Public Perceptions of Nanotechnology-enabled Water Treatment in a Mining Community in South Africa: A study of Bekkersdal

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DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

07 day of February 2020 in Johannesburg

ABSTRACT

A considerable proportion of the global population lacks access to safe drinking water. Several factors are responsible for this situation including pollution by acid mine drainage due to mining activity. Nanotechnology is a relatively new approach at addressing water contamination. It involves the use of materials in the nano-scale (1-100 nanometres), as adsorbents or catalysts to remove or degrade pollutants. However, as with many new technologies, public perceptions are key to its successful deployment in water treatment. This study investigated the key factors that influence the perceptions of laypeople about nano-enabled water treatment. Using the mental model's approach, data were collected using in-depth interviews and focus groups. Fourteen experts in the nanotechnology domain (researchers, nanotoxicologists, manufacturers) and forty-five laypeople from the Bekkersdal community took part in the study. Results show that laypeople had limited knowledge of nanomaterials and nanotechnology, or their application is water treatment. An analysis of the data nevertheless, revealed themes around the safety of these materials, the cost of nanotechnology-enabled water treatment devices, environmental implications of these materials, as well as health implications of accidentally ingesting them. Importantly, however, the ranking of these concerns amongst experts and lay people differed. These findings are discussed in nanotechnology development in the water domain in developing country context. These results suggest that people's opinions about an innovation result from interplay of benefits and risks together with psychological and socio-economic factors associated with the outcome of the application.

Keywords: *nanotechnology, portable water treatment, expert-laypeople comparison, perceptions, societal acceptance*

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NOMENCLATURE

Benefit- The increase in the welfare of a society that is derived from a course of action

Expert- One with the special skill or knowledge representing mastery in that specific subject

Laypeople-A person without professional or specialised knowledge in a particular subject

Nanomaterials- tiny particles used to manufacture bigger things

Nanosafety- focus on assessment of nanomaterials risks in environments and biological system

Nanoscale- Dimension between approximately 1nm and 100nm

Nanotechnology- Control of matter at nanoscale for wider range of applications

Nanotoxicity- Focus on the physiology, pathology and biomolecular mechanisms of nanomaterials

Point-of-use water filter- Filter water at the point where water is used e.g. household

Risk- Possibility of a person being harmed on physical health resulting from exposure to hazards

ABBREVIATIONS

AMD- Acid mine drainage

CSIR- Council for scientific & industrial research

NGO- Non-profit organisation

NIOH- National Institute for Occupational Health

NM- Nanomaterial

NT- Nanotechnology

OECD- Organisation for economic co-operation development

R&D- Research & development

SABS- South African Bureau of Standards

SANI- South African nanotechnology initiative

UNISA- University of South Africa

US EPA- United State Environmental Protection Agency

WHO- World Health Organisation

CHAPTER ONE

FRAMES OF REFERENCE

1.1 Background to the study

Safe drinking water is a necessity for life. However, in some regions of the developing world, it is, regrettably, a luxury. South Africa is one of the water stressed regions in the sub-Saharan Africa region (World Wide Forum, 2016). There are several factors responsible for water scarcity including increasing populations, cost, industrial and agricultural demands and climate-driven challenges (Adeleye *et al.*, 2016). The prevalent contamination sources in South Africa include poorly treated sewage effluent, poor sanitation in rural areas and informal settlements, agricultural and mining activities (WWF-SA, 2016). Poor communities without access to municipality water supplies often must use contaminated water from wells, rivers and streams for drinking and other domestic purposes (WWF, 2013). The contamination of fresh water resources by industry and mining poses a major challenge for the availability of clean drinking water (Schwarzenbach *et al.*, 2006). The mining industry is responsible for approximately 80% of the waste production including salts and acid mine drainage which negatively impact several important catchments in the country (Heath *et al.* ,2009). Nevertheless, Heath *et al.* (2009) argues that although other industries generate small waste quantities, the impact maybe equal or more drastic than the mine-related impacts. Mining-derived pollution results in water with high concentrations of metals and radioactive element as result of acid mine drainage (AMD) formation. AMD which enters surface and underground water due to run-off from mine slimes dams and rock dumps, often contains toxic elements including uranium, mercury and lead (van Eeden *et al.,* 2009). Mine drainage results from the reaction of pyrite (an iron sulphide) with air and water producing sulphuric acid and dissolved iron elements. The current study focuses on mine-related water contamination because it is the key contributor to water crisis in the Gauteng region and other surrounding provinces and AMD poses a notable risk for the availability of freshwater if left untreated and it can be extra water source that can be harnessed if it is treated with the appropriate technology (WWF-SA, 2016).

Nevertheless, nanotechnologies can provide efficient, eco-friendly and cost-effective techniques for water decontamination (Anjum *et al.*, 2016). Nanotechnology is a fast-developing field of nanoscience which involves manipulation of matter at nanoscale level (1-100nm) (van Dijk *et al.*, 2017). The materials used (nanomaterials) may be in the form of particles, tubes or films with at least one dimension in the range of 1-100nm (Amin *et al.*, 2014). Nanotechnologies are depicted as a solution to many problems and it has found applications in fields ranging from medicine, the automotive industry, energy, cosmetics, and water treatment (Olvera *et al.*, 2017). In the treatment of contaminated water, nanomaterials may be used as adsorbents, catalysts or membranes (Anjum *et al.*, 2016). Nanomaterial-enabled water treatment solutions have been investigated for the removal of dissolved salts (desalination) (Surwade *et al.*, 2015), elimination of micro pollutant (Muppalla, 2011), water softening (Asmatulu *et al.*, 2013) and for the removal of metal ions from wastewater (Ihsanullah *et al.*, 2016). Household water filters have been proven to significantly improve the quality of water and reduce water borne diseases. However, Živković *et al.*, (2014) asserted that there are risks associated with the use of engineered nanomaterials. Guseva *et al.* (2018) asserted that nanomaterials represent an emerging technology therefore the risks to human health are still indistinct. The unclear risk information is a consequence of lack of information about modes of action, target organs and prospective dose-response functions (Guseva *et al.*, 2018). However, there are anticipated impacts which include penetrating biological systems leading to tissue damage, transportation to other vital organisms resulting in cardiovascular or extra pulmonary complications and it can be source of eco-toxicological risk, biodegrade the environment or bioaccumulate the food chain. These risks may influence the public perceptions and acceptance of nano-enabled water treatment devices. Furthermore, risk perceptions of experts and laypeople differ significantly (Hagemann and Scholderer, 2009; Gupta *et al.*, 2015; Kalantzis *et al.*, 2016). This suggests that whatever perceptions that researchers and manufacturers of nano-enabled water treatment devices may expect the public to have may not materialise, and that other perceptions may surface. As such, it would not be prudent to infer the perceptions of one group from those of the other, or to assume that addressing whatever risks expert perceive will address the perceptions of laypeople.

To understand the perceptions of these two groups therefore, this work used the mental models approach put forward by Johnson-Laird (1980) to investigate their perceptions with respect to nanotechnology and its use in the treatment of AMD-contaminated water. The mental models approach assumes that in the process of decision-making, people generate mental representations associated with the challenge, which they then use to make inferences and decisions (Kalantzis *et al.* 2016). Laypeople's constructions can be used to inform experts on lay people's perceptions, and help to design appropriate communications to address misconceptions as laypeople sometimes have erroneous information or misconceptions about a subject.

The experts in this study comprised nanotechnology researchers, manufacturers, toxicologists and water sector. Lay-people were drawn from a community currently facing water scarcity due to AMD contamination of their water sources, and who would be the target market for a nano-enabled water treatment membrane currently under development.

1.2 Research Statement

Approximately 884 million people lack access to safe water worldwide (Vijaya *et al.*, 2001). Nanotechnology promises to provide portable and safe drinking water to meet this need. The need to provide safe drinking water to poor developing countries cannot be overemphasised as this will contribute to poverty alleviation, effective water filtration thereby increasing health benefits and sustainable solutions for complex water quality problems in developing countries. This study seeks to understand the perceptions of experts and laypeople – the producers and consumers of the technology with respect to water treatment specifically.

However, as stressed by Hlophe & Hillie (2009), the successful application of nanotechnologies can only be reached with community involvement. If social aspects are ignored, researchers run the risk of their technological solutions not being accepted or even opposed. Importantly, experts' views and considerations in many domains, including nanotechnology, often differ from those of lay people as a result, the views and optimism of experts about this technology are unlikely to predict public acceptance of this new technology as they may have diverging opinions and expectations (Siegrist *et al.*, 2007).

1.3 Research aim, objectives and research questions

The overarching aim of this study was to investigate the perceptions of nanotechnology-enabled drinking water treatment amongst experts and laypeople, the latter being drawn from a community currently facing water stress due to contamination of their water by acid mine drainage.

The following objectives were pursued to achieve this aim

1. To examine and compare the perceptions of nanotechnology-enabled water treatment by experts and lay people
2. To determine factors that contribute to the acceptance or rejection of the nanotechnologies for water treatment by lay people.

Research questions

In view of this, the following research questions framed the study

1. Which attributes frame the acceptance of nanotechnology by laypeople?

2. What concerns do laypeople have when new technologies are introduced?
3. What are the hallmarks of experts and laypeople perceptions regarding the risks of nanotechnology in water treatment and do these differ in any way?

1.3 Theoretical considerations & Literature Review

There is a wide range of literature on the perceptions of nanotechnology on the general applications of nanotechnology especially in the food domain, and its influence on the uptake of the technology (Hagemann and Scholderer, 2009; Rollin *et al.* 2011; Gupta *et al.*, 2015; Bearth and Siegrist, 2016). However, there is very limited research that specifically addresses drinking water treatment (Hillie *et al.*, 2007; Westerhoff *et al.*, 2016; van Dijk *et al.*, 2017).

As a background to this work, I reviewed literature that provides a background to the problem of mining water contamination and acid mine drainage specifically. I then went on to look at the different means by which mine-drainage contaminated water is treated, and the current state of research around the use of nanomaterials in for this purpose. Next, I examined the literature on perceptions of nanotechnology in the food domain, and the divergence of expert and lay opinions in risk perception. A detailed discussion of these concepts is given in chapter two of this dissertation.

1.4 Methodological consideration

In Chapter Three of this dissertation, the methodology which was adopted for this study, has been presented and discussed comprehensively. The mental models' approach was used because it allows for elucidation of participants' constructions of the concept under investigation. The main research instruments for this study included interviews and focus group discussions. The participants were experts from different disciplines including nanotechnology researchers, academics, a nanotoxicologist, and water sector and health practitioners. A detailed discussion of this approach is presented in this section of the thesis.

1.5 Ethical consideration

Ethical considerations were of primary importance in this study. Silverman (2000) reminds us that when a researcher conducts the study, they enter private spaces of their research participants, which calls for attention to issues including the protection of participant's identity and privacy. Creswell (2003) states that the researcher has a responsibility to respect the rights, needs, values and desires of the participants. As such, in this study, participants were informed, beforehand, that their participation in the study was voluntary and could be withdrawn at any time during the study. To make sure that participants understood what the participation in the study involved, informed consent was obtained before the start of the interview and before taking photographs. The names of the participants from both experts and public were kept anonymous and they participated voluntarily. The research was thoroughly explained using a language of preference by the participant; an interpreter was used where there was language barrier between the participant and researcher. The researcher was honest with the participants and made it clear that there are no benefits for participating. Lastly, the data were stored securely and locked using passwords and was accessible to those who were involved in the study, i.e. the assistant coders and supervisors. In view of this ethics clearance was obtained from the Human Research Ethics Committee (non-medical), University of Witwatersrand (H18/07/07). Further detail on what was presented to the participants is given in the appendix.

1.6 Scope of the study

The study focuses on public perceptions of the use of nanotechnology use in water treatment amongst experts and lay people. The latter group were from the Bekkersdal mining area. This study site was chosen because water that is sometimes used for drinking and other purposes by residents of this area is polluted by heavy metals and other contaminants, posing health risks to community members. This area suffers from poor service delivery, including access to municipally-supplied water. The need for a simple, affordable, household level treatment system makes the Bekkersdal residents potential users of the nano-enabled water filter. The necessity for alternative water supplies or at the very least, a technology (e.g. nano-enabled water filters) that would enable community members to clean and use the available water is prominent. However, for nano-enabled filters to be implemented, the community needs to be involved and approve.

1.7 Structure of the overall dissertation

This dissertation comprises seven chapters. Chapter one provides a background of the study and a summary of the research aims, research questions and objectives. Chapter two presents the theoretical considerations that framed this study which include the impacts of mining on the water resource, perceptions of nanotechnology for different applications, review of opportunities and drawbacks associated with nano-enabled water treatment and lastly, review of the global to local perspective of nanotechnology. Chapter three presents exhaustive discussion of the methodology adopted for this study including research approach, instruments used for data collection and analysis. Chapter four presents the research findings of the study and chapter five presents analysis and discussion of the findings. Chapter six is the conclusion together with recommendations and suggestions for future research.

CHAPTER TWO

THEORETICAL CONSIDERATION AND LITERATURE REVIEW

2.1 Introduction

This chapter seeks to evaluate different pieces of literature and arguments that exist on perceptions of nanotechnology applications in water treatment from a global to a local perspective. The chapter begins with section 2.2, background on mining-related water contamination in Gauteng, South Africa, as a result of previous mining activity, and the potential health and environmental effects of consuming such contaminated water. Section 2.3 reviews the current state of knowledge on nanotechnology in water treatment including different nanomaterials used, together with their benefits and limitations. Section 2.4 reviews perceptions of nanotechnology, delineating the factors underlying these perceptions and examine the differences between experts and laypeople as previous work indicates that these two groups perceive risks differently. Previous work on perceptions of nanotechnology in the food domain shows that new technologies do not always receive widespread acceptance and the factors to acceptance are discussed in section 2.5. Section 2.6 reviews the global response to nanotechnology and state of nanotechnology application in South Africa. Section 2.7 is the mental models approach which was employed in this study. Finally, section 2.8 assesses the gaps in the existing literature and this is important because it provides a background and justification for my chosen methodology.

2.2 Impacts of mining on water resources in South Africa

The history of mining in South Africa goes back to the 1880s. During this time, mining has shaped the country both economically and demographically. Existing literature has focused on the value of mining in economic growth and social development. However, more recently, the devastating impacts of mining on the environment and water resources have increasingly been recognised. van Eeden *et al.* (2009) argue that the contribution of mines has been overvalued while the social injustices and negative environmental impacts that are associated to mining have been underrated or disregarded by the authorities. Part of the problem in creating the current status was, in part, due to the absence of a sustainable framework for evaluating the impacts of mining on the environment (Mudd 2007).

Several mines in the North West and Gauteng provinces are located close to rivers, on top of or near dolomitic substrates. To make mining feasible at gold reef in the Witwatersrand, underground water was pumped and directed to nearby streams and dams e.g. the Donaldson dam (Coetzee *et al,* 2006; Krige, 2006). This water was often polluted by acid, metals and sulphates. Water contamination by the mine effluent is characterised by red /orange flocs in streams (US EPA 2016) similar to those in the Wonderfonteinspruit in the West Rand (International Human Rights Clinic 2012). Although there are several impacts from mining activity, the major impact of concern is acid mine drainage in which mine effluent containing sulphates, acids and heavy metals enter the surface and underground water due to run-off from mine slimes dams and rock dumps (van Eeden *et al.* 2009). This effluent contains metals such as manganese, aluminium, iron, nickel, zinc, cobalt, copper, cadmium, lead, radium, thorium, mercury and uranium (van Eeden *et al.*, 2009).

Increased levels of suspended solids leads to increased transportation of contaminants and decreases the pH of the river water Ochieng *et al.* (2010). Such deterioration of surface water can have negative effects on the quality of water used for domestic, industrial and agricultural purposes. In the West Rand, AMD has resulted in devastating impacts on the aquatic life in the Wonderfonteinspruit, Tudor Dam and the Robinson Lake (Environmental News Press Centre SA, 2016). This toxic water has also seeped into the groundwater (International Human Rights Clinic 2012) and negatively impacted the aquatic life (van Eeden *et al.,* 2009).

Mining activity did not only lead to negative environmental impacts. Another major drawback has been in the health of communities around mining areas. Besides silicosis that affected miners, the wider community has also been exposed to dust and water contaminated by toxic elements and chemicals used in ore processing. Some of the major health impacts identified in the literature that can result from such exposure include aggressive disorders, poor concentration, mood swings, depression, increase in allergic reactions, vascular and memory loss necrosis, cancer, liver and kidney damage, hypertension, muscle and joint pain, and the impairment of several organs (Venter 1995; Jooste and Thirion 1999; Ihsanullah et al. 2016). Health impact depends on duration of exposure and the concentration of the metal. Concentrations of uranium (U-238) in Donaldson dam were found to be between 100-1000 Bq/g which far exceeds μg/l set by world health organisation (WHO, 2005). Exposure to uranium has been linked to kidney and liver failure and has neurotoxic effects *(*van Eeden *et al.* 2009).

Uranium has long-term impacts on the environment and water resources because its accumulates in sediments and leaches out of the tailings into ground and surface water (van Eeden *et al.* 2009). Drinking water that has been contaminated by mine tailings may thus poses threat to the health of consumers even though, often, these are from low-income communities with no other alternative sources. The risk also comes from consuming crops or livestock watered by such contaminated water (van Eeden *et al. (*2009).

In addition to the health and environmental impacts, mine effluent introduced massive strain on the water resources as it requires intense treatment. Currently, limestone is used to treat AMD water, but this method is not enough to treat the water to drinking standards. For low-income communities using contaminated water because of limited access to tap water, an efficient solution that can be used at household level e.g. a point-of-use water filter is an attractive solution.

2.3 Why use nanotechnology-enabled technologies in drinking water treatment?

Different water treatment techniques exist for small-scale water treatment including chemical coagulation, gravity sedimentation, sand or membrane filtration (Water Research Commission 2006). However, these have varying efficiencies for elemental contaminants. Nanomaterials offer a wide spectrum of properties not available in bulk materials including high surface area, fouling resistance, and high efficiency (Westerhoff *et al.* 2016). The use of these materials provides portable water supply and can be easily cleaned and these systems purify, detoxify, and desalinate water more efficiently than conventional bacterial and virus filters (OECD & Allianz, 2014). Rashidi *et al.*, 2012; Kootenaei and Rad, 2013; Zhang *et al.*, 2014; Faccini *et al.*, 2015; Thakura *et al.,* 2015; Anjum *et al.*, 2016; Yang *et al.*, 2019). Several nanomaterials have been used in water treatment including carbon-based nanomaterials (carbon nanotubes and graphene) (Faccini *et al.* 2015; Lawler 2016; Yang *et al.* 2019; Ihsanullah *et al.* 2016), silica-based nanomaterials (Sheet, Kabbani, and Holail 2014; Ferroudj *et al.* 2013), zero-valent metal-based nanomaterials, metal oxide-based and nanocomposite nanomaterials (Yang *et al.* 2019).

The application of this technology in water treatment is favoured by its phenomenal properties which include high surface area due to very small size, photosensitivity, magnetic properties, catalytic activity, electrochemical and optical properties (Qu *et al.* 2013). Nanomaterials may be used as adsorbents, catalysts and membranes. Nano-catalysts act by degrading pollutants (Anjum *et a*l. 2016) while membranes use pressure to eliminate the pollutants (Pawar *et al.* 2017; Anjum *et al.* 2016).

However, the properties which make nanomaterials more efficient and phenomenal are the very ones responsible for the fear and uncertainty amongst consumers (European Commission 2010). Different studies have been conducted about nanomaterial adsorption in waste and drinking water treatment to investigate the removal of pollutants using carbon nanotubes, graphene-based materials, metal oxides and other nanomaterials as adsorbents (Arshad *et al.* 2019; Sheela *et al.* 2012; Musico *et al.* 2013; Abiad *et al.* 2019; K. Zhang *et al.* 2018) (Table 2.1). Nano-adsorbents show different adsorption capacities for different metals contained in the water at similar concentrations.

Graphene oxide, for example, has a higher affinity for lead (Pb) than cadmium (Cd) (Arshad *et al.* 2019). Nevertheless, these materials have relatively high removal capacities (Fig 2.1).

Table 2.1: Nanomaterials used in water treatment with different adsorption capacity (mg. g^{-1}) for different metals

Nanomaterial	**Target metal**	**Adsorption capacity (mg. g^{-1})**	**Reference**
Functionalised graphene oxide embedded calcium alginate (GOCA) beads	Pb (II) Hg (II) Cd (II)	602 374 181	Arshad *et al.* 2019
ZnO nanoparticles	Zn (II) Cd (II) Hg (II)	357 387 714	Sheela *et al.* 2012
Polymer based graphene oxide nanocomposite (PVK-GO)	Pb (II)	887.98	Musico *et al.* 2013
Silica-based nanocomposite SiTF$_s$PP	Cu (II) Cd (II) Zn (II) Pb (II)	49 35 20 92	Abiad *et al.* 2019
Reduced graphene oxide /NiO (RGO/NiO)	Cr (VI)	198	Zhang *et al.* 2018

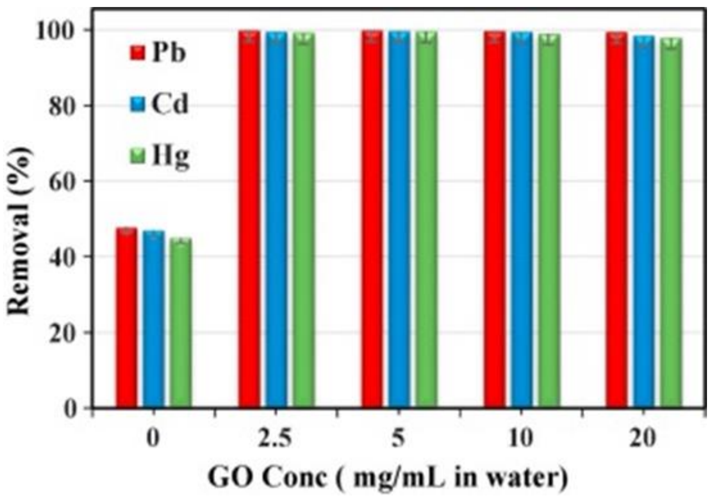


Figure 2.1: Percentage Removal Capacity of Pb, Cd & Hg using functionalised graphene oxide nanomaterial (**Source:** Arshad *et al.*, 2019)

However, the use of nanomaterials has not received wide uptake due to cost implications: large-scale production is complex and expensive. To counter this, researchers have opted for production from naturally available materials such as agricultural wastes. Westerhoff *et al.* (2016) asserts that nanotechnology promises to decrease the size and cost of point-of-use devices and improve pollutant selectivity thereby providing engineers with properties difficult or inefficient to obtain using traditional chemicals or bulk materials.

