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LYDIA KWOYIGA

Institutions, Groundwater Resources and Climate Change Adaptation in Northern Ghana

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Dissertation

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Editor

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Institutions, Groundwater Resources and Climate Change Adaptation in Northern Ghana

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by

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ABSTRACT

Climate change and its impacts are evident both globally and locally, manifesting in every sphere of life including natural resources. The African continent is considered the most vulnerable to these impacts while Ghana was ranked the 59th most vulnerable country to climate change in the world in 2014. Studies about groundwater resources under climate change point to some already occurred impacts with more anticipated. It is noted that climate change will exacerbate water stressing situations in Ghana as groundwater resources will be negatively affected. For instance, future scenarios indicate a general reduction in groundwater recharge of 5-22 % for 2020 and 30-40% for 2050. Already, the northern part of the country where most of the population depends on groundwater is noted for fallen groundwater tables. Therefore, in order to address these impacts in Africa, the role of institutions in promoting adaptation has been identified as one of the strategies. It is realised that institutions shape the nature of the impact of climate change, influence the way communities respond to climate change and serve as the intermediaries for external support. A glean of institutions in Ghana shows a plethora of them that are directly or indirectly regulating activities relating to water resources in the face of climate change. The thesis, therefore, looks at the nature of these institutions (state/formal) and their roles in promoting groundwater adaptation to climate change. In order to understand in detail the "how" and "why" of adaptation in relation to groundwater resources and also have a multi-perspective discussion that considers the voices of all relevant groups of actors together with their interactions in promoting groundwater resources adaptation, the study adopted a qualitative approach and made the Atankwidi catchment a case study area. Using triangulation, data were drawn from both primary (community/office interactions) and secondary sources and augmented by analyses of policy documents. The results of the study revealed that at both the national and sub-national levels, there is a multiplicity of state formal institutions in the form of laws, policies and administration even though there is currently no legislation designed in Ghana that focuses specifically on climate change adaptation. Focusing on the themes of groundwater adaptation, managing groundwater demand for domestic purposes appear to be receiving greater attention while storage, discharge and recharge need improvement. Like the Inuit in the Canadian Arctic, groundwater farmers of Atankwidi based on local knowledge have identified methods of adapting to the impacts of climate change on groundwater in the form of deepening wells, changing crop types, conjunctively using both surface and groundwater water and migrating to other places. Nonetheless, this local knowledge for promoting adaptation is limited. Therefore, formal institutions can enhance the scope of this knowledge by first of all recognising and documenting this knowledge as part of adaption efforts. Additionally, these institutions should educate and update local knowledge holders about some scientific methods of groundwater adaptation. This will create a new form of knowledge which is integrated and comprehensive enough to function independently to promote adaptation. Associated with this, farmers should be guided in adopting artificial methods of groundwater recharge that are anchored on local knowledge to boost groundwater availability. Inspired by the achievements of some existing artificial groundwater recharge methods in same northern Ghana, the thesis identified that the adoption of Managed Aquifer Recharge methods such as a subsurface dam in Atankwidi is feasible. This is premised on the fact that apart from the geophysical parameters of the catchment, it is realised that the institutional environment (both formal and informal) and the existence of local materials coupled with local knowledge support the construction and management of a subsurface dam. The thesis concluded that artificial recharge will contribute to promoting adaptation since natural recharge may be negatively affected over time due to the

nature of rainfall pattern caused by climate change coupled with increasing population growth and booming groundwater dry season irrigation.

Zusammenfassung

Der Klimawandel und seine Auswirkungen sind global und lokal sichtbar und manifestieren sich in allen Lebensbereichen, einschließlich denen der natürlichen Ressourcen. Der afrikanische Kontinent gilt als am anfälligsten für diese Auswirkungen. Ghana wurde 2014 auf Rang 59 der für den Klimawandel anfälligsten Länder geführt. Studien über Grundwasserressourcen und Klimawandel zeigen bereits eingetretene Auswirkungen und deuten auf darauf hin, dass sich der Einfluss des Klimawandels auf das Grundwasser zukünftig noch verstärken wird. Der Klimawandel wird die Wasserknappheit in Ghana verschärfen, da die Grundwasserressourcen negativ beeinflusst werden. Zukunftsszenarien zeigen beispielsweise, dass die Grundwasserneubildung im Jahr 2020 um 5-22% und bis 2050 um 30-40% zurückgehen wird. Der nördliche Teil des Landes, in dem der Großteil der Bevölkerung vom Grundwasser abhängig ist, ist bereits jetzt von fallenden Grundwasserspiegeln betroffen. Um diesen Auswirkungen in Afrika entgegenzuwirken, wurde die Rolle der Institutionen bei der Förderung der Klimawandelanpassung als eine mögliche Strategie identifiziert. Institutionen können die Auswirkungen des Klimawandels auf eine Region mitprägen, sie können beeinflussen wie Gemeinschaften auf den Klimawandel reagieren, und als Vermittler für Unterstützung von außen dienen. Eine Zusammenstellung relevanter Institutionen in Ghana, die direkte oder indirekte Aktivitäten im Zusammenhang mit Wasserressourcen und Klimawandel regulieren, zeigt deren Fülle. Diese Arbeit beschäftigt sich mit der Art dieser (staatlichen) Institutionen und ihrer Rolle bei der Förderung der Klimawandelanpassung des Grundwassers. Um das „Wie“ und „Warum“ dieser Anpassung im Detail zu verstehen und eine multiperspektivische Diskussion zu ermöglichen, bei der die Stimmen aller relevanten Akteursgruppen zusammen mit ihren Interaktionen bei der Förderung der Grundwasserressourcenanpassung berücksichtigt werden, verfolgt diese Studie einen qualitativen Ansatz mit dem Atankwidi-Einzugsgebiet als Fallstudie. Mittels Triangulation wurden Daten aus primären (Gemeinebefragungen) und sekundären Quellen gesammelt und durch Analysen von Richtlinien ergänzt. Die Ergebnisse der Studie zeigen, dass es sowohl auf nationaler als auch auf subnationaler Ebene eine Vielzahl staatlicher, formaler Institutionen in Form von Gesetzen, Richtlinien und Verwaltung gibt, obwohl in Ghana derzeit keine Gesetzgebung existiert, die sich speziell mit der Klimawandelanpassung befasst. Bezogen auf die Anpassung des Grundwassermanagements, wird der Bewirtschaftung des Grundwasserbedarfs für häusliche Zwecke viel Aufmerksamkeit zuteil, während die Speicherung, Entsorgung und Anreicherung von Wasser ungenügend betrachtet werden. Wie die Inuit in der kanadischen Arktis, haben die Landwirte von Atankwidi auf Grundlage des lokalen Wissens Methoden zur Anpassung an die Auswirkungen des Klimawandels auf das Grundwasser entwickelt, beispielsweise in Form von Vertiefungen von Brunnen, Änderung der Kulturpflanzenart, gleichzeitiger Nutzung von Oberflächen- und Grundwasser oder der Umsiedlung in andere Gebiete. Trotz der Tatsache, dass ihr lokales Wissen eine Anpassung ermöglicht, ist der begrenzte Umfang dieses Wissens als eine Schwachstelle anzusehen. Formale Institutionen können den Umfang dieses lokalen Wissens nutzbar machen und erweitern, indem sie dieses Wissen über Anpassungsmaßnahmen anerkennen und dokumentieren. Darüber hinaus sollten diese Institutionen lokale Gemeinden über weitere wissenschaftliche Methoden der Grundwasseranpassung informieren. Dadurch wird zusätzliches Wissen geschaffen, das integrierbar und umfassend genug ist, um eine unabhängige Anpassung zu fördern. Zusätzlich sollten Landwirte angeleitet werden, auf lokalem Wissen basierende Methoden der künstlichen Grundwasseranreicherung anzuwenden, um die Verfügbarkeit von Grundwasserressourcen zu erhöhen. Inspiriert von den Erfolgen einiger Anlagen zur künstlichen Grundwasseranreicherung

im Norden Ghanas, empfiehlt diese Doktorarbeit die Implementierung von künstlichen Grundwasseranreicherungsanalagen in Atankwidi. Diese Empfehlung stützt sich auf den günstigen geophysikalischen Gegebenheiten des Einzugsgebiets und der Tatsache, dass das (formelle und informelle) institutionelle Umfeld eine Implementierung ermöglicht. Diese Arbeit kommt zu dem Schluss, dass die Anpassung der Grundwasserressourcen im Norden Ghanas mehr Aufmerksamkeit im Bereich der künstlichen Anreicherung erfordert, da die natürliche Grundwasserneubildung aufgrund der durch den Klimawandel verursachten veränderten Niederschlagsmuster in Verbindung mit einem zunehmenden Bevölkerungswachstum und einer boomenden Trockenzeitbewässerung im Grundwasser starke Veränderungen hervorrufen wird.

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ABBREVIATIONS AND SYMBOLS

AMOR	Aquifer Management Organisation
ASR	Aquifer Storage and Recovery
CIDA	Canadian International Development Agency
CSIR	Centre for Scientific and Industrial Research
CWSA	Community Water and Sanitation Agency
DA	District Assembly
DAAD	Deutscher Akademischer Austauschdienst
DANIDA	Danish International Development Agency
ECOWAS	Economic Community of West African State
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organisation
GCM	General Circulation Models
GMet	Ghana Meteorological Agency
GSB	Ghana Standard Board
INOWAS	Innovative Web-Based Decision Support System for Water Sustainability under a Changing Climate
IUNC	International Union for Conservation of Nature
IWRM	Integrated Water Resource Management
IPCC	Intergovernmental Panel on Climate Change
LI	Legislative Instrument
MA	Municipal Assembly
MAR	Managed Aquifer Recharge
MESTI	Ministry of Environment, Science Technology and Innovation
NGO	Non-Governmental Organisations
NIE	New Institutional Economics
PI	Pit Infiltration
RCC	Regional Coordinating Council
SWAT	Soil and Water Assessment Tool
TCPD	Town and Country Planning Department
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate change
WASCAL	West African Science Service Centre on Climate Change and Adapted Land Use
WATSAN	Water and Sanitation Management Committees
WCED	World Commission on Environment and Development
WHO	World Health Organisation
WRC	Water Resources Commission

1. GENERAL BACKGROUND

Groundwater resources constitute a major and reliable source of water supply to many people globally. According to FAO (2016), groundwater is locally available, more reliant especially during droughts, regulates ecosystems and microclimates and provides quality water. Calow and MacDonald (2009) therefore, explained that most rural areas depend on groundwater for water supply: as there is a low cost associated with its development, easily accessed by population centres and more reliable than surface water. In Africa, groundwater meets the drinking water needs of 60% of the 1 billion population in the continent and addresses growing food insecurity through irrigational activities (Vaessen and Brentführer, 2015).

Ghana is endowed with groundwater resources (Johnston and McCartney, 2010) of which most communities rely on for potable water supply because it is safer than surface water, easier to develop in remote areas and reliable even in protracted drought (Ofosu-Addo et al., 2008). According to Kortatsi (1994), groundwater is seen as a cheaper means of meeting the domestic and agricultural water needs of most rural and some urban areas. As such, about 80% of domestic water needs are met through groundwater with approximately 56% of rural communities nationally depending on it (Johnston and McCartney, 2010), while 80% of the urban population in the Upper East and West Regions of Northern Ghana depend on it for their water supply (Martin and Giesen, 2005).

Nonetheless, studies show that climate change will affect groundwater resources globally. Regarding the situation in Ghana, Kankam-Yeboah et al. (2009) noted that even without climate change and its impacts, the country will become water stressed by 2025. Climate change will further exacerbate the situation as it will for instance result in a general reduction in groundwater recharge of 5-22 % for 2020 and 30-40% for 2050. Using WATBAL model to evaluate potential impacts of climate change on subsurface and base flow for groundwater resources in the Volta Basin, the results showed a reduction in recharges of 17%, 5% and 22% for Pra, Ayensu and the White Volta respectively in the year 2020 while for 2050 these values will increase to 29%, 36% and 40% for the representative basins (Water Resources Commission, 2008).

Specifically on Atankwidi catchment (a tributary of the White Volta basin) where the population depends almost entirely on groundwater for their livelihood activities, with some smallholder farmers relying on shallow aquifers for groundwater to undertake irrigation, Martin (2006) in her study D*evelopment of a water balance for the Atankwidi catchment, West Africa: a case study of groundwater recharge in a semi-arid climate* brought to the fore that groundwater abstraction seems to have already exceeded sustainable levels in the Atankwidi catchment. Further more, it is revealed that there are already records of incidence of fallen water tables in the entire northern part of the country (Johnston and McCartney, 2010). Characterised by these, the situation implies that the impacts of climate change on groundwater resources in Atankwidi (though yet to be established clearly) will be more severe if measures are not taken.

Rather than ignore the impacts of climate change, Taylor et al. (2010) recommended the adoption of adaptative measures as far as groundwater use is concerned while enhancing groundwater resource development. In order to achieve this, Clifton et al. (2010) suggested the creation of institutions to regulate the process. FAO (2016) opined that institutional framework of groundwater systems can contribute to adapting to the impacts of climate change. The IPCC (2014) also supported this by stating that institutional development can contribute to achieving adaptation.

Regarding the situation in Africa, Niang et al. (2015) argued that institutional development is critical for addressing climate change and its impacts on the continent, as this will justify Africa's

ability to move forward regarding adaptation. Madzwamuse (2011) added that institutions are critical in Africa for climate change adaptation as a number of them are already in place spearheading policy formulation and implementation, conducting research, building capacities of stakeholders and guiding in implementing climate change initiatives.

A glean of institutions in Ghana shows a plethora of them that are directly or indirectly regulating activities relating to water resources in the face of climate change. The first two objectives of the study are therefore to assess those formal government (state) institutions that promote adaptation of groundwater resources in Atankwidi and how these are performing.

Local knowledge is considered important for adaptation. Salick and Byg (2007) admitted that based on local observations and cultural framework, local people in the Arctic regions have been globally recognized for their ability to build strong ties with scientists regarding climate change impacts and adaptation. Pearce et al. (2015) asserted that local knowledge built around the natural environment has enabled the Inuit in the Canadian Arctic to adapt to climate impacts. The importance of this knowledge is also recognised in Ghana in the country's Climate Change Adaptation Strategy, 2013 (Ministry of Environment, Science and Technology, 2013). However, the document bemoaned its weaknesses especially its scope (ability to stand on its own) in addressing the impacts of climate change. Thus, the next objective of the study is to identify how institutions can enhance/strengthen local knowledge for adaptation in Atankwidi.

Artificial methods that employ engineering techniques have been hailed as a way of boosting groundwater recharge and storage to promote groundwater adaptation to climate change. These methods which include Managed Aquifer Recharge (MAR), therefore, have been adopted (Stefan and Ansems, 2018) as they are considered tools capable of promoting groundwater adaptation to climate change and its impacts (Dillon et al., 2018). One therefore, finds MAR methods in the form of Pit Infiltration and Aquifer Storage and Recharge schemes in some parts of northern Ghana for their ability to make groundwater available for livelihood activities especially irrigation in the dry season. The last objective of the study looks at the feasibility (institutions) of implementing MAR schemes in Atankwidi as part of efforts to promote groundwater availability in the face of climate change and its impacts. The overall aim of the thesis is, therefore, to assess the role of formal government institutions in regulating groundwater resources adaptation to the impacts of climate change in the Atankwidi catchment of Northern Ghana.

1.1. The objectives of the study

The following therefore, cover the general objectives and specific research questions of the study:

1. To examine the nature of formal groundwater resource institutions in relation to climate change adaptation.
    a. What formal government institutions exist at the national level?
    b. What formal government institutions exist at the subnational (district/municipal) level?
2. To assess the performances of these institutions in regulating groundwater resources adaptation to climate impacts with a focus on Quality; Recharge; Discharge; Demand; Storage
3. To discuss local knowledge for groundwater development and use for dry season irrigation and how institutions can strengthen it for adaptation.
    a. What are the limitations of this knowledge regarding adaptation in Atankwidi?
    b. How can formal government institutions strengthen this knowledge for adaptation?

4. To explore the feasibility of implementing Managed Aquifer Recharge as a method of augmenting groundwater availability for dry season irrigation as part of adaptation.

   Which specific MAR type may be suitable in the catchment?

1.2. The scope of the study

As a transboundary catchment, the Atankwidi catchment which covers six (6) communities and four (4) districts all in the Upper East Region in the northern part of Ghana is the main focus of the research. In order to understand the nature of groundwater resources adaptation in the catchment, formal (state) government institutions at both the national/state level and subnational (district/municipal) level that deal with groundwater adaptation in the catchment will be mapped out. The performances of these institutions will further be explored. Local perceptions of climate change will be sought from all groundwater users in the catchment. However, in the study of how institutions can enhance local knowledge for adaptation, local knowledge of dry season groundwater farmers will only be discussed. Moreover, the search for alternative means of boosting groundwater availability will be to primarily address the groundwater needs of dry season groundwater farmers. Primary data are needed for the study and will be obtained through two fieldstrips in northen Ghana. The first fieldtrip will be undertaken between May and October 2017 while the second one will take place between September and October 2018.

