resource management depends on the partnership/integration of citizen at local institutional level and relevant institutions. Therefore, by means of the endorsement of the citizen science framework in implementation planning, this study explores how the role of citizens at local levels is fundamental to monitoring of groundwater levels and furthermore to the planning of a collaborative groundwater monitoring network.
The research question is what are the current challenges in terms of the implementation of the monitoring of groundwater levels within the institutional setting and to what extent can citizen participation lead to the planning of a collaborative monitoring of groundwater levels?

1.4 STUDY AIM

1.4.1 Aim

The main objective of this study was to use West Coast to demonstrate the role of citizen science in the planning of a collaborative monitoring of groundwater levels.

1.4.2 Objectives

The detailed objectives of this study are to:

1. Establish current practices of monitoring of groundwater levels based on the institutional arrangement.

2. Determine current gaps and barriers in terms of the implementation of monitoring of groundwater levels.

3. Design a collaborative action plan for the monitoring of groundwater levels.

1.5 SIGNIFICANCE OF STUDY

The global groundwater abstraction rate has at least triple over the past 50 years and continues to increase at an annual rate of 1 to 2% (UNESCO, 2012). It is estimated that 75% of Africa's population uses groundwater as their main source of drinking water (UNEP, 2010 as cited by UNESCO 2012).

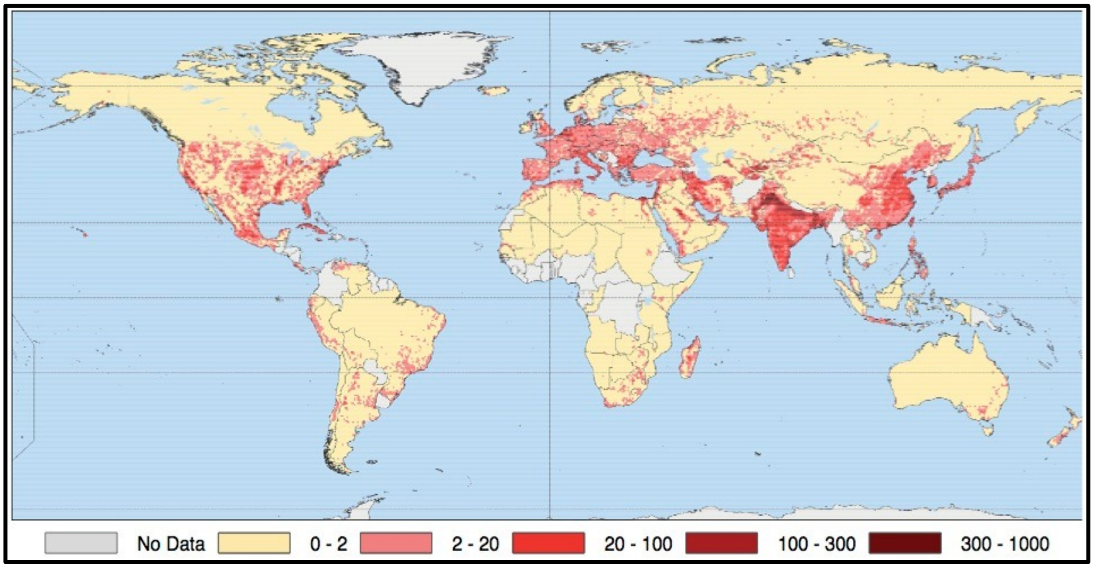

Figure 2: Map of the intensity of groundwater abstraction by the year 2000 (in mm per year). Source (UNESCO, 2012)

South Africa as a semi-arid region with an average rainfall of about 600mm is currently faced with increasing population, socio-economic, industrial growth, etc. According to DWS, (2016) groundwater contribute 15% of all water resources been used in South Africa and a major source for irrigation (66%). Similarly, the study area (West Coast) depends largely on groundwater for irrigation and source of water supply for local communities (especially in communities without surface water supply infrastructures). More so, aquifer such as the Langebaan Road Aquifer System located in the West Coast remains crucial for the supply of groundwater to augment the water supply system of City of Cape Town during periods of drought (City of Cape Town – online). Eventually, without an adequate groundwater resource management system, the chances of water shortage are high and the impacts will be enormous on agriculture dependent sector, drought prone area and rural communities that depend solely on groundwater.

Therefore, responding to the challenges in groundwater resource management and the inadequate implementation plan for the monitoring of groundwater levels (refer to section 1.1); this study is significant to enriching the understand of management of groundwater resources in the study area that is typically drought prone. Furthermore, this study will increase the knowledge of water resource managers, hydrologists and researchers on collaborative planning for the implementation and management of groundwater resources. The study also provides an understanding of the current gaps and barriers in groundwater resource management.

At local – community level, this study is considered significant to groundwater users, community members and the public at large, as it teaches and share knowledge regarding their roles and responsibilities in the management of groundwater. Eventually, the knowledge acquired from this study will be significant to broadening the understanding of the role of citizen science as an emerging and multidisciplinary approach to the management of groundwater resources.

1.6 CONCEPTUALIZATION OF STUDY

Conceptualization of this study is founded on extensive review of literature conducted in the key areas that aligns with the objectives. Citizen science is cross – disciplinary (Pettibone, Vohland & Ziegler, 2017). Therefore the study will adopt concepts across humanity and sciences amongst other disciplines – in the development of methodology and analysis. The theme used included implementation of monitoring/groundwater management, challenges to monitoring of groundwater, management, governance and institutional framework, to name but a few.

Through a systematic review of the existing challenges, pertinent solution to research question became clearer. Number of authors has released publications to identify key challenges to the monitoring of groundwater levels and management of groundwater resources (Knüppe, 2011; Reimann, Chimboza & Fubesi, 2011; Pietersen et al., 2012). These authors amongst others such as Anderson, Karar & Farolfi, (2008) and Wijnen et al., (2012) have established and demonstrated that lack of adequate implementation at local levels are substantially as a result of inadequate community and relevant stakeholder participation and the lack of collaboration between groundwater institutions. However, due to the scientific/technical and hydrological characteristics of groundwater resource, developing an adequate action plan demand recognizing the linkage between science and governance (Knüppe 2011; UNESCO 2012; Kulkarni, Shah & Shankar, 2015).

Literature on world best practices on groundwater monitoring shows innovative implementation plans aimed at achieving effective citizen participation must narrow the knowledge gap between local citizen and scientist at the same time should be integrated into the broader institutional framework (Jousma et al., 2006; Jørgensen & Stockmarr, 2009; Sophocleous, 2010; UNESCO, 2012). Eventually, this implies that there is a strong conceptual link between citizens, scientists and governance setting/institutional framework. The case study by Buytaert et al., (2014) demonstrated that citizen science framework provides an innovative solution to hydrological monitoring and Jollymore et al., (2017), demonstrated the success made by the citizen science framework in environmental monitoring, policy related issues and governance. These drew the researcher's attention to relevance of the citizen science framework in developing an implementation plan.

However, with an aim of developing a collaborative action plan, the research during literature review realized that there is an ambiguity in the definition of "collaboration" and the are no clearly adopted collaborative framework in most citizen science framework on groundwater monitoring, therefore based on the "collective management and participatory" framework designed by Wijnen et al., (2012) the research developed collaborative drivers for analyzing collaboration within case study of groundwater monitoring at local-community levels. Shirk et al., (2012) and Pareja et al., (2018) demonstrated the amalgamation of action and participatory frameworks respectively with that of citizen science, in resolving fundamental groundwater management issues.

1.7 STUDY AREA

1.7.1 Geographical Location of West Coast and economy

The West Coast Municipality covers an area of 31,119 km^2 and is located along the Atlantic coast of the Western Cape, Province of South Africa (Municipalities of South Africa - online). It is comprised of five local municipalities: Swartland, Bergrivier, Matzikama, Cederberg and Saldanha Bay; with Moorreesburg as the seat of the District. The West Coast stretches for over 400km from north to south; sharing a border with the Atlantic Ocean on the West and the Swartland on the east. The largest towns in the district are Vredenburg and Saldanha and other major towns include Langebaan, Hopefield, Darling, St Helena Bay, Paternoster, Velddrif and

Yzerfontein. The West Coast lies within the geographical location of 32°30′S 18°45′E.

Figure 3: Map of West Coast showing Municipalities and Administrative center. Source (westcoastdm.co.za)

According to the Municipalities of South Africa (online), economics sectors comprised of finance, insurance, real estate and business services (24%), manufacturing (18%), agriculture, forestry and fishing (15%), wholesale and retail trade, catering and accommodation (13%), general government (11%), transport, storage and communication (9%), construction (5%), community, social and personal services (4%).Currently, the population of West Coast is about 391 766

1.7.2 Hydrogeological Setting

West Coast region is formed by basement (Malmesbury Group and various plutons of the Cape Granite Suite), overlain by the Sandveld Group, which is laterally continuous over large areas, and also reaches significant thicknesses, (DWS 2017). It consists of four main aquifer systems namely the Langebaan Road Aquifer, Elandsfontein (Elandsfontyn) Aquifer, Adamboerskraal Aquifer and Grootwater

Aquifer units. This region has limited surface water and relatively low rainfall (DWS, 2017).

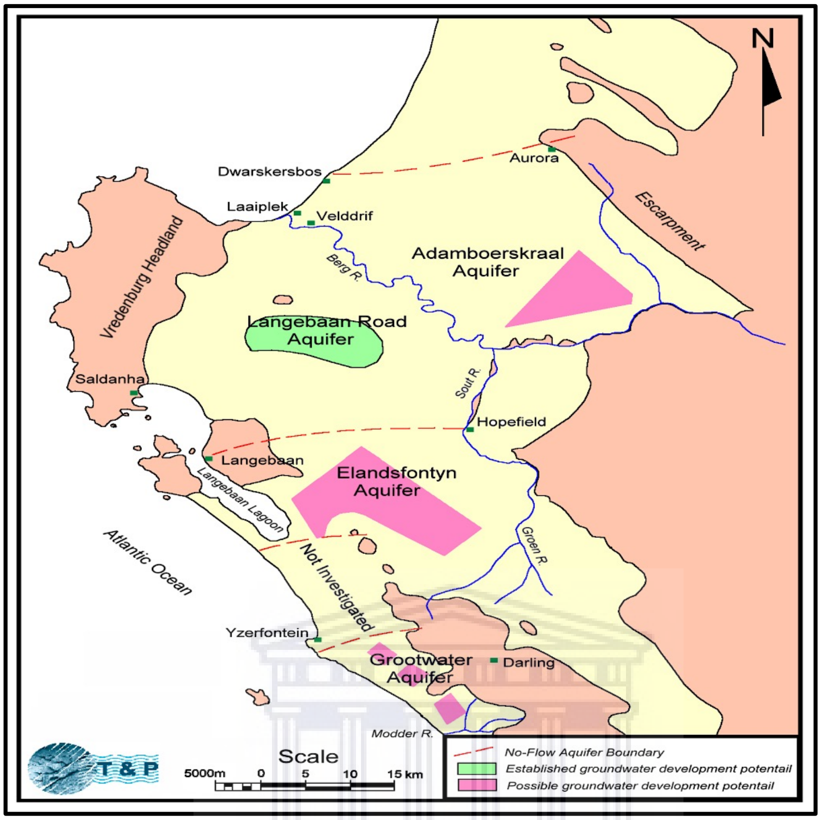

Figure 4: *Extended map of West Coast showing major aquifer units.* Source (Du Plessis, 2009)

The Geological-groundwater survey of the West coast began as far back as 1972, initially aimed at establishing industries in the Mamrewhile. Adamboerskraal Aquifer system near Aurora shows an association with the Table Group Aquifer and the Malmesbury contact among various faults and contacts (Vermaak, Havenga, de Haast, n.d.). Elandsfontein Aquifer and Grootwater Aquifer are separated by a groundwater flow divides but are in hydraulic connection (DWS 2017).

Most productive aquifers of the Langebaan Road Aquifer System are found in the Cenozoic sediments overlying the bedrock were sediments can be as thick as nearly 80 meters (Vermaak, Havenga, de Haast, n.d.). Langebaan Road Aquifer systems, Elandsfontein Aquifer system and the Adamboerskraal Aquifer system are the three most significant Aquifer systems in the West Coast (DWAF 2008b). The systems comprise of unconfined, aquitard and confined aquifers of various thickness. Table

1.1 presents an outline of the major geological formation and members with properties relating to the type and thickness of aquifers with the system.

Aquifer Unit	Lithostratigraphic unit		Aquifer Type	Thickness (m)
	Formation	Member		
Langebaan Road Aquifer system	Bredasdorp Elandsfontyn	Langebaan Limestone Clay Sand and Gravel	Unconfined Aquitard Confined	10-20 10-20 40-60
Elandsfontein Aquifer System	Bredasdorp Varswater Elandsfontyn	Springfontyn Noordhoek Clay Sand and Gravel	Unconfined Aquitard Aquitard Semi-confined Aquitard Confined	5-20 5-60 0-20 0-30 10-30 10-30
Adamboerskraal Aquifer Unit	Bredasdorp Elandsfontyn	- Clay Sand and Gravel	Unconfined Aquitard Confined	10-20 20-30 20-40

Table 1.1: *Hydrostratigraph of three major aquifer systems in West Coast.* Source **(**DWAF, 2008b citing Timmerman, 1985b)

1.7.3 Previous studieson groundwater resource management

There are few studies conducted in terms of groundwater resource management in the West Coast region. Plessis (2009) established that the earliest record of monitoring that took place was in the 1980s as a result of industrialization and the need to source an additional source of water to meet the industrial uses. Before then the Berg River was the main supply of water to West Coast therefore groundwater abstraction was required as a supplementary source.

Based on hydrogeological analysis and management intent to establish the Berg Catchment, a number of models such as the Langebaan Road and Elandsfontein Aquifer System Models Aquifer; were considered for evaluating the groundwater availability (DWAF 2008b). The study focused on the management of groundwater abstraction. This is likely due to the fact the study was a water availability assessment study. In 2012, the report to classify the water resource of the Olifants-

Doorn Water Management Area was conducted (DWA 2012). The key objective of the report was to identify how the recommendation of a Management Class, Reserve, Resource Quality Objective, Catchment Management Strategy and allocation of schedules will impact on specific group of people. The Management Class of an aquatic ecosystem will reflect the future desires condition or health of the system, and will be used to guide the amount and quality of water to be reserved for that ecosystem. The West Coast has limited groundwater management studies and this concurs with Knüppe & Pahl Wostl, (2013) view; that the current groundwater regime lack analytical framework

1.8 RESEARCH LAYOUT

This study is made up of five chapters, with the following layouts:

Chapter 1: This chapter provides background of study, problem statement, thesis statement, study aim, significance of study, conceptualization of study and the study area.

Chapter 2: This chapter provides literature review as well as conceptual and theoretical framework of the study.

Chapter 3: This chapter provides the research design and methodology in addition to the data collection and analysis methods. It also presents the limitation and ethical consideration.

Chapter 4: This chapter presents the result and discussion.

Chapter 5: This chapter draws conclusion to the study as well as presenting recommendations.

2. LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews and discuses existing literature, developed in the fields of groundwater resource management, groundwater governance and citizen science amongst other relevant literatures. Section 2.2 presenting standard procedures and technicalities to monitoring of groundwater levels. Section 2.3 reviews current practices of monitoring of groundwater levels based on institutional framework. Section 2.4 focuses on gaps and barriers to the implementation of the monitoring of groundwater levels. Section 2.5 presents an overview of existing implementation plans for the monitoring of groundwater levels, with a focus on institutional roles and Section 2.5 draws to attention on theoretical and conceptual frameworks on monitoring of groundwater levels.

2.2 GROUNDWATER MONITORING

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2.2.1 Monitoring of groundwater levels

Monitoring of groundwater is defined as the regular or routine sampling, analysis and evaluation of one or more elements of the groundwater resource such as quality, quantity and levels for specific management purpose(s) (DWAF, 2008a: DWAF 2010**).**Monitoring of groundwater levels entails the routine collection of data through measurement on groundwater levels on field, followed by storage, analysis and management of such data to provide a record of the response of the water levels in the aquifers (Taylor & Alley 2001).

2.2.1.1 Purpose of monitoring of groundwater levels

Among a list of the purpose of monitoring of groundwater, DWAF (2004a) listed the fundamental purposes as; classifying groundwater resources; assessment and deterring the impact of anthropogenic and non-anthropogenic influences. Nomquphu, Braune & Mitchell (2007) argued that monitoring of groundwater levels is a science-led management aspect, aimed at assessing water resources to resolve the more often competing human need and environmental sustainability. Monitoring of groundwater levels is based on technical, scientifically, socio economic and management goals (Taylor & Alley, 2001; DWAF 2004a; Sehkar et al., 2017).

According to Kumar, 2014, data collected are used to determine:

(a) Impact of groundwater recharge and abstractions.
(b) Monitor groundwater level changes.
(c) Assess depth of water levels.
(d) Detect long-term trends.
(e) Compute groundwater resource availability.
(f) Assess the stage of development.
(g) Design management strategies.

2.2.1.2 Selection of monitoring points

Groundwater resource management depends on a systematic flow of relevant hydrological information (Nomquphu, Braune & Mitchell, 2007); therefore data on groundwater levels are measured in order to capture spatial-temporal variation and dimensions. As such monitoring points are located along aquifers based on hydrogeological consideration. These processes are often conceptualized as selection and frequencies of monitoring (Taylor & Alley, 2001). Selection of monitoring sites supports the acquisition of user specific and relevant information/data (DWAF 2004a; DWAF, 2010). However, while the geographical coverage of monitoring programs is design-specific to deal with adequate spatial representation, groundwater levels monitoring networks are linked to other networks, such as surface water, meteorological, land use etc.

Other factors considered during selection includes maximizing of capacity (human/institutional capacity), avoiding overlapping and irrelevant information, minimizing cost and on the technical side, generating sound scientific understanding of aquifer property in relation to surface-groundwater interaction (DWAF, 2004a, 2004b), effect of natural recharge/net flow, artificial recharge and abstraction (Weaver, Cave & Tamla 2007; Jovanovic et al., 2017; Sehkar et al., 2017).

In South Africa monitoring of groundwater levels are established based on networks, which are classified into four types (DWAF, 2004a):

- National/Reference monitoring: Type 1

  Monitoring is to be conducted on a national scale and monitoring points should be selected to represent ambient groundwater conditions that are not impacted by short-term conditions. The physical measurements are to be conducted by the Catchment Management Agencies, but the collected data must be stored and managed by the central authority and funded by the Department of Water Affairs and Forestry (currently known as Department of Water and Sanitation).

- Regulatory monitoring: Type 2

  Monitor the impacts of the functions and uses of groundwater resources on regional scales to assess the impact of controlled management. Catchment Management Agencies are to play the leading roles. However, the Department of Water Affairs and Forestry Regional offices are expected to take up these role areas where Catchment Management Agencies are not yet established. The funding will be the responsibility of the Catchment Management Areas.

