguaw & Hunter, 2013).

Rewards, such as money and points (gamification), are regarded as powerful motivators when the sensing activity does not bring any immediate benefits to the participants (Jaimes, Vergara-Laurens & Raij, 2015). On the other hand, non-monetary incentives allow citizens to volunteer to participate, preferable in projects where monetary rewards might not be possible. In this regard, this research study will only explore non-monetary incentives to fit the context of a developing country.

4.2.2.3 Categorising Incentives

Incentives can be classified based on the types of stimuli that encourage user participation (Jaimes, Vergara-Laurens & Raij, 2015). Jaimes, Vergara-Laurens and Raij (2015) conducted a survey on crowdsensing incentive mechanisms documented in published articles and conference papers and found that collective, intrinsic, social interaction and self-benefit incentives were the most significant factors affecting the level of participation in crowdsensing projects. Rotman *et al.* (2014) suggest self-efficacy as a significant category of incentives. These five categories of incentives have been found to influence the level of participation in crowdsensing projects (Figure 4-6).

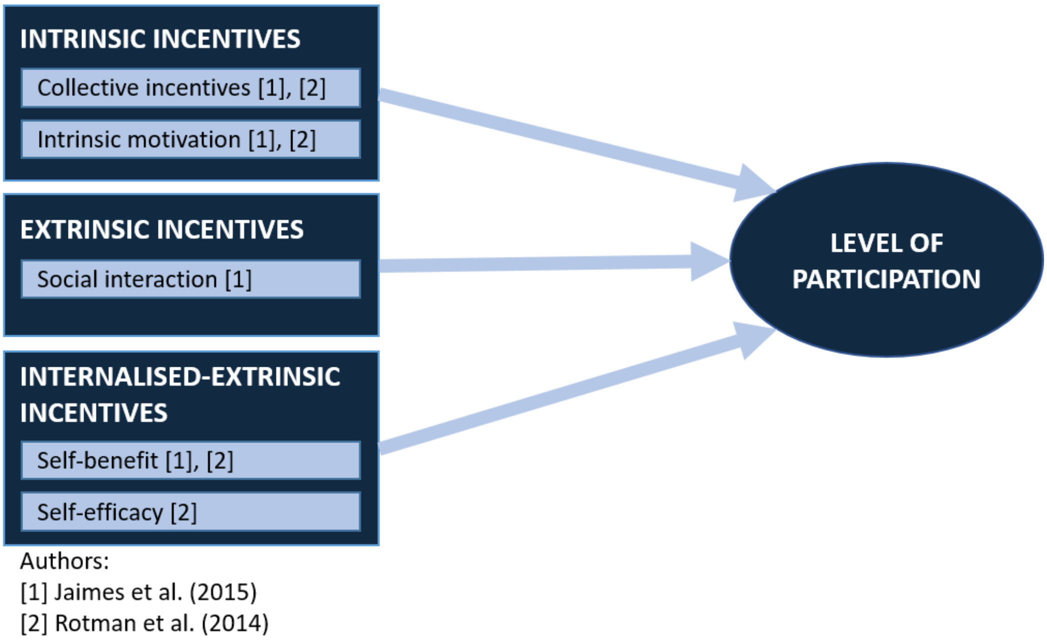


Figure 4-6: Categories of Incentives based on the Incentive Theory for Participatory Crowdsourcing (Author's Own Construct).

Collective incentives encourage working together for a common good. Such incentives may motivate citizens interested in bettering society for the greater good, social responsibility and/or conservation (Rotman *et al.*, 2014; Jaimes, Vergara-Laurens & Raij, 2015). For example, monitoring pollution benefits the community and not just the participants (Jaimes, Vergara-Laurens & Raij, 2015). However, Simon *et al*. (1998) state that collecting data to better the community might not be enough to motivate citizens to participate in crowdsensing. Thus, it is necessary for researchers to investigate other sources of motivation for the design of incentive mechanisms.

Users can be involved in crowdsensing projects based on their own **intrinsic motivation** (Wiggins, 2011). Intrinsic incentives allow participants to volunteer due to their inherent interest, enjoyment or leisure. EBird focuses on a target group of bird watchers that contribute data about bird distribution and abundance (Sullivan *et al.*, 2009). The participants of eBird contribute to the database based on inherent interest, and have managed to attain two million observations per month (Nov, Arazy & Anderson, 2011). Tuite, Snavely and Tabing (2011) introduced PhotoCity, an online game that implores participants from all over the world to take photos at targeted locations for the purposes of large-scale, targeted data collection. Although the study only managed to secure a small number of participants (only 45), the incentive design drove the participants to contribute thousands of highly relevant photos each. An important component of the incentive design was that participants gained more points for contributing photos of a less-photographed area.

Self-benefit incentives (also known as self-interest or self-promotion) allow participants of the crowdsensing scheme to receive gratification for their data contributions (Jaimes, Vergara-Laurens & Raij, 2015). Gratification can be in the form of self-promotion and furthering the participants' opportunities, as well as receiving feedback from the system only after making a data contribution. Tomasic *et al*. (2014) recommend the quid pro quo (QPQ) approach to be effective in maximising data contributions. With the QPQ approach, users can only access the system if they contribute data, and is ideal for highly useful crowdsensing systems. Rotman *et al.* (2014) propose **self-efficacy** as a category of incentives where citizens participate for the purposes of generating scientific knowledge or being part of scientific work (citizen science). In addition, Han *et al*. (2011) and Jaimes *et al*. (2015) report that participants are motivated by **social interaction** such as feedback from their peers and reinforcing others information. Crowdsensing systems may use technologies such as social networks, blogs and SMS to allow participants to interact with each other. Social networks are also used for recruitment and participation. Table 4-2 provides several examples of crowdsensing and the incentives they utilise for user participation.

SYSTEM	DESIRED OUTCOME	RESEARCHERS	INCENTIVE CATEGORY
The Mahali Project	Space weather monitoring	Pankratius *et al.* (2014)	Self-efficacy Collective incentives
CrowdHydrology	Hydrologic measurements	Lowry and Fienen (2013)	
Ebird	Bird distribution and abundance	Wiggins (2011)	Self-efficacy Intrinsic motivation
NoiseTube	Noise maps	D'Hondt, Stevens and Jacobs (2013)	Collective incentives Social interaction
Public Safety Project	Public safety reports	Bosha (2015)	Collective incentives
NMBM App	Service delivery reports	NMBM (2018)	Collective incentives Self-benefit
Tracking the Wild	Capture and share wildlife sightings	Tracking the Wild (2013)	Collective incentives Social interaction
CrowdAnswer	Question-answering	Zhou *et al*. (2013)	Social interaction
Disease Surveillance Project	Disease surveillance	Haddawy (2015)	Collective incentives Self-benefit
PetaJakarta.org	Acquire flood-related data in real-time	Turpin and Holderness (2015)	Social interaction
Location tracker for elderly in a smart city	Track and monitor the elderly	Shien and Singh (2017)	Self-benefit

Table 4-2: Incentive Categories used by Crowdsensing Systems.

4.2.2.4 Conceptual Model of Motivation Factors for Crowdsensing

Based on the discussed categories of incentives suggested by Jaimes, Vergara-Laurens and Raij (2015) and Rotman *et al.* (2014), an extended framework for motivational factors and barriers for crowdsensing was designed by the researcher (Figure 4-7). This framework extends the framework presented by Minkman (2015) to include motivational factors that encourage long-term participation as stated by Rotman *et al.* (2014). In addition, the extended framework groups the motivational factors based on the incentive category they can influence. One motivational factor from the original framework (Table 4-1), financial compensation, was omitted from the extended framework as it is not relevant to the purposes of this study which only explores non-monetary incentives. Three more motivational factors were added to the framework based on a research study into motivations for participating in citizen science performed by Geoghegan *et al*. (2016).

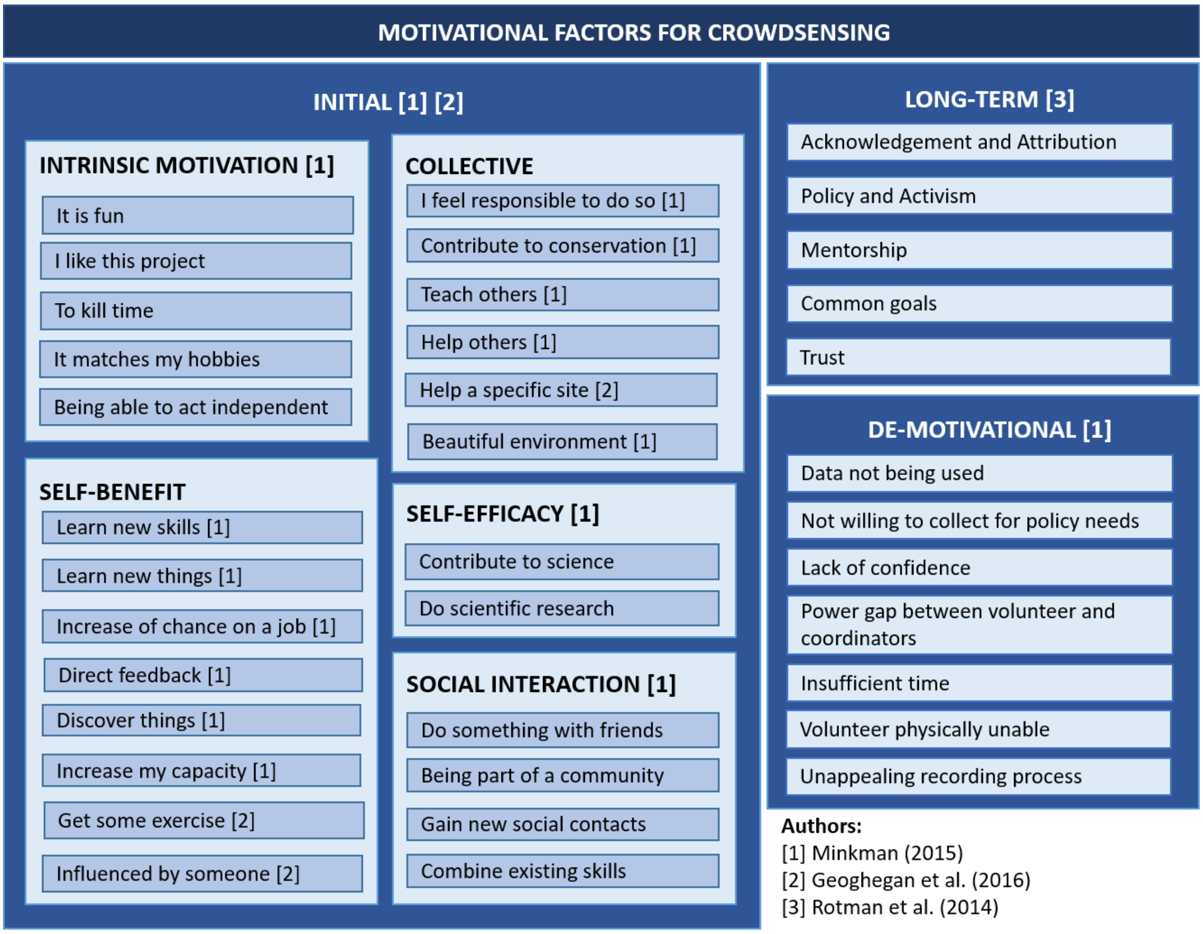


Figure 4-7: Framework of Motivational Factors for Crowdsensing (Author's Own Construct).

4.2.3 Summary of Problem Formulation and Theory Building

The two supplementary research questions (Figure 4-2) initiate two iterations of the engaged scholarship research activities (Figure 4-8). The first iteration addresses the research question

RQ1.1: *"How do past behaviour, behavioural attitude, subjective norms and perceived behavioural control influence the intention to participate in crowdsensing for water resource monitoring?"* TPB is the theory used to develop the Conceptual Model for Submissions of Water Data (Figure 4-4), which will guide the data collection process required to address the research question **RQ1.1**. The second iteration addresses the research question **RQ1.2**: *"What are the factors that affect the citizens' motivation to participate in crowdsensing for water resource monitoring?"* Minkman's (2015) framework of motivational factors for participation in citizen science (Table 4-1) and the Incentive Theory for Participatory Crowdsourcing (Bosha, Cilliers & Flowerday, 2017) guided the development of a conceptual model to address this research question. The Framework of Motivational Factors for Crowdsensing (Figure 4-7) will guide the data collection process for Iteration 2.

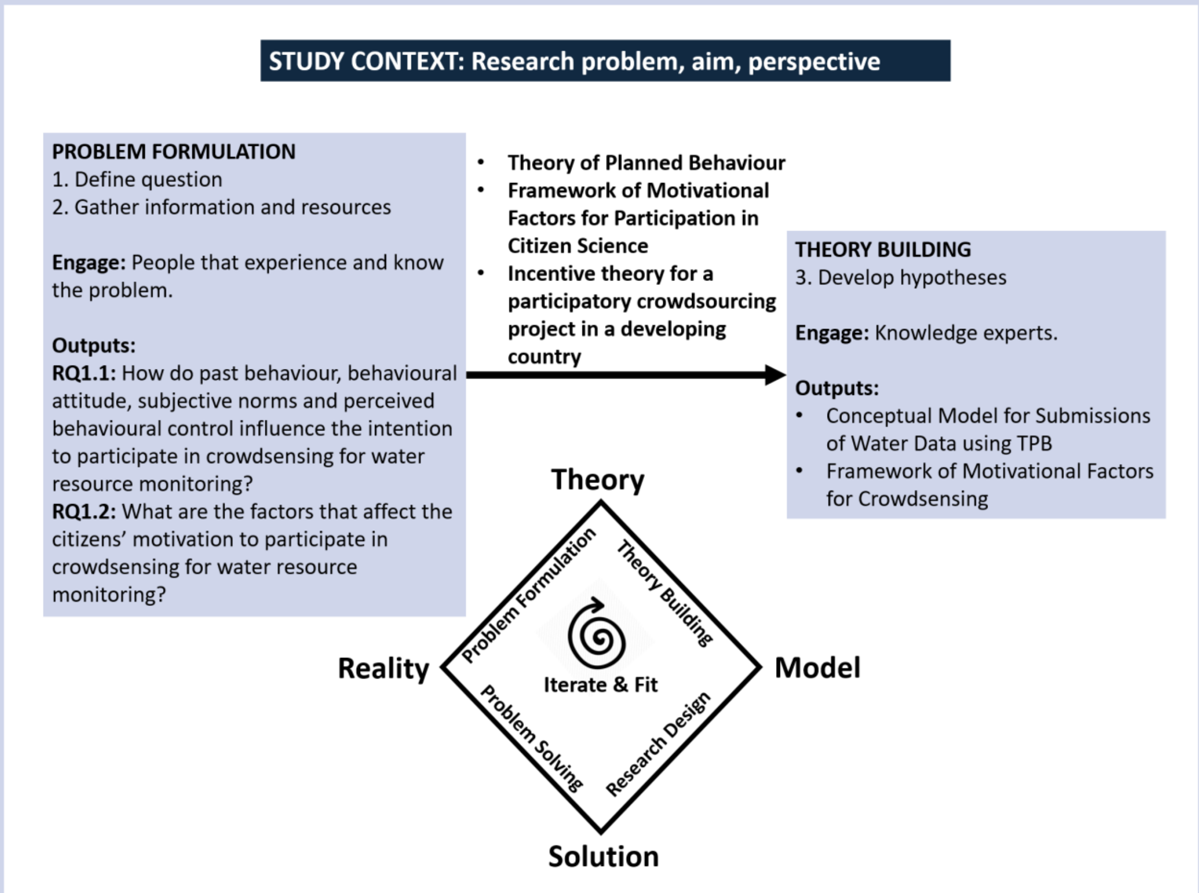


Figure 4-8: Problem Formulation and Theory Building for Iterations 1 and 2.

4.3 Research Design

The survey method, using an online questionnaire, was chosen as the empirical method for the collection of quantitative and qualitative data from citizens on their views toward water resource monitoring. The survey aimed to answer the two subsidiary research questions RQ1.1 and RQ1.2 which fuel Iterations 1 and 2 respectively (Figure 4-9).

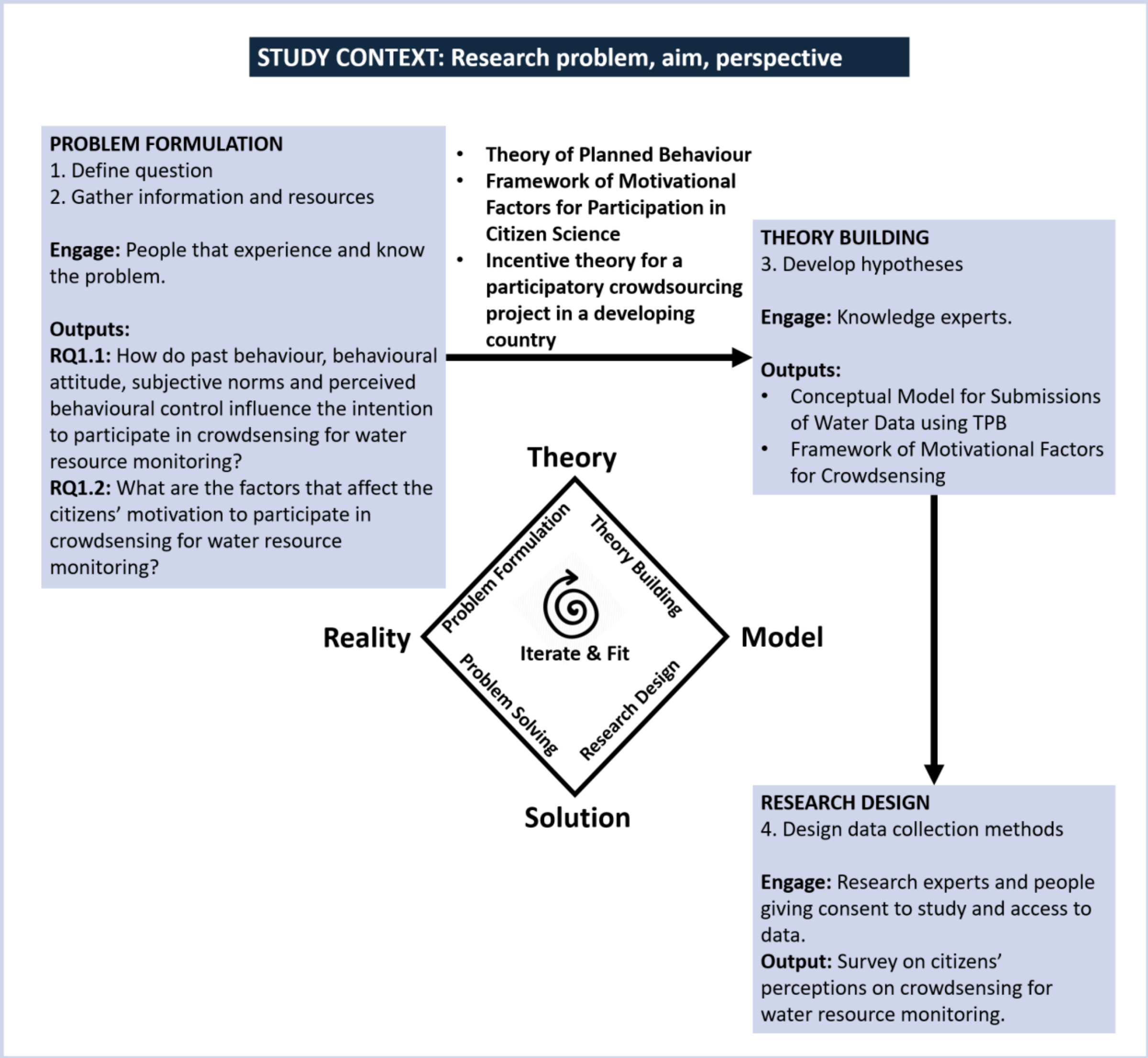


Figure 4-9: Research Design for Iterations 1 and 2 of Engaged Scholarship Research Activities.

An online questionnaire was used to obtain a cross-cultural sample of respondents and to achieve a large sample size. The questionnaire had four sections (Figure 4-10):

- **Introduction:** The introduction section introduces the survey as a survey aimed at understanding the perceptions of citizens regarding contributing data on their water resources and water pollution such as littering, dirty water, water leaks, burst pipes and tanks. The introduction also stated that only persons over the age of 18 could take part in the study. The respondents were informed that their responses are voluntary and will be confidential as they will be anonymous. The introduction concludes with a mandatory option for respondents to give their consent to voluntarily participate in the study.
- **Demographics:** The demographics section collected demographic information about the respondents, such as gender, age, level of education, employment status, residential information and their involvement in the water sector.

- **Intention to participate:** This section, aimed at addressing the first research question, was guided by the TPB (Ajzen, 1991) to understand citizens' intentions to participate in water resource monitoring. The questions in this section utilised a 5-point Likert scale, ranging from 1 to 5, where 1 represents a negative response and 5 represents a positive response.
- **Motivational and De-motivational Factors:** This section of the questionnaire was designed to answer the second research question related to factors that influence citizen's motivation to participate in crowdsensing for water resource monitoring. This section was guided by the Extended Framework of Motivational Factors for Crowdsensing (Figure 4-7) and the de-motivational and initial motivational factors from the framework were translated into closed and open-ended questions. The respondents were asked to select the three most important motivational factors and at least three de-motivational factors.

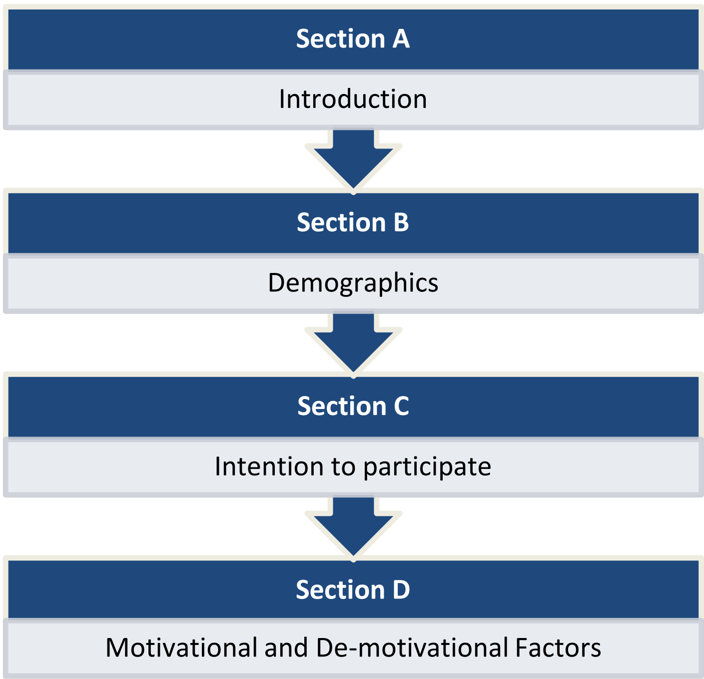


Figure 4-10: Survey Design.

4.3.1 Piloting the Questionnaire

A pilot study was carried out before deploying the questionnaire to identify issues with the instrument and find possible solutions. The researcher selected five respondents to pilot the questionnaire and comment on the items. The respondents were asked to comment on the following:

- Are any questions ambiguous or difficult to answer?
- Does the questionnaire feel too repetitive?

- Does it feel too long?
- Are there any annoying features of the wording or formatting?

Table 4-3 shows the issues identified by the respondents. The responses showed a consensus in the clarity and the ease in answering the questions. However, two respondents suggested splitting the questionnaire into smaller sections to make it seem less long. The responses led to minor changes in wording or formatting. The final questions in the questionnaire can be seen in Appendix B.

RESPONDENT	ISSUES	COMMENT
1	Clarify the questions on barriers, "based on the previous question" Certain questions can be skipped based on the previous answer, rectify.	Done
2	Remove "Student" from employment status as "Not employed" already exists.	Done
3	Divide the questions into more sections to make the questionnaire seem less long	Done
4	I felt the wording in the linear questions was a bit odd (e.g. I don't know if it's appropriate to use undesirable and desirable to describe reporting water.) It does feel a bit long, maybe if you split it into smaller sections?	Swapped for important/ unimportant
5	Change up the order of questions to make them more random. Clarify questions on barriers to make them more directed e.g. "Based on the number of barriers you submitted"	Done

Table 4-3: Results from Piloting the Questionnaire.

4.3.2 Profile of Respondents

To get respondents from all over the world, a link to the survey was posted on several websites including Poll-Pool.com, SurveySwap.io, App.SwapSurvey.com, SurveyCircle.com. In addition to this random sampling of participants, the link to the online questionnaire was distributed using the snowball sampling technique to expand the geographical scope of the study and access hidden populations that do not visit survey websites (Baltar & Brunet, 2012). Snowball sampling uses existing participants of the study to recruit their acquaintances who fit the eligibility criteria and can potentially contribute to the study. A link to the survey was sent to any citizens, social media influencers, researchers and government officials. Per the snowball sampling technique, all the people who were contacted were asked to spread the link to the questionnaire through their mailing lists and social network accounts (such as Facebook, Twitter and LinkedIn). The contacted persons were also asked to send a link to the survey to anyone they knew could meet the criteria (age limit of 18).

4.4 Analysis of Survey Results

In the five weeks that the survey was online, 123 responses were obtained, and 120 respondents completed the full questionnaire, representing an overall response rate of approximately 98%. The following sections presents the analysis of the survey results.

4.4.1 Survey Results from Demographics Section

A variety of descriptive statistics were calculated on the seven items of the Demographics section of the survey. The respondents were classified based on their age (Table 4-4), gender (Table 4-5), level of education (Table 4-6), employment status (Table 4-7), country of residence (Table 4-9), type of residential and work/school community (Table 4-8) and their involvement with the water sector or water resources (Table 4-10). Figure 4-11 summarises the distribution of respondents across demographics.

Over half of the respondents (57%) were between the ages 21 and 29 while the lowest percentage of respondents (3%) were over 59 years old. Only six respondents (5%) were between the ages of 18 and 20 and 14 respondents (12%) were within the 30 to 39 age group. Over a sixth of the respondents (18%) were within the age group 50 to 59 while only seven of the respondents (6%) were between the ages of 40 and 49. The sample of respondents had a higher number of female respondents than male respondents with 68 respondents out of the total of 120 respondents (57%) being female. A total of 52 respondents (43%) were male.

Age Group	n	%
18-20	6	5
21-29	68	57
30-39	14	12
40-49	7	6
50-59	22	18
60+	3	3

Table 4-4: Frequency Distribution: Age (n=120).

Gender	n	%
Female	68	57
Male	52	43

Table 4-5: Frequency Distribution: Gender (n=120).

Almost half of the respondents (48%) had a postgraduate degree while 41 respondents (34%) only had an undergraduate degree. Only eight respondents (7%) had a high school education while 14 respondents (12%) had a college qualification as their highest level of education. Most of the respondents (62%) were employed while only two respondents (2%) were retired. Almost a third of the respondents (33%) were students while five respondents (4%) were unemployed.

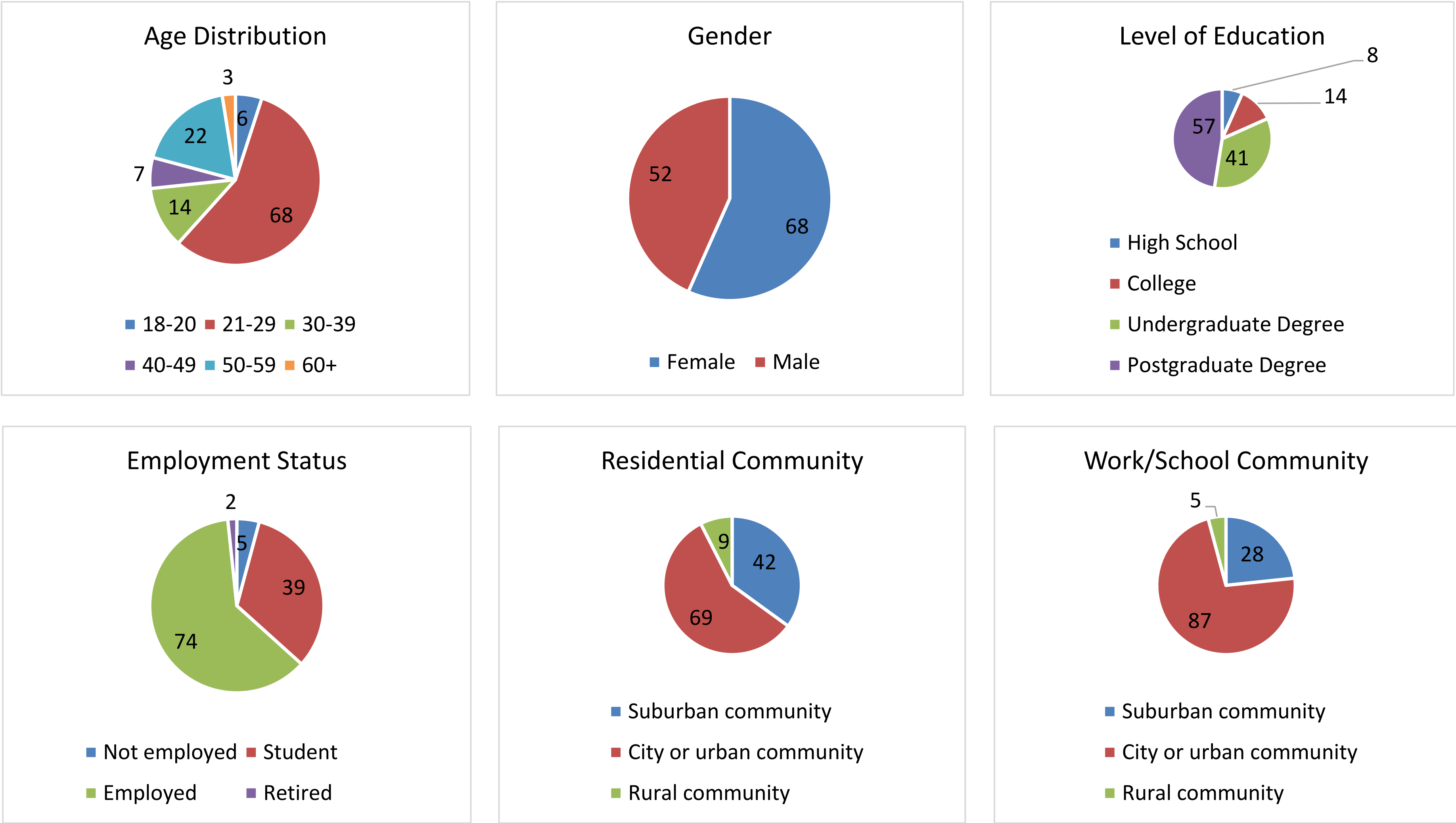


Figure 4-11: Demographics of Respondents.

Level of Education	n	%
High School	8	7
College	14	12
Undergraduate Degree	41	34
Postgraduate Degree	57	48

Table 4-6: Frequency Distribution: Level of Education (n=120).

Employment Status	n	%
Not employed	5	4
Student	39	33
Employed	74	62
Retired	2	2

Table 4-7: Frequency Distribution: Employment Status (n=120).

While many of the respondents (73%) go to school or work in the city or an urban community, only five respondents (4%) work or go to school in a rural community. Over a fifth of the respondents (23%) work or go to school in a suburban community and over a third of the respondents (35%) live in a suburban community. Over half of the respondents (58%) live in the city or in an urban community while only nine respondents (8%) live in a rural community.

	Residential Community		Work/School Community	
Employment Status	n	%	n	%
Suburban community	42	35	28	23
City or urban community	69	58	87	73
Rural community	9	8	5	4

Table 4-8: Frequency Distribution: Type of Community (n=120).

The 120 respondents are resident in 12 countries of which six of the countries are developed countries and the other six countries are developing countries. Although the countries are evenly split in terms of their developed and developing categories, most of the respondents (75%) are resident in developing countries and over half of the respondents (57%) reside in South Africa (Figure 4-12). These numbers are appropriate for this study as the research problem (Section 1.2) highlights a need for a crowdsensing method in developing countries and the case study focuses on South Africa (Section 2.4.2.4).

The lowest number of respondents came from Uganda and Canada with each having one respondent (1%). Australia, Benin and Kenya had two respondents (2%) each and three respondents (3%) are resident in the United States of America. The United Kingdom and the Netherlands had eight (7%) and seven (6%) respondents respectively while Swaziland and Germany had six respondents (5%) each.

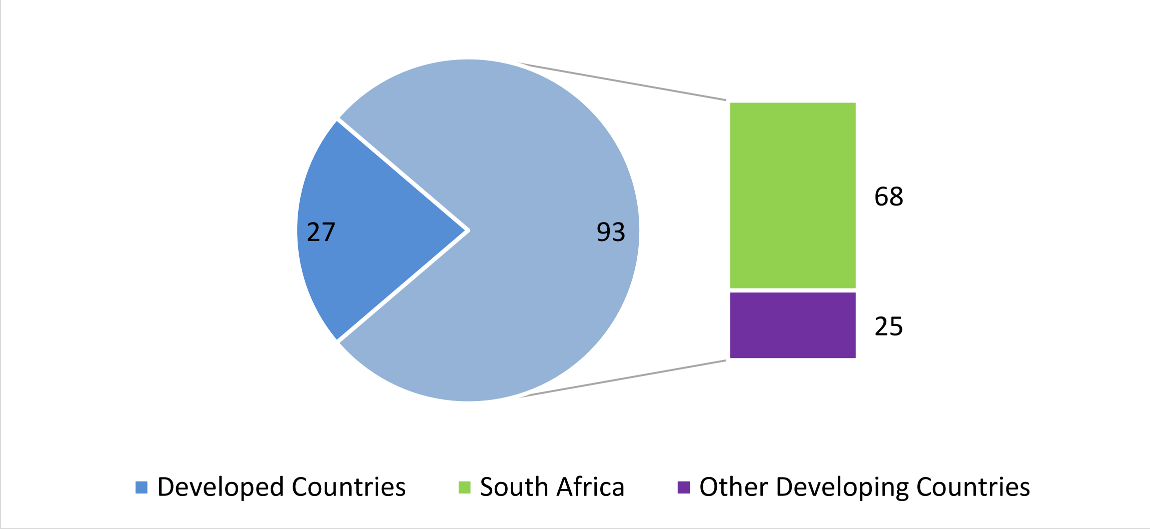


Figure 4-12: Respondents from Developed Countries vs Developing Countries.

Country	Developing Country	Developed Country	n	%
South Africa	✓		68	57
Malawi	✓		14	12
United Kingdom		✓	8	7
Netherlands		✓	7	6
Swaziland	✓		6	5
Germany		✓	6	5
United States of America		✓	3	3
Australia		✓	2	2
Benin	✓		2	2
Kenya	✓		2	2
Uganda	✓		1	1
Canada		✓	1	1
TOTAL	**6**	**6**	**120**	**100**

Table 4-9: Frequency Distribution: Country (n=120).

A majority of the respondents (54%) stated that their hobbies, home life or work do not revolve around the water sector or water resources. On the other hand, 55 of the respondents (46%) of the respondents stated that their hobbies, home life or work revolve around the water sector or water resources. Some of the reasons for the respondents' involvement with the water sector or water resources include:

- Irrigation for farming and sugarcane production.
- For academic research in areas such as agricultural water management, rainwater harvesting flood protection, water and waste management and estuarine ecology.
- Work in water supply and resources engineering.
- Work on water awareness campaigns.
- Hobbies such as swimming and canoeing.

Involvement with Water Sector/ Resources	n	%
Hobbies, home life or work **do not** revolve around the water sector or water resources.	65	54
Hobbies, home life or work revolve around the water sector or water resources.	55	46

Table 4-10: Frequency Distribution: Involvement with Water Sector/ Resources (n=120).

4.4.2 Investigation into the Intention to Participate

The third section of the survey used the Conceptual Model for Submissions of Water Data using TPB to investigate the respondent's intention to participate in water resource monitoring. As illustrated in Figure 4-4, the variables were operationalised in a manner consistent with the TPB model (Francis *et al.*, 2004). As previously stated in Section 4.3, all questionnaire items required respondents to indicate their agreement on a 5-point scale. Based on recommendations by Harpe (2015), statistical ranges were applied to the data from the Likert scale question responses to categorise the responses as negative [1 to 2.6), neutral [2.6 to 3.4] and positive (3.4 to 5].

4.4.2.1 Measuring Past Behaviour

To determine a measure of past behaviour, the respondents were asked if they had ever reported water issues before. Most of the respondents (70%) had never reported water issues before while 30% of the respondents had reported issues to water authorities before. Even though the mean ratings for both respondents who had never reported before and respondents who had reported before were both positive, respondents that had reported water issues before had a much higher intention rating (μ =4.43, SD = 0.62) compared to respondents who had never reported water issues before (μ =3.77, SD = 1.06).

4.4.2.2 Measuring Behavioural Attitude

Questionnaire items on the behavioural attitude where structured to elicit the behavioural beliefs that are shared by the target population (Francis *et al.*, 2004). Direct measurement of behavioural attitude involves using evaluative bipolar adjectives such as *pleasant – unpleasant*. As guided by Francis *et al*. (2004), the items on direct measures included instrumental items that investigate whether the behaviour achieves something (e.g. *useful – worthless*) and experiential items that investigate how it feels to perform the behaviour (e.g. *pleasant – unpleasant*). The overall attitude score based on direct measures was measured by calculating the mean of the item scores (Table 4-11).

Statements	Mean	Std. Deviation	St. Error
BA1: In my opinion, reporting cases of water pollution and wastage issues to the municipality is: Worthless/Useful	4.01	1.15	0.106
BA2: In my opinion, reporting cases of water pollution and wastage issues to the municipality is: Unpleasant (for me)/ Pleasant (for me)	3.40	1.14	0.105
BA3: In my opinion, reporting cases of water pollution and wastage issues to a trusted organisation is: Worthless/ Useful	4.05	1.05	0.096
BA4: In my opinion, reporting cases of water pollution and wastage issues to a trusted organisation is: Unpleasant (for me)/Pleasant (for me)	3.80	1.05	0.096
Overall	3.81	0.76	0.070

Table 4-11: Descriptive Statistics of Direct Measures of Behavioural Attitude across all Respondents (n=120).