1.3. Structure of the study

The thesis starts by exploring the importance of groundwater resources globally and the situation in Ghana. It then looks at the state of these resources under climate change and its impacts and how institutions can contribute to adaptation especially in African countries such as Ghana. Chapter Two of the study reviews the existing literature relating to definitions, theories/debates and discussions of the concepts embedded in the topic. This is to offer a clear understanding and give a direction to and approach for tackling the topic.

In order to address the research objectives of the topic, a methodological approach is desired and this is contained in Chapter Three. Largely as a qualitative study, the general research design, the study area, methods of data collection and analyses and research limitations are discussed here. Chapter Four provides some background information about the nature of climate change and its impacts using two climate parameters such as rainfall and temperature. Meteorological data from the Navrongo Weather Station, the nearest station to the Atankwidi catchment and local views from catchment dwellers provide some insights. Chapter Five addresses the first research objective that is identifying those institutions concerned about groundwater adaptation to climate change. The discussion is put into two levels: national and subnational.

Chapter Six looks at the performances of these institutions in relation to the five thematic areas of adaptation. Though local knowledge proves relevant for adaptation, it needs to be strengthened which can be achieved through institutional support. This is discussed in Chapter Seven. As a way of proposing MAR to boost groundwater availability for dry season irrigation, a feasibility study advocating for the construction of a subsurface dam is discussed in Chapter Eight. The last chapter which is Chapter Nine concludes the discussion of the thesis by reflecting on the relationship between the existing literature and the topic. It further highlights the key issues noted in the study with some recommendations made.

2. REVIEW OF THE EXISTING LITERATURE

This chapter explores the existing literature in view of the concepts, definitions and theories embedded in the study topic. It further tries to show the linkages or relationships that exist between and among the key components or parts of the topic which is illustrated by the conceptual framework (Figure 1). The conceptual framework depicts the nature of the problem which is climate change manifesting in changes in rainfall and temperature which correspondingly affects both groundwater quality and quantity. The role of formal institutitons is therefore proposed as seen in the four research objectives whose activities must focus on the five thematic areas of adaptation. It is expected that when the five themes of groundwater adaptation are addressed, this will in the long run positively affect groundwater quantity and quality.

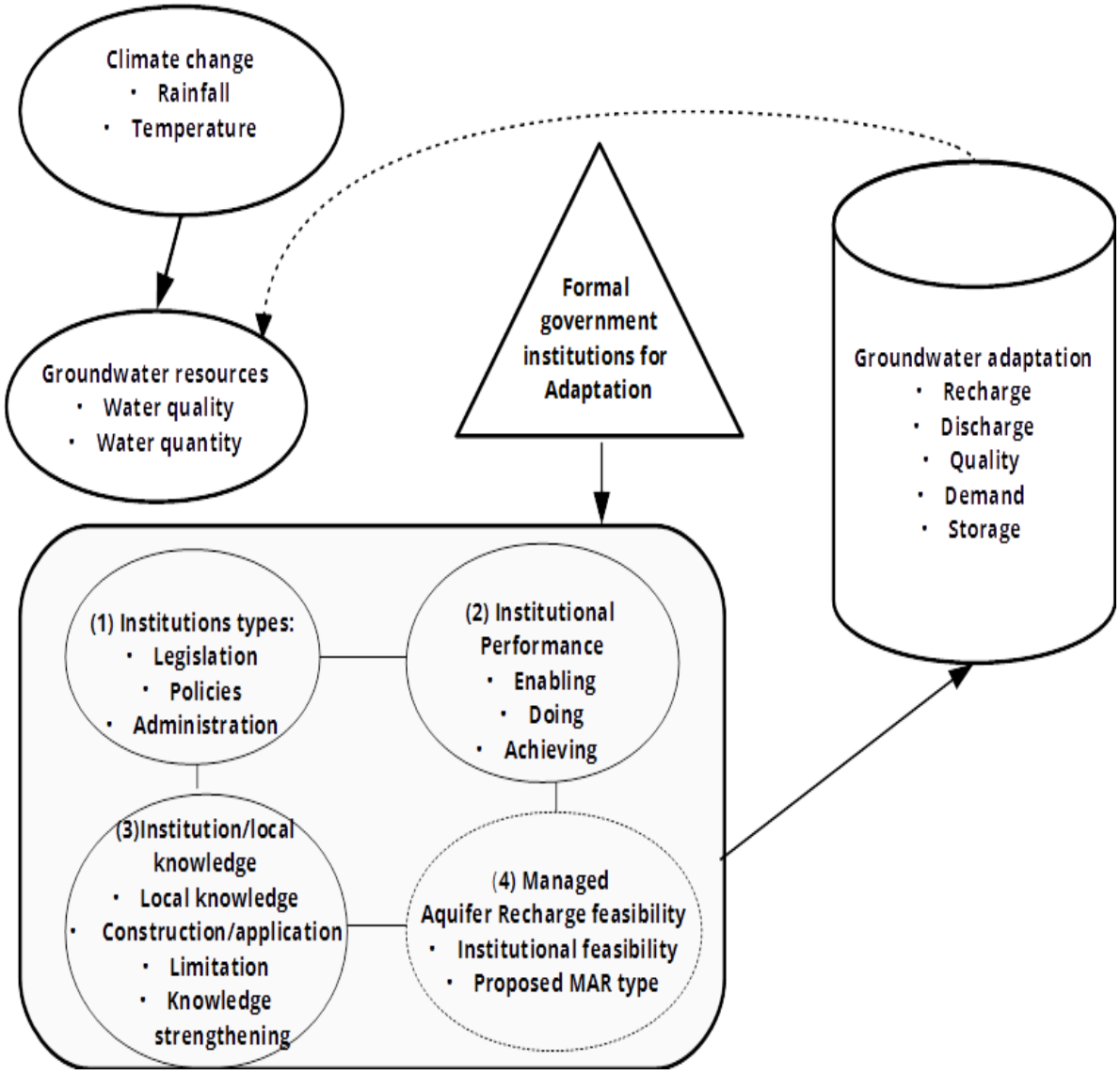


Figure 1. Conceptual framework of the topic

2.1. Definitions, concepts and theories

2.1.1. What are Institutions?

Institutions connote different things to different people and this makes it difficult to identify any clear definition of it in academic literature (Rauf, 2009). Vatn (2005), therefore, stated that it is not possible to have a commonly agreed definition of institutions because according to De Koning (2011) there are several schools of thought that discuss institutions, with these discussions still going on.

Notwithstanding this, North (1990:1) in his seminal book *Institutions, Institutional change and Economics Performance* defined institutions as "the rules of the game in a society". Ostrom (2010) explained that institutions are the rules, norms and strategies which guide the activities and behaviour of individuals in an organisation. A definition by Helmke and Levitsky (2004) stated that institutions are the rules and procedures (both formal and informal) that structure social interaction by constraining and enabling actors' behaviour.

Situating institutions within the context of resources use, Bandaragoda (2000:4) discussed that "institutions set the ground rules for resource use and establish the incentives, information, and compulsions that guide economic outcomes". This definition though good, has failed to recognise that the outcomes of institutions as being applied in resource use go beyond just economic gains as there may be others like religious and social outcomes. Focusing specifically on formal institutions in relation to water resources, they have been defined as the "rules that define action situations, delineate action sets, provide incentives and determine outcomes… in the context of water development, allocation, use and management" (Saleth, 2006:4). Within the context of climate change adaptation, O'Riordan and Jordan (1999) defined institutions as the various ways of bonding society with a sense of purpose and ability to adapt. More literature about institutions within the context of groundwater resources has been reviewed already (see Kwoyiga, 2019).

2.1.2. Nature of Institutions

Regarding their nature, Vatn (2005:9) demonstrated that "institutions can be viewed as both formal and informal structures. The latter is made up of norms and conventions….they are normally not written down, but highly internalised and almost invisible. In the distribution of resources under the informal structures, kinship ties and social positions play immense roles". The formal and informal nature of institutions has also been recognized by Fukuyama (2006) who viewed the former as the written or codified laws while the latter constituted norm or inherited social practices. Drawing from social theory, legal pluralism, ethnography and political ecology using examples from Africa, institutions are "both formal and informal; they are often multi-purposed, intermittent and semi-opaque in operation. These include designed arrangements of varying degrees of publicness and formality, institutionalised interactions as embodied in kinship and social networks, relations to reciprocity and patronage and in sets of norms and practices deeply embedded in the habits and routines of everyday life" (Cleaver, 2017:13-14). Hodgson (2006) has, however, cautioned the distinction between "formal" and "informal" institutions or rules, which he said is sometimes misleading. As such one is required to specify more clearly what is meant in each case.

Putting it differently, Polski and Ostrom (1999) treated institutions as an embodiment of laws, policy or procedure, or informal norms, standard operating practices or habits which evolved over time. Similarly, Bandaragoda (2000) viewed them as a composition of policies in the form of national policies, local government policies and organizational policies; laws like formal laws, rules and procedures, informal rules, norms and practices and internal rules of organizations;

administration encompassing organizations at policy level for resources management and organizations at implementation level for delivery management.

Still on their nature, O'Riordan and Jordan (1999) viewed institutions as rules that embody values, norms and views of the world, they take time to develop and once developed, they have a degree of permanence and are relatively stable and they are continually re-negotiated in the permanent interplay between conscious human agency and the wider structures in society over which individuals have relatively little control.

Furthermore, institutions by their nature operate at different levels. This has been noted by Kemper (2007) who put it that institutions in the form of formal and informal structures are applied at the national, state, provisional or community level. This has been supported by Livingston (2008) who discussed institutions as being "nested" at several levels.

Drawing from the myriad of these definitions and the nature of institutions, the thesis sees institutions as both formal and informal structures. The formal institutions are in the form of policies, laws or legislative instruments and administrative structures while the informal institutions entail norms, taboos, traditions, practices among others which have historical connotations, hold important the social environment, and operate outside officially sanctioned channels. These institutions shape social interactions among people and groups on daily basis, evolve to serve several purposes and are dynamic in nature. Therefore throughout the discussion in the thesis, formal government institution will be viewed in line with Saleth and Dinar (2004) discussion of institutions in their study *Evaluating Water Institutions and Water Sector Performance* where they decomposed these in the form of **laws, policies and administration** which in other discourses are termed the Institutional Environment as will be noted soon. Limiting the discussion to only formal institutions does not mean that informal institutions are insignificant. As a matter of fact, Kwoyiga and Stefan (2019) and Kwoyiga (2019) revealed the importance of informal institutions as far as groundwater resources and irrigation are concerned in the catchment. The thesis chooses to carry out the discussion along the lines of formal institutions in order to tailor it towards formal adaptation efforts usually initiated and spearheaded by states or governments in the discourses of climate change adaptation. It is also to offer the thesis a specific but limited focus which allows for detailed discussions of the topic.

2.1.3. Debates/theories of Institutions

There is a lot of literature that theorise institutions depending on the given school of thought. Theories in the late 20th and the beginning of the 21st centuries looked at institutions within the domain of Economics (Veblen, Commons and Schumpeter), Political Science (Burgess and Willson) and Sociology (Weber, Durkheim and Parson). This discussion according to De Koning (2011) is considered the traditional perspective (Old Institutionalism) where formal institutions (state) were the point of focus with the individual at the centre. Viewed as being functionalistic and deterministic, this perspective was criticised.

These discussions continued and gained momentum in the 1980s. Dominant among the institutional debates at this time were arguments by the New Institutional Economics (NIE) which criticised Mainstream Economics for being abstract and far removed from real life situations (Coase, 1998). This school of thought is grounded in the fields of transaction cost economics, property rights economics and economic contract (Richter, 2005). Notable contributors to the NIE are Douglas North, Ronald Coase and Oliver Williamson (who is believed to have coined the term NIE in 1975). The core argument of the NIE is that, "institutions matter and are susceptible to analysis" (Williamson, 1996:3). Central to these discussions is the role of formal institutions. This group of writers while acknowledging the importance of informal institutions tended to focus largely on formal institutions. For instance, Hart (2001) who associated informal institutions with

norms argued that although norms are important, it is difficult to integrate them into theory and this may continue in the future. Williamson (2000) who came out with what is called the Institutional Environment (laws, policies and administration) also acknowledged the importance of informal institutions but contended that they are underdeveloped and change very slowly hence NIE prefers neglecting it in its discussions.

Nonetheless, the NIE has also received a backlash for its analysis and focus of institutions. This critique comes from what De Koning (2011) called Critical Institutionalism, an aspect of emergent Post Institutionalism. The Critical Institutionalism perspective draws examples from the nature of institution in Africa to critique the NIE for being limited in defining institutions and for focusing more on formal institutions. Detail discussions of New Institutionalism and Critical Institutionalism and their applications within the context of groundwater irrigation in Ghana is captured in Kwoyiga (2019).

2.1.4. Institutions and climate change adaptation

The role of institutions in influencing behaviour regarding resources management and decisions is evident in some discourses. For instance, Hall and Soskice (2001) noted that institutions influence human behaviour by reducing the uncertainty that actors have of one another as they enable the exchange of information among the actors, they monitor behaviour and define the sanctions for non-compliance. In the words of Vatn (2005), institutions regulate life in society. "Institutions enable ordered thought, expectation, and action by imposing form and consistency on human activities" Hodgson (2006:2). In the same vein, Bandaragora (2000) asserted that "some water-related institutions, such as those governing water user associations, are designed to promote organised behaviour and equity and provide various opportunities for individual and group advancement, thereby serving to liberate human action." (Bandaragora, 2000:7). They also define instruments for managing natural resources management (Kemper, 2007). Instruments in the form of water markets, tariffs, taxes, charges, subsidies among others determine the amount or volume of water that a user may be entitled to at a given point in time. The goal is to promote the optimum use of resources especially under challenging conditions such as climate change.

Within the context of climate change adaptation, O'Riordan and Jordan (1999:81), posited that "institutions help to define climate change both as a problem and a context, through such socialised devices as the use of scientific knowledge, culturally defined interpretation of scientific findings, and politically tolerable adaptation strategies". Looking at the way local level institutions influence climate change, Agrawal et al. (2008) posited that local institutions shape the impact of climate change on communities, shape the way communities respond to climate change and serve as the intermediaries for external support to adaptation. "Institutions such as insurance and the pooling of resources have a long history of dealing with hazards and hedging property rights against uncertainty and are indeed being investigated as a form of adaptation against climate change" (Roggero et al., 2018:417). It is realised that for society to adapt to impacts of climate change, institutions are important because they enable society to respond to damages or benefits of climate by guiding that society to choose the best adaptation option (Gupta et al., 2010).

In their study of *the role of institutions in managing local level climate change adaptation in semi-arid Zimbabwe,* Mubaya and Mafongoya (2017) concluded that institutions facilitate adaptation while institutional arrangements which are informal in nature encourage collective actions which support vulnerable communities to adapt. Using Nepal as an example, Chhetri et al. (2012) revealed that a multilevel institutional partnership involving farmers and non-governmental organizations combined with local knowledge is accelerating agricultural adaptation to climate change. Maharjan and Maharjan (2017) confirmed that institutions are contributing to

formulating and implementing national plans and strategies of adaption in Nepal. After examining what constitutes institutions, it will be prudent to delve into what groundwater means in order to establish a connection between it and institutions hence the need for the subsequent discussions.

2.2. Groundwater and climate change

2.2.1. Groundwater in the hydrologic cycle

According to Job (2010), groundwater is a component of the hydrologic cycle found in the subterranean region and constituted the second smallest of the four 'pools' of water in the earth's ecosystem. Page (1987) explained that groundwater refers to the subsurface water found specifically below the water table in the saturated zone. Gupta (2011) related to the explanation given by Page (1987) and stressed that groundwater should not be confused with subsurface water as the latter refers to the total water column lying below the earth's surface. He explained that the region between the soil and water table is considered the unsaturated or vadose zone as this zone is occupied by both air and water. The water table separates the unsaturated zone from the saturated zone and as the water table (pressure is equal to atmospheric pressure) is often mistakenly equated to the groundwater, it only denotes the upper part of the groundwater where hydraulic pressure is equal to atmospheric pressure. Groundwater, therefore, is only located in the saturated zone where all voids are filled with water.

Regarding its importance Vaux (2011) noted that groundwater provides reliable water particularly during times of drought and shortage of surface water. Therefore, it is realised in the United State of America, groundwater serves as the means to meeting the water needs of about half of the population with many large cities relying entirely or almost entirely on ground water for their drinking water, notwithstanding its contribution of about 40% to irrigation in the country (Raven et al., 2013). Similarly, Kumar (2012) admits that about 85% of rural water supply in India is tied to ground water. The picture in Africa shows that not only does ground water meet the domestic water needs of the people but also enable them cope with perennial or seasonal shortages of surface water. For instance, across Ethiopia, Johnson and McCartney (2010) state that over 75 % of rural communities depends on ground water for drinking with most large towns having their water supply coming from shallow or deep boreholes.