- Purposive monitoring: Type 3

  Monitor specific aspects/issues/functions of groundwater (such as recharge and water balance) and surface water/groundwater interactions. The Catchment Management Agencies will be responsible for the implementation and data management, while the water user, land owner or a person appointed by the user shall undertake the actual data collections. The Department of Water Affairs and Forestry will provide guidance, protocols, and requirements, as well as audit the monitoring undertaken at a local scale.

- Early Warning/Surveillance monitoring: Type 4

  This is short term monitoring to address point-source impacts and will probably be a conjunction between Catchment Management Agencies and Department of Water and Forestry

2.2.1.3 Frequencies of monitoring of groundwater levels

Frequencies of measurement of groundwater levels are one of the most important considerations in the design of monitoring of groundwater levels program(s) and may either be continuous or periodic measurement (Taylor & Alley, 2001). In South Africa, selection of monitoring frequency depends on intended use of data and the rate of response of the aquifer to transient events (DWAF, 2004a). In conception of project design, frequencies are determined by objective of the monitoring project. For instance, there may be need to increase the frequency of monitoring, if there are evidences or signs of increase draw-down on a regular basis as in the case of Surveillance Warning (DWAF, 2004b). According to the DWAF, (2000) as cited by Adelana et al., (2009) and du Plessis, (2009) the frequency of groundwater levels monitoring needs to be assigned on a borehole-borehole basis and should be conducted on a monthly basis.

2.2.1.4 Data quality

Data collection and improved sharing are central to improving the data quality accessibility and exchange. In monitoring of groundwater levels, quality assurance must include the establishment of permanent reference points (datum), permanent filing and comparison of measurement under similar hydrological conditions to identify anomalies as a result of faulty equipment or failing well/borehole structures. Therefore, periodic inspection of well structure and hydraulic testing are crucial to ensure that adequate communication of boreholes structure with aquifers is attained. Adequate communication can be achieved by ensuring that there are no construction defects present and no silting or corrosion of well screen and casing, which could have occurred over time (Taylor & Alley, 2001). This is important to ensuing that data collected on groundwater levels meet desired standards for decision maker to rely upon (Weaver, Cave & Tamla, 2007).

2.2.1.5 Reporting, storage and data sharing

DWA, (2012) noted that data sharing between stakeholders in the South Africa's water sector is insufficient and resulting in inadequate information. Globally, the advancement made in information technology allows for the development of high-resolution groundwater database management systems (DWAF, 2004b; Riemann, Chimboza & Fubesi, 2012).South Africa has developed the groundwater database to enable adequate reporting and storage of data in electronic form. While data on groundwater levels could be collected on log books in the fields the availability of databases allow for such data to be further converted and stored in electronic formats. Such information technology infrastructure, also serves as a platform to easy access, retrieval of needed/specific data as well as the provision of feedbacks. In South Africa, the foundation for all groundwater resource assessment and mapping was the development of the National Groundwater Database (NGDB) in 2004. However, it was realized that information from private drilling were not been captured in the National Groundwater Database. Thus in 2009/2010, the National Groundwater Archive was developed as a more accessible and user-friendly database, whereby users can now upload and control their own data (DWS, 2016).

2.3 CURRENT PRACTICES OF MONITORING GROUNDWATER LEVELS (INSTITUTIONAL FRAMEWORK)

There are multiple institutions involved in the management (including the monitoring of groundwater levels) of water resources in South Africa (Matshini, 2016).An important principle underpinning the South African approach to water/groundwater resources management is that the National Government, through the Minister and the Department of Water and Sanitation, acts as the custodian of South Africa water resources (DWAF, 1997).

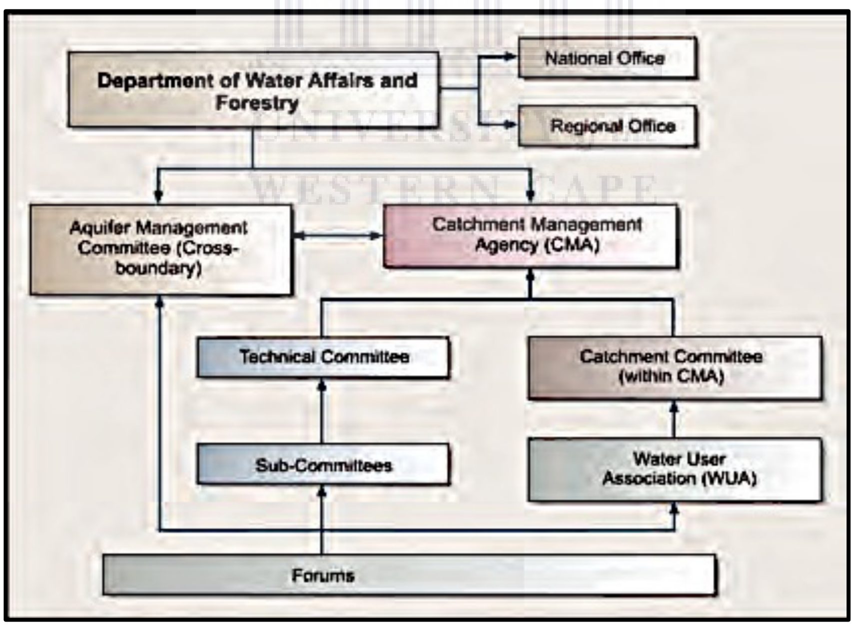

Figure 5: *Institutional framework for groundwater resource management in South Africa.* Source (DWAF, 2008 as cited in Pietersen, Beekman & Holland, 2011)

Pietersen, Beekman, & Holland (2011) affirmed that DWA provides a national policy and regulatory framework for regional and local institutions to management water resources, whereby implementation of strategy are assigned to the regional offices and the two existing Catchment Management Agencies (Inkomati and Breedes-Gouritz Catchment Management Agencies). The functions of these Catchment Management Agencies include the management of water resources, water related activities and facilitating the task of the development of Catchment Management Strategies, in close collaboration with local bodies (DWA 2010). It also requires that the Catchment Management Agencies identify functions to be delegated to the Water Users Associations (DWS 2016).

According to DWAF (2004a) the National Water Act 1998 assigns power and duties to the Catchment Management Agencies to assist in carrying out groundwater monitoring to include:

- Lead role in the design and implementation of monitoring
- Assessment and interpretation of monitoring data.
- Authority to require that water users install a recording or monitoring device to monitor and store the abstraction or use of water.
- To ensure that users establish link with any monitoring or management systems.
- Keep records on storing, abstraction and use of water and submit to the Catchment Management Agencies.
- To undertake the installation or establishment of such link as required on behalf of user, and if the user fails to comply with a written request from the Catchment Management Agency; to recover any reasonable cost from the water users for such installation
- To ensure the establishment of additional monitoring programs when needed.

Subsequently, these roles varies form regional to local level and depends on the type of monitoring network Importantly, the Catchment Management Agencies should act as an integrating institution for the collaborative management of groundwater amongst water resource management. According to Riemann, Chimboza & Fubesi, (2012), while the Catchment Management Agencies are responsible for the management of groundwater resource, within the WMA, Water Users Association are responsible for the function at local level; representing individual water users (citing DWAF 2004b).

Yet, in the current state of institutional reforms, there exist challenges of integrating groundwater management into the broader institutional framework (Riemann, Chimboza & Fubesi, 2012; Wijnen et al., 2012). As a result, government often fails to provide the capacity and budget needed for implementing groundwater management aspects (Wijnen et al., 2012). To exacerbate these challenges the incomplete development of the Catchment Management Agencies have impacted not only on the devolution of roles to the respective institutions, but on a broader scale, has impacted institutional mechanism required to ensure adequate capacity and coordination for the implementation of groundwater resource management (Braune & Xu, 2008; DWA 2013). For instance DWA (2013) outlined that uncertainty around the establishment of the Catchment Management Agencies has unsettled staffs and negatively affected staff recruitment and retention.

At local levels, role of citizen (especially local communities) and other stakeholders seem not to be well established either as a result of the transitional period, whereby current institutional setting are still in the process of transformation from a centralized top-down system to a bottom–up and decentralized one. For instance, the development of Catchment Management Agencies and replacement of the Irrigation Board by the Water User Associations have remained incomplete leaving gaps in term of roles and responsibilities (DWA, 2013). Though, it remains arguable whether there are adequate institutional structures for the management of groundwater (Wijnen et al., 2012), a simplified and modified version of roles and responsibilities of institutions in water resource management (refer table 2.1) developed by Pietersen, Beekman & Holland, (2011), provides a synopsis to roles and responsibility at local level as expected by the National Water Resource Strategy and the NWA.

Institutions	**Roles and responsibilities**
Catchment Committee	Day to day management of water resources within the Catchment Management Agencies or local catchment
Water Users Association	Management of groundwater resources being utilized
District and Local Municipalities	Planning and developing groundwater services and infrastructure and managing local water sources

Water Boards	Organs of state established to provide water services to other water service institutions
Water Forums and Reference groups	Monitoring and management of water resource development schemes
Ward Councilors and Ward Committees	Representation of committee needs; local management of water schemes and setting up and operating water management committees
Task Teams	Responsible for specific projects of a short-term nature, relating to assessment, plan and management of water resources.

Table 2.1: *Simplified and modified version of roles and responsibilities of institutions in water resource management.* (Source: Pietersen, Beekman & Holland, 2011 citing DWAF, 2008)

2.4 BARRIERS AND GAPS IN THE IMPLEMENTATION OF MONITORING OF GROUNDWATER LEVELS

There have been many approaches to exploring or investigating the factor(s) influencing the monitoring of groundwater levels. From the scientific point of view, Esquivel, Morales & Esteller, (2015) investigated factors influencing the monitoring of groundwater levels to include rate of decline and increase of groundwater levels, hydraulic properties and density of wells. The study based on hydrogeological perspective focused on the analyzing factors that impact on network design.

Capacity (institutional and human) has been demonstrated to be crucial to the successful implementation of the monitoring of groundwater levels and the entire groundwater resource management (DWA, 2010, Pietersen et al., 2016). Institutional capacity refers to the way in which water management institutions are structured and mandated, and the way they collaborate in addressing groundwater management and problems (DWA, 2010). This is strongly linked to the human capacity such as skilled or experience hydrologist, managers, specialists, researchers (Adams et al., 2015) required for the implementation of management aspects, critical at all levels (DWA, 2010). Adequate institutional capacity is therefore crucial to the availability of adequate resources, cooperation and coordination within departments and government. Adequate institutional capacity must be based on collaboration between all sectors including the private sector. As this is paramount for the provision of needed human capacity (DWA, 2010; Adams et al., 2015).

The spatial distribution of the aquifer makes the monitoring of groundwater levels to rely on multiple points in the design of networks. DWA (2010) warned that the specific lack of groundwater capacity is strongly related to the continued undervaluing of the resource at decision-making level coupled with a lack of systematic investment in management of groundwater resources. Monitoring of groundwater levels depend on the availability of hydrologists, hydrogeologists, technicians, managers and so on, for both administrative and on field data collection, data capturing, not to say the operation and maintenance of monitoring points. Groundwater is characteristically widely spread and locally accessible (Braune & Xu, 2008) therefore monitoring of groundwater needs to be localized and well distributed to provide adequate understanding of groundwater resources. These attributes of groundwater make monitoring to require increased number of sites; some located in easily accessible places and others in areas difficult to access.

Best practices for sustainable groundwater management at local levels depended on adequate funding mechanisms. Adequately distribution of groundwater monitoring infrastructure and expansion of network coverage is pertinent to providing high resolution of information on groundwater and this depends on adequate funding (Riemann, Chimboza & Fubesi, 2012; Varady et al., 2016). Monitoring programs are capital intensive and development requires funding for costly network installations, cost of sampling (instrumentation, personnel and logistics) and analysis (data processing and storage) and labor amongst other cost. Tuinhof et al., (2016) argued that a significant reason for reduced funding is the notion that "return on the investments of monitoring of groundwater levels on a short term is not likely". However, on long-term bases, returns are realized as substantial monitoring represent an integral part of management processes, required to circumvent possible loss that can be incurred due to inadequate management practices and poor decision regarding groundwater resources

DWAF (2004a) asserted the importance of social acceptance in groundwater resource management. Through social acceptance projects such as monitoring of groundwater levels can attract increased participation (Wijnen et al., 2012), commanding increase in human capacity and sustainable management of groundwater resources (DWAF, 2010). Nonetheless, effective participation in the monitoring of groundwater levels does not only depend on social acceptance but also on the amount of knowledge and awareness (Knüppe et al. 2011).

Narrowing of knowledge gap between scientists and the public is fundamental to the monitoring of groundwater levels and management of the resource. Knüppe, (2011) characterized this knowledge as a hydrogeological knowledge required to understand the state of aquifers and the scientific/technical dimension imperative for the successful implementation to groundwater monitoring (Taylor & Alley, 2001; Pareja et al., 2018). In response to narrowing such knowledge gap, initiatives for the creating awareness and knowledge building are achievable through engaging communities amongst stakeholders, capacity building through training (Knüppe, 2011; DWA, 2010; DWS, 2016).

Quite recently, the study conducted by Jones et al., (2014) on the Realignment and Associated infrastructure Project in Cape Town, draws an attention to the crisis of vandalism, theft of monitoring equipment and the detrimental impacts of these actions on the existing challenges of limited and less funded monitoring projects. This is an illustration of the importance of "security" of infrastructures to the implementation of groundwater monitoring station. In recollection, Adelana et al., (2009) warned that uncertainty in ownership of water resource/management projects have contributed toward a less effective groundwater management. It becomes clear that the need to increase the sense of ownership of community can avert the crises of vandalism and ensure the security of infrastructure. This implies that when community members perceive the monitoring stations as theirs the security of such infrastructures is further boosted.

Shershen et al., (2016) affirmed that shared ownership of infrastructures and management projects can leads to effective participation, which is crucial for effective implementation of groundwater management and water security. As an indication of the state of ownership of projects, there is a need to establish commitment to sustain water resource management through processes that enable communities amongst stakeholders to take ownership (DWAF, 2004b). As noted earlier, groundwater monitoring depends on multi-institutions relating at different levels. Wijnen et al. (2012) argued that there is a need for institutional mechanism to meet the challenges of the management of groundwater resource. The authors argued from the perspective groundwater governance that the collective management and participatory approach are fundamental to resolve the problem of the management of groundwater at local/institutional levels.

List of factors influencing the monitoring of groundwater levels are inexhaustible and calls for more research. Other crucial factors include appropriate quality assurance in term of monitoring, transparency of information, data sharing and willingness of public amongst other stakeholder to participate in the monitoring of groundwater levels (Adelana et al., 2009; Pietersen et al., 2016; Jollymore et al., 2017).

2.5 EXISTING IMPLEMENTATION PLAN FOR THE MONITORING OF GROUNDWATER LEVELS

2.5.1 Paradigm shift in South Africa groundwater monitoring environment

Historically, groundwater resource management in South Africa was highly centralized and largely supply driven and monitoring of groundwater levels amongst other management tools were preliminarily aimed at supporting development of national water infrastructure (Nomquphu, Braune & Mitchell 2007). As against the previous Water Acts, (Water Act 54 of 1956) were groundwater was considered as private resource, the Water Act of 1998 considers groundwater as public water. This implies that groundwater is now considered as a natural resource that belongs to all people, which should be equally accessed and used to the benefit of all. The new phase of water resource management required that much greater attention be given to the interaction between status of water resource, effect of human interaction and the response of management to the monitoring process (Nomquphu, Braune & Mitchell 2007).

Eventually, with an inclination of the Water Act of 1998 towards the Integrated Water Resource Management, in addition to a change in status of groundwater resources, establishing policies and legislations were crucial. Subsequently, developing and restructuring of water institutions and management instruments became a requisite to achieving the successful management of both groundwater and surface water resources (Taylor et al., 2010).

2.5.2Groundwater Resource Management in South Africa based on Integrated Water Resource Management

According to Riemann, Chimboza and Fubesi, (2012) groundwater management framework forms a part of the Integrated Water Resource Management. The authors outlined that evidences of this can be seen in the context of guidelines/documents (listed below) and activities such as catchment management, water service, water resource planning and assessment, to name but a few.

These documents include:

- Guideline for Assessment Planning and Management of groundwater resources in South Africa (DWAF, 2008a)
- DANIDA IWRM framework
- National Groundwater Strategy (DWA, 2010)
- National Water Resource Strategy (DWAF, 2004b)

Apparently, based on the NWA and NWRS, Nomquphu, Braune & Mitchell, (2007) argued that Integrated Water Resource Management approach cuts across the water management hierarchies for the purpose of implementation, coordination and where necessary monitoring. Nomquphu and co, outlined the hierarchy as presented in the NWRS:

- National level (tier 1): involves a national policy, regulatory framework, strategic and development planning at the national and international level, reporting on the state of the environment and meeting international agreements.
- Regional level (tier 2): focusing on water management at catchment scale (e.g. authorization license and coordination of water related activities).
- Local level (tier 3): responsible for provision of water services and management of own water. Local levels management is responsible for meeting the requirement as establish at level 1and 2.

Based on integrated management framework various partnership and action learning approach are essential element of integrating different discipline, institutions and business processes. Nevertheless, the implementation of Integrated Water Resource

Management framework requires a balance between policy and institutional support and community level projects (Anderson, Karar & Farolfi, 2008). This implies that irrespective of institutional arrangement, consideration has been made not only in the development of institutional structure to respond to groundwater resource management but must be built on the key elements of Integrated Water Resource Management framework such as promoting public/stakeholders participation at appropriate levels, collaboration, integration, continued capacity building (Taylor et al., 2010; Wijnen et al., 2012). In confirmation of this assertion, Riemann, Chimboza & Fubesi, (2012) noted that the guideline (DWAF 2008a) intends to assist in the sustainable development, protection and management of groundwater resources through achieving the overall goal of Integrated Water Resource Management.

2.5.3 Implementation of monitoring of groundwater based on Integrated Water Resource Management framework

Integrated Water Resources Management can be defined as a process/framework that promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare (Taylor, et al., 2010). This needs to be conducted in an equitable manner without compromising the sustainability of vital ecosystems (DWAF, 2004 cited in DWA, 2010). The scopes of the Integrated Water Resource Management include reconciliation of sources of water, development of groundwater and water resource, but are not limited to physical resources, as it involves the management of all water resource and the reformation of human systems to enable people (man and woman) to benefit from these resources (Taylor et al., 2010).

Even though, Taylor et al., (2010) stated that there are no simple blueprints to integrating water resource management, the author inferred that Integrated Water Resource Management is well positioned to strengthen groundwater governance and foster good decisions. In order to achieve this, implementing Integrated Water Resource Management framework is based on key action areas of:

- Enabling environment: policies, legislations, regulations, regulations and incentives.

- Institutional roles: considering institutional models that allows for aquifer & river, central-local and public-private interests
- Management instrument- includes resource assessment, allocation and protection as well as information management tools.