The overall attitude scores of all respondents show that respondents have positive attitudes towards reporting cases of water pollution and wastage issues (μ = 3.81, SD= 0.76). The results show that respondents believe that reporting the issues to the municipality or a trusted organisation tasked to rectify the issues can be useful with positive mean ratings of 4.01 and 4.05 respectively. Furthermore, the respondents gave a neutral response (μ = 3.40, SD= 1.14) to reporting the issues to the municipality while giving a positive response to reporting the issues to a trusted organisation (μ = 3.80, SD= 1.05). Most of the respondents (83%) had positive responses, thus are in favour of participating in water resource monitoring while only 17 (14%) respondents had negative attitudes toward participation.

TPB also allows the indirect measurement of behavioural attitude by assessing the strength of the behavioural beliefs shared by the target population and the outcome evaluations of those beliefs (Francis *et al.*, 2004). Table 4-12 shows the questionnaire items to assess the behavioural beliefs and outcome evaluations. The results show that the respondents feel that the discovery of water issues is important (μ = 3.63, SD = 1.17) and contributes to the management of water resources (μ = 4.40, SD = 0.83). Furthermore, the respondents believe that assisting in the management of water resources by reporting cases of water pollution and wastage issues is extremely important with positive ratings of 4.13 and 4.19 respectively. In addition, the respondents feel they will be doing something good for the community if they report cases of water pollution and wastage (μ = 4.52, SD = 0.88), and that their reports will somewhat improve the management of their water resources (μ = 3.50, SD = 1.16).

Statements	Mean	Std. Deviation	St. Error
Behavioural Beliefs			
BA5: If I report cases of water pollution and wastage issues, I will feel that I am doing something positive for the community: Unlikely/Likely	4.52	0.88	0.080
BA6: Discovering cases of water pollution and wastage issues will contribute to the management of our water resources: Unlikely/Likely	4.40	0.83	0.076
BA7: If I report cases of water pollution and wastage issues, there will be an improvement in the management of our water resources: Unlikely/Likely	3.50	1.16	0.107
Total Behavioural Beliefs	4.14	0.68	0.062
Outcome Evaluations			
BA8: Reporting cases of water pollution and wastage issues is: Extremely unimportant/ Extremely Important	4.19	0.97	0.089
BA9: Discovering cases of water pollution and wastage issues is: Extremely unimportant/ Extremely Important	3.63	1.17	0.107
BA10: Assisting in the management of water resources is: Extremely unimportant/ Extremely Important	4.13	0.99	0.091
Total Outcome Evaluations	3.98	0.85	0.077
TOTAL	4.06	0.67	0.061

Table 4-12: Descriptive Statistics of Indirect Measures of Behavioural Attitude across all Respondents (n=120).

The standard calculation of an overall attitude score based on indirect measures in TPB research is to multiply each behavioural belief score by the relevant evaluation score and sum up the resulting products:

$$\boldsymbol{A = (BA5 * BA8) + (BA6 * BA9) + (BA7 * BA10)}$$

Where A is the total attitude score
BA5, BA6 and BA7 are scores for each of the three behavioural beliefs
BA8, BA9 and BA10 are scores for outcome evaluations relating to each behavioural belief

If the total attitude score is positive, the respondent is in favour of performing the behaviour while a negative score means the respondent is against performing the behaviour. The positive range of scores is -30 to +30, therefore, the total attitude scores across the respondents were categorised as negative (score < 0), neutral (score = 0) and positive (score > 0). The positive attitude scores were further divided into subcategories of weak (score ranging from 1 to 10), moderate (score ranging from 11 to 20) and strong (score ranging from 21 to 30) positive attitudes towards water resource monitoring. Table 4-13 presents the total attitude scores across respondents.

	Negative	Neutral	Positive			Total
			Weak	Moderate	Strong	
South Africa	5	0	16	25	22	**68**
Developing Countries	15	1	23	31	23	**93**
Developed Countries	2	2	5	6	12	**27**
Overall	**17**	**3**	**28**	**37**	**35**	**120**

Table 4-13: Total Attitude Scores across Respondents (n=120).

The total attitude scores of all the respondents reflect a positive attitude towards being involved in water resource monitoring and making water data submissions. The results are consistent with respondents from South Africa, developed and developing countries, with most respondents having a moderate or strong positive attitude towards water data submissions.

4.4.2.3 Measuring Subjective Norms

The direct measurement of subjective norms involves the use of items that refer to the opinions of important people regarding reporting cases of water pollution. Francis *et al*. (2004) recommend calculating the mean of the item scores to come up with the overall subjective norm score based on direct measures (Table 4-14).

Statements	Mean	Std. Deviation	St. Error
SN1: Most people important to me think that I should report cases of water pollution and wastage issues: Strongly disagree/ Strongly agree	3.16	1.15	0.105
SN2: It is expected of me to report cases of water pollution and wastage issues: Strongly disagree/ Strongly agree	3.78	1.23	0.113
SN3: I feel under social pressure to report cases of water pollution and wastage issues: Strongly disagree/ Strongly agree	2.68	1.35	0.124
Overall	3.21	0.96	0.088

Table 4-14: Descriptive Statistics of Direct Measures of Subjective Norms across all Respondents (n=120).

Although the respondents feel it is expected of them to report cases of water pollution and wastage ($\mu = 3.78$, SD = 1.23), the respondents do not feel any social pressure to report (or not report) water issues ($\mu = 2.68$, SD = 1.35). Subsequently, the overall subjective norm rating is neutral ($\mu = 3.21$, SD = 0.96).

TPB also allows the indirect measurement of subjective norms by assessing the strength of normative beliefs with respect to groups, organisations and categories of individuals ("reference groups") who are likely to apply social pressure with respect to the behaviour (Francis *et al.*, 2004). In addition, the indirect measurement of subjective norms includes the assessment of the motivation to comply with the pressure of each reference group. Table 4-15 shows the questionnaire items that assess the normative beliefs and the respective motivation to comply with the belief.

Statements	Mean	Std. Deviation	St. Error
Normative Beliefs			
SN4: Members of my community would (approve/ disapprove) of me reporting cases of water pollution and wastage issues so the issues can be rectified.	3.92	1.07	0.098
SN5: The municipality and other organisations tasked with resolving water pollution and wastage issues would (approve/ disapprove) of me reporting cases of water pollution and wastage issues so the issues can be rectified.	3.88	1.10	0.101
SN6: Other people report cases of water pollution and wastage issues: Strongly disagree/ Strongly Agree	3.10	1.07	0.098
Total Normative Beliefs	3.63	0.82	0.075
Motivation to Comply			
SN7: The approval of my community is important to me: Not at all/ Very much	2.93	1.38	0.127
SN8: Helping the municipality and other organisations tasked with resolving water pollution and wastage issues is important to me: Not at all/ Very much	3.92	0.97	0.089
SN9: Doing what other people do in regards reporting is important to me: Not at all/ Very much	3.46	1.45	0.133
Total Motivation to Comply	3.44	0.94	0.086
Overall	3.53	0.71	0.065

Table 4-15: Descriptive Statistics of Indirect Measures of Subjective Norms across all Respondents (n=120).

The respondents feel that the municipality and other organisations tasked with resolving water pollution and wastage issues would approve of them reporting cases of water pollution and wastage so the issues can be rectified with ratings of 3.92 and 3.88. However, the respondents neither agree nor disagree that other people report cases of water pollution and wastage (μ = 3.10, SD = 1.07). Although the respondents report feeling neutral about the approval of their community (μ = 2.93, SD = 1.38), helping the municipality and other organisations tasked with resolving water pollution and wastage issues is important to them ($\mu = 3.92$, SD = 0.97).

Following the standard of TPB research, each normative belief score is multiplied by the relevant motivation to comply score and the resulting products are summed up to calculate the overall subjective norm score based on indirect methods.

$$N = (SN4 * SN7) + (SN5 * SN8) + (SN6 * SN9)$$

Where N is the total subjective norm score
SN4, SN5 and SN6 are scores for each of the three behavioural beliefs
SN7, SN8 and SN9 are scores for outcome evaluations relating to each behavioural belief

If the total subjective norm score is positive, the respondent experiences social pressure to perform the behaviour while a negative score means the respondent experiences social pressure to not perform the behaviour. The range of scores is -30 to +30, therefore, the total subjective scores across the respondents were categorised as negative (score < 0), neutral (score = 0) and positive (score > 0). Positive subjective norms scores were further divided into subcategories of weak (score ranging from 1 to 10), moderate (score ranging from 11 to 20) and strong (score ranging from 21 to 30) positive social pressure to be involved in water resource monitoring. Table 4-16 presents the total subjective norms scores across respondents.

	Negative	Neutral	Positive			Total
			Weak	Moderate	Strong	
South Africa	21	3	25	11	8	**68**
Developing Countries	24	4	36	16	13	**93**
Developed Countries	9	2	12	3	1	**27**
Overall	**33**	**6**	**48**	**19**	**14**	**120**

Table 4-16: Total Subjective Norm Scores across Respondents (n=120).

The total subjective norm scores of all the respondents reflect fairly weak social pressure to be involved in water resource monitoring and making water data submissions. The results also show that almost a third of respondents experience social pressure **not to** make water data submissions.

4.4.2.4 Measuring Perceived Behavioural Control

The perceived behavioural control items reflect people's confidence in their capabilities to perform the target behaviour by assessing their self-efficacy and their beliefs about their controllability of the behaviour (Francis *et al.*, 2004). Self-efficacy investigates the respondents' beliefs about how difficult it is to perform the behaviour and their confidence in being able to perform the behaviour. On the other hand, the assessment of controllability involves the respondents reporting whether performing the behaviour is up to them and whether their behaviour is controlled by factors beyond their control. The scale included statements such as "I am confident that I could report cases of water pollution if I wanted to." The overall perceived behavioural control is also measured by calculating the mean of the item scores. Table 4-17 shows the questionnaire items that assess the perceived behavioural control.

Statements	Mean	Std. Deviation	St. Error
Self-efficacy			
PB1: I am confident that I could report cases of water pollution and wastage issues if I wanted to: Strongly disagree/ Strongly agree	4.15	0.99	0.091
PB2: For me to report cases of water pollution and wastage issues is: Extremely difficult/ Extremely easy	3.22	1.05	0.096
Total Self-Efficacy	3.68	0.84	0.077
Controllability			
PB3: The decision to report cases of water pollution and wastage issues is beyond my control: Strongly disagree/ Strongly agree	2.08	1.21	0.111
PB4: Whether I report cases of water pollution and wastage issues or not is up to me: Strongly disagree/ Strongly agree	3.82	1.31	0.120
Total Controllability	2.95	0.82	0.075
Overall	3.31	0.58	0.053

Table 4-17: Descriptive Statistics of Perceived Behavioural Control across all Respondents (n=120).

Although the respondents feel confident that they would participate in water resource monitoring by reporting cases of water pollution and wastage if they wanted to, with a positive mean rating of 4.15, they find the task neither easy nor difficult with a neutral mean rating of 3.22. However, only 20% of the respondents lack the confidence in their abilities to participate in the monitoring. Almost a third (32.5%) of the respondents feel that they do not have control over making water data submissions. Even though the respondents feel that whether to make water data submissions is up to them ($\mu = 3.82$, SD = 1.21), the respondents feel that the ultimate decision to report the issues is beyond their control ($\mu = 2.08$, SD = 1.21). Section 4.4.3 continues the analysis of perceived behavioural control to explore the initial factors that can motivate or demotivate them to participate in water resource monitoring, thus exploring the self-efficacy and controllability of the respondents.

4.4.2.5 Measuring the Generalised Intention

Although it can be said that the relationship between intention and behaviour is not perfect, one of the most important contributions of the TPB is that the model allows researchers to use intention as a proximal measure of behaviour. Francis *et al.* (2004) propose calculating the mean of three statements (Table 4-18) to measure the generalised intention to perform a certain behaviour. The three statements can be assessed for correlation using the Pearson correlation test. According to Sarstedt *et al*. (2014), the findings of the test show strong positive relationships between the three statements because the correlations ranged from 0.744 to 0.778. In this regard, the overall mean of these three statements can be used to accurately represent the generalised intention of the respondents to continuously make water data submissions.

Statements	Mean	Std. Deviation	St. Error
I expect to report cases of water pollution and wastage: Strongly disagree/ Strongly agree	3.83	1.12	0.103
I want to report cases of water pollution and wastage: Strongly disagree/ Strongly agree	4.08	1.04	0.096
I intend to report cases of water pollution and wastage: Strongly disagree/ Strongly agree	4.01	1.10	0.101
Overall	3.97	1.00	0.091

Table 4-18: Mean Ratings of Generalised Intentions across all Respondents (n=120).

The overall mean of generalised intention across all respondents was positive (μ = 3.97, SD = 1.00). Most of the respondents (74%) show a positive response to participating in water resource monitoring by reporting cases of water pollution. However, the data showed that while the overall mean across respondents from developing countries was positive (μ = 4.14, SD = 0.91), the overall mean across respondents from developed countries was neutral (μ = 3.40, SD = 1.08). Table 4-18 shows that the overall mean across respondents from South Africa was also positive (μ = 4.04, SD = 0.95).

Statements	Mean	Std. Deviation	St. Error
I expect to report cases of water pollution and wastage	3.94	1.07	0.131
I want to report cases of water pollution and wastage	4.12	1.01	0.123
I intend to report cases of water pollution and wastage	4.07	1.10	0.135
Overall	4.04	0.95	0.116

Table 4-19: Mean Ratings of Generalised Intentions across South African respondents (n=68).

The positive rating towards water data sharing in South Africa and other developing countries reinforces the research problem (Section 1.2) of the lack of shared and relevant information between communities and service providers in developing countries (Jiménez & Pérez-Foguet, 2010; Glotzbach *et al.*, 2013). In addition, there is a lack of improvement in service delivery (Champanis *et al.*, 2013), and a third of water sources in rural areas are non-functional and require servicing (Glotzbach *et al.*, 2013). Thus, there is a need for improvement in the sharing of relevant information between communities and service providers in developing countries.

4.4.2.6 Prediction of Intention using Predictor Variables

A Pearson Correlation test and hypothesis tests were used to answer the subsidiary research question:

> **RQ1.1:** How do past behaviour, behavioural attitude, subjective norms and perceived behavioural control influence the intention to participate in crowdsensing for water resource monitoring?

A Pearson correlation test was performed to express the degree of correlation among intention and the predictor variables: past behaviour, attitude, subjective norms and perceived behavioural control (Table 4-20). The Pearson correlation between intention and each of the other variables (0.16 to 0.63) show positive relationships, and that as each variable increases, the individual's intention to participate also increases, irrespective of the country of residence. However, it is worth noting that attitude, subjective norms and perceived behavioural control (0.34 to 0.63) show stronger positive relationships as compared to past behaviour (0.16 to 0.30).

Regression analysis was used to measure the extent to which the intention to make continuous water data submissions is significantly associated with the three explanatory variables: past behaviour, behavioural attitude, subjective norms and perceived behavioural control. Only 54% of the variation in intentions (r^2=0.54) is explained by the independent variables past behaviour, behavioural attitude, subjective norms and perceived behavioural control. However, the interpretation of r^2 is subjective depending on the field, and low r^2 values (such as 0.25) are not unusual in social sciences due to person-to-person variability (Larose, 2006). Thus, due to the r^2 value of 0.54, it can be concluded that each of the four variables influences the intention to perform the behaviour.

While the r^2 value of all the samples is 0.54, past behaviour, behavioural attitude, subjective norms and perceived behavioural control account for 60% of the variance in intentions in the developed countries (r^2=0.60), 49% and 48% of variance in intentions in the developing countries (r^2=0.49) and South African (r^2=0.48) samples respectively. The r^2 values, which represent subsets of the overall sample, still confirm that each of the four variables influences the intention to perform the behaviour, irrespective of the respondents' country of residence.

	Descriptive Statistics			Pearson correlations			
	Mean	Std. Dev	Std. Error	BI	BA	SN	PBC
South Africa (n=68)							
BI	4.04	0.95	0.12				
BA	3.76	0.69	0.08	0.49**			
SN	3.35	1.00	0.12	0.56***	0.28		
PBC	3.32	0.58	0.07	0.43*	0.32	0.24	
PB	-	-	-	0.30	0.30	0.38	0.02
Developing Countries (n=93)							
BI	4.14	0.91	0.09				
BA	3.87	0.74	0.08	0.53***			
SN	3.34	0.91	0.10	0.50***	0.30		
PBC	3.36	0.56	0.06	0.44***	0.33	0.18	
PB	-	-	-	0.28	0.22	0.32	-0.03
Developed Countries (n=27)							
BI	3.40	1.08	0.211				
BA	3.62	0.78	0.153	0.62			
SN	2.77	1.00	0.196	0.63**	0.50		
PBC	3.17	0.62	0.122	0.34*	0.28	-0.06	
PB	-	-	-	0.16	0.32	0.08	0.38
Overall (n=120)							
BI	3.97	1.00	0.09				
BA	3.81	0.76	0.07	0.56***			
SN	3.21	0.96	0.09	0.57***	0.37		
PBC	3.31	0.58	0.05	0.43***	0.33	0.15	
PB	-	-	-	0.30	0.26	0.31	0.07

*Note: * p<0.05; ** p<0.01; ***p<0.001. BI= Behavioural Intention, BA=Behavioural Attitude, SN=Subjective Norms, PBC=Perceived Behavioural Control, PB=Past Behaviour.*

Table 4-20: Descriptive Statistics, Pearson Correlations and Alphas.

Hypotheses tests were also performed to calculate the probability (*p*-value) that the results did not occur by chance. $H_{1.1}$ predicted that *an individual's intention to continuously submit water data is influenced by their past behaviour.* The standard coefficient of 0.17 (*p*=0.24) was not significant in the overall data set. These results were consistent as the standard coefficients in the developed countries, developing countries and South African samples were not significant. Thus, $H_{1.1}$ was not supported. It is expected that engaging different stakeholders may produce contradictory or inconsistent perspectives of the same problem. In this case, the results presented in Section 4.4.2.1 indicate that citizens are more likely to submit water data if they have submitted before while the hypothesis test of past behaviour and intention is not supported. Engaged scholarship stresses that diverse perspectives must never be dismissed as outliers, errors or noise but must be explained through methods of paradoxical reasoning (Van de Ven, 2007). In this regard, the results of the hypothesis test regarding past behaviour are acceptable because citizens may not return to the crowdsensing system because of various reasons. For example, the issue the citizen reported may not have been resolved or the citizen never experienced any other water issues resulting in the citizen not intending to submit water data again. Therefore, it is acceptable that past behaviour cannot predict the intention to make data submissions again.

$H_{1.2}$ predicted that *an individual's intention to continuously submit water data is influenced by their behavioural attitude towards the behaviour.* The overall and developing countries produced highly significant relationships between attitudes toward water data submissions and intentions to continuously submit water data, with standardised coefficients of 0.41 (p<0.001) and 0.39 (p<0.001) respectively. In the South African sample, the standardised coefficient was significant at 0.38 (p<0.01) while the coefficient was not significant in developed countries at 0.43 (p=0.07). Overall, $H_{1.2}$ was supported but it must be noted that *an individual's intention to continuously submit water data is not influenced by their behavioural attitude towards the behaviour in developed countries.*

$H_{1.3}$ predicted that a*n individual's intention to continuously submit water data is influenced by their subjective norms towards the behaviour.* The overall, developing countries and South African samples produced highly significant relationships between subjective norms toward water data submissions and intentions to continuously submit water data, with standardised coefficients of 0.41 (p<0.001), 0.39 (p<0.001) and 0.38 (p<0.001) respectively. In the developed countries sample, the standardised coefficient was significant at 0.54 (p<0.01). Thus, $H_{1.3}$ was supported.

$H_{1.4}$ predicted that a*n individual's intention to continuously submit water data is influenced by their perceived behavioural control over the behaviour.* The overall and developing countries samples produced highly significant relationships between perceived behavioural control over water data submissions and intentions to continuously submit water data, with standardised coefficients of 0.46 (p<0.001). In the developed countries and South African samples, the standardised coefficients were significant at 0.56 (p<0.05) and 0.42 (p<0.05). Thus, $H_{1.4}$was supported.

The standard coefficients for each of the variables are presented in Figure 4-13. The results of the hypotheses tests (Table 4-21) show that the first hypothesis is not supported and therefore that *an individual's intention to continuously submit water data* ***is not*** *influenced by their past behaviour.* On the other hand, the other three hypotheses are supported and that *an individual's intention to continuously submit water data* ***is*** *influenced by their behavioural* *attitude and subjective norms towards the behaviour, and their perceived behavioural control over the behaviour.*

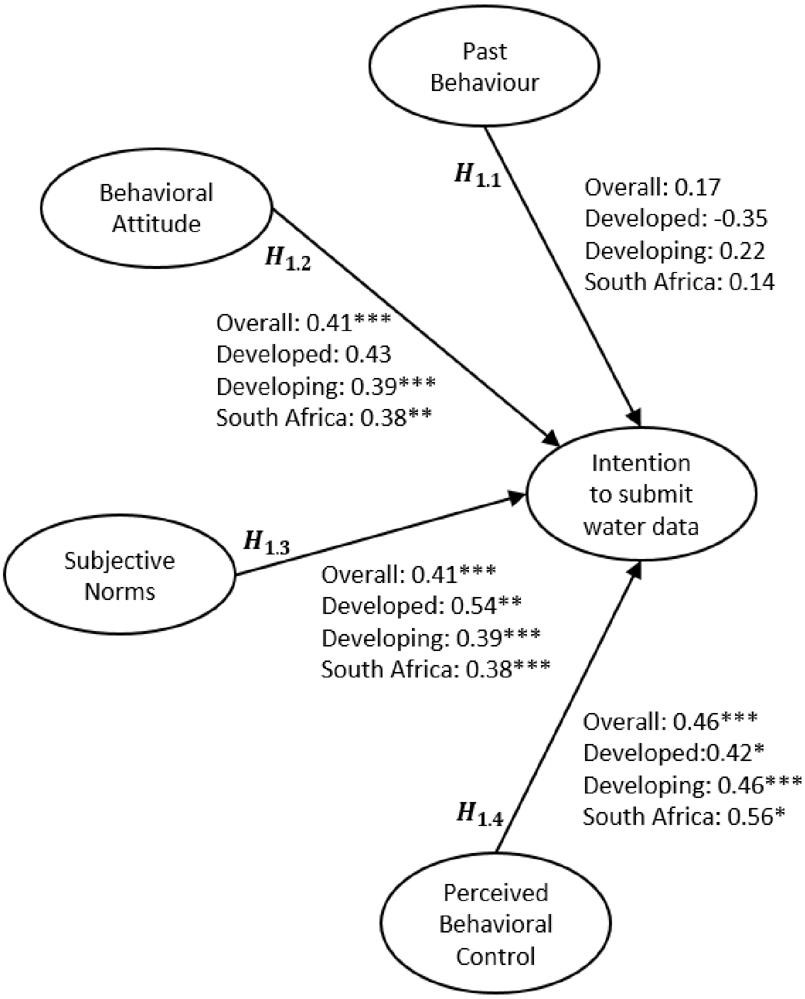


Figure 4-13: TPB and Water Data Submissions Intentions - Coefficients by Country Groups.

HYPOTHESES		RESULT
$H_{1.1}$	Intention ↔ Past Behaviour	Not supported
$H_{1.2}$	Intention ↔ Behavioural Attitudes	Supported
$H_{1.3}$	Intention ↔ Subjective Norms	
$H_{1.4}$	Intention ↔ Perceived Behavioural Control	

Table 4-21: Results of Hypothesis Tests.

4.4.3 Investigating the Motivational and De-motivational Factors

The previous section covered an analysis of the respondents' intentions to participate in water resource monitoring using crowdsensing. However, having an intention to participate in a behaviour does not guarantee the engagement in the behaviour (Martin *et al.*, 2017).

Researchers seeking behaviour change need to explore what cognitive, emotional and social forces activate the behaviour (Joachim *et al.*, 2015). Those forces, whether internal or external, must be able to induce an individual's motivation and stimulate their desire and energy to be continually interested and committed to performing a given behaviour. Thus, the second objective of the study was to investigate the key motivational factors for participation in water resource monitoring, as well as factors that would make it difficult or impossible for the respondents to participate. This section addresses the subsidiary research question:

> **RQ1.2**: What are the factors that affect the citizens' motivation to participate in crowdsensing for water resource monitoring?

4.4.3.1 Motivational Factors for Participating in Water Resource Monitoring

The last section of the questionnaire presented a close-ended question which required the respondents to select a minimum of three motivational factors from a list of motivational factors. The list of motivational factors comprised of all the initial motivational factors from the extended framework of motivational factors (Figure 4-7). The factors were randomised to allow the respondents to go through all 25 factors and select a minimum of three that most apply to them. Out of the 25 factors, the respondents selected 19 factors. The 19 factors were categorised according to the incentive category they pertain to (Table 4-22). The respondents selected a total of 376 factors, which is appropriate as the minimum number of selections was 360 (120 participants * 3 motivational factors).

Rank	Incentive Category	n	%	Highest Number of Respondents on a Factor	%
1	Collective	274	73	84	70
2	Social	45	12	45	38
3	Self-efficacy	23	6	18	15
4	Self-benefit	21	6	11	9
5	Intrinsic	13	3	7	6
TOTAL		**376**	**100**		

Table 4-22: Motivational Factors per Incentive Category.

The results of the analysis show that collective incentives are the most powerful motivators to participate in water resource monitoring, with 84 respondents selecting one of the motivational factors under the category (Table 4-23). The most popular motivational factor in this category is to participate in water resource monitoring to keep the environment beautiful, with 70% of the entire population selecting this factor. All motivational factors in this incentive category were selected by at least eight respondents.

Motivational factor	n	%
Beautiful environment	84	31
I feel responsible to do so	76	28
To contribute to conservation	70	26
To help others	20	7
To teach others	16	6
To help a specific site	8	3
Total	**274**	**100**

Table 4-23: Motivational Factors under the Collective Incentives Category.

The second popular incentive category is the social incentive category, with 45 respondents selecting a motivational factor from that category (Table 4-24). The only motivational factor in this category that was selected was to participate in water resource monitoring to be a part of the community (n=45). The other three motivational factors under the social incentive category that were not selected are:

- Do something with friends.
- Gain new social contacts.
- Combine existing skills.

Motivational factor	n	%
Being part of community	45	100
Total	**45**	**100**

Table 4-24: Motivational Factors under the Social Incentives Category.

All motivational factors under the self-efficacy category were selected by at least five respondents (Table 4-25). However, the most popular motivational category under this category was participating in water resource monitoring for scientific research (n=18). The self-benefit category was not very popular with a maximum of only 11 respondents selecting a motivational factor under this category (Table 4-26). The top motivational factor in this category was to participate in water resource monitoring to get direct feedback (n=11). However, two motivational factors under the self-benefit category were not selected:

- Discover things.
- Get some exercise.

The intrinsic incentive category was the least popular category with a maximum of only seven respondents selecting a motivational factor under that category (Table 4-27). The most popular motivational factor in this category was the ability to act independently in water resource monitoring. However, only one motivational factor under the intrinsic incentives' category ("It is fun") was not selected.

Motivational factor	n	%
For scientific research	18	78
To contribute to science	5	22
Total	**23**	**100**

Table 4-25: Motivational Factors under the Self-Efficacy Incentives Category.

Motivational factor	n	%
Direct feedback	11	52
To learn new skills	3	14
Influenced by someone	2	10
To increase chance on job	2	10
To learn new things	2	10
To increase my capacity	1	5
Total	**21**	**100**

Table 4-26: Motivational Factors under the Self-Benefit Incentives Category.

Motivational factor	n	%
Being able to act independently	7	54
It matches my hobbies	4	31
I like this project	1	8
To kill time	1	8
Total	**13**	100

Table 4-27: Motivational Factors under the Intrinsic Incentives Category.

Table 4-28 shows a summary of the motivational factors that were not selected by any respondent while Table 4-29 presents the top five most important factors as selected by respondents. A majority of the respondents (n=84, 70% of the population) would participate in water resource monitoring to keep their environment beautiful while about two-thirds of the respondents (n=76, 63%) would participate in water resource monitoring because they feel responsible to do so. Although only 20 respondents (17%) would participate in water resource monitoring to help others, over a third of the respondents (n=45, 37.5%) would participate in the monitoring to be a part of their community. The results show that a majority of respondents would be incentivised by collective incentives to participate in water resource monitoring while only 45 of the respondents would be motivated by a social incentive.

Motivational factor	Incentive Category
Do something with friends.	Social
Gain new social contacts.	Social
Combine existing skills.	Social
Discover things.	Self-benefit
Get some exercise.	Self-benefit
It is fun	Intrinsic

Table 4-28: Motivational Factors not selected by any Respondent.

Rank	Motivational factor	Incentive Category	n	%
1	Beautiful environment	Collective	84	22
2	I feel responsible to do so	Collective	76	20
3	To contribute to conservation	Collective	70	19
4	Being part of community	Social	45	12
5	To help others	Collective	20	5
	Others		81	22
TOTAL			**376**	**100**

Table 4-29: Top Five Motivational Factors.

4.4.3.2 De-motivational Factors for Participating in Water Resource Monitoring

The questionnaire also required the respondents to select at most three factors the respondents perceive would hinder them to participate in water resource monitoring. The questionnaire item was a checkbox list that listed all the de-motivational factors in the extended framework for motivational factors (Figure 4-7). Table 4-30 presents the frequency of responses for each de-motivational factor.

De-motivational factor		n	% of respondents
F1	Data not being used	68	57%
F2	Insufficient time	55	46%
F3	Power gap between volunteer and coordinators	43	36%
F4	Unappealing recording process	26	22%
F5	Lack of confidence	12	10%
F6	Not willing to collect for management purposes	9	8%
F7	I do not own a smartphone	6	5%
F8	Volunteer physically unable	3	3%
	Other	13	10%

Table 4-30: De-motivational Factors for Crowdsensing for Water Resource Monitoring (n=120).

Over half of the respondents (57%) reported that they do not believe the data they submit will be used, while 46% of the respondents feel they do not have the time to participate in water resource monitoring. Over a third of the respondents (36%) feel a negative power relation between themselves and the people in charge of water resource monitoring projects (such as the municipality). Almost a quarter of the respondents find the data collection process unappealing, and 5% of the respondents do not own a smartphone hence cannot be involved in crowdsensing projects that require smartphones. While 10% of the respondents lack the confidence to perform the tasks required in the monitoring process, 8% of the respondents are not willing to collect data for management purposes.

The questionnaire went further to allow the respondents to list any other factor that can demotivate them in participating in water resource monitoring that is not listed in the provided list. Thematic analysis, which is useful in the identification, analysis and reporting of themes within data (Braun & Clarke, 2006), was used to identify common themes (or factors) in the factors that the respondents provided. Six factors that were not present in the framework for motivational factors (Figure 4-7) were identified and added to the framework of motivational factors (Figure 4-14):

- F9: Long waiting time for issue resolution.
- F10: Lack of flexibility in communication modes.
- F11: Unaware of the monitoring process.
- F12: Unclear on the goals and benefits of monitoring.
- F13: Insufficient feedback from project coordinators.
- F14: Unsure if the issue has already been reported.

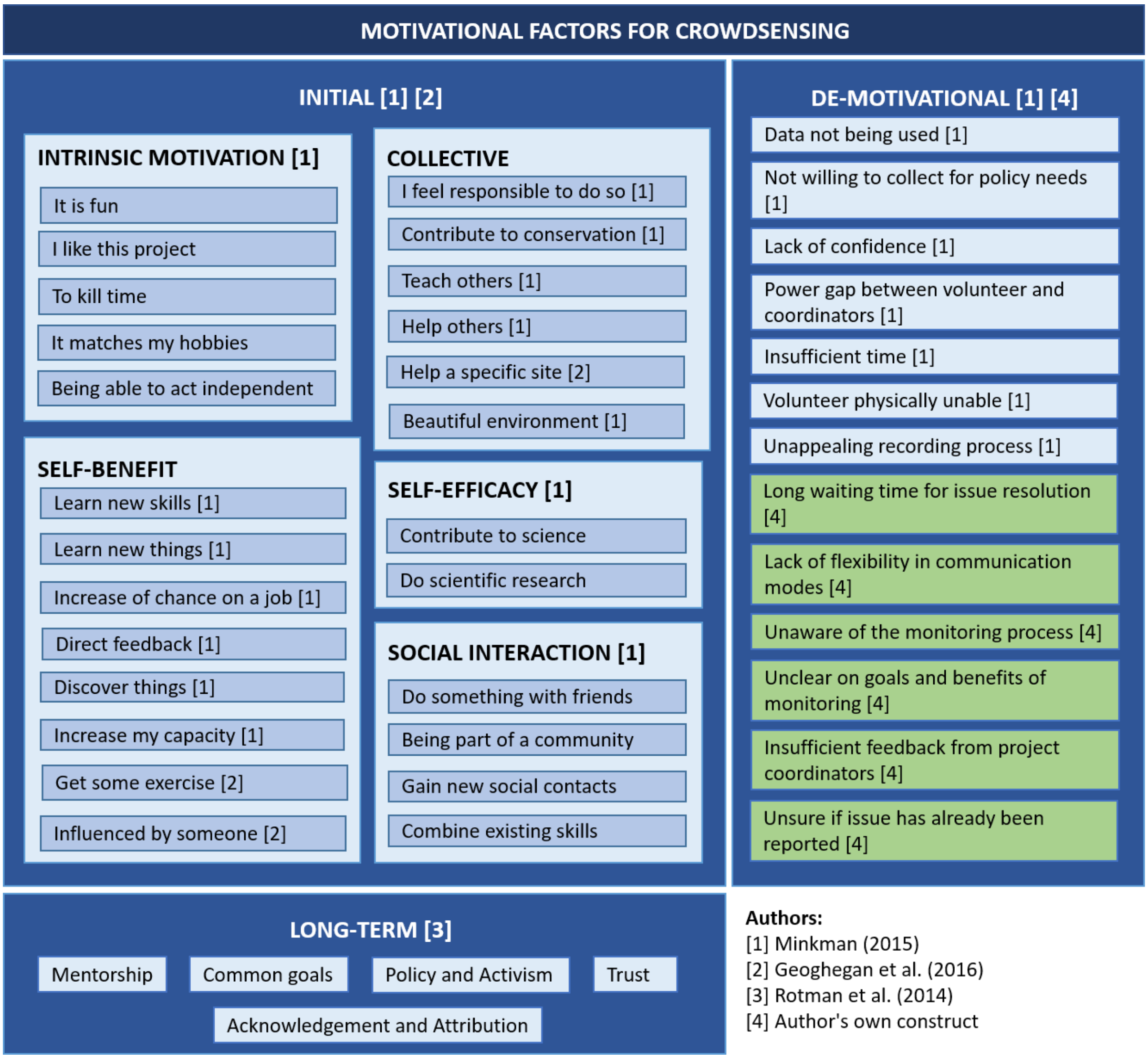


Figure 4-14: Framework of Motivational Factors for Crowdsensing Version 2 (Author's Own Construct).

4.4.4 Guidelines for Citizen Participation in Crowdsensing for Water Resource Monitoring

Based on the findings of the analyses, several guidelines can be deduced for the recruitment and coordination of citizens in crowdsensing projects. The guidelines are informed by the Framework of Motivational Factors for Crowdsensing (Figure 4-14), which also includes de-motivational factors F1 to F8, as well as additional factors F9 to F14 (Section 4.4.3.2). These can also be considered as factors that can contribute to the participation (initial and long-term/continuous) of citizens in crowdsensing projects and ultimately the success of such a project. The guidelines are:

- The project coordinators must ensure the **clear communication of goals and results** to assure citizens that their submitted data is being used (F1) and how the data is being used (F12).

- Project coordinators must prioritise having **flexible communication modes** for the users of crowdsensing systems (F10) thus allowing users to submit data in various forms (such as audio, video, text and images) and platforms (such as Web sites, native mobile applications and short message service). Aggregating data from multiple sources can provide supplemental (and more accurate) information, which can generate a holistic view of the PoI.
- The crowdsensing system must have **simple data collection protocols** to minimise the learning curve for participants (F5), improve the appeal of the monitoring process (F4) and reduce the data collection and submission time (F2).
- Citizens may not always be motivated to be involved in water resource monitoring for the good of the environment and as such, project coordinators must explore **other types of incentives**. Appealing to citizens' impulse to help others is one of the incentives that was ranked highly (Table 4-29), while none of the respondents viewed the monitoring process as fun (Table 4-28). Such insights provide opportunities to recruit and maintain participants that are not motivated by the altruistic values.
- Project coordinators must prioritise **participant retention strategies and feedback mechanisms** because it is easier to retain a participant than to gain a new one. Progress updates on issue resolution and notification alerts of contamination events detected close to users' location (Table 3-4) are examples of feedback mechanisms that can retain participants.
- Citizens are sometimes unaware of the project (F11) or feel that the project coordinators give insufficient feedback (F14). Acknowledgement and attribution, trust and common goals are some of the long-term factors that can motivate citizens to stay continuously involved in a crowdsensing project (Figure 4-7); thus, neglecting the citizens can negatively impact the success and sustainability of the crowdsensing project. There is a need to increase the involvement of citizens in crowdsensing projects to motivate the citizens to keep using the system, not just to report their issues, but to help other people in their community. Citizens are also wary of not being able to visualise the data that has been submitted to the system (F13). Citizens would like to visualise issues that have been reported to the system so that they can add more details to the issue or the progress of the issue resolution. Thus, crowdsensing systems must employ **effective and robust feedback visualisation systems**.
- There was an overall neutral rating for subjective norms which highlights that participants do not feel social pressure to participate in water resource monitoring (Section 4.4.2.3). The results of the hypothesis tests show that subjective norms have a significant influence in shaping behaviours (Section 4.4.2.6), therefore, project coordinators must develop programmes or marketing campaigns that incite community **pro-environmental behavioural change**.

4.5 Conclusions

The TPB was used to develop a conceptual model for water data submissions (Figure 4-4) that allowed the researcher to investigate citizens' intentions to participate in water resource monitoring for crowdsensing. The results of several hypotheses tests show that behavioural attitude, subjective norms and perceived behavioural control have a positive influence on a citizens' intention to participate in water resource monitoring. On the other hand, a citizen's past behaviour did not influence their intention to submit water data continuously even though citizens are more likely to report water issues if they have reported water issues before. The first contribution of this research reported on in this chapter is therefore the updated conceptual model for water data submissions that excludes past behaviour as a predictor of intention to submit water data (Figure 4-15). Past behaviour was excluded from the updated conceptual model due to the results of the hypothesis tests (Section 4.4.2.6) which state that there is no significant correlation between a citizen's past behaviour and their intention to submit water data.