Nanomaterials can be used to target both organic and inorganic pollutants from water, and to treat it to drinking standards (OECD & Allianz, 2014). Another benefit is that the retrieved residual of substances can then be recycled thereby reducing waste generated (OECD & Allianz, 2014). Nanotechnology therefore presents opportunities to develop the next-generation of water supply systems which that are simple, affordable and low-maintenance, thereby extending the water supply to unserved communities (Qu *et al.* 2013).

For the successful application of nanomaterials in water treatment, however, a number of other factors must be considered including social acceptability (Qu *et al.* 2013). The use of nanomaterials has introduced different concerns as they are anticipated to present higher toxicity than bulk material if they penetrate biological membranes. This can have negative impacts on human health as nanoparticles can also act as carriers of other toxic elements. In the water treatment process the most pressing concern is release of nanoparticles from the membrane to drinking water (Westerhoff *et al.*, 2016). To counteract possible toxicity and high costs, Westerhoff *et al.* (2016) suggested that in the design of nanomaterials, the elements with known human toxicity must be avoided. Furthermore, the nanomaterials must be embedded e.g. in membranes (Westerhoff *et al.* 2016).

Disposal of nanomaterials also remains a dilemma as regulation of nanotechnology-enabled products is often unclear about this aspect (Westerhoff *et al.*, 2016). Nanomaterials may be released from households when products get exhausted and are discarded (OECD & Allianz, 2014). The fate of the engineered particles in water treatment remains unclear and difficult to quantify. This is because concentrations of engineered nanoparticles are often much lower than those of natural nanoparticles Park *et al.*, (2016).

Engelmann *et al.* (2018), however, the toxicological impacts of nanomaterials on humans and the environment have not received the same attention as benefits. There has been more focus on the promises and exceptional properties of nanomaterials with very minimal consideration of the shortcomings that come with these materials. Overall, these studies provide important insights on the different nanomaterials that exist, their capabilities and shortcomings, however, they do not highlight the need for strategic techniques to monitor and manage nanomaterials from manufacturing to disposal. In addition, most of the studies reviewed in this study used nanomaterials for waste water treatment and very little research on drinking water. There are many issues which have not been considered in terms of handling and the whole lifecycle of the NMs and more studies are needed to look at cradle to the grave stages and mitigate any unintended threats to the environment and humans.

2.4 What are the key factors influencing public perceptions of nanotechnology?

Perceptions of the public in a development of a new technology are very important as they influence acceptance and wider uptake. These perceptions are influenced by or dependent on where participants live and the worldviews that frame their opinions. They may also be influenced by factors including knowledge, general views about technology, trust, fairness, costs, perceived risks and benefits as well as problem perception i.e. appreciation of the problem to be solved by the technology (Seigo *et al.*, 2014). Pillai and Bezbaruah (2017) group these factors into three categories: cognitive, affective and socio-cultural. Cognitive factors are related to thinking, reasoning and intellectual processing of information and include prior knowledge and expertise, as well as attitude towards science and information processing styles. There is concern that technologies will negatively affect them biologically. This shows that people do not always process information in a rational way but may be influenced by their emotions. Sociocultural factors are related to people's social relationships with other individuals and institutions. The norms of a society have a lot to do with how people will perceive a technology as they are often judged by whether they conform to existing cultural norms. Sociodemographic factors and the context in which nanotechnology information was encountered by laypeople also play a role in how the target population perceive this technology (Pillai and Bezbaruah ,2017). Figure 2.2 summarises the different dependent (perceptions of nanotechnology by the public) and independent variables (psychological and sociological factors) and intervening factors.

A large and growing body of literature has investigated the different factors that influence general perceptions of nanotechnology in different disciplines including food industry, medicine, energy and water treatment (van Dijk *et al.* 2017; Besley 2010; Bearth and Siegrist 2016; Michael Siegrist 2010). Gupta *et al.* (2015) maintain that people judge applications of nanotechnology in relation to their benefits as well as need and usefulness. In addition, decisions are also based on perceptions of fear, ethical concerns and levels of knowledge.

Cobb and Macoubrie (2004) emphasised the importance of public engagement and dialogues in shaping public perceptions. Science and society are a marriage of two actors with differing priorities bonded by a common goal of shared support (the European Commission 2010). Societies are affected by scientific achievements whether in a good or a bad way while science and technological systems need societal support for different reasons which can be to get funded, to create marketable product and/or to receive moral legitimacy and gratification.

The prominent societal issues associated with this technology include potential health and environmental risks and the nano-divide i.e. the potential unequal distribution of the benefits and risks of nanotechnologies between the rich and the poor (Kamarulzaman *et al.*, 2017).

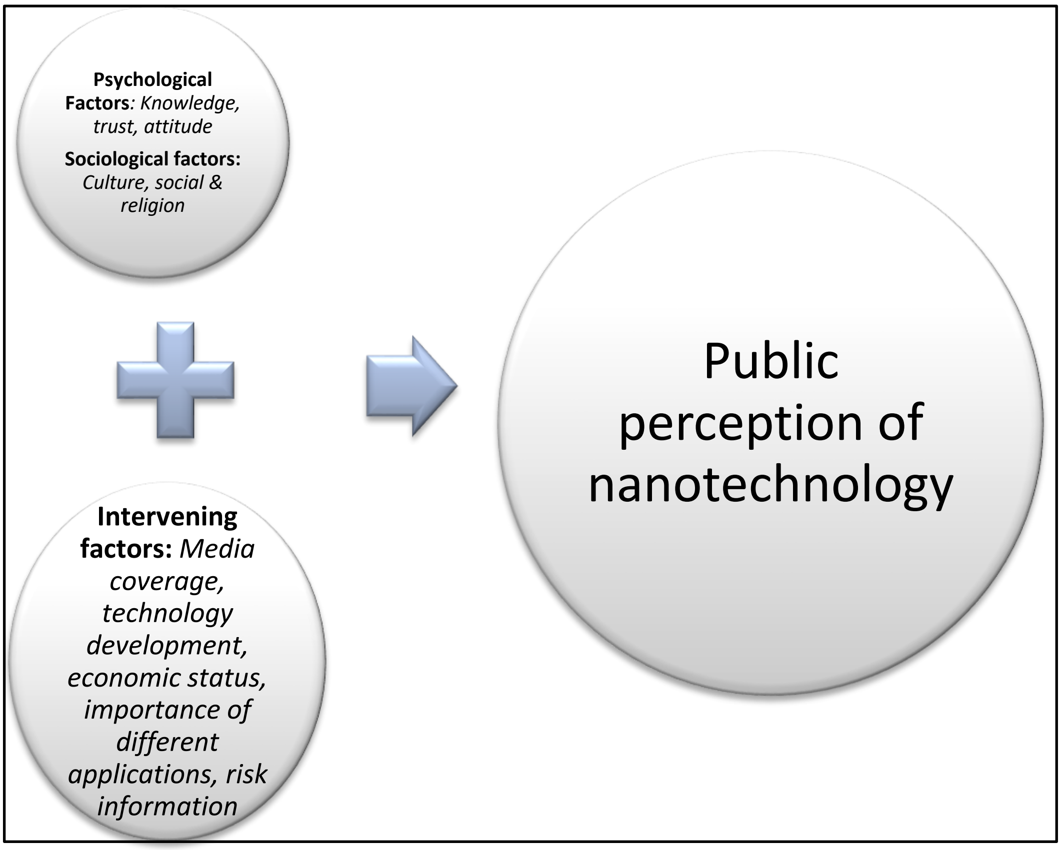


Figure 2.2: Factors influencing public perception of nanotechnology (**Source**: Kamarulzaman *et al.*, 2017) (Modified)

2.4.1 Psychological and sociological factors (knowledge, trust and attitude)

2.4.1.1 Knowledge &Attitude

Most surveys about public opinion of nanotechnology have measured perceived levels of nanotechnology knowledge (Besley, 2010; Bertoldo *et al.*, 2015; Larsson *et al* 2019) even though the relationship between knowledge and risk perception remains controversial. Some studies suggest that knowledge is only a weak predictor of acceptance (Michael Siegrist 2010) while others e.g. Seigo *et al.* (2014) argue that knowledge about a new technology exerts significant influence on how a person perceives the risks. In agreement with Seigo *et al.*, (2014), Federal Institution for Risk Assessment (2008) asserts that both estimation of the risk and general attitude about nanotechnology are linked to the level of information. It has however, not been determined whether knowledge leads to a more positive attitude or whether people with a positive attitude are more likely to acquire knowledge (Federal Institute for Risk Assessment 2008).

Highly educated people report more knowledge of nanotechnology than those with lower levels of education (Cacciatore *et al.*, 2011). Nevertheless, the Federal Institution for Risk Assessment (2008) acknowledges that awareness of the term has increased significantly since the 2000s with over 50% having an idea of what nanotechnology or nanomaterials were. However, while 50% the European population had some knowledge of nanotechnology, only one-third of Americans did (Figure 2.3) (European Commission 2010).

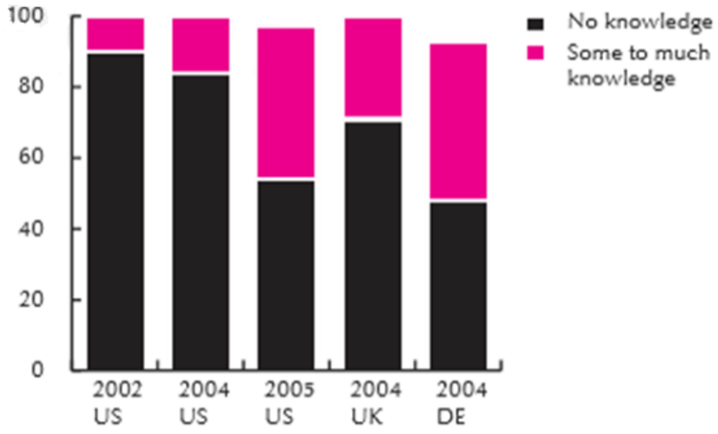


Figure 2.3: Knowledge of nanotechnology in different countries (**Source**: European Commission, 2010)

In the study conducted by Scheufele & Lewenstein (2005), high awareness of the technology showed higher level of support compared to respondents who are less aware of nanotechnology (Scheufele & Lewenstein, 2005). However, the results from this study might have been influenced by other factors including that some people do not like commenting or supporting any new initiative if no information is presented. The study would have been more convincing if the authors presented or conducted nanotechnology awareness programme or information session because the results are only based on those who had no support without considering those who did not agree or disagree.

The public also makes judgements of acceptance based on risk-benefit perceptions. Research by the Federal Institute for Risk Assessment (2008) showed that two-thirds of the respondents perceived that the benefits of nanotechnology appear to outweigh the risks, although Terentev and Maloshonok, (2019) contend that these results were maybe biased by response order effects. The study by Federal Institute for Risk Assessment (2008) more than 72% of the respondents completely agreed to development of nanotechnology but proposed a closer look on the potential risks.

2.4.1.2 Institutional trust

Another factor shown to predict perceptions is institutional trust i.e. in the researchers, government regulators and industries, responsible for development and regulation of nanotechnologies (Seigo *et al.*, 2014). Siegrist (2010) asserted that trust is a shortcut people use to make decisions when their knowledge about a subject is limited. The trust is based on two concepts: social relations and shared values, and confidence resulting from experience Seigo *et al.* (2014). In a study by Terwel *et al.* (2009) about confidence and trust it is evident that high confidence and trust by the laypeople on the organisation meant the organisation has strong influence on acceptance of the technology and the opposite is true. This is further supported by Siegrist (2010) where people who had more trust in the industry and regulating agencies perceived more positive applications compared to people who did not have trust. A study by Federal Institution for Risk Assessment (2008) showed that agreement that the government can be trusted to protect the public from environmental and technical risks was low. This was thought to result from a lack of trust in the actions of the government. There is also the belief governments have limited ability to test for and ensure safety of new technologies, resulting in lower trust (van Dijk *et al.* 2017). Both Federal institute for risk assessment (2008) and van Djik *et al.* (2017) showed low level of trust for government, but lack of trust in the former study was based on people's personal experiences with the government and populism, whereas in the latter study, trust was based on governments' capacity to do the complex tests required with use of nanomaterials. Both studies, however, suggest that public concerns about nanotechnology would diminish if lay people's trust for the government was enhanced (Federal institute for risk assessment, 2016).

Trust in science produces positive assessment of the technology (Federal Institute for Risk Assessment (2016). If trust in institutions is high, perceptions of the risks are lower and perceived benefits higher. Studies show that people have greater trust in doctors, environmental organisations and health and safety authorities as compared to industry and government (Figure 2.4). A question that needs to be asked, however, is whether the low trust for government officials is universal.

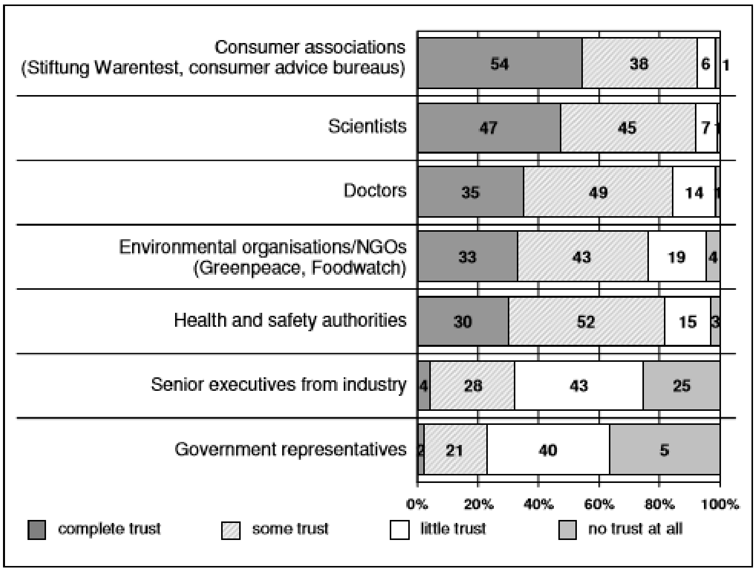


Figure 2.4: Trustworthiness of groups of individuals and institutions in the dissemination of information on nanotechnology (**Source**: Federal Institute for Risk Assessment, 2008)

Nanotechnology has been received differently in different contexts. wider uptake in some places such as United States of America and less in some regions due to opinions and past experiences of people with new technologies. In the Madibogo community in the North West province of South Africa, the use of nanomaterials in treatment of water with high concentrations of nitrate and fluoride seems to have been successful (Hillie *et al.* 2007). Although they had their own ways of softening the water by adding paraffin, cement, or foam bath, however, they were optimistic about nanotechnology. This was achieved through involvement of the community and providing infrastructure which can be operated by local people and capacity development. Nevertheless, this study was not aimed at identifying factors which influencing acceptance of nanotechnology water treatment.

2.1.4.3 Trust in technology

In Epworth, Zimbabwe, nanotechnology was proposed to clean water but it was not approved because of past experiences with technologies in the form of technical difficulties in operation, replacing damaged parts (Grimshaw *et al.*, 2009). This left Epworth residents preferring simple, home grown solutions such as the rope and washer pump, to technologies developed elsewhere that they would not be able to operate or maintain. Grimshaw *et al.* assert that people like to use what they are familiar with and it takes thorough education and convincing for them to adopt new techniques. Key issues which were expressed by the residents included anxieties about detectability of the nanoparticles once they are released into the environment, environmental impact, cost, maintenance and capabilities to sustain the technology (Grimshaw *et al.,* 2009). Other concern was issue of applicability. Further, residents were curious about job creation for local people.

2.4.1.4 Cost

Olvera *et al.* (2017) speculates that the current cost of nanofiltration devices is equivalent to five times the minimum wage in Mexico which leads to questions about affordability for low-income communities. Olvera *et al.* (2017) argue that the high costs of NTs have limited the link between R&D, production, consumption, and commercialization of NTs for water remediation, treatment, and potabilization. If the cost of these materials continues to be expensive, it faces a risk of failure because majority of the people who need it cannot afford it and only those who have money will be able to enjoy the luxurious services it provides.

2.4.2 Sociological factors

Kamarulzaman *et al.* (2017) define culture as a set of shared values and beliefs that shape someone's view based on the group, they are part of. Socio-cultural factors have an influence on people's views and the norms of the community. Evidence is seen in China where the culture to support science and technology as a driver for economic development has led to greater support for nanotechnology as they believe it will increase their competitiveness globally (Zhang *et al*., 2015). From a social context, nanotechnology perception goes beyond benefits and risks to issues of ethics and inequality (Kamarulzaman *et al.,* 2017). This highlights the need for comprehensive studies that incorporate cultural factors in investigations of what shapes perceptions. Sociological factors are important in evaluating people's perspectives because they are based on intra- and interpersonal values. Social norm theory dictates that acceptance can also be influenced by significant others so that if influential members of a community accept and recognise the potential of nanotechnology, other members who were sceptical at the beginning may be influenced to also follow suit.

2.4.3 Intervening factors

There are different factors used to judge new technologies in cases of incomplete knowledge. These factors include media coverage, development of technology, economic status, importance of different application of nanotechnology and risk information provided (Kamarulzaman *et al.,* 2017). Public uses the information portrayed by the media to decide on nanotechnology, whether it is beneficial or risky. Cacciatore *et al.* (2011) argued that media has a huge influence on public attitudes which then impacts their perceptions. Dissemination of false information and focus on negative impacts can cause a huge drawback as it will affect attitude even to other applications. A study by the European Commission (2010) show that 70% of the media coverage is favourable to nano-application, showing genuine interest and exploring possible applications.

Development of the technology also has an influence because people's perceptions about the technology also evolve as more information is generated thereby increasing familiarity (Kahan

2009). Familiarity with the technology changes the views, attitude and reaction towards the technology and this effect can either be positive or negative overtime and the driving factors to this change are not yet clearly demonstrated. Moreover, people show different perceptions for different applications (M Siegrist *et al.* 2008) and application of nanotechnology in food was the most unaccepted application by the public compared to any other application (M Siegrist *et al.* 2007; van Dijk *et al.* 2017; Cormick 2009). The different applications were judged based on sense of urgency & need and medical advances, solutions to climate change threats and computer and internet technology received positive attitude as they were seen to have clear benefits (Cormick 2009). In addition to these intervening factors, risk information play a huge role as it intensifies people's attentiveness due to negative information being more powerful and influential to people than good news (Kamarulzaman *et al.* 2017). The effect of risk information was noted by Cobb (2005) in product labelling where products stated to contain nanoparticles received increased risk perception than unlabelled products. These results show the negative relationship that exist between increased awareness and benefit perceptions.

2.4.4 Differences in perceptions between experts and lay people

Studies show that risk assessments of experts often deviate from those of lay people (Siegrist *et al.*, 2007). Experts and lay people agree that benefits outweigh the risks, but laypeople perceive higher risk than experts (Cobb and Macoubrie, 2004; Scheufele *et al.*, 2007; Kamarulzaman *et al.,* 2017). Researchers, government and private companies perceive nanotechnology as the breakthrough to solving the water crisis despite the uncertainties about risks, ethics and benefits to the lay people (Rejeski and Michelson 2009).

Experts and laypeople differ in types of risks of concern to them. Scientists are more optimistic about nanotechnologies but also concerned about risks to the environment and human beings (Scheufele et al. 2007; Michael Siegrist 2010). However, scientists argue that based on knowledge and experience with the nanotechnologies, the hazards are less likely to have direct impacts to humans. This argument can be challenged because humans are involved in the processing of nanomaterials. Bertoldo *et al.*, (2015) found experts with physics or chemistry background perceived more benefits than risks of nanotechnologies compared to toxicologists and social scientists. Powell, (2007) also found that upstream scientists (engineers, chemists, physicists and material scientists) did not think nanotechnologies posed new or significant risks, while majority of downstream scientist (toxicologists, epidemiologists and public health scientists and NGOs) are more concerned about potential environmental and health hazards. NGO's are often the least positive about nanotechnology while industries saw more potential benefits of nanotechnology use (van Dijk *et al.* 2017). This variability is because some experts focus on risks and others focusing on benefits. For example, experts in government organizations perceived higher risks, were more in favour of stronger government regulation, and expressed more concern about ethical implications than industry experts who perceived greater benefits (Federal institute for risk assessment, 2008; van Dijk *et al.*, 2017).

Identically-worded questions in surveys were used among the leading U.S. nano-scientists and the representative of U.S. larger population and the results show that scientists were more concerned about human health and environmental pollution than the public. Lay people's and expert's risk and benefit perceptions diverge because experts overlook minor uncertainties about detrimental effects of the technology (Bearth and Siegrist 2016). However, this approach means that major incident can occur as a result of these minor uncertainties and these can be challenging to manage.

Figure 2.5 shows findings of the study by the European Commission (2010) where laypeople saw great opportunities with use of nanomaterials in response to prospects of quality of life enhancement and opportunity for production of new materials although more research is still needed.