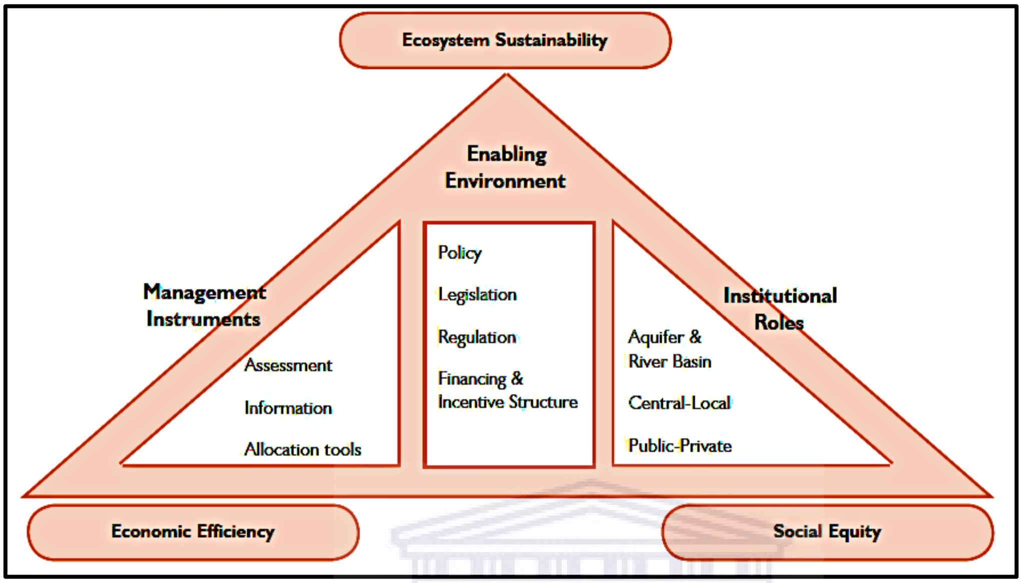

Figure 6: *Integrated Water Resource Management implementation triangle.* Source (Taylor et al., 2010)

In elaboration, enabling environment is based on the development of legislations and policies to respond to the dynamic changes in water resource management and the society. This includes financial allocation for water resource management and the rule of enforcement needed to meet policy objectives. Institutional roles or framework constitute all partnership between the government institutions, agencies, local authorities, private sectors, civil society and organizations, that are geared towards the implementation of the policies and legal provisions. On the other hand, management instruments such as monitoring are based on competence and skills required to implement objectives established in policies and legislative levels. Nevertheless, management instrument is a combination of diverse instruments required to address circumstantial issues such as groundwater depletion, water scarcity, groundwater /surface interaction etc.

Pietersen, Beekman and Holland, (2011) argued in the case of groundwater resource management in South Africa, that the enabling environment is well defined.

Nevertheless, a well-defined institutional landscape and adequate policy required for the implementation of groundwater resource management are only successful, if there is adequate collaboration between institutions and adequate stakeholders participation (Wijnen et al., 2012), because even Pietersen and co further demonstrated the prevalence of weak institutional capacity and arrangement for the collection of data (citing DWA, 2010) and a lack of institutional and human capacity for groundwater management at local levels.

2.5.4 Participatory Approach to Groundwater water management.

The National Water Act that provides the legislative framework for the delegation of role and responsibilities to stakeholders, also recognizes that people at all levels in society should participate in the management of water resources in order to ensure that social, economic and environmental needs are met **(**DWAF, 2004a**).** Decentralization promotes stakeholders' involvement and participation through restructuring of institutional landscape to distribute/enable a shift of roles and responsibilities within the Department of Water and Sanitation, Catchment Management Agencies and the local community (Braune &Xu, 2008; Anderson Karar & Farolfi, 2008). At the local level, participatory management is fundamental to achieving adequate level of citizen participation through community engagement, training of citizen, such as the Water Users Association for the monitoring of groundwater levels and capacity building at community levels (DWA, 2010; Knüppe, 2011; Wijnen et al., 2012).

Many authors demonstrated the need of support for local participation (Anderson, Karar & Farolfi, 2008), involvement of grass-root local users and citizen (Wijnen et al., 2012) and increase adaptive capacity through high-level of integration with greater connectivity to local stakeholders (Knüppe & Pahl-Wostl, 2011). While there are limited guidelines on the implementation plan for stakeholders' participation in the monitoring of groundwater levels, table 2.2presents a summary of the procedures for stakeholders' participation in Integrated Water Resource Management.

Stages	Procedure	Summary
1	Identify the stakeholders	Representation must include of water users in the management area
2	Work to build awareness of the IWRM process	Approaching exist Water Users Association and catchment groups to make stakeholders aware of IRWM process in the WMA
3	Workshop stakeholders long-term goals for use of the	workshops would be to establish a process of change, and to ensure that short-term practicalities don't hamper

	resource	the long-term goals That is stakeholders must made aware of existing and future groundwater issues
4	Identify conflicting needs for use of the resource	Process should address different conflict that occurring under different regimes
5	Identify a common goal	Stakeholders must understand the technical processes that will identify a range of options in realizing their goal for use of water resources
6 & 7	Identifying interim objective, management objectives and local actions	Stakeholders would have to contribute to identifying how objectives will be achieved, and who will do it and must be outline in action plans

Table 2.2: *Summary of the procedure for stakeholder participation in IWRM.* (Source: DWAF, 2004c)

Within the Integrated Water Resource Management framework, capacity has formed a key concern (DWA, 2010). Participation can lead to capacity building, whether building existing water management institution or building a new one. In addition, it can serve to upgrade the skills and understanding of decision makers, water managers, and professionals in all sectors (Taylor et al., 2010). According to DWAF, (2004a) the Catchment Management Agencies must play a role in educating community to protect, use, develop, conserve and control their own groundwater resources, by the implementation of initiative and programs (DWAF 2004a). Riemann, Chimboza and Fubesi, (2012), inferred that at local levels the Water Users Association should represent individual water user and provide a vehicle for public participation.

2.5.5 Collective Management approach to groundwater resource management

Groundwater management is cross cutting linking communities that were traditionally isolated to other sectors such as government and scientific sector (Nomquphu, Braune & Mitchell, 2007; DWAF, 2004b) as such requiring community participation alongside other stakeholders in the implementing of groundwater management strategies. Collaboration through collective management of groundwater resources have been acknowledge as a vital component for successful management of groundwater resources (Wijnen et al., 2012).

DWA, (2010) affirmed that in term of the Water Act, the function of the Catchment Management Agencies includes management of water resources and water related activities in collaboration with local bodies. Eventually, this implies the relevance of collaboration across sectors and levels in the implementation of groundwater management. Referring to the development of national information system, DWAF (2004a) affirmed that implementation planning must lead to coordination between institutions, including government, provincial and private institutions.

Taylor et al., (2010) noted that in countries where water reforms have taken place, it is often found that stakeholders are found in water law (as a legal platform) to enhance their formal involvement and collaboration. DWA, (2010) defined institutional capacity as the way in which water management institutions are structured and mandated; in addition to the manner they collaborate in addressing groundwater management and problems.

2.5.6 Challenges to the implementation of groundwater resource management

Despite the provision of the Water Act and subsequent policy documents, management of groundwater resources has endured a long-standing history of debates, changing policies, innovative strategies and institutional reforms and implementation of the monitoring of groundwater at local levels have remained a difficult arena to navigate (DWAF 2004b, DWA, 2010; Wijnen et al., 2012; Pietersen et al., 2016). As noted earlier, Wijnen et al., (2012) argued that one of the most crucial challenges to groundwater resource management remains that of an inadequate institutional framework to implement the Integrated Water Resource Management. The weak and inadequate public sector/stakeholders cooperation and weak coordination at local level contributes to the list of constrains to factoring groundwater into the Integrated Water Resource Management framework (Wijnen et al., 2012; Anderson, Kara & Farolfi, 2008; Pietersen et al., 2016). Anderson, Karar& Farolfi, (2008) questioned whether there exists an implementation plan, while from Wijnen et al., (2012), point of view, current institutional framework is not well positioned to enable the management of groundwater in requisite to decentralization. This implies that as much as decentralization results in the fragmentation of institutions, mechanism remains inadequate to enhance collective management between these institutions.

Reimann, Chimboza & Fubesi, (2012) connotes that the challenge is that of an overarching framework to groundwater resource management. Pietersen et al., (2012) as well presented the challenge as that of poor groundwater governance. Wijnen et al., (2012) expressed that participatory and local collective management offers a solution to the many challenges presented by other governance approaches. As against adopting *a right and regulation approach* that relies on a regulatory system to ensure that users are respecting the terms of award; or *incentive approach (*whether positive or negative); or *subsidiarity* whereby responsibility of groundwater management is delegated to local level-stakeholder interest groups, the participatory and collective management framework presents a mean to align institution at all levels, through vertical and horizontal integration.

2.5.7 Conclusion

The implementation plan for the monitoring of groundwater levels in South Africa have remained challenging from legislative, policy and institutional perspective. However, it is clear through literature reviewed that a framework for implementation of management of groundwater resource must be based on co-ordination and collaboration between institutions, including government provincial and private institutions. At local level, such framework must encompass participatory mechanism within a collaborative institutional setting. The conceptual framework proposed in section 2.5 combines the Wijnen et al., (2012) framework for collective management and participation with that of citizen science for developing a collaborative action plan.

2.6 CONCEPTUAL FRAMEWORK

2.6.1 Introduction

Albeit limited framework for the monitoring of groundwater, management of groundwater/water at local level has been explored from many orientations. List of studies comprises of policy approach, strategic approach using regulatory and incentive as well as institutional approaches (Knüppe, 2011; Riemann, Chimboza & Fubesi, 2010; Wijnen et al., 2012). Currently, the emergence and growth of the citizen science framework presents a novel approach for the analysis and development of plans that can integrate citizens amongst other stakeholders in the monitoring of groundwater.

Citizen science ranges from crowd sourcing to active community participation in high-level decision-making (Paul et al, 2018). Within this range of involvement, citizens could be ordinary data collectors or as part of an integral process where they are active participant in decision-making and implementation (Buytaert et al., 2014).Citizen science is a process whereby concerned citizens, government agencies, academia, community groups and local institutions collaborate to monitor, track and respond to issues. The involvement of this multiple segments in monitoring of groundwater levels, hydrological or environmental monitoring relies on array of institutions, which demands a framework that acknowledges multi sector coordination and collaboration in developing an action plan.

This section, presents the conceptual framework for developing a collaborative action plan for monitoring of groundwater levels, based on the application of drivers for collective management and participation (Wijnen et al., 2012) on citizen science framework. This concept is developed as a variant of existing researches conducted that have showcased the capability of combination of pertinent frameworks with that of citizen science in resolving conceptual issues(Pareja et al., 2018; Shirk et al., 2012)

2.6.2 Collaborative framework for groundwater resource governance

Many African countries have adopted Integrated Water Resource Management as a comprehensive and integrated approach towards sustainable water resource governance (World Water Council, 2006 as cited by Braune & Xu, 2010). Knüppe (2011) argued that despite groundwater integration into the Integrated Water Resource Management as far back as 1990s, the discourse primarily focused on scientific studies of the physical/scientific characteristics of aquifers and neglecting the social, economic and cultural values associated with groundwater (citing World Water Council, 2006; Colvin & Saayman 2007). The author argued that even though advances have been made recently to integrate groundwater resource management through the development of the Catchment Management Agencies, the challenges is that of a complex institutional relationship involving a myriad of organizations fulfilling different functions at different levels.

Pietersen, Beekman & Holland, (2011) highlighted the need for understanding the impediments to groundwater governance as fundamental to ensuring that groundwater forms a key element of Integrated Water Resource Management in developing countries. Such impediments include, weaknesses in legislation and policy setting at local level, and lack of integration, coordination and collaboration between institutions. Wijnen et al., (2012) argued that advancement towards improved groundwater governance must include building strong groundwater organizations and identifying the scopes of collective management and devising ways to support it. This eventually will lead to and secure groundwater's place in Integrated Water Resource Management.

In the case of South Africa, amongst host of developing and developed countries, the key premises for assessing groundwater resource management takes place within the Integrated Water Resource Management framework (Braune & Xu 2010). In 2004 the DWAF developed a guideline for groundwater resource management to provide the clear instruction for the coordination of groundwater resource management within the Water Management Area (Knüppe, 2011). The guideline affirmed the need to establish national monitoring systems to provide information, achievable through the collaboration between institutions, including government, provincial and private institutions (DWAF, 2004a). The implementation plan is to be developed in phased and progressive manner and should be driven by integration and collaboration between institutions.

Wijnen et al., (2012) argued groundwater management cannot work without stakeholders' collaboration and this is a basic rationale for factoring citizen participation amongst other stakeholders into groundwater governance. However, as much as the authors outlined the advantages, they established a list of impediments to participatory and collaborative management (refer to table 2.3).

Advantages	Impediments
Devise solution due to access to information that is better than or complementary to those delivered from top down approach	Legal and institutional provision do not frequently empower collective institutions
Key to coping with complexity and uncertainties of governance	Risk of existing inequalities (who gets to participate or whose voice is heard)
Align governance objective with that of local communities	Social barriers, such as gender, minority groups exclusion
Lead to increase stakeholders' ownership	Characteristics of aquifers and limited knowledge
Negotiating cost and benefits	Willingness to participate
Sustainable groundwater use, management and development	Lack of mobilization to support long term participation

Table 2.3: *Advantages and impediments to participatory and collective management* (Source; Wijnen et al., 2012)

In the implementation of groundwater resource management, communication with stakeholders and transparency remain vital to strengthening stakeholders' ownership and increasing compliance (Wijnen et al., 2012). Thus, this assertion set the feeling or perception of owning a project as an important component towards achieving collaboration. Once stakeholders perceive that projects are equally theirs, the chances of stakeholders willing to share responsibilities, risks, benefits and cost becomes eminent. This is important to the state of water resource management in South Africa as a result of the changes made to historic water rights, as explained earlier (refer to section 2.5.1). For instance, DWS, (2016) noted that working cooperatively is still new to groundwater users, due to the private ownership status of the past, still playing a role.

Wijnen et al., (2012) argued that lack of willingness is not only limited to water users such as farmers, as even government lacks the willingness to release information publicly, which can result to a lack of trust by local communities of higher-level institutions. On the other hand, the lack of awareness or limited knowledge of the understanding of the properties and nature of aquifers in comparison to surface water further impacts of the stakeholders' participation. Perhaps, Wijnen et al., (2012) reflected on the characteristics of aquifers when the authors titled their publication “managing the unseen”.

The need to further the course of collaboration at local level, through collective management approach and adequate participation has been demonstrated by other researchers (Knüppe & Pahl, 2013). For instance, Pietersen Beekman & Holland, (2011), outlined issues such as, the non- adherence of Municipality to the DWA's Blue Drop certification process, weak cross sector policy coordination amongst inadequate public awareness and participation.

In the analysis of the challenges to groundwater governance during shale gas development in South Africa; Pietersen et al., (2016) highlighted issues such as:

- Governance gap existing at local levels.
- Institutional barriers existing at all levels.
- Lack of support to groundwater governance at local levels.

Consequently, as institutions work close together in the monitoring of groundwater, it is important that implementation plans are developed incognizance of the opportunities and impediments that collaboration groundwater resource management.

2.6.3 Collaboration through the application of citizen science framework

The application of citizen science presents a means through which implementation plan for monitoring and management can be align with governance initiatives, plans, frameworks and objectives, especially at local levels (Conrad & Hilchey, 2011; Buytaert et al., 2016; Pareja et al., 2018). The emergence of citizen science as framework in environmental monitoring and subsequently gaining grounds in hydrological monitoring has led to the reconsideration of diverse implementation plans and the realignment of such plans to that of citizen science. For instance, the study conducted by Pareja et al., (2018), despite been anchored on the concept of Participatory Water Management (PWM) was realigned with the citizen science framework in order to optimize the outcome. Another instance is that of Shirk et al., (2012) that showcased the amalgamation of the citizen science framework with the participatory action research. Shirk and others, resultantly proposed a framework that can answer key questions such as ‘whose interest can and should be addressed’ and how the end goals or desired outcomes are defined, when involving public in scientific researches.

Not only have citizen science shown considerable uptake in academic literatures but have also gained recognition in government, non-government and community organizations (Jollymore et al., 2017). In environmental issues, policy related science, public engagement, governance and crosscutting or trans-disciplinary aspects; citizen science has made considerable progress (Buytaert et al., 2014; Jollymore et al., 2017). Shirk et al., (2012) affirmed that citizen science should be considered instrumental to addressing complex socio-ecological question, at the same time scientific interest towards achieving and negotiating multiple and integrated goals.

2.6.3.1 Application of citizen science in hydrological monitoring

The potential of citizen science as a promising method of citizen participation (Lowry & Fienen, 2013), which complement the traditional way of scientific data collection and knowledge generation (Buytaert et al, 2014) have been acknowledged in hydrological context. In hydrological monitoring (monitoring of water), citizen science have been used to monitor water quality, soil moisture, vegetation dynamics, water usage, stream flow, precipitation and by means, has been effective in the collection of data, and in some cases as a means of verifying data collected by scientists (Lowry & Fienen, 2013).

Characteristically, the involvement of citizen in the monitoring of groundwater levels is that of involving public in scientific research. Literature reviewed show that collaboration remains a crucial component of citizen science framework (Conrad & Hilchey, 2011; Walker et al., 2016; Buytaert et al., 2016; Minkman et al., 2017 Pareja et al., 2018). However, the definition or conceptualization of collaboration depends on perspective, discipline, nature of project, and anticipated role of citizen in project design. Paul et al., (2018) referring to the Haklay's framework, inferred that collaborative projects are those whereby citizens are involved from the problem definition to the dissemination of results.

From another perspective, Little, Hayashi & Liang, (2016), identified collaboration based on close interaction between the stakeholders (volunteers, university and county staffs) in the implementation and operation of monitoring networks. The study focused on an automated-information approach through web-based database that can be shared between stakeholders. Kobori et al., (2016) inferred collaboration as a trans-disciplinary matter that can couple natural and human approach, through which citizen science can help researchers to access local knowledge and implement conservational projects. Bonney et al., (2009) classified citizen science projects into *contributory, collaborative and co generated*. In explanation, contributory is when citizens roles are basically to collect data required by scientist, who are sole designers of projects. Citizen in collaborative design are conditionally involved in developing the question, data collection, analysis and dissemination of information, but in co-generate citizen science project, citizen are involved through all phases.

Shirk et al., (2012) noted that the nature of participation could significantly affect the way a project is design and the outcomes that the projects achieve. From the viewpoint of citizens participating in scientific research, the authors offered a framework on the bases of how scientists and public interests are negotiated in designing. Based on the degree of participation; the authors classified Public Participation in Scientific Research (PPSR) into contractual, contributory, collaborative, co-generated and collegial projects. *Contractual* is when communities ask professions to conduct investigation and report results; *Contributory* is whereby members of public primarily contribute data on projects designed by scientist; and *Collaborative* projects are design by scientists and public contribute data, but also help to refine projects, analyze data as well as disseminate findings. *Co-created* implied co designed and implemented by both scientist and public, while the *Collegial* is when non-credentialed individuals conduct research independently.

The relevance of institutional or organization structure to the design of citizen science projects have been explored/cited in many studies (Conrad & Hilchey, 2011; Buytaert et al., 2016). Pareja et al., (2018), citing Conrad & Hilchey, (2011) noted that three types of governance conditions citizen roles: (a) a central agency identifies situation to be monitored, design project and ask community to operates it; (b) a multi actor board of directors is created in a collaborative fashion and later the board designs monitoring schemes and perform the monitoring; and (c) the community identifies situation, design scheme and executes it. Pareja and others confirmed that within this governance framework the three stages of citizen participation are conveying, designing and execution.