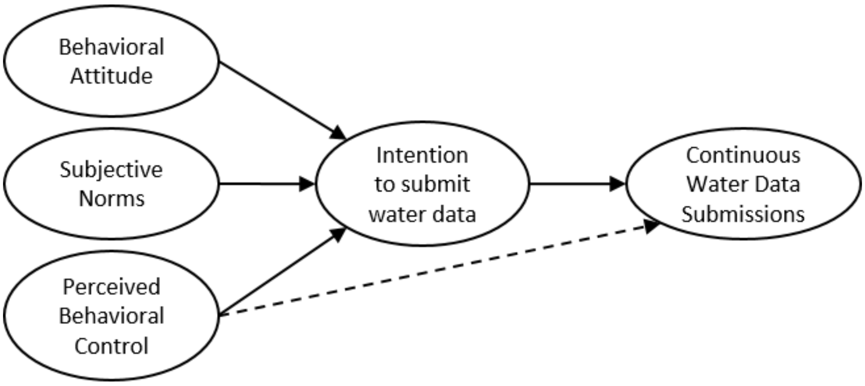


Figure 4-15: Updated Conceptual Model for Continuous Water Data Submissions (Author's Own Construct).

A second contribution from this chapter is the Framework of Motivational Factors for Crowdsensing (Figure 4-14). The results of the survey into citizens' perceptions into water resource monitoring show that citizens are mostly motivated by their sense of community and drive to keep the environment beautiful. The results also showed that the citizens would be willing to participate in water resource monitoring to help other people. Several guidelines are made regarding citizen participation in crowdsensing for water resource monitoring such as employing effective feedback mechanisms and incentive mechanisms based on different types of incentives. This chapter has therefore answered the following research question from a real-world perspective:

> **RQ1:** What are the problems faced by citizens and water service providers regarding crowdsensing and water resource monitoring as identified by literature and within a real-world context?

The Conceptual Model for Submissions of Water Data using TPB (Figure 4-4) and the Framework of Motivational Factors for Crowdsensing (Figure 4-14) inform the sociotechnical design of the Crowdsensing Method as they allow the researcher to investigate the social design considerations (Section 1.5.1). As illustrated in Figure 1-2, social design considerations such as perceptions, incentives and barriers are critical to developing the sociotechnical design for the Crowdsensing Method.

The Guidelines for Citizen Participation in Crowdsensing for Water Resource Monitoring (Section 4.4.4) serve as an addition to the sociotechnical design by providing some guidelines on how crowdsensing project coordinators can implement social design aspects in their crowdsensing systems. The guidelines are a significant contribution to the Crowdsensing Method as they can guide project coordinators on how to use the results of investigating potential participants' perceptions, incentives and barriers in the design of a crowdsensing system.

Figure 4-16 shows how the following contributions apply to the sociotechnical design of the Crowdsensing Method:

- A Conceptual Model for Submissions of Water Data using TPB (Figure 4-4).
- The Framework of Motivational Factors for Crowdsensing (Figure 4-14).
- Design Guidelines for Crowdsensing Systems (Table 3-4).
- Guidelines for Citizen Participation in Crowdsensing for Water Resource Monitoring (Section 4.4.4).

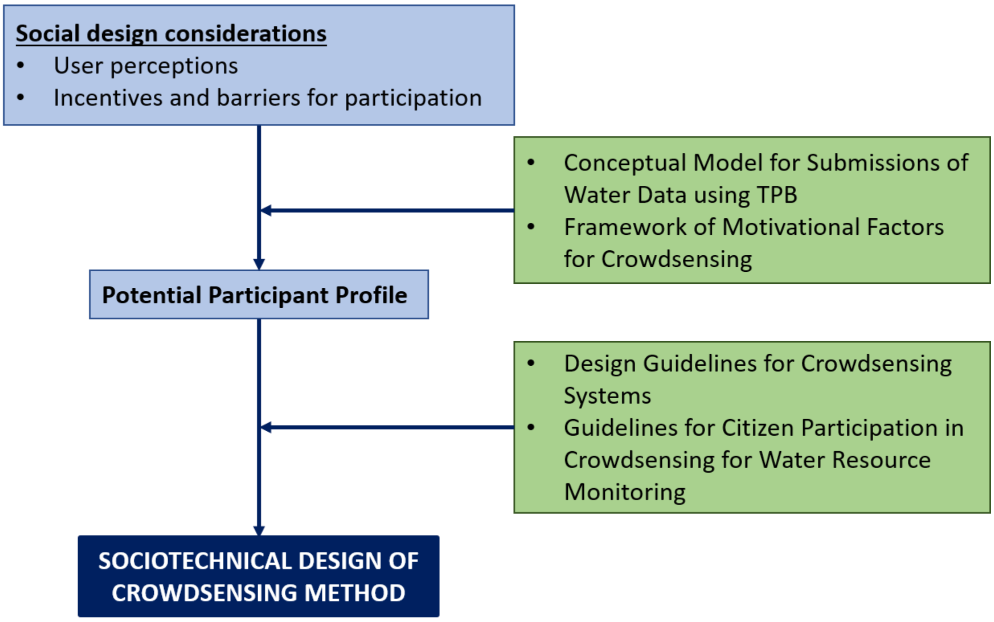


Figure 4-16: Developing the Sociotechnical Design for Crowdsensing Method (Author's Own Construct).

The social design considerations are used to develop a potential participant profile using the Conceptual Model for Submissions of Water Data using TPB and the Framework of Motivational Factors. The Guidelines for Citizen Participation in Crowdsensing for Water Resource Monitoring are used to guide the crowdsensing project coordinator in how to address the perceptions of the potential participants in the sociotechnical design. Figure 4-17 illustrates the updated Crowdsensing Method (Version 2) that includes the three additional contributions.

Therefore, the following two research questions have been partially answered by the literature review and the results of the survey:

> **RQ3:** What sociotechnical design can be used for a crowdsensing system that recruits and incentivises participants to collect data continuously for water resource monitoring?
>
> **RQ4:** What design guidelines can be used for crowdsensing for water resource monitoring to create a smart community?

The next chapter will report on the development of the recruitment and incentive policies for the Crowdsensing Method based on the results presented in this chapter.

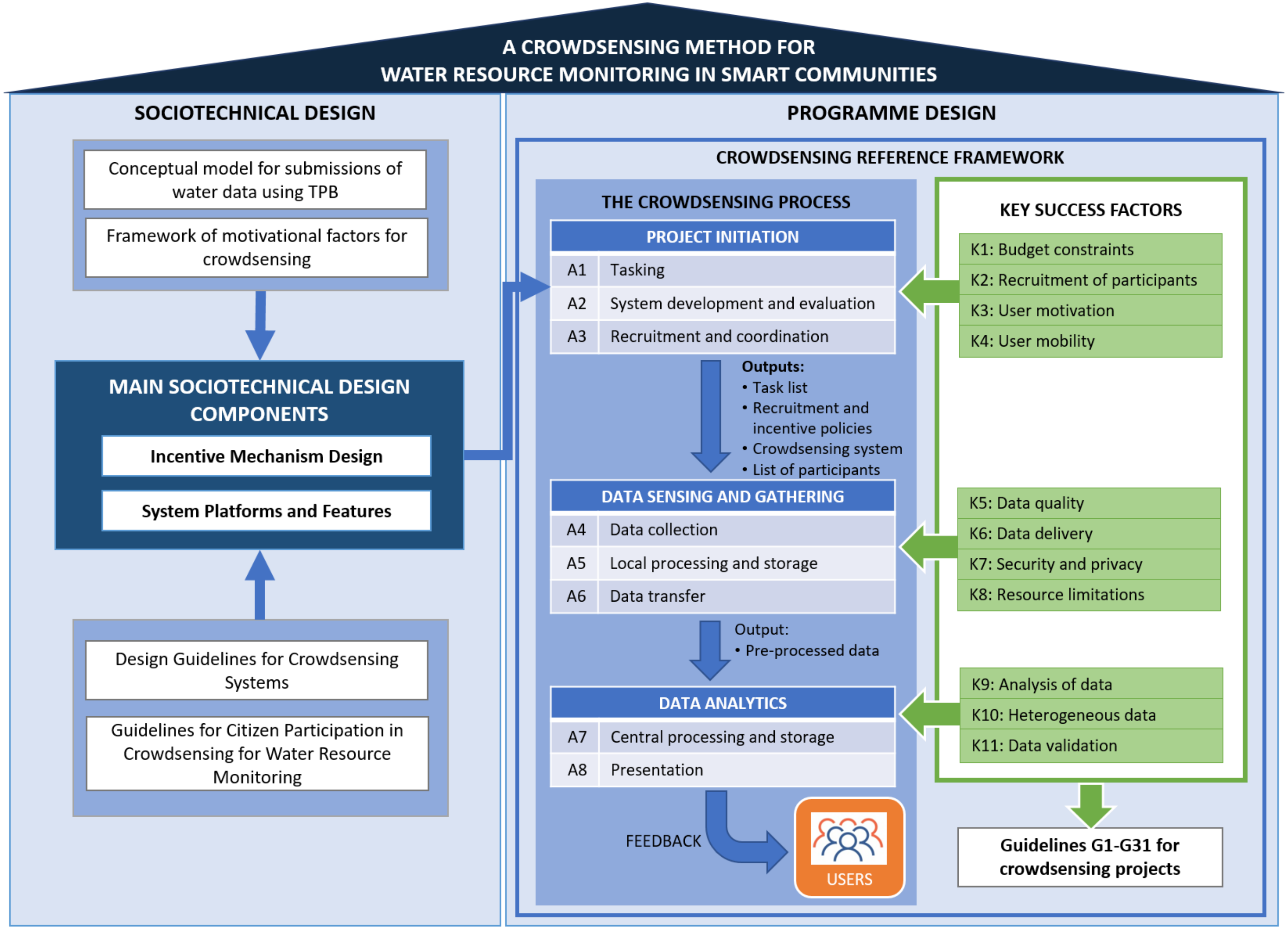


Figure 4-17: A Crowdsensing Method for Water Resource Monitoring in Smart Communities Version 2 (Author's Own Construct).

5 THE OVERSENSE POLICIES

5.1 Introduction

The previous chapter reported on an investigation into citizens' perceptions regarding crowdsensing for water resource monitoring to further expand the understanding of the problem and assist in developing the Crowdsensing Method. This chapter reports on the third iteration of the engaged scholarship research activities to develop the sociotechnical design of the Crowdsensing Method. This chapter will thus address the following research question (Section 1.4):

> **RQ3:** What sociotechnical design can be used for a crowdsensing system that recruits and incentivises participants to collect data continuously for water resource monitoring?

A significant challenge that crowdsensing projects face in the Crowdsensing Process, specifically the Recruitment and Coordination activity (A3), is the recruitment and motivation of citizens to continuously submit data (Section 5.2). Researchers need to use citizens' perceptions of the phenomena being studied by crowdsensing to develop recruitment and incentive policies (Section 5.3). Based on literature, this study proposes the OverSense recruitment and incentive policies that form part of the sociotechnical design of the Crowdsensing Method (Section 5.4). This study uses the NMBM data set to evaluate the recruitment of participants (Section 5.5). Several conclusions are made based on the activities conducted (Section 5.6). This chapter presents several deliverables that are theoretical and practical contributions to P and A:

- The OverSense Recruitment and Incentive Policies (Section 5.4).
- A Crowdsensing Method for Water Resource Monitoring in Smart Communities Version 3 (Figure 4-17).

The full structure of Chapter 5 is illustrated in Figure 5-1.

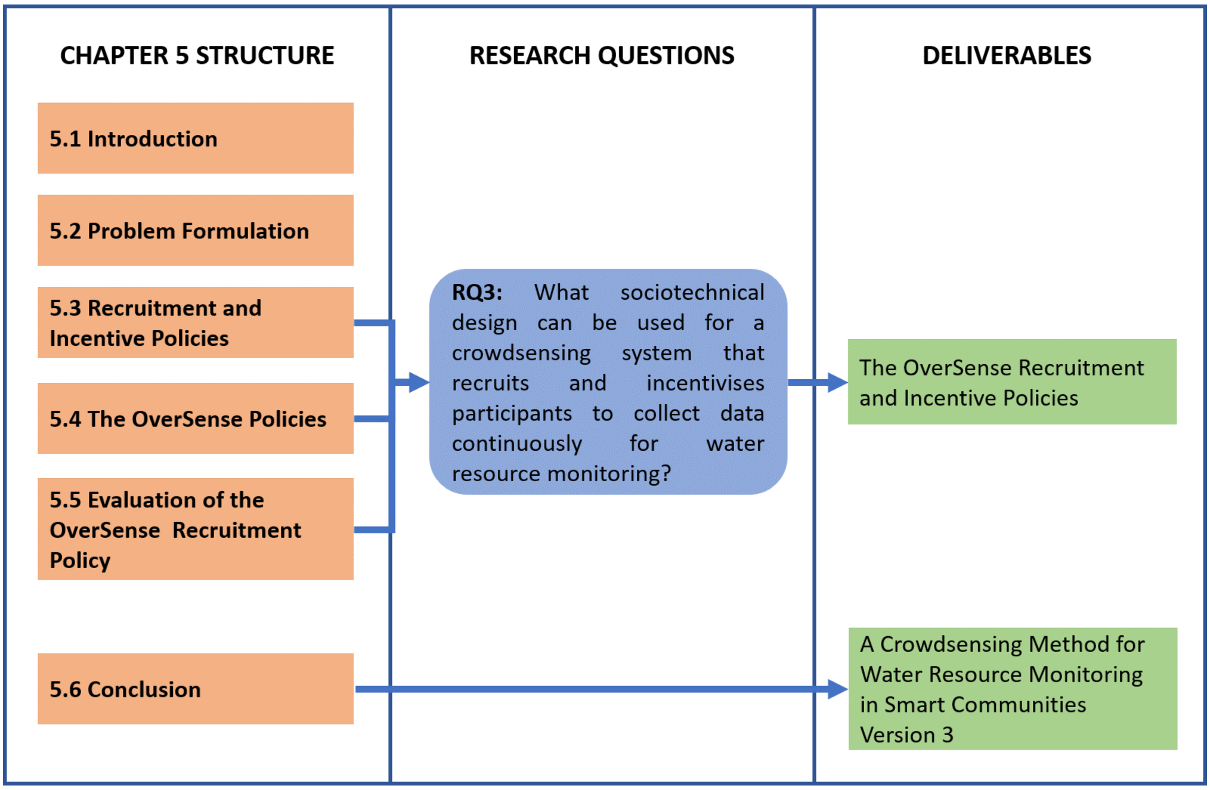


Figure 5-1: Structure and Deliverables of Chapter 5.

5.2 Problem Formulation

The social challenges identified in Section 3.4.1.2 all revolve around ensuring the crowdsensing project enlists a large number of participants that guarantee area coverage and data quality. Respondents of the survey into citizens' perceptions into crowdsensing for water resource monitoring (Section 4.4.3.2) reported that some of the barriers for their involvement in water resource monitoring is the belief that the submitted data will not be used (F1), that insufficient feedback from the coordinators is received (F13) and that participants are unsure of whether the issue has been reported or rectified already (F14). Project coordinators reserve a limited budget to recruit and reward participants for their participation in crowdsensing projects (Anjomshoa & Kantarci, 2018). It is vital for crowdsensing projects to have solid recruitment and incentive policies in place to minimise the costs and ensure that the participants recruited for the project will produce the highest possible quality of the analytics result. Thus, it is necessary to develop a sociotechnical design that addresses the challenges around the recruitment and coordination of participants.

To solve the problem of recruiting and incentivising participants to continuously participate in water resource monitoring, two subsidiary research questions were developed from ***RQ3:*** *What sociotechnical design can be used for a crowdsensing system that recruits and* *incentivises participants to collect data continuously for water resource monitoring?* The two questions are:

> **RQ3.1:** How can crowdsensing participants be recruited to monitor the progress of issue resolution?
>
> **RQ3.2**: How can participants be rewarded for their participation in crowdsensing projects with a service delivery focus?

The two subsidiary research questions initiated the third iteration of the engaged scholarship research activities (Figure 5-2).

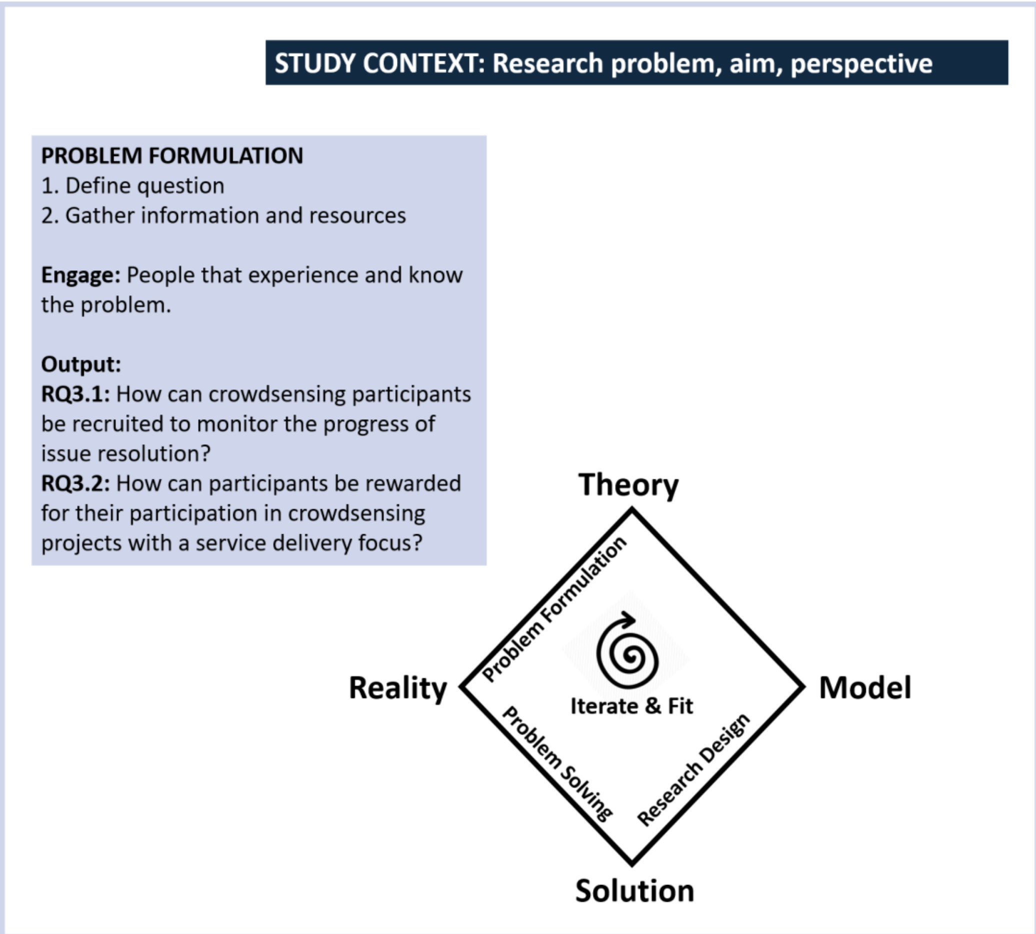


Figure 5-2: Problem Formulation for the Development of a Sociotechnical Design (Iteration 3).

5.3 Recruitment and Incentive Policies

Recruitment and incentive policies are a significant component of the sociotechnical design for the Crowdsensing Method because the policies around the recruitment and rewarding of crowdsensing participants must ensure citizens' continued willingness to participate in the data collection process to guarantee coverage and data quality (Jaimes, Vergara-Laurens & Raij, 2015). As shown in Figure 4-16, the recruitment and incentive policies, which are a significant component of the sociotechnical design, must be based on the potential participant profile to decipher how to recruit and motivate participants to participate in crowdsensing.

5.3.1 Related Work on Recruitment Policies

Requirements for participant selection vary from project to project. Campaign requirements may look at factors such a participant's social network affiliations, device capabilities and location. For example, Reddy *et al*. (2010) concentrate on the participants' reputation in the crowdsensing project and their availability. Reddy *et al*. (2010) define reputation by considering the participants' willingness to collect data given the opportunity, and their diligence in the data collection (in terms of relevance, quality and timeliness of the collected data). On the other hand, availability is learned from the participants' spatial and temporal coverage based on their mobility traces in the campaign coverage area. Hachem, Pathak and Issarny (2013) propose a cycle assignment framework that uses participants' current location and spatial coverage to predict their future locations in the next sensing cycle (or task). Hachem *et al*. (2013) use the prediction to select a minimum number of participants they expect to cover the target area in the cycle. Fiandrino *et al*. (2016) leverage participants' sociability and spatial distance between the tasks and the participants as criteria for the recruitment of participants. Sociability can be defined as the willingness of the participants to participate and contribute to sensing tasks.

More recently, Dai *et al*. (2018) selected participants based on the quality requirement of the task. Dai *et al*. (2018) propose Geo-QTI, a quality-aware truthful incentive mechanism for geographic crowdsensing. The Geo-QTI system platform publishes a total set of tasks, making each participant aware of tasks available for completion in their sensing coverage. Each participant can only complete tasks in their sensing coverage, which is determined by the participant's current location. After the total task set is published, each participant submits the tasks they are interested in performing to the platform and the amount of effort they are willing to put into completing the task. The platform then selects participants based on the quality requirement, which is the amount of effort required for the task such as the length of the sensing time or the number of sensing measurements. Geo-QTI's participant selection uses a greedy algorithm under the condition that the set of selected participants satisfies the quality requirements. iCrowd (Xiong *et al.*, 2016) uses a similar approach to Geo-QTI in considering the number of required samples in a certain subarea (coverage quality). The iCrowd framework uses historical mobility traces to select participants in order to maximise the overall coverage quality goal. iCrowd uses the depth *k* as the maximum number of measurements desired in each subarea and strives to achieve the highest *k*-depth coverage possible.

5.3.2 Related Work on Incentive Policies

After participants are selected using the recruitment policies, some crowdsensing systems use recruitment incentives to motivate the selected participants to participate in the crowdsensing (Wang, 2016). The participants can then be further rewarded depending on the data contributions they make (contribution incentives). Incentive mechanisms may utilise either recruitment and contribution incentives or use either of the two. For example, Lee and Hoh (2010) use virtual participation credit and recruitment credit as incentive mechanisms for user recruitment and participation. On the other hand, Zhang, Parkes and Chen (2009) consider a Markov decision process by providing limited rewards to influence the user's behaviour. The assumption, which they term environment design, makes limited changes to the user's environment to influence their behaviour. Musthag *et al*. (2011) use uniform, variable and hidden incentives to motivate participants. Uniform incentives are fixed amounts given to participants for completing a task. Variable incentives vary based on tasks while hidden incentives are only revealed when a task is completed. Musthag *et al*. (2011) reported that 62% of the participants were retained in the crowdsensing program and noted that participants prefer the variable approach.

To categorise the varied application of incentives in crowdsensing systems, Angelopoulos *et al*. (2014) offer several policies to reward the effort of participants for making data contributions:

- The **proportional incentive policy** recommends dividing the total of the residual reward budget by the tasks.
- The **participation-aware incentive policy** advocates providing high incentives at project initiation to attract the minimum number of participants then providing rewards conservatively to retain the existing participants.
- **The behavioural-aware policy** provides rewards based on the history of the participants' commitment to the project and their calculated trustworthiness.
- **Quality-aware incentive policy** rewards participants based on the quality of the data they contribute.
- The **location-aware incentive policy** rewards participants based on the location of their contribution.
- **Mobility-aware incentive policy** rewards the effort of the participant's mobility.

5.4 The OverSense Policies

This study aims to advance existing research works on recruitment and incentive policies for crowdsensing by proposing the OverSense Policies. The OverSense Policies consist of two policies, namely:

- A recruitment policy that identifies which participants must be selected to accomplish a specific task. This recruitment policy is generic and can be used in any crowdsensing project that is interested in selecting their participants based on their mobility traces and their loyalty and satisfaction with the system.
- An incentive policy that rewards participants based on factors such as the urgency level of the task, their response time and location of submission.

The OverSense Policies will be used to design the incentive mechanism which is one of the components of the sociotechnical design of the Crowdsensing Method (Figure 5-3). The OverSense incentive policy combines several policies (Zhang, Parkes & Chen, 2009; Lee & Hoh, 2010; Musthag *et al.*, 2011; Angelopoulos *et al.*, 2014; Wang, 2016) to provide a more comprehensive incentive policy. The Incentive Mechanism Design describes how the crowdsensing system will interact with the participants, as well as the policies and guidelines that will be used to recruit and motivate the participants to participate in the crowdsensing.

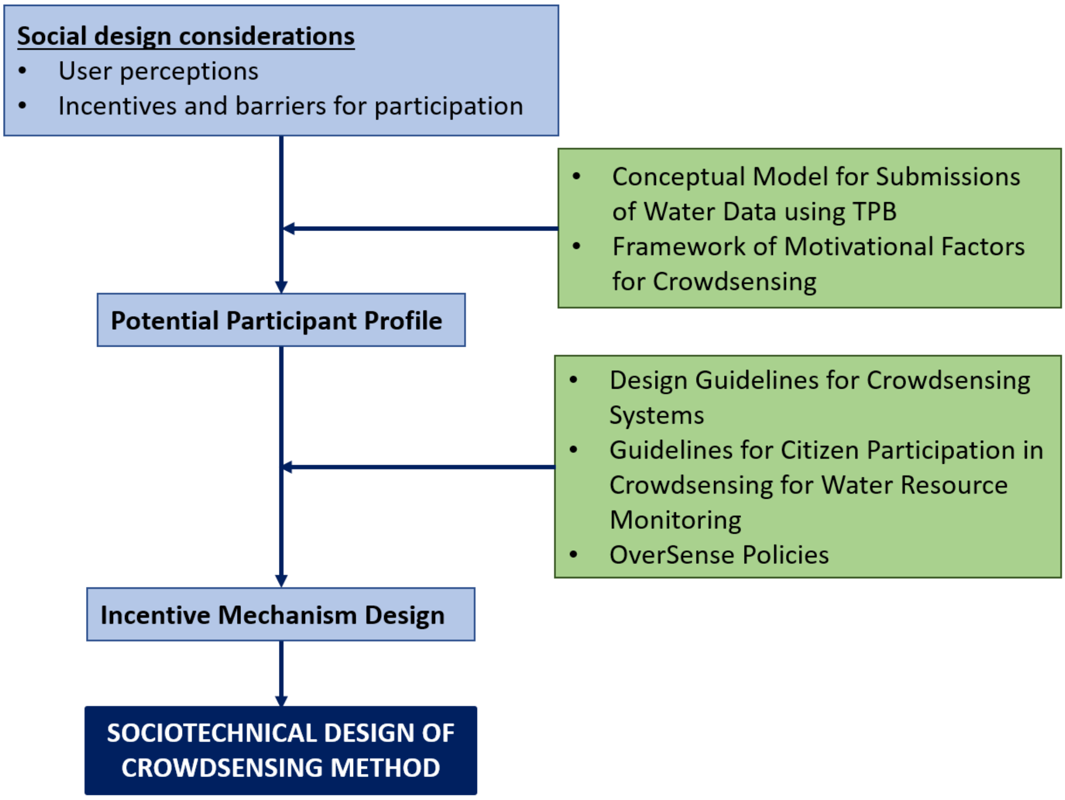


Figure 5-3: Sociotechnical Design of the Crowdsensing Method Version 2 (Author's Own Construct).

5.4.1 The OverSense Recruitment Policy

Figure 5-4 shows how the OverSense recruitment policy works. During the Task Classification phase of the recruitment policy, the crowdsensing system platform classifies tasks according to the privacy needs of the participant. The tasks refer to complaints that citizens submit to the crowdsensing system. The OverSense recruitment policy satisfies the Design Guidelines for Crowdsensing Systems (Table 3-4). For example, the tasks that are classified as public are opened up for collaboration, and any participant can explore and add more information to the task (D4 to D7). During the Participant Selection phase, a specific number of participants are selected from the system's database of past participants to visit the PoI and report the progress of the resolution of the issue. Lastly, the selected participants choose whether to accept or refuse to perform the task during the Task Allocation phase. After the participants accept and perform the allocated tasks, the system platform sends progress updates to the citizen who submitted the issue (D3).

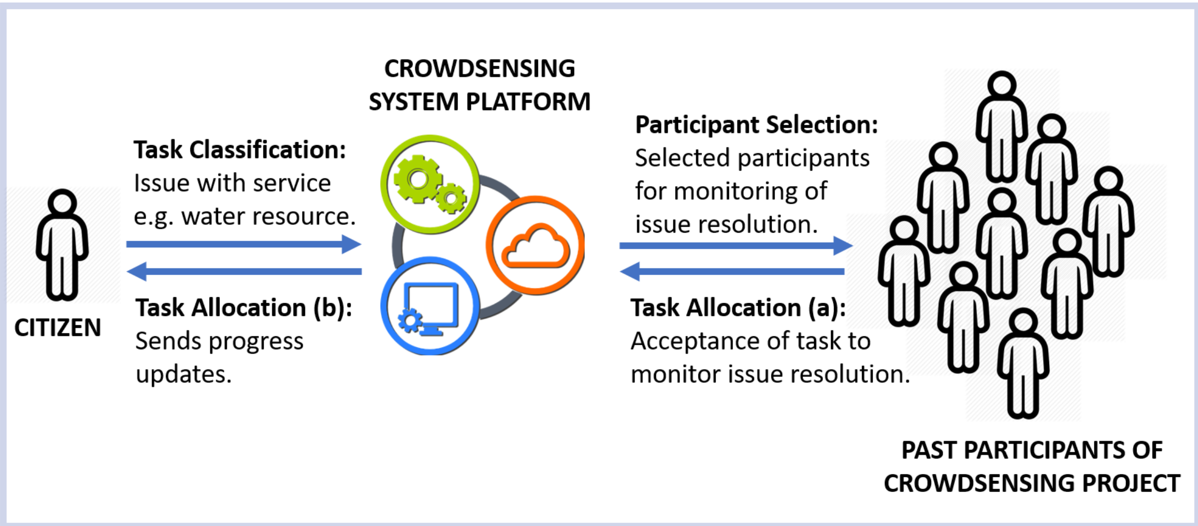


Figure 5-4: The OverSense Recruitment Policy (Author's Own Construct).

5.4.1.1 Formulas and Notations

Many studies (Reddy *et al.*, 2007; Kawajiri, Shimosaka & Kahima, 2014; Fiandrino *et al.*, 2016; Yang *et al.*, 2017) use formulas and notations to describe recruitment policies. This study follows this trend and Table 5-1 shows the notations that will be used to describe the OverSense recruitment policy.

NOTATION AND MEANING			
T_{all}	Set of all tasks	n	Identification number of each participant
t_i	Task i	F_n	Participant n's recruitment factor
N	Maximum number of elements in the set	L_n	Loyalty factor of each participant
g	Location of participant or task	D_n^i	Distance factor of each participant based on the location of task i
y_i	Type of task i: private or public	S_n	Satisfaction factor of each participant
$T_{private}$	Set of private tasks	D_{max}	Maximum allowable distance
T_{public}	Set of tasks publicised for collaboration	d_i	Distance between participants and task
R_{all}	Set of participants who have publicised tasks for collaboration: "requesters"	G_n	Set of locations of participant n
Q_i	Quality requirement of task i	W_{all}	Set of selected participants; "winners"
b_l	Popularity factor of location l	w_n	Selected participant n; $w_n \in W_{all}$
P_{all}	Set of all participants in the database of the crowdsensing system	A_n	Acceptance factor of each participant
p_n	Participant n	P'	Copy of the participants' set

Table 5-1: Notations and their Meanings.

5.4.1.2 Phase 1: Task Classification

One of the key success factors of crowdsensing is to ensure the privacy of the system users, therefore, guideline G18 recommends that participants must control their own privacy settings (Table 3-3). The OverSense recruitment policy takes inspiration from Geo-QTI (Dai *et al.*, 2018) to use task classification to separate tasks submitted by participants who want to keep their tasks private from tasks that do not require privacy. The total task set, with *N* number of tasks, can be denoted as $T_{all} = \{t_1, t_2, \ldots, t_N\}$. Each task, t_i, $i \in \{1,2, \ldots N\}$, is described by its geographical location g_i and a value y_i, which is a private type and is only known to the participant who submitted the task and the platform. The tasks in T_{all} are split into two sets:

- $T_{private} = \{t_1, t_2, \ldots, t_N\}$, a set of all the tasks that have been deemed private by the submitting participant. These tasks can only be completed by the project coordinators.
- $T_{public} = \{t_1, t_2, \ldots, t_N\}$, a set of all the tasks that have been opened to the public by the submitting participant. In this case, the participants who have made submissions are referred to as "requesters" as they are requesting information from other participants. The requesters set is denoted as $R_{all} = \{r_1, r_2, \ldots, r_N\}$. Each requester R_i has one or more tasks, $t_i \in T_{public}$ which they have submitted to the platform to be completed.

The platform then publishes the set T_{public}, ready for the selection of participants to complete the task.

5.4.1.3 Phase 2: Participant Selection

The Participant Selection phase involves identifying the quality requirements of the task and selecting the appropriate participants to recruit to perform the task.

Popularity Factors and Quality Requirements

Fiandrino *et al*. (2017) assign a popularity factor to each PoI as some locations in a city attract more people than others. Crowdsensing project coordinators need to be able to manage their issue resolution process to ensure that issues that affect many people should be dealt with as quickly as possible. The OverSense recruitment policy determines the quality requirement of a task based on the popularity factor of the location. Each task, $t_i \in T_{public}$ has a quality requirement, Q_i which is the number of participants that are required for the task to be accomplished. Each location in the sensing area is assigned a popularity factor, b_l, which is a real value within the range [0,1] depending on the number of submissions made from the location. Coordinators of crowdsensing projects must determine what quality requirements must be assigned to the range of popularity factors.

Once the parameters for the quality requirements and popularity factors are set, the crowdsensing system platform must be set to periodically request a set of participants to report the progress of the resolution of the issue $t_i \in T_{public}$. The selected participants must satisfy the set quality requirement Q_i. For example, if the project coordinators have decided that locations with a 0.4 popularity factor have a quality requirement Q_i of eight, the system only records the task t_i as successful when eight selected participants accept to perform the task and submit the required data. The platform selects participants for the performance of tasks from the system's database of past participants of the crowdsensing project. The set of all users in the database of the crowdsensing system is denoted by $P_{all} = \{p_1, p_2, \ldots, p_N\}$.

The Recruitment Factor

Inspired by the work done by Fiandrino *et al*. (2017), the OverSense recruitment policy uses a recruitment factor to select participants for crowdsensing tasks. Each participant's recruitment factor F_n is computed based on the participant's:

- **Loyalty** to the crowdsensing project.
- **Satisfaction** from their past experiences with crowdsensing service.
- **Distance** between their closest previous location and the location of the sensing task.

Loyalty and satisfaction with the system are selected as factors due to the results presented in Section 4.4.2, which state that participants that have reported before have a much higher intention rating than participants that have never reported before. As such, the study assumes that the higher the number of contributions the participant has made to the system, the more likely they are to accept tasks.

For each task, t_i, the recruitment policy selects participants with the highest recruitment factors from P_{all}. The crowdsensing platform uses the recruitment policy to compute the recruitment factor F_n of every participant p_n based on the three parameters, loyalty L_i, distance D_n^i and satisfaction S_n. The three parameters are unit-less and assume real values in [0,1]. Each participant p_n is defined in terms of their loyalty, distance and satisfaction (L_n, D_n^i, S_n). Therefore, for every participant p_n, the recruitment factor F_n is defined as:

$$F_n = \alpha \cdot L_n + \beta \cdot D_n^i + \gamma \cdot S_n$$

where the parameters α, β, γ are balancing coefficients that can take any real value in [0,1]. These parameters define the importance of each of the three criteria to compute the recruitment factor F_n. The parameters α, β, γ must equal unity, therefore, high values of a criteria (such as loyalty) will result in the prioritisation of participants with the highest loyalty in selecting participants for the task.

A. Calculation of Loyalty Factor

L_n represents the loyalty of the participant and is determined by the number of contributions the participant has made to the system. The platform computes the highest number of contributions made by a single participant and this number is used to convert the number of submissions made by the participant p_n into a real value between [0,1].

B. Calculation of Satisfaction Factor

Each issue that has been resolved by the project coordinators has a variable that denotes the number of days it took to resolve the issue. To compute a participant's satisfaction factor S_n, the platform computes the average resolution time of a participant's past submitted issues and converts it into a real value between [0,1].

C. Calculation of Distance Factor

An additional factor, D_n^i is used to compute a participant's recruitment factor, F_n. There are two methods to computing a participant's distance factor using their: 1) current location and 2) past locations. During participant selection for each task, the platform computes the distance between the participant's current location and the maximum allowable distance D_{max}. D_{max} is a constant value that is determined by the project organisers that limits the platform to only consider participants that are not located farther than D_{max} for the specific task. The distance between the location of the participant and the location of the sensing task is denoted as d_i and if $d_i > D_{max}$, the participant is not eligible for the task, t_i. In Figure 5-5, participants 1, 2 and 3 are not eligible to be selected for the task as they are outside the maximum allowable distance D_{max}. However, participants 4 to 7 can be considered to perform the task because they satisfy the criteria: $d_i > D_{max}$.

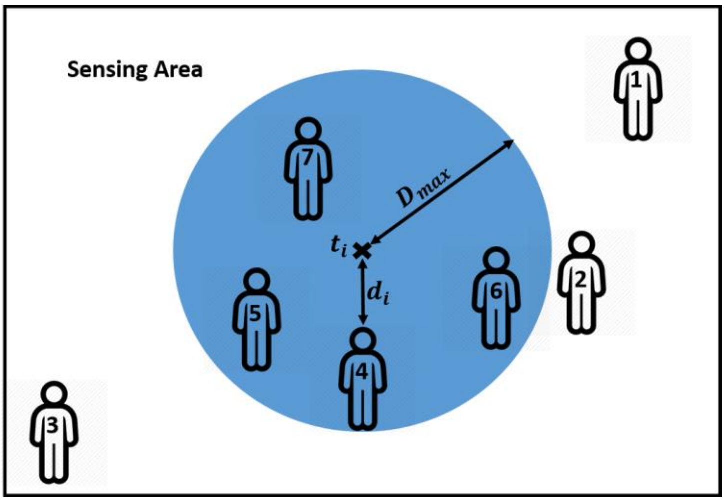


Figure 5-5: Distance Factor in Recruitment (Author's Own Construct).