2.2.2. Climate change and groundwater issues

Climate change refers to a change in the state of the climate that can be identified with respect to changes in the mean and or the variability of its properties and that persists for an extended period, typically decades or longer (Bernstein et al., 2007). Regarding groundwater and climate impacts, the IPCC Technical Paper VI, 2008 held it that there existed limited data on groundwater coupled with the slow reaction nature of groundwater systems to changes in recharge; conditions that hinder the observation of groundwater recharge response to climate-related changes (Bates et al., 2008). Opined by this, Clifton et al. (2010) stated that the impacts of climate change still remain less understood.

Nonetheless, some insights have been offered about the nature of the impacts on groundwater. According to the IPCC, 2007 Working Paper 11, climate change will not only affect recharge of shallow aquifer but will also bring about saltwater intrusion into aquifers as well as on the salinization of groundwater due to increased evapotranspiration. As indicated by Taylor et al. (2010), projections show that climate change will cause an increase in temperature of water in shallow aquifers worldwide, and with places that may record an increase in rainfall, pollution of groundwater (for those that are recharged by surface water bodies) will occur due to the wash

down of pollutants from soils. It adds that in regions that will record a decrease in groundwater recharge, water quality will also be compromised as a result of lower dilution as this may also lead to intrusion of poorer quality water from neighbouring aquifers.

A projection of some of these situations by Döll (2009) indicated that by the 2050s, climate change will cause a decrease in groundwater resources by more than 10% in more than one-fifth of the land area, with about one-fifth of the global population (10.7 billion) to be affected. In West Africa, Oyebande and Odunuga (2010) observed that six countries in this region namely Benin, Burkina Faso, Ghana, Mauritania, Niger and Nigeria will battle water crisis by 2025 with this situation to be aggravated by climate change as there will be a reduction in rainfall and an increase in evaporation with an effect also on water quality.

2.2.3. Climate scenarios of Ghana

The discussion here explores the trends of two climate parameters: rainfall and temperature in Ghana. The Notre Dame Global Adaptation Index, 2015, a project of the University of Notre Dame in studying countries' vulnerability to climate change and other global challenges in combination with its readiness to improve resilience in the year 2014 placed Ghana as the 59th most vulnerable country to climate change in the world (University of Notre Dame, 2015). This is a situation which is worrisome.

Considering the nature of impacts of climate change in the country, the Ghana National Climate Change Policy, revealed that there has been an increase in temperature and decrease in mean annual rainfall in all the country's ecological zones (Ministry of Environment, Science and Technology, 2013). The van Drunen et al. (2006) study of the Volta Basin shows that temperature in the entire basin has increased by 1 ^{o}C over a 30 year period with reductions in rainfall and runoff in the historical data sets. Owusu and Waylen (2009) on the trends of annual rainfall in Ghana (1951-2000) observed that mean annual rainfall totals within all the four agro-ecological zones in the country have decreased.

In a study by McSweeney et al. (2010), annual rainfall in Ghana is highly variable on inter-annual and inter-decadal timescales and there is a challenge in identifying the long term trends. Nonetheless, high records of rainfall over Ghana were experienced in the 1960s but this took a decreasing trend with the late1970s and early 1980s in particular considered periods with low levels. This accelerated an overall decreasing trend in the period 1960 to 2006, of an average 2.3 mm per month (2.4%) per decade.

Regarding future scenarios, it is worth noting that "future climate scenarios, and the predicted effects that climate change might have on the country, vary considerably according to which Global Circulation Model is used. However, models generally agree on the general trend for temperature changes, which are predicted to increase more in the northern region than in the rest of the country. Based on a review of 15 different models, the mean annual temperature is expected to increase by 1.0 °C - 3.0 °C by 2060, and by 1.5 °C - 5.2 °C by 2090 with changes expected to be more pronounced severe in the north. Model results for changes in rainfall precipitation are more uncertain than those for temperatures. Half of the models predict a decrease while the others showed an increase" (Pinto et al., 2012).

This uncertainty is expressed in some of the following studies. Kasei (2009) simulated with WaSiM using REMO data, predicted a decrease in rainfall and consequently decrease in surface runoff from the Volta Basin. On the contrary, Obuobie (2008) projected an increase in rainfall and subsurface flow. Jung (2006) also predicted an increase in rainfall and surface runoff for the Sahel and the Guinea coast for the period between 2030 and 2039. Andah et al. (2003) also claimed that future climate predictions show an increased rainfall pattern.

2.2.4. Climate change impacts on groundwater in Ghana

In Ghana, efforts to understand climate change and its impacts on groundwater resources are limited and with uncertainties just like those on rainfall as most of the existing studies focus on projections. However, climate change and its impacts on groundwater have been a major concern. According to Mul et al. (2015), a transboundary diagnostic analysis initiated by the Volta Basin Authority revealed that climate change and its impacts are one of the major concerns of the Volta Basin (covering parts of Ghana). This points to the findings put by Oyebande and Odunuga (2010) that the Niger and Volta Basins will witness a reduction in stream flow and groundwater recharge in the arid and semi-arid zones of the sub-region as the recharge of the region's aquifers have already significantly decreased. There is also the likelihood of lowering groundwater level, a situation resulting from a reduction in recharge.

The CSIR-WRI, 2000 report on climate change and water resources in Ghana showed that climate change will *inter alia* bring about a general reduction in groundwater recharge of 5-22 % for 2020 and a 30-40% for 2050 (Kankam-Yeboah et al., 2009).

McCartney et al. (2012) applied SWAT and WEAP models to study climate change impacts on water resources in the Volta Basin. Their findings show that by 2050, annual average rainfall, runoff, and mean groundwater recharge will decrease. For instance, under A1B scenario, average annual discharge and groundwater recharge will decrease by approximately 45 % and 53 % respectively by the end of the century.

There is, however, a point of departure from these studies above. Obuobie (2010) in his study E*stimation of groundwater recharge in the context of future climate change in the White Volta River Basin, West Africa* found out that annual recharge to the groundwater in the basin which is about 7 % of the annual rainfall, may increase in the future to about 33 % for the period 2030-2039.

2.2.5. Boosting groundwater adaptation to climate change

While discussions are still going on regarding the nature of impacts of climate change on groundwater, measures in the form of adaptation are suggested. Taylor et al. (2010) defined adaptation within the context of groundwater as a way of lessening the vulnerability of groundwater dependent systems to climate change and hydrological variability. Therefore, it is suggested (Dillon et al., 2009; Taylor et al., 2010) that in order to promote effective adaptation of groundwater in the face of climate change, the following five (5) thematic areas of groundwater must be given attention:

- Managing groundwater recharge: this has to do with the management of groundwater recharge areas by way of protecting or enhancing water resources while maintaining or improving water quality at the same time. Clifton et al. (2010) noted that measures like the following can enhance groundwater recharge: river regulation to maintain flows over recharge beds, the practice of Managed Aquifer Recharge (MAR), regulating development in key recharge areas and managing or reducing the level of woody vegetation cover to optimize groundwater recharge.
- Protecting groundwater quality: technologies and management systems to enable treatment and reuse of contaminated water and avoid contamination of higher quality water by water of lesser quality are required. Clifton et al. (2010) stated that quality can also be enhanced through the application of MAR to coastal aquifers, manage the utilization/drawdown of groundwater to avoid contamination of higher quality groundwater by poor quality water in overlying or underlying systems, research to develop water treatment processes that are less expensive and require less energy, education and behavior change campaign, with appropriate monitoring and regulatory

support, emphasize avoidance of contamination of water resource aquifers, develop water quality standards that can be applied to different uses and many others.

- Managing groundwater storage: it entails searching for opportunities that allow for groundwater storages and reduce the vulnerability of systems that are groundwater dependent. Clifton et al. (2010) added that increase storage capacity in aquifers—through hydro-fracturing, dissolution (in karst systems) or pressurization of cavities and increasing research and/or resource assessments to improve understanding of aquifer properties and define opportunities and management practices for more effective storage management can boost storage.
- Managing the demand for groundwater: it requires assessing how the demand for groundwater is being managed in relation to surface water. Clifton et al. (2010) added that water allocation framework, the use of economic tools like pricing, community-level participation in groundwater planning especially irrigation, research more on efficient irrigation systems and defining water allocations based on resources share rather volume can all contribute to managing demand.
- Managing groundwater discharge: this according to Clifton et al. (2010) can be achieved by avoiding or limiting establishment of industrial forestry plantations or other deep-rooted, high water use species in areas with shallow, fresh groundwater that is used for other purposes and the use of market mechanisms that account for groundwater uptake by land uses.

2.2.6. Local knowledge (groundwater) and climate change adaptation

Local knowledge sometimes is used to represent traditional knowledge, indigenous knowledge, traditional ecological knowledge, traditional environmental knowledge, native science, adaptive management and some others. Local knowledge according to Pearce et al. (2015), represents knowledge that is pegged to people experiences and interactions with others and transmitted through stories, apprenticeship and practices, with this knowledge being fluid, adaptable and updated with time as new observations and experiences are gathered. Local knowledge is regarded as rational and reliable knowledge which people have accumulated over time out of the connections that they have with their lands (see Kimmerer, 2002). Furthermore, it is realised that "the processes in local knowledge production involve the interaction between local communities who have their own practices and discourses, and external agents of change, who have their own practices and discourses" (Derbile, 2010:29).

Regarding the application of this knowledge in adaptation context, it is established that local knowledge is proving to be an effective tool for managing climate change and its impacts. In a study by Hiwasaki et al. (2014) in coastal and small island regions, it is evident that the local people in these areas possess a wealth of knowledge and practices which enable them to closely observe and monitor any changes in their environment, celestial bodies, and are able to predict hydro-meteorological hazards.

For instance "to effectively detect climatic changes, the Inuvialuit of Canada and Alaska developed the Arctic Borderlands Ecological Knowledge Co-op, joining forces with interested locals and officials to monitor various climate change indicators. In September 2011, the monitoring data were used to produce a report on 13 years of community-based monitoring by Inuvialuit harvesters in Aklavik, Northwest Territories" (see Vinyeta and Lynn, 2013:12). Colding et al. (2003), therefore, admitted that the integration of this age-long store of knowledge with scientific knowledge can speed up adaptive management.

As a result, this knowledge has been recognised in the Ghana National Climate Change Policy, where it is indicated that traditional knowledge can contribute to adaptation through the

provision of assets, weather prediction, conservation of natural resources, protecting the environment, making farming decisions, and coping with extreme climate variability. This and other related documents, therefore, advocate for the integration of local knowledge into all adaptation measures by all sectors of the country's economy.

The place of this knowledge in the Atankwidi catchment cannot be overestimated. Local knowledge has enabled farmers, in particular, to cope with environmental impacts on their livelihoods (Derbile, 2010). The nature of this knowledge regarding groundwater development in, particular, has been discussed, as it also enabled farmers to identify methods of coping with limited groundwater situations in the catchment (Kwoyiga and Stefan, 2018).

3. GENERAL RESEARCH DESIGN/METHODOLOGY

This chapter provides details about how the topic was approached. That is, the methods adopted, and the generation and analyses of data to address the research objectives. Considering the nature of the topic which deals largely with institutional mapping, performances, knowledge production and feasibility studies, a qualitative approach together with triangulation was employed to draw literature and data from different sources. Data collection was put at two levels and periods. Different tools were also used to analyse the data. A summary of these are illustrated in the methodological framework (Figure 2). The framework denotes the approach applied to the study, in this case a qualitative one considering the nature of the topic . It highlights the stages that were passed through in order to address the concerns of the research objectives. It further depicts the source of data, that is primary and secondary data, all gathered at both macro and micro level for the study.

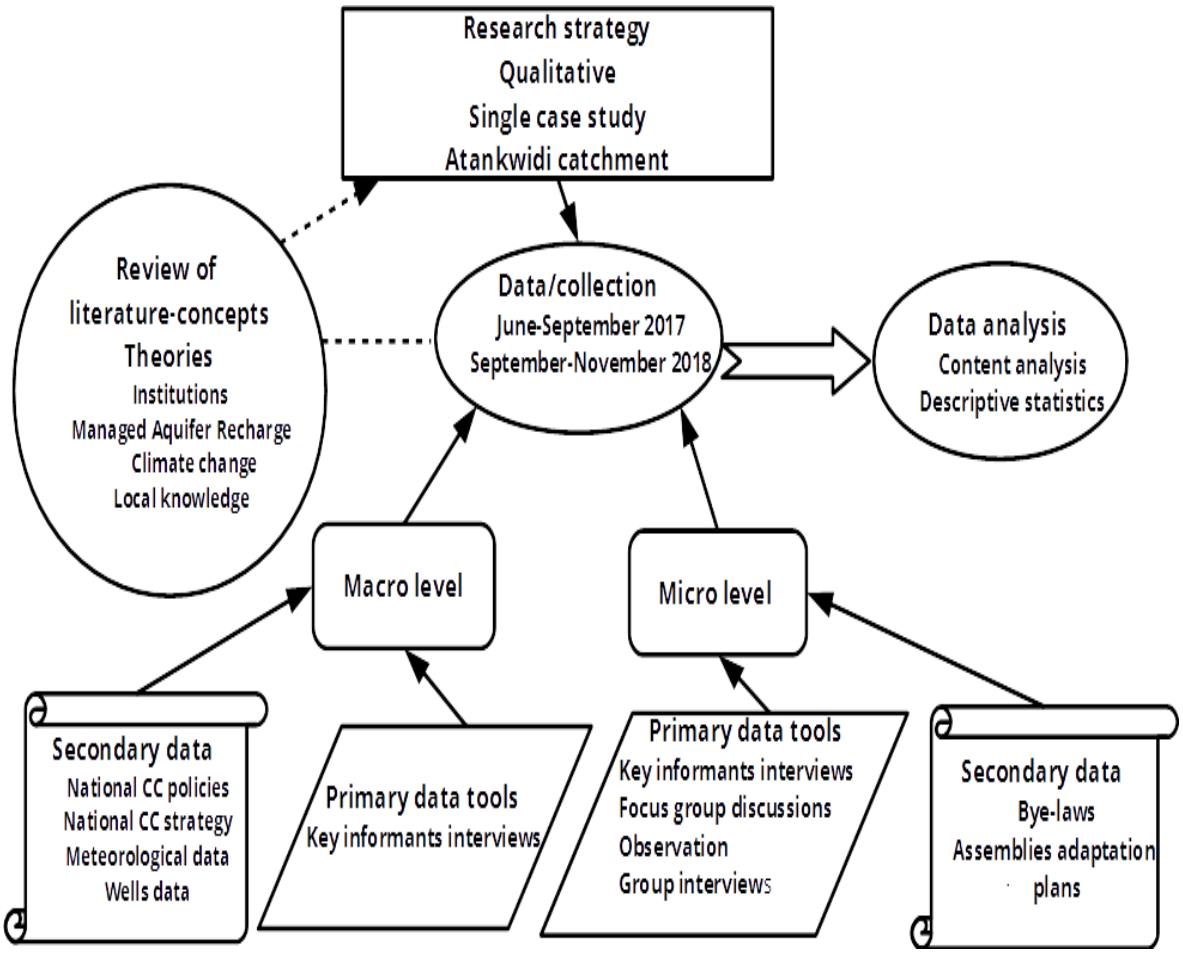


Figure 2. Methodological framework

3.1. Case study

The thesis adopted the case study method to explore the nature of climate change adaptation in the Atankwidi catchment. This was because the aim of the research topic was to understand in detail the "how" and "why" as Baxter and Jack (2008) put it of climate adaptation in relation to groundwater resources in Ghana. Another rationale for the choice of a case study in this research was that case study analysis is multi-perspective: it considers the voices of all relevant groups of actors together with their interactions (Tellis, 1997).

With the debates about climate change still going on, a case study is deemed appropriate because according to Yin (2014:16), a case study "is an empirical inquiry that investigates a contemporary phenomenon (the 'case') in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident".

Also, the topic covered several variables which require multiple data sources, theories and methodologies and this made it appropriate to be approached as a case allowing for triangulation to be used (see Tellis,1997). The single case study specifically was chosen. This is premised on the fact that there will not be an exact repetition of such a study in the future eventhough similar ones may be undertaken (Yin, 2014).

3.2. Choice of the study area

Since the aim of the study is to gain in-depth knowledge and understanding of what pertains to climate adaptation vis a vis groundwater resources in northern Ghana, the Atankwidi catchment was purposively chosen. The population of the Atankwidi catchment depends almost entirely on groundwater resources for domestic, industrial and agricultural purposes even though one finds surface water bodies like the Atankwidi River in this area.