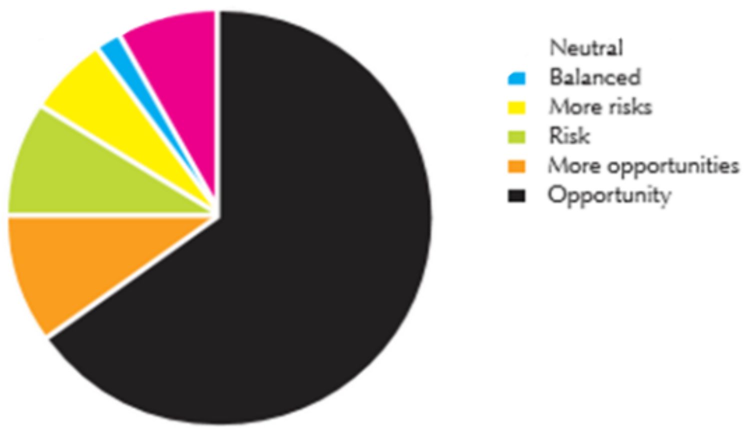


Figure 2.5: Perceived benefits and risks by laypeople (**Source**: European Commission, 2010)

Lay people on the other hand, tolerate innovations if the perceived benefits are high and risks relatively low whereas experts base their judgement more on quantitative risk assessments lay risk perceptions are driven by psychological factors underlying risk perception (van Dijk *et al.* 2017).

Siegrist (2010) and Scheufele *et al.* (2007) support van Djik *et al.* (2017) by adding that experts and laypeople differ in the kinds of risks they are more concerned about where laypeople are more concerned about societal risks such as loss of jobs, and experts consider health and environmental issues more. Scheufele *et al.* (2007) claim that experts are more sceptical about contamination and health risks whereas the public anticipate risks especially negative economic impacts in terms of job losses.

2.5 Public perceptions of nanotechnology in the food domain

The food industry is one of the disciplines in which nanotechnologies application have been proposed based on their unique properties. Nanomaterials are perceived as a better choice because they can improve the quality and shelf life of the food. One of the examples is application of nanomaterials in juice making, vitamins are insoluble in water, and however, they can be easily mixed with cold water when in nanoparticle form. Nanoparticles are also used to provide an attractive colour to fruit juices and other drinks (OECD and Allianz 2014). However, the use of the emerging innovative food technologies like nanotechnologies is also characterised by consumer uncertainty and concerns about the safety of the food (Rollin *et al.,* 2011; Bearth and Siegrist, 2016). Berth and Siegrist (2016) mentioned that there are several aspects that need consideration in investigations of acceptance (or rejection) of new technologies including demographic factors, public understanding of the technology, trust in the regulators of the technology and naturalness. A study which was conducted by van Dijk *et al.* (2017) about application of nanotechnologies in four domains, medicine, water treatment, energy and food industry showed low support for the use nanomaterials in food due to uncertainties around the risks to consumers (van Dijk et al. 2017).

Nevertheless, nanotechnology acceptance is greater for food packaging than for an application which involves direct change in the food (Siegrist *et al*, 2008). In addition, benefit considerations seem to have a significant influence, greater benefits seem to be perceived from the application of nanotechnology in energy and medicine than in the food domain and uncertainty about long-term consequences contribute to lower acceptance in food applications (Djik *et al.,* 2017). Toxicity of nanoparticles in food, water and energy has received little attention to date whereas in medicine there is more adequate information about toxicity and exposure (Djik *et al.,* 2017). In terms of perceived urgency of application for medicine and food, urgency in medical application was perceived to be more as there is often no alternative contrary to food in which a person can decide not to have nano-based product. It would have been more interesting if the studies gave in-depth assessment of the perceptions between water treatment and the food domain as these are relatively similar although water treatment is more pressing.

2.6 Global response to nanotechnology use

Since nanotechnologies have been around for more than two decades, it is essential to review the responses of the countries to this technology. Since nanotechnology has been around for this long, one can expect for it to be at a stage to be freely used with all the benefits and risks clearly stated, however, there is still a long way to go. Nanotechnology development is greatest in the USA and the UK (Fig. 2.6) (Lee and Rwanda 2006). This may be because these countries have experience and skills needed to work with nanotechnologies.

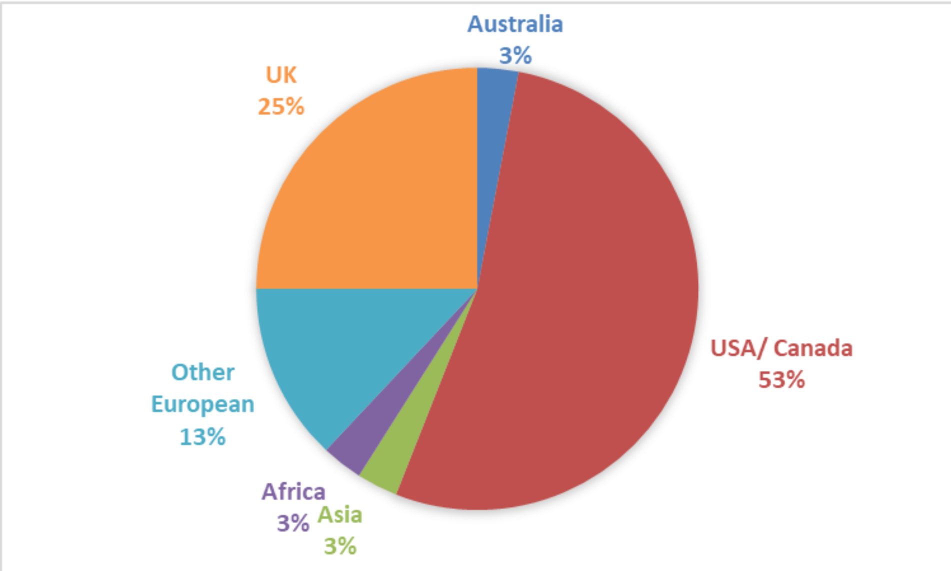


Figure 2.6: Nanotechnology Advocacy by NGO's, globally (**Source**: Lee and Rwanda, 2006)

NGOs from all over the world were assembled to discuss their views on what still needs to be done to increase support for nanotechnology (Lee and Rwanda 2006). The major response was enforcement of regulation in production and distribution of goods containing nanoparticles and more research into safety, ethical safety aspects and public dialogues (Lee and Rwanda 2006). There is more demand for regulation, followed by moratorium on the distribution of nanoparticles and public engagement. Nanotechnologies also involve multiple-disciplines, making it difficult to determine government bodies that can adequately regulate them (Figure 2.7). This is a cause for concern because in developing countries the skills and resources required to function with nanomaterials are minimal.

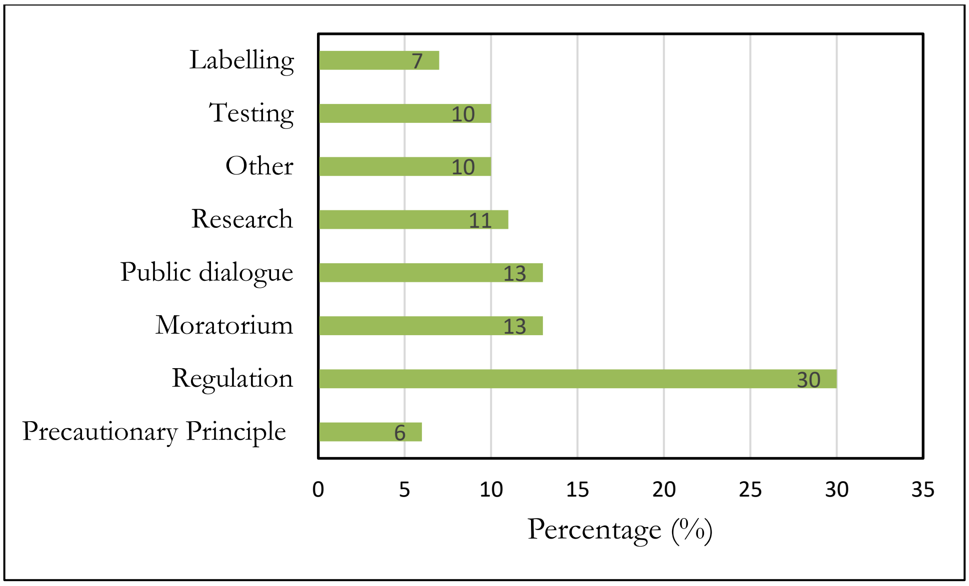


Figure 2.7: Suggestions by NGO's about use of nanotechnology globally (**Source**: Lee and Rwanda, 2006)

There is apprehension that there might be economic oppression in developing countries resulting from inflated prices of the nanotech products thereby increasing the gap between rich and the poor. In addition, fears of nanotechnologies disrupting economic and trade patterns leading to job losses also exist(Lee and Rwanda 2006; OECD and Allianz 2014). As such, many developing countries are sceptical about investing in this technology, especially considering more pressing issues. The UN's international centre for science and high technology (2005) argue that nanotechnology may offer benefits even to developing countries and the perception that its complex with inflated prices is incorrect. However, very few nanotech projects currently target the needs of the poor.

The issue of cost has been a controversial and unclear subject within the field of nanotechnology, with many surmising that products would be unaffordable based on the infrastructure investments as well as skills needed. However, others think that nanomaterials will be cost-effective as some materials are naturally available and abundant.

High cost is, therefore, a hurdle towards application of nanomaterials in water treatment (Ihsanullah *et al.* 2016). However, there is an expectation that costs will go down as demand increases (Ihsanullah *et al*, 2016).

2.6.1 The state of nanotechnology in South Africa

South Africa is endeavouring to strengthen its expertise in the technology to ensure strong competitiveness and competence. The National Nanotechnology Strategy approval in 2005 was an important milestone in South Africa's quest to use nanotechnology to address a wide range of social and economic challenges in South Africa. The nanotechnology initiative aims to address the challenges faced by the country by initiating application of the technology in different fields which include water treatment, health, and energy and in improving in the strategic industries to advance the mineral and mining industry, material and manufacturing and chemical bioprocessing industry (van de Groenendaal, 2018). The South African nanotechnology Initiative (SANi) which was established in 2002 comprises of different stakeholders including academics, researchers, engineers, private sector companies and research councils. In addition, the Department of Science and Technology's National Strategy on Nanotechnology made South Africa one of the pioneer countries to have nanotechnology strategy, globally (OECD, 2015). There are numerous projects underway which concentrate on different aspect from synthesis of nanoparticles, atomic modelling to mention few and these researches are conducted by different institutions such as UNISA, MINTEK, CSIR and others. South Africa collaborated with other developing countries like the India-Brazil-South Africa which is a joint project which focuses on equipping researchers with the emerging nanotechnology skills. Other international initiative is the collaboration of South African and European scientists under the EU's Framework Programme Six. Since it has been more than a decade since nanotechnology was introduced in the country, there are existing queries about economic contribution of this technology in the country and it can be noted that although there has been good progress in research and development, there has not been materialisation of nanotechnology benefits. There is still work being done on developing national multi-user facilities, enhance interdisciplinary, national and international collaboration, develop human capacity (skills needed to work with nanotechnology) and implementation on project where benefits of nanotechnology can be demonstrated (van de Groenendaal, 2018). The biggest challenge to this development as stated by Mbali (2011) is that dissemination of knowledge about nanotechnology in South Africa is not efficient as many people are still clueless about existence and application of this technology.

However, due to limited funding from the government or industrial partners, research on the risks of nanotechnology-based materials is limited. However, there are opportunities for risk assessment efforts to progress due to more projects underway focusing on nanotechnology (Department of Science & Technology, 2015).

2.7 Mental models approach as the model used for this study

Public engagement demands an approach which is appropriate to both the society as well as the technology and for that to happen, a pertinent strategy is required to concur with the new water treatment technologies that are innovated (Street *et al,* 2009). For this research, mental models approached was used which assumes that in the process of decision-making and solving conflicts, people generate mental representations of their views associated with the issue at hand and use these representations to make inferences and decisions (Nuclear Energy Agency, 2004). Mental models approach requires mapping views of the experts and laypeople for developing risk communication (Fleishman *et al.*, 2010). The content of the risk communication is framed by what experts think is important but not known by laypeople. This approach provides education to fill the gaps in lay knowledge by improving and correcting the metal models (which is the knowledge people have about specific subject), imaginary versus the facts so as to have indirect impact in decision making by stakeholders. It is stated that "Research on mental models is strongly related to theories associated with the organisation of human memory" p.12 (NEA, 2003). According to Kleindorfer *et al.* (1993) human memory is based on individual's experiences as well as information from other sources or people. Mental model's approach include several steps which include creating an expert model, identifying critical concepts for application in laypeople surveys, developing interview questionnaire, mapping lay people's beliefs into the expert model, identifying correct beliefs, gaps and misconceptions and lastly, creating and evaluating a communication (Bostrom *et al.,*1992). The major strength of this approach is that participants engage with the task by exploring their individual cognitive construction. However, the limitation maybe ifthe information presented is complex, participants may find it hard to comprehend the information. In addition, delays between action and response may compromise the impact of the communication. The mental models has been applied to study perceptions on different subjects including climate change, nuclear energy sources, sexually transmitted diseases, carbon capture and sequestration, air pollution and many other projects (Binder and Schöll 2010; Nuclear Energy Agency 2004; Seigo, Dohle, and Siegrist 2014; Vissers 2010).

2.8 Gaps in the existing literature

The studies presented thus far provide evidence that although engineered nanomaterials have been around for over two decades, regulatory frameworks for safe use lag far behind. Further, while studies reviewed showed application of nanomaterials in waste water treatment, little exists on drinking water, perhaps due to regulations on drinking water treatment having more restrictions (van Dijk *et al.* 2017; Federal Institute for Risk Assessment 2008). The biggest challenge is that there is handful of studies about perceptions of nanotechnology in the African context and dissemination of knowledge to the public is not satisfactory. In addition, most studies used over-simplified quantitative polling, and this reduced the explanation of the complex attitudes that exist amongst humans.

Any new technology faces obstacles related to public perception and regulatory issues. To date there has been a little agreement on the benefits and risks involved with use of nanomaterials in water treatment. There is still little agreement about which factors influence the perceptions and attitudes that people have, and more balanced discussion of benefits and risks is still needed. In-depth risk assessment of the nanomaterials is still required to investigate the fate of the materials after long-term use including possible risks and benefits and to clarify and clear the uncertainties.

Whilst there is emerging volume of literature addressing the issue of nanotechnology perception and acceptance, the influence of knowledge to nanotechnology still needs to be clearly defined. It is also not yet clear what the impact of background on experts' perceptions is as the existing literature is not concordant, making it difficult to generalise the views of the experts. The contributory factors to public perceptions of nanotechnology have been established, however, there seems to be little development in this area in South Africa and other developing countries.

CHAPTER THREE

METHODOLOGICAL CONSIDERATIONS

3.1 Introduction

Research is "creative and systematic work undertaken to increase the stock of knowledge, be it of humans, culture and society, and the use of this stock of knowledge to devise new applications" (OECD 2015). This is done through a process that involves collecting and analysing information (Creswell 2008). This chapter is dedicated to a discussion of the methodology adopted for this study. It starts with a background of the epistemological approach and research approaches adopted, and the philosophical positioning used for this study. This is followed by a quick recap of the study objectives, and then a detailed description of the research design. Under this section, I delve into the details of the study with respect to the study site, population sampling procedure, data collection tools and data analysis. This is followed in Section 3.5 by reflections on the methodology used, in the form of a discussion of the strengths, limitations and challenges faced during the research process and measures taken to ensure validity and reliability of the presented information.

3.2 Research approach and philosophical positioning

For this qualitative study, the epistemological approaches of interpretivism and constructivism were combined. These approaches are underlain by the assumption that precise, systematic and theoretical answers to complex human problems are not possible because cultural and historical differences make every situation unique (Creswell *et al.*, 2007). According to Willis (1995) interpretivists are anti-foundationalists i.e. they do not believe in a single correct route or method to knowledge. This approach was adopted in this study to acquire as much information as possible from respondents. In other words, this approach was chosen because it facilitates understanding of people's views. Gephart (1999) argues that one of the elements of interpretivist philosophy is that knowledge and meaning result from interpretation; In interpretive research dependent and independent variables are not predefined and the however, its focus is on the full complexity of humans as the situation emerges (Kaplan and Maxwell 1994).

Turning to constructivism, this approach is based on the premise that the researchers understanding of the subject of his / her investigation is co-constructed with that of participants through mutual interaction within the research setting and dialogues which they build (Constantino, 2008). As Elkind (2005) put it

> *"Constructivism is the recognition that reality is a product of human intelligence interacting with experience in the real world. As soon as you include human mental activity in the process of knowing reality, you have accepted constructivism*".

Suffice it to say that both approaches enable the researcher to understand how people construct meanings of their social world. In the context of this study, therefore, the researcher was able to understand, interpret the different meanings associated with nanotechnology by respondents, (Creswell *et al.*, 2007). People form their opinions based on variety of factors which include personal experience, media coverage, analogy and inference also from other communications which are meant to inform people about that topic (Lazrus *et al.*, 2016). It is acknowledged that the opinions formed by people are not always accurate (Boase *et al.*, 2017) which is why for this study different data collection instruments were used including observations. Hagemann and Scholderer (2009) defined what people form in their minds as a "mix of factual knowledge, erroneous assumptions, value judgements and uncertainty", pg. 1044.

Nevertheless, points out that the researcher must acknowledge that his background, shaped by personal, cultural and historical experiences, influence his or her interpretation of observations and data (Creswell *et al.* (2007). It is therefore necessary to acknowledge that being human, as well as our values, intuitions, beliefs and a priori knowledge all act to inform and direct our understanding of the subject at hand.

3.3 Recapping research aims and objectives

The aim of the study was to investigate perceptions of nanotechnology-enabled drinking water treatment amongst experts and laypeople. The latter were drawn from a community currently facing water stress due to contamination of their water resources by acid mine drainage. The overall objective was to examine and compare the perceptions of nanotechnology-enabled water treatment by experts and lay people and to determine factors that contribute to the acceptance of the nanotechnologies for water treatment by lay people.

3.4 Research design

3.4.1 Description of the study site

The study was conducted in the community of Bekkersdal which is in the Westonaria Local Municipality in the West Rand of Johannesburg. The basement in Bekkersdal is comprised of Archean rocks, the Kaapvaal Craton is composed of granite (Krige, 2006). The dominium group, the Witwatersrand Supergroup is overlain by the Transvaal Supergroup with Black reef at its base. Overlying the Black Reef is the dolomite of the Malmani subgroup. As a residential area, Bekkersdal was established in 1949 as a mining community for the black labour force (Van Eeden, 2014). The expansion of Bekkersdal has been noticeable since the first mine shaft, the Pullinger shaft, was established in the area in 1910. This resulted in the development of Westonaria in 1938 and then Bekkersdal (Liefferink, 2015). The community involved in this study is located 7 km from the east of Westonaria with a population of 47,213 and 18,957 both formal and informal settlements (Statistics South Africa, 2014). Bekkersdal comprises of formal and informal sections, the former consisting of the neighbourhoods of uptown Bekkersdal, Skierlik, Spook Town, Mandela, Silver city, Ghana, Holomisa and Tambo Section.

Only 14.2% households from the formal section had piped water inside their dwellings (Statistics South Africa 2014). As a result, many residents of the informal section of Bekkersdal had to use water from the Donaldson Dam as a water source for several years. The Dam, which is within Wonderfonteinspruit, runs along the western part of Bekkersdal (Fig 3.1) with the informal settlement forming the border of the catchment. However, the Wonderfonteinspruit is highly polluted due to mine effluent leading to high concentrations of uranium, sulphates and other dissolved metals in the water and sediments (Krige, 2006; Liefferink *et al.*, 2017). Elevated concentrations of uranium have been found in plants and cattle of the area (Liefferink *et al.*, 2017). Nevertheless, the Wonderfonteinspruit is a perennial stream due to influx of underground water pumped by the surrounding mines. As such, although the water is not in a great state, its constant availability provides opportunities for use (Liefferink *et al.,* 2017). More than ten percent of the Bekkersdal residents indicated that they regularly use water from the Wonderfonteinspruit, despite experiencing such unpleasant effects as skin rashes, diarrhoea and vomiting (Liefferink *et al.,* 2017).

Indeed, even though water from the Donaldson dam is officially prohibited for human and animal consumption due to high concentrations of heavy metals and toxins contained in the water, it is often used as an alternative water source in the absence of water as the municipal water sometimes is not available (Liefferink *et al.*, 2017). This water is being used for domestic purposes including laundry, bathing, drinking, and irrigation, watering of livestock, recreation and religious practices (Liefferink et al., 2017). Important to note, however, is that Bekkersdal grapples with several complex issues which also impact the health and well-being of community members (Van Eeden, 2014).