The following formula is used to compute the distance factors of the eligible participants:

$$D_n^i = 1 - (\, d_i / \, D_{max})$$

If the number of participants recruited for the task is less than the quality requirement (number of required participants), the platform uses participants' mobility patterns. Every participant has a set of locations they have made submissions from, denoted as G_n = {g_1, g_2, …, g_N}, with N being the total number of locations. Each location $g_j \in G_n$ is unique. This method of using previous locations uses the same formula to get the distance factor: $D_n^i = 1 - (\, d_i / \, D_{max})$. However, instead of using the participant's current location for d_i, the platform selects the location, $g_j \in G_n$, that satisfies the following requirements to become d_i:

- The distance between g_j and the sensing task is not more than D_{max}.
- g_j has the highest distance factor of all the locations in the G_n set.

5.4.1.4 Phase 3: Task Allocation

After determining the participants to recruit for the task t_i, the platform must allocate and send the tasks through to the set of the selected participants, denoted by $W_{all} = \{w_1, w_2,$ …, $w_N\}$. Each selected participant w_n can decide whether to accept or refuse the task. To satisfy Q_i, the platform contacts the participants with high recruitment factors to increase the probability of the participants accepting the task. When a participant refuses a task, the participant is removed from W_{all} and the platform selects the participant with the highest recruitment factor who has not been selected for the task yet. Following the work done by

Dai *et al*. (2018), the platform uses a greedy algorithm to select participants and ensure Q_i is met as is provided in the Task Allocation Algorithm below.

Task Allocation Algorithm (P_{all}, t_i, Q_i)

$W_{all} \leftarrow \emptyset,\ P' \leftarrow P_{all}$
for each $p_n \in P_{all}$ do
    $F_n \leftarrow$ compute(L_n, D_n^i, S_n)
while $P' \neq \emptyset$ do
    for all $p_n \in P'$ do
        $W_{all} \leftarrow$ max($p_n : F_n$)
end
return W_{all}

Participants with high loyalty and satisfaction factors are more likely to accept the task, thus, acceptance of the task is based on the participant's loyalty and satisfaction factors. The acceptance factor A_n is modelled as a logarithmically increasing function (Fiandrino *et al.*, 2017):

$$A_n = \log(1 + L_n) + \log(1 + S_n)$$

5.4.2 OverSense Incentive Policy

The OverSense incentive policy uses the environment design concept (Zhang, Parkes & Chen, 2009) to dynamically compute rewards and provide variable rewards to influence participants' behaviour. To adhere to the budget constraints using the environment design concept, the OverSense incentive policy uses the logic of the participation-aware incentive policy (Angelopoulos *et al.*, 2014). The policy provides high rewards to new participants then provides rewards conservatively to retain the participant. The rewards provided to retain participants are calculated based on the participant's history in the project and the quality of their submitted data, in line with the behavioural-aware and quality-aware policies (Angelopoulos *et al.*, 2015, 2014). Based on the offered reward, each participant decides on whether they will participate in the crowdsensing. The reward that a participant receives for their completion of a task depends on four main factors:

- **Response time:** how long it took the participant to complete the task from the time they were selected by the platform.
- **Popularity factor:** the lower the popularity factor of the PoI, the higher the reward (location-aware incentive policy). The rewards are higher in less popular locations to increase their popularity.
- **Distance factor:** the lower the distance factor, the greater the reward to provide higher rewards to participants who have travelled long distances (location-aware incentive policy).
- **Urgency level of task:** determined by project coordinators.

Section 6.2.2.1 describes how the OverSense recruitment and incentive policies aid in the development of the sociotechnical design for the Crowdsensing Method.

5.5 Evaluation of the OverSense Recruitment Policy

Many researchers use simulation experiments to assess the performance of crowdsensing systems because it is difficult to perform experiments in the real world as crowdsensing involves a high number of participants (Fiandrino *et al.*, 2017). Simulation experiments, therefore, provide researchers with the ability to evaluate their recruitment and/or incentive policies. This study used simulation experiments as an empirical method to evaluate the performance of the OverSense recruitment policy. Due to time limitations, the researcher could only evaluate the recruitment policy and not the incentive policy, since an incentive policy needs to be evaluated over several years to see how citizens interact with the rewards system and how adjusting the rewards affects their motivation. Therefore, the research design for Iteration 3 used the simulation experiments to evaluate the OverSense recruitment policy with the NMBM data (Figure 5-6).

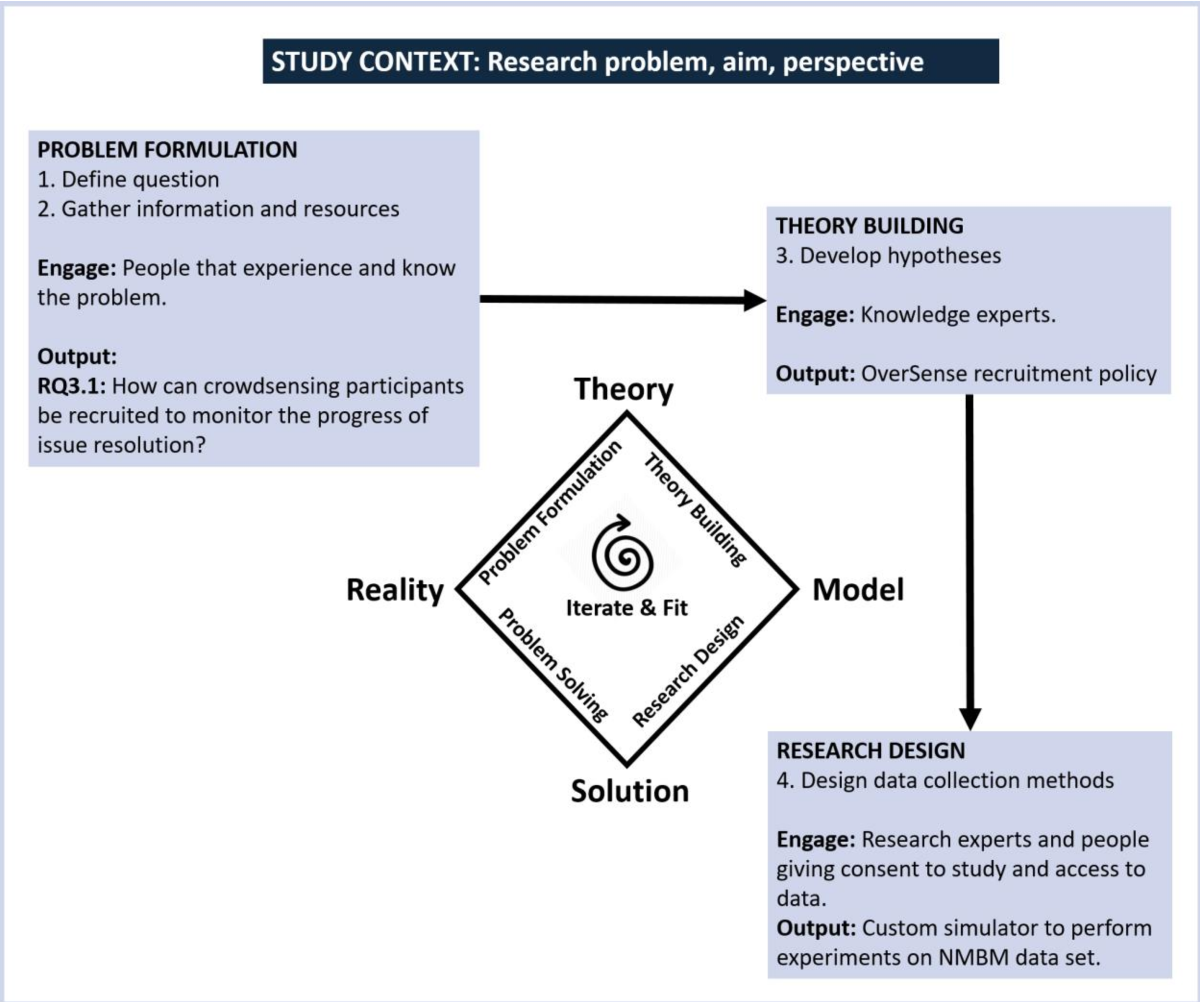


Figure 5-6: Research Design for Iteration 3 of Engaged Scholarship Research Activities.

The researcher built a custom simulator that allowed the researcher to perform experiments in an environment that mimics the real world. The simulation experiments evaluated the recruitment policy using the NMBM data set, since the NMBM was used as a case study that is experiencing problems that are representative of the real-world problematic situation (Section 2.4.2.4).

5.5.1 Data Pre-processing

The NMBM was able to provide the researcher with 434,173 records of complaints data dated from 1 January 2014 to 22 May 2018. However, only 390,066 records of this data were water complaints. This study differentiates between a water complaint and water issue because a complaint is the record of a citizen complaining about a water issue. A summary of the content of each water complaint record is provided in Table 5-2.

DATA FIELD	DESCRIPTION	TYPE
Callerlog_No	Required identifiers	Integer
Complaint_Date	Complaint data content and identifiers	Integer
Complaint_Time		
Allotment	Location data	String
Street		
House_No		Integer
Complainant	Complaint data content	String
Tel_No		
Call Operator Comment	Complaint data content	
Complaint_Type	Complaint category	
Directorate		
Investigation_No	Required identifier	Integer
Inspector_Comment	The progress of issue resolution	List of strings
Jobcard_No	Identifier; can be null if the job completed is at investigation and the job card is never created.	Integer
Jobcard_Comment	Comment on job performance	String
Complaint_Status	Job completed at investigation, with job card or still outstanding.	String

Table 5-2: Structure of the NMBM Water DataSet.

Each record has the Caller_Log number, as well as the date and time the complaint was submitted by the caller (i.e. the citizen) as the primary key. Each record is supposed to have location data describing the location of the water issue. Location data is described by the area/town (Allotment), street and house number (if applicable). Each record is also supposed to have the details of the citizen making the complaint (Complainant), specifically their name and telephone number. The Complainant field does not always have to be an individual; the complainant can also be an organisation such as a group home or company. The call operator comment field records the call operator's description of the water issue and the call operator files the type of complaint under Complaint_Type and Directorate.

One shortfall of the hotline recording process is that the water complaints and details of resolution are manually recorded by municipality employees. Resolutions made to issues submitted through the mobile application are also manually recorded by the inspectors and other NMBM employees. The manual recording process leaves the data with many missing values, inconsistencies and noise, therefore, it was impossible to run complex analyses without first performing deep data pre-processing and cleaning. In addition, data sourced from the mobile application could not be distinguished from data sourced from the telephone hotline. The researcher could not assume that if certain fields such as Call Operator Comment were blank, then the records were from the mobile application because of the large number of records with missing values.

A significant amount of effort was put into cleaning the data to get it ready for analysis. Data gaps in certain data fields were unacceptable as those fields were required for analysis purposes. The mandatory fields were the required identifiers, location data, complainant name, complaint category, and investigation and job card comments. Some records did not have any location data thus the issues were left unresolved. In some cases, the issues did not have any job or inspection records signifying the resolution of the issue. Complaint records with data gaps in the mandatory fields were discarded from the data set using the Pandas Python library and Excel analysis tools.

The most difficult task in the data pre-processing was identifying the dates when issues were resolved. The investigation and job card comments provided details on the progress of issue resolutions and each comment added was supposed to be dated. Comments for each complaint were concatenated together as one string without a strict order in terms of the date the comment was added. In addition, not all comments had resolution dates. As such, some records did not have details on if, or when, the issue was rectified. It was pertinent for the purposes of this study to have a resolution date for each record in the data for analysis and as such, there was a need to search through every comment string to identify if the issue was resolved and when it was resolved. All the records that did not have resolution dates were removed from the data set. However, the remaining dataset (390,066 records) was enough for analysis purposes.

5.5.2 Analysis of NMBM Data Set

A comparative analysis of the number of complaints per year (Figure 5-7) revealed an increase in complaints from 2014 to 2016. There was an 87% increase in the number of complaints from 2014 to 2015 while there was a 7% increase from 2015 to 2016. However, the number of complaints per year declined by 32% from 2016 to 2017. It was difficult to project the increase or decrease of complaints in 2018 since only the first month's data was received for 2018 (Table 5-3).

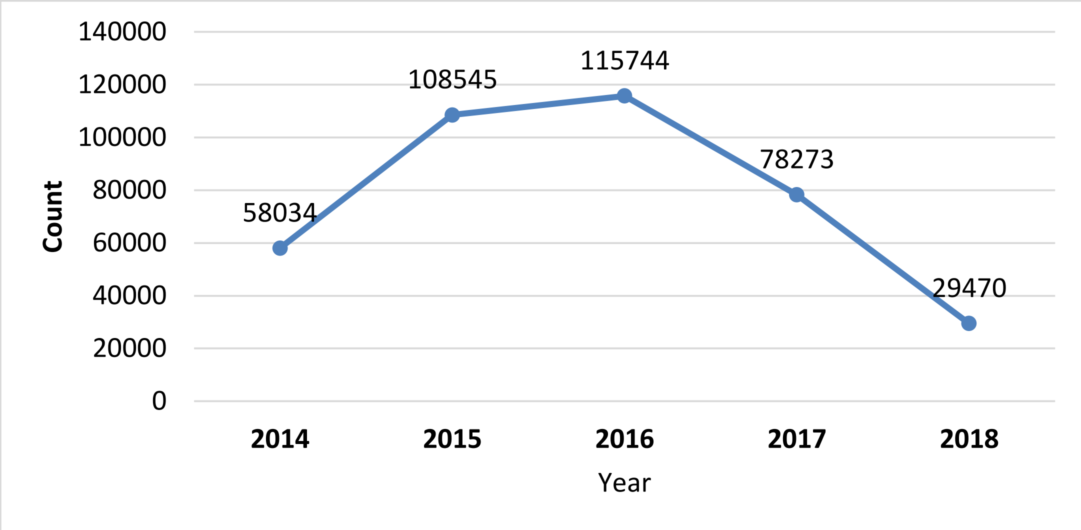


Figure 5-7: Complaints per Year.

MONTH	2014	2015	2016	2017	2018	TOTAL
Jan	5 631	4 822	8 899	8 833	6 509	**34 694**
Feb	4 802	4 553	10 348	6 286	6 060	**32 049**
Mar	4 826	5 405	10 730	6 962	5 955	**33 878**
Apr	4 333	4 923	10 798	5 238	6 189	**31 481**
May	4 661	5 258	5 522	7 157	4 757	**27 355**
Jun	4 713	4 658	7 955	6 066	-	**23 392**
Jul	5 727	18 852	7 730	7 057	-	**39 366**
Aug	5 083	33 308	19 772	7 422	-	**65 585**
Sep	4 925	8 764	8 430	6 741	-	**28 860**
Oct	5 275	7 610	8 962	5 902	-	**27 749**
Nov	4 262	6 406	9 396	5 393	-	**25 457**
Dec	3 796	3 986	7 202	5 216	-	**20 200**
TOTAL	**58 034**	**108 545**	**115 744**	**78 273**	**29 470**	**390 066**
% increase per year	**-**	**87%**	**7%**	**-32%**	**-**	

Table 5-3: Count of Complaints per Month and Year.

Table 5-4 shows the number of complaints per year categorised by the status of resolution while Figure 5-8 illustrates the number of complaints by directorate. The resolution rate was as high as 98% in 2014 with only 2% of the complaints left outstanding by the end of the year. However, the resolution rate dipped to 68% in 2015 and then 67% in 2016. The resolution rate improved in 2017 with a 17% increase to 84%. The data shows a large number of complaints (n=24,489) rejected by the NMBM employees for various reasons such as incomplete location data and issues not under the jurisdiction of the municipality (leaks on private property).

	RESOLVED		OUTSTANDING		REJECTED		NULL		TOTAL	
	n	%	n	%	n	%	n	%	n	%
2014	56 759	98	1 261	2	14	1	-	**0**	**58 034**	**15**
2015	74 017	68	22 324	21	12 202	11	2	**1**	**108 545**	**28**
2016	77 699	67	27 256	24	10 789	9	-	**0**	**115 744**	**30**
2017	65 413	84	11 604	15	1 253	2	3	**1**	**78 273**	**21**
2018	21 862	74	7 365	25	231	1	12	**1**	**29 470**	**8**
TOTAL	**295 750**	**76**	**69 810**	**18**	**24 489**	**6**	**17**	**1**	**390 066**	

Table 5-4: Count of Complaints categorised by Resolution.

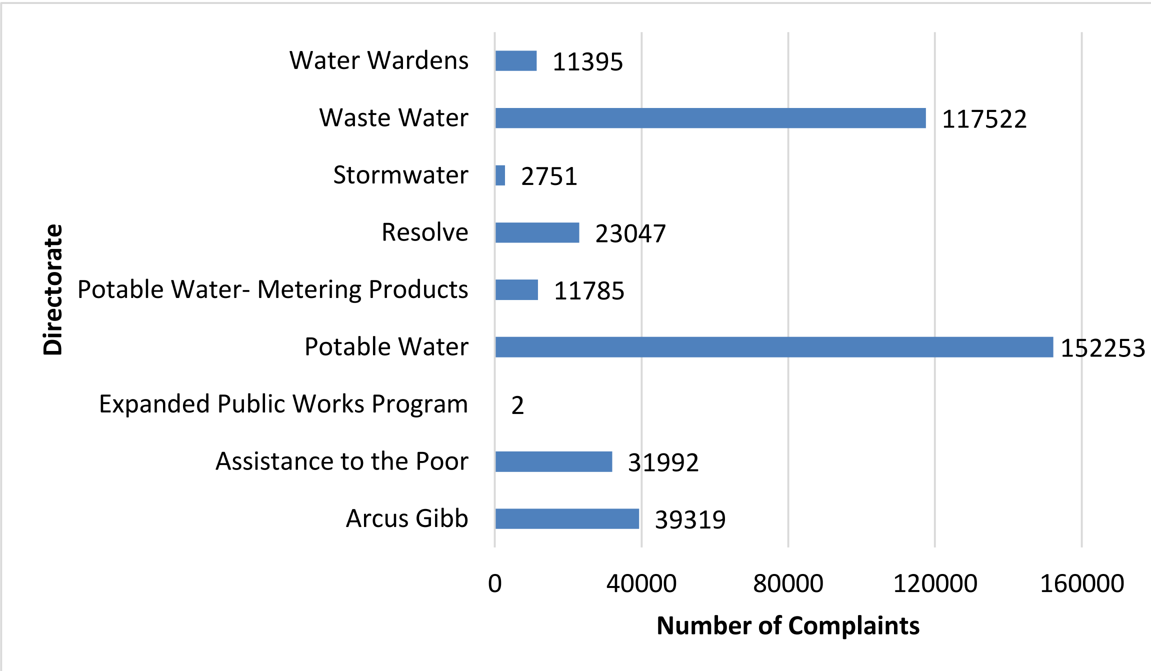


Figure 5-8: Complaints by Directorate.

5.5.3 Simulation Experiments

The simulation experiments were only run on the 2018 data. Although the 2018 data was not a full set of 12 months of data, there were still sufficient records for simulation and it was the most recent set of water data from citizens.

5.5.3.1 Experiment Design

For evaluation purposes, the number of tasks that required monitoring by other citizens (T_{public}) was limited to 25. The 25 tasks were a random sample of complaint records from the 2018 NMBM data as the tasks represented complaints submitted in the real-world. There were no set parameters (such as location) for the selection of the tasks to emulate the real-world scenario where the project coordinators cannot predict where the tasks generate from. Since the NMBM dataset only provides street names, the coordinates of the locations of the tasks and participants were obtained from an open source address validation tool that uses the Google geocoding engine to provide coordinates for street names (Figure 5-9).

Figure 5-9: Locations of Random Sampled Tasks (Author's Own Construct).

A further sample of complaint records was sampled from the 2018 NMBM data to generate a set of 100 participants for the set P_{all}. Only 100 participants were used for P_{all} as recommended by a statistician at the Nelson Mandela University who stated that 100 participants were enough to simulate the real-world scenario and develop conclusions. Engaged scholarship allows for the engagement of research experts in the Research Design activity thus, the statistician's knowledge of research is used in this study.

The study assumed that the allowable distance for a participant to be considered eligible for contribution (D_{max}) to each task t_i was set to five kilometres (5000 meters), as five kilometres is still within walking distance for a participant to complete their assigned task. For each task, the simulator computed a set of eligible participants W_{all} that satisfy the criteria: $d_i \leq D_{max}$. For the experiments, all tasks in T_{public} are assumed to have a quality requirement Q_i of 10. Therefore, for a task to be classified as accomplished, 10 participants from W_{all} must accept to perform the task.

5.5.3.2 Evaluation using Experimental Methods

Three methods were used to evaluate the recruitment policy. The first two methods did not include the OverSense policy and were used to compare the effectiveness of participant recruitment using the OverSense policy to other types of recruitment policies. For each method, three experiments were run in the simulator where a set number of participants were randomly selected from W_{all} to perform each task t_i. Out of the 25 sampled tasks, only 19 can be accomplished with each task having 10 participants from W_{all} accepting to perform the task. An experiment was deemed successful if ten participants out of the participants who were selected accepted the task. In the simulated environment, participants are referred to as "selected" if they are selected to perform the task and "recruited" when they accept the task.

Method 1: Random Participant Selection

The first set of experiments used a random method of participant selection that selects participants arbitrarily, without considering any factors such as their distance to $t_i(d_i)$, mobility patterns or past experiences with the crowdsensing system. Figure 5-10 shows the number of participants that were selected and recruited using random participant selection. When 10 participants were selected, no task was able to satisfy the quality requirement Q_i of 10 participants (a). Thus, no tasks were accomplished for that experiment. When 15 random participants were selected, only ten tasks out of the accomplishable 19 tasks were accomplished, which is only 40% of the tasks (b). The target of 19 accomplishable tasks were only accomplished if 20 participants were selected (c). The results show that as the number of selected participants increase, more tasks are accomplished.

Method 2: Participant Selection based on the Distance Factor Only

The second set of tasks only used the distance factor to select participants. In this regard, participants were selected based on their proximity to the PoI. Figure 5-11 shows the results of the experiments using the distance factor to select participants. Firstly, for each task t_i, 10 participants with the highest distance factors (i.e. closest to the location of t_i) were selected to perform the task (a). For each of the tasks, the quality requirement was not met for each of the tasks, thus, no tasks were accomplished. When the 15 closest participants to t_i were selected, only 48% (n=12) of the 25 tasks were accomplished (b). When 20 participants were selected, only 18 of the 19 accomplishable tasks were accomplished (c), which shows that selecting participants randomly (the previous method) accomplishes more tasks (n=19) as compared to using the distance factor (n=18). However, both methods use a large amount of resources because 20 participants will have to be selected to accomplish at least half of the tasks. In a real-world situation where 8000 water issues can be submitted in a month, the project coordinators would require many computing resources to support the crowdsensing system. In addition, most of the selected participants refuse the tasks which further wastes resources.

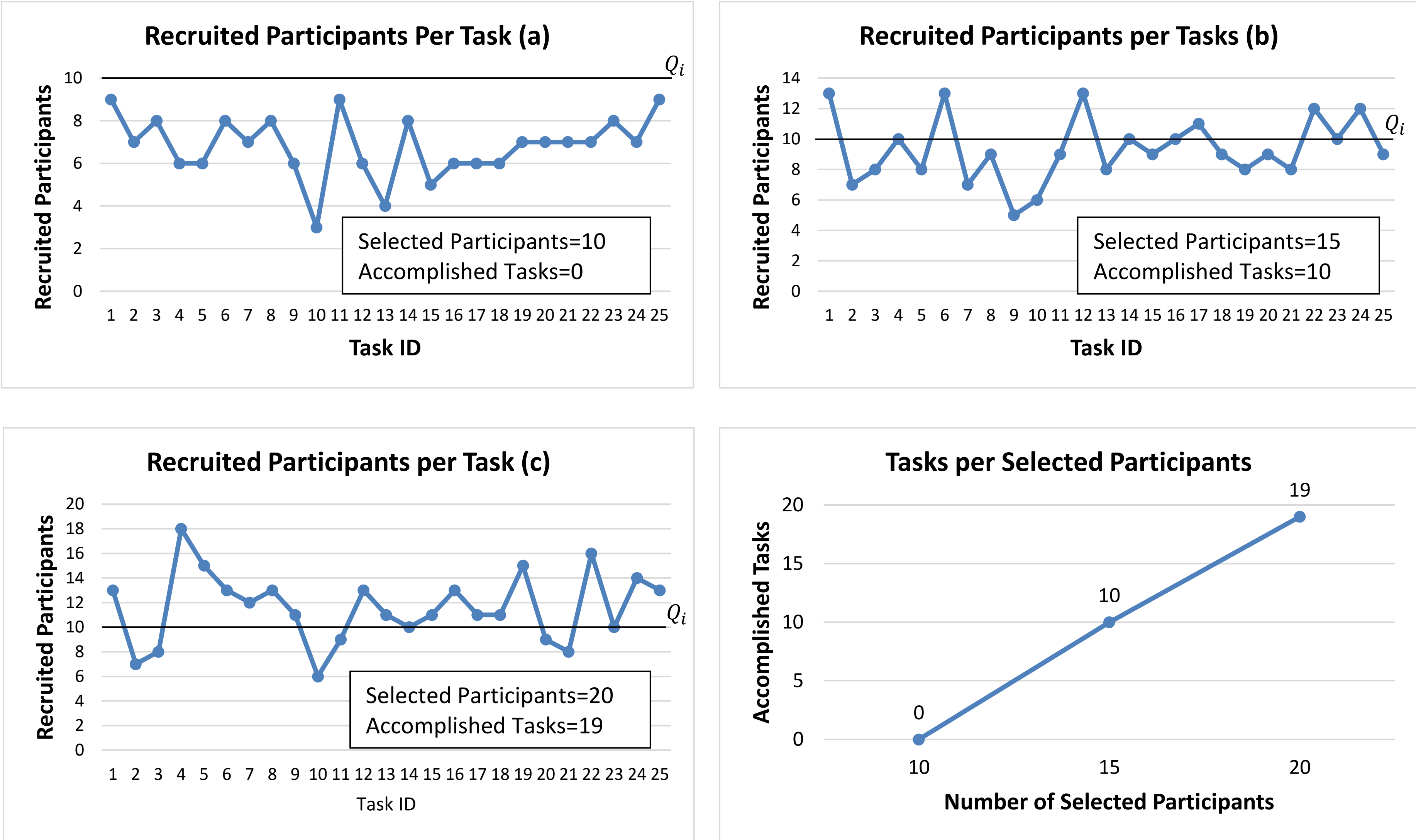


Figure 5-10: Results of Participant Selection using the Random Method (N=100).

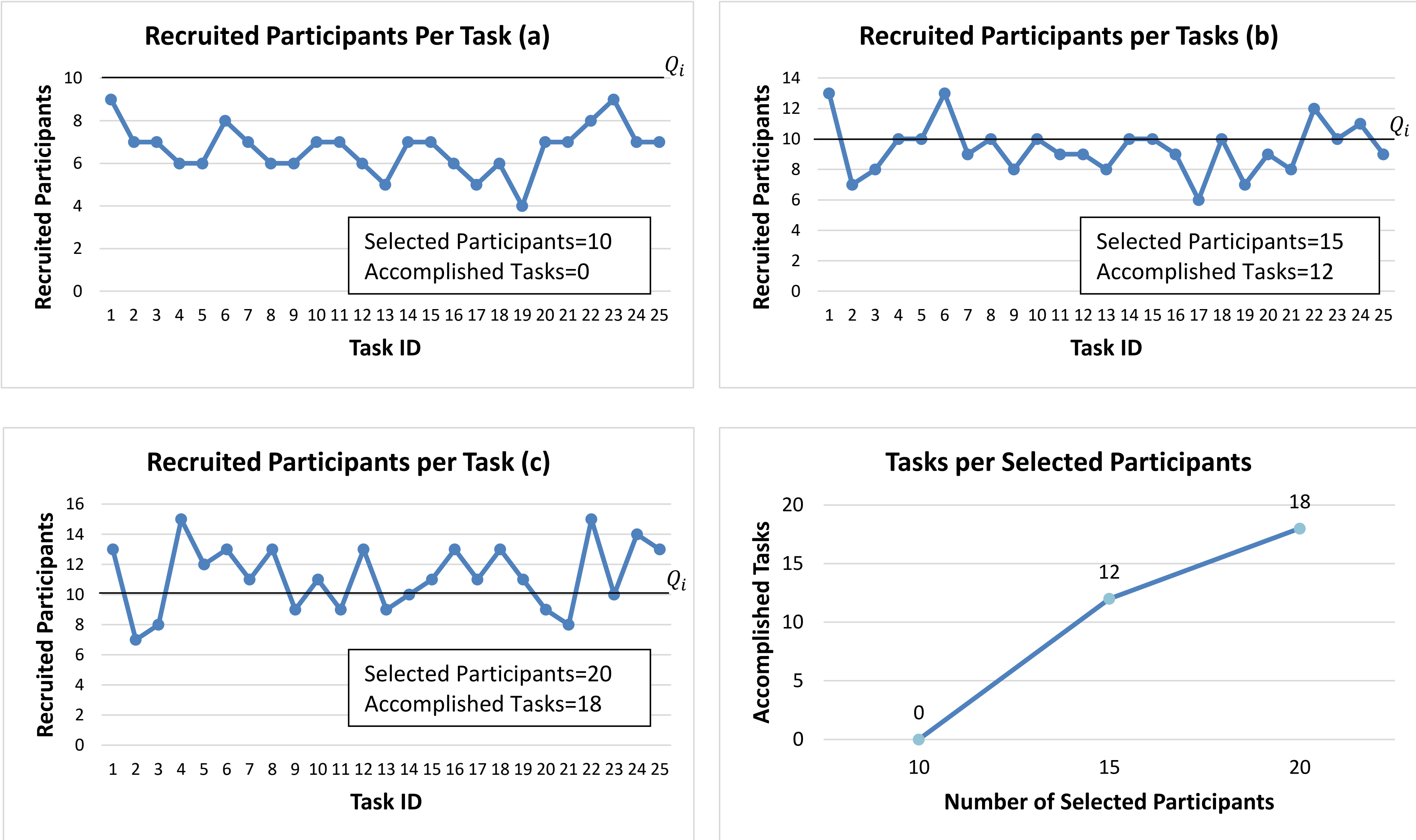


Figure 5-11: Results of Participant Selection using the Distance Factor only (N=100).

Method 3: Participant Selection using the OverSense Recruitment Policy

The third set of experiments was conducted using the OverSense recruitment policy to select participants. The motivation to use the OverSense recruitment policy is that the recruitment policy uses participants' recruitment factors to select the best candidates to ensure task completion. The policy uses the participant's loyalty, satisfaction and distance to the task to ascertain their recruitment factor (Section 5.4.1.3).

The OverSense recruitment policy selects participants greedily and the required number of participants with the highest recruitment factors first, and then selects one additional participant with the highest recruitment factor from the remaining participants to replace each selected participant that refuses a task. This method saves resources because it strives to make the locally optimal choice at each stage with the intent of finding a global optimum by always selecting the participants with the highest recruitment factors at each stage to accomplish the quality requirement, as quickly as possible. For the first stage of the OverSense recruitment policy, the number of participants that will satisfy the quality requirement with the highest recruitment factors are selected and contacted to perform the task. When a participant refuses to accept the task, the next participant with the highest recruitment factor is selected. This is done until the quality requirement is met.

In the experiments performed, when 10 participants with the highest recruitment factors were selected for each task, 13 tasks were accomplished. In comparison, the previous two methods were not able to accomplish any tasks when 10 participants were selected (Figure 5-12). The results show that that the OverSense recruitment policy performs better than the random or distance method because it guarantees that at least 50% of the tasks will be completed if the exact number of participants that will satisfy the quality requirement are selected.

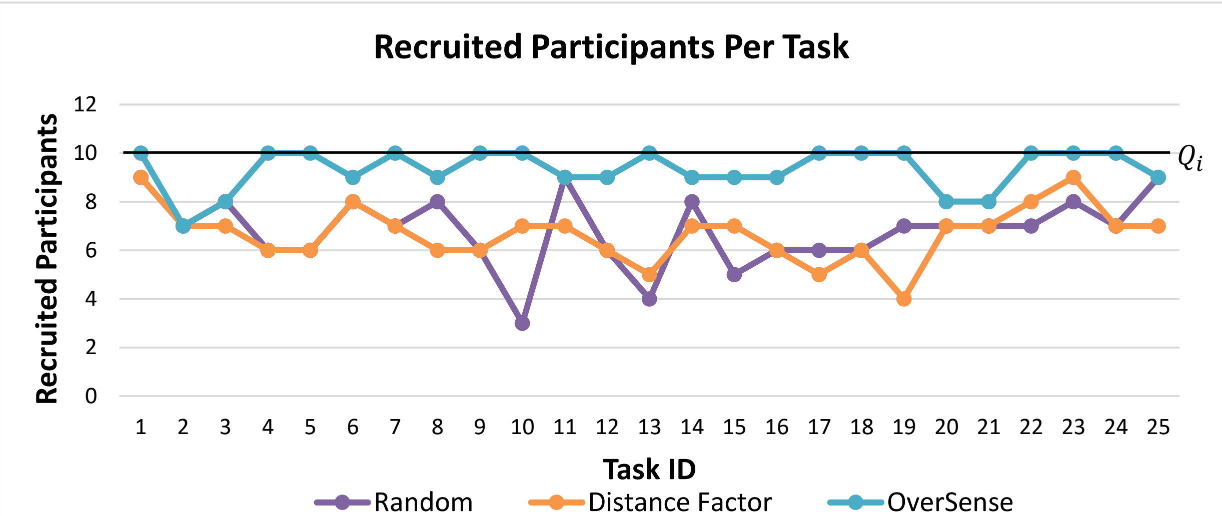


Figure 5-12: Comparison of Recruited Participants per Task across Methods (N=10).

Fiandrino *et al*. (2017) propose a performance metric to evaluate the effectiveness of a recruitment metric called User Recruitment Effectiveness (URE). URE defines the effectiveness in terms of the number of selected participants that are actually recruited. The formula for URE is:

$$URE = \frac{\mathbb{E}N^r}{\mathbb{E}N^s}$$

where $\mathbb{E}N^r$and $\mathbb{E}N^s$are the average numbers of recruited and selected participants respectively. The URE metric also assumes real values in the range [0, 1] and values close to 1 indicate efficient recruitment policies. As shown in Figure 5-13, the OverSense policy has the highest URE values of the three methods ranging from 0.7 to 0.8. With the OverSense policy, more than half of the 25 tasks (n=13) have a URE of 1, indicating that all selected participants were recruited. On the other hand, the random and distance factor method have URE values ranging from 0.3 to 0.9 with at least 40% of the tasks falling below or equal to 0.6. The average URE of all 25 tasks for the random and distance methods are 0.68 and 0.67 respectively while the average URE for the OverSense policy is 0.93. These results show that the OverSense policy is approximately 30% more efficient than the other methods.

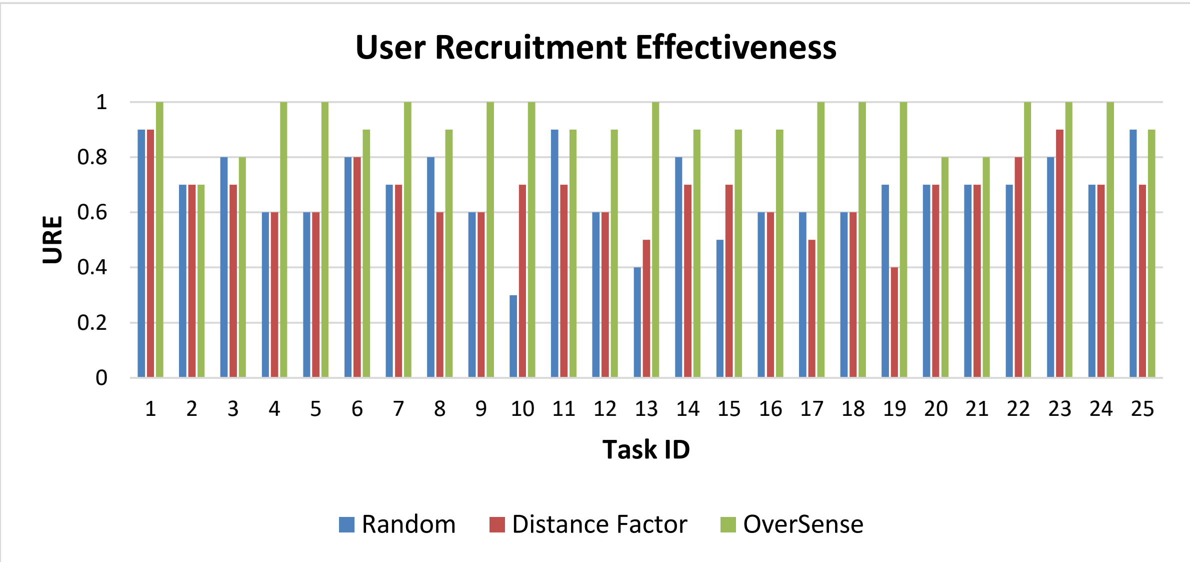


Figure 5-13: URE of the Methods.

Another benefit of the OverSense recruitment policy is the use of the greedy algorithm to select participants. The greediness of the policy ensures that the system only contacts enough participants to satisfy the quality requirement. Since this study is investigating what recruitment policy would be the best solution for recruiting participants to monitor issues with service providers, the recruitment policy must ensure that the location of the issue does not have too many participants visiting the area to check the progress of the issue resolution. The recruitment policy should ensure that the number of participants that accept to perform the task must be the exact number of participants required to fulfil the quality requirement. Figure 5-14 shows that the number of recruited users using the OverSense recruitment policy is never higher than the quality requirement of 10. While the random and distance methods both required contacting 20 participants to accomplish the expected 19 tasks, the OverSense recruitment policy only had to add one more participant to meet the quality requirements of the remaining tasks (Figure 5-15). Thus, the OverSense policy not only saves computing resources to accomplish the tasks, but also eliminates the excess human resources that the other methods may incur to accomplish the tasks.