The transboundary nature of the catchment also has implications for groundwater governance and adaptation which makes it suitable to study. Additionally, some of the aquifers here are shallow and as noted already, shallow aquifers easily respond to climate change and its impacts, thus the need for choosing the catchment. The catchment is also located in northern Ghana, a zone which is noted for extreme weather conditions. Furthermore, the catchment is found in a region which is considered the second poorest in the country and this region has also recorded already fallen groundwater tables coupled with the fact that the catchment population is largely rural. These have implications for climate change adaptation (adaptive capacity) by the catchment population.

3.3. Description of the study area/catchment characteristics

The Atankwidi Catchment, a tributary of the White Volta Basin, covers an area of about 286 km^2 (Figure 3). According to Salifu and Agyare (2012), the area of the basin found in Ghana is about 159 km^2. As noted by Barry et al. (2010), the climate of the catchment is that of Sudan-Savanna where temperatures are high and rainfall is mono-modal. It can be said that the catchment exhibits typical characteristics of the White Volta Basin and regarded the areas with the highest groundwater use per km^2 in the Volta River basin (Martin, 2006).

The catchment covers six (6) communities in Ghana namely Kandiga, Sirigu, Zorkor, Yuwa, parts of Sumbrugu and Mirigu. Demographically, the catchment had a population of 45, 841 in 2010 with 47% males and 53% females with the growth rate being 1.1% (Ghana Statistical Service, 2012). The settlement patterns are largely rural.

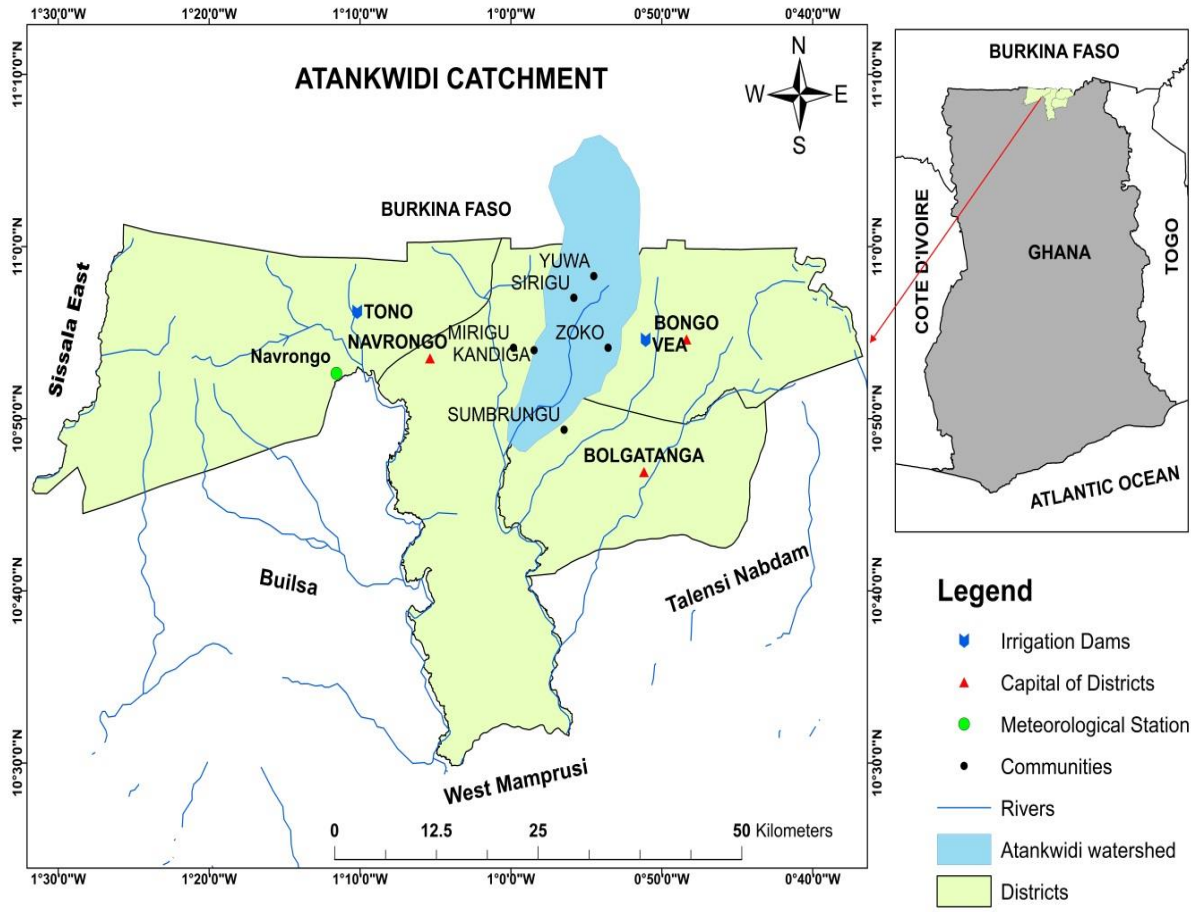


Figure 3. Map of Ghana showing the location of Atankwidi

According to Martin (2006), Atankwidi catchment is characterized by three aquifers (Figure 4). These are the discontinuous, shallow, perched aquifer, the regolith aquifer and the fractured aquifer. Among these three, the regolith aquifer constitutes the principal aquifer in the weathered mantle resulting in a continuous aquifer whose average saturated thickness is 25m and hydraulic conductivity being 2.5E-6 to 2.5E-5 m/s and supplies the yield of most boreholes. The discontinuous shallow perched aquifer is characterized by coarse soils of 0.5 m to 1.5 m thickness and covered by less permeable clayey or lateritic layer. Regarding groundwater and surface water interaction, Martin (2006) explains that "although infiltration from streams occurs at certain locations, discharge from groundwater to streams is more frequent".

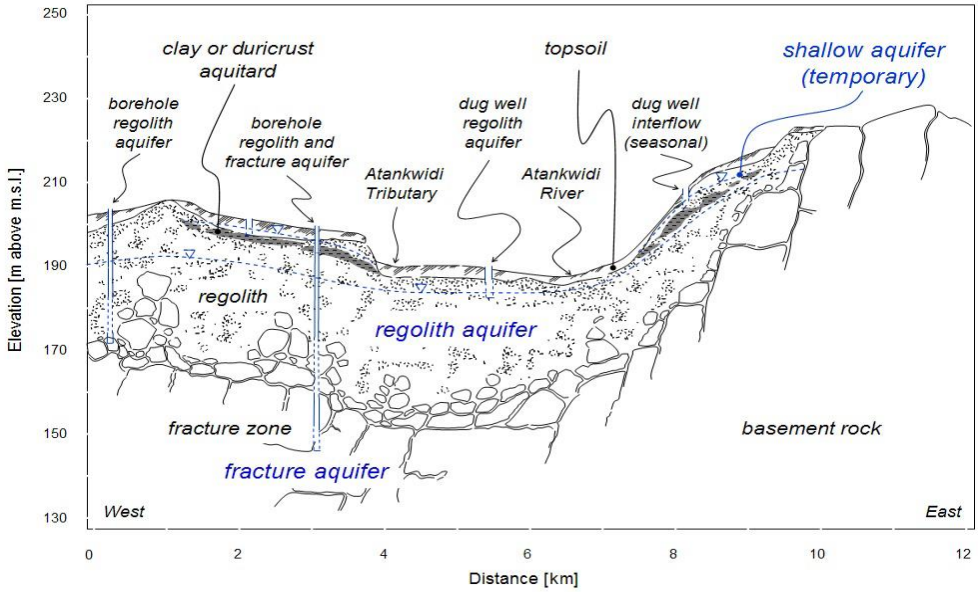


Figure 4. Hydrogeological cross section of the Atankwidi catchment

Source: Martin (2006)

3.4. Data for the study

In order to generate data to address the research objectives, the researcher embarked on two periods of fieldwork. Fieldwork within the context of the study referred to visiting the study communities and taking responses from the respondents. It also involved observing some groundwater facilities/infrastructure and groundwater uses in the area. The first fieldwork was conducted from June-September in 2017 and second field trip was from September-November 2018. The data collected were put at two levels: macro and micro (Table 1). At the micro level respondents were from the catchment, officials of the District/Municipal Assemblies and decentralised government agencies like the Water Resources Commission, Environmental Protection Agency, university lecturers and an official from the Savannah Research Institute. At the macro level, respondents were drawn from the Environmental Protection Agency and the Meteorological Service Agency.

During the fieldwork in 2017, the first two (2) months of it were used to gather data at the micro level. This decision was made to grant the researcher easy access to participants at this level. Even though with the onset of the rains from late June, most participants were busy on their farms, most of them were able to participate in the process. The last two months of this fieldwork were devoted to gathering data from experts and government officials in the aspects of groundwater resources and climate change adaptation. In 2018, the researcher visited the catchment again to interact with only groundwater farmers and to also observe the irrigational activities as well as groundwater development for such purposes which were not possible to do during the 2017 fieldwork.

All respondents, that is users of groundwater for domestic and irrigational purposes volunteered and showed willingness to be interviewed as none of them was purposely selected. Information was shared with farmers through the community leaders to identify respondents who were willing and had the time to be interviewed. Such respondents availed themselves at the various meeting points. Whoever was available at the borehole at the time of our arrival and was willing to respond was interviewed. However, some groundwater farmers were pre-informed of the

researcher's visits to their farms for observation. Interesting enough, farmers who were not even pre-informed but accidently met on their farms actively particpated. The rationale for not purposely selecting respondents was that at the time of the first fieldwork (2017), most farmers were busy as the rainy season had started. Therefore, any attempt to use strict criteria to get respondents at that time would have yielded no attendance. Nonetheless, in the afternoon, farmers during break (taking a rest) assembled for the interviews. Noteworthy was the high level of attendance of the farmers as some group interviews had at least twenty (20) people.

All questions for the data collection were open-ended, as close-ended questions were completely avoided. This was to grant respondents the opportunity to respond to the questions without any restrictions or limitations. Furthermore, some of the data needed particularly about local knowledge were special, and not easily obtained from other sources other than the knowledge holders themselves hence the need to allow respondents to discuss what they know in a natural flow manner. A field assistant was appointed and he supported with the data collection and also served as a translator: translating the responses from *Gurine* to English.

Table 1. Categorisation of data

Level	Respondents	Data type
Macro level (National Government agencies)	– EPA – National Climate Change Committee of MESTI – Ghana Meteorological Agency – Water Research Institute, – Hydrological Service Department	– climate/meteorological data, -hydro-geology data – the country's climate change policies, strategies and adaptation projects documents
Micro level (local government units, formal government parastatals, research institutes, catchment dwellers)	– drinking water users – shallow groundwater farmers in the basin – *tindana* – chiefs and elders – officials from the planning and coordinating unit – Environmental Management Committee of the District Assemblies – regional planning officer – officials from EPA, CWSA in the Upper East Region	– local knowledge about the following: groundwater resources distribution in the community, local perceptions of climate change and its relationship with groundwater resources. – local perceptions of climate change and its relationship with groundwater resources – shallow groundwater irrigation and groundwater/land arrangement around such activities – bylaws pertaining to water resources governance

3.5. Data collection tools

Considering the many variables embedded in the research topic, various tools were required to arrive at data capable of addressing them. As a result, different tools were employed to gather both primary and secondary data. A summary of the primary data tools and the category and compositions of respondents has been provided (Table 2). A detailed discussion of these tools, how they were used and the category of data generated are also presented. Additionally, the nature of secondary data and the source from which the data were retrieved forms part of the discussion here. It must be noted that most of these tools were used during the first fieldwork (2018) in the catchment as only observation and individual interviews were used during the second fieldtrip (2018).

It is needful also to state also that all interviews were conducted face-to-face and at places like the sites of the boreholes, village squares, groundwater farms and in the offices of officials. As noted already, the field research assistant assisted with translations only with interviews involving the catchment dwellers. This was because, most of the people here are illiterates and the inability of the researcher to speak *Gurune* created a communication barrier. Nonetheless, interviews with all government officials were held in English and handled only by the researcher herself. Interviews in the catchment were largely recorded and later transcribed while those with government officials were only written down as such people refused to allow their responses to be recorded.

Table 2. Details of research respondents and primary data collection tools

Respondent type	**Number**	**Data collection tool**
Catchment domestic users		
Individual	5/community (30)	Individual interviews
Group	10/group/community (60)	Group interviews
Total communities	6	
Total	90	
Catchment irrigators		
Individuals	10/community (60)	Individual interviews
Groups	20/group/community (120)	Group interviews
Key informants	5/community (30)	Key informant intreviews
Total respondents	210	
Local government entities		
Bolgatanga Municipality	5	Focus group discussion
Bongo District	7	Focus group discussion
Kasena/Nankana Municipality	3	Focus group discussion
Kasena/Nankana West	5	Focus group discussion
Total respondents	20	
Government Organisations		
Savanna Research Institute	1	Key informant interviews
University for Development Studies	7	Key informant interviews
Environmental Protection Agency	2	Key informant interviews
Water Resources Commission	2	Key informant interviews
Total respondents	12	
Total respondents studied	**332**	

3.5.1. Local observation

Local observation formed an important tool as far as the research is concerned. This enabled data that could not be obtained through verbal means to be gathered in its natural state. Observation was used to collect data about the physical characteristics of the facilities that provide both domestic and irrigational groundwater. As depicted in Figure 5, permanent wells (complete and under construction wells), seed nursery beds and young vegetables farm and a farmer on a his farm near River Atankwidi (the author inside the river) were observed.

The surroundings of boreholes were also observed (Figure 6) by the author to ascertain their conditions as defined by the Community Water and Sanitation Agency (CWSA). Observation was further employed to assess wells development, equipment for lifting groundwater, cropping lands, the distance between the crops and locations of wells, and the processes involved in the application of groundwater to crops.

Pictures A, B and C show local wells constructed by groundwater irrigators usings local knowledge. While the contruction of wells in pictures A and B has been completed, the well in picture was still under construction. Pictures D, E and F depict the crop fields of groundwater farmers. Picture D shows seedlings of vegetables being nursed on the farm while pictures E and F show young vegetables (spinach). Pictures G and I depict the Atankwidi river which is a borderline separating Ghana from Burkina Faso. It serves as source of water for farmers during the early stages of their dry season irrigation activities. Picture H shows a farmer who is preparing his land (ploughing and making beds) for dry season farming.

Figure 6 depicts potable water supply facilities in the form of boreholes/storage tank that provide water to the people in the catchment. It is realised from these pictures that the borehole facilities here are operated either manualyl or by electrical means.

3. General research design/methodology

Figure 5. Fieldvisits to hand-dug wells, crop farms and River Atankwidi

Source: fieldwork (2017)

Figure 6. Drinking water sources

Source: fieldwork (2018)

3.5.2. Interviews

Both individual and group interviews (Figure 7 and Figure 8) were conducted depending on the type of data needed. Individual interviews were used to obtain data from domestic water users about the average distance covered to access the borehole and the time spent at the borehole to fetch water. Group interviews with the same category of users were conducted to ascertain the demand management of borehole water. Data about the interactions between such users and the District Assembly Water and Sanitation Committees were also obtained. General knowledge about climate change and its impacts on groundwater resources as well as formal institutions concerned about adaptation was also obtained from all domestic water users.

On the part of irrigation, individual interviews were used to elucidate farmers' views about access to land, cost of irrigation, preparations before the start of irrigation, water management practices and financial/labour support for irrigation. Individual interviews were also used to obtain information from both categories of users about climate change, groundwater institutions and adaptation measures.

Group interviews were conducted to ascertain the regulations of institutions regarding groundwater for irrigation, perceptions of climate change, impacts of climate change on groundwater, local knowledge for irrigation, marketing of irrigation products, conflicts resolution, farm security, networking and land tenure system in the catchment.

Figure 7. Group interviews with respondents in Sirigu

Source: fieldwork (2017)

Figure 8. Group interviews in Zorkpo

Source: fieldwork (2017)

3.5.3. Key informants interviews

This tool allowed for the collection of special data considered to be in the hands of some specific persons. This group of respondents are considered important as they possess a wealth of knowledge that is not common. Apart from the special knowledge that they possess, some of them in this study were important gatekeepers without whose permission, access to other respondents would have been difficult. For instance, in the Mirigu community, the key informants here supported with mobilising the respondents in the afternoon for interviews. The sub-chief of Mirigu was present during the group interview with his community members. As a literate, he helped to explain and clarify the questions and responses during the interviews. During the group interview in Sumbrungu, the Assemblyman who is also a literate played an enomous role in organising the respondents and participated actively when his community members were being interviewed. He made sure his members provided the right responses and everyone was given an opportunity to express him/her self.