Buytaert et al., (2016) presented the concept of polycentric monitoring; derived from polycentric governance as a potential alternative to Integrated Water Resource Management. Based on the authors' argument, polycentrism provides clarity in terms of roles; assessment of the capacity that exist for actors at different scales and levels and high level of co-ordination between actors to avoid duplication and waste of resources. The author argued that the nature of citizen science bears strong resemblance to that of polycentric governance. Buytaert et al., (2016) further argued that monitoring based on citizen science captures the concept of polycentric monitoring, however there are still considerable uncertainty about the concept of polycentric governance, its application and how polycentric monitoring needs to be implemented.

There is a growing recognition in recent citizen science research that citizen science projects are conditioned, linked to, or can be amalgamated with governance-institutional frameworks. This affirmation is reinforced by Pareja et al., (2018) proposing a framework to improve Participatory Water Management within the mining sector and remarking that notwithstanding the success made in conceptualization, data collection and data interpretation, there is a strong need for improving water governance aspects when applying the Participatory Water Management in analysis. Conformably, Buytaert et al., (2016) despite asserting the distributive ability and informality of citizen science based monitoring as highly compatible with polycentric governance model; both studies (Buytaert et al., 2016; Pareja et al., 2018) were unable to adequately link their conceptualization/analysis with groundwater governance framework and or existing institutional frameworks.

In elaboration, Pareja et al., (2018) waned that even though Participatory Water Management programs are a likely response to lack of trust between companies and communities, no actual collaboration seems to be occurring. The study argued that the role of communities and stakeholders varied from one initiative to another, but stakeholder (especially communities) often loss the potential to benefit from equal collaboration. Without clearly identified roles for collaboration, the result is often monopolization of leadership, misunderstanding and conflicts. This is often as a result of communities and or stakeholders having different expectation about their degree and extent of involvement.

Pareja et al., (2018) further outlined the need for monitoring programs to establish a place for collaboration based on framework of water governance than mere collection of data. This conclusion aligns with the perspective of resistance to polycentric monitoring which can be a symptom of lack of integration and collaboration (Buytaert et al., 2016). This demonstrates the need to position monitoring and management of groundwater in line with collaborative elements of good groundwater governance framework, such as the Integrated Water Resource Management framework whereby collective management and participation are fundamental elements of collaboration (Wijnen et al, 2012).

2.6.3.3 Case studies on the use of citizen science in monitoring of groundwater levels

There is limited literature on the application of citizen science in the monitoring of groundwater levels. Minkman et al, (2017), presented a case study of Dutch regional water resource management to determine Dutch practitioners' viewpoint on the use of citizen science in water management based on three parameters.

- Viewpoint A: considers citizen science as a potential solution that can serve several purposes, thereby encouraging citizen participation.
- View Point B: as a method for additional and illustrative data.
- Viewpoint C: viewed citizen science as primarily a means of education.

Applying the framework for Public Participation in Scientific Research developed by Bonney et al., 2009, the author presented the result of the case study based on the levels of accepted participation of citizen in water resource management. The study showed that a central point of agreement is that all categories of the practitioners acknowledged the use of citizen science for the collection of samples and/or recording of data.

The feasibility of establishing a large-scale water level monitoring network for private water supply was demonstrated by Little, Hayashi & Liang, (2016) in a case study of Rocky View County in Alberta, Canada. Based on community-based monitoring, community volunteers measured the water levels in their boreholes and entered these data through a web-based portal; open to the public to view and download the data. Depending on community for data collection with close collaboration with university and county staff, implementation of the project was successful.

A fundamental instrument behind the success of the program was the integration of communication/education and outreach programs. For instance, the use of newsletter prepared by project coordinators, to explain data trend and background information was important to keep the volunteers interested (retention of participants). A key lesson learnt from the case study was that collaboration was not limited to the university and county but included an organization such as Agriculture and Agri-FoodCanada (manufacturer) that jointly installed transducer for testing purpose. Though the project started with 50 volunteers to meet up a target of 50 wells, a number of volunteers left due to variety of reasons such as loss of interest, relocation or changing lifestyles. Nonetheless, the result (refer to figure 7) showed that majority of the wells was monitored once in every two months (frequency greater than 0.5 points per month).

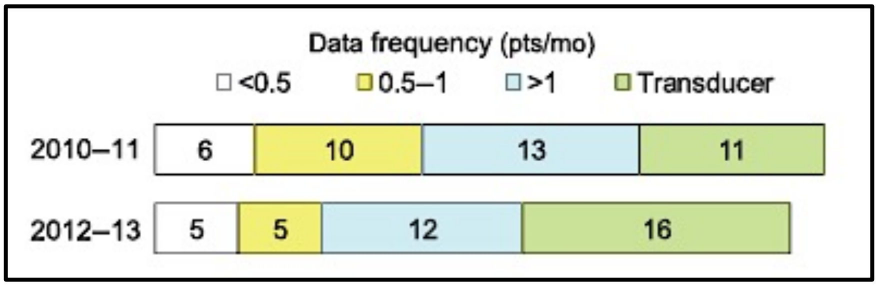

Figure 7: Average frequency of monitoring (points/month) during 2010 to 2011 and 2012 to 2013. The numbers indicate the number of wells with the frequency range. Source (Little et al., 2016)

In combination with automated transducers (represented in green), a total of 40 and 38 boreholes were monitored between 2010 to 2011 and 2012 to 2013, respectively. While the wells with pressure transducers had daily data, the authors further demonstrated that irrespective of the decrease in the cost of maintaining transducer, the advantages of citizen scientists supersede automation. Volunteer monitoring creates an avenue to engage communities and in turn can lead to sustainable water resource management practice and not only data collection (Little et al., 2016).

The Water Board of California demonstrated the use of the collaborative application of citizen science (online-www.waterboards.ca.gov). Dedicating an office to volunteers (refer to https://californiavolunteers.ca.gov), in 2009, the California Department of Water Resource, adopted the California Statewide Groundwater Elevation Monitoring (CASEM) program through which local agencies, counties and association have volunteered to serve as CASEM monitoring entities providing groundwater data statewide (online-water.ca.gov).

The Water Resource Institute of the University of Carolina, Virginia, USA, also reported on coastal groundwater watch using citizen science. Using 29 shallow wells and 2 silted wells in the superficial aquifer, the researchers engaged stakeholders through telephone, emails communication, in-person discussion, recruitment sessions, training workshops and educational activities. Collaboratively, the municipalities and organizations at the local levels (coastal communities); were used by the researchers to recruit citizen scientists required to collect data on groundwater levels (Manda & Allen, 2016).

Accordingly, the study showed that seven citizen scientists out of 10 recruited recorded water levels in 12 well out of 20 wells designated to volunteers (representing 70% of the recruited and 60% of the wells). To fill the capacity gap as a result of volunteersquitting, data were augmented with water level data from automated water level loggers. The case study revealed that citizen science, presents an opportunity to increase scientific knowledge and environmental awareness. Manda & Allen (2016) further argued that in context of economic deficits whereby financial resources may be unavailable to maintain large scale groundwater monitoring station with automated water level recording, adoption of citizen sciencepresents a means whereby volunteers become viable options for measuring and recording data on groundwater levels.

2.6.6 Conclusion

The application of citizen science has been acknowledged as a viable option for the monitoring of groundwater. However, due to the ambiguity in the definition of collaboration - importance of institutional setting under which a citizen science projects is designed it is important to understand the institutional framework in context of project area. Hence, the conceptual framework adopted in this study is built on the amalgamation of citizen science with the collective management and participatory framework (developed by Wijnen et al., 2012: refer to section 3.5.3). Wijnen et al., (2012) demonstrated that the collective management and participatory are fundamental for the management of groundwater under the IWRM setting. This study showcases the possibility of integrating citizen science along other governance frameworks towards developing a collaborative action plan for the monitoring of groundwater levels at local institutional level.

3. RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

This chapter presents the research design, sampling techniques and the procedures for data collection and analysis. In addition, the section provides ethical issues and the limitation of the study.

3.2 RESEARCH DESIGN

The purposes of this research design are to present and describe the sampling techniques, data collection methods, data analysis methods and procedures. The research design approach to this study is based on objective-to-objective bases. Van Wyk, (2012) defined a research design as the overall plan for connecting the conceptual research problem to the pertinent (and achievable) empirical research. The research design adopted in this study is the exploratory-qualitative design, best considered for the inter-disciplinary nature of the study. In addition, it is considered appropriate to meeting the research goal due to the relatively few information available on monitoring of groundwater as well as, on the application of citizen science in groundwater monitoring.

Van Wyk (2012) identified three types of research design as exploratory, experimental and descriptive. The advantage of the exploratory design is that it provides a means for addressing subjects of high level of uncertainty, and/or little existing research on subject matter. This type of research design is considered crucial to understanding the role of citizen science in the design of a collaborative action plan for the monitoring of groundwater levels.

3.3 SAMPLING

Sample can be defined as the portion of the total quantity of people, things or cases, which are the subject of a research (Etikan, Musa & Alkassim, 2016). There are two main categories of sampling methods: the probability and non-probability methods. The convenience and purposive sampling are non-probability sampling techniques chosen for this study. The convenience sampling method allows the researcher to select sample that meet certain criteria, such as accessibility, geographical proximity, availability of time and willingness to participate (Dörnyei, 2007 cited by Etikan, Musa & Alkassim, 2016). This sampling method allowed for the researcher to benefit from workshops such as workshops held in Elim, Goudini Spa and Fossil Park where experts, researchers, stakeholders and focus groups from different Universities, Department of Water and Sanitation, Council of Scientific and Industrial Research, and other institutions converged. This sampling is advantageous as it is considerably easy, cost effective and subjects are readily available, especially with regards to the time frame and resource available for the study (Etikan, Musa & Alkassim, 2016).

Purposive sampling allows for deliberate choice of participants based on the quality of participants and documents. It allows for the selection of samples that are well informed or have required information regarding the subject matter. Yet again, it is considered instrumental in qualitative research as it captures a range of view or experience that a researcher intends to focus on. The idea behind purposive sampling is to concentrate on people with particular characteristics who will better be able to assist with the relevant research (Etikan et al., 2016).The purposive sampling was use to select key informants to be interviewed. Key informants included fellow researchers and experts in the field of hydrogeology with relevant knowledge of the study area. This specifically includes those who have been working within the study area and attending meeting where stakeholders met in term of monitoring. In addition, this sampling technique was adopted in selecting documents on the monitoring of groundwater levels, implementation plans, citizen science, amongst a list of relevant documents required in meeting the study objectives. The combination of the convenience and purposive sampling methods allow the research to select the most constructive sample to respond to the research questions (Matshini et al., 2016).

3.4 DATA COLLECTION METHODS

Primary and secondary data collection methods were used this study. Interview of key informants, observations during field trips and workshops were sources of primary data. The secondary data comprises of reports, literatures, and policies documents. In a similar study developed to understand the institutional framework for the governance of groundwater, existing policy documents, guidelines (Pietersen et al., 2016) and interviews (Knüppe, 2011) were crucial method of data collection. Similarly, Conrad & Hilchey, (2011) adopted the secondary approach by reviewing existing literature in citizen science and Hardy & Koontz (2010) adopted the key informant interview as means of primary data collection.

3.4.1 Document review

Document review is a systematic procedure for reviewing or evaluating existing documents, records - both printed and electronic (computer-based and internet transmitted) material (Bowen, 2009). This research generated substantial information through the review of relevant literature. Due to the limited amount of literature on the institutional governance and groundwater management practices in West Coast, there was a need to review existing scientific articles and relevant documents that capture groundwater management from local institutional perspectives. In addition, document review provided information for cross-referencing during data analysis as well as strengthening themes as they emerged. Amongst the document reviewed were national policy and legislative documents, articles, reports as well as international documents relevant to the objectives. However, in cases whereby there were limited documents to answer the research question, international documents formed a source of data.

Documents reviewed were based on the objectives (refer to table 3.1). Document review as a data collection method allows the researcher to identify pertinent information and separate it from that, which is not pertinent (Corbins & Strauss, 2008 as cited by Bowen, 2009). Therefore, amongst the list of documents available this method allows the researcher to select those documents that are of direct relevance to understanding the current practices for monitoring of groundwater levels, gaps and barriers to the implementation of the monitoring of groundwater and furthermore meeting the final objective of developing an action plan and answering the research questions.

The use of Google, Google Scholar, Web of Science and Scopus as search engines was instrumental to meeting these ends. The search for articles was based on themes such as collaboration, monitoring of groundwater, institutions, hydrological monitoring, citizen science and participation amongst other relevant ones. Pareja et al., (2018) used Google search and Scopus engines to identity relevant grey literatures and affirmed the capability of the built-in-filter to keep search within focus. The search engine presented a means to located relevant materials due to the availability of published article regarding groundwater management and other relevant literatures.

3.4.1 Key informant interview

In this study, the face-to-face interviews were conducted with key informants. The purpose of the interview was to get an in-depth understanding and to generate data for analysis. Interview with the participants varied in time. In order to keep in touch with the large amount of data generated, interviews were recorded in some occasion (using audio recorder) for transcription at latter stages. Often as a lengthy process, for the researcher to be able to retain the participants' willingness, researcher-participant interaction formed an important aspect. Hence, gesture, and tone of researcher during interviews were considered vital.

The interviews were semi structured and key questions were developed based on the objective of the study. Worth noting, before the main interview, pre-interview was conducted briefly with key informants during workshops, departments meeting, focus group meeting and field trips. This was helpful in harnessing the level and depth of knowledge of the key informants. Accordingly, pre-interview helped to determine whether the interview questions were suitable for obtaining rich data that answers the proposed research question (Elo et al., 2014). The study of collaborative water shed partnership by Hardy & Koontz, (2010) demonstrated the relevance of key informant as people with first-hand knowledge of the events being studied and a reliable means of data collection.

3.4.3 Field observation

Project progress meetings, stakeholder forums and field trips attended were avenues for observation. During attendance, observation of participants at the workshop was conducted in a systematic way, by watching and listening to concerns and responses during sessions. This was documented in order to broaden understanding on participants, institutional issues and other relevant subject matters. It also helped the researcher to reevaluate the approaches adopted in the study. During meetings and workshops, the researcher took down notes using an observation sheet. These form an important source of information and knowledge for reinforcing the conceptual approach, materials and methods as well as a mean for cross validation during analysis.

3.4.4 Validity and reliability of data collection methods

3.4.4.1 Validity and reliability of key informant interview

The reason for the choice of the semi structure questionnaire is that it can be tailored to meet the objectives of the study. At the same time, while the interview questions were designed to collect accurate answers from key informants, the semi structure orientation allows for new knowledge to emerge. During the interview, questions were repeated when the interviewer felt that a respondent have not completely answered the question, or when there was a need for clarity and/or the respondent deviated from the focus of the research objective. Questions might be repeated to validate previous responses. In order to remain focused on the research question and to capture the objective, the lead questions were to identify the current practices based on the institutional setting and the role of stakeholders already identified through the key literatures reviewed.

The choice to use the key informants as a means of interview presents a data collection method that the researcher can trust the source of information received. The willingness of the key informant to provide information relevant to this study was fundamental. Yet still, key informants are considered less biased and reliable means of data collection, especially in the case of the study whereby the researcher intends to get an in-depth knowledge of the current practices of the monitoring of groundwater levels in the study area. Hardy & Koontz, (2010) affirmed that key informants can provide factual information about the organizations from an insider perspective.

3.4.4.2 Validity and reliability of document review

Validity refers to the adequacy of data, which depends on strong sampling and saturation (Whittemore, Chase, &Mandle, 2001 as cited by Elo et al., 2014). There are host of documents developed in groundwater management, governance, institutional framework, citizen science amongst other themes relevant to the research questions. Thus, there was a need to be thorough in the selection of literature. The literatures sampled are based on the relevance of the content to the objectives, the numbers of citation in goggle scholar, the date of publication, amongst the alignment of the conceptual framework adopted in selected literatures to the broader research questions. Importantly, as required by some of the objectives, certainly, there was a need to focus on documents that captured the status quo at local level within the context of West Coast This was achievable through a systematic review of current documents and reference sections in order to identify key documents. Many researchers have adopted document review as a means of qualitative data collections (Knüppe, 2011; Riemann, Chimboza & Fubesi, 2012 Pietersen et al., 2016). This approach has been demonstrated as a reliable means of data collection in qualitative - exploratory studies (Hardy & Koontz, 2010; Pareja et al., 2018).

3.5 DATA ANALYSIS METHODS

Based on the research design this section presents the data analysis methods based on objectives. For each objective, sections are categorized into tools, process, reliability and validity.

3.5.1 Data analysis method: Establishing current practices of monitoring of groundwater based on institutional framework

To achieve the objective of understanding the current practice of monitoring of groundwater level, document analysis was used to yield data, essentially to support the analysis of data collected through the interview of key informants.

3.5.1.1 Tools

Five key informants provided data on the role of current practices of monitoring of groundwater in West Coast. Bowen (2009) defined key informants as knowledgeable insiders from communities and external agencies that are able to provide data and clarification on specific issues. The informants selected have strong knowledge of/and have worked with the various stakeholders/institutions in the groundwater monitoring in the West Coast. Based on the objective of the study, document reviewed was used to identify the agencies responsible for the monitoring of groundwater level at local levels (refer to table 3.1). However, due to limited literature on the monitoring of groundwater levels, document regarding the management of groundwater levels, governance and institutional framework were reviewed to strengthen the analysis.

Since the study focused on understanding the current practice of monitoring of groundwater levels at local institutional level, the study amalgamates document review with interview from key informants. There is limited information on institutional framework for the monitoring of groundwater levels, therefore, the study builds on the list of stakeholders (refer to Table 3.2) established by Du Plessis (2009) and Pietersen, Beekman & Holland, (2011). The choice of the literature review was not arbitrary, as these documents presented a list of stakeholder and the later a more recent list focusing on local level.

Author (Pietersen Beekman & Holland, 2011)	**Author Du Plessis, 2009**
Catchment Committee	West Coast District Municipalities
Water Users Association	DWAF (now Department of Water and Sanitation)
District and Local Municipalities	Monitoring Committees
Water Boards	Farmers
Water Forums and Reference groups	Industries
Ward Councilors and Ward Committees	
Task Teams	

Table 3.1: *List of stakeholders in the monitoring and management of groundwater resources.* (Source: Du Plessis, 2009; Pietersen, Beekman & Holland, 2011)

3.5.1.2 Procedure

The transcripts and recording from the interview were read or listened to line by line, with relevant sections annotated, highlighted, commented on or noted down (as in the case of recorded audio). These sections include words, sentences and paragraphs and those emphasized and repeated were taken note of. The interpretive analysis applied in this study is basic, as the questions are direct and simplified in order to understand the current practices.