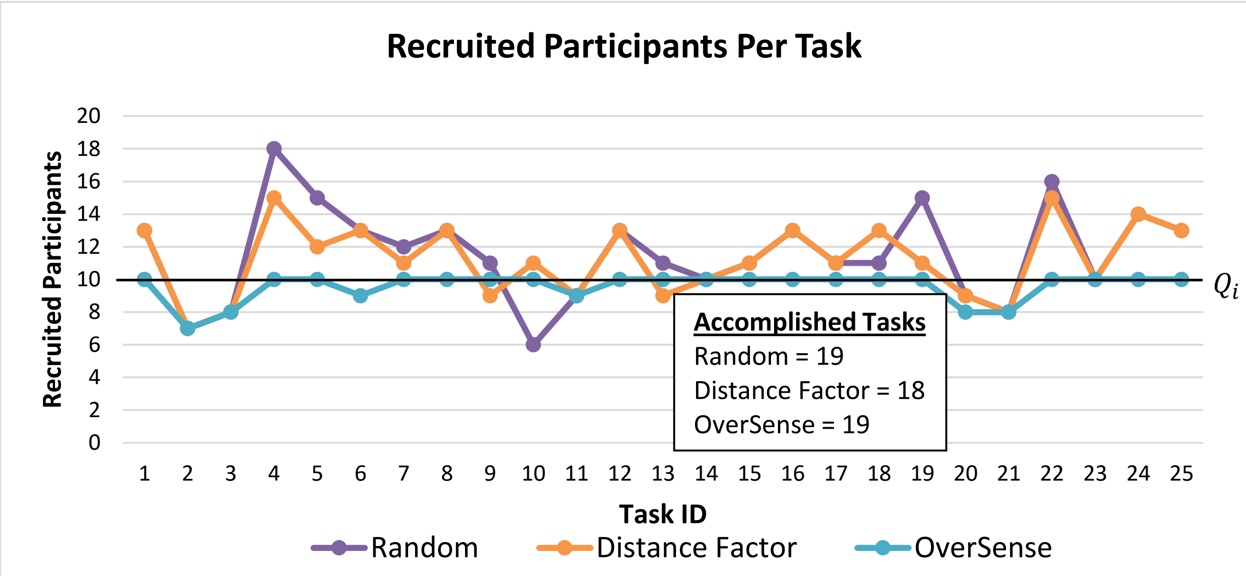


Figure 5-14: Comparison of Recruited Participants per Task across Methods (N=100).

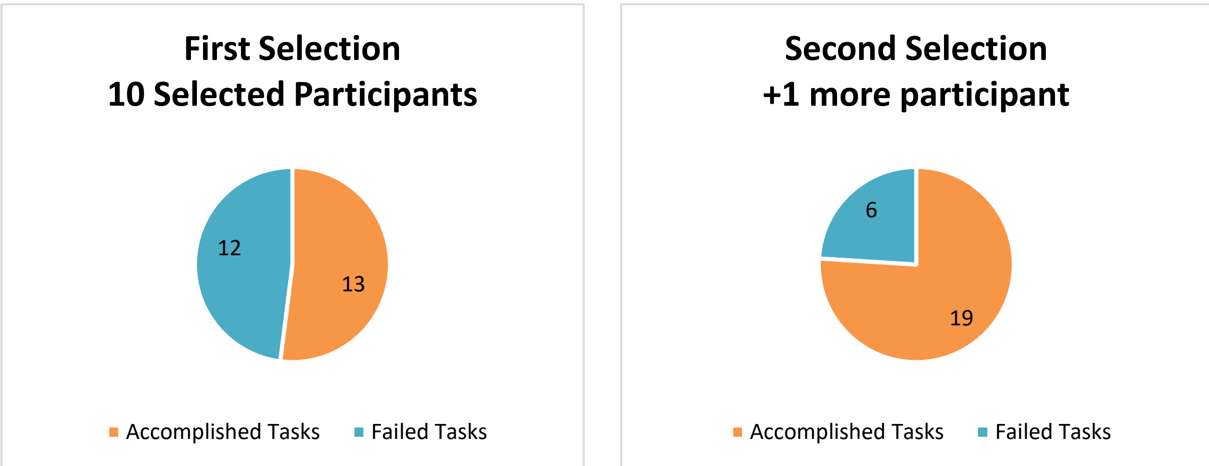


Figure 5-15: Participant Selection with the OverSense Recruitment Policy.

5.6 Conclusions

Many researchers have highlighted recruitment and incentive policies as important components of crowdsensing as the policies determine how participants will be recruited and rewarded to ensure large quantities of data. This study proposes the OverSense recruitment policy to recruit participants to monitor the progress of issue resolution. The recruitment policy was evaluated using a set of simulation experiments. The data used to simulate the real-world environment was obtained from the NMBM, the case study for this research. The results of the evaluation of the recruitment policy show that the OverSense recruitment policy is more effective than selecting participants randomly or based on their distance to the tasks only.

This study also proposes the OverSense incentive policy that guides how rewards must be disseminated to participants who participate in crowdsensing projects with a service delivery focus (such as water resource monitoring). Due to scope and time constraints, the researcher was unable to evaluate the incentive policy. Incentive policies require a long period of time to monitor in order to see the effect of the rewards on the participant's motivation over a long period of time. It would not be possible to evaluate the incentive policy; hence, future research is needed to evaluate the OverSense incentive policy.

This chapter reported on the findings of the third iteration of the four research activities of this study. The results of the survey reported on in Chapter 4 led to the development of two subsidiary research questions:

> **RQ3.1:** How can crowdsensing participants be recruited to monitor the progress of issue resolution?
>
> **RQ3.2**: How can participants be rewarded for their participation in crowdsensing projects with a service delivery focus?

A conceptual model in the form of the OverSense Policies was developed to answer these two questions; thus, both subsidiary research questions were addressed. The OverSense Policies are used to develop the Incentive Mechanism Design for the sociotechnical design of the Crowdsensing Method. By proposing the OverSense policies, this chapter has partially addressed the research question:

> **RQ3:** How can a sociotechnical design of a crowdsensing system be modelled to recruit and incentivise participants to collect data continuously?

The Crowdsensing Method will be presented and evaluated in the next chapter. The Crowdsensing Method is evaluated using an ecosystem of success factors for mobile-based solutions.

6 THE CROWDSENSING METHOD

6.1 Introduction

The previous chapter presented a significant contribution to the sociotechnical design of the Crowdsensing Method, the OverSense policies. This chapter presents the evaluation and reflection of the main contribution of this study, the Crowdsensing Method. This chapter will report on the Crowdsensing Method's contribution to the area of concern (A) and problematic situation (P) that were initially identified in Chapter 1. These are:

> **A:** Adoption of crowdsensing for water resource monitoring in smart communities.
>
> **P:** There are several problems with the sharing of relevant information between communities and water service providers. The main problems relate to the deployment of sensing infrastructure, the lack of responsiveness by the service providers to the generated information, the lack of access to the information and the sustainability of the technology solutions.

The Crowdsensing Method has a sociotechnical and programme design (Section 6.2). The Crowdsensing Method was evaluated using an ecosystem for success in the implementation of mobile-based interventions (Section 6.3). Several conclusions can be made from the evaluation of the Crowdsensing Method (Section 6.4).

6.2 Design Considerations for the Crowdsensing Method

As stated in Section 1.5, the Crowdsensing Method considers two designs of crowdsensing projects, the sociotechnical and programme designs. Several contributions were made to the Crowdsensing Method in the previous chapters. Figure 6-1 shows the final version of the Crowdsensing Method.

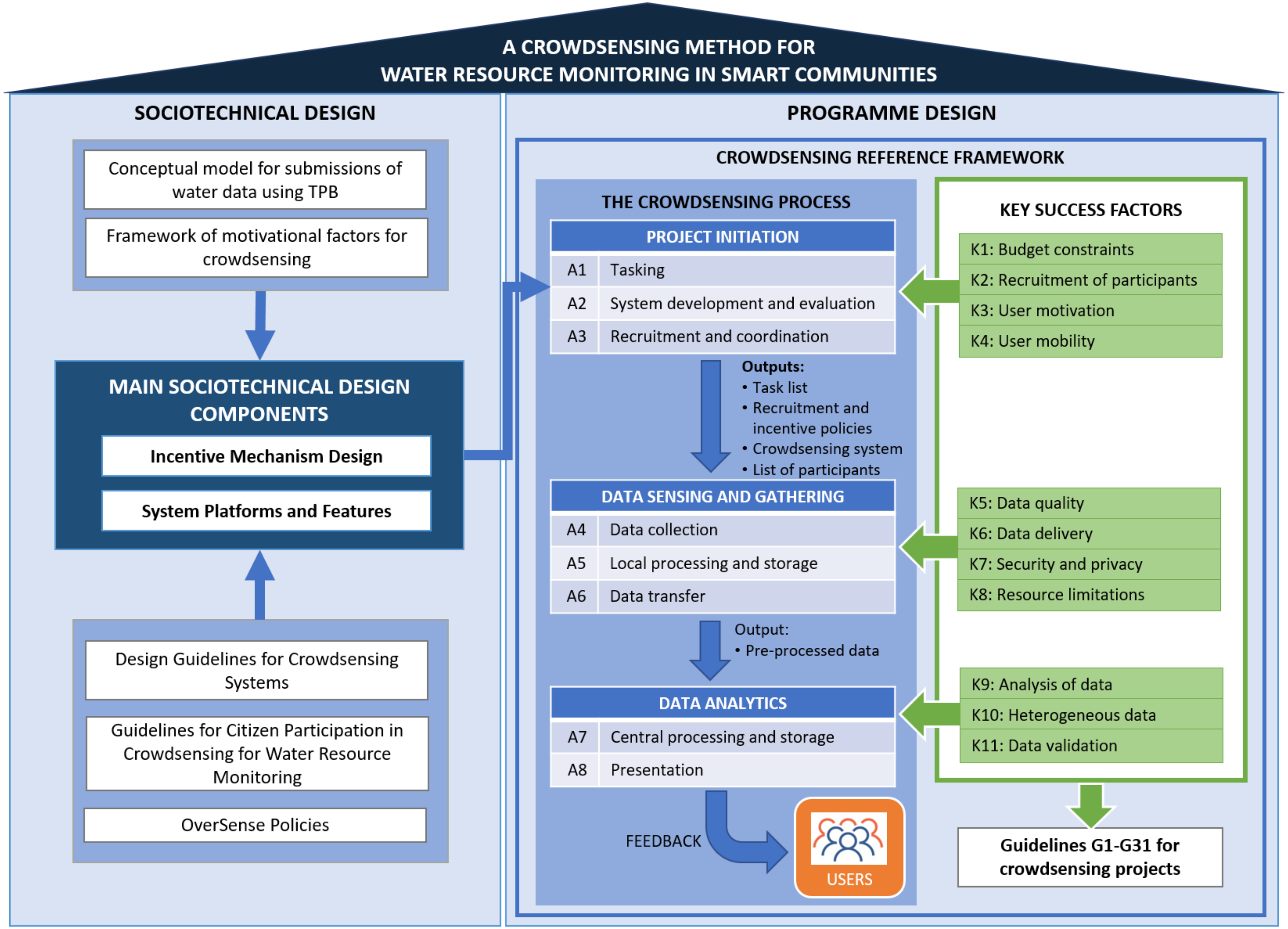


Figure 6-1: A Crowdsensing Method for Water Resource Monitoring in Smart Communities Version 3 (Author's Own Construct).

6.2.1 The Programme Design

This study proposes a Crowdsensing Reference Framework (Figure 3-6) as the plan for the implementation and coordination of a crowdsensing project, equivalent to the programme design for the Crowdsensing Method. The framework comprises of:

- The Crowdsensing Process with the activities labelled from A1 to A8 (Figure 3-4).
- Key Success Factors for Crowdsensing Projects labelled from K1 to K11 (Table 3-3).
- Guidelines for Crowdsensing Projects, labelled from G1 to G30 (Table 3-3).

6.2.2 The Sociotechnical Design

The sociotechnical design for the Crowdsensing Method consists of two main components: the Incentive Mechanism Design and the System Platforms and Features. As shown in Figure 5-3, the two main components are informed by the following contributions:

- The Conceptual Model for Submissions of Water Data using TPB (Figure 4-15).
- The Framework of Motivational Factors for Crowdsensing (Figure 4-14).
- Design Guidelines for Crowdsensing Systems (Table 3-4).
- Guidelines for Citizen Participation in Crowdsensing for Water Resource Monitoring (Section 4.4.4).
- The OverSense Policies (Section 5.4).

6.2.2.1 Incentive Mechanism Design for the Crowdsensing Method

The Incentive Mechanism Design for the Crowdsensing Method outlines the technique for providing incentives to motivate the behaviour of crowdsensing participants. The Incentive Mechanism Design is based on the Stackelberg game (Fudenberg & Tirole, 1991), a popular technique used in crowdsensing incentive mechanism design. There are two players in a Stackelberg game, a leader and a follower. The leader makes a move and the follower moves sequentially. In this context, there are two stages of the Stackelberg game in the Incentive Mechanism Design (Figure 6-2). In the first stage, the crowdsensing system platform acts as the leader and provides a total incentive budget derived using the OverSense incentive policy to recruit participants to perform a task. The task in this case is making a data submission to the crowdsensing system. The second stage begins when a participant makes a data contribution to the crowdsensing platform and opens it up for resolution according to the OverSense recruitment policy.

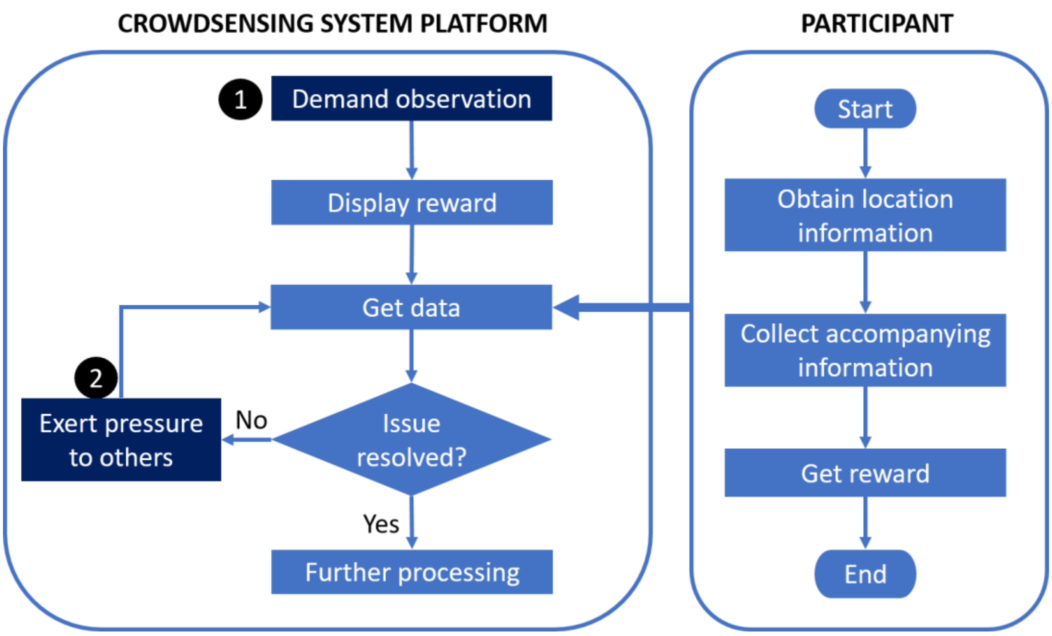


Figure 6-2: The Incentive Mechanism Design (Author's Own Construct).

The Incentive Mechanism Design uses the steered crowdsensing framework (Kawajiri, Shimosaka & Kahima, 2014) to steer the participants to a specific location to monitor the progress of resolution of an issue (Figure 6-3). The steered crowdsensing framework uses gamification to obtain data from remote regions and reward participants who perform the assigned tasks at different locations. The rewards change dynamically based on the frequency of the location visits and the quality of the data.

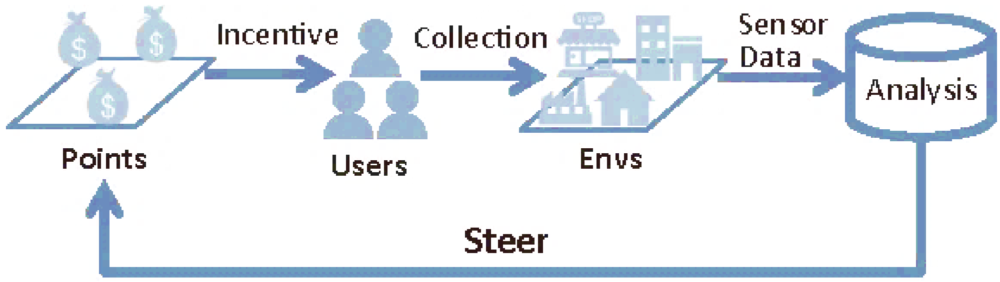


Figure 6-3: Flow of Steering Users (Kawajiri, Shimosaka & Kahima, 2014).

In addition to the OverSense policies, the Incentive Mechanism Design is guided by the proposed two sets of guidelines:

- Design Guidelines for Crowdsensing Systems (Table 3-4).
- Guidelines for Citizen Participation in Crowdsensing for Water Resource Monitoring (Section 4.4.4).

For example, the Incentive Mechanism Design follows the fifth guideline G5, which recommends using social translucence as a design approach, thus, applying Design Guideline

D5 to the incentive mechanism and allowing participants to explore reports and add more information.

6.2.2.2 System Platforms and Features

The typical crowdsensing model has smartphones as sensory devices for data collection (Figure 1-1). Although smartphones continue to grow in market shares, a large number of people continue to use basic feature phones due to their affordability (Perrier, DeRenzi & Anderson, 2015). It is particularly important for development initiatives to reach owners of feature phones as they represent a significant number of the poorest people. Three studies (Dabas & Dabas, 2009; Parikh *et al.*, 2014; Ochoa, Talavera & Paciello, 2015) have modelled the use of universal mobile applications as sensors.

Universal mobile applications are mobile applications that make services uniformly available on every mobile phone (Perrier, DeRenzi & Anderson, 2015). Two main universal apps are Short Message Service (SMS) and Unstructured Supplementary Service Data (USSD). USSD is a communication technology that supports the exchange of textual data, similar to SMS. USSD differs from SMS as it is a session-based protocol that allows bi-directional transmission of information between a mobile phone and an application server (Mosweunyane *et al.*, 2014; Ochoa, Talavera & Paciello, 2015; Perrier, DeRenzi & Anderson, 2015). Although SMS is the most common universal app for technical solutions initiatives, USSD has several advantages over SMS:

- USSD is almost seven times faster than SMS, offering a minimal delay between sending a query and receiving a response (Sanganagouda, 2011; Suddul *et al.*, 2011)
- USSD allows data to be sent back and forth because it is a session-based protocol (Mosweunyane *et al.*, 2014).
- USSD works even when the users are roaming with no charges while SMS can incur charges when roaming (Dabas & Dabas, 2009; Sanganagouda, 2011).
- USSD supports interactive menus as they can be initiated by the application or the user (Dabas & Dabas, 2009).
- USSD is much cheaper than SMS and a USSD user does not need to remember anything apart from the code to connect to the application (e.g. *147#), making it easy to use (Sanganagouda, 2011).

USSD and SMS are commonly used for interactions between mobile carriers and their customers, such as recharging prepaid handsets, mobile banking, mobile chats and subscribing to information services. The universal applications allow development initiatives to involve rural communities because they do not require an Internet connection or the installation of any application (Sanganagouda, 2011; Suddul *et al.*, 2011).

Figure 6-4 shows the recommended data collection tools for crowdsensing for water resource monitoring in smart communities. Yadav *et al*. (2013) recommend the use of web-based tools, mobile applications and social media feeds as data collection tools for crowdsensing.

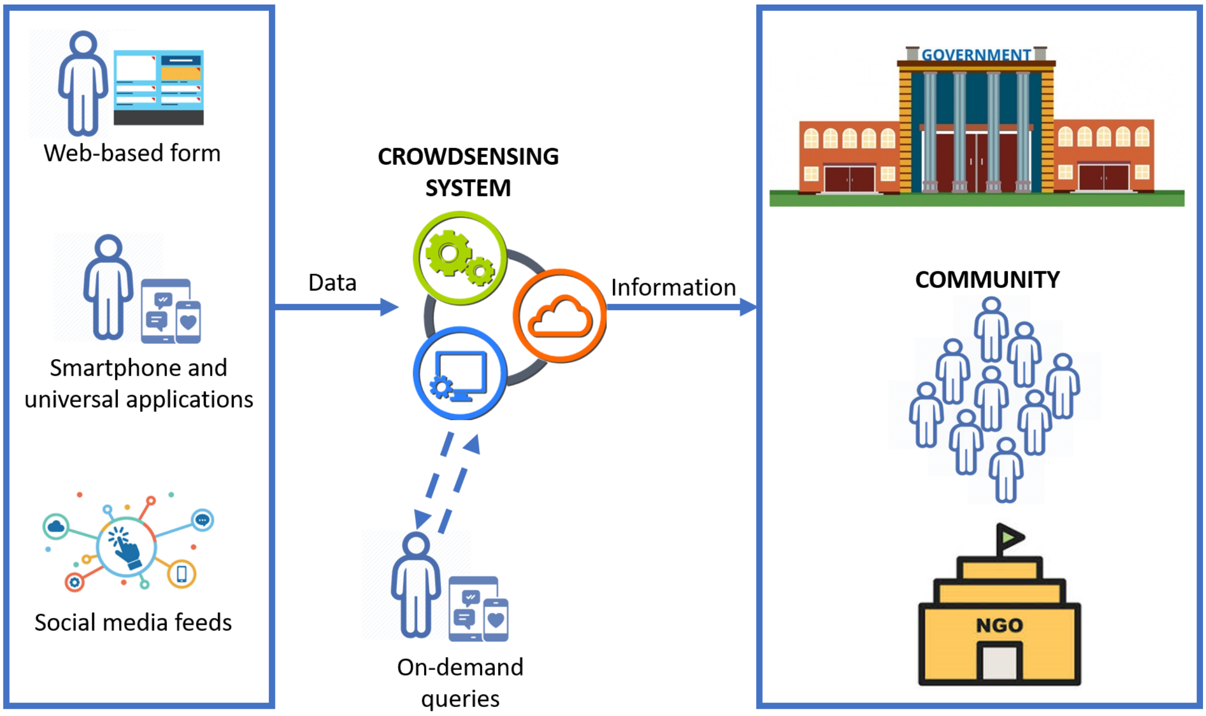


Figure 6-4: Data Collection Tools for Crowdsensing for Water Resource Monitoring [Adapted from Yadav *et al*. (2013)].

Hutchings *et al*. (2012) report that the use of forms for data collection allows for structured responses which prove useful for ensuring data accuracy. Manual text entry is prone to errors and data gaps as noted in the analysis of the NMBM data (Section 5.5.1), while structured responses reduce the processing load. In addition to forms, crowdsensing systems use mobile device sensors to collect accurate data. For example, GPS can pinpoint the exact location of the water issue and the camera can be used to capture an image or video of the issue.

Due to time constraints, this research study did not investigate tools for the distribution of information to recipients of the crowdsensing system-generated information. However, studies on crowdsensing show that the most commonly used data dissemination tools include web dashboards, broadcast messages and direct responses (Hutchings *et al.*, 2012; Yadav *et al.*, 2013; Guo *et al.*, 2014).

6.3 Evaluation of the Crowdsensing Method

Hutchings *et al*. (2012) propose an ecosystem for success that considers STP elements in the implementation of mobile-based interventions (Figure 6-5). This study uses this ecosystem to evaluate and reflect on the proposed Crowdsensing Method (for water resource monitoring in smart communities). The method is intended for use by organisations or individuals who intend to implement a crowdsensing project for water resource monitoring.

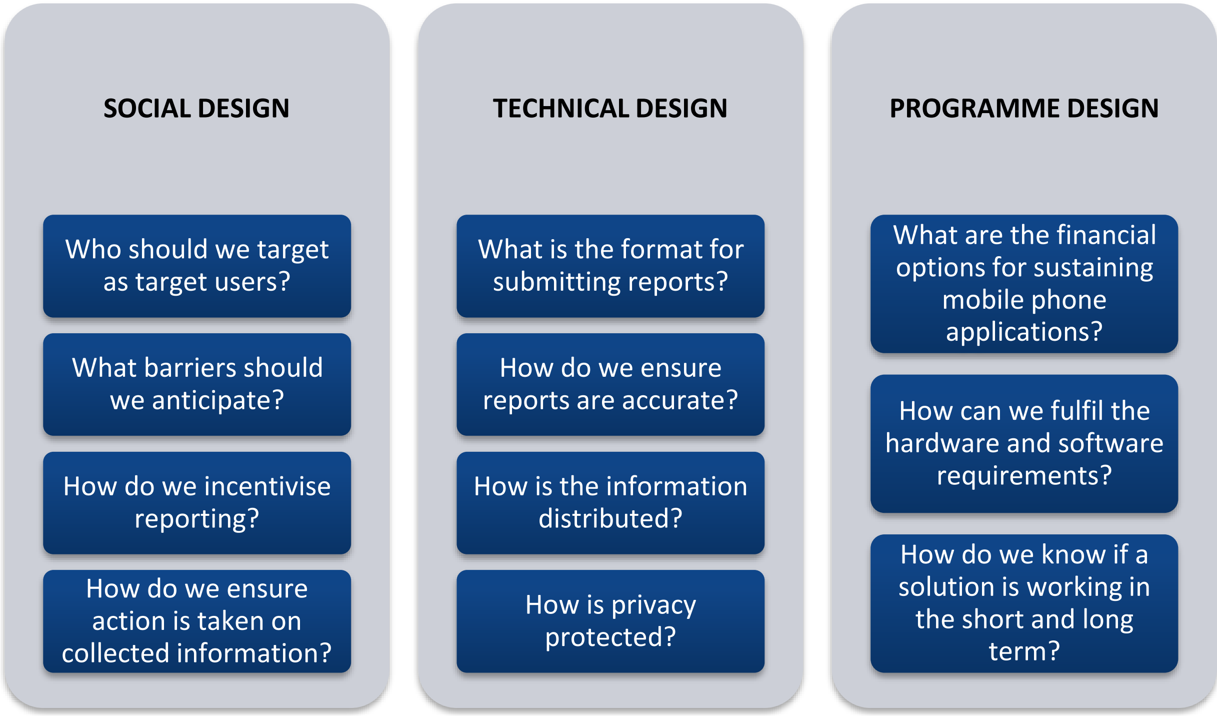


Figure 6-5: Success Factors in Mobile-based Solution Design (Hutchings *et al.*, 2012).

6.3.1 Social Design

The social design of the Crowdsensing Method requires project coordinators to consider the perceptions of their target users, the barriers and incentives for participation and the privacy of the collected data. In addition, project coordinators' work must be verifiable to ensure action is taken on collected information.

6.3.1.1 Target Users

The proposed Crowdsensing Method (Figure 6-1) satisfies the first success factor proposed by Hutchings *et al*. (2012) relating to target users since it provides frameworks, guidelines and policies for recruiting and incentivising participants (or users). While the Crowdsensing Method is intended for coordinators of crowdsensing projects, there are several other entities that may be interested in the information produced from the data submissions (Figure 6-6). Governments may use the produced information to manage the infrastructure of water resources and oversee the activities of all water sector institutions. Water authorities such as the NMBM water department require such information for their operational services. Non-governmental organisations can use the information to plan their charitable efforts to help communities in developing countries. Communities also need to access this information for visibility, accountability and awareness purposes.

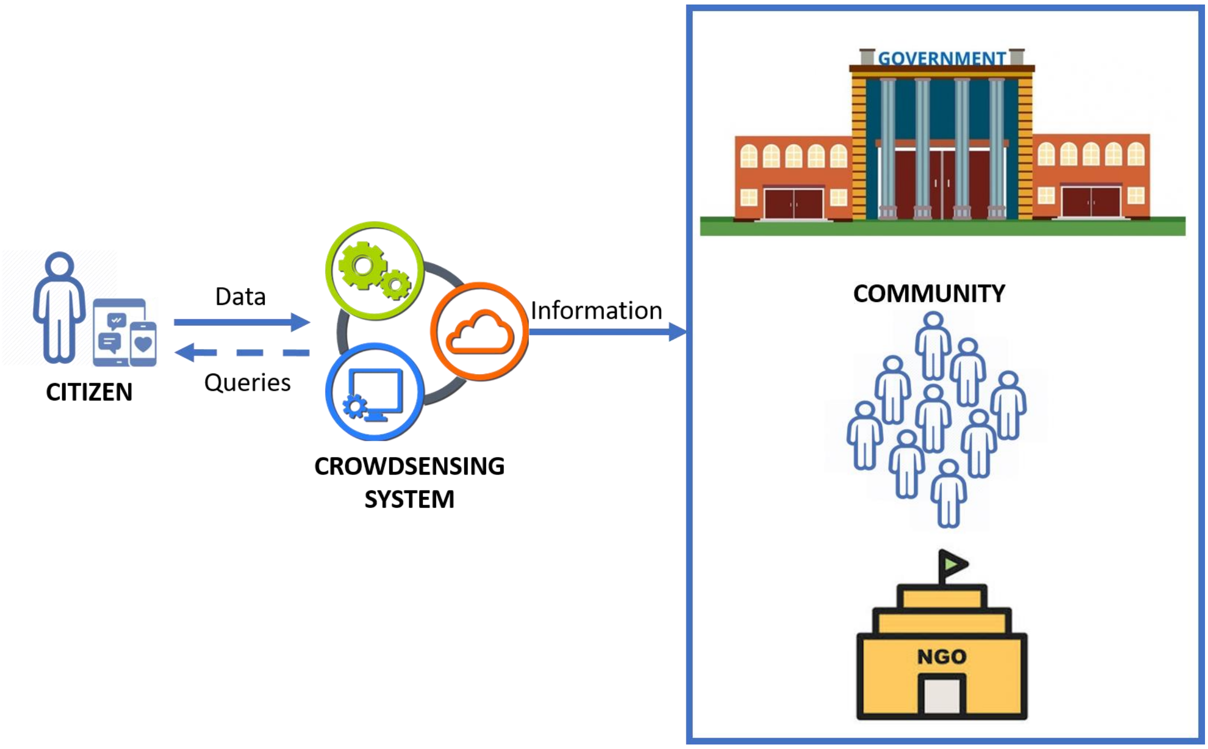


Figure 6-6: Target Users of the Crowdsensing System [Adapted from Yadav *et al*. (2013)].

6.3.1.2 Barriers to the Success of Crowdsensing Projects for Water Resource Monitoring

One of the social design considerations for a crowdsensing project is identifying the barriers the project coordinators could face in the duration of the project (Section 1.5.1). Earlier in the study, the researcher proposed a Challenge Framework for Crowdsensing (Figure 3-5) that can provide the project coordinators with key success factors for crowdsensing projects. In addition, the Framework of Motivational Factors for Crowdsensing (Figure 4-14) identifies several factors that can demotivate citizens to participate in water resource monitoring. The Crowdsensing Method considers both challenges (in the Challenge Framework for Crowdsensing) and demotivational factors (in the Framework of Motivational Factors for Crowdsensing) for crowdsensing. Since both challenges and demotivational factors can also be viewed as barriers, the Crowdsensing Method satisfies the criteria of addressing barriers to the success of crowdsensing projects for water resource monitoring. The de-motivational factors and challenges are considered as barriers as the challenges and factors could hinder the success of the project. The challenges are the barriers to success from an organisational standpoint while the de-motivational factors are the barriers to success from a citizen perspective (Figure 6-7). These barriers should be used to guide project coordinators in developing a crowdsensing system and a management structure that seeks to overcome the barriers.

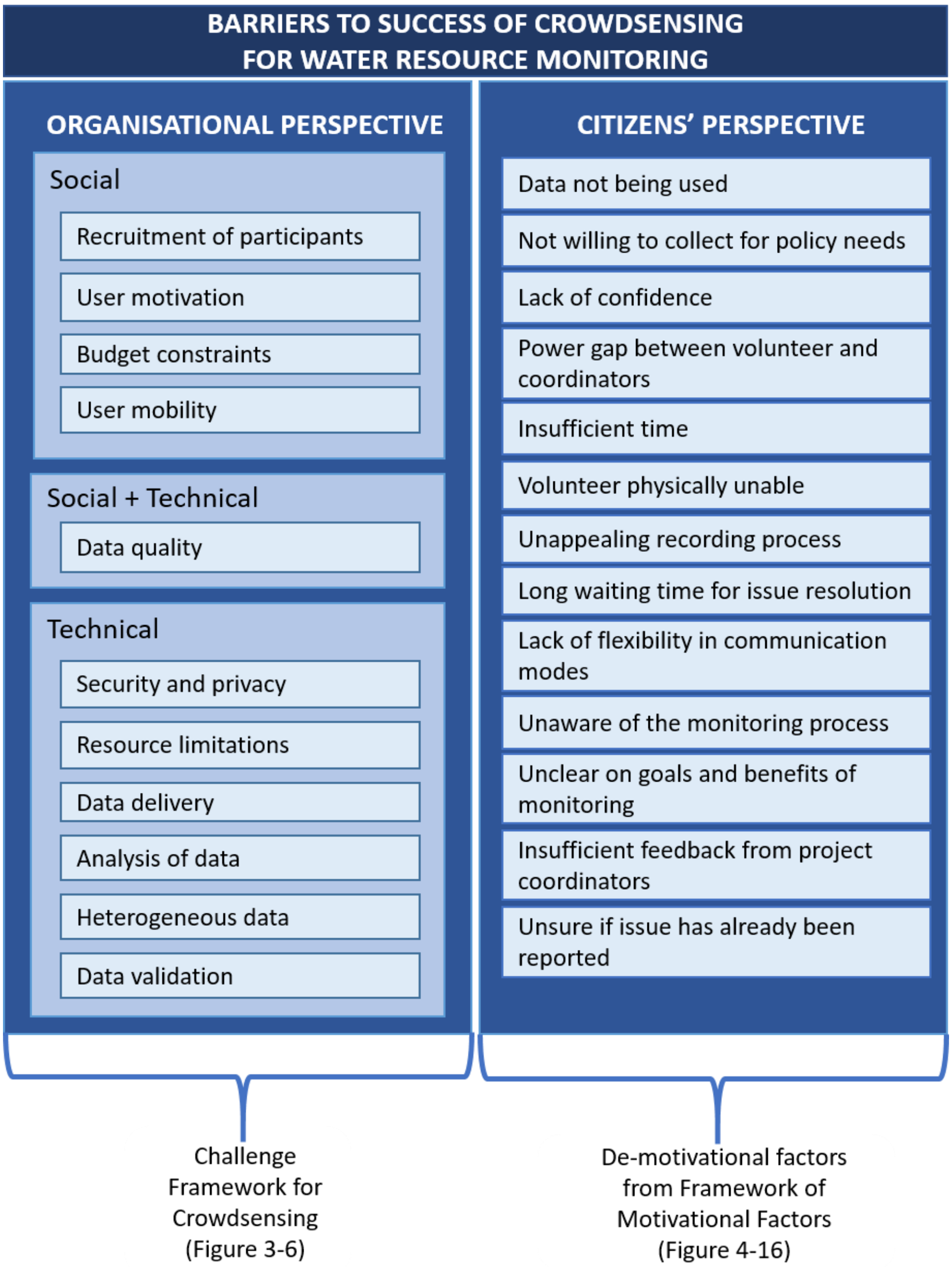


Figure 6-7: Barriers to the Success of Crowdsensing Projects for Water Resource Monitoring (Author's Own Construct).

6.3.1.3 Incentives for Citizen Participation

The Crowdsensing Method satisfies the criteria of providing incentives by proposing the Incentive Mechanism Design as the technique that can provide incentives to participants (Figure 6-2). The Incentive Mechanism Design was developed using several inputs. One of the inputs was the Framework of Motivational Factors for Crowdsensing (Figure 4-14). Five categories of initial motivational factors were proposed in the Framework of Motivational Factors for Crowdsensing (Figure 4-14). These are:

- Collective.
- Self-benefit.
- Self-efficacy.
- Intrinsic motivation.
- Social interaction.

The framework also includes consideration of five long-term (continuous) motivational factors. These are:

- Mentorship.
- Trust.
- Acknowledgement and attribution.
- Policy and activism.
- Common goals.

Citizens are willing to participate in water resource monitoring for collective incentives (Section 4.4.3.1). The necessity for monetary incentives is eliminated if citizens see the impact of their work through benefits such as improvements to service provision (Hutchings *et al.*, 2012). As long as citizens are able to recognise that the goals of the project align with their goals of contributing data for the good of themselves, the community and the environment, citizens may remain in the project long term. In addition, it is important to give crowdsensing participants recognition and attribution for the work they perform in the crowdsensing project as attribution and acknowledgement are significant long-term motivational factors.

One of the Design Guidelines for Crowdsensing Projects is to allow the participants to take on more complex measurements (Table 3-4), so they can move up the citizen science pyramid (Figure 2-3). The technical design of a crowdsensing system for water resource monitoring must employ a progression technique that arranges tasks in difficulty levels ranging from low to high. Progression is a mode of engagement that motivates individuals to learn more about the phenomena being captured and can motivate participants to discover and learn new things and skills, increase their capacity, as well as contribute to conservation and science (Figure 4-7). Progression is a technique that can fuel the mentorship long-term motivational factor as sequencing tasks is an effective technique that captures and holds the attention of the participant (Kapp, 2012).

6.3.1.4 Action Taken on Collected Data

The fourth success factor, which can be used as a criterion to evaluate the Crowdsensing Method, is that action must be taken on collected crowdsensing data. Service providers are in the best position to publish progress updates for service provision, however they are not interested in publishing their assessments due to the negative effect the updates may have on their organisation (Oliveira *et al.*, 2017). The proposed OverSense Policies, which forms part of the Crowdsensing Method, enlists the assistance of past participants of the crowdsensing system to monitor the resolution of issues, thus, verifying action was taken on the collected data. This study proposes the use of the OverSense recruitment policy to select participants to monitor issue resolution and reward the participants based on the OverSense incentive policy. The OverSense Policies enlist social translucence by displaying all issues submitted by participants on an open platform where any citizen can access the reports and add additional information. The public updates of issue resolution allow citizens to visualise how their data is being used by the project coordinators. For these reasons, it is believed that the Crowdsensing Method satisfies this success factor.