Within the catchment, key informant interviews were conducted involving chiefs, elders, earth priests and Assembly members and some leaders of farmers (Figure 9 and10). This was to collect data about land tenure system in the catchment, groundwater governance, nature of informal institutions, perceptions of climate change and climate change institutions and nature of groundwater farming in the catchment. At the regional level, key informants from the Water Resources Commission and the Environmental Protection Agency were interviewed to find out about the implementation of climate change adaptation measures and water resources governance in the region. At the national level, one key informant interview was also held with an official of the Environmental Protection Agency. This was to obtain data about climate change, groundwater, local knowledge and climate change, climate change institutions and their performances. It must be noted that all interviews were conducted face-to-face.

Figure 9. Key informants interviews with a sub-chief and elders in Mirigu

Source: fieldwork (2017)

Figure 10. Key informant interviews with some farmer leaders in Yua

Source: fieldwork (2017)

3.5.4. Focus group discussions

At the local government units (District offices), focus group discussions were held. Respondents from the District Planning Unit and Environmental and Sanitation Committees of the four studied districts were interviewed to obtain information about local climate change policies/projects relating to groundwater and their scope, and level of their performances..

3.5.5. Questionnaire

Questionnaires were administered to obtain data about the knowledge level of climate change among Ghanaians, and degree of climate change issues captured in both local and national policy documents. Data about the state of groundwater irrigation at the local level were also obtained. Respondents were from the University for Development Studies, Savannah Agricultural Research Institute (SARI) and Water Resources Commission (Regional Office).

3.5.6. Secondary data

Secondary data were obtained from journal articles, books, magazines, official documents, brochures and websites about the research topic. This was particularly useful to understand climate change policies and strategies in Ghana. Additionally, it was to gain insights into groundwater development globally and in Ghana, institutions and their nature, local knowledge, groundwater adaptation measures such as Managed Aquifer Recharge. Secondary data were again obtained from some offices in Ghana like the Meteorological Service Agency on some climate parameters for the period 1977-2009 for Navrongo weather station. Bye-laws from the four study Districts were also obtained from the various District Assemblies.

3.6. Methods of data analysis and representation

In order to analyse and represent the chunk of data generated from both primary and secondary sources, mixed methods involving both quantitative statistics and qualitative descriptions were applied. Firstly, to sort out the large primary data generated through interviews, the computer

software programme MAXQDA 12 was used (MAXQDA, 2018). The software allows for qualitative and mixed methods data analysis. These tools sorted out the data and coded them. Diagrammatic representations of the themes particularly those relating to institutional mapping in the research were also constructed using this software. The meteorological data obtained were analysed using Excel package to provide some descriptive statistics of the data and to also represent the data diagrammatically. The data from Excel were transported to R software programme to produce the climate diagram after Walter and Lieth (1967). The R software (Paradis, 2002) is used for statistical computing and graphics and allows for data manipulation, calculations and graphical display. Some aspects of the data particularly on local knowledge were analysed manually.

3.7. Limitations of the study

3.7.1. Time for data collection

The time for the data collection especially in 2017 posed some challenges. At the time of the data collection, most of the respondents were busy on their farms cultivating rainy season crops. This affected the ability to get farmers to interview them individually hence the group interviews. Even though this yielded data, controlling the interview process was difficult as some few people nearly hijacked it. Secondly, it was not possible to meet dry season groundwater dependent farmers on their farms because, at the time of the fieldwork, dry season irrigation was over. This compelled the author to conduct second fieldwork to enable her to visit these farms to have first-hand information about them.

3.7.2. Data quality

Firstly, it was challenging to get the meteorological data as such could only be obtained from the Ghana Meteorological Agency in Accra. Secondly, the data obtained were not of high quality since there were missing values or wrongly recorded values for some years. It was impossible to address these challenges. The researcher was not also willing to download weather data from online sources as such are also with a lot of errors since these sources depend on the same agency for meteorological data.

Still on data, it was impossible to identify an official at the Regional Coordinating Council (Upper East Region) to interview even though the council is obliged to supervise the Climate Change Committees at the district. As a result, the researcher though visited the office of the regional council several times, could not obtain any responses. Further, one of the categories of respondents that the researcher intended to interview and obtain secondary data from was an official of the Ghana Hydrological Services Department in Accra. Though the researcher was able to locate the office, efforts to interview one of the hydrologists were confronted with bureaucratic obstacles. The researcher managed to get only a single sheet of a hydrological map of Ghana which was not even relevant to the study as the official refused to share any data or information with the respondent.

3.7.3. The attitude of officials at the national level

Getting officials in the office of the Water Research Institute in Accra to respond to the questions never materialised. Though the researcher was welcomed into their offices and the questionnaires were given to them to administer later, none of them provided their responses. All efforts to contact them later proved futile. Also, a representative of the National Climate Change Committee who works with the National Disaster Management Committee directed all

phone calls to her children at home who then had to relate discussions to her. All efforts to get her to respond also yielded no results.

4. BACKGROUND ISSUES OF CLIMATE CHANGE IN ATANKWIDI CATCHMENT

The importance of this chapter lies in the fact that although it does not address any of the research objectives or discuss the application of scientific models to determine the impacts of climate change on groundwater resources as this is beyond the scope of the thesis, it provides simple but quick background information about the nature of climate change in the catchment. The chapter discusses the trends of climate change in the catchment from 1977-2009 using both meteorological data and primary data in line with two climate parameters: rainfall and temperature. It further tries to elucidate local people's interpretations of the impacts of climate change on groundwater in terms of quality and quantity.

4.1. Trends of climate change using meteorological data

In terms of temperature, holistic analysis and representation of mean annual temperature (Figure 11) showed that temperature in the catchment had increased within the study period (1977-2009) by 0.4 ^{o}C annually. Analysis of the mean monthly temperature (Figure 12) revealed that both maximum and minimum temperatures recorded usually lower values in the middle of the year (starting from May). Therefore, the annual cycle of monthly mean temperature changes corresponded with changes in humid conditions.

To throw more light on the trend of temperature, an individual assessment of both the Annual Mean Minimum (Figure 13) and Maximum (Figure 14) temperatures depicted increasing trends of temperature for the past 30 years. This agrees with the findings of a lot of studies both at the local and national levels (see Amadou et al., 2015; Kasei, 2009; van Drunen et al., 2006).

Regarding rainfall (Figure 15), it is realised that there was an increase though not significant by 62.75mm annually. However, there is wide variability in annual rainfall between the period 1980 and late 1990s which agrees with Derbile (2010) observation of the catchment. This variability within the study period manifested in terms of onset, distribution and amount of rainfall. The months March, April and May are usually those of onset of rainfall.

A critical look at the driest and wettest years revealed a variation that correlates with total annual rainfall and the number of days. For instance, it is realised that driest year (1977) recorded lower values with the onset of rains at the tail end of March while wettest year (1999) experienced rainfall as early as February with high values. The wettest years also showed that rainfall is largely concentrated in the months of July and August with almost no rains from November to early parts of February.

A holistic representation of both temperature and rainfall (Figure 16) is depicted based on Walter and Lieth (1967) discussion of climate trends. This diagram showed that the months that humid conditions are above threshold are June, August and September which agrees with the results of Kasei (2009) modelling of the Volta basin, with 60 mm of rainfall serving as the ceiling below which arid conditions occur.

The implication of the trend of temperature and rainfall for groundwater resources and their use is that in the driest years, groundwater dependent farmers are not able to conjunctively use surface water sufficiently with groundwater. Thus, pressure on groundwater in those years is high. The late onset of rainfall (in those years) also negatively affect the recharge especially of shallow aquifers (since there is a delay) as Martin (2006) noted of some traditional wells that easily respond to rainfall.

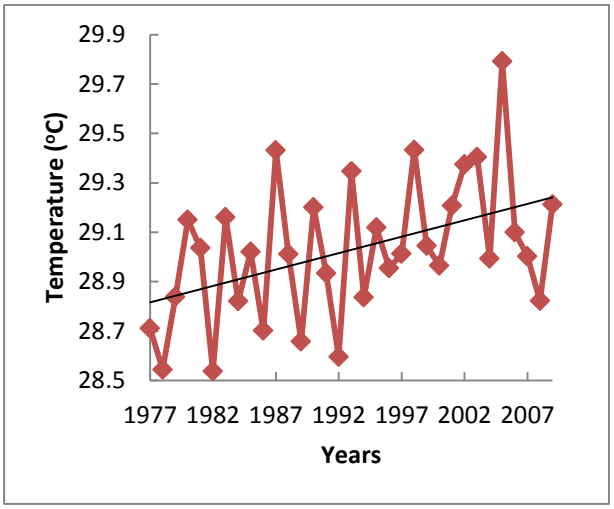


Figure 11. Mean annual temperature in °C (1977-2009)

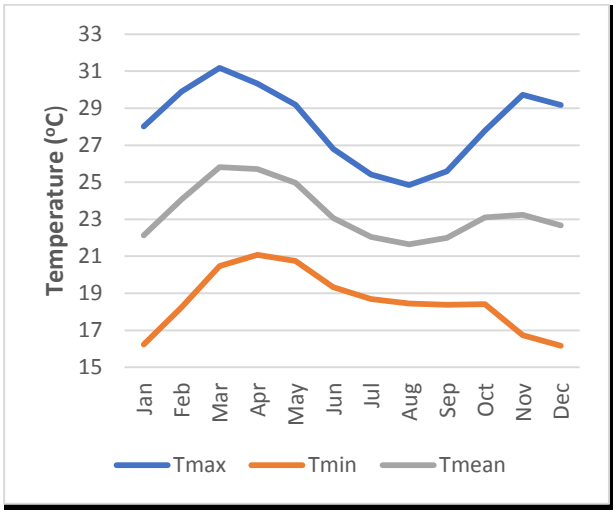


Figure 12. Mean monthly temperature in °C (1977-2009)

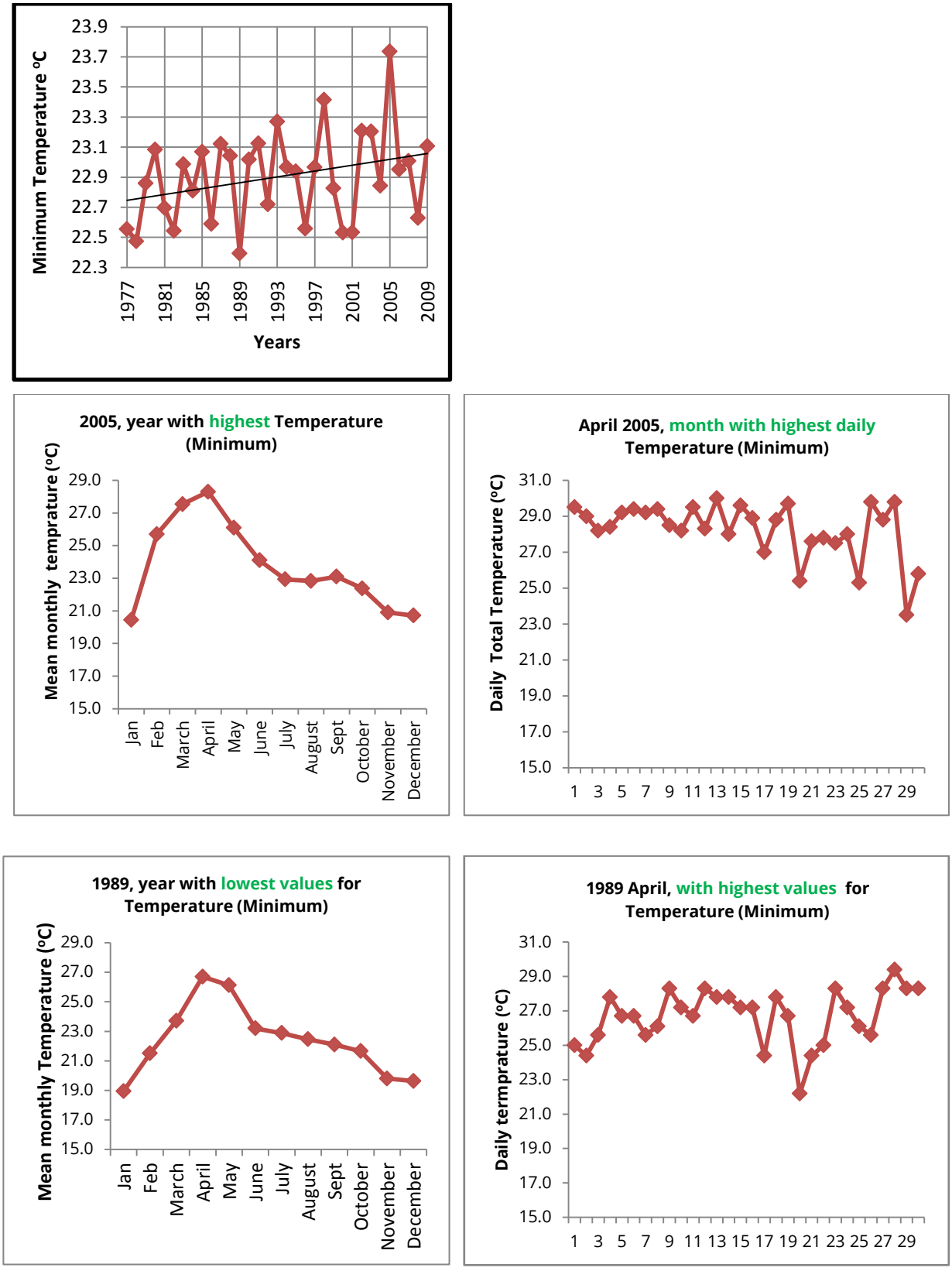


Figure 13. Details of Mean Minimum Temperature (1977-2009) in terms of years and months

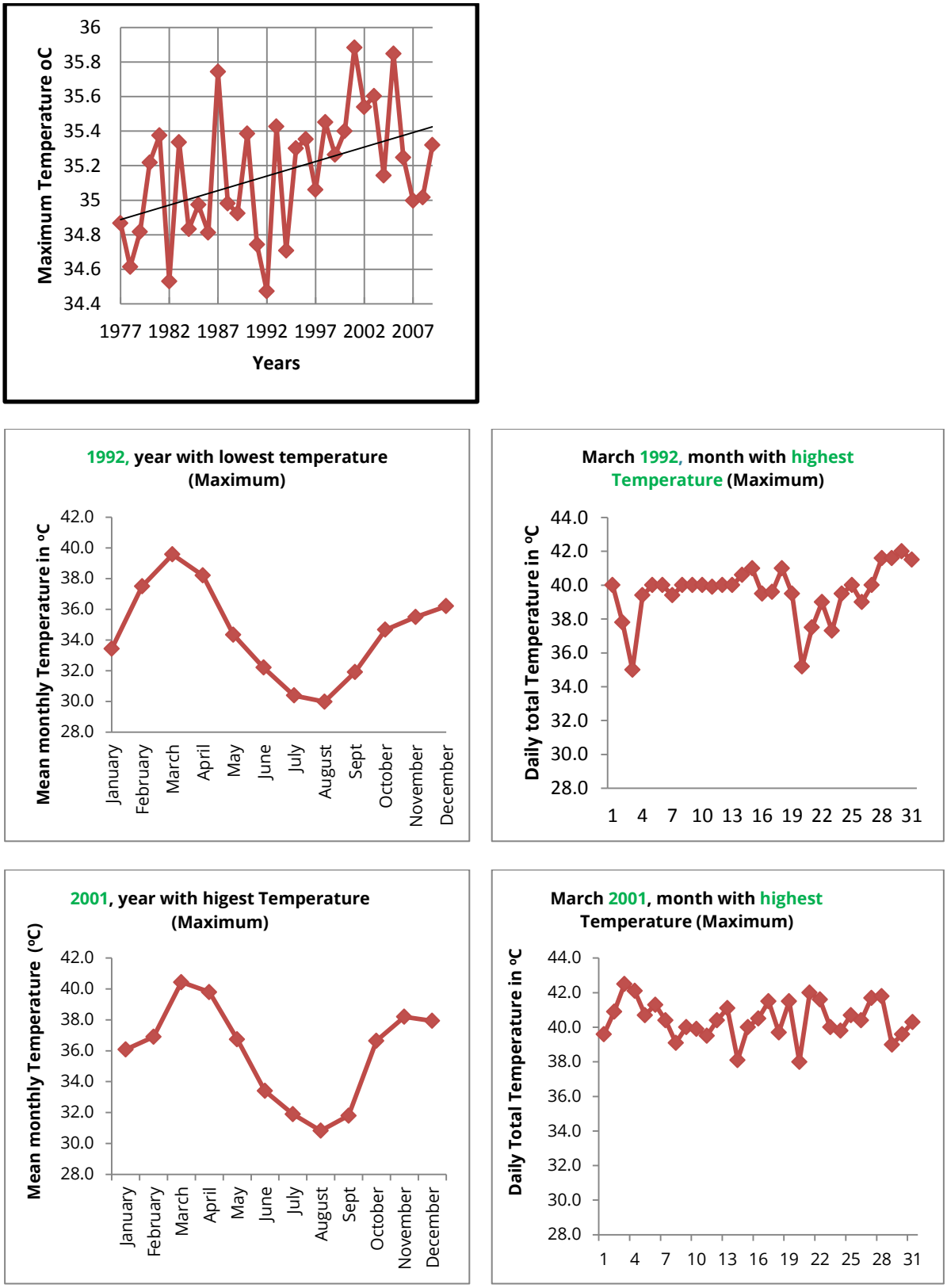


Figure 14. Details of Mean Maximum Temperature (1977-2009) in terms of years and months