3.5.1.3 Validity and Reliability

The use of the interpretive analysis for analyzing data collected through interview was considered appropriate to meet the objective of understanding the current practices of monitoring of groundwater levels based on the institutional setting. The underlying assumption for the use of the interpretive analysis is to extract the direct quotes from the key informants and supported with literatures. Therefore, in triangulation with document analysis, emerging labels were evaluated to ensure that they were consistent with the objectives and research questions. The application of the interpretive analysis has been demonstrated in recent researches regarding the groundwater resource management, especially in the term of institutional framework (Matshini, 2016) and was considered reliable in this study.

3.5.2 Data analysis methods: Determining current gaps and barriers in terms of the implementation of the monitoring of groundwater levels

To understand the barrier and gaps in monitoring of groundwater levels the study applies a combination of document analysis and content analysis. Content analysis is one of the most used methods for analyzing qualitative data, as it represents a systematic and objective means of describing and quantify phenomenon (Downe & Wamboldt 1992; Schreier, 2012 as cited by Elo et al., 2014); which in triangulation with document analysis forms a compatible analytical tool (Bowen, 2009).

3.5.2.1 Tools

To understand the gaps and barriers to the implementation of the monitoring of groundwater levels demand that the researcher acquires adequate information regarding the monitoring of groundwater levels before analyzing. Relevant information was developed through document analysis and further used to conduct the content analysis. In the description of Bowen (2009) citing Labuschagne, (2003), the fundamental difference between document analysis and content analysis is that document analysis yield data- excerpts, quotation or entire passage that are then organized into major themes, categories or case examples through the application of content analysis. The literature analyzed for meeting the objective proposed in this section are those produced on groundwater management, monitoring of groundwater and institutional framework; mostly focusing on local context, documents include reports, flyers, website pages and international documents found relevant.

3.5.2.2 Procedure

The process of analysis started with the researcher familiarizing with document. This involved skimming, annotation, highlighting, commenting, and examination. During the skimming, basic coding skills were used to annotate passages and section that are pertinent to the key theme. Factors or theme emerging were categorized (Bowen, 2009) in relation to challenges and barriers to the implementation of the monitoring of groundwater levels. The procedure was not limited to content analysis, as there was a continuous triangulation with document analysis and document review. When new factors emerged, it is cross-matched with other relevant articles. Intermittently, document review was conducted to provide data to evaluate new set of emerging themes. In cases whereby, there are no documents to support an emerging theme, such themes were ignored due to lack of substantial evidence.

3.5.2.3 Reliability and Validity

Analyzing data in an organized pattern enhanced the reliability of the analysis. When similar themes appear in different literature, they were reviewed thoroughly to ensure consistency across literatures (source). The themes developed were cross-examined to ensure they align with research question(s). Yet, the use of triangulation presented a means to validate the themes developed during analysis. The researcher was sensitive to source of bias. Therefore, understanding the conceptual framework of the literatures analyzed was important to avoiding themes that would have emerged as a result of conceptual predisposition.

On the other hand, the researcher was careful not to misrepresent information as a reason of imposing the conceptual framework on literatures. Braun & Clark, (2006) noted that to some extent, what may count as accurate representation depends on a researcher's theoretical or analytical approach. Result from an analysis should be reported systematically and logically (Elo et al., 2014). The research ensured that the result was presented in order of relevance and supporting arguments, so that readers are able to trace the key findings to the sources.

3.5.3 Data analysis methods: Design a collaborative action plan for the monitoring of groundwater levels.

3.5.3.1 Tools

To meet the requirement of this objective, analysis was based on articles identified through Web of Sciences and Scopus. The use of the Scopus and Web of Science provided effective search tools to collect data (Follett & Strezov, 2015). These search engines have in-built filters that allow for the search of documents based on themes and furthermore allowed the research to probe the search using the 'search within result' interface to narrow the search to meet the focus of the study. The themes searched for included citizen science, community-based monitoring, groundwater management, participation, local communities and governance. The type of documents includes journals, articles, reports, conference objects, reports and reviews. The diagram below presents approach to classification of document and instruments.

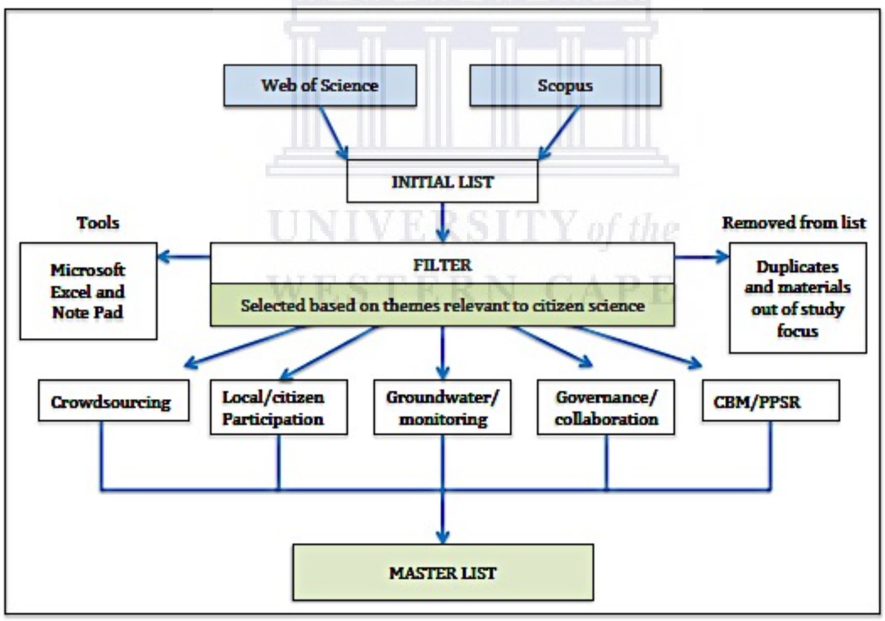

Figure 8:*Modified approach to extraction of documents.* Source (adopted from Follett & Strezov, 2015)

A general/initial list was developed based on the selected themes, which were further probed bases on themes relevant to conceptual framework.

Author of selected case	Nature of projects
Jadeja et al., (2015).	Empowering community for groundwater management through participatory monitoring
Little, Hayashi & Liang, (2016).	Community-Based Groundwater Monitoring Network
Pandya (2012).	Designing a participatory project that aligned with community priorities
Walker et al., (2016)	Using community-based monitoring to improve spatial and temporal characterization of rainfall, river flow and groundwater levels
Manda & Allen, (2016)	Coastal Groundwater Watch using citizen science
Minkman et al., 2017	Understand Practitioners' viewpoints on citizen science in water management
Thornton & Leahy, (2012)	Investigate factors that influence participant trust and community member perceptions of a citizen science groundwater data collection effort
Minnesota Pollution Control Agency (2017) - online	Demonstrate volunteers reflection on their participation in Citizen science
Pareja et al., 2018	Understanding collaboration between mining and communities involved in the collaborative monitoring of water
Buyaert et al., 2016	Understand citizen science to monitoring and management of Upper Kaligandaki basin, Nepal (key section)
Jollymore et al., 2017	Using citizen science campaign to investigate watershed impacts on water quality and citizen involvement in producing scientifically and societally relevant data
Lowry, & Fienen, (2013)	Crowdsourcing hydrologic data and engaging citizen scientists

Table 3.2:*Master list: major citizen science cases analyzed*

Using the analytical tools available on the sites, the researcher was able to export the results in "delimited text files" and CSV files to create the initial set of documents. The documents were assessed using Microsoft Excel and Notepad, and the initial list was examined and filtered. Afterwards the title, abstracts and key words of the documents collected were re-evaluated to remove duplication. The documents were further analyzed to ensure that they comply with the citizen science definition. The resulting list became the "master list" for the analysis (refer to figure 8 and table 3.2). Finally, a thematic analysis was conducted on the master list using the ATLAS.ti Software.

3.5.3.2 Procedure

There are two ways of identifying themes or patterns within a data in thematic analysis. These are inductive- bottom up and deductive/theoretical top-down approaches (Braun & Clarke, 2006). The authors stated thatan inductive approach means that themes established are strongly linked to the data and may bear little relationship with the research questions. On the other hand, a deductive approach is driven by the researchers' theoretical or analytical interest. In this study the deductive thematic analysis was adopted. This allows for the researcher to focus on the data pertinent to the research questions within the literatures. The analysis focused on identifying sections, passages and paragraphs that can be coded based on the conceptual framework.

The researcher started by familiarization of the literatures and then coded the documents based on the theoretical framework using the open coding. Wijnen et al., (2012), presented a framework for assessing readiness and capacity for participatory and collective institutional management. This modified version of the framework was adapted to drivers for collaboration within citizen science case study. The codes were established based on the themes identified within the framework (refer to table 3. 3).

Criteria	Key questions	Drivers relevant to monitoring of groundwater levels
Adequately defined boundaries of the resources	Do stakeholders have enough knowledge to be able to relate action to results?	Knowledge
Agreement on Access	Do stakeholders agree on who may access the resource and how?	Clarity of roles and responsibility
Fair distribution of risk benefits and costs	Are big well owners prepared to cooperate with decision?	Shared cost Willingness
Collective choice	Are all stakeholders empowered to take part in decisions?	Empowerment
Monitoring and reporting	Do stakeholders have confidence in the measurement and reporting on compliance with decisions and on result?	Trust
Graduated sanctions	Can stakeholders use appropriate sanctions to compel compliance?	Enforcement
Conflict resolution	Do all stakeholders agree on a mechanism for adjudicating disputes?	Conflict resolution
Recognition of groups	Is there an external challenge to the stakeholders' right to organize and operate?	Ownership
Adaptive capacity and flexible process	Can stakeholders adapt in the light of experience or changing circumstances?	Adaptive
Link to other governance systems	Can stakeholders fit in with other governance systems for the same resource?	Collaboration, engagement

Table 3.3:*Analytical framework* (Source: modified from Wijnen et al., 2012)

The motivation for the use of this framework includes the fact it that it was developed based on the status of groundwater resource management and groundwater governance dynamics in South Africa. It as well embraces collective management and participation aspects within an Integrated Water Resource Management setting and presents a tool adoptable locally. Yet again, it is consistent with the definitions/perspectives of collaboration within reviewed literature that acknowledge the significance of institutional framework in the successful management of groundwater resources (Knuppe et al., 2011, Pietersen et al., 2016).

Coding was used to code sections or themes that aligned with the research question. Codes were organized and later grouped into levels, categories and sub categories. Once grouped; codes, sub categories and categories were merged to develop the findings. The research is conceptually driven and aimed at identifying how collaborations are achieved within the cases studies. The developed themes were categorized based on role of citizens and that of other institutions and was used to develop an action plan for the collaborative monitoring of groundwater levels.

3.5.3.3 Reliability and Validity

To ensure validity, during coding the researcher ensured that codes and themes developed are concise and coherent to the information carried by the data (Braun & Clark, 2006). This implies that the research needed to thoroughly understand section, passages or paragraphs before assigning a code. In some occasion in order to avoid misinterpretation, dictionaries were used to get clear meaning of words that the researcher was not entirely sure of. To ensure the reliability of the analysis, codes were thoroughly guided by the conceptual framework. This entailed strong reflection of themes established. The themes were reviewed and those not defined within the conceptual framework were omitted before report writing. Using triangulation, the themes were revaluated based on the review of related document.

3.6 QUALITY ASSURANCE

The research design in this study is one that is aimed at quality assurance. In addition to the chosen methods, sampling techniques; the design is based on objective-to-objective. This enables the research systematically and thoroughly structure and present each objective. To ensure quality assurance, reliability and validity of methods were considered through data collection to data analysis stages (refer to section 3.4 and 3.5). The methodology was strengthens by triangulation, reflection and adequate reporting.

3.7 ETHICAL CONSIDERATIONS

The study involved the researcher interacting with public, experts, key informants, colleagues, government organizations, and representative of funding organization. These interactions took place in workshops, department, seminars and designated places of interviews, thus ethical consideration was crucial. During workshops, protocols were observed when the researcher needed to ask questions. For instance, the researcher will only ask questions during ‘questions and answers’ section or chosen time of convenience (such as during tea time breaks) by respondent. However, question asked in workshop were not directly included in the research but were aimed at broadening the researchers understanding (refer to section 3.4.3).

The research did not require an ethical clearance from the University, as most of the data collected were by means of document review. Such documents were published documents readily available to the public online. The use of key informants’ interview as well, did not necessitate the need for clearance as the interview was designed to get an understanding of the institutional setting/framework regarding the practices of monitoring of groundwater levels, and not about personal opinions or perspectives. Yet, key informants were informed about the nature/scopes of the study and the intended use of the information. Additionally, appointments were made, and informants’ permission received before recording audios during interviews. Other ethical issues include proper referencing of articles and literatures cited or used in the study.

3.7 LIMITATIONS

The limitations of the study were those issues that impacted on the study, that were not controllable by the researcher. This includes the lack of or limited literatures on the monitoring of groundwater levels and limited or no research conducted on the institutional setting for groundwater management in the study area and locally. Notwithstanding, the thoroughness of research design and methodology, chosen tools and instrument bears inherent limitations. For instance, secondary data may be subjective or biased due to the conceptualization, exploratory study are often flexible in procedures and resulting in frail structure. On the other hand, too much or too little information provided by respondent as well constitute a limitation.

4. RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the results and discussions of the study. Monitoring of groundwater levels in South Africa is crucial to science-based decision-making on the management of groundwater resources. However, the implementation of the monitoring of groundwater levels requires adequate participation of stakeholders in a collaborative manner. Based on institutional setting, institutions at the local levels such as the Water Users association, Interests groups and individuals are fundamental to the implementation of monitoring objectives and strategies developed at the national and regional levels. Such presents a case of multiple institutions interacting at different levels.

The study argues that unless the roles of citizens at the local community levels are understood, implementation contrast the bottom-up institutional arrangement that recommends that management of groundwater should be conducted at the local levels where groundwater resources resides, get extracted and can best be developed and managed. Refusing to conform to this order in a collaborative approach, as anticipate by the Integrated Water Resource Management framework that guides groundwater resources management in South Africa, will lead to increased fragmentation of institutions, lack of clarity of roles and responsibilities, weakened human/institutional capacity and a broader challenge to groundwater governance.

To achieve this, the study established the current practices of the monitoring of groundwater levels based on institutional framework and determined the gaps and barriers to the implementation of monitoring of groundwater levels in West Coast. Subsequently, the theoretical framework adopted in the study in developing a collaborative action plan for the monitoring of groundwater levels is based on amalgamation of the citizen science framework on adapted drivers of participatory and collective management of groundwater institutions.

4.2 CURRENT PRACTICES OF MONITORING GROUNDWATER LEVELS (Institutional framework)

4.2.1 Introduction

Varady et al, (2016) affirmed that the institutional setting for groundwater resource management and governance comprises of governmental, non-governmental, private sector agencies, amongst other organizations. Such institutions interact at national, regional and local levels in vertical-horizontal pattern in the development and management groundwater resources. With a focus on current practices of monitoring of groundwater levels, this section identifies the institutions and their roles and responsibilities at a local institutional level. As noted in the course of the literature review, the outcome of interview with key respondents emphasized inadequate understanding of the role of stakeholders in the monitoring of groundwater resource in West Coast. Monitoring of groundwater levels has remained segmented without an adequate implementation plan. This section present the outcome of the interview in addition to document reviewed on the current implementation of the monitoring of groundwater levels in West Coast.

4.2.2 Department of Water and Sanitation

Pietersen, Beekman & Holland, (2011) outlined that implementation of groundwater levels should be carried out by the Department of Water Affairs - Regional Offices (now Department of Water and Sanitation) and Catchment Management Agencies (citing DWAF, 2008). In essence, the Department of Water and Sanitation is supposed to be involved in the national and regulatory monitoring. These roles should include retrieving and managing of the data collected from Catchment Management Agencies as well as conduct the regulatory monitoring in the absence of the Catchment Management Agencies.

Key informants established that the Department of Water and Sanitation remains dominate in the monitoring. Currently, both national and regulatory monitoring of groundwater levels are been conducted by the Department of Water and Sanitation. Most often the Department of Water and Sanitation have remained reliant on consultant for the monitoring of groundwater levels, as there tend to be a shortage of trained hydrologist within the Department. The Department of Water and Sanitation has remained custodian of the data collected through the monitoring. For instance, the figure below (Figure 9) represent a map of West Coast (G10M) groundwater monitoring route monitored by the Department of Water and Sanitation. Observably, the charts show decline the levels of water in boreholes G1N0260 and G1N0271 (from about 27.7meters to -31.7 and -22.1meters to -23.5meters, respectively) between 1985-2014.

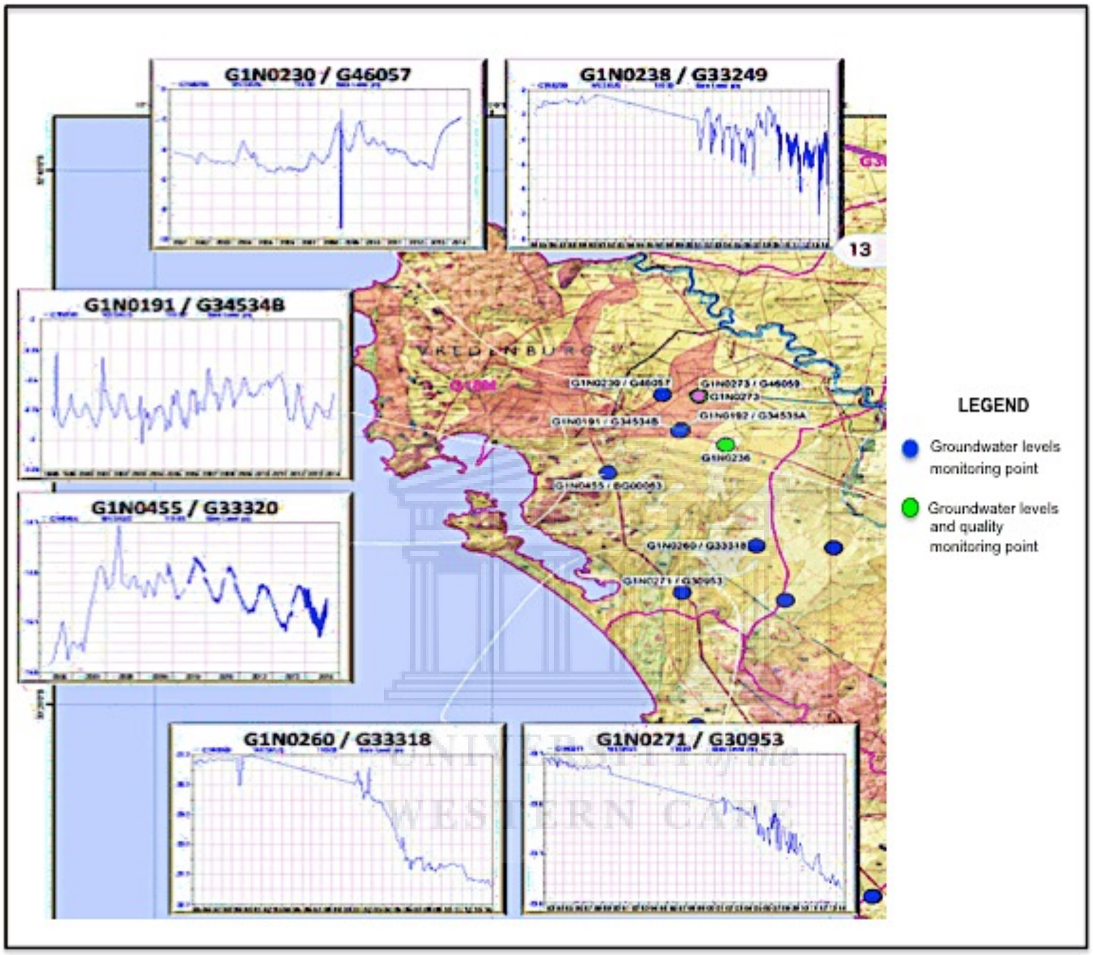

Figure 9:Map showing West Coast (G10M) groundwater monitoring route. Source (DWS 2015)

Currently, with growing concerns about groundwater resource management amongst the declining levels of groundwater, the Council of Geoscience, Department of Water and Sanitation and the Center of Scientific and Industrial Research have become major players at different points in time, through Memorandum of Understanding to share and capacitate each other in various field of expertise (DWS, 2016).