6.3.2 Technical Design

The technical design of a crowdsensing system must highlight the format for submitting reports, in terms of how citizens will collect and submit data and how the data will be distributed. In addition, the technical design must highlight how the system will ensure the accuracy of data, distribution of information and privacy of citizens' data contributions.

6.3.2.1 Format for Submitting Reports

The Crowdsensing Method proposes the use of various types of applications for citizens to make data contributions including smartphone and universal applications, Web-based forms and social media feeds (Section 6.2.2.2).

6.3.2.2 Accuracy of Reports

Government officials may have reservations about the additional burden of cleaning data and providing responses to individual reports (Freifeld *et al.*, 2010). The Crowdsensing Method satisfies the factor related to accuracy of reports, since the OverSense Policies propose making use of crowds to evaluate data quality and provide feedback to citizens seeking issue resolution. In addition, the use of forms as a format for submitting data (Section 6.2.2.2) provides structured responses that reduce the data processing load.

6.3.2.3 Distribution of Information

There are several guidelines from the set of Guidelines for Crowdsensing Projects (Table 3-3) that address information distribution. For example, Guideline G12 recommends that the project coordinators visualise the variability of interest in regions using a density map. Guideline G31 urges the project coordinators to ensure that the data that is provided to the citizens is accurate, adequate, available and affordable. However, as stated earlier, this research study did not investigate tools for the distribution of the generated information.

6.3.2.4 Privacy of Data

The Crowdsensing Method includes several guidelines, G16 to G20 of the Guidelines for Crowdsensing Projects (Table 3-3), that relate to ensuring the privacy of the data that citizens contribute. However, the scope of this study did not cover the technical design of privacy-preserving mechanisms for crowdsensing data.

6.3.3 Programme Design

The programme design must consider the financial options for sustaining a crowdsensing project, the hardware and software requirements for crowdsensing systems and the sustainability of the technology solution.

6.3.3.1 Financial Options for Sustaining Applications

The Crowdsensing Method satisfies the criteria for providing financial options for sustainability, since the Guidelines for Crowdsensing Projects proposes that crowdsensing project coordinators must develop a solid economic model (G1) and recommends the use of non-monetary rewards to ease the financial burden (G2). However, due to scope constraints alternative financial options were not explored in this study and could be researched in future work.

6.3.3.2 Hardware and Software Requirements

This study does not investigate the hardware and software requirements of crowdsensing systems as the requirements differ depending on the goals of the crowdsensing project. However, this study proposes several Design Guidelines for Crowdsensing Systems (Table 3-4) based on an extant system analysis. The Guidelines for Crowdsensing Projects (Table 3-3) can also be applied in determining hardware and software requirements for a crowdsensing system because the guidelines specify the requirements for significant aspects of crowdsensing systems such as data quality, analysis, privacy and validation. In addition, system platforms and features (Section 6.2.2.2) were identified as potential hardware and software options.

6.3.3.3 Sustainability of Solution

The Crowdsensing Method satisfies the criteria of sustainability since the Guidelines for Crowdsensing Projects (Table 3-3) G8 to G11 suggest how project coordinators can evaluate the sustainability of the solution. Project coordinators can use the results of analyses into the frequency of contributions, the variability of interest in different regions and density maps to ascertain if the crowdsensing system is able to maintain the set minimum number of participants. In addition, the Framework of Motivational Factors (Figure 4-14) considers long-term motivational factors to sustain citizen participation in crowdsensing.

6.4 Conclusions

The Crowdsensing Method was evaluated and reflected upon using the ecosystem for the success of mobile-based interventions as proposed by Hutchings *et al*. (2012). The evaluation was designed to clarify the components of the Crowdsensing Method and identify which success factors of the STP ecosystem were addressed by the Crowdsensing Method. The evaluation showed that the Crowdsensing Method was able to adhere to approximately 90% of the key success factors of the ecosystem. The remaining 10% are the areas that could warrant future research, which are in areas of data privacy, information distribution, financial options and hardware and software requirements.

The next chapter presents the conclusions drawn from the activities conducted in this study, outlines the limitations of the study and provides recommendations for future research.

7 CONCLUSIONS AND DISCUSSION

7.1 Introduction

The main aim of this study was to design an effective crowdsensing method for water resource monitoring in smart communities. The main research question (RQ-M) for this study was: "***How can crowdsensing be used for effective water resource monitoring in smart communities?***" This chapter will report on the contributions to the area of concern (A) and problematic situation (P) which were initially identified. These are:

> **A:** Adoption of crowdsensing for water resource monitoring in smart communities.
>
> **P:** There are several problems with the sharing of relevant information between communities and water service providers. The main problems relate to the deployment of sensing infrastructure, the lack of responsiveness by the service providers to the generated information, the lack of access to the information and the sustainability of the technology solutions.

This chapter begins with an assessment of how the problem statement was addressed (Section 7.2).The research questions were reviewed to determine if all the research questions were addressed and whether the study was successful (Section 7.3). There were several research contributions made to theory and practice throughout the duration of the study (Section 7.4). There were several limitations to this study and the researcher presents several recommendations for future research (Section 7.5). Lastly, the entire study is summarised (Section 7.6).

7.2 Problem Statement Reviewed

Four main problems were identified in P with the sharing of relevant information between communities and water service providers (Section 1.2). Table 7-1 outlines how each of the problems was addressed in the study.

PROBLEM	HOW PROBLEM WAS ADDRESSED IN STUDY	SOURCE
Deployment of sensing infrastructure	Crowdsensing was proposed as the mobile-based intervention that can address the problems with deploying sensing infrastructure in smart communities. Crowdsensing provides affordability, scalability and a minimal learning curve because citizens and their mobile devices, and are used as sensors instead of deploying hardware sensors around the community.	Sections 3.2 and 3.3
Lack of responsiveness by the service providers to the generated information	This study proposes the OverSense Policies which use social translucence for visibility, awareness and accountability purposes. In addition, the OverSense Recruitment Policy allows citizens to check up on the progress of issue resolution.	Section 5.4.
Lack of access to the information		
Sustainability of the technology solutions	A framework of motivational factors is proposed, and the framework comprises several long-term motivational factors. The sociotechnical design incorporates this framework to improve the sustainability of crowdsensing solutions.	Figure 4-14 and Section 6.2.2.

Table 7-1: Addressing the Problem Statement.

7.3 Research Questions Reviewed

The first research question was:

> **RQ1:** What are the problems faced by citizens and water service providers regarding crowdsensing and water resource monitoring as identified by literature and within a real-world context?

The identification of problems faced by citizens and water resource providers regarding crowdsensing and water resource monitoring aided in grounding this research study in both the real-world problem and area of concern. Challenges for crowdsensing projects for water resource monitoring include the recruitment of participants, data quality, user motivation and budget constraints. While citizens' de-motivational factors include physical inability, lack of belief in the usage of the data, lack of awareness of the crowdsensing project and insufficient time. Based on the results of the survey into citizens' perceptions, there was no significant difference between citizens in South Africa, developing and developed countries in regard to contributing water data. However, it can be noted that developing countries (including South Africa) have a higher intention to contribute water data.

The second research question was:

> **RQ2:** What are the common activities and key success factors for crowdsensing projects?

This research question was addressed by proposing a Crowdsensing Reference Framework (Figure 3-6). Through a review of literature, eight activities were identified as common activities in crowdsensing projects while the researcher identified 11 key success factors of crowdsensing projects. The identified activities presented as the crowdsensing process in Figure 3-4. The key success factors are presented alongside Guidelines for Crowdsensing Projects in Table 3-3.

The third research question was:

> **RQ3:** What sociotechnical design can be used for a crowdsensing system that recruits and incentivises participants to collect data continuously for water resource monitoring?

Developing a sociotechnical design of a crowdsensing system requires an investigation of citizens' perceptions and the incentives and barriers to their participation in the crowdsensing system, as well as the consideration of the technical design components such as the systems platforms and features. Through a literature review and survey, the study proposed a sociotechnical design that includes an Incentive Mechanism Design, and System Platforms and Features as the main sociotechnical design components (Section 6.2.2).

The fourth research question was:

> **RQ4:** What design guidelines can be used for crowdsensing for water resource monitoring to create a smart community?

There were several sets of guidelines proposed during this study. The guidelines were developed through a review of literature, the survey of citizens' perceptions and an extant system analysis. These guidelines provide a valuable contribution to IS design theory and consist of the following three sets of guidelines:

- Guidelines G1-G30 for crowdsensing projects (Table 3-3).
- Design Guidelines for Crowdsensing Systems (Table 3-4).
- Guidelines for Citizen Participation in Crowdsensing for Water Resource Monitoring (Section 4.4.4).

The main research question of this study was:

> *How can crowdsensing be used for effective water resource monitoring in smart communities?*

The main research question was answered by answering all the subsidiary research questions. The three iterations of the engaged scholarship research activities enabled the development of the Crowdsensing Method. The effectiveness of the Crowdsensing Method is evaluated in Chapter 6 using an ecosystem for the success of mobile-based interventions as proposed by Hutchings *et al*. (2012). Individual components of the Crowdsensing Method were also evaluated using simulation experiments and a survey. In answering the main research question, the study also successfully adhered to the principles of engaged scholarship (Section 2.2). Table 7-2 shows how some of the engaged scholarship principles were applied to this study.

Principle of Engaged Scholarship	Application to the Study
Theory-laden data, facts and observations	The entire research study was grounded in theory and all three iterations of the engaged scholarship research activities adhered to the Theory Building activity of engaged scholarship.
Engagement of multiple stakeholders	Several stakeholders were involved in the study including citizens, employees of the case study organisation (NMBM), knowledge experts and methodology experts.
Theoretical and methodological triangulation	The three main methods that allowed the triangulation of the complex problem were literature reviews, a survey and experiments. The researcher also engaged with knowledge and methods experts, as well as NMBM officials who gave consent to access the data. These methods allowed the researcher to access different kinds of knowledge. The mixed methods approach was adopted in this study since both qualitative and quantitative methods were used to get different perspectives of the research problem. Qualitative data was obtained from the literature review and the open-ended feedback from the survey. Quantitative data was obtained from the experiments and the closed-ended feedback from the survey.
Contribution to theory and practice	The research contributions contribute to both theory and practice.
Start conversation about issues in P and A	The survey and interacting with knowledge experts and NMBM employees started a conversation about the issues with water resource monitoring in South Africa. Henceforth, the NMBM have requested to be given access to the research outputs of this study for use to improve their programmes.

Table 7-2: Reflection of the Study according to Engaged Scholarship Principles.

This study also investigated the applicability of crowdsensing to create a smart community that integrates the cyber, physical and social worlds for the service delivery in communities. Xia and Ma (2011) propose several properties of smart community (Section 3.2.1) and Table 7-3 describes how each property was addressed by the Crowdsensing Method.

Property of Smart Community	Application to the Study
A physically and socially aware system	The Crowdsensing Method proposes developing a crowdsensing system that uses citizens and mobile device sensors to collect data about the physical world. The Crowdsensing Method proposes an extensive sociotechnical design that can guide researchers and practitioners on how to navigate the social systems of a community for the success of the crowdsensing project.
Varied number of members and lifecycle	The Crowdsensing Method can be adapted for various contexts with varied number of crowdsensing participants.
Not dependent on Internet connection	The Crowdsensing Method proposes the use of USSD and SMS as data collection tools to allow community members without Internet access to participate in crowdsensing.
Good scalability	The nature of crowdsensing to use citizens' mobile devices for data collection (crowdsensing) allows for the expansion of communities.

Table 7-3: Reflection of the Study according to the Properties of a Smart Community proposed by Xia and Ma (2011).

7.4 Research Contributions

The main research contribution of this study is the Crowdsensing Method (Figure 6-1). The Crowdsensing Method has two main components, which are also considered research contributions namely, the sociotechnical and programme designs.

7.4.1 Sociotechnical Design

The contributions that form the sociotechnical design of the Crowdsensing Method are:

- The Challenge Framework for Crowdsensing (Figure 3-5).
- Design Guidelines for Crowdsensing Systems (Table 3-4).
- The Conceptual Model for Submission of Water Data using TPB (Figure 4-4).
- The Framework of Motivational Factors for Crowdsensing (Figure 4-14).
- Guidelines for Citizen Participation in Crowdsensing for Water Resource Monitoring (Section 4.4.4).
- The OverSense Policies (Section 5.4).
- The Incentive Mechanism Design (Figure 6-2).

The Challenge Framework for Crowdsensing (Figure 3-5) and Framework of Motivational Factors for Crowdsensing (Figure 4-14) were used to identify the main issues around engaging with participants in crowdsensing projects. It was confirmed that by identifying the motivational factors and barriers to the success of a crowdsensing project, researchers or practitioners can develop a potential participant profile. The potential participant profile was used to develop an Incentive Mechanism Design (Figure 6-2) using the Design Guidelines for Crowdsensing Systems (Table 3-4), Guidelines for Citizen Participation in Crowdsensing for Water Resource Monitoring (Section 4.4.4) and OverSense Policies (Section 5.4).

The case study mobile application, the NMBM application, was evaluated against the design guidelines to identify the shortcomings of the application as a crowdsensing system. It was noted that the application was lacking social translucence and a fun element. This was confirmed by the survey data which reported that participants did not consider crowdsensing for water resource monitoring fun or socially stimulating. One of the Guidelines for Citizen Participation in Crowdsensing for Water Resource Monitoring (Section 4.4.4) is using different types of incentives to motivate participants. The Incentive Mechanism Design can be used to improve citizen participation in existing crowdsensing systems such as the NMBM application.

7.4.2 Programme Design

This research makes a programme design contribution by proposing a Crowdsensing Reference Framework, which consists of:

- The Crowdsensing Process consisting of three phases and eight activities - A1 to A8 (Figure 3-4).
- Key Success Factors for Crowdsensing Projects - K1 to K11 (Table 3-3).
- Guidelines for Crowdsensing Projects - G1 to G30 (Table 3-3).

The Crowdsensing Process highlights the plan for the implementation and coordination of a crowdsensing project. The three phases of the crowdsensing process are Project Initiation, Data Sensing and Gathering and Data Analytics. The crowdsensing process can guide organisations on how to set up a crowdsensing project.

7.5 Limitations of Study and Recommendations for Future Research

There were several limitations related to this study. The first limitation was that due to scope and time constraints, the researcher was only able to evaluate the OverSense recruitment policy as the OverSense incentive policy requires evaluating crowdsensing participants' responses to incentives over a long period of time. Future research should build on the sociotechnical design recommended in this study to implement a technical solution for water resource monitoring and test the resulting crowdsensing system across different social systems. Furthermore, there is a need to test the OverSense Policies in the real world.

Future work should also work towards collaborating with citizens to develop the crowdsensing system. Designing technology solutions collaboratively with the intended community provides a better understanding of the cultural nuances that can easily affect the use and adoption of an intervention (Ssozi-mugarura, Blake & Rivett, 2015).

7.6 Summary

The proposed Crowdsensing Method serves as a helpful instrument for project coordinators of crowdsensing projects as it offers several contributions. A common aspect of technology interventions in communities is that they are externally conceived and address an assumed need with little or no buy-in from the citizens (Dodson, Sterling & Bennett, 2013). The risk of not exploring the social systems around technical solutions is that the interventions are plagued with uncertain sustainability. To mitigate this risk and increase the chances of technology acceptance, this study emphasises the importance of investigating the social systems around technical solutions and proposes several frameworks and guidelines based on literature and empirical input of citizens. Researchers, crowdsensing project coordinators and practitioners (such as water authorities) can derive value from the Crowdsensing Method proposed in this study to assist with the planning and design of crowdsensing projects and systems.

------ The End ------

BIBLIOGRAPHY

Afreen, Goyal, S., Arora, A. & Aggrawal, N. (2017) Speak up: Get Rid from Daily Problems. *Procedia Computer Science*. [Online] 122, 924–931. Available from: doi:10.1016/j.procs.2017.11.456.

Ajzen, I. (1991) The Theory of Planned Behaviour. *Organisational Behaviour and Human Decision Processes*. [Online] 50, 179–211. Available from: doi:10.1016/j.drugalcdep.2011.10.011.

Alsheikh, M.A., Jiao, Y., Niyato, D., Wang, P., et al. (2017) The Accuracy-Privacy Tradeoff of Mobile Crowdsensing. *IEEE Communications Magazine*. [Online] Available from: http://arxiv.org/abs/1702.04565.

Anderson, A., Huttenlocher, D., Kleinberg, J. & Leskovec, J. (2013) Steering user behavior with badges. In: *Proceedings of the 22nd international conference on World Wide Web - WWW '13*. [Online]. 2013 pp. 95–106. Available from: doi:10.1145/2488388.2488398.

Angelopoulos, C.M., Evangelatos, O., Nikoletseas, S., Raptis, T.P., et al. (2015) A user-enabled testbed architecture with mobile crowdsensing support for smart, green buildings. In: *IEEE International Conference on Communications*. [Online]. 2015 pp. 573–578. Available from: doi:10.1109/ICC.2015.7248383.

Angelopoulos, C.M., Nikoletseas, S., Raptis, T.P. & Rolim, J.J.D.P. (2014) Characteristic utilities, join policies and efficient incentives in Mobile Crowdsensing Systems. In: *2014 IFIP Wireless Days (WD)*. [Online]. 2014 pp. 1–6. Available from: doi:10.1109/WD.2014.7020795.

Anjomshoa, F. & Kantarci, B. (2018) Sober-MCS: Sociability-oriented and battery efficient recruitment for mobile CROWD-sensing. *Sensors (Switzerland)*. [Online] 18 (5), 1–22. Available from: doi:10.3390/s18051593.

Baltar, F. & Brunet, I. (2012) Social research 2.0: Virtual snowball sampling method using Facebook. *Internet Research*. [Online] 22 (1), 57–74. Available from: doi:10.1108/10662241211199960.

Beier, L. (2014) *Evaluating the Use of Gamification in Higher Education to Improve Students Engagement*. Technische Universität Dresden.

Beza, O. (2011) Gamification-How games can level up our everyday life. *Universidad de Ambsterdan, Holanda.* [Online] (June), 1–21. Available from: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Gamification+?+How+games+can+level+up+our+everyday+life+?#1.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., et al. (2009a) Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. *A CAISE Inquiry Group Report*.

Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., et al. (2009b) Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *BioScience*. [Online] 59

(11), 977–984. Available from: doi:10.1525/bio.2009.59.11.9.

Bosha, E. (2015) *Factors Influencing Continuous Data Collection for a Public Safety Crowdsourcing Smart City Project*. University of Fort Hare.

Bosha, E., Cilliers, L. & Flowerday, S. (2017) Incentive theory for a participatory crowdsourcing project in a developing country. *SA Journal of Information Management*. [Online] 19 (1), 2017. Available from: doi:10.4102/sajim.v19i1.739.

Boyer, E.L. (1996) The Scholarship of Engagement. *Journal of Public Service and Outreach*. 1 (2), 11–20.

Brabham, D.C. (2008) Crowdsourcing as a model for problem solving: An introduction and cases. *Convergence*. [Online] 14 (1), 75–90. Available from: doi:10.1177/1354856507084420.

Braun, V. & Clarke, V. (2006) Using Thematic Analysis in Psychology. *Qualitative Research in Psychology*. [Online] 3 (2), 77–101. Available from: doi:10.1191/1478088706qp063oa.

Breslin, N. (2013) Changing relationships: ICT to improve water governance. *World Water Week report*. [Online] 1–16. Available from: doi:accessed April, 15, 2014.

Brewer, E.W., Hollingsworth, C. & Campbell, A. (1995) Incentive motivation psychology: an exploration of corrective learning behaviour. In: E. W. Brewer (ed.). *SAEOPP Journal*. 2nd Edn. p.

Bryman, A. (2012) *Social research methods*. 4th edn. [Online]. New York, Oxford University Press Inc. Available from: doi:10.1017/CBO9781107415324.004.

Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., et al. (2014) Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science*. [Online] 2 (October), 1–21. Available from: doi:10.3389/feart.2014.00026.

Caragliu, A., del Bo, C. & Nijkamp, P. (2011) Smart cities in Europe. *Journal of Urban Technology*. [Online] 18 (2), 65–82. Available from: doi:10.1080/10630732.2011.601117.

Cavalier, D. & Kennedy, E. (2016) *The Rightful Place of Science: Citizen Science*. Tempe, AZ, Consortium for Science, Policy & Outcomes.

Champanis, M., Rivett, U., Gool, S. & Nyemba-Mudenda, M. (2013) *ICTs in the water sector – where do we stand ?* [Online]. Available from: doi:10.13140/RG.2.1.3848.5928.

Chen, P.Y., Cheng, S.M., Ting, P.S., Lien, C.W., et al. (2015) When crowdsourcing meets mobile sensing: A social network perspective. *IEEE Communications Magazine*. [Online] 53 (10), 157–163. Available from: doi:10.1109/MCOM.2015.7295478.

Cherry, K. (2018) *The Incentive Theory of Motivation*. [Online]. 2018. Available from: https://www.verywellmind.com/the-incentive-theory-of-motivation-2795382 [Accessed: 7 December 2018].

Christin, D. (2016) Privacy in mobile participatory sensing: Current trends and future challenges. *Journal of Systems and Software*. [Online] 116, 57–68. Available from: doi:10.1016/j.jss.2015.03.067.

Cilliers, L., Flowerday, S. & Mclean, S. (2016) A crowdsourcing , smart city model for a developing country. *Association for Information Systems*. (May).

Cooper, C.B., Dickinson, J., Phillips, T. & Bonney, R. (2007) Citizen science as a tool for conservation in residential ecosystems. *Ecology and Society*. [Online] 12 (2). Available from: doi:11.

Copos, B., Levitt, K., Rowe, J., Kianmajd, P., et al. (2016) Security and privacy for emerging smart community infrastructures. *International Conference on Internet of Things and Big Data (IoTBD)*. 148–155.

D'Hondt, E., Stevens, M. & Jacobs, A. (2013) Participatory noise mapping works! An evaluation of participatory sensing as an alternative to standard techniques for environmental monitoring. *Pervasive and Mobile Computing*. [Online] 9 (5), 681–694. Available from: doi:10.1016/j.pmcj.2012.09.002.

Dabas, A. & Dabas, C. (2009) Implementation of Real Time Tracking using Unstructured Supplementary Service Data. *World Academy of Science, Engineering and Technology*. 54, 241.

Dai, W., Wang, Y., Jin, Q. & Ma, J. (2018) Geo-QTI: A quality aware truthful incentive mechanism for cyber–physical enabled Geographic crowdsensing. *Future Generation Computer Systems*. [Online] 79, 447–459. Available from: doi:10.1016/j.future.2017.04.033.

David, N., Justice, J. & Mc Nutt, J.G. (2015) Smart cities are transparent cities: The role of fiscal transparency in smart city governance. In: *Transforming City Governments for Successful Smart Cities*. [Online]. pp. 69–86. Available from: doi:10.1007/978-3-319-03167-5_5.

Davis, K.J. & Coskie, T.L. (2008) Project BudBurst: Analyzing Data. *Science and Children*. [Online] 45 (9), 52–54. Available from: http://bp8fd8su2n.search.serialssolutions.com/?ctx_ver=Z39.88-2004&ctx_enc=info:ofi/enc:UTF-8&rfr_id=info:sid/ProQ%3Aenvscijournals&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&rft.genre=article&rft.jtitle=Science+and+Children&rft.atitle=Project+BudBurst%3A+A.

Denscombe, M. (2008) Communities of Practice. *Journal of Mixed Methods Research*. [Online] 2 (3), 270–283. Available from: doi:10.1177/1558689808316807.

Discharge (2018) *Discharge - Apps on Google Play*. [Online]. 2018. Available from: https://play.google.com/store/apps/details?id=ch.photrack.discharge&hl=en [Accessed: 11 May 2018].

Dodson, L., Sterling, S.R. & Bennett, J.K. (2013) Considering Failure: Eight Years of ITID Research. *International Journal for Service Learning in Engineering*. [Online] 9 (2), 19–34. Available from: doi:10.1145/2160673.2160681.

Erickson, T. & Kellogg, W.A. (2000) Social translucence: an approach to designing systems that support social processes. *ACM Transactions on Computer-Human Interaction*. [Online] 7 (1), 59–83. Available from: doi:10.1145/344949.345004.

Fan, W. & Bifet, A. (2013) Mining Big Data : Current Status , and Forecast to the Future. *ACM SIGKDD Explorations Newsletter*. [Online] 14 (2), 1–5. Available from: doi:10.1145/2481244.2481246.

Fiandrino, C., Anjomshoa, F., Kantarci, B., Kliazovich, D., et al. (2017) Sociability-Driven Framework for Data Acquisition in Mobile Crowdsensing over Fog Computing Platforms for Smart Cities. *IEEE Transactions on Sustainable Computing*. [Online] 2 (4), 1–1. Available from: doi:10.1109/TSUSC.2017.2702060.

Fiandrino, C., Kantarci, B., Anjomshoa, F., Kliazovich, D., et al. (2016) Sociability-driven user recruitment in mobile crowdsensing internet of things platforms. *2016 IEEE Global Communications Conference, GLOBECOM 2016 - Proceedings*. [Online] 0–5. Available from: doi:10.1109/GLOCOM.2016.7842272.

FirstPost (2014) *Delhi Jal Board launches app to receive complaints on sewage, water supply - Firstpost*. [Online]. 2014. Available from: https://www.firstpost.com/india/delhi-jal-board-just-launched-app-receive-complaints-suggestions-sewage-water-supply-1768303.html [Accessed: 11 May 2018].

Fishbein, M. & Ajzen, I. (2010) *Predicting and changing behaviour: The reasoned action approach*. [Online]. New York, NY, Psychology Press, Taylor & Francis Group. Available from: doi:10.4324/9780203937082.

Francis, J.J., Eccles, M.P., Johnston, M., Walker, A., et al. (2004) *Constructing Questionnaires based on the Theory of Planned Behaviour: A Manual for Health Services Researchers*. [Online]. Newcastle upon Tyne, Centre for Health Services Research, University of Newcastle. Available from: doi:0-9540161-5-7.

Freifeld, C.C., Chunara, R., Mekaru, S.R., Chan, E.H., et al. (2010) Participatory epidemiology: Use of mobile phones for community-based health reporting. *PLoS Medicine*. [Online] 7 (12). Available from: doi:10.1371/journal.pmed.1000376.

Fudenberg, D. & Tirole, J. (1991) *Game Theory*. [Online]. Cambridge, MA, MIT Press. Available from: doi:10.2307/2554596.

Ganti, R.K., Ye, F. & Lei, H. (2011) Mobile Crowdsensing : Current State and Future Challenges. *IEEE Communications Magazine*. [Online] 49 (11), 32–39. Available from: doi:10.1109/MCOM.2011.6069707.

Gao, J., Li, Q., Zhao, B., Fan, W., et al. (2015) Truth discovery and crowdsourcing aggregation. *Proceedings of the VLDB Endowment*. [Online] 8 (12), 2048–2049. Available from: doi:10.14778/2824032.2824136.

Gassenheimer, J.B., Siguaw, J.A. & Hunter, G.L. (2013) Exploring motivations and the capacity for business crowdsourcing. *AMS Review*. [Online] 3 (4), 205–216. Available from: doi:10.1007/s13162-013-0055-8.

Geoghegan, H., Dyke, A., Pateman, R., West, S., et al. (2016) *Understanding Motivations for*

Citizen Science. Final Report on behalf of the UK Environmental Observation Framework (UKEOF). [Online]. (May). Available from: http://www.ukeof.org.uk/resources/citizen-science-resources/MotivationsforCSREPORTFINALMay2016.pdf.

Giannetsos, T., Gisdakis, S. & Papadimitratos, P. (2014) Trustworthy People-Centric Sensing : Privacy , Security and User Incentives Road-Map Trustworthy People-Centric Sensing : Privacy , Security and User Incentives Road-Map. In: *13th Annual Mediterranean Workshop on Ad Hoc Networking*. [Online]. 2014 pp. 39–46. Available from: doi:10.1109/MedHocNet.2014.6849103.

Glotzbach, R., Barakzai, S., Adisu, J. & Tiwari, C. (2013) Functionality: The Challenge to Sustain Rural Water Supply Services. *SNV Practice Brief*. (5).

Goncalves, A., Silva, C. & Morreale, P. (2014) Design of a Mobile Ad Hoc Network Communication App for Disaster Recovery. In: *2014 28th International Conference on Advanced Information Networking and Applications Workshops*. [Online]. 2014 pp. 121–126. Available from: doi:10.1109/WAINA.2014.26.

Gong, X. & Shroff, N.B. (2017) Truthful mobile crowdsensing for strategic users with private qualities. *2017 15th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks, WiOpt 2017*. [Online] Available from: doi:10.23919/WIOPT.2017.7959903.

Graham, P.M., Dickens, C.W.S. & Taylor, R.J. (2004) miniSASS - A novel technique for community participation in river health monitoring and management. *African Journal of Aquatic Science*. [Online] 29 (1), 25–35. Available from: doi:10.2989/16085910409503789.

Granier, B. & Kudo, H. (2016) How are citizens involved in smart cities? Analysing citizen participation in Japanese 'smart Communities'. *Information Polity*. [Online] 21 (1), 61–76. Available from: doi:10.3233/IP-150367.

Greenfield, A. (2013) Against the Smart City. In: *The City is Here for You to Use*. [Online]. pp. 6–13. Available from: http://urbanomnibus.net/2013/10/against-the-smart-city/%5Cnhttp://urbanomnibus.net/2013/10/against-the-smart-city/#footnote.

Guo, B., Yu, Z., Zhou, X. & Zhang, D. (2014) From participatory sensing to Mobile Crowd Sensing. *2014 IEEE International Conference on Pervasive Computing and Communication Workshops, PERCOM WORKSHOPS 2014*. [Online] 593–598. Available from: doi:10.1109/PerComW.2014.6815273.

Gurstein, M. (2014) Smart Cities vs. Smart Communities: Empowering Citizens not Market Economics. *The Journal of Community Informatics*. [Online] 10 (3), 1–10. Available from: http://ci-journal.net/index.php/ciej/article/view/1172/1117 [Accessed: 25 September 2017].

Gustafsson, J. (2017) *Single case studies vs. multiple case studies: A comparative study*. Master Thesis, Academy of Business, Engineering and Science, Halmstad University, Sweden.

Gustarini, M., Wac, K. & Dey, A.K. (2016) Anonymous smartphone data collection: factors influencing the users' acceptance in mobile crowd sensing. *Personal and Ubiquitous*

Computing. [Online] 20 (1), 65–82. Available from: doi:10.1007/s00779-015-0898-0.

Hachem, S., Pathak, A. & Issarny, V. (2013) Probabilistic registration for large-scale mobile participatory sensing. In: *2013 IEEE International Conference on Pervasive Computing and Communications, PerCom 2013*. [Online]. 2013 pp. 132–140. Available from: doi:10.1109/PerCom.2013.6526723.

Haddawy, P. (2015) A Bayesian Approach to Situation Awareness in Crowdsensing for Disease Surveillance. In: *SPATIAL 2015 Un-conference— Spatial Information for Human Health*. 2015 pp. 1–3.

Haklay, M. (2013) Citizen Science and Volunteered Geographic Information – overview and typology of participation. In: D.Z. Sui, S. Elwood, & M.F. Goodchild (eds.). *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice*. [Online]. Berlin, Springer. pp. 105–122. Available from: doi:10.1007/978-94-007-4587-2.

Hall, N., Acosta Jaramillo, C.M., Jagals, P., Currie, D., et al. (2016) *Strengthening community participation in meeting UN Sustainable Development Goal 6 for water, sanitation and hygiene*. [Online]. Brisbane, Global Change Institute, The University of Queensland, Australia. Available from: http://gci.uq.edu.au/un-sustainable-development-goals-water-sanitation-and-hygiene.

Han, K., Graham, E.A., Vassallo, D. & Estrin, D. (2011) Enhancing motivation in a mobile participatory sensing project through gaming. In: *Proceedings - 2011 IEEE International Conference on Privacy, Security, Risk and Trust and IEEE International Conference on Social Computing, PASSAT/SocialCom 2011*. [Online]. 2011 pp. 1443–1448. Available from: doi:10.1109/PASSAT/SocialCom.2011.113.

Hannah, D.M., Demuth, S., van Lanen, H.A.J., Looser, U., et al. (2011) Large-scale river flow archives: Importance, current status and future needs. *Hydrological Processes*. [Online] 25 (7), 1191–1200. Available from: doi:10.1002/hyp.7794.

Harpe, S.E. (2015) How to analyze Likert and other rating scale data. *Currents in Pharmacy Teaching and Learning*. [Online] 7 (6), 836–850. Available from: doi:10.1016/j.cptl.2015.08.001.

He, D., Chan, S. & Guizani, M. (2015) User privacy and data trustworthiness in mobile crowd sensing. *IEEE Wireless Communications*. [Online] 22 (1), 28–34. Available from: doi:10.1109/MWC.2015.7054716.

Hellström, J. & Jacobson, M. (2014) 'You Can't Cheat the Community Anymore' – Using Mobiles to Improve Water Governance. In: Ibrahima Niang, Christelle Scharff, & Caroline Wamala (eds.). *Proceedings of 4th International Conference on M4D Mobile Communication for Development*. [Online]. Karlstad, Karlstad University Studies. pp. 48–59. Available from: http://kau.diva-portal.org/smash/get/diva2:709233/FULLTEXT03.pdf.

Hochachka, W.M., Fink, D., Hutchinson, R.A., Sheldon, D., et al. (2012) Data-intensive science applied to broad-scale citizen science. *Trends in Ecology and Evolution*. [Online] 27 (2), 130–137. Available from: doi:10.1016/j.tree.2011.11.006.

Huang, W.H. & Soman, D. (2013) Gamification Of Education. *University of Toronto - Rotman School of Management*. [Online] 1–29. Available from: doi:10.1111/j.1467-8535.2011.01259.x.

Hutchings, M.T., Dev, A., Palaniappan, M., Srinivasan, V., et al. (2012) *mWASH: mobile phone applications for the water, sanitation, and hygiene sector*. Nancy Ross & Paula Luu (eds.). [Online]. California, Pacific Institute and Nexleaf Analytics. Available from: http://www.indiasanitationportal.org/sites/default/files/Full_Report_MWASH.pdf.

Iivari, J., Hirschheim, R. & Klein, H.K. (1998) A Paradigmatic Analysis Contrasting Information Systems Development Approaches and Methodologies. *Information Systems Research*. [Online] 9 (2), 164–193. Available from: doi:10.1287/isre.9.2.164.

Irwin, A. (1995) *Citizen science: A study of people, expertise and sustainable development*. [Online]. London, Routledge. Available from: doi:10.1177/017084069701800109.

ISO 9241-210 (2010) *Ergonomics of human-system interaction - Part 210: Human-centered design for interactive systems*. [Online]. Available from: doi:10.1039/c0dt90114h.

Jaimes, L.G., Vergara-Laurens, I.J. & Raij, A. (2015) A Survey of Incentive Techniques for Mobile Crowd Sensing. *IEEE Internet of Things Journal*. [Online] 2 (5), 370–380. Available from: doi:10.1109/JIOT.2015.2409151.

Jiménez, A. & Pérez-Foguet, A. (2010) Challenges for water governance in rural water supply: Lessons learned from Tanzania. *International Journal of Water Resources Development*. [Online] 26 (2), 235–248. Available from: doi:10.1080/07900621003775763.

Jin, J., Gubbi, J., Marusic, S. & Palaniswami, M. (2014) An Information Framework for Creating a Smart City Through Internet of Things. *IEEE Internet of Things Journal*. [Online] 1 (2), 112–121. Available from: doi:10.1109/JIOT.2013.2296516.

Joachim, O.I., Kamarudin, N., Aliagha, G.U. & Ufere, K.J. (2015) Theoretical Explanations of Environmental Motivations and Expectations of Clients on Green Building Demand and Investment. *IOP Conference Series: Earth and Environmental Science*. [Online] 23 (012010), 2–3. Available from: doi:10.1088/1755-1315/23/1/012010.

Johnson, R.B., Onwuegbuzie, A.J. & Turner, L.A. (2007) Toward a Definition of Mixed Methods Research. *Journal of Mixed Methods Research*. 1 (2), 112–133.

Kanhere, S.S. (2011) Participatory sensing: Crowdsourcing data from mobile smartphones in urban spaces. In: *2011 IEEE 12th International Conference on Mobile Data Management*. [Online]. 2011 Lulea, Sweden. pp. 3–6. Available from: doi:10.1007/978-3-642-36071-8-2.

Kapadia, A., Kotz, D. & Triandopoulos, N. (2009) Opportunistic sensing: Security challenges for the new paradigm. *2009 First International Communication Systems and Networks and Workshops*. [Online] 1–10. Available from: doi:10.1109/COMSNETS.2009.4808850 [Accessed: 13 December 2017].

Kapp, K.M. (2012) *The gamification of learning and instruction: game-based methods and strategies for training and education*. San Francisco, Pfeiffer.

Karlin, B. (2012) Public Acceptance of Smart Meters: Integrating Psychology and Practice. *ACEEE Summer Study on Energy Efficiency in Buildings*. 102–113.

Kawajiri, R., Shimosaka, M. & Kahima, H. (2014) Steered Crowdsensing: Incentive Design towards Quality-Oriented Place-Centric Crowdsensing. In: *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing - UbiComp '14 Adjunct*. [Online]. 2014 pp. 691–701. Available from: doi:10.1145/2632048.2636064.

Khatoun, R. & Zeadally, S. (2016) Smart Cities: Concepts, Architectures, Research Opportunities. *Communications of the Acm*. [Online] 59 (8), 46–57. Available from: doi:10.1145/2858789.

Kim, S., Robson, C., Zimmerman, T., Pierce, J., et al. (2011) Creek Watch: Pairing usefulness and usability for successful citizen science. In: *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11*. [Online]. 2011 p. 2125. Available from: doi:10.1145/1978942.1979251.