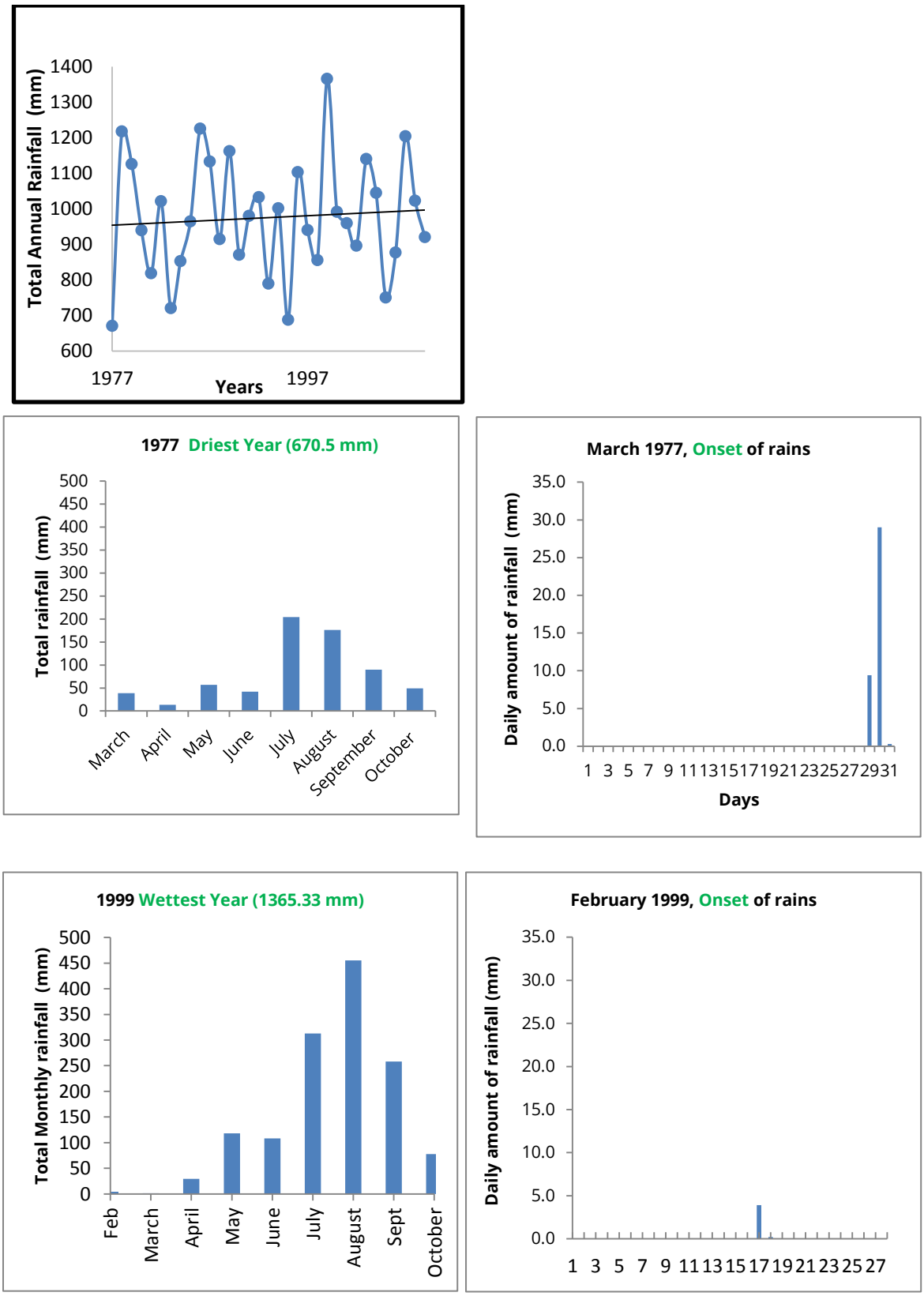


Figure 15. Details of Total Annual Rainfall (1977-2009) in terms of years and months

Figure16 denotes Walter and Lieth (1967) climate diagram for northern Ghana based on data collected at Navrongo Meteorological Station (latitude 10°54'0" N and longitude 1°06'0" W; elevation 201 m above sea level). Rainfall and temperature data were measured between 1960 and 2011. The values at the top of the graph show the long-term annual mean temperature and total rainfall. The value at the top-left of the temperature axis is the mean of the average daily maximum temperature of the hottest month; the value at the bottom of the same axis is the mean of the average daily minimum temperature of the coldest month. The horizontal black line at 100 mm and 50 °C indicates the threshold above which rainfall is rescaled by factor of 10. The blue line represents the annual cycle of monthly rainfall. The red line indicates the annual cycle of monthly mean temperature. The area with blue shaded lines stands for the humid conditions below the threshold, while area dotted in red represents the arid conditions. The area filled in blue indicates the humid conditions above threshold (excess of water).

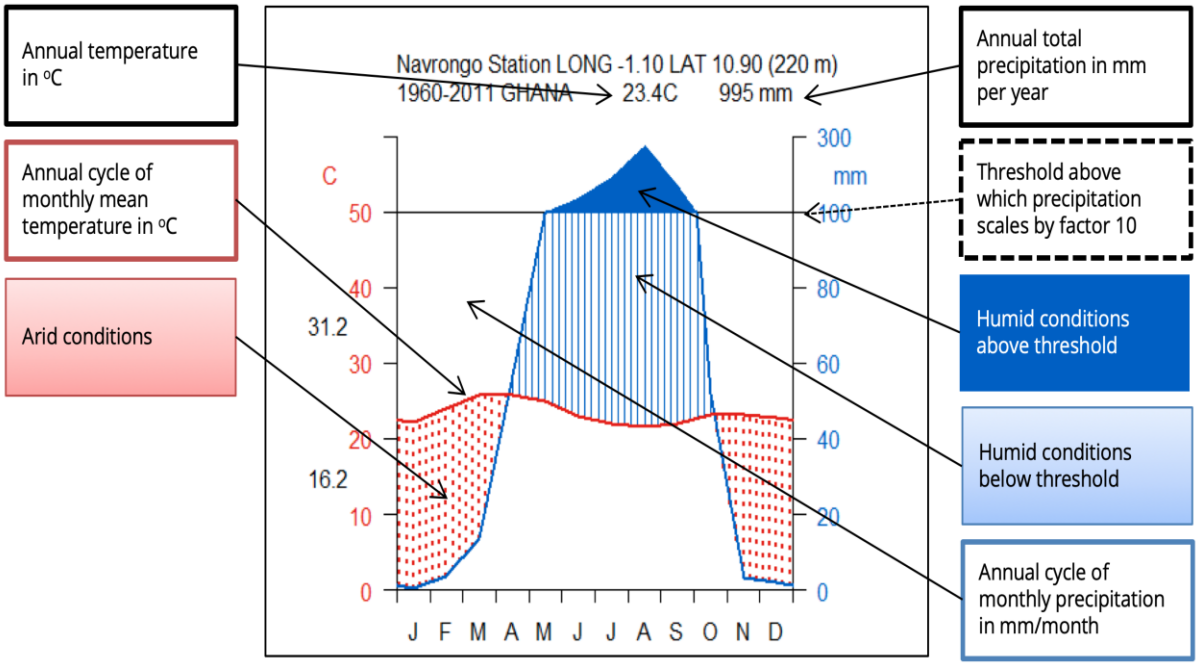
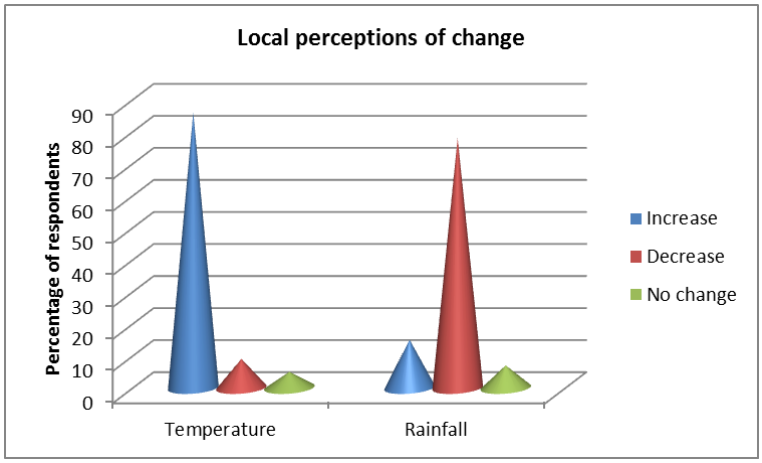


Figure 16. Walter and Lieth (1967) climate diagram of the Navrongo Station (1977-2009)

4.2. Local people's perceptions of climate change

It is realised that respondents have some knowledge (Figure 17) of climate change of the studied period. About 86 % of respondents said that temperature had increased, 9 % said temperature rather decreased with the remaining 5 % stating that there was no change. On the part of rainfall, 15 % of irrigators said there was an increase, 78 % stated that there was a decrease and 7 % observed no change.



Note: Population of respondents (n) =210

Figure 17. Local perception of climate change

Characterising the changes in rainfall in detail, it is noted that there have been changes regarding the intensity, volume and seasonal variation. The following excerpts from the interviews illustrate the local people's perceptions of the situation.

4.2.1. Volume/amount of rainfall

Regarding the volume of water associated with rainfall, responses from the group interview in Yua revealed this:

> There is a reduction in the volume of rainwater when compared with the past 30 years. In the past, one sees pools of rainwater everywhere after the downpour but these days it is difficult to see such water. Years ago, after it had stopped raining, one would see women spending hours trying to sweep away pools of water in the compounds, we do not see this happen again.

A similar observation has been made by respondents in Mirigu regarding the changes in the amount of rainfall in recent times.

> In the past, rivers, streams and ponds were all filled with water especially in the month of July and one could hear the cry of toads and other aquatic organisms especially in the night from these water bodies. This is not the case in recent time, as most of these ponds no longer get filled up and there is no cry of such mammals again. In fact, it is recently that even in July those of us from Mirigu, Kandiga and Yua can wade through the water in the rivers and cross to the other side to attend Navrongo and Bolgatanga markets even after a heavy downpour. This was not the case in the past.

4.2.2. The intensity of rain

All the groups in the study communities admitted that rainfall intensity has changed. They noted that over some decades, there has been an increase in the intensity of rainfall. A synthesis of their views is seen in the excerpt of the interviews below;

> The rains though they last for some few hours, they are torrent in recent times. The rains come so intensely that sometimes we get scared that our roofing sheets of our rooms may get ripped off.

4.2.3. Seasonal variation in rainfall

All respondents attested to the fact that there is a change in the season of the rainfall. The respondents admitted that the rainfall pattern decades ago appear uniform. However, this

pattern has been altered which makes it difficult to predict about when it will rain. The group interview from Mirigu revealed this,

> Decades ago, the rainy season used to start from April and end in October but these days the rains come around June and by the end of September, there are no rains again. That is, the rainy season starts late and ends early. Rainfall pattern has changed. In the past it was regular and crops did well. Recently, the rains come late and last for a short period of time. This affects farming which translates into hunger. At the time of the interview (June), instead of the second weeding, we are rather sowing. The timing of the arrival of rains has affected the farming season.

4.2.4. Temperature

The use of temperature to describe climate change also appeared well understood by all respondents in the six communities. Respondents offered explanations with the following illustrations:

The respondents in Sumbrugu explained this,

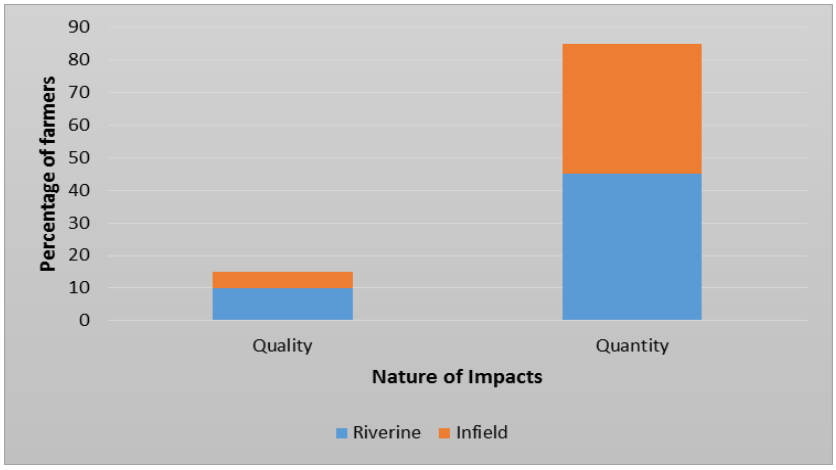
> Temperatures have changed. We use to record the highest temperatures in March but now as early as November, temperatures begin to rise. In those days, one could walk bare-footed in the ground around November, because temperatures were not that high to heat up the ground. However, one will not even try this and since our dry season farming starts around this time we always hope that our footwear does not get torn on our way to the farms to expose our feet to the scourging sun.

The respondents from Yua also made the revelation below about temperatures in recent times.

> Nowadays, during the rainy season, temperatures still remain high that one finds it difficult to sleep inside their room. We usually sweep the water away in our compounds immediately it stops raining and shortly afterwards, the compound gets dry immediately. We then spread our mats and sleep in the compounds if not one cannot endure the heat inside the rooms.

4.3. Perceived impacts on groundwater resources

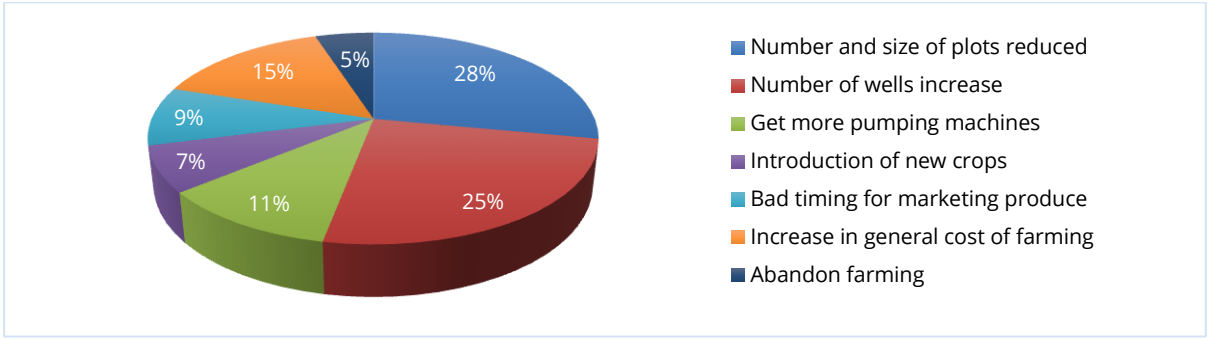
Regarding the impacts of climate change on groundwater, farmers who depend on groundwater stated that groundwater quantity has been more affected. In fact, the proportions of both riverine (45%) and infield (40%) were almost the same. This means that all farmers have observed the changes that climate change has had on groundwater (Figure 18). No significant changes have, however, been observed with regards to quality as only 10% of riverine and 5% of infield farmers noted some changes.



Note: Population of respondents (n) =210

Figure 18. Perceived impacts of climate change on groundwater

To get an insight into what happens to irrigational activities as a result of the impacts on groundwater caused by changes in temperature and rainfall, most of the farmers mentioned that this has resulted in an increase in the number of wells needed to secure enough groundwater while the worse is for irrigators to abandon dry season farming (Figure 19). This is because most riverine farmers rely on shallow aquifers which easily respond to any changes (seasonal changes and climate change). Increasing the number of wells has both economic and environmental implications, which affects the total cost of production and consequently, farmers total benefits/returns from groundwater irrigation.



Population of respondents (n) =210

Figure 19. General outcomes due to climate change impacts on groundwater

4.4. Summary

The discussion in this chapter examined the nature of climate change in the catchment in terms of rainfall and temperature. On the part of rainfall, there is a slight difference in results. While local observation points to a drecreasing trend, the meteorological data shows an insignificant increase. However, the total annual rainfall shows wide values of rainfall variability within the study period. An analysis of the rainfall data of driest (1977) and wettest (1999) years reveal that the earlier the onset of the rains the higher the volume and intensity of it. Moreover, it is reaslied that when the onset of rains is early, the rainy season becomes longer. This confirms what local obseveration have about rainfall where it is noted that when the rains come late, they last for a short period of time.