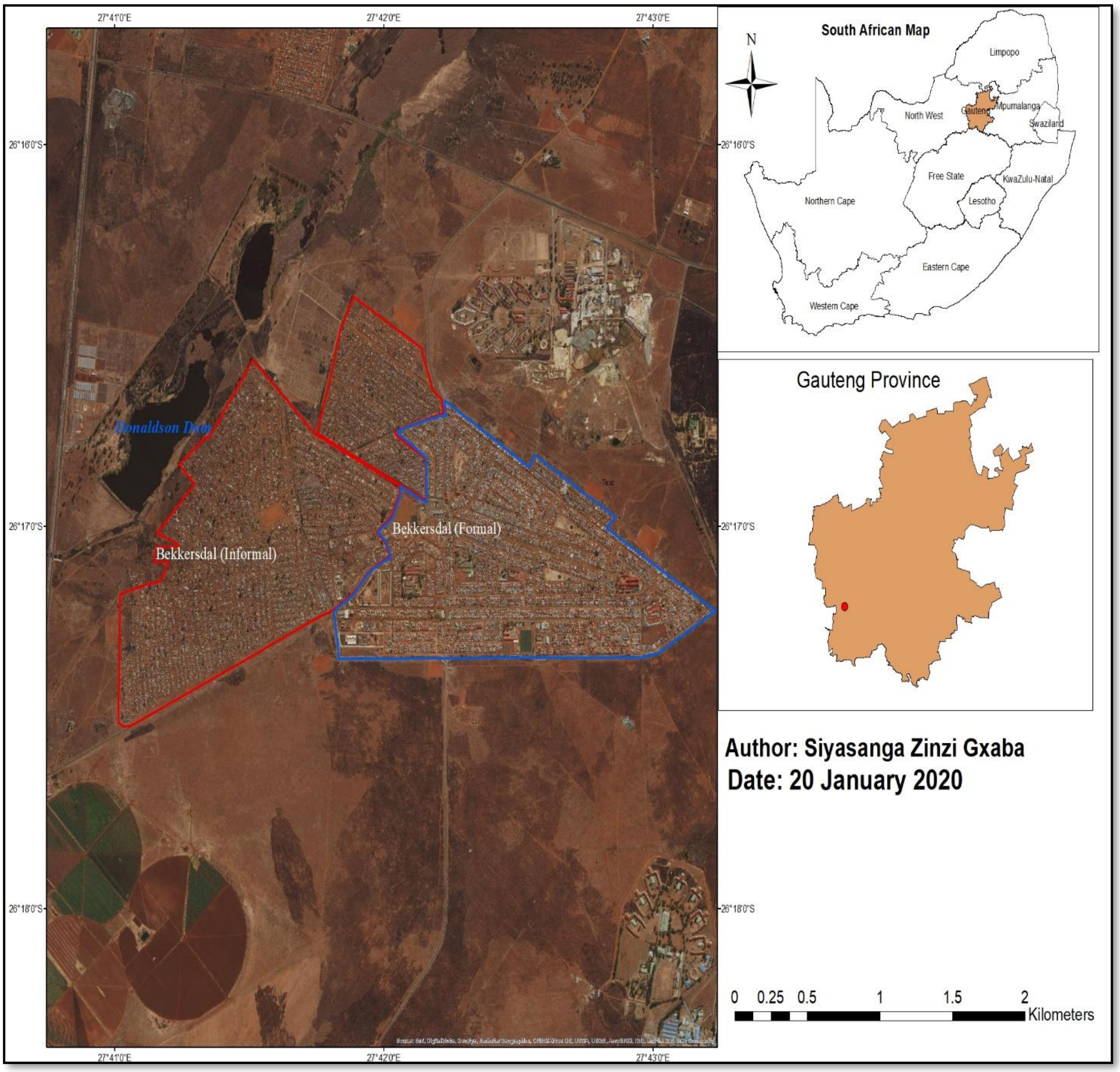


Figure 3.1: The study area of Bekkersdal mining community (Compiled by: Miss Gxaba)

3.4.2 The study population and sampling procedure

This study involved the participation of two categories of participants: nanotechnology experts, and lay people who were from Bekkersdal community. Experts were defined as highly trained individuals involved in the nanotechnology field as researchers, academics, nanomaterials manufacturers, nano-toxicologists and municipal water treatment professionals. The involvement of these two categories was important because people depend on those who have greater knowledge in a field (experts) to provide information relevant for decision-making (Boase *et al.*, 2017). On the other hand, the opinions of the public are essential for the development and successful uptake of new technologies. This approach allowed experts, knowledgeable about nanotechnology application in water treatment and possible toxicity, secondly, people who represent the end users of the technology to have an opportunity to express their views about nano-enabled water treatment so that their voice can be incorporated in the design of the filter.

Experts were identified via a stratified purposive sampling in conjunction with snowballing. Purposive sampling procedure requires targeting specific people. A main criterion which was used was that the experts needed to have more than three years' experience in their respective fields (as it was assumed that they will have enough experience working with the nanomaterials), be working with nanomaterials (whether manufacturing, application or toxicity assessment) i.e. research & development and possibly policy developers and regulators. The nanotechnology experts were identified through a google search using specific keywords such as nanotechnologists, nano-toxicologist, nanotechnology water treatment, nanotechnology research. During the online search several institutions came up such as council for scientific & industrial research (CSIR), Mintek, Nanocoworld and several institutions of higher learning. A review of the organisations mission statements and the activities that the institution was involved in was assessed and only those who were most relevant for the study were approached for an interview session through their public contacts. Only those who resided in the Gauteng province were approached with majority residing in Johannesburg and very few from Pretoria. A total of eight institutions was then approached and in some organisations several participants from different departments were interviewed which led to the total number of 15 experts as research participants. Snowballing was then employed to recruit the expert sample until analysis of the data showed that saturation had been attained.

As earlier mentioned, laypeople were drawn from the Bekkersdal community. However, because this community covers an expansive area, it was important to identify an appropriate entry point. The first contact made involved community leaders, specifically, ward councillors who are the leaders of the different sections. The sample size of laypeople was not determined prior to data collection, but it was based on theoretical saturation (i.e. the point in data collection where no new concepts are brought up to give more insights). Both stratified purposive sampling and snowballing were used here too. These sampling approaches were deemed appropriate in order to both not oversample or exclude important information from respondents as result of the limit set. The recruitment of participants was done in close consultation with the community leaders (Councillors) and a key informant who worked with an NGO in the community. This NGO focuses on tackling all the service delivery issues, youth development, job creation and other issues faced by the community.

Seventy percent of participants were from the informal section of the settlement because they are more affected by the water issues and have experience with using Donaldson Dam water meaning they are potential nanotechnology users. The rest of the 30% was from the formal settlement as they could also benefit from the nano-enabled filter. A key informant and existing contacts were used to approach the people for individual interviews and to organise the community meetings. Forty-five individual, and three group interviews were conducted, as well as three focus groups. The research participants were met at central points, convenient for them and these participants represented a wider part of the area as they were from different sections. All the participants in the study were 18 years and older and fair distribution ensured by selecting at least eight participants in each section as Bekkersdal is divided into eight sections. This method assisted in finding hidden populations or groups that were not easily accessible to the researcher. Finally, a confirmatory meeting was held to which community members were invited. This meeting had two aims. The first aim was for triangulation data that is to confirm that data provided the community members through interviews and focus groups had been accurately captured. The second aim of this meeting was to increase awareness of nanotechnology, thereby leaving them more informed than they were at the beginning of the study.

3.4.3 Data collection protocol

This study was based on grounded theory which is a design of inquiry where a general theory of a process, action, or interaction is grounded in the views of participants (Creswell *et al.*, 2007). Data collected using the methods described above were then evaluated to delineate emerging themes.

For the collection of data, the research site was visited, and observations were made of the behaviour of individuals without predetermined questions and individuals could express themselves openly about their understanding of water treatment, water quality and their perceptions about nanotechnology with little prompting from the researcher. These tools assisted in identifying the similarities, gaps, misconceptions about water treatment processes, nanotechnology thereby influencing change and developing awareness.

3.4.3.1 Interviews with experts

Experts in this study were chosen with the aim to understand their views on nanotechnology application in water treatment. A varied array of experts e.g. manufacturers, nano-toxicologists were selected because and shown in the study by (Morss *et al.*, 2015) that the opinions of the experts are not always shared or overlapping due to their differences in expertise which result in variations in depth of knowledge. The opinions of the experts varied according to their area expertise. Including multiple disciplines results in data that is both varied and rich in meaning.

Experts' interviews, which lasted for an average of 30 minutes, were recorded with participant consent. A typical first question posed to the interviewees was "Tell me about the use of nanomaterials in water treatment" and the participant was given a platform to elaborate. There were minor modifications in subsequent questions based on experts' area of expertise. The interviews proceeded according to the responses of the participants and the researcher asked follow-up questions about other aspects which were considered important but not mentioned by the respondent.

3.4.3.2 Interviews with Bekkersdal community members

Semi-structured interviews were used to elicit people's beliefs about the quality of water in their area and if they would accept a nano-based filter to purify their drinking water. A small sample size was selected until they became repetitive and then the participants were drawn from different sections of the research area. The qualitative approach provided values that drive attitudes and factors influential to mitigate or increase concerns rather than quantitative polling where participants are sort of restricted.

Table 3.1: Socio-demographics of the participants from Bekkersdal Community

Age range	18-24	9%
	25-29	20%
	30-39	22%
	40-49	27%
	50-59	17%
	60+	4%
Gender distribution	Females	49%
	Males	51%
Employment status	Employed	38%
	Unemployed	68%

In-depth interviews began with general questions about water quality and water treatment in the area to allow the participants to share their intuitive theories, which is a rich source of people's beliefs. The interview session continued to present information about nanotechnology using an information sheet (Appendix A) and participants were then asked about their perceptions of this new technology. This information sheet started by introducing the problem, followed by definitions of terms and how nanomaterials are used in water treatment and lastly about advantages and disadvantages of these materials, accompanied by diagrams to enable easy comprehension.

The interviews were very flexible and were modified when new concepts that were important to the discussion emerged. In a typical interview, the researcher introduced herself and it was explained that the research was conducted for the completion of a degree and it was clarified that there was no compensation for participating. Consent was asked from the participant before digitally recording the interview. The participants were then asked about the state of the water quality in the dam. Next question was "Do you know anything about nanotechnology", if the response was "yes" then a participant was given time to elaborate. The nanotechnology information sheet was then handed over to the participant and any information which was unclear to the respondent was then explained using the preferred language. The participants were then asked about their perceptions and concerns about this technology and then follow-up questions would emerge based on the conversation and relevance on the study.

Verbal conversations allowed for an assessment of community members' awareness of water treatment and their opinions about nanotechnology as a technique. Themes discussed with the participants included access to water, opinions about the quality of water in the Wonderfonteinspruit observed, health effects caused by consumption of this water, main source of the catchment pollution and the uses of the water collected from the dam. The second category was about knowledge of nanotechnology, trust in the technology and institutions, concerns about use of this technology, whether the filter will be a solution to their problem and lastly their willingness to pay for the filter. These interviews were audio-recorded following consent from the participants and later interview transcripts were produced.

3.4.3.3 Focus groups and group interviews

Focus groups are effective in eliciting data on the cultural norms of a group and in generating broader perspectives of issues of concern and interest to the sample population (Creswell *et al*, 2007). Creswell *et al.*, (2007) assert that it is more advantageous to use focus groups and group interviews because they widen the range of responses, producing data which is rich in detail, and difficult to achieve using other research methods. However, some participants may feel threatened in groups and keep their comments or views to themselves due to dominance of outspoken individuals (Creswell *et al.*, 2007).

In this study, participants were first presented with general questions regarding the quality of their water, before discussions moved to nanotechnology and potential concerns. Through this approach, participants were able to articulate their views and argue amongst each other with minimal involvement of the researcher unless they wanted to clarify things and they built on each other's views and comments. This was valuable as it cannot be attained with individual interviews. Unexpected concepts and perceptions developed, and this added value to the research. The main difference between the focus groups and group interviews is the number of participants, in focus groups the number was between 5 and 12 whereas in group interviews the sample size was 12 and more. The other factor is that in group interviews, participants often asked questions or comments directly to the researcher, there was no discussion amongst the participants.

Figure 3.2: Students of a tailoring school in the Bekkersdal area, some of whom took part in group interviews (**Source**: Field Survey Material, 2019)

Figure 3.3: A group of community workers who were part of the focus group discussions (**Source**: Field survey materials (2019))

3.4.3.4 Observations

The researcher became part of the participants to get a deeper insight into their lives by recording behavioural patterns of participants in addition to what was stated to gather bits of data and moving around the community, getting to know the area. Relationships were built with the participants where they were able to share their problems and concerns about water issues. This helped to understand their assumptions, values and beliefs and the social dynamics of the community as recommended by Creswell *et al.* (2007). Field notes and photographs of observations and experiences were kept during the process. The observations included verbal and non-verbal actions to capture other participant's reactions on what was said by other participants as this can be a good indicator of whether they agree or disagree with what was being said.

3.4.3.5 Confirmatory meeting

The community meeting was aimed at achieving two goals; verifying data obtained from the interviews conducted previously and as a community awareness about water and processes involved in water treatment and giving in-depth information about nanotechnology and its application in water treatment. The participants were asked to verify the data gathered from interviews which were conducted earlier to check whether interpretations were in line with their personal experiences and perceptions. In addition, the meeting aimed at giving clear understanding of bulk water treatment process as most participants claimed that they do not know much about the process.

A nanotechnology researcher from academia was invited to give a talk in a local vernacular language about nanotechnology and its application, particularly in water treatment. The goal was to increase knowledge and awareness of nanotechnology within the community. It was important to invite a person from academia who has neutral stance to prevent any biases in terms of the content presented. Both the risks and benefits of nanotechnologies were discussed. This meeting followed a prescriptive approach i.e. focused on what people still needed to know for them to make informed decisions. Simple language was used to ensure that people easily understood the communication and complexity of the terms was reduced. The content was revised by experts including supervisors to ensure balance and accuracy and for the lay-people to be able to easily comprehend.

Figure 3.4: Community meeting: (a) Nanotechnology Researcher giving in-depth information (b) Researcher presenting water treatment and how nanotechnology can be applied in this field (c) Attendants (d) Demonstrating the size of nanomaterials (Source: Field survey material)

3.5 Data Analysis

Triangulation of sources was used to examine the consistency of different data sources from the same method (qualitative) by comparing people with different viewpoints. Using participants from multi-disciplines facilitated in-depth understanding as it produced data which is complete and holistic representation of the perceptions. It also reflected distinction and variability found in humans. This method is beneficial because it can be used to confirm findings, generation of comprehensive data, increase validity and deepen the understanding of the research question (Bekhet and Zauszniewski 2012).

A key task in data analysis involved comparing experts and lay people's beliefs in order to identify knowledge gaps and misconceptions. To do this, interviews were digitally recorded, transcribed verbatim in Zulu, Xhosa and Sotho and then translated into English. Thematic analysis was then conducted by axial coding using Nvivo 12.A theme was recorded once for each person. Content analysis was then used to interpret the data. These results were used to describe individual's beliefs and experiences. This data consisted of hierarchical themes from more general to more specific conceptual units and a model was developed. A model was developed from the expert's interviews which aided in the public interviews and the results from these two categories were recorded. During the coding of laypeople's' data, when new themes arose i.e. that had not appeared in the data from experts' interviews, the coding scheme or list was modified to accommodate the new themes. Intercoder reliability was ensured by using two other coders and comparing their classifications with those of the researcher.

3.5.1 Statistical data analysis

Fisher's exact test is good for interrelation between two variables and for this study it was used to compare the perceptions of experts and laypeople in order to understand if there were any significant differences between the two groups on any of the identified themes (McDonald, 2015). This statistical test was suitable for this study as it allows analysis using very small sample sizes. The advantage of this test is that it calculates the exact results unlike other statistical tests which rely on approximation. JavaScript- Star free software was used at a significance level of 0.05. P-values smaller than 0.05 led to rejection of the null hypothesis (that there is no significant difference between experts and laypeople) this implies that a significant difference exists. In contrast, p values greater than 0.05, lead to a failure to reject the null hypothesis, implying non-existence of a significant difference between the two groups with respect to a theme or concern e.g. health risks.

3.6 Methodological reflections

The research approach was beneficial in achieving the aim of the study and its objectives, however, there were some limitations and unanticipated incidences, however, measures were put to ensure that these limitations do not tamper with the findings of the study. Given the unfamiliar and intangible nature of the technology amongst the laypeople, low knowledge formed the biggest challenge hence interviews were more appropriate for this study because under circumstances of low familiarity people offer answers to any survey question even though they have little knowledge. This makes the data unreliable and not a true representation of the reality. Low reliability or accuracy of survey questionnaires justifies the use of qualitative data only.

Semi-structured interviews were also used because highly structured questions would force people to guess the meanings of the questions and researcher to guess the meaning of the answers given. Semi-structured interviews allowed the participants to express themselves in the most comfortable manner. Also, the researcher was able to ask questions of interest at the same time open to new insights and views. Triangulation of these different sources gave rich information and holistic picture of the research participant's perceptions and bases for their concerns.

However, while the inconsistency inherent in semi-structured interviews does not allow generalisation of findings, it allows for an appreciation of the complexity involved in the opinions given by people and highlights the fact that many factors can influence decision making. In addition, the limited knowledge about nanotechnology among respondents might have influenced the results because people utilised the little information presented by the researcher.

Other limitations include experiences of the researcher during the research process. Firstly, some experts did not respond to emails nor calls and those who responded either said they were not fit or relevant for this study. The most difficult expert to find was a toxicologist working with nanomaterials and eventually two of them were interviewed. Other limitations were experienced including that in the informal settlement municipal water is in the process of being installed which influenced the attitude towards nanotechnology-filter as they believe they will no longer have water issues and these perceptions are also influenced by sense of need, importance and urgency for the technology (Gupta *et al.,* 2015). However, majority of the people were open-minded that they may need the nano-filter as the tap water is not always pure and sometimes it's not there due to different reasons and many other areas in South African villages and some informal settlements need this filter as they still use water from dams and rivers.

Another issue is that Bekkersdal is ruled by political rivals and community participants were always interested to know who introduced or who was with the researcher and if it was someone from the opposition party, attitudes immediately changed. This forced the researcher to meet other participants alone as the key informant was one of the community activists who were thought to be against the ruling party. For other people when they hear water pollution/contamination they associated it with the contamination by the mine companies as acid mine drainage is the main challenge in the area. The conversation would move from water treatment to how the mining companies are not taking care of the community, not taking responsibility for their activities which left majority of the community members suffering and the researcher had to try and steer the conversation back to nanotechnology use in water treatment. Other research participants declared that they cannot comment about what they do not know, and they demanded prototype and workshops for them to decide whether they would accept the technology or not. In response to this, an information session was conducted with the community members where in-depth knowledge was given by experts in the field.

CHAPTER FOUR

EMPIRICAL EVIDENCE

4.1 Introduction

This chapter presents the findings that answer the research questions which were investigated. The research questions investigated attributes that frame acceptance of nanotechnology as it is an emerging technology and looked at how these perceptions differ between laypeople and experts. Expert's perceptions about risks of nanomaterials use in water treatment are presented first, followed by those of laypeople. These results are then compared to evaluate their responses on how they differ. To establish whether perceptions of experts and laypeople differ in anyway, the results were compared using Fisher's exact test which allows analysis of small sample size.

4.2 Experts' perceptions of nanotechnology-enabled water treatment

This section presents results of one of the key questions of the research: the perceptions of nanotechnology experts with respect to the use of nanomaterials in drinking water treatment. The number of responses for each theme is quantified in Table 4.1. As noted earlier, first question in experts' interviews was typically "Tell me about use of nanomaterials in water treatment". A range of responses was elicited in response to this question, but conversations would often be soon directed at potential risks and benefits. Experts largely perceive nanotechnology positively, seeing it as a best solution in the context of advancements in science and technology facilitating better things and improved performance. For water treatment, some experts were quick to point out that due to their energy efficiency during operation compared to conventional treatment techniques, nanomaterials could provide an opportunity for water treatment processes to adapt to climate change.

Table 4.1: Quantified data of mentions for each theme by the experts (N=15)

Theme	Number of mentions
Safety	8
Cost	7
Legislation	6
Institutional trust	2
Socio-economic impacts	4

More broadly, however, a variety of perspectives were expressed, and five broad themes emerged from the analysis: Safety, cost, legislation, institutional trust and socio-economic impacts (Figure 4.1). Experts were mostly concerned about the safety of nanomaterials for human health and the environmental protection, as well as about the policy and regulations governing nanotechnology research in the country. Themes around the cost of nanomaterials, institutional trust and the wider societal benefits of developing nanotechnology in general were also identified. A more detailed discussion of these themes is provided in the next section.

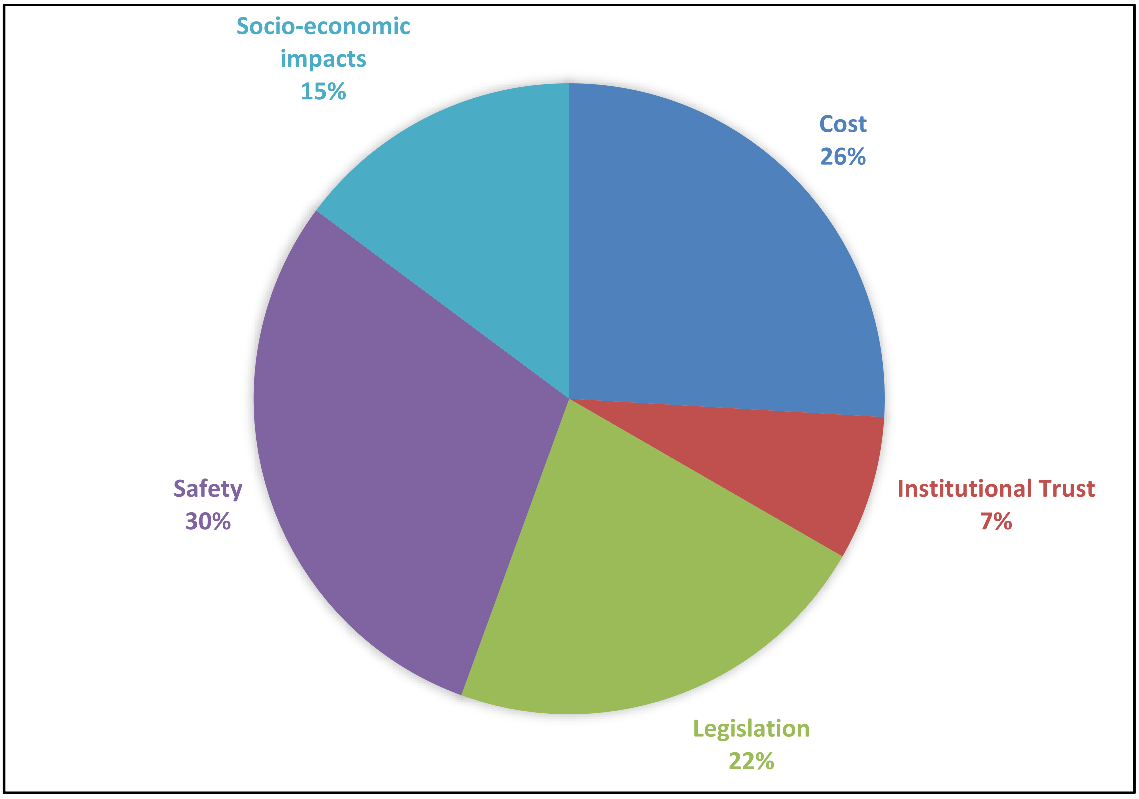


Figure 4.1: Themes emerging from semi-structured interviews with experts around the use of nanotechnology in water treatment (**Source**: Based on fieldwork survey (2019))

The views of the experts about nanotechnology application in water treatment

When the participants were asked about progress of nanotechnology in South Africa, specifically for water treatment, one of the participants commented:

Nanotechnology in S.A is advancing, it is still developing, it hasn't reached a maturity stage, and we are following behind other countries like US and China. My thought is that in S.A. we are probably 20-40 years behind what is happening in other countries, in terms of acceptance and use.