4.2.3 Catchment Management Agencies

Catchment Management Agencies are categorized into two groups, which are the regional and local agencies. In term of monitoring they all have significant roles, distinguished by the tier of monitoring projects or the type of monitoring (DWAF, 2004a). Generally, the Catchment Management Agencies are responsible for the designing of groundwater levels' monitoring projects, assigning of task to specific individual or groups at local levels. The Catchment Management Agencies are responsible for the development of the Catchment Management Strategies based on the requirement of the designated Water Management Area. However, due to the pending development of the Catchment Management Agencies such as the Berg-Olifants Catchment Management Agencies there are no significant contributions of the Catchment Management Agencies in the study area.

With the Department of Water and Sanitation currently tasked with the responsibility of the monitoring of groundwater levels pending the completion of the Catchment Management Agencies, there tend to be an overlap and poor coordination of the monitoring of groundwater levels. Such is as a result of the Department not been able to take over the full roles and responsibilities of the Catchment Management Agencies. For instance, the investigation conducted revealed that a key role of the Catchment Agencies such as the delegation of roles to be assigned to the Water Users Association has not been adequately catered for by the Department of Water and Sanitation.

4.2.4 Municipalities

The roles and responsibilities of the West Coast Municipality and its Local Municipalities have remained unclear in terms of the management of groundwater resources. The study showed that the municipality of West Coast utilizes groundwater on regular bases. However, their focus in groundwater resource appears to be on the development of groundwater for abstraction. Management of groundwater tends to be indirect and/or rarely mentioned in development plan. For instance, according to the West Coast District Municipality - Integrated Development Plan (WCDM, 2017),groundwater is steadily declining in the past 30 years and suggested the strict water utilization over the next 2-3 years to allow dam levels to recuperate. Other measure noted that can indirectly sustain groundwater included the provision of desalination plants as an alternative source of water.

Further investigation into the monitoring of groundwater levels, showed that the Municipality appears is involved in monitoring, but mostly conducted as a purposive monitoring as well as to access the availability of water. The study established that the monitoring of groundwater levels tends to be conducted by the municipality to take the baseline measurement of groundwater levels before siting a well or borehole and often there are no record of continued monitoring for most of the boreholes until there are low yield. Yet still, Municipality and Local Municipalities appears to retain such baseline data. This concurred with the study of Pietersen, Beekman & Holland, (2011) that highlighted some irregularity such as, Municipalities collecting groundwater data but retaining it for internal use and is not aware of the requirement for wider distribution.

A key observation that further confirmed the limited involvement of the municipality in the monitoring of groundwater levels is that even though there is a representative in the municipality for groundwater resource management, their roles were most often limited to development of groundwater resource and authorization. For instance, in Cerderberg, the municipality had groundwater representatives, but inquiries regarding monitoring of groundwater levels were out of the scope of the groundwater office.

4.2.5 Consultants

There is strong society of hydrogelogist and groundwater technical corps as many new groundwater-consulting companies were established throughout South Africa during the past twenty years (DWS, 2016). According to DWAF, (2008a) it is the responsibility of the Water Manager/Planner at catchment or local level to determine whether specialized hydrogeological consultant is needed. According to the DWAF, (2004), local monitoring that are aimed at the assessment of groundwater impacts on a local scales can be contracted to consultants, depending on the availability of funds.

The study shows that there is a high level of dependence on consultants for monitoring of groundwater levels. The Department of Water and Sanitation, Municipalities and Commercial farmers regularly outsource consultant to monitor groundwater levels. Despite the crucial role of the consultants, they most often have no interest in disclosing the results or data on groundwater to the public or government, depending on who employed the consultants. This implies that the objectives or goals of monitoring of groundwater levels are disintegrated, as consultants monitor in response to the interest and the location (if boreholes or of intended site) of the outsourcing institution(s). This scenario is a reaffirmation of DWS, (2016) which highlighted the need to develop a process to centralize private data held by private consultants and drillers.

4.2.6 Academic Institutions

Adequate groundwater capacity required for the implementation of groundwater strategies and/at the local level of management will depend on new partnerships that can harness the capacity of the academic sector (Adams et al., 2014). Academic institutions supported by research organization have formed a strong pillar for groundwater resource management. Academic institutions such as the University of the Western Cape, Institute for Groundwater Studies University of Free State, University of Pretoria, University of Witwatersrand, University of Venda, University of Stellenbosch, to name but a few, have played an important role in groundwater research, through support from funding organization such as Water Research Commission (WRC), National Research Funds (NRF), Council for Scientific and Industrial Research (CSIR) etc., (in no particular order) (Pietersen, Beekman & Holland, 2011; DWS, 2016). As such, student, researchers and scholars have been actively involved in the monitoring of groundwater levels and developing understanding on groundwater resources management and aquifer systems in the study area. Such research include the work of Seward (2006) and Eiler (2018) titled; 'Regional Groundwater Monitoring in Olifants-Doorn Water Management Area' and 'Deep groundwater characterization and recharge estimation in the Verlorenvlei catchment', respectively.

4.2.7Water Users

The Project Report for the Classification of Significant Water Resources in Olifants-Doorn indicated that the Lower Olifants Water Users Association has been an active stakeholder in the management of water resources. However, the investigation conducted in this study showed that the Lower Olifants Water Users Association has limited or no role in the monitoring of groundwater levels. Based on the analysis of key informants, the Water Users show concern about the status of groundwater, but most often only in situations whereby there is a decline in the pumping rate of borehole or there is a shortage of groundwater. Such involvement is only limited to querying the

Municipality or Department of Water and Sanitation, in search of a mitigation to the shortage of groundwater.

It was also observed in the course of the study that there tend to be a deficit in the delegation of roles to the Water Users Association and as such the Water Users Association have remained only active in raising concerns (usually through communication with other stakeholders by mails, phone calls or during stakeholder meetings or workshops) but not in the direct management of groundwater resource and or monitoring. The involvement of the Water Users Association have remained as noted by Pietersen, Beekman & Holland, (2011), because even though Water Users Associations are perceived as a water management institutions that operate at local levels, they are not directly involved in the management of groundwater management and or monitoring of groundwater resources. Accordingly, the study conducted shows that till now there tend to be little known, if any, about Water Users Association with regards to their roles or responsibilities management of groundwater.

On the other hand, investigations conducted show that farmers generally have interests in the monitoring of groundwater levels, however due to lack of capacity (in terms of skills or knowledge) - commercial framers depend strongly on consultant for the monitoring of groundwater levels. In West Coast there have been a growing numbers of emerging farmer, who have shown interest in the water resource management projects. For instance, figure 8, shows the distribution of emerging farmers and their involvement in the Integrated Water Resource Management projects (DWAF 2008c).

Even though the Integrated Water Resource Management projects (DWAF, 2008c) was aimed at engaging community such as Olifants-Doorn Water Management Area(amongst other communities such as Crocodile West – Marico Water Management Area, Mvoti Water Management Area to name but a few), on how the implementation aspect of the Integrated Water Resource Management can improve livelihood of the communities, the project demonstrated that relevance of emerging farmers in the management of water and groundwater resources. The report shows the interest of emerging farmer to include the management of groundwater. Such interests include protecting groundwater from pollutions, drilling of groundwater for extraction and wind powered pumping. Emerging Farmers Association such as the Lutzville Emerging Farmers Association established in 2004, and the Vredendal

Samewerk Boere Emerging Farmers Project, showed adequate involvement in the projects.

However, despite this representation and interests showed by emerging farmers, currently there are no records or strong evidence of the continued involvement of emerging farmers in groundwater resource management.

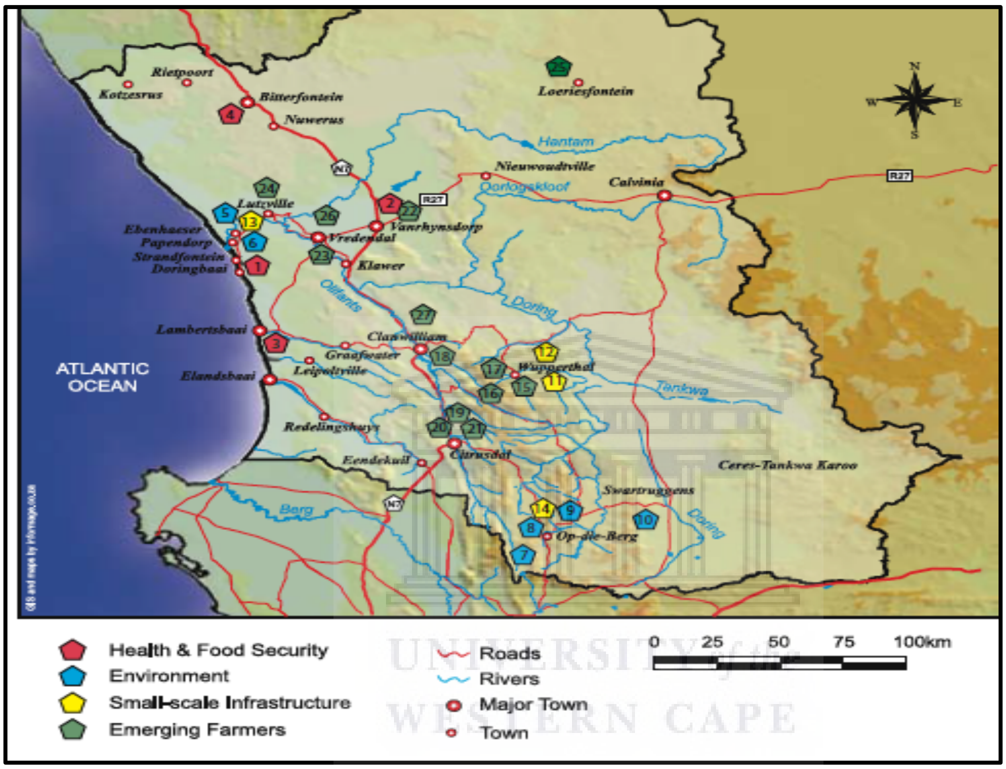

Figure 10: Map showing the localities of the Integrated Water Resource Management and other community-based projects in the Olifants-Doorn Catchment. Source (DWAF, 2008c)

Currently, emerging farmers have remained marginalized as a result of lack of integration or representation in the management of groundwater. According to informants, emerging farmers have shown interest in groundwater resource management, but are most often not knowledgeable or resourced to partake in the monitoring of groundwater levels. Emerging farmers often lack the resources to outsource consultant(s) to monitoring groundwater levels. Additionally, there were no records of individual or community based groups with interest in the management of groundwater. This could be as result of lack of institutional structure that can promote the integration of individual or interest groups.

4.3 GAPS AND BARRIERS TO THE MONITORING OF GROUNDWATER LEVELS

4.3.1 Complexity of hydrogeological setting

The geological formation of West Coast comprises of complex basement rock (refer to section 1.7.2). For instance, the Mamelsbury group and Gariep super group are soft, easily weathered whilst the Cape Super Groups are thick quartzose sandstones (Conrad, Nel & Wentzel, 2004).DWAF, (2008b) showed concern about the present conceptual model of the Langebaan Road Aquifer System and Edlansfontein that is not readily explained by obvious geomorphological process (Woodford et al., 2003). In event the Aquifer systems in the West Coast are more often complex than considered. Conrad, Nel & Wentzel, (2004) demonstrated such complexity based on interaction between surface water and groundwater and the deep seated inflow of aquifer in Sandveld. With a strong interaction between the primary and secondary aquifer systems as a result of unconsolidated primary and fractured secondary aquifers, the design of monitoring of groundwater levels networks has to take into consideration the hydrogeological status (Zhou et al., 2013).

For example, Parsons, (2014) suggested that the numbers and location of monitoring sites is a function of flow pattern. Yet again, there are evidences of a geological setting with high faults in West Coast. Conrad, Nel and Wentzel, (2004) highlighted that due to the properties of the basement rock the geological formation of West Coast comprises of multiple faults and structures (refer to Figure 11).

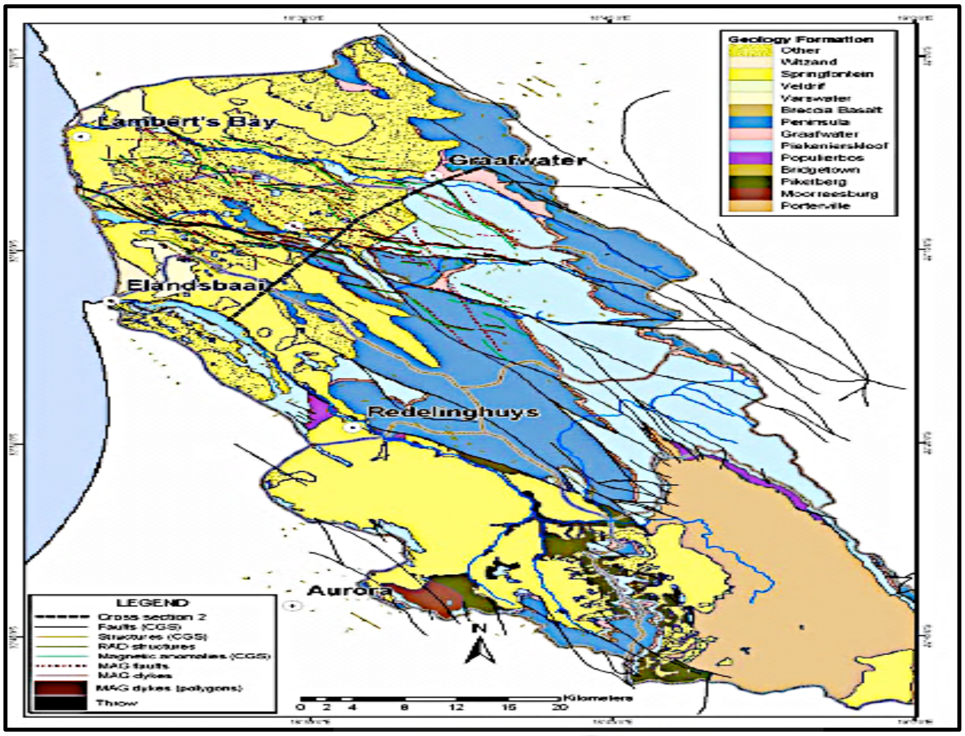

Figure 11:*Geological formation and structure of Northern Sandveld, West Coast.* Source (Conrad, Nel & Wentzel, 2004)

Significant literatures reviewed show that hydrogeological setting a considered crucial in groundwater monitoring (Jousma et al., 2006; Bense et al., 2013). For instance, Bense et al., (2013) study of "Fault Zone Hydrology showed that hydrogeological setting with faults could stimulate a more multi facet hydrogeological data or data collections, hence monitoring of groundwater levels networks have to be designed to characterize the hydrodynamics of such aquifer setting as a whole. Jousma, et al., (2006), highlighted the difference between the use of distributive and indicative monitoring points based on hydrogeological setting. Whilst indictative points are relevant to understanding the overall behaviour of systems or when a system is in danger, it is not very productive when it comes to large and complex groundwater system. Assigning of different monitoring network density to zone of unconfined and confined aquifers is essential to understanding groundwater regime. Nevertheless, such monitoring network designs are better enhance if there is a good deal of hydrogeological information or knowledge of the aquifer systems.

4.3.2 Limited scientific knowledge of the aquifers in West Coast

Jovanovic et al., (2017) demonstrated the relevance of increased knowledge of aquifer systems to management of groundwater resources in West Coast. Monitoring of groundwater should be in respond to hydrological-geological conditions. Thus, the lack of knowledge of the aquifer systems has a huge impact not only on the decision making on groundwater resources (Vermaak, Havenga & de Haast, n.d) but resultantly on the siting of monitoring of groundwater stations (Zhou et al., 2013). In designing an adequate monitoring network, hydrogeological knowledge acquired through groundwater regime/hydrological mapping can identify areas where groundwater levels may have unique spatiotemporal characteristics (Jousma et al., 2006; Zhou et al., 2013).

4.3.3 Lack of adequate capacity

Monitoring of groundwater levels have to be conducted in a way that strengthens groundwater governance at local governance level, address existing and potential hazards to aquifer systems; thus depends on the effectiveness of groundwater management capacity (Pietersen, Beekman& Holland, 2011). Braune, Adams & Fourie, (2014) argued that in 2012, the lack of technical and managerial expertise led to the decision to reduce the number of Catchment Management Agencies to 19 from nine. Even though, Anderson Karar & Farolfi, (2008) argued the need for capacity building was important in the face of the changing dynamics of groundwater resources management from a single sector to a multi institutional sector, Pietersen, Beekman & Holland, (2011) highlighted that hydrogeological capacity remains an issue within the Department.

Adams et al., (2014) suggested the need to build local capacity for monitoring through the empowerment of local sectors, which can be achieved through improved institutional cooperation and public-private partnerships to assist in managing aquifers (Pietersen, Beekman & Holland, 2011). However, the case study of Sandveld demonstrated lack of appropriate capacity of critical stakeholders such as the municipality (Knüppe & Pahl, 2013), as much as DWS, (2016) warned that there is a complete lack of capacity for the management of local groundwater resources. Therefore, moving forward to ensure adequate capacity will depend on acknowledging the criticality of local institutions to successful management of groundwater resources and assigning responsibility to local levels institution such as the Water Users Association (Riemann, Chimboza & Fubesi, 2012).

4.3.4 Vandalism

Jovanovic et al., (2011) noted that the safety and possibilities of vandalism of monitoring sites are amongst key criteria for siting of groundwater monitoring stations. A recent survey of monitoring points in Atlantis indicates that a large number of boreholes have been damaged or lost due to vandalism (Bugan et al., 2016). In 18th March 2018, News24 reported that in Cape Town, a list of stolen equipment (such as hydrants and valves) is worth more than R5 million since July 2017 to date of report (News24 online). This signal the lack of security of monitoring infrastructures that is continuously vulnerable to vandals - as they contain materials that can be stripped and sold as scraps. The issue of security of monitoring sites remains crucial to the implementation of the monitoring of groundwater levels and cannot be overlooked.