The meteorological data as displayed in the Walter-Lieth (1967) diagram shows also that it is from June–September that highest volumes of rainfall are recorded (with low temperatures) which

results in humid conditions above the threshold. It can thus be said that it is within these months that groundwater recharge occurs. Still on the trend of rainfall, the monthly analysis show that, for at least 4 months after the onset of rainfall, volumes of rains increase consectively and usually reach their peaks either by August or September (depending on whether it is a dry or wet year) which is followed just by at most 2 months of decreasing raifall, marking the end of the rainy season. These trends have implications for both rainy season farming and dry season groundwater farming.

While there is unanimous agreement of the changes in trend of temperature as increasing, the meteorological data point to high variations in the trends characterising both Maximum and Minimum. It is noted that tempeatures begin to increase from November to March which coincides with the period of no or little rains, indicating that groundwater recharge does not occur at all within this period. This further affects soil moisture as evaporation is often high at this time. Available groundwater in wells also experiences evaporation while surface water, which these farmers may conjunctively use, is near to dry up. It is therefore, laudable if subsurface dams could be constructed to capture and store rainwater in the rainy season for dry season irrigation.

5. FORMAL INSTITUTIONS AND GROUNDWATER ADAPTATION TO CLIMATE CHANGE

This chapter discusses the first research objective of the study which aims at identifying and mapping out (see Appendix H for map) institutions that are concerned about groundwater adaptation in the country. The discussion here looks at these institutions at two levels. That is the national and subnational levels.

A discussion of these at the two levels in relation to climate change adaptation in Atankwidi showed the presence of legislation, policies and administration, which connotes the representation given by Dinar and Saleth (2004) of water sector institutions or what the New Institutional Economics called the Institutional Environment. However, these institutions are multi-purposed which confirms the argument by Critical Institutionalism of the nature of institutions, particularly in Africa.

Although climate change adaptation has been embraced by Ghana, there is currently no legislation currently in the country that focuses specifically on climate change adaptation (groundwater), existing legislation from sectors like Water, Local Government, and Environment are applied. This critiques the New Institutional Economics that institutions are crafted for a specific purpose. The situation in the country has, however, resulted in institutional pluralism as far as groundwater adaptation is concerned.

As noted by Kemper (2007), these institutions operate at different levels: national and sub-national. However, their roles and functions depict a top-down hierarchy. Those at the national level form the basis of those at the subnational level. The subnational level ones operate at the municipal and district levels with some of their climate change focal points being local in nature as they factor in local geographical and physical conditions of these places. Nonetheless, the existence of these is the first step towards boosting groundwater resources adaptation to climate change. Details of the situation are presented below.

5.1. Formal institutions at the national level-Legal Provisions (laws)

The role of formal institutions as far as climate change adaptation in Ghana is concerned remains crucial. The discussion here brings to light these institutions at the national level and their significance for adaptation.

There is a plethora of legislative instruments (Figure 20) that regulate the activities of the citizenry as far as the use of water resources in Ghana is concerned. These legislative instruments are constituted in conformity with international water standards while taking cognisance of local and national conditions. They cover all the various water uses such as domestic, municipal, industrial, agricultural, power, fisheries among others. However, as indicated already, only groundwater used for domestic and irrigation purposes will be considered. The consideration of any legislation here is based on the fact that its objects reflect groundwater adaptation (recharge, demand, quality, storage and discharge).

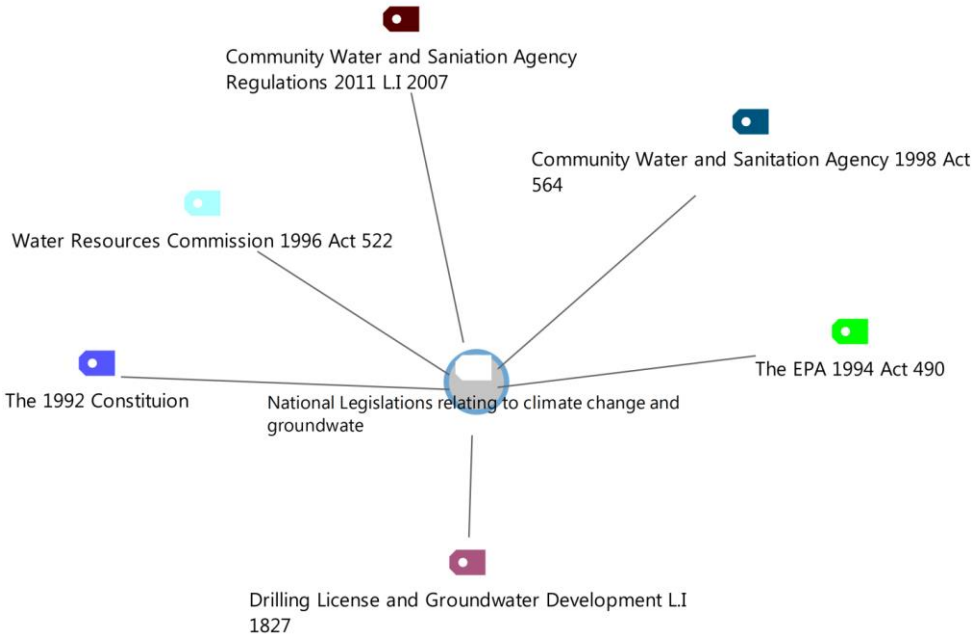


Figure 20. Legislation at the national level

5.1.1. The 1992 Constitution of the Republic of Ghana

As Vatn (2005) noted, institutions define resources regimes. Land and water resources are inseparable. Although the 1992 constitution of Ghana in chapter 21, Article 257 vests all natural resources in the country in the president on behalf of and in trust for the people of Ghana, caution is given about the ownership of land in northern Ghana. This Article in the constitution categorically declares in clause (3) that: for the avoidance of doubt, it is hereby declared that all lands in the Northern, Upper East and Upper West Regions of Ghana which immediately before the coming into force of this Constitution were not vested in the Government of Ghana are not public lands.

The provision of the constitution is necessary for understanding the ownership, governance of groundwater resources and for that matter climate change adaptation measures in the study area which fall within the northern part of the country. By the provision of the 1992 constitution which is similar to the Traditional English Common Law as noted by Nanni et al. (2004) land rights in the catchment were tied to water rights and landowners held the exclusive rights of groundwater resources in general within their areas of control. This remained the situation in the Atankwidi catchment up to date even though water rights have been redefined per the dictates of the Water Resources Commission (WRC), 1996 Act 522. The WRC recognises the customary land tenure system in northern Ghana but detached water rights from land rights.

5.1.2. Water Resource Commission, 1996 Act 522

This Act establishes the Water Resources Commission to regulate and manage the utilization of water resources in the country. This Act further broadens the scope of ownership of natural resources in the country of the president by declaring that all water resources is vested in the President on behalf of, and entrust for the people of the Republic.

The other part of this Act which is also relevant for this discussion is about the obligation for the use of water with authorization or water use permits. That by except in accordance with the provisions of this Act, a person shall not (a) divert, dam, store, abstract or use water resources, or (b) construct or maintain any works for the use of water resources. This Act, therefore, ensures

that the use of water including groundwater is in conformity with the Water Use Regulations (L.I 1692) 2001. The act further spells out that a person may apply to the Commission in writing for the grant of water right.

The Act further prescribes those situations that may result in water pollution and spells out the sanctions for offenders. In addition, this Act which established the Water Resources Commission gives authority to this commission by Legislative Instruments (L.I) to make regulations for water use as in the case of the Drilling License and Groundwater Development Legislative Instrument (L.I) 1827 which will soon be discussed.

The relevance of this Act for groundwater resource adaptation to climate change cannot be overestimated. This is because it touches on the need to regulate groundwater use by issuing water use permits as a way of controlling groundwater abstraction (quantity). The act again defines precautionary measures as far as water pollution, in general, is concerned and the corresponding sanctions that follow should anyone fall culpable. This in part addresses issues of groundwater quality.

5.1.3. Drilling License and Groundwater Development (L.I), 1827

This Legislative Instrument passed by the Water Resources Commission covers two broad areas relating specifically to groundwater resources and adaptation. These areas are Water Drilling Licence and Wells Construction. The first part of the regulations stipulates that a person shall not construct a well for the abstraction, or monitoring of groundwater or for research if that person does not have a drilling licence granted in accordance with these Regulations.

This section of the regulation is apt for climate change adaption of groundwater resources because it regulates who is permitted to drill and abstract groundwater and the required drilling process. This is to curtail the unnecessary abstraction of groundwater which may result in aquifer depletion. It is also to make sure that people with requisite skills and equipment undertake drilling. This is to prevent situations that may cause groundwater pollution. It also allows for District Assemblies to monitor the activities of well drillers as these drillers are expected to be registered by the Assembly, a situation that will also bring about a compilation of data on groundwater activities at the local level.

The second part of the regulations which touches on wells construction holds it that a drilling contractor shall not construct or begin to construct a well without notice to the Commission of the intention to do so. A person shall not also construct a well in a manner that leads to contamination or pollution of groundwater or aquifer. As noted in the literature, groundwater quality is one of the areas that need to be considered in the face of climate change adaptation vis a vis groundwater resource. This provision of the regulation is, therefore, relevant as it ensures that wells construction, especially for large scale projects, is done in such a manner that groundwater quality is not comprised as environmental protection requirement is expected to be met as details of such are indicated in the regulations.

5.1.4. Water Use Regulation (L.I 1692), 2001

These regulations were made by the Water Resources Commission by the powers vested in it by the WRC 1996 Act 522. The regulations cover primarily water use permits by defining the various types of water uses in the country and the conditions under which one is supposed to apply for a water use permit. Nonetheless, the regulations make some exemptions: any water use resulting from the abstraction of water by manual means is exempted from these Regulations. The importance of this Act to groundwater resources in the face of climate change lies in the fact that apart from the various water uses spelt out here, water cannot be put to any other use without

prior notice given to the institutions concerned. It, therefore, creates the opportunity to monitor the various use of water in the country so as to prioritise where necessary in the quest to address climate change and its impacts on groundwater resources.

5.1.5. Community Water and Sanitation Agency (CWSA) Act 564 of 1998

This Act establishes the Community Water and Sanitation Agency with an object to facilitate the provision of safe water and related sanitation services to rural communities and small towns. The provisions of this Act are important for climate change adaptation as far as groundwater resources are concerned in the country. This is because groundwater resources constitute the only source of water that the CWSA relies on to supply water to users especially in the rural and small towns particularly in the northern part of the country. The creation of guidelines, codes and standards will safeguard the quality of groundwater for human use while ensuring that the natural state of groundwater resources remains in a balance.

5.1.6. Community Water and Sanitation Agency Regulations L.I 2007, 2011

As noted already in the Community Water and Sanitation Agency (CWSA) Act 564 of 1998 section (18), the board of the agency may make regulations with the approval of the sectorial minister by a legislative instrument on some aspects of the water resources. This obligation recognised in the CWSA Act 564 of 1998 has culminated into these regulations. The regulations state that the District Assembly shall serve as an authorizing body to approve any application for the provision of any water facility. A District Assembly shall also establish a Water and Sanitation Management Team to manage a water or sanitation facility for the benefit of a community. A District Assembly shall, on a recommendation of the agency, approve the levels of the tariffs proposed by a management team (in consultation with the community).

The regulations further elaborate requirements for the drilling and sitting of boreholes. For instance, (1) a person responsible for the construction of a borehole and the installation of a pump for the supply of water to a community shall ensure that the minimum yield of water from the borehole is at least ten litres per minute (2) a person shall not drill a borehole unless a qualified person has carried out the appropriate groundwater investigations. (3) a selected borehole site shall be at a minimum distance of fifty meters from (a) Sanitation facility; (b) a form of garbage disposal point or cemetery; (c) sacred grove; or (d) any other known source of real or potential contamination within the community.

There are a lot of core issues that this Legislation Instrument touches on looking at groundwater adaptation to climate change. For instance, one of the key areas of adaptation is about the management of groundwater demand. This instrument has identified the District Assembly as a key agency which must work with the local community to manage water facilities. Groundwater tariffs are but another key component of groundwater demand. This has again been addressed in this instrument. The last part of this legislation instrument deal with issues of protecting groundwater quality and regulating groundwater storage. It addresses aquifer pollution prevention and the need to avoid over-abstraction of groundwater in the process of increasing groundwater supply to users.

5.1.7. The Environmental Protection Agency (EPA) Act 1994, Act 490

This Act establishes the Environmental Protection Agency (EPA) some of whose functions will be dealt with in the ensuing discussions. The Act also hammers on the enforcement and control of environmental regulations and guidelines for large scale development projects by subjecting them to Environmental Impact Assessment (EIA) before licences are issued. The Act further looks at the control and management of pesticides. In summary, the Act is important for adaptation

because it treats issues of pollution control in the environment, enforcement of environmental standards and need for regulatory agencies to support local governments as critical to ameliorate the numerous challenges characterizing Ghana. In the area of groundwater resources, it is realised that groundwater pollution can sometimes emanate from the poor handling of chemicals and this has been highlighted in this act whereby the use of pesticides is subject to rigour control.

5.1.8. Critical issues

From the review of some of the legal provisions that centre on groundwater and climate change, the following issues have emerged and are worth discussing.

- There is currently no Act of Parliament or Legislative Instrument formulated for the sole and specific purpose of climate change adaptation in Ghana. The review above shows that existing but relating legal provisions are resorted to and these are plural and usually general in scope. As a result, application and enforcement of some of these legal provisions within the context of climate change sometimes are difficult.
- None of these legal provisions above makes room for groundwater recharge or storage. However, an emphasis is placed on abstraction. This may affect groundwater adaptation if efforts are not taken to control abstraction and boost recharge.
- There is little knowledge among the general population especially groundwater users at the catchment level about most of these legal provisions. From the interviews conducted in the Atankwidi basin, no person was able to mention one legal provision in Ghana that has to do with groundwater. Some of the respondents are educated yet could not exhibit any knowledge about some of these legislations. It is also realised that most of the people at the catchment still trace water rights to the definition of the 1992 constitution, as they have not been updated about the Water Resources Commission 1996 Act 522. This implies that the rate of violating the contents of these legal provisions regarding groundwater resources and their use by users is high.
- Even where the Water Resources Commission creates sub-committees or bodies for the management of water resources or basins/catchments in the country, it is seldom about groundwater resources. This is reflected in the formation of boards like the White Volta River Basin Board in the Upper East Region responsible for managing the White Volta.

5.2. Formal institutions at the national level-Policies

Ghana's efforts at designing policies aim at safeguarding the environment and its resources date back to the outcomes of 1972 UN Conference on the Human Environment (1972) in Stockholm through to the Brundtland report - Our Common Future (WCED, 1987) and finally to the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil in 1992, an event that saw the opening for signatures on the United Nations Framework Convention on Climate Change (UNFCC). The UNFCCC came into force in 1994 of which Ghana became a signatory to it in 1995. As a result, the first environmental policy of the country was enacted after the Rio 1992 Declaration with the support of the Environmental Protection Agency with a follow up of a National Environmental Action Plan. As the country continues to participate in global environmental discussions like Ghana's National Communications for instance in the years 2001 and 2011 to UNFCC and negotiations like the Cartagena, St Petersburg dialogue, Africa Group, Economic Community of West Africa States (ECOWAS) Planning and Green Power Africa, issues about climate change adaptation began to gain momentum in the country. It was therefore not surprising that the country came out with its Ghana National Climate Change Policy in 2013, the first of its kind to focus specifically on climate change in the country. Apart from this policy, other

policies in the country are in support of climate change adaptation in general and groundwater resources in particular as summarised in Figure 21. However, it is needful to mention again that any policy reviewed here contains some elements that relate to the five (5) thematic areas of groundwater adaptation as noted by Dillon et al. (2009).

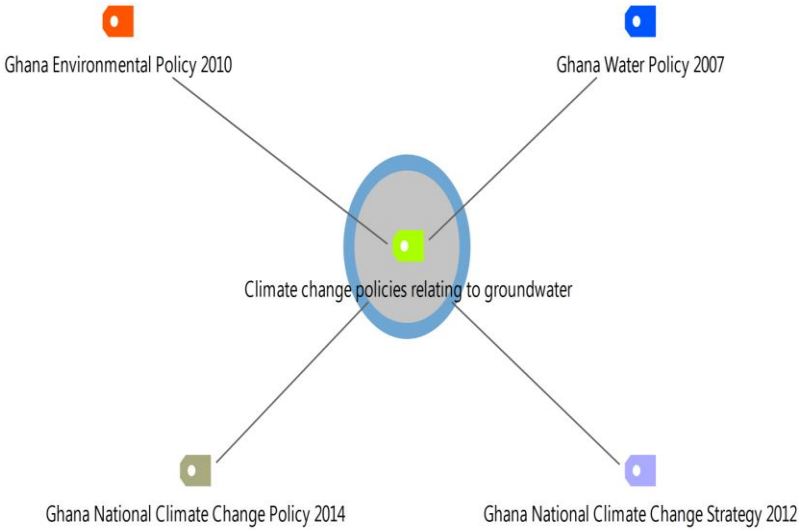


Figure 21. National level policies of climate change adaptation

5.2.1. Ghana National Climate Change Strategy, 2012

This document which hit the public in 2012 was put together with contributions from the United Nations Environmental Programme (UNEP) and the United Nations Development Programme (UNDP) and funded by the Danish Ministry of Foreign affairs. The focus of the strategy regarding water resources adaptation to climate change includes the preservation/conservation of water resources, improving and sustaining the quality of water resources, and building capacity in water resources management. This policy though a 37 paged document does not contain sufficient information about the issues raised above. It only provided a summary of the country's ideas about climate change in general terms.