The interview went to look at the barriers to full nanotechnology development and implementation and participants were asked what the key concerns about this new technology are.

4.2.1 Safety Perceptions

When the experts were asked about their key concerns of nanomaterials use, safety recurred across all the interviews conducted. Due to the size of the nanomaterials, there is a concern about the possibility of nanomaterials leaching into treated water and potentially endangering consumers' health over time or being released into the environment from used and dumped water filters, with similar safety concerns. Underlying this concern is the fact that the very small size of nanomaterials makes environmental monitoring challenging.

"*There are many aspects that you look for which include material performance, environmental implications of the process, safety issues because we do not want to solve a problem by creating another problem*"- Nano-researcher C

"*Owing to the small size, e.g. for drinking water, there is a potential that the nanomaterial can leak into the water that means there are a lot of studies which still need to be conducted and regulative standards that need to be passed as a result they cannot be declared safe although some other materials are not toxic.*"- Nano-researcher A

Experts conceded that the long-term effects of nanomaterials on human health are still not fully understood. Nanomaterials can enter the human body via ingestion e.g. drinking water, through inhalation, or by dermal exposure. While nano-toxicity is dependent on various nanomaterial properties including size and shape, a full understanding on effects within the human body is still lacking. To highlight this limited understanding about health effects, several interviewees stated that:

"Effects of ingesting nanomaterials depend on each and every nanomaterial, its size, its nanomaterial and its surface properties, whether it is functionalised, shape (whether round or what) and it also depends on where does it land in the human body as we have different environments in our system like in terms of the pH, iron extremes and other factors."- Nano-toxicologist A

"The world does not really know how they will behave in the environment and when they enter the human system"- Nano-toxicologist B

Although there were concerns about possible leaching, nevertheless, some experts argued that immobilization of the nanomaterials in membranes would reduce the risk, meaning the damage can be mitigated and also using materials known to be safe:

"*Using material like graphene in water I don't think there would be a real risk because there is graphene that is immobilised on the surface, it does not go into the water. We may be worried about the rate it is going into the water because slowly with time it may be released into the water that's where the risk is going to come from, otherwise if it is immobilized nicely on the surface, I do not think there will be a huge risk*"- Nano-toxicologist A

Another safety-related concern arises from disposal of nanomaterials. Improper disposal can cause major damage in the ecosystem. Experts suggested that life cycle assessments still need to be performed for each of these nanomaterials. The interviewees confirmed that disposal information is still missing and the vacuum that surrounds this aspect concerns them as it will affect sustainable application and efficient use with minimal negative implications.

"It depends on the performance of the product, on how much water can be passed through before it gets exhausted and it cannot be just disposed anywhere but in an environmentally friendly way"- Nano-researcher A

"*There is always that risk of how it's disposed. We still do not know how to handle nanomaterials, we are supposed to look at all stages, from manufacturing, to use and then disposal. Some of the materials are not even labelled as containing nanomaterials, just take it and dump it as any other material. Even the waste pickers who go to the landfills are at risk as they start to sort out the waste and selling it.*"- Nano-toxicologist B

4.2.2. Cost implications

All the experts felt that cost was key for the successful development of this field in South Africa. In-depth analysis of this theme revealed that cost was conceptualised in ways that ranged from the cost of infrastructure required to develop nanotechnology to its full capacity in South Africa, to the cost of efficiently producing the nanomaterials so that nano-enabled water treatment is economically viable and competitive. However, there were differences in opinions amongst the experts in terms of how much the nanomaterials cost. Majority assumed that use of the materials will be very expensive and complex to operate.

"Yes, that particular material can be able to remove the material but at what cost? If the material is expensive even if it is good and efficient, if it is expensive, it cannot be adopted"- Nano-researcher A

"Nanotechnology involves high operating costs and complex technology"- Municipal water treatment official

Contrary to this opinion, other experts believed that the cost of the nanomaterials depends on the type of material and how easy it can be produced as some are naturally available whereas others need intense processing.

"The cost depends on how cheap you can make it, efficiency of the materials, how it compares to your competitors"- Nano-researcher B

Experts also showed an awareness of the context they operated in and that even if solutions were efficient, they also needed to be affordable.

"I think people would be willing to accept whatever that will help them; the issue will be cost of the products"- Nano-researcher B

4.2.3 Legislation

Experts were of the view that for nanotechnology to develop in South Africa to the point of tangible commercialised products, regulations governing research and commercialisation would be key.

"Certainly, because human beings and animals are involved, so the regulation must be mandatory"- Nano-researcher A

However, there is no exhaustive data on potential risks and existing risk assessments and frameworks are unsuitable for nanomaterials. Several factors are contributing to this situation including the stage at which nanotechnology research in South Africa is currently at.

"…. as nanotechnology is still in its infancy in South Africa, and policy should be governed by results or data and there are less people generating data especially in the nanotoxicity aspect …"- Nano-researcher D

More funding is needed to do risk assessments and produce data that can then be utilised for formulation of regulations.

"There is no regulation, which is specific to nanomaterials and nano commercial product. The reason is nano-engineered products are a relatively new field, so our understanding of the implications is very limited. To be specific, you cannot have a regulation or policy on something you cannot measure. Materials at nano-scale are not easy to measure"- Nano-toxicologist BIn addition, the long-term effects also need to be studied. This information will assist policy makers in developing sustainable policy which will allow taking full advantage of nanotechnology.

However, experts felt that they faced a dilemma regarding the extent to which risk assessments would need to go before certainty could be achieved that the possible safety issues were accounted for. They reckoned that this was one of the reasons regulation and policy were still not available:

"*The challenge is establishing to what length we must go test these materials to declare these nanomaterials as safe or not safe considering size, dissolution, concentration and other things. It will take a long time to actually say we have analysed for each one of them."*- Nano-toxicologist A

4.2.4 Institutional Trust

One of the key things identified to be important for public acceptance is institutional trust. People need to trust the institutions responsible for production of nano-enabled products, as well those responsible for certifying their safety for use. For the former, experts identified research institutions while for the latter, experts conceded that trust in government agencies responsible for policies and enforcing laws that will hinder or lower the risks were key. There was an agreement that greater trust in authorities involved would increase the public's willingness to accept the technology.

"*First, for the rest of the world to accept it, they need to know that it is coming from a good research environment, whether the scientists legit and do they know thoroughly about what they tell the people. It is about building trust with people based on quality of research and publications, which is why this research must be done at a well-reputed organisation*"- Nano-researcher B

4.2.5 Societal benefits

Nano-researchers commented about the socio-economic impacts of nanotechnology. It was highlighted that the development of nanotechnology in South Africa would provide additional job opportunities, however, they were quick to note that these would largely be highly skilled jobs.

"For the high-end skills, people need to be educated; however, the unskilled labour can be used for maybe transportation of the products, only postgraduates are trained"- Nano-researcher D

"Because the technology is new, only post-grads are trained to work with this technology, it's going to take time for the general public to benefit from this technology. Also, investments are needed especially from the government in order for the technology to reach the people."- Nano-researcher C

However, other experts expressed different views, arguing that there might not be direct benefits, however, there are benefits to the general wealth of the country and its prestige.

"It's not like every day, poor people of South Africa will benefit from this technology, but there are things that can be benefited, it boost the economy, support universities, build prestige, so there are social advantages to it." - Nano-researcher B

Experts also noted about dangers of automation which is part of 4th industrial revolution which is replacement of unskilled labour force with robots and there was an emphasis to consider long-term employment opportunities when these high-skilled technologies materialise.

"Robots are not paid, reliable, high output and they work faster, people are not needed. South Africa is behind in that technology but in the future, we will see more use of robots. We should be thinking about long-term, yes getting

more jobs for people is important, but how will we provide jobs for a long-term, when the technology is up and running because there is no point of giving people jobs for 2-3 years only"- Researcher B

4.3 Lay perceptions of nanotechnology-enabled water treatment

Lay people from Bekkersdal community were interviewed about perceptions of nanotechnology use in water treatment, however, participant understanding of water pollution and conventional water treatment was examined to evaluate awareness of the problem before introducing this new term. To fully understand the concerns and priorities of the participants, they expressed their views in their own words. Themes emerging from laypeople data included cost, potential human health impacts, and environmental impacts, institutional trust, legislation, socio-economic impacts and trust in the technology.

4.3.1 Use of Donaldson dam water as a water source and understanding of mine-derived water pollution and water treatment

It was determined beforehand that an appreciation of the poor state of water in the Donaldson dam was important for understanding community member's acceptance of any water treatment solution. As such, interviews began by determining perceptions of water quality in the Bekkersdal area.

On this aspect, several participants claimed even though they now relied on municipally-supplied water collected from communal taps on the street right outside their shack dwellings for all their domestic needs, they had previously consumed water from the Donaldson dam for decades, and that this often resulted in severe health effects including diarrhoea and skin ailments. Interestingly, one participant indicated that he still used this water due to its laxative effects. Nevertheless, community members were clear that water from the Donaldson dam is contaminated and unsafe for consumption.

"That water firstly causes skin rash, I went there in the past few months and I developed an infection so that water is not clean."- (Female, 30-39 years, Sangoma)

"If you just drink it as it is then you will have diarrhoea, it's very salty like sea water they become diluted when it rains."- (Female, 50-59 years, unemployed)

"I remember when we were growing up, we used to swim there and when we swum our skin would crack so badly"- (Male, aged 30-39 years, unemployed)

It seems that present uses of the Donaldson dam are now largely centred on religious activities and artisanal mining.

It was also notable that the interviewed community residents were uninformed of the source of their water or the processes involved in purifying it. Knowledge of reticulation i.e. transport to and consumers and the transfer of sewage to treatment plants was also limited:

"*We really don't know where the water we drink comes from, we just drink*"- (Female, aged 40-49 years, unemployed)

Some believe that water is from a fresh source located in a neighbouring country and that recycling water would be offensive.

"I believe that Gauteng get water from Lesotho, they can't abuse us and give us recycled water without telling us. That won't work"- (Male, aged 30-39 years, unemployed)

Regarding the sources of pollution of the Donaldson dam, most interviewees implicated the mine effluent from the Wonderfonteinspruit, even though their knowledge of acid mine drainage formation was clearly limited. Still, other community members blamed the poor drainage system in the area, claiming that sewage from the settlement flows into the river.

"It's the sewage and drainage from the mines"- (Male, aged 30-39 years, employed part-time)

"The dam water is not in good state because when it rains, all the rubbish from the community is washed into that water; although the water flows, I am sure some other things remain in the water."- (Male, aged 50-59 years, former miner)

However, others just noted on the quality and colour of the water but did not know the reason for this poor state of the water in Donaldson dam could be.

"Sometimes the water would be yellowish, and I would think it's the dirty things surrounding the dam even animals used that water so I can't tell you what was contaminating the water"- (Female, aged 40-49 years, unemployed)

(a) **(b)**

Figure 4.2: (a) Donaldson Dam (b) The lower part of Donaldson dam when it forms part of Wonderfonteinspruit (**Source**: Based on fieldwork survey (2019))

The community has municipal water supply which is still being introduced in the informal settlement, however, infrastructure seems to be the biggest problem because there is constant leaking of the taps, damaged pipes and possibility of the pipes supplying water to the community being connected to the one from the mines which make the water purity questionable.

(a) **(b)**

(C)

Figure 4.3: The images above show that the water resource is wasted due to damage to infrastructure as shown by the leaking taps: (a) & (b) Leaking taps (c) broken water supply pipe (**Source**: Based on fieldwork survey (2019))

Figure 4.4: A female with her child fetching water from the stand-alone tap (**Source**: based on fieldwork)

4.3.2 Understanding of nanotechnology and its potential use in water treatment

Having determined perceptions on water pollution amongst the respondents, we then moved on to determine perceptions around nanotechnology-enabled water treatment. Questioning on this line of inquiry often started with establishing how familiar respondents were with nanotechnology.

The results showed that participants had limited to no knowledge at all, with ninety eight percent of the participants indicating they had never even come across the term (Figure 4.4).

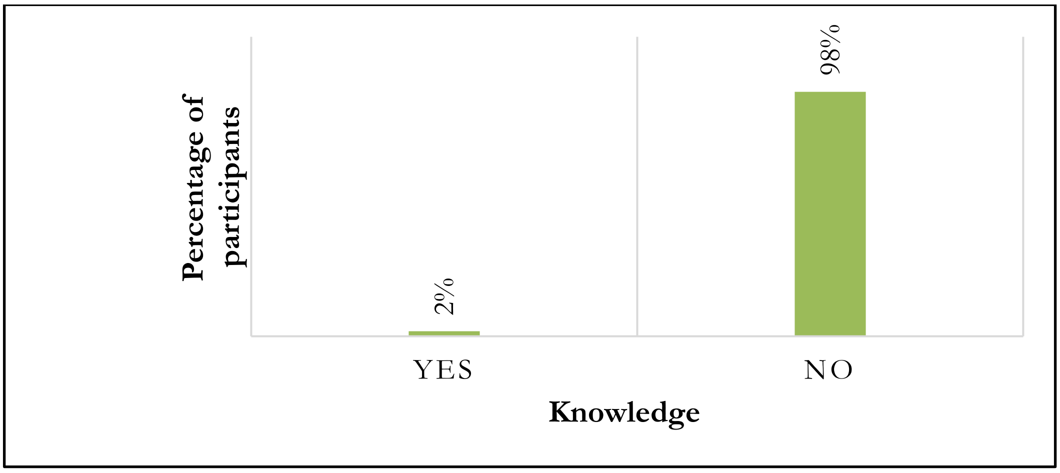


Figure 4.5: Knowledge of nanotechnology by lay people in Bekkersdal

"I hear you saying these words, but I don't know a thing about them". (Male, aged 40-49 years, unemployed)

"My child it's the first time I am hearing about this technology" (Female, aged 40-49 years, unemployed)

Nevertheless, participants they were still able to express their views after reading the information sheet and explanations using analogies to other well-known technologies, which led to such questions as:

"So, this nanotechnology, where is it from? Who came with this concept or system and how much far they can assist with purifying Donaldson dam water?"- (Male, 40-49 years, employed part-time)

4.3.3 Themes that emerged concerning application of nanotechnology in water treatment

Themes that emerged from laypeople data included cost (30%), potential human health impacts and environmental impacts (27%), institutional trust (16%), socio-economic impacts (9%) and additional two themes: functionality (9%) and trust in the technology (3%) (Figure 4.6). The questioning about perceptions of nanotechnology often started with establishing how familiar respondents were with nanotechnology. The results showed that participants had limited to no knowledge at all, with ninety eight percent of the participants indicating they had never even come across the term (Figure 4.5).

Table 4.2: Quantified data on mentions for each theme by community participants (N=45)

Theme	Number of mentions
Cost	32
Institutional trust	17
Legislation	7
Safety	29
Socio-economic impacts	6
Technology trust	3
Functionality	10

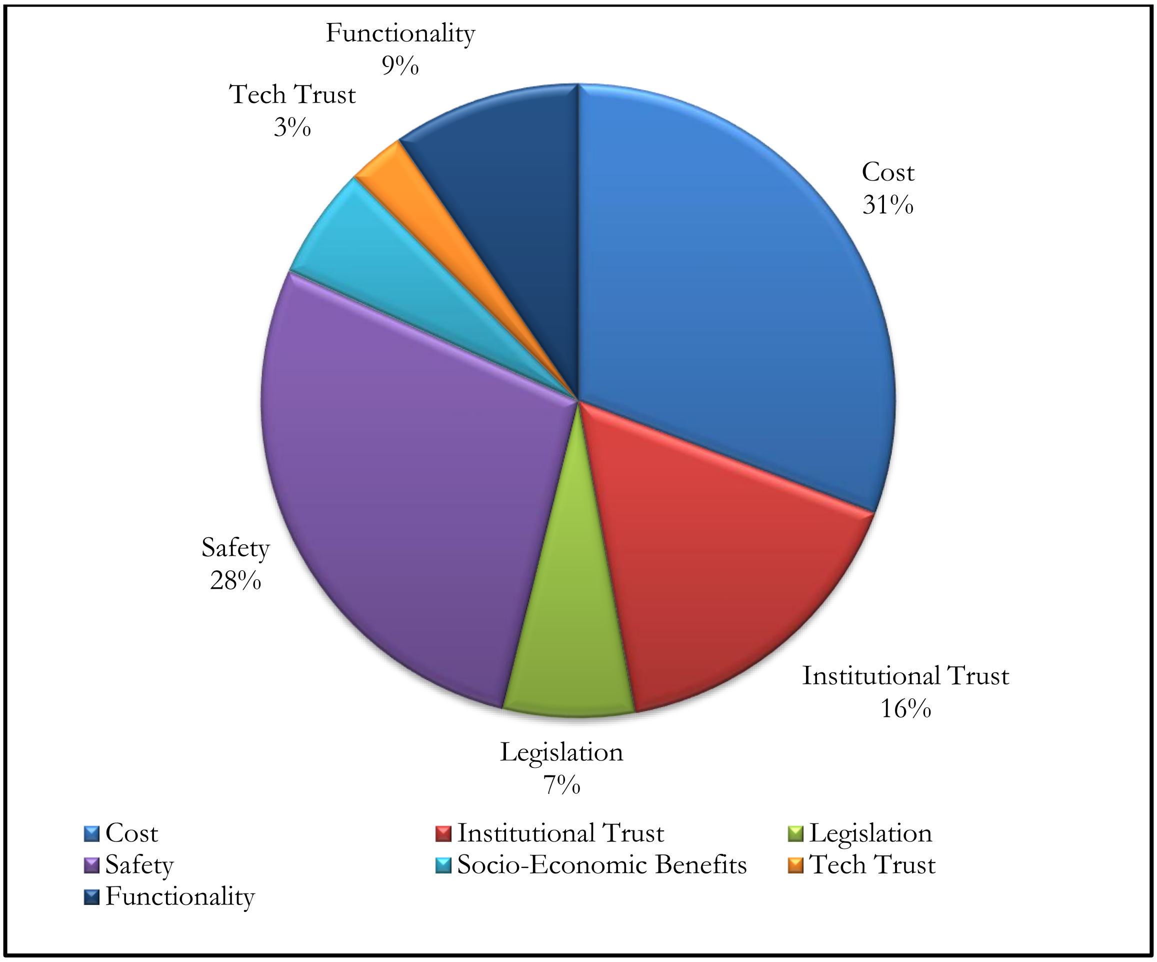


Figure 4.6: Themes emerging from semi-structured interviews with laypeople around the use of nanotechnology in water treatment (**Source**: Based on fieldwork survey (2019))

4.3.3.1 Cost

Cost came out as the most significant concern amongst the study participants. Due to high unemployment rate in the area, participants felt that they would not afford the filter as the new technology was likely to be expensive. Others stated that there are other competing priorities which need more attention before they can invest in this technology. In the end, a majority hoped that filtrations units would be provided free of charge or at least subsidised by the government.

"Don't you think nanotechnology will not be affordable for us, even though it is going to help people, but even in terms of implementation, is it not going to be difficult to maintain." (Male, aged 20-29 years, Bachelor of commerce graduate)

"We are very poor, we don't have money to buy that filter and use it in our houses, you need to approach the municipalities and government from provincial and local level so that they can be able to purchase those materials" (Male, aged 60+, political figure)

One of the interviewees argued that although the technology has been introduced to them, there is a possibility that they will never reap the benefits as they cannot afford this technology.

"What is the use of hearing about ice cream that you not even going to eat?"- (Male, aged 20-29 years, Bachelor of Commerce graduate)

4.3.3.2 Safety

Safety, both for humans and the environment, was the second most mentioned concern. The participants expressed a need for assurances on the safety of these nanomaterials and that they wouldn't come to any harm if they accidentally consumed them e.g. if they leached from filters, or that they would not be harmful to other species in the environment.

"I was not going to give it a green light until such time you are sure and conclusive and with good evidence that it is properly tested and does not have harmful effects."- (Male, 60+ years, retired teacher)

"Has the safety of the people who are going to use these nanomembranes been considered? Has enough research gone into studying the type of diseases that may occur due to this new thing?"- (Female, 30-39 years, employed part-time)

One of the participants argued that there is a possibility that the chemicals used in synthesis of nanomaterials may form new sources of pollution, introducing new hazards.

"*Chemicals come with pollution, maybe air or soil pollution I don't know, it comes with its own consequences, I can't say when this system comes everything is going to be fine. Yes, the water will be fine and all, but the soil might be a problem instead of the water, the air will be a problem instead of the water, the environment might be a problem in its own. Yes, this thing is good but at the same time, it also has these negativities*."- (Female, aged 20-29 years, college student)

4.3.3.3 Institutional Trust

Study participants acknowledged the need for cooperation amongst stakeholders for the success on nanotechnology in South Africa.