4.3.5 Lack of adequate access

Groundwater is a complex common pool resource that is widely distributed with dispersed abstraction points and many stakeholders involved in its use, and development (DWA, 2016a). Taken into account the nature of groundwater which is wide spread, monitoring of groundwater levels depends on monitoring points sited along dispersed network to ensure adequate spatial representation of groundwater levels. Even though, getting permission from landowners to site a monitoring station (DWAF, 2004a; Tuinhof, 2006) remains a challenge, in West Coast, location of sites is further challenging due to poor road conditions as a result of inadequate gravel layer thickness (http://westcoastdm.co.za/about/roads/) and/or limited graveled roads.

4.3.6 Lack of adequate awareness

During the last two decades, there is a tremendous increase in ecological thinking, awareness of ecosystem function and processes supporting humans' well-being (Knüppe, & Pahl-Wostl, 2013). Citizen and public awareness have become central to sustainable management of environmental resources. As a fundamental component, knowledge and awareness raising programs and mechanisms can contribute to the foundation of good groundwater governance and sustainable management of groundwater (Knüppe, 2011; Adams et al., 2014). This is achievable through the development of initiatives to create awareness and knowledge building. Such initiatives, programs amongst campaigns focus on engaging communities amongst stakeholders and capacity building through, training and workshops as well as media presentations (DWAF, 2004a; Braune & Xu 2008; DWA, 2010; Knüppe, 2011; Pietersen et al., 2012).

In groundwater resource management and governance the expectation is that for the success of management projects there is a need for public awareness (Wijnen et al., 2012). However, an analysis conducted through Google/Google Scholar, on the availability of awareness campaigns in West Coast, shows that there are no listed campaigns or programs regarding groundwater. Ones listed online include, awareness campaigns on areas such as tourism, fire prevention, flood protection (Google online). In terms of water resource management, campaigns include school support plans for minimizing the use of water and Day Zero Campaign (Cape Argus, February 18-online).

Lack of awareness is a cross cutting issue that affects groundwater strategies (DWA, 2010) as a result of poor perception and lack of understanding of the occurrence, use, value and threats to groundwater by public amongst other role players. Hence, awareness remains a key issue in management of groundwater in the West Coast. As noted by DWS (2016); ongoing campaign on groundwater management shouldbe carried out to increase local/public awareness through education and communication. Without awareness and understanding of groundwater systems, citizens will most likely not be willing to participate in the monitoring of groundwater levels amongst other groundwater management practices (Wijnen et al., 2012; DWS, 2016).

4.3.7 Lack of adequate funding

According to Jovanovic, et al., (2011) financial constraints are often the biggest barrier to the implementation of groundwater monitoring program. Such constraints are due to budget cuts and/or limited budget assigned to groundwater resource management. Investment in groundwater resource management is crucial to meeting the goals of management. Wijnen et al., (2012) emphasized that investment is important to improving knowledge of the physical characteristics of aquifers. This is achievable through investment in infrastructures, staffing and training of hydrologist/hydro geologist, operations and logistics required for the monitoring of groundwater.

The evaluation of the Department of Water and Sanitation Budget (2018) shows that there is no adequate provision for groundwater management all levels (Refer to table 4.1). An analysis of DWS (2018) shows that there are no budgets for monitoring of groundwater levels as allocation of funds tend to be more supply driven in addition to non-specifically targeted at the management of groundwater resources in West Coast.

Groundwater Specific Project	Projects	Status	Cost(R)
Strydenburg groundwater project	Provision of groundwater development	Handed over	75000
PixleykaSeme bulk water supply	Upgrade of existing groundwater scheme	Feasibility	40000
ThabaChweu groundwater development	Provision of groundwater development	Construction	8 500
Oudtshoorn groundwater supply	Provision of groundwater development	Feasibility	190 000
Hofmeyer groundwater supply (phase 1 completed)	Development of borehole to augment existing bulk water scheme	Construction	47 407
Middelburg groundwater supply	Development of borehole to augment existing bulk water scheme	Construction	31 105
Van Wyksvlei groundwater	Construction of new bulk water scheme	Design	97 644
Van Wyksvlei groundwater phase 1 (pipeline upgrade)	Construction of new bulk water scheme	Design	94 700
Middelburg groundwater supply	Development of borehole to augment existing bulk water	Construction	32 505
Hofmeyer groundwater	Development of borehole to augment existing bulk water scheme	Construction	64 000
TOTAL			**680, 861**

Table 4.1: *Total amount of funds budgeted on groundwater related project out of total of R200, 711, 926.* (Source, DWS, 2018)

Funds are required for the design of monitoring networks, drilling, and operation of monitoring sites. Parsons (2014) outlined that irrespective of other costs drilling of monitoring boreholes take accounts for a large part of the monitoring budget. Wijnen et al., (2012) urged that successful management of groundwater relies on adequate budget for groundwater specific management. On the other hand, despite the relevance of researchers to the management of groundwater, through provision of groundwater data and increasing knowledge and understanding of aquifer system (amongst outcome of various studies), Parsons (2014) noted that their recent research was without formal financial support and was essentially self-funded with Institute for Groundwater Studies covering some fees and travel cost.

4.3.8 Lack of adequate community-public participation

Supporting local participation in the monitoring of groundwater is crucial to meeting capacity required for the management of groundwater resource as well as enhancing sustainable practices (DWA, 2010; Pietersen et al., 2016). The 2012, report on the classification of significant water resources in the Olifants-Doorn Water Management Area, indicated an active involvement of stakeholder. In the report, stakeholders' involvements were limited to classification of water resource systems and process. While such report brought together diverse stakeholders from areas such as Vredendal, Clanwilliam, Sandveld, Crustadal, to identify key challenges within the WMA, no recommendations were made in term of further/future participation in the management of groundwater resource (DWA, 2012).

According to the study of Nchoung (nd), community participation which ranked highest in terms of its importance to bringing about sustainable groundwater management seems to be the most ambiguously handled aspect. Knüppe & Pahl-Wostl, (2013) also observed that participation tends to occur only during informal programs at local levels and at higher level, participation are not considered in any formal procedures.This implies that there are limited formal recognition and mechanism in place for the effective participation of citizen in the monitoring of groundwater levels especially at the local community levels.

4.3.9Poor cross-sector collaboration

Knüppe, & Pahl-Wostl, (2011) argued that as much as participation is instrumental to management, it requires adequate representation, integration, and facilitators to support and enhance communication between groundwater users and government. The authors argue the absence of collaboration has led to a fragmentation of groundwater institutions. Wijnen et al., (2012) argues that groundwater management cannot work without collaboration. Knüppe, & Pahl-Wostl, (2013) outlined that compared with other natural resource, groundwater resources management, lacks not only participation but also multi-level interaction and sector integration. The authors presented a multi-level interaction based on actors' levels versus level of actors' situation involvement in groundwater management in Sandveld, West Coast.

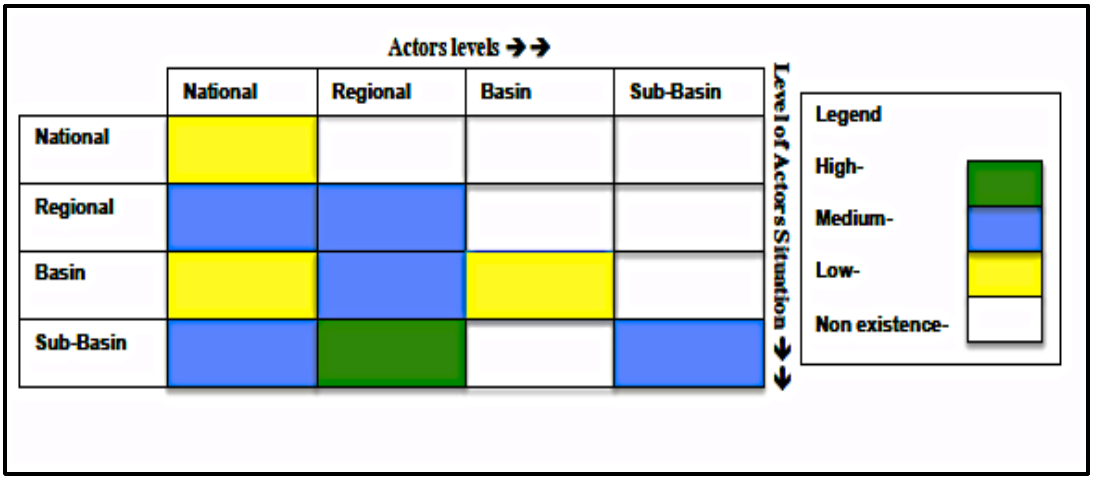

Figure 12: Modified multi-level interaction on intensity of actors' involvement in groundwater resource management, Sandveld, West Coast. Source (Knüppe & Pahl-Wostl, 2013)

There appears to be the strongest involvement of the regional level on sub basin matters; that is a strong downward interaction between regional and local level organization in the management of groundwater. The result also presents the weak involvement of sub-basin and basin actors in matter at their institutional levels. The weakest vertical interactions occur between local organizations and higher levels institutions. This result further indicates the need for integration within institutions responsible for the management of groundwater resources.

4.4 COLLABORATIVE ACTION PLAN DISCUSSION

To develop a collaborative action plan for the monitoring on groundwater levels, establishing the current practices based on institutional framework provided a starting point. Afterwards the gaps and barriers to the implementation of the monitoring of groundwater levels were identified. This section discusses the collaborative action plan by discussing the essential component of a citizen science project in section 4.4.1 and collaborative drivers in section 4.4.2. In section 4.4.3 a plan for collaborative monitoring of groundwater levels was developed based on the scenario of the study area.

4.4.1 Essential components of a citizen science project

4.4.1.1 Identifying the purpose and viability of monitoring projects

The objectives of monitoring projects vary from one project to another and at the same time different stakeholders may have diverse interests. Therefore, scientists and/or project coordinators should ensure that problem definition and project design include managers, funders or government official as well as representatives of communities amongst other key stakeholders (Shirk et al., 2102; Lowry & Fienen, 2013; Buytaert et al 2014). This is important to achieving the required level of interest, willingness and buy-into projects, which is crucial for effective participation, cooperation and success of projects. At the initial stage, it is important to ensure that the resources needed to execute all phase of the projects and infrastructures are planned and provisions are made for the availability (Manda & Allen, 2016).

4.4.1.2 Participants recruitment

Recruiting of participants is an integral part of any citizen science projects (West & Pateman, 2016). Even though citizen science projects are often developed for specific audience recruiting audience can often be challenging, difficult, time intensive and costly (Bonney et al., 2009; Jollymore et al., 2017). It becomes more challenging when there are weak partnerships between participants (citizens) and relevant institutions (Bonney et al., 2009). As such it is often considered necessary to recruit participants based on their proximity, interest and willingness to participate in a citizen science project. Dickinson et al, (2010) demonstrated that recruitment could include target monitoring whereby participants are recruited for specific, high effort or short-term purpose or surveillance monitoring for addressing unanticipated threats with less effort or long-term purpose.

This implies that recruitment processes must take into consideration the type of monitoring, whether ambient, surveillance or other types of monitoring. Hence, recruiting participants need to reconcile the length of program and the level of technical skills required. West and Pateman, (2016) citing Morias et al., (2013) argued that low levels of recruitment or decline in participation could lead to project seizing, therefore it of great significance for project managers to understand the demography of participants in order to ensure that relevant sections of local community are represented; hence, tailoring their recruiting materials accordingly (West & Pateman, 2016).

4.4.1.3 Training

Training implies the progression of skills from experts to new recruits. Lack of training can lead to insufficient data, irregular sampling and unaccountability of some hydrologic events (Lowry & Fienen, 2013), such as groundwater levels in storm peaks. As such training programs must incorporate data collection techniques in various hydrologic occasions and sampling protocols (Lowry & Fienen, 2013). For instance, training may entail given sampling kits to participants or new volunteers, while scientists guiding them as they measure phenomenon or depths of water table as in the case of groundwater levels (Jollymore et al., 2017).

Training can range from formal training sessions to offering online training and/or materials (Newman et al., 2012). Lowry & Fienen, (2013) suggested that protocols should be scientifically robust, yet easy to follow, and must emphasis safety. In addition, the authors stated that procedures for reporting of data and accessing of feedback must be catered for during training. West & Pateman, (2016) argued that projects that require participants to undertake adequate training appear to have high results.

4.4.1.4 Data collection and reporting and feedback

Hydrological data collections typically rely on technologically complex and expensive measurements (Buytaert et al., 2014). Eventually, it is often assumed that during the training stage, citizens would have developed the needed skills for handling equipment. As noted earlier, the fundamental aim of citizen science in hydrology is the collection of hydrological data. In definition, Silvertown, (2009) refer to a citizen scientist as a volunteer who collects and/or processes "*data*" as part of a scientific enquiry. Noticeably, citizen science can extensively expand data collection, but irrespective of these potential, there are concerns about the quality of data collected by the non-scientist/citizen (Minkman et al., 2017). In addition to quality issue, Jollymore et al., (2017) warned that citizens and citizen lead community groups can insert their own interest(s) into data. Thus, for the reliability of project, validation of data is important and can be done through the use of secondary volunteers and experts' intermittent visits to data collection sites (Newman et al., 2012).

Furthermore, data collected and unreported is of no use, therefore the design of citizen science projects must shift to an innovative phase of data reporting. The advancement in technology presents an opportunity that must be harnessed in hydrological data collection, for improved data management, automated quality control and data reporting (Newman et al., 2012). Through, the use of mobile phones, citizens can send text to a server that stores and displays data on websites (Lowry & Fienen, 2013). The text format was recommended by Lowry& Fienen, (2013), since virtually all phones can send a text message. Reporting of data and feedback, through information technology has to be developed in a well-structured manner. For instance, data reported from a citizen, must show phone number, location and data must be backed up in case of crashed database.

4.4.2Collaborative drivers discussion based on citizen science cases study

This section discusses the collaborative driver based on case studies. As an important part of the design the final objective of a collaborative plan, the discussion of drivers focused on establishing the roles of stakeholder or institutions, the response of the institutions to the drivers.

4.4.3.1 Knowledge

The most common purpose of citizen science is knowledge generation (Minkman et al., 2017). Successful projects seek expertise from all participants and building processes and procedures to facilitate and validate expertise through the incorporation of multiple kinds of knowledge (Israel et al., 1998 & Jolly, 2006 as cited by Pandya, 2012). This implies that require knowledge for the monitoring and management of groundwater resources can be generated by the incorporating scientific knowledge of aquifer and groundwater systems and knowledge new to professionals (Minkman et al., 2017) such as demographic and socio-economic dynamics and the same time synthesizing it with a thorough understanding of traditional knowledge systems (Jadeja et al., 2015).

The most successful monitoring projects are a synthesis of formal science, experiential subject knowledge and understanding of local social ecology. Buytaert et al., (2014), argued that, members of a community whose livelihood depends on their local environment (e.g. farmers) may also seek scientific knowledge to form a better understanding of their environment. Thus, through the synthesis and acquisition of knowledge, management practices for the monitoring of groundwater levels can be enhance multilaterally.
Most of the case studies evaluated presents knowledge from a more indigenous and scientific perspective, but Minkman et al., (2017) affirms that the application of citizen science in monitoring can as well close the gap of knowledge between governance and public. Using Groundwater websites part of the monitoring program to educate the residents both of the fundamental concepts, site can be used to plan project, disseminate information and tap into community knowledge (Little, Hayashi & Liang, 2016).

4.4.3.2 Clarity of roles and responsibility

Citizens' internalization of their roles in the monitoring of groundwater level is fundamental, as it allows them to perform assigned duties as per the requirements of programs (Jadeja et al., 2015). Studies show that the scientists are more than often clear about their roles in monitoring (Buyteart et al., 2014; Minkman et al., 2017). Nevertheless, citizen science can offer citizen scientists part of scientific processes, but ultimately must lead to a broader role in term of decision making as a part of bottom up approach (Minkman et al., 2017). To clarify roles, there is an agreement that project coordinators are responsible for and should make the roles of participants clear - through effective communication, training and adequate project design (Manda & Allen, 2016; Little, Hayashi & Liang, 2016).

4.4.3.3 Shared cost

Walker et al., (2016) demonstrated that relevant scale to inform local resource management are increasingly being obtained by local communities, providing a low-cost options and highly useful source of time series data. Funding has been at the center of the success of every monitoring project. (Pandya, 2012) noted that the extent that which citizen science progresses is a result of federal investment. The cases studied reveal that most of the funding for citizen science projects comes from grants, government funding (Jadeja et al., 2015; Little, Hayashi & Liang, 2016). Most groundwater monitoring cases reveals that costs are seldom shared between the citizens and other stakeholders in projects. Manda & Allen, (2016) that adequate finances are required to set up training programs, purchase expensive monitoring equipment such as water level sounders, water tape etc.

(Walker et al., 2016) noted that institutions embarking on cost cutting practices are an issue that is particularly severe in less economically developed countries. Nevertheless, the increase availability of cheaper monitoring equipment presents a viable option to minimizing the cost of monitoring projects. In summary, as much as community volunteers present a cost-effective means, there is a need for provision of finance for citizen science projects.

4.2.3.4 Willingness

Understanding the factors that influence community's participation in citizen science project and why they participate/continue to be involved are important in the monitoring of groundwater (West & Pateman, 2016). As noted earlier (refer to section 2.6.2)Wijnen et al., (2012) recorded the unwillingness of the government to release information on groundwater, nevertheless cases studied indicate that "unwillingness" in terms of participation are typically in the forms of citizen not willing to participate in project. Moreover, Minkman et al., (2017) demonstrated that government institutions, managers and water practitioners are often willing to undertake citizen science projects, with strong acknowledgement of the relevance participation of citizens as a means of meeting data collection goals. Little, Hayashi & Liang, (2016) affirmed that government is starting to rely in local –community-based monitoring programs to provide an effective and affordable tool for sustainable water resource management.

Walker et al., (2016) demonstrated that community simply trying to or getting involved in a project a sign of willingness (Walker et al., 2016). However, to retain or secure their willingness will depend on a collection of factors, some are implicit, and others are response to socioeconomic conditions. Such intrinsic factors may include trust, motivation and perceptions (Thornton & Leahy, 2012; Buytaert et al., 2014). Thus known and respected community members who live or work in close proximity to the monitoring point should be selected (Walker et al., 2016). This reduces the challenges of socio-economic aspects, such as cost of transportation to sites, time management etc.

Yet, studies have shown that not all volunteers will participate until the final stage of projects (Manda & Allen, 2016) due to diverse reasons, including loss of interest, relocation and changing life style (Little, Hayashi & Liang, 2016). This demands that monitoring of groundwater levels project must envisage change in capacity between start periods to conclusion and create the needed mechanisms for renewed recruitment of community members or capacity from higher institutions.