Kimura, A.H. & Kinchy, A. (2016) Citizen Science: Probing the Virtues and Contexts of Participatory Research. *Engaging Science, Technology, and Society*. [Online] 2, 331–361. Available from: doi:10.17351/ests2016.099.

Kitchenham, B.A., Pfleeger, S.L., Pickard, L.M., Jones, P.W., et al. (2002) Preliminary guidelines for empirical research in software engineering. *IEEE Transactions on Software Engineering*. [Online] 28 (8), 721–734. Available from: doi:10.1109/TSE.2002.1027796.

Klein, L. (2014) What do we actually mean by 'sociotechnical'? On values, boundaries and the problems of language. *Applied Ergonomics*. [Online] 45 (2 Part A), 137–142. Available from: doi:10.1016/j.apergo.2013.03.027.

Kranz, J.J. & Picot, A. (2011) Toward an End-to-End Smart Grid : Overcoming Bottlenecks to Facilitate Competition and Innovation in Smart Grids. *National Regulatory Research Institute, June*. (June) p.41.

Lanfranchi, V., Wrigley, S.N., Ireson, N., Wehn, U., et al. (2014) Citizens' observatories for situation awareness in flooding. *ISCRAM 2014 Conference Proceedings - 11th International Conference on Information Systems for Crisis Response and Management*. [Online] (May), 145–154. Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-84905845529&partnerID=40&md5=e5b0648560fbc7c586e1a09b67531619.

Larose, D.T. (2006) *Data Mining Methods and Models*. [Online]. John Wiley & Sons, Inc. Available from: doi:10.1002/0471756482.

Lee, J.S. & Hoh, B. (2010) Dynamic pricing incentive for participatory sensing. In: *Pervasive and Mobile Computing*. [Online]. 2010 pp. 693–708. Available from: doi:10.1016/j.pmcj.2010.08.006.

Lendák, I. (2016) Mobile crowd-sensing in the Smart City. In: C Capineri, M Haklay, H Huang, V Antoniou, et al. (eds.). *European Handbook of Crowdsourced Geographic Information*. pp. 353–369.

Lindskog, H. (2004) Smart communities initiatives. *Proceedings of the 3rd ISOneWorld Conference*. (April), 16.

Liu, J., Shen, H. & Zhang, X. (2016) A survey of mobile crowdsensing techniques: A critical component for the internet of things. *2016 25th International Conference on Computer Communications and Networks, ICCCN 2016*. [Online] Available from: doi:10.1109/ICCCN.2016.7568484.

Louta, M., Mpanti, K., Karetsos, G. & Lagkas, T. (2016) Mobile crowd sensing architectural frameworks: A comprehensive survey. In: *IISA 2016 - 7th International Conference on Information, Intelligence, Systems and Applications*. [Online]. 2016 Chalkidiki, Greece. pp. 1–8. Available from: doi:10.1109/IISA.2016.7785385.

Lowry, C.S. & Fienen, M.N. (2013) CrowdHydrology: Crowdsourcing hydrologic data and engaging citizen scientists. *GroundWater*. [Online] 51 (1), 151–156. Available from: doi:10.1111/j.1745-6584.2012.00956.x.

Mackinnon, C.A. (2010) Engaged Scholarship as Method and Vocation. *Yale Journal of Law & Feminism*. 22 (2).

Martin, V.Y., Weiler, B., Reis, A., Dimmock, K., et al. (2017) 'Doing the right thing': How social science can help foster pro-environmental behaviour change in marine protected areas. *Marine Policy*. [Online] 81 (April), 236–246. Available from: doi:10.1016/j.marpol.2017.04.001.

Massung, E., Coyle, D., Cater, K.F., Jay, M., et al. (2013) Using crowdsourcing to support pro-environmental community activism. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '13*. [Online]. 2013 p. 371. Available from: doi:10.1145/2470654.2470708.

Mathiassen, L. (2017) Designing Engaged Scholarship: From Real-World Problems to Research Publications. *Engaged Management ReView*. [Online] 1 (1), 1–15. Available from: doi:10.28953/2375-8643.1000.

Mendez, D. & Labrador, M.A. (2012) Density maps: Determining where to sample in participatory sensing systems. In: *Proceedings - 2012 3rd FTRA International Conference on Mobile, Ubiquitous, and Intelligent Computing, MUSIC 2012*. [Online]. 2012 pp. 35–40. Available from: doi:10.1109/MUSIC.2012.14.

Merriam-Webster.com (2018) *Mechanism*. [Online]. 2018. Available from: https://www.merriam-webster.com/dictionary/mechanism [Accessed: 6 December 2018].

Mingers, J., Mutch, A. & Willcocks, L. (2013) Critical Realism in Information Systems Research. *MIS Quarterly*. [Online] 37 (3), 795–802. Available from: doi:10.1080/00369220601100075.

Minkman, E. (2015) *Citizen Science in Water Quality Monitoring*. MSc Thesis, Delft University of Technology.

Mosweunyane, G., Seipone, T., Nkgau, T.Z. & Makhura, O.J. (2014) Design of a USSD System for TB Contact Tracing. *Environment and Water Resource Management*. [Online] (January 2014). Available from: doi:10.2316/P.2014.815-026.

Musthag, M., Raij, A., Ganesan, D., Kumar, S., et al. (2011) Exploring micro-incentive strategies for participant compensation in high-burden studies. In: *Proceedings of the 13th international conference on Ubiquitous computing - UbiComp '11*. [Online]. 2011 p. 435. Available from: doi:10.1145/2030112.2030170.

Myers, M.D. & Venable, J.R. (2014) A set of ethical principles for design science research in information systems. *Information and Management*. [Online] 51 (6), 801–809. Available from: doi:10.1016/j.im.2014.01.002.

Nahrstedt, K., Lopresti, D., Zorn, B., Drobnis, A.W., et al. (2016) Smart Communities Internet of Things. *Computing Community Consortium (CCC) Computing in the Physical World Task Force*. 1–9.

Nam, T. & Pardo, T.A. (2011) Conceptualizing smart city with dimensions of technology, people, and institutions. *Proceedings of the 12th Annual International Digital Government Research Conference on Digital Government Innovation in Challenging Times - dg.o '11*. [Online] (June), 282. Available from: doi:10.1145/2037556.2037602.

Nascimento, I., Silva, W., Lopes, A., Rivero, L., et al. (2016) An empirical study to evaluate the feasibility of a UX and usability inspection technique for mobile applications. *Proceedings of the International Conference on Software Engineering and Knowledge Engineering, SEKE*. [Online] 2016–Janua, 595–599. Available from: doi:10.18293/SEKE2016-127.

Nel, P.J.C., Booysen, M.J. & Van Der Merwe, B. (2014) ICT-enabled solutions for smart management of water supply in Africa. *Proceedings or the 1st International Conference on the Use of Mobile ICT in Africa 2014*. [Online] 40–44. Available from: http://scholar.sun.ac.za/handle/10019.1/96153.

Nelson Mandela Bay Municipality (2016) *Nelson Mandela Bay Municipality Integrated Development Plan 2016/17-2020/21*. [Online]. 15. Available from: doi:10.1017/CBO9781107415324.004.

Nique, M. & Opala, K. (2014) The synergies between mobile, energy and water access: Africa. *GSMA's Mobile enabled community Services programme*. [Online]. (March). Available from: http://www.gsma.com/mobilefordevelopment/wp-content/uploads/2014/04/MECS_Synergies-between-Mobile-Energy-and-Water-Access_Asia.pdf%5Cnhttp://www.gsma.com/mobilefordevelopment/wp-content/uploads/2014/04/MECS_Synergies-between-Mobile-Energy-and-Water-Access.

NMBM (2018) *NMBM Mobile Application – Apps on Google Play*. [Online]. 2018. Available from: https://play.google.com/store/apps/details?id=compumade.nmm&hl=en_ZA&rdid=compumade.nmm&pli=1 [Accessed: 21 October 2018].

Norman, D. & Nielsen, J. (2018) *The Definition of User Experience (UX)*. [Online]. 2018. Available from: https://www.nngroup.com/articles/definition-user-experience/ [Accessed: 11 March 2018].

Noureen, J. & Asif, M. (2017) Crowdsensing : Socio-Technical Challenges and Opportunities. *International Journal of Advanced Computer Science and Applications*. 8 (3), 363–369.

Nov, O., Arazy, O. & Anderson, D. (2011) Dusting for science: Motivation and participation of digital citizen science volunteers. *iConference*. [Online] 68–74. Available from: doi:10.1145/1940761.1940771.

Ochoa, S., Talavera, J. & Paciello, J. (2015) Applying a Geospatial Visualization Based on USSD Messages to Real Time Identification of Epidemiological Risk Areas in Developing Countries: A Case of Study of Paraguay. *Studies in Health Technology and Informatics*. [Online] 216, 396–400. Available from: doi:10.3233/978-1-61499-564-7-396.

Ogie, R.I. (2016) Adopting incentive mechanisms for large-scale participation in mobile crowdsensing: from literature review to a conceptual framework. *Human-centric Computing and Information Sciences*. [Online] 6 (24). Available from: doi:10.1186/s13673-016-0080-3.

Oliveira, L.F., Schneider, D., Souza, J.M. De & Sérgio, A. (2017) Crowd sensing to monitor the waiting time of day-to-day services. *International Journal of Computer Science: Theory and Application*. (January), 1.

Pankratius, V., Lind, F., Coster, A., Erickson, P., et al. (2014) Mobile crowd sensing in space weather monitoring: The mahali project. *IEEE Communications Magazine*. [Online] 52 (8), 22–28. Available from: doi:10.1109/MCOM.2014.6871665.

Parikh, S., Kathiria, P., Vaghela, Y., Shah, H., et al. (2014) A Geo-Location based Mobile Service that Dynamically Locates and Notifies the nearest Blood Donors for Blood Donation during Medical Emergencies. *International Journal of Computer Applications*. 88 (3), 975–8887.

Perrier, T., DeRenzi, B. & Anderson, R. (2015) USSD: The Third Universal App. *Proceedings of the 2015 Annual Symposium on Computing for Development*. [Online] 13–21. Available from: doi:10.1145/2830629.2830645.

Petrushyna, Z., Klamma, R. & Jarke, M. (2014) The Impact of Culture On Smart Community Technology: The Case of 13 Wikipedia Instances. *Interaction Design and Architecture(s) Journal*. 22, 34–47.

Pistolato, A.C. & Brandão, W.C. (2016) Connectcity : a Collaborative E-Government Approach To Report City Incidents. In: *15th International Conference WWW/Internet 2016*. 2016 pp. 233–237.

Pocock, M.J.O., Chapman, D.S., Sheppard, L.J. & Roy, H.E. (2014) *Choosing and using citizen science: A guide to when and how to use citizen science to monitor biodiversity and the environment*. [Online]. Available from: https://www.ceh.ac.uk/sites/default/files/sepa_choosingandusingcitizenscience_interactive_4web_final_amended-blue1.pdf.

Quoc Viet Hung, N., Tam, N.T., Tran, L.N. & Aberer, K. (2013) An evaluation of aggregation techniques in crowdsourcing. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. [Online] 8181 LNCS (PART 2), 1–15. Available from: doi:10.1007/978-3-642-41154-0_1.

Rapousis, N. & Papadopouli, M. (2016) Performance analysis of a user-centric crowd-sensing water quality assessment system. In: *2016 International Workshop on Cyber-physical Systems for Smart Water Networks, CySWater 2016*. [Online]. 2016 pp. 13–18. Available from: doi:10.1109/CySWater.2016.7469058.

Reddy, S., Burke, J., Estrin, D., Hansen, M., et al. (2007) A framework for data quality and feedback in participatory sensing. *SenSys '07: Proceedings of the 5th international conference on Embedded networked sensor systems*. [Online] 417. Available from: doi:10.1145/1322263.1322324.

Reddy, S., Estrin, D. & Srivastava, M. (2010) Recruitment framework for participatory sensing data collections. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. [Online] 6030 LNCS, 138–155. Available from: doi:10.1007/978-3-642-12654-3_9.

Riesch, H. & Potter, C. (2014) Citizen science as seen by scientists: Methodological, epistemological and ethical dimensions. *Public Understanding of Science*. [Online] 23 (1), 107–120. Available from: doi:10.1177/0963662513497324.

Rogstadius, J., Kostakos, V., Kittur, A., Smus, B., et al. (2011) An Assessment of Intrinsic and Extrinsic Motivation on Task Performance in Crowdsourcing Markets. *Icwsm*. [Online] 11 (January 2017), 17–21. Available from: doi:10.13140/RG.2.2.19170.94401.

Rotman, D., Hammock, J., Preece, J., Hansen, D., et al. (2014) Motivations Affecting Initial and Long-Term Participation in Citizen Science Projects in Three Countries. In: *iConference 2014 Proceedings*. [Online]. 2014 pp. 110–124. Available from: doi:10.9776/14054.

Sanganagouda, J. (2011) USSD - A Potential Communication Technology that can Ouster SMS Dependency. *International Journal of Research & Reviews in Computer Science*. 2 (2), 295.

Sarstedt, M., Ringle, C.M., Smith, D., Reams, R., et al. (2014) Partial least squares structural equation modeling (PLS-SEM): A useful tool for family business researchers. *Journal of Family Business Strategy*. [Online] 5 (1), 105–115. Available from: doi:10.1016/j.jfbs.2014.01.002.

SF311 (2018a) *Create a New Request - SF311*. [Online]. 2018. Available from: https://sf311.org/index.aspx?page=797 [Accessed: 11 May 2018].

SF311 (2018b) *SF311 Mobile App*. [Online]. 2018. Available from: https://www.sf311.org/mobile [Accessed: 11 May 2018].

Shien, L.K. & Singh, M.M. (2017) A secure mobile crowdsensing (MCS) location tracker for elderly in smart city. In: *AIP Conference Proceedings*. [Online]. 2017 pp. 1–10. Available from: doi:10.1063/1.5005418.

Simon, B., Loewy, M., Stürmer, S., Weber, U., et al. (1998) Collective identification and social movement participation. *Journal of Personality and Social Psychology*. [Online] 74 (3), 646–658. Available from: doi:10.1037/0022-3514.74.3.646.

Ssozi-mugarura, F., Blake, E. & Rivett, U. (2015) Designing for Sustainability : Involving Communities in Developing ICT Interventions to Support Water Resource Management. In: *IST-Africa 2015 Conference Proceedings*. 2015 pp. 1–8.

Ssozi-Mugarura, F., Blake, E. & Rivett, U. (2016) Supporting community needs for rural water management through community-based co-design. *Proceedings of the 14th Participatory Design Conference*. [Online] 1, 91–100. Available from: doi:10.1145/2940299.2940311.

Starkey, E., Parkin, G., Birkinshaw, S., Large, A., et al. (2017) Demonstrating the value of community-based ('citizen science') observations for catchment modelling and characterisation. *Journal of Hydrology*. [Online] 548, 801–817. Available from: doi:10.1016/j.jhydrol.2017.03.019.

Suddul, G., Bahadoor, U., Ramdoyal, A., Doolhur, N., et al. (2011) An open USSD enabler to simplify access to mobile services in emerging countries. *International Conference on Emerging Trends in Engineering and Technology, ICETET*. [Online] 323–326. Available from: doi:10.1109/ICETET.2011.53.

Sullivan, B.L., Wood, C.L., Iliff, M.J., Bonney, R.E., et al. (2009) eBird: A citizen-based bird observation network in the biological sciences. *Biological Conservation*. [Online] 142 (10), 2282–2292. Available from: doi:10.1016/j.biocon.2009.05.006.

Sun, Y., Song, H., Jara, A.J. & Bie, R. (2016) Internet of Things and Big Data Analytics for Smart and Connected Communities. *IEEE Access*. 4.

Surowiecki, J. (2004) *The Wisdom of Crowds: Why the Many Are Smarter Than the Few and How Collective Wisdom Shapes Business, Economies, Societies and Nations*. [Online]. New York, NY, US: Doubleday & Co. Available from: doi:10.3174/ajnr.A3417.

The Office of the Compliance Advisor/Ombudsman (2008) Participatory water monitoring. *Office of the Compliance Advisor/Ombudsman*. (June).

Tilak, S. (2013) Real-World Deployments of Participatory Sensing Applications: Current Trends and Future Directions. In: *ISRN Sensor Networks*. [Online]. 2013 pp. 1–8. Available from: doi:10.1155/2013/583165.

Tomasic, A., Zimmerman, J., Steinfeld, A. & Huang, Y. (2014) Motivating Contribution in a Participatory Sensing System via Quid-pro-quo. In: *Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing.* [Online]. 2014 pp. 979–988. Available from: doi:10.1145/2531602.2531705.

Tracking the Wild (2013) *Tracking the Wild | Wildlife Sightings App for your African Safari*. [Online]. 2013. Available from: https://www.trackingthewild.com/ [Accessed: 31 January 2018].

Traverso, P. (2015) Keynote abstract: From smart cities to smart communities: The case of children's independent mobility. In: *2015 10th International Workshop on Semantic and Social Media Adaptation and Personalization (SMAP)*. 2015 Trento, Italy, IEEE. p. xv.

Tuite, K., Snavely, N. & Tabing, N. (2011) PhotoCity : Training Experts at Large-scale Image Acquisition Through a Competitive Game. In: *CHI 2011 - Session Crowdsourcing*. [Online]. 2011 pp. 1383–1392. Available from: doi:10.1145/1978942.1979146.

Turpin, E. & Holderness, T. (2015) From social media to geosocial intelligence: Crowdsourcing civic co-management for flood response in Jakarta, Inddonesia. In: *Social Media for Government Services*. [Online]. pp. 115–133. Available from: doi:10.1007/978-3-319-27237-5_6.

UNICEF & WHO (2017) *Progress on Drinking Water, Sanitation and Hygiene*. [Online]. Available from: doi:10.1111 / tmi.12329.

United Nations (2017) Progress towards the Sustainable Development Goals. *Report of the Secretary-General*. [Online] E/2017/66, 19. Available from: doi:10.1017/S0020818300006640.

Van de Ven, A.H. (2007) Engaged scholarship: A guide for organizational and social research. *Oxford University Press*. [Online] 344. Available from: doi:10.1017/CBO9781107415324.004.

Vergara-Laurens, I.J. & Labrador, M. a. (2011) Preserving privacy while reducing power consumption and information loss in LBS and participatory sensing applications. In: *2011 IEEE GLOBECOM Workshops (GC Wkshps)*. [Online]. 2011 pp. 1247–1252. Available from: doi:10.1109/GLOCOMW.2011.6162381.

Wanda, E.M.M., Manda, M., Kushe, J., Msiska, O., et al. (2017) Using Citizen Science Approach to monitor water, sanitation and hygiene Related Risks in Karonga Town, Malawi. *African Journal of Environmental Science and Technology*. [Online] 11 (6), 304–323. Available from: doi:10.5897/AJEST2017.2308.

Wang, L. (2016) *Facilitating Mobile Crowdsensing from both Organizers ' and Participants ' Perspectives*. Institut National des Télécommunications.

Washburn, D. & Sindhu, U. (2010) Helping CIOs Understand "Smart City" Initiatives. *Growth*. [Online] 17. Available from: http://c3328005.r5.cf0.rackcdn.com/73efa931-0fac-4e28-ae77-8e58ebf74aa6.pdf.

Weber, S. (2010) Design Science Research: Paradigm or Approach? In: *Americas Conference on Information Systems (AMCIS) 2010 Proceedings*. [Online]. 2010 p. 214. Available from: http://aisel.aisnet.org/amcis2010http://aisel.aisnet.org/amcis2010/214.

Wiggins, A. (2011) eBirding: Technology Adoption and the Transformation of Leisure into Science. In: *Proceedings of the 2011 iConference on - iConference '11*. [Online]. 2011 pp. 798–799. Available from: doi:10.1145/1940761.1940910.

Wiggins, A. & Crowston, K. (2011) From conservation to crowdsourcing: A typology of citizen science. In: *Proceedings of the Annual Hawaii International Conference on System Sciences*. [Online]. 2011 pp. 1–10. Available from: doi:10.1109/HICSS.2011.207.

Wilson, P. (1997) *Smart Communities Guidebook*. Governor of California.

Wohlin, C., Höst, M. & Henningsson, K. (2006) Empirical Research Methods in Web and Software Engineering. *Web Engineering, Springer*. 409–430.

Xia, F. & Ma, J. (2011) Building smart communities with cyber-physical systems. *Proceedings of 1st international symposium on From digital footprints to social and community intelligence - SCI '11*. [Online] 1–5. Available from: doi:10.1145/2030066.2030068.

Xiao, Y., Simoens, P., Pillai, P., Ha, K., et al. (2013) Lowering the barriers to large-scale mobile crowdsensing. In: *Proceedings of the 14th Workshop on Mobile Computing Systems and Applications - HotMobile '13*. [Online]. 2013 p. 1. Available from: doi:10.1145/2444776.2444789.

Xiong, H., Zhang, D., Chen, G., Wang, L., et al. (2016) ICrowd: Near-Optimal Task Allocation for Piggyback Crowdsensing. *IEEE Transactions on Mobile Computing*. [Online] 15 (8), 2010–2022. Available from: doi:10.1109/TMC.2015.2483505.

Yadav, K., Chakraborty, D., Soubam, S., Prathapaneni, N., et al. (2013) Human Sensors : Case-study of Open-ended Community Sensing in Developing Regions. In: *IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom '13)*. 2013 pp. 389–392.

Yang, D., Xue, G., Fang, X. & Tang, J. (2015a) Incentive Mechanisms for Crowdsensing: Crowdsourcing With Smartphones. *IEEE/ACM TRANSACTIONS ON NETWORKING,*. 24 (3), 1732–1744.

Yang, G., He, S., Shi, Z. & Chen, J. (2017) Promoting cooperation by the social incentive mechanism in mobile crowdsensing. *IEEE Communications Magazine*. [Online] 55 (3), 86–92. Available from: doi:10.1109/MCOM.2017.1600690CM.

Yang, H., Zhang, J. & Roe, P. (2013) Reputation modelling in Citizen Science for environmental acoustic data analysis. *Social Network Analysis and Mining*. [Online] 3 (3), 419–435. Available from: doi:10.1007/s13278-012-0087-3.

Yang, K., Zhang, K., Ren, J. & Shen, X.S. (2015b) Security and privacy in mobile crowdsourcing networks: Challenges and opportunities. *IEEE Communications Magazine*. [Online] 53 (8), 75–81. Available from: doi:10.1109/MCOM.2015.7180511.

Yerva, S.R., Saltarin, J., Jeung, H. & Aberer, K. (2012) Social and sensor data fusion in the cloud. In: *Proceedings - 2012 IEEE 13th International Conference on Mobile Data Management, MDM 2012*. [Online]. 2012 pp. 276–277. Available from: doi:10.1109/MDM.2012.52.

Yin, R.K. (2014) *Case Study Research: Design and Methods*. 5th Edn. [Online]. Thousand Oaks, CA, Sage. Available from: doi:10.1097/FCH.0b013e31822dda9e.

Zhang, H., Parkes, D.C. & Chen, Y. (2009) Policy Teaching Through Reward Function Learning. *Applied Sciences*. [Online] 166 (2), 295–304. Available from: doi:10.1145/1566374.1566417.

Zhang, M., Yang, P., Tian, C., Tang, S., et al. (2016) Toward Optimum Crowdsensing Coverage with Guaranteed Performance. *IEEE Sensors Journal*. [Online] 16 (5), 1471–1480. Available from: doi:10.1109/JSEN.2015.2501371.

Zheng, Y. & Dedrick, J. (2012) Learning Strategies in Smart Grid Adoption : An Explorative Study in the U.S. Electric Utility Industry. *iConference 2015 Proceedings*.

Zheng, Y.U., Capra, L., Wolfson, O. & Yang, H. (2014) Urban Computing : Concepts , Methodologies , and Applications. *ACM Transactions on Intelligent Systems and Technology*. 5 (3).

Zheng, Z., Wu, F., Gao, X., Chen, G., et al. (2017) BEACON : A Budget Feasible Incentive Mechanism for Weighted Coverage Maximization in Mobile Crowdsensing. *IEEE Transactions on Mobile Computing*. 16 (9), 2392–2407.

Zhou, X., Chen, K., Wu, S. & Zhang, B. (2013) Crowd-answering system via microblogging. In: *Proceedings - International Conference on Data Engineering*. [Online]. 2013 pp. 1284–1287. Available from: doi:10.1109/ICDE.2013.6544925.

APPENDICES

Appendix A

NELSON MANDELA UNIVERSITY

FACULTY OF SCIENCE RTI COMMITTEE

To: Dr B. Scholtz/ C. Mloza-Banda
From: Lynette Roodt
Date: 27 November 2017
Ref: H17-SCI-CSS-008

Dear Dr B. Scholtz/ C. Mloza-Banda

TITLE OF PROJECT: A CROWDSENSING PARADIGM FOR WATER RESOURCE MONITORING IN SMART COMMUNITIES

Your above-entitled application was considered and approved by the Sub-Committee for Ethics in the Faculty of Science on 20 November 2017.

The Ethics clearance reference number is H17-SCI-CSS-008 and is valid for three years. Please inform the Committee, via your faculty officer, if any changes (particularly in the methodology) occur during this time.

An annual affirmation to the effect that the protocols in use are still those, for which approval was granted, will be required from you. You will be reminded timeously of this responsibility, and will receive the necessary documentation well in advance of any deadline.

We wish you well with the project. Please inform your co-investigators of the outcome, and convey our best wishes.

Yours sincerely

Lynette Roodt
Manager: Faculty Administrator
Faculty of Science

Appendix B

Questionnaire

QUESTIONS	RESPONSE FORMAT
BEHAVIOURAL INTENTIONS	
BI1: I expect to report cases of water pollution and wastage issues BI2: I want to report cases of water pollution and wastage issues BI3: I intend to report cases of water pollution and wastage issues	Strongly disagree 1 2 3 4 5 Strongly agree
BEHAVIOURAL ATTITUDES	
Direct Measurement	
BA1: In my opinion, reporting cases of water pollution and wastage issues to the municipality is:	Worthless 1 2 3 4 5 Useful
BA2: In my opinion, reporting cases of water pollution and wastage issues to the municipality is:	Unpleasant (for me) 1 2 3 4 5 Pleasant (for me)
BA3: In my opinion, reporting cases of water pollution and wastage issues to a trusted organisation is:	Worthless 1 2 3 4 5 Useful
BA4: In my opinion, reporting cases of water pollution and wastage issues to a trusted organisation is:	Unpleasant (for me) 1 2 3 4 5 Pleasant (for me)
Behavioural Beliefs	
BA5: If I report cases of water pollution and wastage issues, I will feel that I am doing something positive for the community.	Unlikely 1 2 3 4 5 Likely
BA6: Discovering cases of water pollution and wastage issues will contribute to the management of our water resources.	
BA7: If I report cases of water pollution and wastage issues, there will be an improvement in the management of our water resources.	
Outcome Evaluations	
BA8: Reporting cases of water pollution and wastage issues is:	Extremely unimportant 1 2 3 4 5 Extremely important
BA9: Discovering cases of water pollution and wastage issues is:	
BA10: Assisting in the management of water resources is:	
SUBJECTIVE NORMS	
Direct Measurement	
SN1: Most people important to me think that I should report cases of water pollution and wastage issues.	Strongly disagree 1 2 3 4 5 Strongly agree
SN2: It is expected of me to report cases of water pollution and wastage issues.	
SN3: I feel under social pressure to report cases of water pollution and wastage issues.	
Normative Beliefs	
SN4: Members of my community would (approve/ disapprove) of me reporting cases of water pollution and wastage issues so the issues can be rectified.	Disapprove 1 2 3 4 5 Approve

SN5: The municipality and other organisations tasked with resolving water pollution and wastage issues would (approve/ disapprove) of me reporting cases of water pollution and wastage issues so the issues can be rectified:	
SN6: Other people report cases of water pollution and wastage issues.	Strongly disagree 1 2 3 4 5 Strongly agree
Motivation to Comply	
SN7: The approval of my community is important to me	Not at all 1 2 3 4 5 Very much
SN8: Helping the municipality and other organisations tasked with resolving water pollution and wastage issues is important to me	
SN9: Doing what other people do in regards reporting is important to me.	
PERCEIVED BEHAVIOURAL CONTROL	
Self-efficacy	
PB1: I am confident that I could report cases of water pollution and wastage issues if I wanted to.	Strongly disagree 1 2 3 4 5 Strongly agree
PB2: For me to report cases of water pollution and wastage issues is:	Extremely difficult 1 2 3 4 5 Extremely easy
Controllability	
PB3: The decision to report cases of water pollution and wastage issues is beyond my control.	Strongly disagree 1 2 3 4 5 Strongly agree
PB4: Whether I report cases of water pollution and wastage issues or not is up to me.	

Appendix C

Crowdsensing for Successful Water Resource Monitoring: An Analysis of Citizens' Intentions and Motivations

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ABSTRACT

Crowdsensing empowers citizens to collect and share sensed data from their surrounding environments using their mobile devices as sophisticated sensors. However, whilst many studies have done research on crowdsensing, very few researchers have investigated the potential participation profile of citizens. Understanding these profiles can assist with designing crowdsensing systems with appropriate incentive mechanisms to achieve adequate user participation and good service quality. The purpose of this paper is to investigate the participation profiles (intentions and motivations) of citizens who potentially could participate in crowdsensing projects for water resource monitoring (WRM). The theory of planned behaviour (TPB) was used to investigate citizens' intentions to participate and to determine the influence of their attitudes, norms and perceived behavioural control on these intentions. An extended framework of motivational and demotivational factors for crowdsensing was used to determine citizens' motivations. The findings show TPB can be effective for predicting behavioural intentions, and that there is potential for citizens to submit data for WRM. The results of this study provide a fundamental basis that can assist researchers and practitioners to gain an understanding of citizens' perceptions of WRM. Recommendations for project coordination and data collection protocols are made that can be used to improve the success of crowdsensing for WRM.

CCS CONCEPTS

• **Information systems → Information systems applications →** Collaborative and social computing systems and tools, Spatial-temporal systems, Decision support systems, Mobile information processing systems**; Human-centred computing → Ubiquitous and mobile computing →** Empirical studies in ubiquitous and mobile computing

KEYWORDS

Crowdsensing; Water resource monitoring; Smart communities; Theory of Planned Behaviour; Data collection protocols

ACM Reference format:

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1 INTRODUCTION

Mobile technologies offer affordability and sustainability in the dissemination of information, monitoring of interventions as well as communication between communities and their service providers [9,26]. Researchers are realising the potential of leveraging millions of personal mobile devices to sense, collect and analyse large amounts of data as an alternative to deploying thousands of static sensors in a community [58]. This paradigm is commonly referred to as crowdsensing. Crowdsensing provides researchers and organisations with the potential to solicit crowd wisdom and amass data over large geographical areas by connecting to a large number of people at once. In crowdsensing, a mobile phone acts as a sensor, collecting, processing and distributing data. Today's high-end mobile phones have general purpose sensors like a camera and a microphone as well as specialised sensors including GPS, digital compasses, proximity sensors, ambient light sensors and accelerometers [58]. The affixing of a sensory device to a mobile phone provides the opportunity to track dynamic information about humans and the environment and to understand their patterns. Crowdsensing allows citizens to act as sensors and actively participate in collecting real-time data [57]. Citizens can sense their surroundings and provide information about their interpretation through text, voice, video, location and other means of communication.

This study is part of a larger study set in South Africa that aims to design a crowdsensing method for successful water resource monitoring (WRM) in smart communities. In 2015, the United Nations' Sustainable Development Goals (SDGs) set targets to be adopted by all nations to tackle climate change and address important areas of human development [53]. Goal 6 of the SDGs strives to "*ensure availability and sustainable management of water and sanitation for all*". This goal sets several targets including reducing water pollution, increasing the efficiency of water use and implementing integrated water resource management. One target focuses on the importance of supporting and strengthening local communities to participate in water, sanitation and hygiene (WASH) projects to ensure the success and sustainability of the implementations [23]. In this regard, WRM is defined as the collection of data reflecting the current situation of water resources at certain points and time intervals in order to manage the infrastructure of water resources and services. Accurate and consistent information is the key to providing sound water supply and sanitation services [12]. Over the past decade, the coverage of mobile networks has outgrown the spread of access to water services and affordable and reliable electricity, providing millions of people with access to modern infrastructure services [43]. For example, approximately 130 million people in sub-Saharan Africa do not have access to a safe water source but are covered by mobile networks. The trend of using pervasive and ubiquitous technologies such as mobile device applications for information dissemination has started gaining momentum in the water sector [41]. Communities that leverage technology (such as mobile devices) to improve the quality of life, make better choices and drive innovation are referred to as smart communities [30]. Building smart communities face three main challenges: the cost of intelligence [40], the technology learning curve [60] and the scalability of the solution [32]. These challenges can be addressed by allocating a huge financial investment to the deployment and maintenance of the smart community. Such an investment may not be feasible for developing countries, especially to scale the "smartness" throughout the country. Thus, this study looks at crowdsensing as a solution that can allow a smart community to leverage the ubiquity and sensing power of mobile devices to collect and map spatial and temporal data about water resource issues. However, little research has been done on the profiles of citizens who could potentially participate in WRM and there is little understanding of what drives or prohibits them from reporting these issues.

The purpose of this paper is to investigate the intentions and motivational factors of citizens towards participation in WRM. An understanding of these profiles can assist in identifying key socio-technical aspects that can lead to successful crowdsensing projects and systems that benefit both citizens and water authorities. Citizens are the main actors in crowdsensing initiatives, and the performance and usefulness of a crowdsensing system depend on the citizens' intentions or willingness to participate in the data collection process [28]. In order to address this purpose, the study conducted a critical review of related literature. The Theory of Planned Behaviour (TPB) and a motivational framework for crowdsensing were used as theories to undergird the research. The findings of the study provide a valuable contribution to the research community since they provide a deeper understanding of the profile of potential participants for WRM. This knowledge and understanding can provide guidance and recommendations for project coordination and data collection protocols, which can be used to improve the success of crowdsensing for WRM.

The rest of this paper is organised as follows: The next section presents an overview of smart communities and crowdsensing and the motivational factors for crowdsensing. Section 3 explains the research design process followed in the analysis of citizens' intentions and motivations. In Section 4, the survey results are analysed and presented and several success factors for successful crowdsensing are made. The final section draws several conclusions and outlines future research directions.

2 LITERATURE REVIEW

2.1 Smart City vs Smart Community

The concept of smart cities is evolving into the concept of smart communities, which includes small towns and rural areas not included in the concept of a smart city. As a result, it is argued that smart communities benefit more people than smart cities [50]. The Smart Communities Guidebook [56] describes a smart community as *a geographical area ranging in size from a neighbourhood to a country whose residents, organisations and governing institutions are using IT to transform their region in significant ways*. A smart city adopts a technology-centric vision based on communication networks, IoT, smart objects and data [52] to *"make the critical infrastructure components and services of a city more intelligent, interconnected and efficient"* [54]. On the other hand, a smart community emphasises the proactive participation of the people living in the territory to improve their quality of life [52]. There are claims that the term "smart city" is a marketing ploy [11] and that smart cities value business over people [21] and widen the gap between who can generate and access information [14]. ICT infrastructure and applications are important but without the citizens' engagement and willingness to collaborate and cooperate with external stakeholders, there is no smart community [56]. Therefore, this study prefers and adopts the more holistic view of a smart community as *a community in which the community members, organisations and governing institutions leverage IT to transform the community in significant and positive ways, regardless of which technologies are utilised.*

The aim of smart communities is to use technology in order to connect citizens and positively transform communities by means of ICT [34,52]. One approach to developing a smart community that has gained increasing popularity in recent years is crowdsensing [13,34]. Crowdsensing aims to empower citizens of a smart community to use their mobile phones to collect and share sensed data from their surrounding environments. Crowdsensing is based on the crowdsourcing concept of engaging a crowd to solve a complex problem through an open forum [7]. The motivation behind crowd-powered problem-solving is the belief in the "Wisdom of the Crowd", which is based on the assumption that aggregating information in groups results in better decisions than those based on an individual [51]. Guo et al. [22] defines crowdsensing as "*the ability to acquire local knowledge through sensor-enhanced mobile devices – e.g. location, personal and surrounding context, noise level, traffic conditions, and in the future more specialized information such as pollution – and the possibility to share this knowledge within the social sphere, healthcare providers, and utility providers.*"

2.2 Motivational Factors for Crowdsensing

The recruitment, motivation and retention of participants is always a significant challenge for crowdsensing [6]. Minkman [38] proposes a framework that describes over 40 citizen motivations and barriers that can motivate citizens to make the first step toward participation in crowdsensing. Several motivational factors can influence participation in crowdsensing.

Motivational factors are the wants and needs that drive a certain behaviour and can activate, direct, and sustain a behaviour [42]. These factors can be those related to initial engagement in a crowdsensing project or long-term motivational factors. On the other hand, incentives are tools that can be used to motivate individuals to engage in certain behaviours. Brewer et al. [10] describe an incentive as a reward, reinforcement or external stimulus that motivates an individual to perform a behaviour. Incentives can be classified based on the types of motivation that encourage user participation [28]. Five categories of motivational factors were identified that can influence the level of participation in crowdsensing projects namely:

- Collective;
- Social interaction;
- Self-efficacy;
- Self-benefit and
- Intrinsic motivation.

Jaimes et al. [28] identified collective, intrinsic motivation, social interaction and self-benefit incentives as the most significant factors affecting the level of participation in crowdsensing projects. **Collective incentives** encourage working together for a common good. Such incentives may motivate citizens interested in bettering the society for the greater good, social responsibility and/or conservation [28,46]. Han et al. [24] and Jaimes et al. [28] report that participants are motivated by **social interaction** such as feedback from their peers and reinforcing others information. Crowdsensing systems may use technologies such as social networks, blogs and SMS to allow participants to interact with each other.

Rotman et al. [46] propose **self-efficacy** as a category of incentives where citizens participate for the purposes of generating scientific knowledge or being part of scientific work. **Self-benefit incentives** (also known as self-interest or self-promotion) allow participants of the crowdsensing scheme to receive gratification for their data contributions [28]. Users can be involved in crowdsensing projects based on their own **intrinsic motivation** [55]. Intrinsic incentives allow participants to volunteer due to their inherent interest, enjoyment or leisure. Crowdsensing systems use gaming or gamification with the aim of motivating participants by eliciting feelings of fun and enjoyment.