All-in-all I think all those people must be involved as this is a puzzle, one cannot operate without the other, yes you can treat the water and we feel they taste good and better than the piped water but if the politicians do not approve its going to be a problem because there are cost implications."- (Male, 60+, retired teacher)

Nevertheless, a majority seemed that they had the highest levels of trust in the government, followed by scientists and the least trust in politician as proponents of new technologies including for water treatment. Trust in the government was largely based on its role and responsibility to ensure consumer protection through such bodies as the bureau of standards (SABS) and the council for scientific and industrial research (CSIR) to do intensive research on these materials before being made available to consumers:

"Anyway, has there been an engagement with the three spheres of government in terms of this technology because we as communities we can say yes, we need nanotechnology to be utilised but there must involvement of our local municipality to approve, they are the ones who have power. All we can do is pressurise the Municipality to assist in this"- (Male, 60+ years, political figure)

However, other participants showed more trust for scientists to manufacture safe products that can alleviate the water shortage based on the innovations which have been done before that helped the people enormously.

"*I trust scientist, the person who invented the technology for cleaning water*" - (Male, aged 30-39 years, unemployed)

There is no trust for the politicians because politicians are political figures with no skills to make sure the technology is safe for use by people.

"*I trust scientists more, politicians are born liars*"- (Female, aged 20-29 years, student)

"You see our minister of water and sanitation is just a political figure, she does not know a thing about water, she is not a technocrat, she is just a mere politician"- (Male, 60+, retired teacher)

Other interesting factor in terms of trust was race: whether the person introducing or developing the filter is black (African) or white. Participants showed less trust in black people compared to white people. This view probably stems from the perception that white people are technologically advanced and less corrupt compared to black people.

"You see white people were good and advanced with technology long time ago, did the white people approve these technologies, and are they interested?"- (Male, aged 40-49 years, employed part-time)

4.3.3.4 Functionality

The interviewees were also concerned about how the nano-filter functions in terms of replacement of filter, flow rate, capacity and type of container, time it takes to clean the water, type of pollutants that can be removed, whether the membrane will be sold separate, service of the filter and whether this filter will allow water reuse. The concern about service of the filter stems from the understanding that any man-made product has a predetermined life span and if they are used beyond their lifetime, they will not be efficient and might lead to development of unwanted pathogens. The prevailing comments were as follows:

"You can't use it forever so what I want to know what is going to happen to the membrane with the contaminants, how does the membrane get cleaned."- (Female, aged 20-29 years, student)

In terms of capacity, the interviewees were referring to the volume (how much water can pass through the membrane and be stored) and efficiency of the nano-sized material in terms of contaminant removal capacity. Majority of the participants were concerned about capacity of the nano-enabled filter to remove all the contaminants 100% and possibility of other pollutants remaining in the water since Donaldson Dam water contains different contaminants and reactions and such concerns made it hard to believe that all the contaminants can be removed in few minutes using a simple technology. These are some of the responses corresponding to the capacity issue:

"*How big is this container*?"- (Male, aged 30-39 years, employed part-time)

"*How much pollutant can be absorbed using these materials compared to the big blocks*?"- (Male, 60+ years, pensioner)

When commenting about lifespan of the filter, most of the participants were interested to know about the life span of these materials and the filter. They wanted to know how long the nanomaterials last before getting exhausted and others included questions asking whether the membrane will be sold separate as it is the key functional part and whether this filter will be serviced.

"*Firstly, I would like to know about the guarantee of this machine."*- (Male, aged 40-49 years, employed part-time)

"*Does it last for long or do I have to buy another one*?"- (Female, aged 20-29 years, student)

Lastly, type of material used to make the container, whether the container will be a glass, metal or plastic and chemical used to clean water. Some of the participants preferred a plastic container as they argued that glass can be easily broken, and metal is likely to be more expensive. Others were concerned about the origin of the raw material and how these materials are synthesised.

"This container, what is used to make it? Is it a metal, plastic or glass? - (Female, aged 20-29 years, unemployed)

Another concern is whether the membrane can remove all the contaminants in one process as the conventional water treatment is usually a long process involving many phases. In addition, the knowledge that different adsorbents usually target specific contaminants not all at once, so there is a query that some of the contaminants will remain in the water.

"*One thing I know cleaning water is a process. You cannot tell me if I pour sewage water, they will be drinkable, how many chemicals are contained in sewage water?* - (Male, aged 30-39 years, employed part-time)

"*Obviously, there will be danger involved because that water is very contaminated so to say we can clean it to drinkable levels using magic, don't you think we will end up being magic too? We will get sick. The food we eat have chemicals already that can kill us*."- (Male, aged 30-39 years, unemployed)

4.3.3.5 Legislation

Legislation refers to policy and practice of nanomaterial use. Most of the participants were concerned about whether policies and standards existed that would govern the use of these materials. There seemed to be an assumption about non-existence of policies governing use of these materials. Although few participants raised this issue, there was good understanding of the protocol which must be followed before a product is introduced to people.

"*Why there are no policies and no legislations because when we take a product to a community level. we need to make sure the legality, we need to check are the community members not put at risk when this water is cleaned using the technology, it can be used only to find that there are disadvantages that can come or that can be hazardous to people's lives. What are the reasons there are no legislations and regulations that guide this whole project*?"- (Male, aged 40-49 years, government employee)

"*This issue of policies and regulations is a challenge. They need to really look at it and introduce it bit by bit because in South Africa everything needs authorization, even the constitution is Act 108 of 1996, so it's difficult with plain document which is not legislated, which is not acted, it's a big challenge. They need to review or recheck if they cannot include a small piece about it and we need to check the mandate, the objective and the vision*" - (Male, aged 40-49 years, government employee)

4.3.3.6 Socio-Economic Impacts

Study participants were mostly unemployed people. As such, it was understandable that the issue of job creation came up time and again during interviews.

"*What is it that nanotechnology is going to bring for the benefit of a local person besides purification of water*?"- (Male, aged 40-49 years, employed part-time)

"*I hope this filter will open job opportunities because people are not working and where will they get money to buy it"*- (Male, aged 30-39 years, unemployed)

Nevertheless, participants showed awareness about that job opportunities cannot be open to everyone especially because of the high level of training and skills required to work in this domain.

"*We don't even have the skills…….*" - (Male, aged 20-29 years, Bachelor of Commerce graduate)

4.3.3.7 Trust in the technology

The overall response to this technology was positive, majority of the people perceived this technology as a solution to provide clean and safe water, however, some participants did not trust that all contaminants would be removed from water. There was concern that other pollutants would remain in the water

"*One thing I know cleaning water is a process. You cannot tell me if I pour sewage water, they will be drinkable, how many chemicals are contained in sewage water? Remember we use different soaps with different components so is it 100% safe to use this thing"*- (Male, aged 30-39 years, employed part-time)

"*Obviously, there will be danger involved because that water is very contaminated so to say we can clean it to drinkable levels using magic, don't you think we will end up being magic too? We will get sick. The food we eat have chemicals already that can kill us.*"- (Male, aged 30-39 years, unemployed)

"*I cannot use the filter even if it gives clean water because my mind will tell me this water is dirty for drinking and I cannot attempt to clean by merely using a filter.*"- (Male, aged 50-59 years, former miner)

4.3.4 Acceptance of a new technology

Although 76% of the participants expressed optimism, 24 % of the participants did not see a need for it, claiming that the government have other priorities (Fig. 4.7):

"How can they invest on this technology? no, it is not realistic, right now the government must make a plan that we get 5G, the new integrated network which will make things faster and it's the next big thing so that information and communication technology (ICT) can develop faster. It will make things even nanotechnology more accessible."- (Male, aged 20-29 years, Bachelor of Commerce graduate)

Another reason for rejecting this technology is the belief that there is no water shortage.

"*No, I don't see a need, it rains often too so the dams should be full, aren't they full?*"- (Unemployed male, 30-39 years)

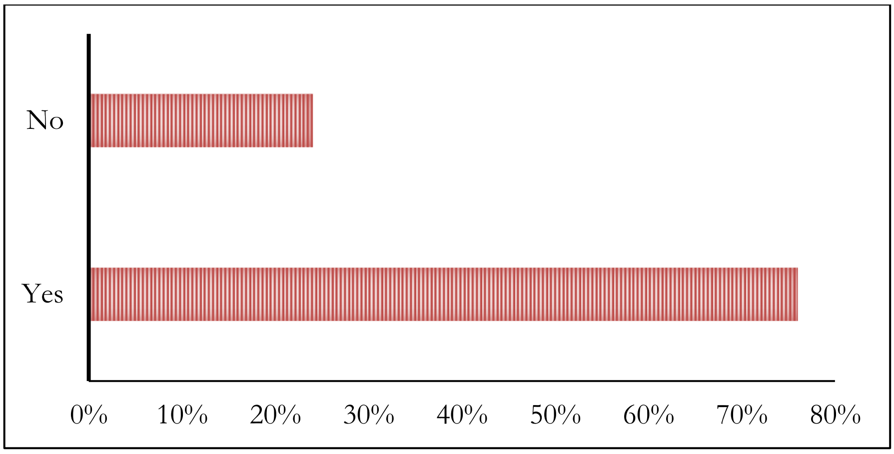


Figure 4.7: Acceptance of nanotechnology for water treatment amongst Bekkersdal residents

4.4 Comparison of the expert and lay people perceptions using Fisher's exact test results

Fisher's exact test was used to analyse for differences in the salience of the various themes as expressed by members of the two groups e.g. if institutional trust was a greater concern for experts than it was for laypeople, based on how often this theme was coded for in the data. The hypothesis of significant differences between the two groups was therefore tested at a significance level of 0.05. The results show that there were significant differences in the salience of all themes identified except for legislation and socio-economic impacts (Table 4.3).

Table 4.3: Comparison of the experts' and laypeople perceptions using Fisher's exact test

Theme	Expert no. of records	Laypeople no. of records	*P*
Cost	6	42	<0.001
Institutional Trust	2	17	<0.001
Legislation	6	7	0.99
Safety	8	29	<0.001
Socio-economic Impacts	4	6	0.75

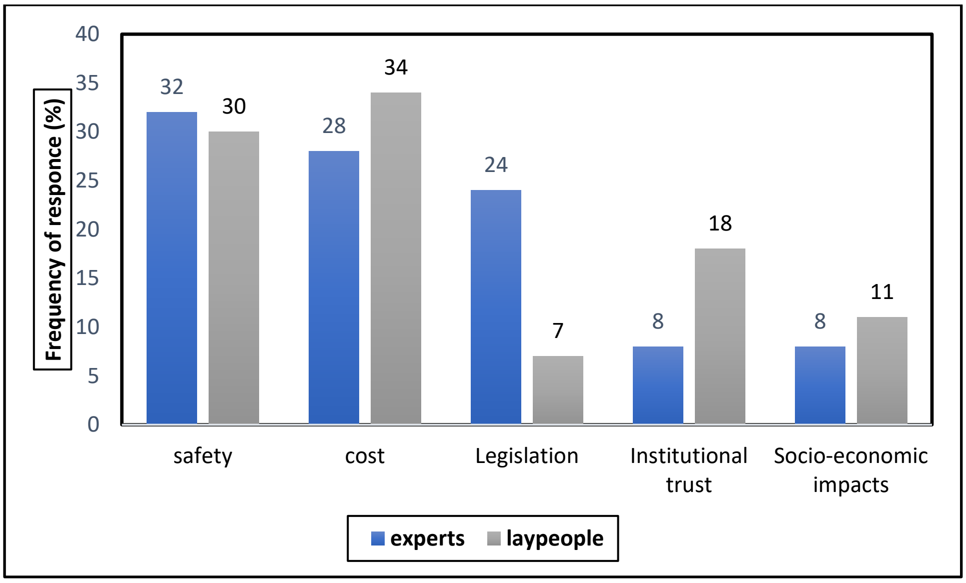


Figure 4.8: Frequency of experts and laypeople responses for each theme around the use of nanotechnology in water treatment

As presented in **Figure 4.8** the experts and laypeople shared similar themes, however, they differed in their priorities. For example although there were safety concerns from both groups, however, laypeople had more concerns about health implications whereas experts considered both health implications and the environment. Furthermore, sub-themes under cost were different for the two groups and laypeople expressed more concern about the cost implications of the nano-products. Experts had more information on the barriers to development of policies as opposed to laypeople where only few individuals were concerned about legislation issues and some had knowledge about the process involved before a product reaches the market. Experts did not mention much about importance of institutional trust in the nanotechnology research and development although it was one of the key important factors for laypeople; this applies also to the socio-economic impacts.

The results in this Chapter indicate that although the experts and grassroots community members perceived similar themes with additional themes from the latter, their priorities and concerns differed significantly except for legislation and socio-economic impacts, the next chapter, therefore, moves on to discuss these differences in perceptions and the key drivers to these factors. These results suggest that there is weak association between knowledge and acceptance because community members showed great optimism for the technology although there was very low awareness or knowledge. The most interesting result that can be noted from these results is the differentiation between government and politicians and the influence of race on institutional trust.

CHAPTER FIVE

ANALYSIS AND DISCUSSION

5.1 Introduction

This chapter focuses on a discussion of the results presented in the preceding chapter. This discussion is interwoven with observations made by the researcher in order to give richer meaning in the context of the research study. An initial objective of the study was to determine factors that influence perceptions of the people when new technologies are introduced and whether these factors differ between experts and laypeople. The effect of involvement of expert and laypeople is to align the two parties to avoid rejection of the nano-products by the laypeople due to unmet needs and erroneous assumptions of the consumer needs by the experts. The results were analysed in conjunction with the extant work to understand how these results support or contrast with the existing literature and the implications of these results.

5.1 Perceptions of experts about nanotechnology application in water treatment

Engagement with experts in the nanotechnology field (researchers, academics, nanomaterials manufacturers, nano-toxicologists and municipal water treatment professionals) revealed that this group was concerned about the safety of the nanomaterials, the cost of production and research and legislation amongst other factors (Fig. 4.1). The experts had these concerns although nanomaterials promise exceptional benefits for point-of-use water treatment, their use would bring with them significant environmental challenges. These concerns stem from the nature of the nanomaterials as they have a very small size which raise concerns about possible health and environmental hazards. There is apprehension that these nanoparticles can leach into the environment thereby impacting the ecosystem negatively. Similar concerns were raised in U.S. Scheufele *et al.*, (2007) and in Australia (Cormick 2009).

Secondly, although experts raised similar concerns, there was some heterogeneity amongst the experts about the risks. Nanotechnologists and researchers were more concerned about opportunities of nanotechnology use whereas nano-toxicologists and the water treatment professionals considered both opportunities and risks. These findings are consistent with those of Babbage and Ronan (2000) and Bertoldo *et al* (2015) who found that upstream scientists such as engineers, chemists, and physicists perceived less serious effects from nanomaterials on the environment and people, than did downstream scientists i.e. toxicologists, epidemiologists and public health scientists.

Nevertheless, some experts mentioned that risks could be minimised by avoiding toxic materials, the application of the precautionary principle. Some experts noted that because the behaviour of nanomaterials in the environment is not fully understood, immobilization in membranes would present as a solution to prevent possible leaching of the nanomaterials. Westerhoff *et al.* (2016) and OECD and Allianz (2014) supported that immobilization is more effective than separation or physical barriers as free nanoparticles would require greater effort to separate from water. Immobilising the nanomaterials could also prevent contact with users thereby reducing concern about personal risks.

The disposal of nanomaterial-containing waste was another concern of the experts. However, experts involved in manufacturing and research suggested that the nanomaterials could be recycled. This approach is supported by Myakonkaya *et al.* (2010) who argue that declaring all nanomaterials as hazardous waste might lead to loss of valuable materials. These arguments show a need for technological solutions for nanomaterials recovery. Živković *et al.* (2014) suggested magnetically recovering supports after the purification process has been done.

Regarding potential impacts on human health, 14% of the experts believed that no significant risks would be presented by nanomaterials if measures such as immobilisation are followed. However, this view was not universal amongst the interviewed experts, with some claiming that more evidence and tests must be conducted.

Most experts were also concerned about the lack of legislation governing nanomaterial use and development in the country. They acknowledge that while a code of conduct exists, this is not sufficient for successful governance of the field. However, they also acknowledge that this absence of legislation is influenced by lack of research data. According to Auplat (2009), regulations area form of constraint set to ensure that users are cautious about their actions. With respect to nanotechnology, this would involve a response to the awareness of consequences and risks involved when using nanomaterials. In support of this statement, Vijaya *et al.* (2001) claimed that even when considering the life cycle of the nanomaterials from production, to use and disposal in places like India, there are no legislations put in place. Iavicoli *et al.* (2014) suggested that more systematic risk assessments are required looking at the influence of size, surface area, concentration of particle numbers, functionalization on NM toxicity. The data from these studies will assist to detect, monitor and track nanomaterials in the environment and biological systems. The experts also explained that the lack of policies and regulations increases the lag time between research and actual products getting into the market. In support of this view about drawbacks resulting from regulation issues, Vijaya *et al.* (2001) argued that lack of knowledge about the toxicity issues concerning this technology have created a major gap between research and development of the nano-products.

On the other hand, the lack of lifecycle data for nanomaterial-containing products presents a dilemma to policymakers. Should they move forward with presumed risks of only accept the risk data once toxicological data has been accumulated? The precautionary principle must be practiced in nanomaterial use by managing and defining the anticipated risks because it is better to prevent damage than to manage it. Conversely, there is a challenge with managing the unknowns as it means there will be a limit to what is performed using nanomaterials. Explaining the dilemma about development of policy for nanotechnologies, Abbott *et al* (2006) argue that early development of regulation for nanotechnologies can prevent exploration of new possible applications whereas late development can be disastrous because the harm would have been done already. These policy and regulation issues can also influence public acceptance negatively because for people to gain confidence and accept the technology, they need assurance that its development has followed the right procedures, undergone testing and certified to be safe. To support this statement, Živković *et al.* (2014) explained that inadequate disclosure about possible impacts on health and safety will cause people to be cynical which will then affect the progress of implementation of this technology.

The findings of this research confirm and add to those of previous studies (Lee and Rwanda 2006) which show a need for more research. In fact, all these challenges about NMs are related to the limited funding invested in this technology. Limited research funding exacerbates the problem as it limits the extent to which risk assessments can be conducted. The toxicologist interviewed for this work argued that, it's nearly impossible to conduct risk assessments for every available nanomaterial. He proposed that testing should proceed by grouping the materials according to functional groups although this generalisation is not the best solution. The need for funding is a major concern because funds are needed to undertake research, fund infrastructure acquisition and for skill development. Vijaya *et al.* (2001) asserted that lack of investment in both research and incubation of technologies hinders the advancement to actual products.

Access to resources, including clean water, is closely linked to economic status. As such, cost is a key factor in the development of water treatment technologies to be available to low-income people. An efficient but expensive product will have limited uptake. Importantly, however, experts interviewed in this study conceptualised cost around the fact that nanomaterials are expensive to produce. They then went on to state that this could lead to a limited technology adoption especially amongst low-income consumers. These sentiments were similar to those expressed by Vijaya *et al.* (2001) who argued that although only small amounts of nanomaterials are required, their unit costs make purification by this approach more expensive. However, experts involved in manufacturing and research held the view that nanomaterials would become cheaper as the demand and production increased. To further emphasise that nanomaterials are not extremely expensive, OECD and Allianz (2014) agreed that nanomembranes and nano-clays are inexpensive, portable and easy to clean at small scale. In summary therefore, when experts thought of costs as a factor in nanotechnology for water treatment, they had infrastructure and efficiency of the nanomaterials in mind (Figure 4.1).

Less than 15% of the experts acknowledged that institutional trust was key for public acceptance of nano-enabled water treatment. Two experts conceded that institutional trust was key as people need to trust the institutions. Trust is based on institutions' reputation, previous contribution to society and quality of research produced. Furthermore, the government agencies responsible for certifying the safety of nano-enabled products need to be trustworthy to protect the users and provide relevant information. In accordance with the present results, Seigo, *et al.* (2014) stated that trust is based on social relations and shared values. The data from this study show that experts thought more in terms of the public needs to trust the quality of research and products, as well as the authorities involved in management, regulation and governance of nanomaterials. Greater trust would increase the chances of acceptance of this technology. A study by Terwel *et al.* (2009) proved that confidence and trust by the laypeople on the organisation meant strong influence on acceptance of the technology. In terms of trust based on shared values, this is crucial because if people know that the developer is working towards meeting their needs and not only to serve his or her own needs then people will show more positive attitude and interest. The effect of shared values shows the reason people need to trust the government to protect them from any risk that can be posed by the nanomaterials by testing and following the right code of conduct.

30% of the experts remarked on socio-economic impacts of this new technology. Experts emphasised that as nanotechnology research and training is currently only available at the higher education levels, nanotechnology development in general would have limited impacts for citizens without high education levels. Nevertheless, nanotechnology for water treatment is one of the areas of the field that is likely to have a large impact on society. By increasing access to clean water, health is improved, less resources are expended on health care, thus great benefits for society.