4.4.3.5 Empowerment

Case studies show that empowerment of citizen in the monitoring of groundwater levels depends on the availability of adequate mechanisms from high institution such as governing bodies. Walker et al., (2016) demonstrated that government has developed ways to empower citizen, such as policy planning that includes citizen participation, with a desire to be more inclusive. Scientists also play decisive roles through increased awareness, knowledge building and capacity development (Buytaert et al., 2014; Walker et al., 2016; Jadeja et al., 2015). Empowerment leads to local community taking responsibility of projects and becoming stewards. As such community members are enabled to consider specific solution around groundwater issues for particular situation based on their knowledge and skills (Jadeja et al., 2015). While it is not viable to get every member of the community involved in the monitoring of groundwater levels, empowerment can be achieved through adequate representation of the community in projects.

4.4.3.6 Trust

Trust need to be improved and reciprocated between external agencies and community. There is strong conflict as a result of lack of trust between scientist and community (Newman et al, 2012). On one hand scientists do not trust the quality of data collected by citizen and on the other citizens do not trust scientific methods, the result published by scientist or higher institutions in response to scientific report. Enhancing the acquisition of scientific knowledge by citizen through the engagement of local community in an open and transparent way is imperative and can be enhanced through adequate line of communication (Pandya, 2012; Thornton & Leahy, 2012). Scientist can develop trust in citizen scientist (community), through adequate mentoring and at the same time higher institutions can achieve citizen trust through adequate feedback (Buytaert et al., 2014). A shallow institutional structure will remove the load of mistrust (Buytaert et al., 2014) and allow for increase rapport, honesty and friendship between stakeholders monitoring groundwater levels (Walker et al., 2016)

4.4.3.7 Enforcement

Enforcement has been less considered or barely available in citizen science projects. Thornton & Leahy, (2012) demonstrated that ownership can be generated through incentives and reduced enforcement; as it is important for ensuring that monitoring projects do not only lead to the availability of data on groundwater levels, but beyond that lead to a sustainable groundwater resource management practice.

4.4.3.8 Conflict resolution

Citizen science projects are typically multi stakeholders' process, involving project coordinators, citizens, and government representatives amongst other relevant stakeholders. In effect, monitoring project should include a process of resolving the inevitable conflicts between competing goals and creating regular opportunities and mechanisms for community oversight (Pandya, 2012). As such a successful monitoring program must be built on strong advisory committee with adequate representation of all stakeholders; whose interest or involvement can determine the success or failure of projects.

4.4.3.9 Ownership

The success of monitoring project depends on the how stakeholder perceives the project as theirs. Co ownership has best been used as a descriptor for citizen science projects (Pandya, 2012). In this sense all stakeholders in the monitoring of groundwater levels, need to attain a sense of ownership. As a common pool resource, knowledge, empowerment, trust, engagement and adequate representation are key component to ensure that community members amongst stakeholders feel the sense of ownership of projects and equipment (Walker et al., 2016; Buytaert et al., 2014). Furthermore, this can be enhanced through focus group meetings, workshop, seminar and adequate reporting.

4.4.3.10 Adaptive

The perception of adaptation in the citizen science framework appears to be more technical than theoretical. Adaptation means that the monitoring projects must be promoted by new practices and technologies. Jadeja et al., (2015) perceived that adaptation depends on the ability for monitoring project to de-mystify issues regarding groundwater resources. This implies that communities/citizens have to understand the science and processes behind monitoring projects. Such response must be guided by the introduction of new technology into monitoring alongside learning mechanisms. According to the case study of Nepal by Buytaert et al., (2014) adaptation appear not to be planned, but a product of socio economic and/or political changes. Thus increased knowledge of groundwater issues, can lead to community getting more curious, or willing to manage groundwater resource in the face of complex socio-economic conditions.

4.4.3.11 Engagement

A key value of citizens' participation in monitoring project is that it creates a means to engage community amongst other interested individuals. Walker et al., (2016), argued that the engaging local community and making them to express or feel a partnership in project should supersede seeing community as a subject of research. Crucial methods of engaging community include training, workshops and allowing members to be hand on projects (Jadeja et al., 2015). For successful monitoring of groundwater levels, engagement can be achieved through building strong partnership with locally based organization (Little, Hayashi & Liang, 2016). It is more often the responsibility a project coordinator/manager to engage community, which can be done through visits well sites, presenting and clarity on the objective of the monitoring projects (Little, Hayashi & Liang, 2016). Development of sound database and strong communication line is vital to engaging community on a regular base (Pandya, 2012).

4.4.3 Collaborative plan for monitoring of groundwater levels

This section present a collaborative action plan for the monitoring of groundwater levels in West Coast. Through the application of collaborative drivers on selected cases, the actions, processes and response were outlined and discussed on driver-driver bases (refer to section 2.4.2). The established institutional roles, processes and outcomes were applied/cross matched with institutional framework in West Coast. The section argues that participation in the monitoring of groundwater can only be achieved when the role of citizens and other stakeholder are clearly understood and integrated, with linkages established based on collaborative drivers. Monitoring of groundwater levels and groundwater management depends of institutions relating at all levels (Pietersen, Beekman & Holland, 2011) and citizen science present a tool for establishing the roles and multiple partnerships (Thornton & Leahy, 2012). Therefore, based on the conceptual framework, this section makes use of the finding from previous section in developing an action plan across various institutions, depending of the type of project.

The result finding shows that at local institutional level, higher institutions includes Department of Water and Sanitation, Municipalities, Catchment Management Agencies and Research Organization. They are classified in terms of governance structure, role played in terms of management, capability to initiate, support or fund monitoring programs as well as provision of experts (DWAF, 2004a: 2004b; Taylor et al., 2012; Pietersen, Beekman & Holland, 2011; DWS, 2016). For instance the, Water Act 1998 places the Department of Water and Sanitation (National/regional) as the highest authority in the management of all water resources and the Municipal Acts 2000 place Municipalities as a key institution in groundwater resource management at local levels (Shershen et al., 2016). In addition the national government works with research institutions such as Water Research Commission in the development and management of groundwater.

Grounded on case study government or higher institutions should play a significant role in the funding and issuing of grant for monitoring of groundwater levels projects. Funds are significant for the acquisition of tools, equipment, human resource management, required to facilitate the recruitment, training and data collection, data management and reporting. Additionally, higher institutions are required to be active in the empowerment of water association, farmers, interested water user and individual. Such empowerment can be achieved, through the provision of incentives, communication planning and feedback to the community on action plans, state of groundwater resources and increase campaigns and awareness programs.

As a crucial role, the higher institutions are responsible for the provision of human capacity in the form of experts (Pandya, 2012). Thus, higher institutions must strengthen provisions for recruiting groundwater experts and training of staffs, such as Managers and Hydrologist. This capacity can be enhanced through in-house training required to develop pertinent skills on the development of citizen science driven projects. On the other hand, the higher institutions can outsource consultants to fulfill the role of project coordinators until the development of the Catchment Management Agencies and/or there are adequate staffs

Project coordinators are expected to design projects as well as actualize it through the phases of recruitment, training and ensuring that appropriate data management practices are used in reporting and feedback (Manda & Allen, 2016; Little et al., 2018). Project coordinators are identified as hydrologist, managers and consultants that have the adequate hydrological knowledge to train citizen to monitor as well as oversee monitoring projects. To achieve collaboration, it is the responsibility of the project coordinator to communicate the role(s) of citizen in clear and articulated manner, in addition to reporting to funders and higher institutions (Jadeja et al., 2015). Between project coordinators and citizens it is important to have a proper line of regular communications, using means such as mobile phone group chats, social media, email, phone calls. Communication methods should be tailor made to meet the requirement of the participants (Lowry & Fienen, 2013).

It is suggestible that the selection of project coordinators should include current hydrologist from the Department of Water and Sanitation and managers from Municipalities and Catchment Management Agencies; especially those with a wealth of knowledge of groundwater management, challenges and institutional dynamics of the West Coast. This is crucial for the success of project; as such experts are able to run the projects with a good understanding of socio-economic and political status, which may have impacts on the success of projects (Walker et al., 2016). In addition, such understanding is important for ensuring adequate recruitment, conflict resolution and developing satisfactory engagement methods.

Citizens/potential citizen scientists are identified as farmers, water user, local industries and interested individual. Based on the case studies, these categories of stakeholders and institutions are often the source of volunteers (Padeja et al., 2015; Buytaert et al., 2014; to list a few). A key concern is whether citizens are willing to participate (West & Pateman, 2016). However, through adequate representation in project design phase, citizens more than often will show more interest and/or take ownership of projects.

According to the case studies, citizens have two key roles that include contribution to identifying the objective for monitoring and project design, and on field monitoring of groundwater levels (data collection, storage and reporting). However, effective participation, willingness to participate and sense of ownership are conditioned by factors such as the trust, knowledge and level of empowerment. The diagram below (refer to figure 13) presents a collaborative action plan.

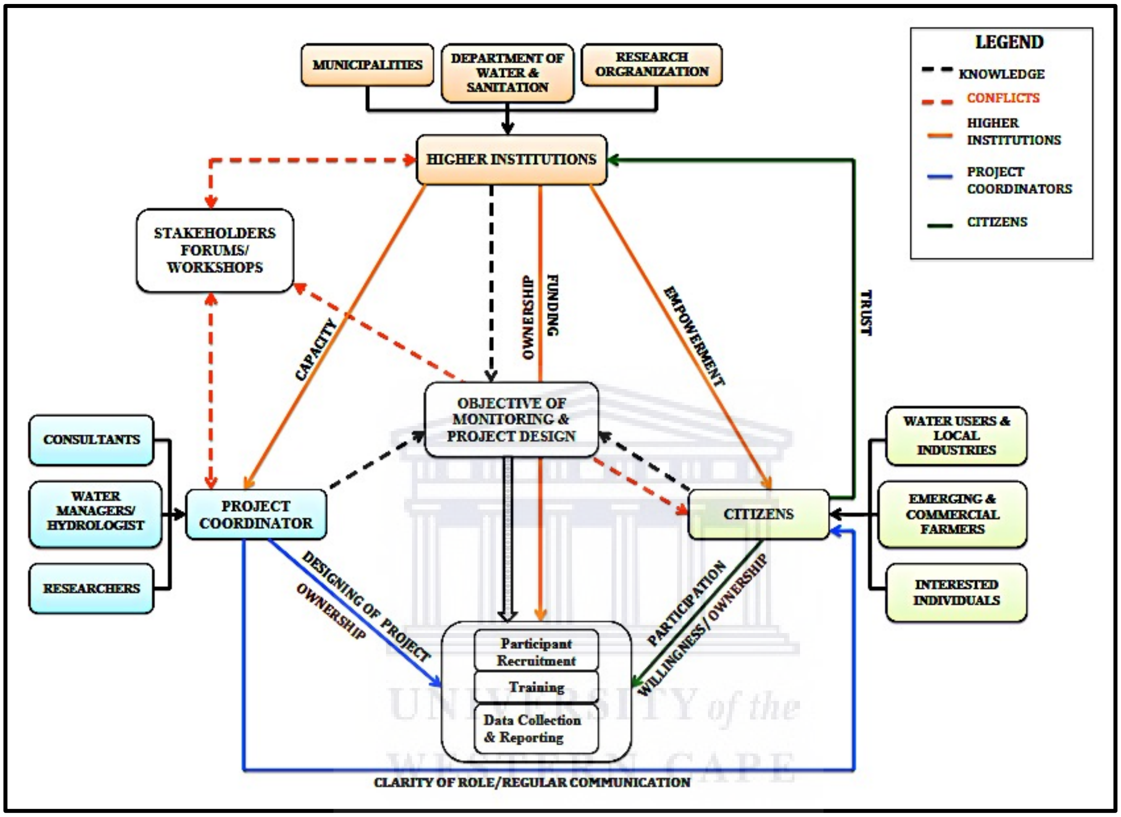

Figure 13: Showing collaborative action plan for the monitoring of groundwater levels.

Knowledge contribution/acquisition and conflict resolution mechanisms are crucial to multi institutional setting. Knowledge ranges from traditional knowledge, scientific literacy and scientific knowledge (Little, Hayashi & Liang, 2016), therefore during the identification of monitoring objectives and project design; an integration of knowledge from community members, project coordinators (scientists) and higher institutions is crucial. For instance, while the objective of the scientist might be to acquire the needed data for modeling, that of a higher institution such as Department of Water and Sanitation could be assessment of water resources and that of the community may include the understanding of groundwater system, or assessment of availability of groundwater for immediate use. The integration of knowledge is supported by the bottom up approach to Integrated Water Resource Management, that anticipate that management practices as much as knowledge must be developed at local levels (Taylor et al., 2010; DWA, 2010; DWS, 2016).

Once more, during implementation there is high chance of conflict due to the multi stakeholder/sector nature of projects (Wijnen et al., 2012); either as a result of a stakeholder not meeting the expectations or conflicting objective. Eventually, there will be a need for a conflict resolution mechanism that allows for all stakeholders to present matters. It is therefore important to have a pathway for conflict, which can be attended to or resolved collectively, through regular workshops, stakeholders' forums, meetings or regular communication.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

South Africa is a semi-arid region whereby groundwater plays a significant role in water supply. Eventually, without adequate implementation of the monitoring of groundwater level, there is an eminent threat to groundwater system; the dependent ecosystems, economy and communities that depend on this source of water either as a sole source or as a means for the argumentation of surface water. As such there is a need to ensure adequate implementation of the monitoring of groundwater levels is achieved, which demands on understanding the role of citizen at community level as well as other institutions that are integrated in groundwater resources management.

Monitoring of groundwater levels remains a key management aspect that provides the data for science-based decision making on groundwater resource management. Such decisions are important for sustainability groundwater resource and water security. However, the implementation of the monitoring of groundwater levels has remained a challenge at all institutional level. Based on governance approach and institutional provisions monitoring of groundwater levels are supposed to be localized and conducted at local-aquifer levels, where the resource resides and can best be managed. There appears to be no concrete evidence of citizen/community participation in the monitoring of groundwater levels. In addition, institutions responsible for the monitoring of groundwater levels tend to be disintegrated, showing less sector collaboration.

This study investigated the use of citizen science in the planning monitoring of groundwater levels network in existing cases. In application of the drivers developed on the case of West Coast, there appears to be a need for the development of a collaborative implementation plan whereby the respective institutions responsible for the monitoring of groundwater levels, understand their roles and responsibilities. Through analysis of the institutional framework, it appears that institutional roles, responsibilities and practices do not align with the integrated water resource framework by which groundwater resource management must take place. There appears to be institutions with overlap of responsibilities and others have remained inactive or uncompleted. For instance, the pending development of the Catchment Management Agencies leaves a void in the coordination and management of groundwater. Even though, pending the completion of the Catchment Management Agencies, it is anticipated based on governance framework (legislative, policies and institutional) that citizen/public at local level are crucial to the management and monitoring of groundwater; currently, the lack of institutional collaboration, private-public partnerships and neglected roles of community in monitoring and management of groundwater seem to be an urgent concern.

The Department of Water and Sanitation has remained the key institution in the monitoring of groundwater levels. However, there is partnership between the Department and research institutions such as the Council for Scientific and Industrial Research to share capacity and expertise. The roles of the municipality have remained unclear in terms of monitoring of groundwater levels. Even when the municipality/local municipalities are involved in monitoring of groundwater levels, the focus tends to be on assessment of water in the aquifer for development purposes/extraction. Still, the data generated in the form of baseline data appears not to be made available to the Department of Water and Sanitation.

Currently, Water Users Associations have remained largely inactive in groundwater resource management. Commercial farmers appear to depend mostly on consultants for the monitoring of groundwater levels; but in the contrary emerging farmers appear to be marginalized. Although, emerging farmers tend to show interest in groundwater resource management, there appears a deficit in term of adequate institutional mechanisms to cater for their integration.

The review of the gaps and barriers to the implementation of groundwater resources shows that challenges include inadequate awareness on groundwater management at local levels, in addition to a complex hydrogeological setting that requires multiple points. Within this complex hydrogeological setting there is a need to be critical in designing monitoring networks that can generate adequate data, requisite to understanding the aquifer system and assessing the effects of anthropogenic and non-anthropogenic factors on groundwater. Yet still, the lack of adequate knowledge or scientific knowledge (such as baseline or historic groundwater levels data) of groundwater system, makes designing of an adequate system exigent. On the social-economic scale, the lack of/or limited funding for the management of groundwater impacts on the needed resources to implement groundwater monitoring. Despite the lack of funding, vandalism of monitoring equipment and poor access (such as lack of/or adequate roads) to groundwater monitoring point has resulted in lack of adequate spatial representation, shutdown and abandonment of monitoring points.

Capacity remains a crucial issue, because even though the institutions contrast the bottom up approach with the Department of Water and Sanitation responsible for most monitoring projects, the department as well suffer a deficit in terms of human capacity and expertise needed to adequately respond to and cater for the dispersed monitoring system. It also appears that at the moment an urgent concern is that there are diverse institutions collecting data on groundwater levels, but due to fragmentation of institutions and lack of cooperation there appears to be weak integration of data.

Even though citizen science presents a framework for the involvement of citizen in science and institutional integration at local levels, there appears to be ambiguity in the definition of collaboration. Additionally, at the moment citizen science appears not to clearly present a mechanism and or a definite blue print applicable to local institutional setting and governance approaches, which varies across the globe. As such, the collective management and participatory approach offered an innovative framework for analyzing collaboration within citizen science case studies. Chosen the framework was not arbitrary as it aligns with/and was developed base on Integrated Water Resource Management approach. The framework also reflects the definitions of collaboration based on world best practices.

To develop a collaborative action plan, the study established which action are linked to the drivers, in cautiously selected citizen science case studies; which stakeholders are involved in such action, and what processes determines the effectiveness of this drivers. Based on analysis it appears that the drivers even though identified differently, in application they are strongly linked in a manner that negating a driver has huge impact on the outcome of the projects. It was as well discovered that different drivers are necessary to link different levels or stakeholders for adequate implementation. For instance, while it's important for the government to provide funds for project development, paying citizen scientists is not a requirement as they assume the role of volunteers. Another instance is that while there is usually a lack of trust between scientists and citizen or citizen and government, issue of trust between the scientist and government seldom appears in any citizen science projects.

Consequently, based on the established actions the drivers were applied within the context of West Coast groundwater resource management institutions. The study demonstrated that implementation of monitoring of groundwater levels can be achieved if the roles of citizens are understood and integrated collaboratively. This approach adopted in the study allows for the understanding of the groundwater institutions and contributes to knowledge of cross-sector integration between groundwater management institutions.

5.2 Recommendation

Good governance remains important to the management of groundwater, thus it is recommends the need to ensure that management is based on a key principles of good governance, as such the bottom up approach should not be conflicted. Again, management of groundwater resource depends of funds; therefore it is recommended that more provisions for funding be made available.

Between stakeholders and institutions, knowledge appears to be a crucial contributor to the success of groundwater resource management, thus there is a need to develop a “community of knowledge” on groundwater resource management. This implies that integration must not only cut across sectors but also need to cut across the wealth of knowledge available within the sectors.

The need to complete the development of the Catchment Management Agencies will be crucial to the collaborative management of groundwater resources. The development of the agencies will be instrumental to assigning roles and delegating institutions towards the effective management of groundwater levels. Mechanisms need to be put into place for adequate representation of the Water Users Association and its integration into management of groundwater resource.

Finally, it is important that further studies be conducted on the institutional frameworks for groundwater management, especially at local levels.

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