This study proposes an extension of Minkman's framework [38] of motivations and barriers applicable to crowdsensing (Table 1). This study extends the framework to include three more factors suggested by Geoghegan et al. [18]. One motivational factor from Minkman's framework [38], financial compensation, was omitted from the extended framework as it is not relevant to the purposes of this study which only explores nonmonetary incentives. The motivational factors are grouped based on the relevant categories of incentives suggested by Jaimes et al. [28] and Rotman et al. [46].

Table 1: Framework of Motivational Factors for Crowdsensing.

INITIAL MOTIVATIONAL FACTORS	
Collective	**Self-Benefit**
I feel responsible to do so [38]	Learn new skills [38]
Contribute to conservation [38]	Learn new things [38]
Beautiful environment [38]	Increase chance on a job [38]
Teach others [38]	Direct feedback [38]
Help others [38]	Discover things [38]
Help a specific site [18]	Increase my capacity [38]
	Get some exercise [18]
Social Interaction	Influenced by someone [18]
Do something with friends [38]	
Being part of a community [38]	**Intrinsic Motivation**
Gain new social contacts [38]	It is fun [38]
Combine existing skills [38]	I like this project [38]
	To kill time [38]
Self-Efficacy	It matches my hobbies [38]
Contribute to science [38]	Ability to act independently [38]
Do scientific research [38]	
LONG-TERM MOTIVATIONAL FACTORS [46]	
Acknowledgement and Attribution	
Policy and Activism	
Mentorship	
Common goals	
Trust	
DEMOTIVATIONAL FACTORS [38]	
Data not being used	
Not willing to collect for policy needs	
Lack of confidence	
Power gap between volunteer and coordinators	
Insufficient time	
Volunteer physically unable	
Unappealing recording process	

The success of crowdsensing relies on both initial and long-term participation of the volunteers [46]. Rotman et al. [46] suggest five motivational factors to encourage long-term participation:

- **Acknowledgement and Attribution:** Volunteers would like to be recognised and attributed for the work they perform and see that the work is bringing value to the area of concern.
- **Policy and Activism:** Volunteers would want to see the impact of their work on the government, institutions or community depending on the project objectives.
- **Mentorship:** Other volunteers may seek deeper involvement in the project.
- **Common goals:** A volunteer may remain in a project long-term because it aligns with their common goals.
- **Trust:** A volunteer may maintain trust in the process, the usage of their data, value and leadership roles.

In this regard, our extended framework also includes the five motivational factors for encouraging long-term participation [46]. In addition to the motivational factors, designers of crowdsensing systems need to also consider the demotivational factors. Yang et al. [58] state that *a user would not be interested in participating in crowdsensing unless it receives a satisfying reward to compensate its resource consumption and potential privacy breach.* Citizens participating in crowdsensing consume their own resources such as computing and battery power [58]. In addition, they expose themselves to potential privacy threats by sharing their sensed data with location tags. Other demotivational factors are for example, that citizens believe the data won't be used or they lack confidence in their abilities to collect the required data [47]. The development of a crowdsensing system, therefore, requires the investigation and understanding of citizens' intentions and motivations for participation in order to design appropriate incentive mechanisms that allow continuous collection of data. The *Merriam-Webster Online dictionary* online defines a mechanism as a "*technique for achieving a result*". In this regard, an incentive mechanism can be described as a technique for providing incentives to motivate behaviour.

3 RESEARCH DESIGN

3.1 Research Objectives

This research aims to address two research objectives:

RO1: Explore the relations between behavioural attitude, subjective norms and perceived behavioural control towards taking part in WRM and how the constructs influence the intention to participate in order to make evidence-based recommendations on how to maximize participation.

RO2: Investigate key motivational factors for participation in crowdsensing in WRM to fuel the design of appropriate incentive mechanisms that allow continuous collection of data.

This study used a quantitative empirical research approach to acquire an in-depth understanding of citizens' intentions and motivations for participating in WRM, specifically for contributing data on water pollution and water wastage (e.g. littering, dirty water, water leaks, burst pipes and tanks) within the general public. A survey was conducted using an online questionnaire. The first part of the questionnaire, aimed at addressing RO1, is guided by TPB [1] to understand citizens' intentions to participate in WRM. The second part of the questionnaire, aimed at addressing RO2, is guided by a theoretical framework of factors affecting citizens' motivations to participate in crowdsensing (Table 1). An understanding of these two elements of a citizens' profile can assist with designing appropriate incentive mechanisms in crowdsensing systems (Figure 1).

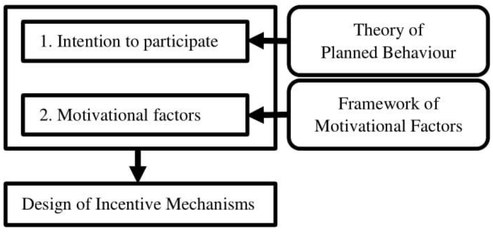

Figure 1: Conceptual Model for This Study.

3.2 Theory of Planned Behaviour

Crowdsensing requires continuous data collection to be successful [28]. The continuous submission of data by participants can be defined as a behaviour. TPB is a commonly-used theory first developed by Icek Ajzen [1] that allows the investigation into specific behaviours. The TPB states that behavioural intention (BI) "is the key predictor of behaviour, with *behavioural attitudes, subjective norms* and *perceived behavioural control* as the most important antecedents of a person's intention to perform the behaviour" [1,16]. **Behavioural attitude (BA)** refers to a person's evaluation of the behaviour which includes beliefs about the consequences as well as their positive and negative judgements about performing the behaviour. Typically, the more positive an individual's attitude is toward a certain behaviour, the higher the chance they will engage in the behaviour. **Subjective norms (SN)** refer to a person's estimation of the social pressure to perform the target behaviour or not. Subjective norms are the beliefs about how other people expect the person to behave and how the person feels about their expectation. **Perceived behavioural control (PBC)** explores how much control a person has over their own behaviour and their confidence in being able to perform the behaviour. Great perceived behavioural control and stronger positive social pressure are also seen to increase the chance of an individual performing the behaviour. Following the work of previous researchers [19,39] who applied TPB to study spatial data sharing behaviour, this study utilises TPB to undergird the research and to predict the intention or willingness of citizens to collect data about water resources (Figure 2). The appropriate application of TPB can predict the intention to perform a behaviour [37].

As illustrated in Figure 2, the hypothesis of our study is that: *An individual's behaviour to continuously collect water data is influenced by their behavioural attitude and subjective norms* *towards the behaviour, and their perceived behavioural control over the behaviour.*

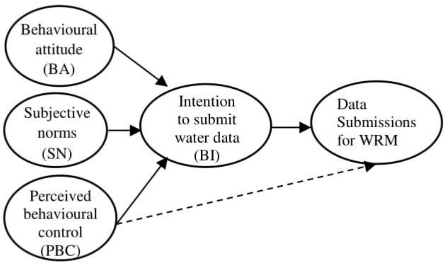

Figure 2: Conceptual Model for Submissions of Water Data using TPB.

However, having an intention does not confirm the engagement of a behaviour [37]. A researcher seeking behaviour change needs to discover what emotional, social or cognitive forces activate the behaviour [31]. Those forces, whether internal or external, must be able to induce an individual's motivation and stimulate their desire and energy to be continually interested and committed to performing a given behaviour. Thus, the second objective of the study was to investigate the key motivational factors for participation in WRM as well as factors that would make it difficult or impossible to participate.

3.3 Selection of Participants

The authors used snowball sampling to expand the geographical scope of the study [2]. A link to the survey was sent to several researchers, social media influencers, government agents and citizens. These individuals were asked to distribute the link through their mailing lists and social networks (LinkedIn, Facebook and Twitter). A link to the survey was also posted on several sites including Poll-Pool.com, SurveySwap.io, App.SwapSurvey.com, SurveyCircle.com to access individuals in other parts of the world. Furthermore, the sample size was extended by asking each respondent if they knew anyone else (online or offline contacts) who could meet the sample criteria (anyone over the age of 18) and participate in the study. The survey was online for five weeks.

3.4 Questionnaire

The questions in the first section of the questionnaire were designed on the conceptual model of TPB for water data submissions as illustrated in Figure 2. The questions in this section utilised a 5-point Likert scale, ranging from 1 to 5, where 1 represents a negative response and 5 represents a positive response. Based on recommendations by Harpe [25], statistical ranges were applied to the data from the Likert scale question responses to categorise the responses as negative [1 to 2.6), neutral [2.6 to 3.4] and positive (3.4 to 5]. A pilot study was carried out before deploying the questionnaire to identify issues with the instrument and find possible solutions. The pilot study involved five individuals and resulted in minor changes being made to the questionnaire. Data analysis was done in Microsoft Excel using the built-in Analysis Toolpak.

4 FINDINGS AND RECOMMENDATIONS

4.1 Profile of Respondents

Of the 123 responses obtained, three were incomplete and had to be removed, leaving 120 valid responses. Of these, over half of the respondents (56.67%) reside in South Africa, which is appropriate as the larger research study has a South African focus. Nearly a quarter (22.5%) of the respondents were from developed countries (USA, United Kingdom, Australia, Netherlands, Germany and Canada) while 77.5% were from developing countries (South Africa, Malawi, Benin, Uganda, Kenya and Swaziland).

4.2 Intention to Submit Water Data

TPB measures the generalised intention to perform a behaviour, in this case the intention to submit water data (BI). TPB uses three criteria were used to measure BI and these were converted to statements, where the respondents were asked to provide individual ratings of whether they (1) expect, (2) want and (3) intend to submit water data. A Pearson correlation test was performed to calculate the relationship between the three statements. The findings showed that the Pearson's correlation ranged from 0.744 to 0.778, which Sarstedt et al. [47] consider as strong positive relationships. For this reason, the overall mean of the three statements can be used to accurately represent their BI.

The mean BI across all respondents was 3.97 (Standard Deviation: 1.00), which is a positive rating. The frequency distribution across all respondents (n = 120) over five groupings is shown in Figure 3. A majority of the respondents (n=84) show a positive response to participating in WRM, seen in the range (3.4 to 5]. Only 11 respondents have a negative response, [1 to 2.6) and 25 respondents have a neutral response, [2.6 to 3.4].

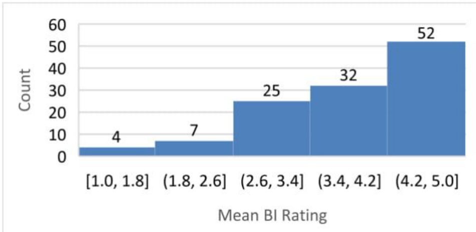

Figure 3: Distribution of mean BI ratings across all respondents (n=120).

An analysis and comparison of mean ratings for BI for respondents from developing versus developing countries were also conducted. Respondents from developing countries were positive ($\mu = 4.14$, std. = 0.91) towards the intention to participate in WRM, while respondents from developed countries had a neutral mean intention (μ = 3.40, std. = 1.08). The positive rating towards water data sharing in developing countries could possibly be attributed to the lack of significant improvement in service delivery they experience as reported by [12]. Developing countries face a lack of shared and relevant information between communities and service providers [20,29]. A third of water sources in rural areas are non-functional and require servicing, thus there is an urgent need for improvement in the sharing of relevant information between communities and service providers in developing countries.

4.2.1 Effects of past behaviour on intentions. Respondents who had reported water issues before had a higher BI rating (μ =4.43) to submitting water data when compared to those who have never reported water issues before (μ =3.77) as indicated in Table 2.

Table 2: Influence of past behaviour on BI (n=120).

Influencing Factor	Count	Mean	Std. deviation	St. Error
Never reported	84	3.77	1.06	0.12
Reported before	36	4.43	0.62	0.11

4.2.2 Prediction of Intention using TPB Variables. The Pearson correlation between the four variables (BI, BA, SN and PBC) was calculated to express the degree of correlation between the variables. The results (Table 3) show that as BA, SN and PBC increase, the individual's intention to participate (BI) also increases. The Pearson correlation between BI and each of the other variables (0.43 to 0.56) show strong relationships [48].

Table 3: Pearson correlation matrix of all variables related to BI (n=120).

	BI	BA	SN	PBC
BI	1			
BA	0.5648*	1		
SN	0.5717*	0.3697	1	
PBC	0.4310*	0.3292	0.1449	1

Regression analysis was used to measure the extent to which BI (the intention to make water data submissions) is significantly associated with the three explanatory variables: BA, SN and PBC (Table 4). Only 53% of the variation in intentions (r^2) is explained by the independent variables BA, SN and PBC. However, the interpretation of r^2 is subjective depending on the field, and low r^2 values (such as 0.25) are not unusual in social sciences due to person-to-person variability [33]. Thus, due to the r^2 value of 0.53, it can be concluded that each of the three variables (BA, SN and PBC) influence BI. In addition, p-values of each coefficient provide the likelihood that the results did not occur by chance. All the coefficients are statistically highly significant at $p<0.001$, which rejects the null hypothesis that *behavioural intentions to make water data submissions (BI) are not influenced by behavioural attitude, social pressure and perceived behavioural control to perform the behaviour.*

Table 4: Regression analysis with BI as the dependent variable (n=120).

	Coefficients	St. Error	t Stat	P-value
BA	0.43	0.09	4.55	0.00001356
SN	0.43	0.07	6.05	0.00000002
PBC	0.45	0.12	3.93	0.00014361

4.2.3 Ratings on TPB variables towards participation.

TPB allows researchers to measure the attitudes of respondents by using bipolar adjectives in both instrumental (e.g. useful - worthless) and experiential (pleasant - unpleasant) items. The respondents have rather positive attitudes towards reporting cases of water pollution to the municipality (μ = 3.70, std. = 0.94) or trusted organisations tasked with rectifying water issues (μ = 3.93, std. = 0.88). Most (83.33%) of the respondents had positive responses, thus are in favour of participating in WRM while only 17 (14.17%) respondents had negative attitudes toward participation. Regarding subjective norms, two-thirds (67.5%) believe other people would like them to participate in WRM while 27.5% of the respondents experience social pressure not to participate. The overall subjective norm rating is neutral (μ = 3.21, std. = 0.96). Only 20% of the respondents lack the confidence in their abilities to participate in the monitoring while 67.5% feel that they have control over whether to make data submissions or not. The next section continues the analysis of perceived behavioural control by eliciting commonly held beliefs shared by the target population regarding motivations for water data sharing.

4.3 Motivational Factors for Participation in Crowdsensing for WRM

The second section of the questionnaire was designed to answer the second research question related to motivational factors for participation in WRM and consisted of closed and open-ended questions. In the closed-ended questions, the respondents were asked to select the three most important motivational factors from a list of all the initial motivational factors in the extended framework of motivational factors (Table 1). The three most important factors based on the respondents' responses are: 1) to keep the environment beautiful (70%), 2) the respondents feeling responsible to do so (63.3%) and 3) to contribute to conservation (58.3%). A checkbox list was also provided in the questionnaire to find out what demotivational factors the respondents perceive in participating. The most commonly reported demotivational factor was the disbelief the respondents have that the data they submit will actually be used (56.7%). Other researchers [9,26,27] report that there is also a lack of responsiveness by service authorities to use generated information to inform their decisions or planning in the WASH sector. The lack of responsiveness can also be seen in the common demotivational factor of feeling a power gap between the respondents and coordinators of such projects (such as municipalities). Table 5 presents the frequency of responses for each demotivational factor.

Table 5: Demotivational factors for submitting data for WRM (n=120).

	Demotivational factor	Frequency	%
F1	Data not being used	68	56.7%
F2	Insufficient time	55	45.8%
F3	Power gap between volunteer and coordinators	43	35.8%
F4	Unappealing recording process	26	21.7%
F5	Lack of confidence	12	10%
F6	Not willing to collect for management purposes	9	7.5%
F7	I do not own a smartphone	6	5%
F8	Volunteer physically unable	3	2.5%
	Other	13	10.4%

In the open-ended questions, respondents were given the option to give other demotivational factors not on the list provided. Thematic analysis is useful in identifying, analysing and reporting themes within data [8], thus, was used to identify the common themes/factors in the data. Several additional demotivational factors were identified and should be added as demotivational factors to the framework in Table 1:

- F9: Long waiting time for issue resolution.
- F10: Lack of flexibility in communication modes.
- F11: Unaware of the monitoring process.
- F12: Unclear on goals and benefits of monitoring.
- F13: Insufficient feedback from project coordinators.
- F14: Not sure if an issue has already been reported.

4.4 Recommendations for Participation in Crowdsensing for WRM

Based on the findings of the analyses, several recommendations can be made for project coordination and designing of crowdsensing projects for WRM. These can also be considered as factors that can contribute to the participation (initial and long-term) of citizens in crowdsensing projects and ultimately the success of such a project.

4.4.1 Clarity of goals and results. The results show that even though citizens want to make water data submissions, many are unclear on how the data will be used (F12) or if the water authorities will actually use the data (F1). Highlighting the goals of the project in the system and disseminating regular reports of data usage can create more positive attitudes towards making submissions as participants can understand the importance of their submissions for their surrounding water resources. As part of the marketing strategy, project coordinators for crowdsensing must communicate the goals and results regularly.

4.4.2 Flexible communication modes. Crowdsensing systems must allow users to submit data in various forms such as text, images, video and audio. Multiple data sources allow the provision of supplemental (and more accurate) information to generate a holistic view of the point of interest. However, multiple data sources may contribute conflicting information about the same object. Truth discovery is a method that can tackle this challenge by aggregating noisy data to estimate the reliability of each source [17,45], and has been successfully used to solve various issues such as data integration and truth detection [17].

4.4.3 Simple data collection protocols. The complexity of the data collection protocols affects the engagement of participants in crowdsensing projects [5] as complex protocols may diminish the PBC of the participants. Data collection protocols must allow for easy data submissions as complexity could result in fewer participants. However, the protocols must still ensure the collection of high-quality data and protect the confidentiality and privacy of participants. Simplified protocols do not only improve the appeal of submitting data (F4) but also minimises the learning curve for the monitoring process (F5) and the time needed to submit data (F2).

4.4.4 Different types of incentives. All three key motivational factors fall within the collective incentive category, which shows that most respondents would participate in WRM for the good of the community and environment. However, collecting data for the good of the community or environment might not be enough to motivate citizens to participate in crowdsensing [49]. Thus, it is necessary for researchers to add other sources of motivation for their incentive models. The Mahali project [44] leverages three types of incentives as motivators for participation. Apart from crowdsensing for the good of the environment, Mahali aims to contribute to science and educate the users in space weather monitoring. CrowdHydrology [36] also leverages the collective, self-efficacy and self-benefit as the main types of incentives.

4.4.5 Effective feedback mechanism. Participants want to know if an issue has already been reported (F14) and the progress of the issue resolution (F9). Most crowdsensing applications require instant answers, thus, there is a need for fast and efficient systems to provide access to, retrieval of and processing of the data [40]. Such systems will enable decision makers to provide instant feedback or react fast to inform the public about upcoming events and/or organise major actions to protect the citizens. In addition, there is a need to aggregate robust machine learning algorithms and decision algorithms into a computing framework that can analyse large data sets to find meaningful domain-specific insights from the data and make the right decision when analysis shows certain behaviours and findings [40,59].

4.4.6 Community pro-environmental behavioural change. The neutral rating for subjective norms reflects there is no social pressure for citizens to participate in WRM. An individual's perceptions of subjective norms have a significant influence on the motivation to comply with those pressures [3]. For example, users of online sites tend to switch or keep using a site based on the positive or negative pressure exerted by their external environment

[4]. Subjective norms play a very important role in shaping behaviours. Seeing others in an individual's immediate environment making water data submissions increases the chance of the individual performing the behaviour. Thus, a critical success factor for crowdsensing is to develop a social marketing approach that promotes pro-environmental behaviour in communities.

4.4.7 Participant retention strategies. It is highly important to develop strategies on how to retain participants in crowdsensing projects as it is more cost-effective to retain a participant than acquire a new one. The results of the analysis show that individuals who have reported issues previously have greater intention to participate than those who have not (Table 2). Participants who have previously reported issues may continue to share data if the return on investment meets their expectations [22]. It is necessary to ensure the participants derive benefits from information sharing [35] to ensure continued motivation and retention of participants. If participants believe making data submissions is useful, their BA will be positive, hence increasing the chance of their continued submissions. Strategies can include effective feedback mechanisms, updates on the progress of issue resolution and notification alerts of contamination events detected close to users' location.

5 CONCLUSIONS

This paper serves as a helpful instrument for project coordinators of crowdsensing projects as it offers several contributions. This work presents a comprehensive framework of motivational and demotivational factors for crowdsensing based on literature and empirical input of citizens. This framework outlines both initial and long-term motivational factors and classifies the factors based on the type of motivation that encourages participation. This paper offers an increased understanding of profiles for potential participation in crowdsensing for WRM, based on the TPB theory. The regression analysis confirms the hypothesis that *an individual's behaviour to continuously collect water data is influenced by their attitude and subjective norms towards the behaviour, as well as their perceived behavioural control over the behaviour.* The study highlights that participants would participate in WRM for the common good, but the top demotivational factors are disbelief in the usage of the submitted data, insufficient time to make submissions and the negative power relations between citizens and the project coordinators. This work proposes several recommendations for crowdsensing based on the citizens' responses that can be used as guidelines for future crowdsensing projects. A common characteristic of technology interventions in communities is that they are externally conceived and address an assumed need with little or no buy-in from the citizens [15]. The risk with such an approach is that instead of empowering communities through technology, the interactions result in short-term and imposed implementations plagued with uncertain sustainability. To mitigate this risk and increase the chances of technology acceptance, this study emphasises the importance of investigating the potential participant profile and understanding the social aspects of crowdsensing. Researchers, crowdsensing project coordinators and practitioners (such as water authorities) can derive value from the recommendations proposed in this paper to assist with the planning and design of crowdsensing projects and systems.

The authors plan to use the initial results and research contributions presented in this paper to design a crowdsensing method for successful WRM in smart communities. As a continuation of this work, the authors intend to identify existing crowdsensing applications for WRM and perform a comparative analysis to find patterns leading to success or failure and explore how the recommendations made in this paper can affect the success of crowdsensing projects in WRM.

REFERENCES

[1] I Ajzen. 1991. The Theory of Planned Behaviour. *Organ. Behav. Hum. Decis. Process.* 50, (1991), 179–211. DOI:https://doi.org/10.1016/j.drugalcdep.2011.10.011

[2] Fabiola Baltar and Ignasi Brunet. 2012. Social research 2.0: Virtual snowball sampling method using Facebook. *Internet Res.* 22, 1 (2012), 57–74. DOI:https://doi.org/10.1108/10662241211199960

[3] Harvir S Bansal and Shirley F Taylor. 2002. Effects in the Theory of Planned Behavior in a Service-Provider Switching Context. *Psychol. Mark.* (2002). DOI:https://doi.org/10.1002/mar.10017

[4] Anil Bilgihan, Albert Barreda, Fevzi Okumus, and Khaldoon Nusair. 2016. Consumer perception of knowledge-sharing in travel-related Online Social Networks. *Tour. Manag.* (2016). DOI:https://doi.org/10.1016/j.tourman.2015.07.002

[5] Rick Bonney, Caren B. Cooper, Janis Dickinson, Steve Kelling, Tina Phillips, Kenneth V. Rosenberg, and Jennifer Shirk. 2009. Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *Bioscience* 59, 11 (2009), 977–984. DOI:https://doi.org/10.1525/bio.2009.59.11.9

[6] Alessandro Bozzon, Joske Houtkamp, Frank Kresin, Natasha De Sena, and Mathijs de Weerdt. 2015. *From Needs to Knowledge. A reference framework for smart citizens initiatives.*

[7] Daren C. Brabham. 2008. Crowdsourcing as a model for problem solving: An introduction and cases. *Convergence* 14, 1 (2008), 75–90. DOI:https://doi.org/10.1177/1354856507084420

[8] V. Braun and V. Clarke. 2006. Using Thematic Analysis in Psychology. *Qual. Res. Psychol.* 3, 2 (2006), 77–101. DOI:https://doi.org/10.1191/1478088706qp063oa

[9] Ned Breslin. 2013. Changing relationships: ICT to improve water governance. *World Water Week Rep.* (2013), 1–16. DOI:https://doi.org/accessed April, 15, 2014

[10] E. W. Brewer, C. Hollingsworth, and A. Campbell. 1995. Incentive motivation psychology: an exploration of corrective learning behaviour. In *SAEOPP Journal* (2nd ed.), E. W. Brewer (ed.).

[11] Andrea Caragliu, Chiara del Bo, and Peter Nijkamp. 2011. Smart cities in Europe. *J. Urban Technol.* 18, 2 (2011), 65–82. DOI:https://doi.org/10.1080/10630732.2011.601117

[12] Michael Champanis, Ulrike Rivett, Saaligha Gool, and Mphatso Nyemba-Mudenda. 2013. *ICTs in the water sector – where do we stand?* Cape Town. DOI:https://doi.org/10.13140/RG.2.1.3848.5928

[13] Liezel Cilliers, Stephen Flowerday, and Sean Mclean. 2016. A crowdsourcing , smart city model for a developing country. *Assoc. Inf. Syst.* May (2016).

[14] Nina David, Jonathan Justice, and John G. Mc Nutt. 2015. Smart cities are transparent cities: The role of fiscal transparency in smart city governance. In *Transforming City Governments for Successful Smart Cities*. 69–86. DOI:https://doi.org/10.1007/978-3-319-03167-5_5

[15] Leslie Dodson, S Revi Sterling, and John K Bennett. 2013. Considering Failure: Eight Years of ITID Research. *Int. J. Serv. Learn. Eng.* 9, 2 (2013), 19–34. DOI:https://doi.org/10.1145/2160673.2160681

[16] M Fishbein and I Ajzen. 2010. *Predicting and changing behaviour: The reasoned action approach.* DOI:https://doi.org/10.4324/9780203937082

[17] Jing Gao, Qi Li, Bo Zhao, Wei Fan, and Jiawei Han. 2015. Truth discovery and crowdsourcing aggregation. *Proc. VLDB Endow.* 8, 12 (2015), 2048–2049. DOI:https://doi.org/10.14778/2824032.2824136

[18] H. Geoghegan, A. Dyke, R. Pateman, S. West, and G. Everett. 2016. *Understanding Motivations for Citizen Science. Final Report on behalf of the UK Environmental Observation Framework (UKEOF).* Retrieved from

http://www.ukeof.org.uk/resources/citizen-science-resources/MotivationsforCSREPORTFINALMay2016.pdf

[19] Mohammad Gharesifard and Uta Wehn. 2016. To share or not to share: Drivers and barriers for sharing data via online amateur weather networks. *J. Hydrol.* 535, January (2016), 181–190. DOI:https://doi.org/10.1016/j.jhydrol.2016.01.036

[20] Rudolf Glotzbach, Shiriin Barakzai, Jane Adisu, and Chiranjibi Tiwari. 2013. *Functionality: The Challenge to Sustain Rural Water Supply Services*.

[21] Adam Greenfield. 2013. Against the Smart City. In *The City is Here for You to Use*. 6–13. Retrieved from http://urbanomnibus.net/2013/10/against-the-smart-city/%5Cnhttp://urbanomnibus.net/2013/10/against-the-smart-city/#footnote

[22] Bin Guo, Zhiwen Yu, Xingshe Zhou, and Daqing Zhang. 2014. From participatory sensing to Mobile Crowd Sensing. *2014 IEEE Int. Conf. Pervasive Comput. Commun. Work. PERCOM Work. 2014* (2014), 593–598. DOI:https://doi.org/10.1109/PerComW.2014.6815273

[23] N. Hall, C.M. Acosta Jaramillo, P. Jagals, D. Currie, J. Ossa-Moreno, A. Dean, H. Ross, T. Bowling, P. Hill, B. Head, R. Richards, J. Willis, E. Abal, and D. Cruz Lopez. 2016. *Strengthening community participation in meeting UN Sustainable Development Goal 6 for water, sanitation and hygiene*. Brisbane. Retrieved from http://gci.uq.edu.au/un-sustainable-development-goals-water-sanitation-and-hygiene

[24] Kyungsik Han, Eric A. Graham, Dylan Vassallo, and Deborah Estrin. 2011. Enhancing motivation in a mobile participatory sensing project through gaming. In *Proceedings - 2011 IEEE International Conference on Privacy, Security, Risk and Trust and IEEE International Conference on Social Computing, PASSAT/SocialCom 2011*, 1443–1448. DOI:https://doi.org/10.1109/PASSAT/SocialCom.2011.113

[25] Spencer E. Harpe. 2015. How to analyze Likert and other rating scale data. *Curr. Pharm. Teach. Learn.* 7, 6 (2015), 836–850. DOI:https://doi.org/10.1016/j.cptl.2015.08.001

[26] Johan Hellström and Maria Jacobson. 2014. 'You Can't Cheat the Community Anymore' – Using Mobiles to Improve Water Governance. In *Proceedings of 4th International Conference on M4D Mobile Communication for Development*, Ibrahima Niang, Christelle Scharff and Caroline Wamala (eds.). Karlstad University Studies, Karlstad, 48–59. Retrieved from http://kau.diva-portal.org/smash/get/diva2:709233/FULLTEXT03.pdf

[27] Misha T Hutchings, Anurupa Dev, Meena Palaniappan, Veena Srinivasan, Nithya Ramanathan, and John Taylor. 2012. *mWASH: mobile phone applications for the water, sanitation, and hygiene sector*. Pacific Institute and Nexleaf Analytics, California. Retrieved from http://www.indiasanitationportal.org/sites/default/files/Full_Report_MWASH.pdf

[28] Luis G. Jaimes, Idalides J. Vergara-Laurens, and Andrew Raij. 2015. A Survey of Incentive Techniques for Mobile Crowd Sensing. *IEEE Internet Things J.* 2, 5 (2015), 370–380. DOI:https://doi.org/10.1109/JIOT.2015.2409151

[29] A. Jiménez and A. Pérez-Foguet. 2010. Challenges for water governance in rural water supply: Lessons learned from Tanzania. *Int. J. Water Resour. Dev.* 26, 2 (2010), 235–248. DOI:https://doi.org/10.1080/07900621003775763

[30] J Jin, J Gubbi, S Marusic, and M Palaniswami. 2014. An Information Framework for Creating a Smart City Through Internet of Things. *IEEE Internet Things J.* 1, 2 (2014), 112–121. DOI:https://doi.org/10.1109/JIOT.2013.2296516

[31] Onuoha Iheanyichukwu Joachim, Norhaya Kamarudin, Godwin Uche Aliagha, and Kalu Joseph Ufere. 2015. Theoretical Explanations of Environmental Motivations and Expectations of Clients on Green Building Demand and Investment. *IOP Conf. Ser. Earth Environ. Sci.* 23, 012010 (2015), 2–3. DOI:https://doi.org/10.1088/1755-1315/23/1/012010

[32] Rida Khatoun and Sherali Zeadally. 2016. Smart Cities: Concepts, Architectures, Research Opportunities. *Commun. Acm* 59, 8 (2016), 46–57. DOI:https://doi.org/10.1145/2858789

[33] Daniel T. Larose. 2006. *Data Mining Methods and Models*. John Wiley & Sons, Inc. DOI:https://doi.org/10.1002/0471756482

[34] Imre Lendák. 2016. Mobile crowd-sensing in the Smart City. In *European Handbook of Crowdsourced Geographic Information*, C Capineri, M Haklay, H Huang, V Antoniou, J Kettunen, F Ostermann and R. Purves (eds.). 353–369.

[35] Jinwei Liu, Haiying Shen, and Xiang Zhang. 2016. A survey of mobile crowdsensing techniques: A critical component for the internet of things. *2016 25th Int. Conf. Comput. Commun. Networks, ICCCN 2016* (2016). DOI:https://doi.org/10.1109/ICCCN.2016.7568484

[36] Christopher S. Lowry and Michael N. Fienen. 2013. CrowdHydrology: Crowdsourcing hydrologic data and engaging citizen scientists. *GroundWater* 51, 1 (2013), 151–156. DOI:https://doi.org/10.1111/j.1745-6584.2012.00956.x

[37] Victoria Y. Martin, Betty Weiler, Arianne Reis, Kay Dimmock, and Pascal Scherrer. 2017. 'Doing the right thing': How social science can help foster pro-environmental behaviour change in marine protected areas. *Mar. Policy* 81, April (2017), 236–246. DOI:https://doi.org/10.1016/j.marpol.2017.04.001

[38] Ellen Minkman. 2015. Citizen Science in Water Quality Monitoring. Delft University of Technology.

[39] Uta Wehn De Montalvo. 2003. Mapping the determinants of spatial data sharing. *Policy* (2003).

[40] Klara Nahrstedt, Daniel Lopresti, Ben Zorn, Ann W Drobnis, Beth Mynatt, and Helen V Wright. 2016. Smart Communities Internet of Things. *Comput. Community Consort. Comput. Phys. World Task Force* (2016), 1–9.

[41] P. J. C. Nel, Marthinus J. Booysen, and B. Van Der Merwe. 2014. ICT-enabled solutions for smart management of water supply in Africa. *Proc. or 1st Int. Conf. Use Mob. ICT Africa 2014* (2014), 40–44. Retrieved from http://scholar.sun.ac.za/handle/10019.1/96153

[42] Jeffrey S Nevid. 2013. *Psychology : concepts and applications*. Wadsworth Cengage Learning, Belmont, CA.

[43] Michael Nique and Kennedy Opala. 2014. The synergies between mobile, energy and water access: Africa. *GSMA's Mobile enabled community Services programme*. Retrieved from http://www.gsma.com/mobilefordevelopment/wp-content/uploads/2014/04/MECS_Synergies-between-Mobile-Energy-and-Water-Access_Asia.pdf%5Cnhttp://www.gsma.com/mobilefordevelopment/wp-content/uploads/2014/04/MECS_Synergies-between-Mobile-Energy-and-Water-Access

[44] Victor Pankratius, Frank Lind, Anthea Coster, Philip Erickson, and Joshua Semeter. 2014. Mobile crowd sensing in space weather monitoring: The mahali project. *IEEE Commun. Mag.* 52, 8 (2014), 22–28. DOI:https://doi.org/10.1109/MCOM.2014.6871665

[45] Nguyen Quoc Viet Hung, Nguyen Thanh Tam, Lam Ngoc Tran, and Karl Aberer. 2013. An evaluation of aggregation techniques in crowdsourcing. *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)* 8181 LNCS, PART 2 (2013), 1–15. DOI:https://doi.org/10.1007/978-3-642-41154-0_1

[46] Dana Rotman, Jen Hammock, Jenny Preece, Derek Hansen, and Carol Boston. 2014. Motivations Affecting Initial and Long-Term Participation in Citizen Science Projects in Three Countries. In *iConference 2014 Proceedings*, 110–124. DOI:https://doi.org/10.9776/14054

[47] Martine Rutten, Ellen Minkman, and Maarten van der Sanden. 2017. How to get and keep citizens involved in mobile crowd sensing for water management? A review of key success factors and motivational aspects. *Wiley Interdiscip. Rev. Water* 4, e1218 (2017). DOI:https://doi.org/10.1002/wat2.1218

[48] Marko Sarstedt, Christian M. Ringle, Donna Smith, Russell Reams, and Joseph F. Hair. 2014. Partial least squares structural equation modeling (PLS-SEM): A useful tool for family business researchers. *J. Fam. Bus. Strateg.* 5, 1 (2014), 105–115. DOI:https://doi.org/10.1016/j.jfbs.2014.01.002

[49] Bernd Simon, Michael Loewy, Stefan Stürmer, Ulrike Weber, Peter Freytag, Corinna Habig, Claudia Kampmeier, and Peter Spahlinger. 1998. Collective identification and social movement participation. *J. Pers. Soc. Psychol.* 74, 3 (1998), 646–658. DOI:https://doi.org/10.1037/0022-3514.74.3.646

[50] Yunchuan Sun, Houbing Song, Antonio J. Jara, and Rongfang Bie. 2016. Internet of Things and Big Data Analytics for Smart and Connected Communities. *IEEE Access* 4, (2016).

[51] James Surowiecki. 2004. The Wisdom of Crowds. *How Collect. Wisdom Shapes Bus. Econ. Soc. Nations New York Doubleday* (2004), 296. DOI:https://doi.org/10.3174/ajnr.A3417

[52] Paolo Traverso. 2015. Keynote abstract: From smart cities to smart communities: The case of children's independent mobility. In *2015 10th International Workshop on Semantic and Social Media Adaptation and Personalization (SMAP)*, xv.

[53] United Nations. 2017. Progress towards the Sustainable Development Goals. *Rep. Secr.* E/2017/66, (2017), 19. DOI:https://doi.org/10.1017/S0020818300006640

[54] Doug Washburn and Usman Sindhu. 2010. Helping CIOs Understand "Smart City" Initiatives. *Growth* (2010), 17. Retrieved from http://c3328005.r5.cf0.rackcdn.com/73efa931-0fac-4e28-ae77-8e58ebf74aa6.pdf

[55] Andrea Wiggins. 2011. eBirding: Technology Adoption and the

Transformation of Leisure into Science. In *Proceedings of the 2011 iConference on - iConference '11*, 798–799. DOI:https://doi.org/10.1145/1940761.1940910

[56] Pete Wilson. 1997. *Smart Communities Guidebook*. Governor of California.

[57] Kuldeep Yadav, Dipanjan Chakraborty, Sonia Soubam, Naveen Prathapaneni, Vikrant Nandakumar, Vinayak Naik, Nithya Rajamani, L. Venkata Subramaniam, Sameep Mehta, and Pradipta De. 2013. Human Sensors : Case-study of Open-ended Community Sensing in Developing Regions. In *IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom '13)*, 389–392.

[58] Dejun Yang, Guoliang Xue, Xi Fang, and Jian Tang. 2015. Incentive Mechanisms for Crowdsensing: Crowdsourcing With Smartphones. *IEE/ACM Trans. Netw.* 24, 3 (2015), 1–13.

[59] Y U Zheng, Licia Capra, Ouri Wolfson, and Hai Yang. 2014. Urban Computing : Concepts , Methodologies , and Applications. *ACM Trans. Intell. Syst. Technol.* 5, 3 (2014).

[60] You Zheng and Jason Dedrick. 2012. Learning Strategies in Smart Grid Adoption : An Explorative Study in the U.S. Electric Utility Industry. *iConference 2015 Proc.* (2012).