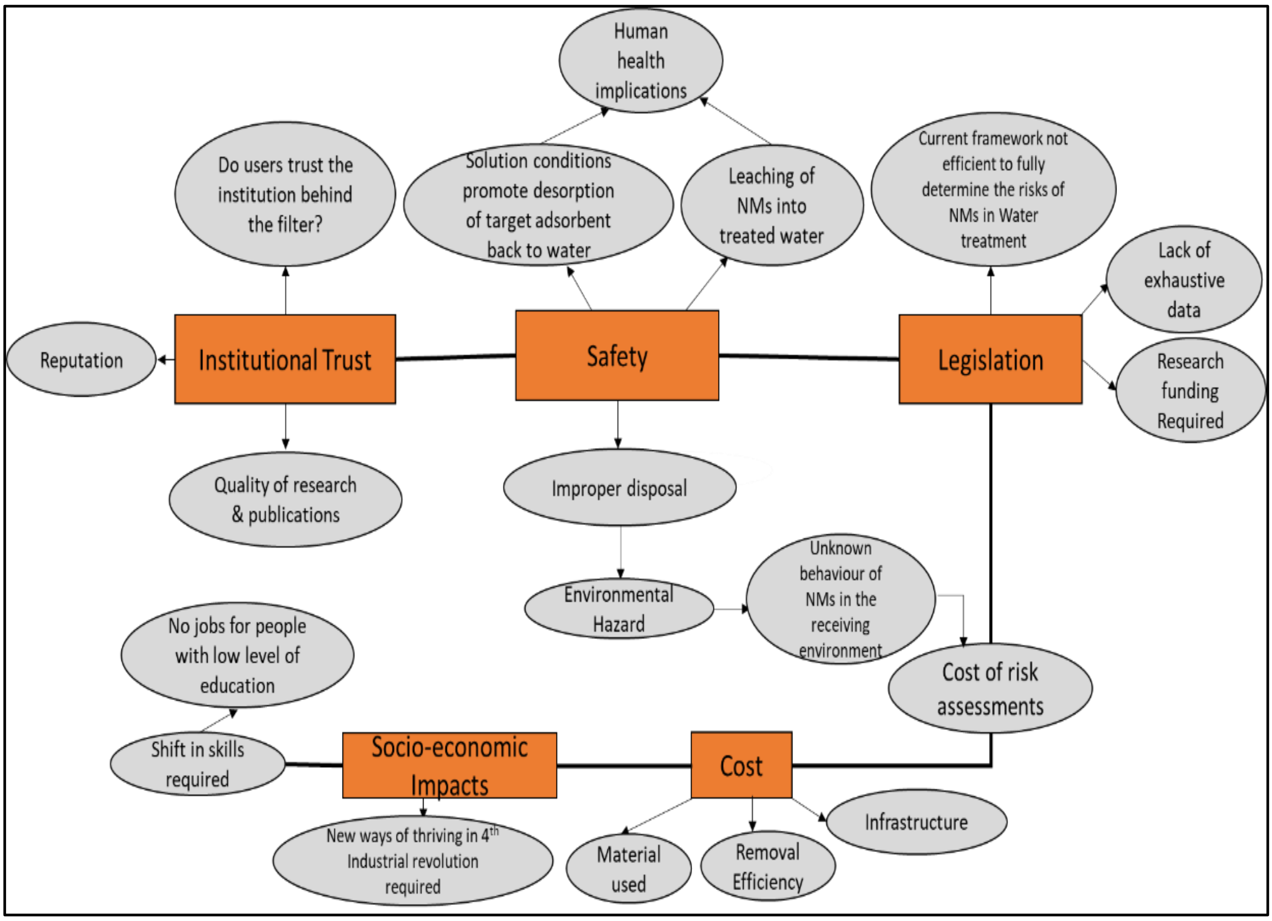


Figure 5.1: Summary of the experts' model about risk perceptions of nanotechnology application in water treatment

Figure 5.1 gives a summary of the views of experts about risks involved with use of nanomaterials in drinking water treatment. The main themes are represented by the rectangles (orange) and subthemes are represented by the oval shapes. The model starts with the influence of institutional trust on the confidence and acceptance of the technology where experts emphasised that the products need to be from a trusted and well-reputed institution. Following institutional trust is safety in which experts commented on the possibility of nanomaterials presenting human health and environmental hazards. Due to lack of safety data, there are regulatory issues as the current framework is perceived to be inefficient to fully determine the risks of NMs and more funding is needed to conduct risk assessments. The cost of risk assessments will then influence the overall cost of the nano-enabled device and this can lead to negative socio-economic impacts as the NMs are predicted to be expensive and experts perceived no direct benefits for unskilled labour as high level of education is required to work with these materials.

5.3 Perceptions of laypeople about nanotechnology solution to water scarcity

As stated earlier, it was important to first establish the perceptions of water quality among Bekkersdal residents, and whether a need existed for cleaner water than currently available, as a background to perceptions towards nanotechnology-enabled water treatment in general, and the nano-enabled water filter being proposed. The results showed that participants were aware that water in the Donaldson Dam was contaminated and unsafe for human consumption. The main pollution sources were thought to be sewage, refuse and acid mine drainage. Although residents did not have extensive knowledge about how acid mine drainage is formed, they understood that AMD resulted in changes in several water parameters i.e. colour of the water to reddish-orange, and damage to soil and crops as well aquatic life in the dam.

Regarding knowledge of water sources and water treatment, a majority of community members asserted that they knew little of where their water came from or how it was treated. Whereas some thought municipally supplied water was sourced from rivers and ground water, they cringed at the idea of water recycling claiming that municipalities should not be allowed to "collect and give back to them sewage water" as it was contaminated and unfit for use. This suggests that some community members had limited knowledge of the water reticulation process. Regarding access to water in the community, several participants indicated that they had access to shared municipal taps outside their yards. However, Liefferink & Wepener (2017) found that over 45% of the Bekkersdal residents had difficulty accessing water for various reasons including that taps were few in number, far away, often broken, or that they had to wait in long queues to collect water. As such, some residents use Donaldson Dam water as an alternative water source.

In response to the question about knowledge of nanotechnologies, 98% of participants showed poor to non-existent knowledge of nanotechnologies (Fig. 4.5). These results are similar to the findings of the European Commission (2010) where more than 75% of the participants did not have any knowledge of nanotechnology. The Federal Institute for Risk Assessment (2008) also reported similar results: over 50% of the participants did not relate to nanotechnology, and even those who had a clue, it was not tangible. Nevertheless, engagement with the community resulted in an interest in the subject and especially on the effectiveness of nanotechnology in water purification. With the limited information provided during engagements, community members expressed positive perceptions and willingness to accept this water treatment option. Increased knowledge decreases risk perception Seigo *et al* (2014). It is plausible that the information provided during engagements decreased perceptions of risk presented by nano-enabled water treatment, resulting in greater willingness to accept it.

Even though participants were keen to accept this water treatment option, it was noted that other factors including safety, institutional trust, functionality, legislation, and socio-economic impacts, and cost would influence uptake. Amongst these factors cost emerged as the key factor. Most respondents expressed concerns that nanotechnology-enabled water treatment would be expensive, and the proposed filter likely unaffordable to them because they were unemployed as 73% of Bekkersdal community members are unemployed Liefferink & Wepener (2017). Similar concerns have been expressed elsewhere i.e. that low incomes may make access to nanotechnology products out of reach Vijaya *et al.* (2001). Olvera *et al.* (2017) reported recently that the current cost of nanofiltration devices was equivalent to five minimum wages in Mexico.

Respondents conceptualised cost in a number of ways including the life span of the proposed filtration devices, whether these devices would use replaceable cartridges as this would be cheaper than buying new devices every time, how long they would go before they would need to be replaced, and whether the filters would require a power source. They were also concerned about device efficiency i.e. the volume of water that could be purified, contaminant removal efficiency of the membrane, and the time it would take to remove all contaminants. Participants felt that a filter with less than 100% removal would be a waste of their minimal resources. Willingness to pay for a nano-enabled water treatment device was also strongly influenced by perceived affordability and low levels of unemployment in the area. Nevertheless, a few people indicated a willingness to pay if use of the filter did not present any harmful effects and was efficient.

A majority of community members expressed expectations that the government would subsidise or provide the filters free of charge, as it is prerogative of governments to ensure access to clean potable water for citizens, and water is a human right in the country. As stated by Molle and Mollinga (2003) there is a link between poverty and access to potable water.

The second major concern was safety of the nanomaterials to the human health and environment. Community members were concerned about the possibility of leaching of the nanomaterials into the treated water which would increase their chances of ingesting the nanomaterials resulting in detrimental health effects. Qu *et al.* (2013) suggested that nanomaterials could be carriers of toxic chemicals. Participants expressed a desire for evidence that nanomaterials are safe in the form of approval by South African bureau of standards (SABS) before they could accept it. In terms of the environment, participants wondered whether nanomaterials would not introduce new environmental impacts which will destroy the fauna and flora and cause decline in crop productivity. There was also scepticism that the suggested filter would be able to remove all the different contaminants in one step because bulk water treatment process usually involves several stages, targeting specific contaminants so it was difficult to comprehend that the whole process could be done in matter of minutes.

Institutional trust was reported as an influence on nanotechnology acceptance where majority of the participants expressed more trust for the government, followed by scientists, and least trust for politicians. Trust for scientists assumed of their knowledge and experience with the technology. FIRA (2008) demonstrated that positive attitude or trust in science produces positive assessment of the technology. There was, however, more trust in Government as the responsible for ensuring safety of the products by enforcing laws and regulations for use of these materials to ensure no harm is posed to people and environment, and if there are any risks for them to be mitigated significantly. The reason for more trust in government is still uncertain, other participants claimed that government provided water and has the authoritative power to make decisions. However, this perception might have been influenced by the positive sentiment derived from the fact that the government is currently supplying water to residents free of charge. The high level of trust for government is contrary to the study by Federation of risk assessment (2008) which had low trust in government to protect the public. The study by Federation of risk assessment (2008) was further supported by van Djik *et al.* (2017) where low trusts in government resulted from the perception that government does not have skills and resources required to test and regulate safety. This latter sentiment was also expressed by a few residents who did not trust the government to have skills and resources needed to regulate the use of nanomaterials.

It was however, not clear why residents expressed greater trust in government than politicians especially since politicians make up a large proportion of the government. A statement from one of the respondents nevertheless clarified that government is sometimes thought of as comprising of technocrats whose decisions are seen less politically-motivated. The lack of trust for politician's also seemed to stem from incomplete projects involvement in corruption. Nevertheless, it was acknowledged that politicians have considerable influence on the progress of any innovation because their opinions influence perceptions as well as investment. Finally, a few participants (13%) held views to the effect that white people were technologically more advanced, and less corrupt compared to black people, and so they would only accept technologies introduced by the former.

Laypeople also emphasised that for the nano-filter to be accepted, it needed to be tested for safety and obtain approval from the South African bureau of standards (SABS). There was clear statement that it would be hard to accept the technology without knowing the pros and cons of using it and inadequate disclosure of the possible health and environmental risks. This demonstrates that regulations improve trust in the technology.

Socio-economic impacts of nanotechnology were also of interest to the participants who were curious as to whether nanotechnology would provide job opportunities given the high unemployment rate in the area. While some participants showed hope that the technology would alleviate unemployment, some anticipated less benefit in this realm citing the special skills that would be required to work in the field. This led to perceptions that poor people will be further marginalised as there will be a shift in skills required and the high cost of the nanomaterials will not be in favour either.

More than three quarters of residents were optimistic about the capability of nano-enabled water treatment to provide clean and safe water, however, health and environmental risks notwithstanding. Of the 24 % of the participants pessimistic about the use of this technology, some claimed they saw no need for a different technology when existing conventional ways were working perfectly. Grimshaw *et al.* (2009) stated people like to use what they are familiar with, and it takes significant convincing to change and adopt new ones. Another reason could be the prioritization of needs by the respondents. Perhaps as noted by Vijaya *et al.* (2001) water purification is not on the spending priority for some community members.

Vijaya *et al.*, (2001) asserted that people do not value water purification products because their perception of safe water is very miscellaneous, if water appears clean, it is assumed to be safe for consumption. This scenario could also result from perceptions that provision of safe water is the government's prerogative. On the other hand, some consumers also perceive that practices such as boiling, filtering using cloths and use of disinfectants such as bleach sufficient to clean any water and so a filter is not necessary.

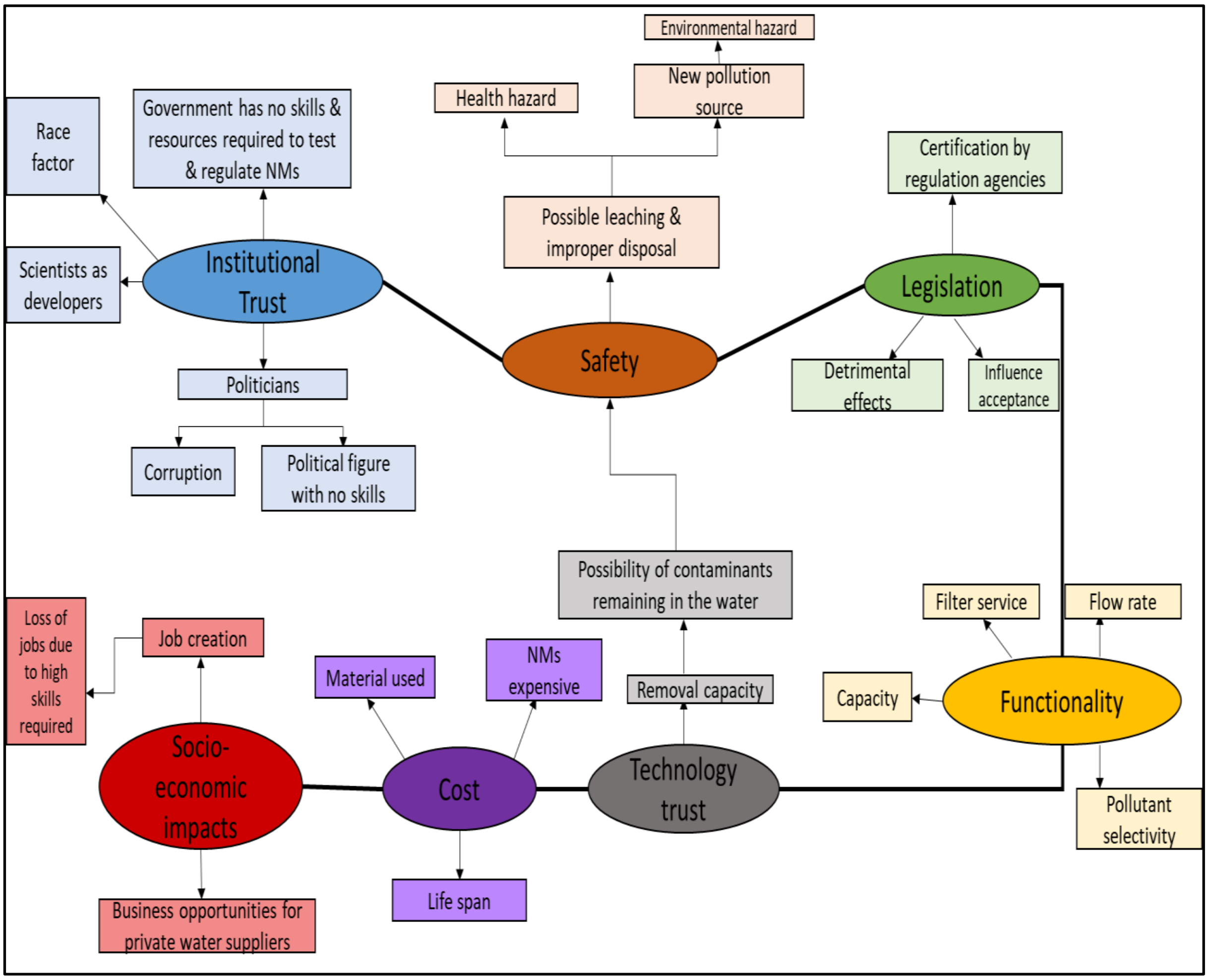


Figure 5.2: Summary of community members perceptions about risks associated with nanotechnology application in water treatment

Figure 5.2 presents the perceived risks by the community members. The model starts with institutional trust where the participants expressed high level of trust for government followed by scientists and least trust for politicians and some of the key concerns are noted above. The next segment is safety related issues due to possible environmental and health hazards. Lack of safety data led to queries about regulation issues whereby participants demanded more tests and research and for these products to be certified as safe by the regulatory agencies. Other themes include functionality of the nano-enabled device referring to what type of contaminants can be removed and at what rate and whether the nanomembrane can be replaced when it reaches its shelf-life. The participants also commented on trust in the technology where they asserted that filtering water is one aspect of water treatment so the possibility of other contaminants remaining in the water was the biggest concern. Concerns about cost were also prevalent including device lifespan, material used, capacity and even effort needed to operate the device. Socio-economic concerns about whether there will be job opportunities for the uneducated people.

5.4 Similarities, differences, misconceptions and gaps which exist between experts and laypeople

According to Porter and Dessai (2017) funding for scientific research is nowadays often directed as work and innovations with visible positive impacts on human and environmental wellbeing. Qu *et al.* (2013) asserted that for nanotechnology to thrive and have positive impacts the efficiency of the nanomaterials, cost effectiveness, potential toxicity and social acceptability must be considered. Beyond this however, public acceptance is key. Unfortunately, the perceptions of experts involved in innovations and development of the field, and those of the intended users, are often not aligned. Where this occurs, consumer backlash can significantly reduce chances of success (Cormick 2009). As such, effective adoption of any technology requires some sort of alignment between experts and consumers' perceptions. Public involvement is important to inform, exchange knowledge and receive feedback from the public (Kamarulzaman *et al.* 2017).

This study has revealed that nanotechnology experts and laypeople have shared values. Both groups perceived more benefits than risks with respect to the use of nanomaterials in water treatment, even though laypeople expressed concern about unknown risks. These results agree with those reported by Besley *et al* (2008), Scheufele *et al.* (2007) and Kamarulzaman (2017) where laypeople perceived higher risk than experts. Similar to the findings of van Djik *et al.* (2017), experts in this study seemed to base their judgements on knowledge and experience whereas laypeople were more influenced by psychological factors in their perceptions. Bearth & Siegrist (2016) also suggest that while experts accept technologies despite uncertainties, laypeople want full and accurate information about the possible benefits and risks. To attain some sort of balance, Bearth

& Siegrist (2016) suggest clear risk communication to laypeople about risks and benefits is necessary to address uncertainties and misconceptions. This balance is vital for a harmonized progress of nanotechnology.

Importantly, even though the themes from experts and laypeople were broadly similar, a deeper look at the data revealed that the concepts under each theme were different. Cost, for instance, was conceptualised very differently by experts than it was by laypeople. Across themes too, the data show that experts were more concerned about hazards to humans and the environment, whereas laypeople were more concerned about cost of the nanomaterials and the filter.

Statistical analyses of the themes showed that the views of the experts and laypeople diverge significantly except for legislation and socio-economic impacts. The divergence of the two categories have been demonstrated in previous studies (Bearth and Siegrist 2016; Scheufele *et al.* 2007). However, the results obtained for legislation and social benefits were not expected as they showed alignment between expert and laypeople. These results are surprising because laypeople are the ones who were more concerned about additional benefits that the technology promises to offer, that is job opportunities, training to meet the shift in skills required and potential business ventures for the private water suppliers. In terms of legislation, experts had more views about the legislative issues which can hinder the progress of this technology and the different experts pointed out the reasons for the long lag-time when it comes to application and the barriers to policy development.

Both groups, however, conceded that regulations were essential. Experts presented factors affecting the dearth of regulation: the relative novelty of nanotechnology in the country, and limited funding for research needed to provide data for policymaking. However, Abbott *et al.* (2006) caution that "*while the lack of regulation has the potential to undercut public confidence in this nascent technology, premature and inappropriate regulation could impede the development of socially beneficial products and applications*" (Abbott *et al.*, 2006, pg. 1). When looking at the response by two of the largest economic performers EU and US, they have come up with diverging methods to regulatory decisions about nanotechnologies, with EU working on introducing official nanotechnology characterization and nano-specific regulations, contrary US has a 'wait and see' policy (Rodine-hardy, 2016). Nevertheless, a balanced trade-off between stricter regulation and cost is key (Siegrist, 2010) as stricter regulation may result in limited development of the field and high costs of products. The expensive price of the products is predicted to cause a "nano-divide", excluding those that would benefit most from the technology.

There is misconception that water is an infinite resource, naturally and abundantly available and that water is not recycled meaning the solutions promised by nanotechnology are not needed. This proves that education about water resources and their treatment is still needed which might influence the attitude and behaviour of people towards water resources. In addition, laypeople showed biggest concern about possible leaching into the environment and possible ingestion by people and experts offer solutions such as immobilization of the nanomaterials to prevent any escape into the wider environment.

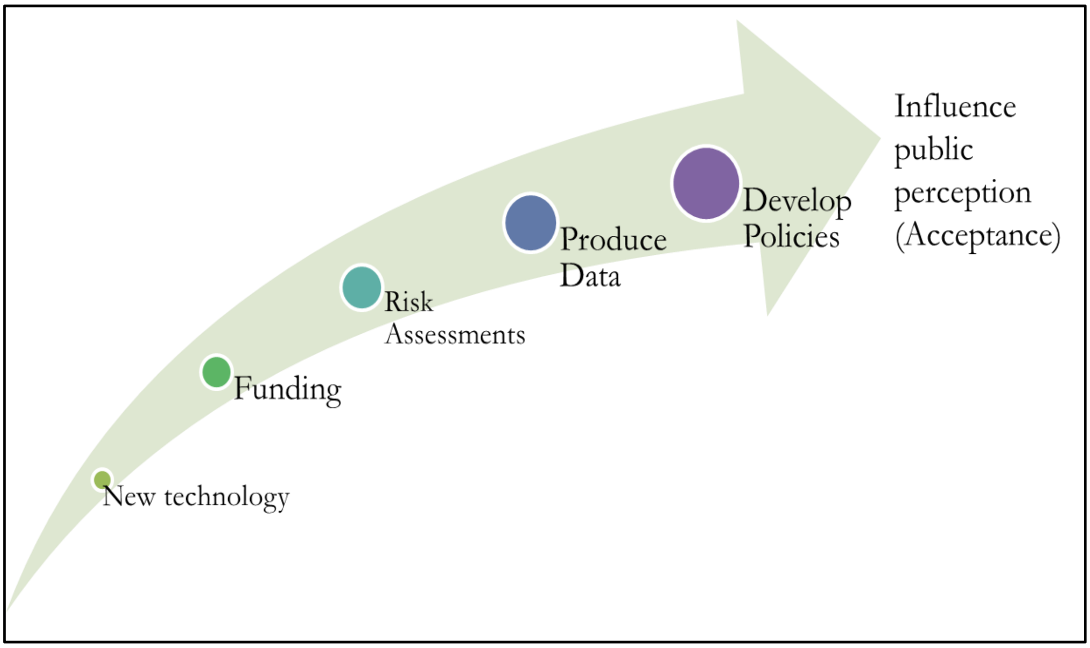


Figure 5.3: The roadmap to increase public acceptance of nanotechnology

Figure 5.3 is an illustration that since nanotechnology is an emerging technology, more funding is needed to do research and risk assessments. The risk assessments will then produce data which will enable development of policies and when there are policies and regulations governing use of nanomaterials, with benefits and risks clearly defined, there will be positive influence on public acceptance therefore uptake of the technology will be increased.

This study provides additional evidence with respect to the influence of psychological, social factors and intervening factors such as economic status and importance of the application to perceptions related to new technologies. Contrary to previous studies, the results show that there is high trust for government and these results can be assumed to be related to the relatively poor economic status of the country and high unemployment rate in the area. The state of economy led to high reliance to the government for the free provision of the nano-products or subsidy. There is high optimism for the technology due to important outcomes of the application as it will alleviate water scarcity faced by the country and globally. This study has demonstrated for the first time the influence of race on perceptions of the people where participants demonstrated low trust on black people compared to white people. This information can be used to develop targeted intervention aimed at harmonized progress of the technology as public acceptance is one of key contributors to development of any new innovation to avoid backlash.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Summary of key findings and conclusion

The limitations on water access in Bekkersdal are apparent and these pose threats to human rights to safe and clean water. Liefferink & Wepener (2017) asserted that the water inadequacies can be noted from both water service delivery and environmental viewpoint. In this study the following key findings have been found: Firstly, knowledge of nanotechnology has limited influence on people to form opinions and acceptance. 98% of the participants claimed no knowledge of nanotechnology, however, they were still able to express their views based on the information provided and using their own knowledge of science and technologies. Secondly, the study has established the importance of having a two-way dialogue between the experts and the public with experts being the pioneers, manufacturers and developers of policies and community members as the intended beneficiaries of the opportunities promised by this technology. The experts and laypeople developed similar themes but diverged in their priorities with experts concerned about safety and laypeople more about the cost. This view shows that experts have their assumptions which do not always align with the expectations of the laypeople. Thirdly, nanotechnology representations amongst the experts displayed heterogeneity which might have been influenced by background and experience with the nanomaterials. The experts in research and manufacturing although they were concerned about threats to the environment and human health, they were more optimistic about the opportunities that nanotechnologies present. Measures are proposed to mitigate the threats to the environment and people which include immobilization and avoiding use of toxic metals. However, there are safety measures which have not been accounted for including disposal of the nanomaterials.

Policy and regulation apprehension were key for both experts and laypeople as this affects the progress in terms of implementation. The extent to which nano-enabled products must be regulated remains unclear. Key contributor to regulation issues is funding for conducting more research on nanomaterials as each one of them requires its own risk assessment. Laypeople are optimistic about nanotechnology as it will alleviate the water issues experienced in the area and in South Africa as a whole, however, they were more worried about the non-existence of legislations, afraid that it will create problems due to lack of safety and approval by regulatory agencies. One of the more significant findings to emerge from this study is the effect of race in terms of institutional trust. Secondly, minor number of the laypeople expressed less trust for the nanomembrane to be able to remove all the different contaminants using a simple point of use device. Safety, cost and institutional trust emerged as reliable factors that influence the perceptions of the public about uptake of new technologies. The following conclusions can be drawn from the study that all the themes are interconnected as legislation depends on risk assessments and safety information which must be produced by liable institutions and the extent to which nano-enabled products are regulated impact the cost and trust in the technology thereby influencing acceptance.

6.2 Key recommendations

Based on the findings of the study the following recommendations are made:

- Firstly, nanotechnology courses are currently offered in post-graduate programmes only, this means people who do not have higher education cannot participate in nanotechnology development as there is shift in skills required and this introduces risk of job losses for most people.
- Nanotechnology application must be included in the curriculum of lower education enable adaptation to the 4^{th} industrial revolution as the technological revolution will involve shift in skills required meaning the current curriculum will not be relevant to work with these new technologies. This calls for new strategies and training to make sure people have skills required to function in 4^{th} industrial revolution which nanotechnology is part of.
- In Bekkersdal there is lack of proper infrastructure associated with poor planning and possibly use of cheap material, however, it is also influenced by the behaviour of the residents as some deliberately break the taps. To counter the breaking of taps in the area there must be basic education programs at school and community awareness programmes about the value of maintaining the infrastructure and saving water.
- More investments are needed for nanomaterials research to generate data in order to fill the gap about the unknowns and concerns currently existing. In addition, investments must be injected into bursaries for undergraduates and post-graduates so that more research can be conducted thereby generating relevant data and to support innovative entrepreneurship to enhance economic empowerment and local businesses to avoid importing all the products from other countries. This will ensure that the government has the skills and resources required to work with the nanomaterials.
- Collaborative effort between the government, private sector and general public must be initiated because multi-disciplinary and multi-institutional cooperation will ensure good progress, indigent households and polluted water resources require a multi-party

participation meaning all the role players must come together find a solution on how to effectively use nanotechnology whilst protecting the environment and people.

- More awareness programmes about water issues and importance of nano-solution as it will help even in adapting the strain introduced by climate change. Adaptation to climate change requires new strategies to provide new sources of water and water reuse might be the only option and robust water treatment methods will be a necessity and nanotechnologies provide these opportunities.

6.3 Future research

Based on the results more research is required as there are still gaps in knowledge about nanotechnology application in drinking water treatment as nanotechnology is still in infant stage in developing countries with many loopholes and unknowns that still need to be addressed. Future research should continue investigating the perceptions by different role players and investigate changes overtime and the influencers to these attitude changes. More community engagements are needed to increase knowledge of the factors that influence nanotechnology particularly in Africa as these perceptions are influenced by the context and socio-geographic setting of the participants. This study shows that one of the key hindrances in the progress of nanotechnology is dearth of policies and regulations and future work could investigate policy issue around nanotechnology. Although institutional trust is well established as one of the key influencers of public perception, it would be interesting to look at the controversy that exists around trust for government agencies. Previous studies showed less trust for government whereas in this study there was more trust in government departments. It is currently not clear if the trust was based on protection from the possible hazard or because there is more reliance on government to provide these filters. Future research could include the investigation of the feasibility of using nanotechnologies in South Africa considering the state of economy, social aspects and technical skills as nano-solution can aid in decreasing the vulnerability or in enhancement of the resilience of human systems to the effects of climate change.

APPENDICES

Appendix A: Nanotechnology for Water Treatment information sheet

Nanotechnology for Water Treatment

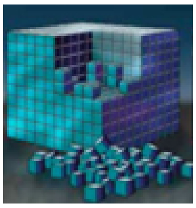
Information Sheet

The problem

- Water in the Donaldson dam contains **high concentrations of toxic metals** due to previous mining activity. This means that the water may not be safe for drinking and other domestic purposes.
- Luckily, various technologies, including nanotechnology are available for treating and purifying water contaminated in this way.

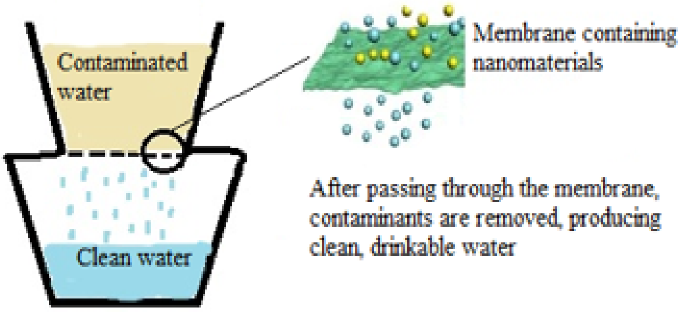
Nanotechnology in water treatment

- In water treatment, the application of nanotechnology involves using very tiny materials, sometimes **10,000 times smaller** than a fine grain of **sand**.
- Because they're so small, these materials, which are referred to as nanomaterials, have very **high surface areas and high reactivities**, which makes them more efficient than larger materials in the removal of pollutants from water.



How are nanomaterials used in water treatment?

- The use of nanomaterials in water treatment usually involves **incorporating them in membranes** made from polymers. This helps to prevent their escape into the treated water.



Some **advantages** of using membranes containing nanomaterials	Some **disadvantages / risks** of using membranes containing nanomaterials
• Membranes containing nanomaterials are more **efficient at removing the toxic metals** from water than membranes without nanomaterials in them; • These membranes also last longer because nanomaterials reduce **fouling** (pore blockage), which means that they will need to be replaced less often.	• Small amounts of nanomaterials may escape into the treated water, but these do not pose severe health risk to humans; • Membranes containing nanomaterials may be more expensive than those without.

Appendix B: Participant Information Sheet

University of the Witwatersrand
1 Jan Smuts Ave
Braamfontein
Johannesburg
2000

Dear Sir/Madam

I am Siyasanga Zinzi Gxaba and I am Masters Student in Geography at the University of Witwatersrand. As part of the research I have to undertake a research project, and the topic is: **Public perceptions of nanotechnology-enabled water treatment: A study of mining community: Bekkersdae, South Africa.** The aim of the study is to investigate public perceptions of nanotechnology-enabled water treatment by a community currently consuming acid mine drainage-contaminated water for drinking purposes.

As part of this project I would like to invite you to take part in a discussion about this technology and this will take about 45 minutes- 1 hour of your time. With your permission, your responses will be recorded using a digital device.

You will not receive any direct benefits from participating in this study, and there are no disadvantages or penalties for not participating. You may withdraw at any time or not answer any question if you do not want to. The interview will be completely confidential and anonymous as I will not be asking for your name or any identifying information, and the information you give to me will be stored securely and not disclosed to anyone else.

If you have any questions afterwards, feel free to contact me. This study will be written up as a research report. If you wish to receive a summary of this report, I will be happy to send it to you.

Yours sincerely,
Siyasanga Gxaba
Siyasanga Zinzi Gxaba, 1764050@students.wits.ac.za , 0734339117
Supervisor: Dr Anita Etale, aetale@gmail.com , 011 717 6081

Appendix C: Consent Sheet

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

School of Geography, Archaeology and Environmental Studies

Private Bag 3, Wits 2050, South Africa Enquiries: **GEOGRAPHY:** TEL: +27 11 717-6503 •
ARCHAEOLOGY: TEL: +27 11 717-6045 •
http://www.wits.ac.za/geography/

Public perceptions of nanotechnology-enabled water treatment: A study of mining community: Bekkersdal, South Africa

I ……………………………………….. agree to participate in this research project. The research has been explained to me and I understand what my participation will involve.

	YES	NO
I agree that my participation will remain anonymous	☐	☐
I agree that the researcher may use anonymous quotes In his research report	☐	☐
I agree that the interview may be audio recorded	☐	☐

…………………………………… (signature)
…………………………………… (date)

APPENDIX D: Ethics Clearance Certificate

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)

RI 4/49 Gxaba

cc: Supervisor: Professor D Simatele PROTOCOL NUMBER: H18/07/07

CLEARANCE CERTIFICATE

PROJECT TITLE	Public perceptions of nanotechnology-enabled water treatment: A study of mining community: Bekkersdal, South Africa
INVESTIGATOR(S)	Miss S Gxaba
SCHOOL/ DEPARTMENT	Geography, Archaeology and Environmental Studies/
DATE CONSIDERED	20 July 2018
DECISION OF THE COMMITTEE	Approved
EXPIRY DATE	07 August 2021

DATE 08 August 2018

CHAIRPERSON (Professor J Knight)

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and ONE COPY returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. I agree to completion of a year progress report.

______________________   _____/_____/_____

Signature   Date

Appendix E: Bekkersdal Community Meeting

Topic: Nanotechnology use in water treatment

Facilitator: Zinzi Gxaba (Researcher)

Duration: 3 hours

Date: 07 August 2019

Time	Agenda Topic	Desired Outcome
09:30	Registration	Get the number of attendants
10:00-10:05	Introduction	Define goal of the meeting
10:05-10:30	Define context	Present results from the interviews
10:30-10:45	Brainstorming & confirmation of the results: Community members	To ensure that the results were correct and true representations of the participant's perceptions
10:45-11:00	Presentation of the bulk water treatment process	To give clear understanding of water treatment process as many participants complained about not knowing anything.
	Coffee Break	
11:15-11:30	Introduction of nanotechnology use in WT	To give a brief background of nanotechnology and why it is important
11:30-12:00	In-depth nanotechnology information session: Mr Sithembele Zikalala (PhD Candidate)	More in-depth knowledge and understanding
12:00-12:15	Q&A Session	Give participants chance to clarify, add any other emerging information, test for agreement and willingness to pay
12:15- 12:45	Wrap up	Repeat initial goals, review decisions that have been made & thank participants for attending
	Refreshments	

NANO-TECHNOLOGY WORKSHOP

ATTENDANCE REGISTER

HELD AT THE BEKKERSDAL COMMUNITY LIBRARY (DATE: 07/08/2019

	NAME AND SURNAME	ADDRESS/EMAIL ADDRESS	CONTACT DETAILS
1	Sharon Gumbo	[illegible] Xuma ST	0782[illegible]
2	Ntombiza Magocoba	CC 39 Mandela Sq	0735618355 [illegible]
3	[illegible] Magaladeng	[illegible] Street	0631994 [illegible]
4	Tsepiso Makgomathe	1552 Kampikomme Str	0745168303 [illegible]
5	Thato Moruane	1350 Kampiloname STR	0787560350 [illegible]
6	Rose Mase	1350 Kampilomane STR	0717891597 [illegible]
7	Sibongile Sitsche	2537 Mosali str	0733678931 [illegible]
8	Zanele Silumo	" "	0787279593 [illegible]
9	Lydia Maqaikele	2940 Modiriso Dikile Str	0726714568 [illegible]
10	Rose Siwela	X208 Silver city	016 [illegible]
11	Tebogo Modise	2864 Godla str	0796960042
12	Lucky Tladi	2615 Nyanga ST	0766625061
13	Lungile Nkosiyane	[illegible]	0763186341 [illegible]
14	Thato Motlhala	3115 Nkosi street	063 890 17 34
15	Bongani Ngomo	1328 Panya-Panya S	073 656 4422 [illegible]
16	Gomolemo Kemong[illegible]	103 Sekpetlhema	071 980 4595
17	Mereetsa Mdlin	m70@mereetsmediagrp.	
18	Mabel Matlou	1[illegible] Godla Str	0832211696
19	Sophie Moratarato	1394 Godlo Str	0832211696
20	Sipho [illegible]	192 Nosi[illegible]	078722 3737
21	Nhosinathi Mgmeka	955 Monroe STR	071 907 2827
22	Lehlohonolo [illegible]	523 Monroe STR	071 847 7013
23	Nontando Ntshiba	525 Monroe STR	0632557727
24	Vuyiswa Sivisi	745 Rabanye STR	063 4386 059 [illegible]
25	[illegible]	2702 Dinnesi STR	0799911984 [illegible]
26	Lindiwe Hlathwayo	143 Hlamo eo [illegible]	073 6546179 [illegible]
27	Lesego Matlhong	2932 Mosidi Street	081 627 7695

	Names / Surnames	Address	Contacts Details
28	Mamoleto Rabuso	K 39	0632254798
29	Otshabiseng Tsotetsi	Z19	0730009973
50	Mpho & Nhlanhla	2632 Cind Street	083 421 5578
51	Mpho Mmakou	5397 Monroe STR	0715714394
32	Lebogang Sehler	802 Nyanye STR	0631276066
33	Tebogo Nabo	837 Xuma STR	060 34 92975
34	Lebogang Fanele	U31 Grootdorp	0535485194
35	Nokuthula Sindiso	3154 Madisoatsile	0783823324
36	Phiane Lesikan	2718 Polao	
37	Malose Sejoe	839 Xuma STR	0732497 2685
38	Rulane Ramotsheta	2099 Rametla Street	060 095 7626
39	Cecilia Molls	247 Xuma Street	0736577127
40	Dipua Phale	579 Hullet Street	072-1686 393
41	Mavis Pheko	3121 Nkosi STR	0711650255
42	Jermina Kesi	175 Hosiz	078 2438 930
43	Nongoele Nono	2551 Mosidi STR	0619607002
44	Tebogo Sebelah	2545 Mosidi STR	076 077 2650
45	[illegible]	[illegible] STR	064 804 8530
46	[illegible] Lukas	3117 Nkosi Str	0733783409
47	Phillip Motobeng	[illegible]	0721885527
48	Samuel Nyamba[illegible]	1372 Mosiane STR	—
49	Maria Dunjani	1447 Kottoetse	0781366996
50	Martha Kumalo	1305 Borwa	0737140550
51	Rosina Segatlhelo	431 Selopethlegwe	0795416372
52	Buma Gakane	1339 Mokeme Str	0770719451
53	Tsepiso Hlalele	3161 Modisaotsile Str	0638672304
54	Mandla Mahonera	3015 Selopethemo Str	078 6012 952
55	Welile Ngomo	1528 Panya-Panya Str	073 7325 693
56	Refilwe Mabota	2581 Mosidi Street	0817899657
57	Rosinah Mogashu	3073 [illegible] St Street	[illegible]
58	Ntswaki Mathabe	2951 [illegible] Street	[illegible]
59	[illegible] Nkotsoe	895 Johnson Str	0823647189
60	Elizabeth Monnela	2990 Mosidi Str	0635405 3[illegible]
61	Charles Rammutle	1365 Borwa	078 6001 959
62.	Alfred Mhlehengwe	Bekkersdal Library	072 426 3642

Appendix F: List of Personal Communications

Experts

Code	Position	Department	Company	Date
Nano-researcher A	Nanotechnology product manufacturer & researcher	Nanotechnology research unit	Council for scientific and industrial research	08 August 2018
Researcher B	Nanotechnology Researcher	Physics Department	University of the Witwatersrand	31 August 2018
Nano-toxicologist A	Toxicologist	Nanotechnology application	NIOH	28 October 2018
Toxicologist B	Toxicologist	Health & safety	CSIR	30 August 2018
Researcher C	Academic/ Researcher	Nanotechnology water research unit	University of South Africa	13 September 2018
Researcher D	Researcher & entrepreneur	Nanotechnology research unit	Mintek/ UNISA	31 August 2018
Municipal water treatment official	Specialist	Water Treatment Plant	Rand Water	20 Sep 2018
*	Civil engineer	Water works	City of Johannesburg	11 Nov 2018
*	Environmental Activist	Management (CEO)	Federation for sustainable development	08 Aug 2018
*	Municipal water treatment official	Water works	Rand Water	10 Sep 2018
*	Nurse	Health	Bekkersdal East clinic	15 Sep 2018
*	Nurse	Health	Bekkersdal West Clinic	28 Sep 2018

***Not quoted in text**

Appendix G: Experts interview guide

Public perceptions of nanotechnology-enabled water treatment: A study of mining community: Bekkersdal, South Africa.

Semi-Structured Interview

I would like to ask you few questions about the origin of nanotechnology, its application, benefits and risks and progress of its adoption to purify contaminated water.

What are your concerns about application of nanotechnology in water treatment?

What are the barriers and side effects towards use of this technology?

Is it clear for use by the general public?

How do you account for concerns which include detectability of the nanoparticles, maintenance and will the unskilled people of the country benefit from it as I assume it requires skilled labour to operate?

Are there any risk assessments currently undertaken regarding the use of this technology?

Are there strategies or preparedness techniques put in place in case nanotechnology introduces new challenges?

Are there regulations or policies that govern the use of these materials both national and international level?

In which stage is utilisation of nanotechnology in South Africa?

Would you say nanotechnology is a solution to the water contamination problem when looking at its benefits and possible risks?

Bibliography of personal communications with community members

• Interview with an unemployed female, aged between 40-49 years, on the 30 January 2019 at Holomisa informal settlement, Bekkkersdal

• Interviews with a male, employed part-time, aged between 30-39 years, on the 12th February 2019 at the settlements NGO site, Bekkersdal

• Interview with a male, employed part-time on the 5th February 2019 at Uptown, Bekkersdal

• Interview with a Bachelor of Commerce graduate on 28 February 2019 at Spook town, Bekkersdal

• Interview with community activist and politician on the 15th February 2019 at Uptown, Bekkersdal

• Interview with Human Resource student on the 5th February 2019 at Uptown, Bekkersdal

• Interview with an unemployed female on 30th January 2019 at Silver city, Bekkersdal

• Interview with a male working in an NGO on the 2nd February 2019 at Skierlik, Bekkersdal

• Interview with a retired male teacher on the 18th February 2019 at Uptown, Bekkersdal

• Interview with former miner on the 20th Feb 2019 at Holomisa informal settlement, Bekkersdal

• Interview with a government employee on the 26th Feb 2019 at Spook town, Bekkersdal

• Interview with a retrenched miner on the 3rd Feb 2019, Thambo informal settlement, Bekkersdal

• Interview with a retired miner, on the 15th Feb 2019, Mandela section, Bekkersdal

• Interview with the councillor, on the 28th Feb 2019, Bekkersdal Library, Bekkersdal

• Interview with a traditional healer (sangoma) on the 28th Feb 2019 at Seriti NGO, Bekkersdal

• Interview with a traditional healer on the 29 Feb 2019 at Westonaria Clinic

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