5.2.2. Ghana National Climate Change Policy, 2014

The National Climate Change Committee led in the preparation and design of this policy with technical support from the EPA and MESTI. This policy has five (5) themes of which two of these address climate change adaptation in relation to water resources. The first theme which is agriculture and food security stated that there is the need for the construction of proper storm drainage systems; protect river banks through afforestation along embankment to reduce flood and the construction of channels and dams to contain floods and store water for dry season farming. It must be noted here that the rationale behind this is to avert extreme hydrological disasters and not to boost water resources availability and quality as such. The second theme which is about equitable social development advocates for the construction of water storage systems through rainwater harvesting and increased use of shallow wells, dug out and dams for water storage. Again, one realizes that nothing has been said about groundwater development and whether the rationale for harvesting rainwater is to reduce the burden on groundwater use or not. This document though bulky fails to give room especially to groundwater resources development as part of adaptation measures, even though groundwater constitutes a major source of water supply to a lot of Ghanaians.

5.2.3. Ghana Water Policy, 2007

This policy focuses on several areas among which is climate variability and change in the country. The chapter in this policy document devoted to climate issues advocates that rainwater harvesting techniques should be incorporated into the country's building code and enforced. The whole idea of climate change adaptation in this policy document is not to boost water resources in general and groundwater resources, in particular, to adapt to climate impact but rather to prepare communities towards extreme hydrological events such as floods and drought. Nonetheless, the policy touches also on the Integrated Water Resource Management, a strategy which aims at integrating water resource management and development with environmental management to ensure the sustainability of water resources in both quantity and quality.

5.2.4. Ghana Environmental Policy, 2010

One of the objectives of this policy is to raise climate change awareness, education and build capacities of Ghanaians about climate change. This is in line with the mandate of the EPA required by the Environmental Protection Agency (EPA) Act 1994, Act 490 which is to undertake environmental education in the country in relation to environmental issues. The policy also holds in high esteem the need to work with the Water Resources Commission of Ghana and to also support the Integrated Water Resource Management as well as the River Basin Approach. The policy remains important for groundwater adaptation in relation to climate change because social development through education and awareness creation is one of the crucial areas of climate change adaptation.

5.2.5. Critical issues

- It is sad to note that even in the National Climate Change Strategy, concrete measures have not been put in place to boost groundwater resilience to climate change and its impacts. Where there is the mention of water resources in the document, the focus is on rainwater harvesting which is even supposed to be on a household basis.
- Agriculture is the mainstay of Ghana's economy where there is so much reliance on water resources. Unfortunately, none of the agricultural policies has mentioned climate change adaption as far the use of water resources is concerned hence their absence in this discussion.

5.3. Formal institutions at the national level-Administration

In order to ensure the enforcement of climate change measures in the country, some agencies have been identified and tasked with this responsibility (Figure 22). These agencies are also expected to coordinate with the other sectoral agencies of the economy. Regarding climate change adaptation in relation to groundwater resources, the following agencies stand out.

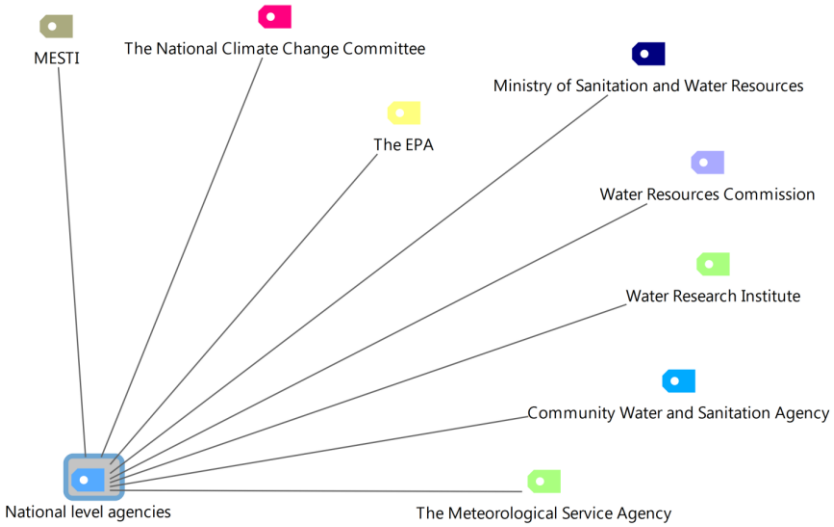


Figure 22. Nation level formal government agencies

5.3.1. The Ministry of Environment, Science, Technology and Innovation (MESTI)

This ministry is the lead implementer of the National Climate Change Strategy and plays an advisory role. It is within this ministry that the National Climate Change Committee is located. The ministry works keenly with agencies like the Environmental Protection Agency (EPA); the Council for Scientific and Industrial Research (CSIR); the Ghana Atomic Energy Commission (GAEC); and the Town and Country Planning Department (TCPD).

Some of the functions of the ministry are to: collaborate with the national development planning commission to ensure that the adaptation strategy is mainstreamed into development planning processes, work with other agencies and organisations which are into climate change issues, assist all climate change actors with technical, financial and logistical support to accelerate the implementation of the strategy, supervise, monitor and evaluate the performance of the strategy and many other functions.

5.3.2. The National Climate Change Committee

As noted already, this committee is hosted by the MESTI. The composition of this committee includes representatives from MESTI, National Development Planning Commission, Ministry of Food and Agriculture, Ministry of Energy, the Energy Commission, Center for Scientific and Industrial Research, Environmental Application and Technology Center and the Meteorological Service Department.

As captured in the National Climate Policy, 2012, the committee is responsible for among other things: the day-to-day management of the National Adaptation Strategy, the supervision of programmes/projects, support for the local institutions in capacity building and participation, establish policy guidelines for programmes/projects operations.

5.3.3. The Environmental Protection Agency (EPA)

The Environmental Protection Agency (EPA) is the agency that provides the MESTI with technical support about climate change adaptation. The agency is represented by its technical wing, the Energy and Climate Change Unit, in such affairs. It is also this unit which has been preparing the country's National Communications reports since 2001 to the UNFCC and constitutes the focal points for the IPCC and the UNFCC. As noted under the National Environmental Policy about the need for environmental education, this unit is further tasked to handle education, training and

public awareness programmes in the country. For instance, this unit has developed the Climate Change and Green Economy Learning Strategy which states among other things that annually there should be the celebration of climate change week in one region of the country. To fulfil this, there was a week-long celebration in October 2016 in the Greater Accra Region with the following activities: community durbar and outdooring of climate change ambassador, policy dialogue with political parties on climate change, educational sector consultative meeting on climate change, and a national symposium on climate change. This unit as part of its educational programmes organizes climate change drawing contest for all students all over Ghana from time to time. Schools in Ghana have also benefited from this unit in terms of the planting of Automatic Weather Stations and the supply of Teaching and Learning Materials about the weather.

5.3.4. Ministry of Sanitation and Water Resources

This ministry has severally been restructured as it was the Ministry of Water Resources, Works and Housing but has metamorphosed into Ministry of Sanitation and Water Resource in 2016. Currently, the Hydrological Service Department is still part of the Ministry of Works and Housing. This frequent restructuring of this particular ministry makes it difficult to trace the performances of water resources in relation to climate change. According to the National Climate Change Policy (2013) the erstwhile Ministry of Water Resources, Works and Housing was to plan, coordinate and monitor programmes for infrastructural development and water management.

5.3.5. Water Resources Commission (WRC)

The creation of this commission has been noted already. The Commission is responsible for the regulation and management of the utilisation of water resources, and for the co-ordination of any policy in relation to them. The regulatory function of the commission manifests in some of the following: grants water rights, collects, collates, stores and disseminates data or information on water resources in Ghana, advises pollution control agencies in Ghana on matters concerning the management and control of pollution of water resources and many others.

With reference to climate change issues, this commission has been collaborating with climate change agencies and integrating climate change programmes into its policies, projects and programmes. The commission also assisted the National Development Planning Commission with technical support about how water security and climate resilience issues can be mainstreamed into Medium Term Development Plans for the period 2014-2017.

5.3.6. Water Research Institute (WRI)

The Water Research Institute (WRI) is among the 13 research institutes that make up the Council for Scientific and Industrial Research (CSIR) in the country. The goal of the institute is to make available scientific information, strategies and services. The institute has six divisions among which, is the groundwater division. The groundwater division is tasked with the responsibility to generate process and disseminate information on the availability of groundwater, the quantity of water to be abstracted for various uses as well as the reliability and sustainability of its recharge. On climate change issues for instance, the groundwater division partners with agencies like, British Geological Survey, Africa Climate Exchange (AfClix), University of Reading (UK), Ghana Meteorological Agency (GMet), CARE International and University of Ouagadougou about how to build understanding of climate variability into planning of groundwater in low storage aquifers of Africa: a project that covers the north of Ghana and parts of southern Burkina Faso.

5.3.7. Community Water and Sanitation Agency (CWSA)

Community Water and Sanitation Agency Act, 1998 establishes this agency with the object to facilitate the provision of safe water and related sanitation services to rural communities and small towns. This is to be realised by providing District Assemblies with technical assistance in the planning and execution of water development and sanitation projects in the districts and provide support to these Assemblies to promote the sustainability of safe water supply and related sanitation services in rural communities and small towns. The agency is also to initiate and pursue in collaboration with the Ministries of Local Government issues of the environment, health and education through formal and non-formal education programmes for the creation of public awareness in rural communities and small towns of water-related health hazard. In fact, since the inception of this agency as created by the then Ghana Water and Sewerage Corporation through the CWSA act 1998, it has been spearheading with rigour potable water provision for rural communities throughout Ghana. This agency has its representatives in all the regional capitals in the country.

5.3.8. The Meteorological Agency

The Ghana Meteorological Agency (GMet) was established by the Ghana Meteorological Agency Act 2004 Act 682 to replace the erstwhile Ghana Meteorological Services Department.

The object of this agency is to provide meteorological services in the country and ensure the operation and maintenance of international standards and practices in meteorology in the country. As contained in the National Climate Change Policy, the primary function of GMet is to provide efficient weather services through the collection, processing, storage and dissemination of meteorological data to end users (MESTI, 2013). Information from this agency is critical especially for adaptation to extreme hydrological events like floods in the country at the peak of the rainy season.

5.3.9. Emerging issues regarding formal administration at the national level

As essential as the existence of these agencies may be to the successful implementation of climate change adaptation in the country, there is still much to be desired. Juxtaposing the functions of these agencies with the real situation on the ground revealed the following, which are worth noting for subsequent considerations.

- There appears to be no clear definition of roles and responsibilities between some national agencies and the District Assemblies as far as climate change adaptation is concerned at the local level. For instance, it is difficult to get the CSWA, and the District Assemblies to easily acknowledge and accept their adaptation roles. While the District Assemblies usually expect that groundwater issues would best be handled by the CWSA, the opposite applies to the CSWA. The two agencies are supposed to work together as the regional representative of the CSWA is even supposed to be an ex-officio member of some statutory committees within the District Assembly.
- The nature and content of programmes designed by these agencies are seen to be skewed and not overarching/comprehensive enough. Compounding this situation is the fact that these programmes do not take cognisance of local geographical conditions. These programmes are not also tied to local livelihoods. This makes it difficult for their implementation at the local level. For instance, most climate change projects in the Upper East Region are about tree planting (carbon sequestration). The EPA in this region has bemoaned this situation and the need to redesign climate change programmes to reflect local conditions for easier implementation.

- The local representatives of the National Climate Change Committee are non-existent. As stipulated in the National Climate Change Strategy, there is supposed to be a Regional Climate Change Monitoring Committee in every region, unfortunately, there is none in the Upper East Region. The District Environmental Management Committees appeared ill-informed about climate change issues and no records at all of climate change meetings in particular. It was difficult to get these persons at the district assemblies to interview.
- The approach adopted by the climate change agencies to addressing climate change in the country creates no room for local level participation especially regarding the design of measures. Academics and researchers have confirmed that every farmer in Ghana is knowledgeable and an expert in climate change issues. Fortunately, most Ghanaians are farmers yet their views are not considered in designing climate change measures. There are little local level consultations and the absence of integrating local people in the process of validating climate change programmes. This affects the implementation of programmes resulting in a few desired outcomes.

5.4. Subnational level formal institutions-Bylaws

5.4.1. Bye-laws of the four study District Assemblies

The Local Government Act 1993 Act 462 forms the basis for the creation of districts in Ghana. In that same vein, there must also be the creation of District Assemblies which in accordance with clause (3) of article 241 of the 1992 Republican Constitution shall constitute the highest political authority in the district.

The task of the District Assembly is to perform deliberative, legislative and executive functions. It is within the domain of these functions as enshrined in the Local government Act 1993 Act 462 that District Assemblies may make by-laws for the purpose of a function conferred on them. In these bylaws shall be the specification as a penalty a fine and make provision for the payment of the fees or charges. The by-laws made by a District Assembly shall be read and construed subject to this Act and any other enactment. Approval of the bye-laws is by the Minister (Minister for Local government) and he shall submit them for publication in the Gazette. This role of the Minister can be delegated to the Regional Coordinating Council. The bye-laws shall not have effect until they have been published in the Gazette. A copy of the by-laws purporting to be made by a District Assembly on which is endorsed a certificate purporting to be signed by the presiding member and the secretary to the Assembly to the effect that they copy is a true copy of the by-laws, shall be prima facie evidence in a court of the due making and the contents of the bye-laws.

All the four districts have bye-laws even though there are issues to be considered. These bye-laws cover a wider spectrum of environment and development. Peruse of the content of these bye-laws showed that each district has about 20 bye-laws. However, this research only selected those that have implications for groundwater adaptation to climate change (Table 3).

Table 3. Applicable bye-laws regarding groundwater and climate change

District/ Municipality	Number of bye-laws	Specific byelaw relating to groundwater	Specification of specific byelaws
Bolgatanga Municipality	24	Cemeteries bye-law 2004	– Plan for cemeteries – Grave space – Depth of graves – Burial in compound houses
		Sanitation bye-law	– Disposal of waste

5. Formal institutions and groundwater adaptation to climate change

District/ Municipality	Number of bye-laws	Specific byelaw relating to groundwater	Specification of specific byelaws
		2004	– Removal of wood and rubbish
		Removal of domestic refuse bye-law 2004	– Dustbins provision and services
Bongo District	26	Environmental Sanitation bye-law 2016	– Disposal of refuse – Control of weeds and rubbish
		Control of pollution bye-law 2016	– Disposal of refuse – Littering of lorry parks – Removal of weeds and other Offensive material – Burial of the dead
		Collection and disposal of waste bye-law 2016	– Licensing for the Collection of Waste
		Wetland protection bye-law 2016	– To protect the wetlands, water resources, and adjoining land areas under the jurisdiction of the Assembly
		Cemeteries bye-law 2016	– Control of cemetery – Plan of cemetery – Grave space – Depth of grave – Cremation – Vaults
Kasena Nankana East District	24	Cemeteries bye-law 2010	– Plans for cemetery – Grave – Depth of grave – Burial in compound house (prohibited)
		Sanitation bye-law 2010	– Disposal of refuse – Removal of wood and rubbish
		Removal of domestic waste bye-law 2010	– Dustbin provision and service (compulsory)
Kasena Nankana West Municipality	28	Cemeteries bye-law 2009	– Plan of cemetery – Grave space – Depth of grave – Vault – Crematorium
		Sanitation bye-law 2009	– Disposal of refuse – Removal of weeds and rubbish
		Control of trees	– Prohibition – Trees to be repealed

District/ Municipality	Number of bye-laws	Specific byelaw relating to groundwater	Specification of specific byelaws
		Environmental sanitation bye-law 2009 (solid and liquid waste bye-law 2004, control of pollution bye-law 2004 and drainage and storm water and sillage conveyance bye-law 2004	– Sewer connection and payment – Disposal of waste – Littering of public place – Removal of weeds and other offensive material – Recycling of wastes in residential area – Burial of the dead – Licensing for waste collection – Plant and equipment – Connections and usage of drains

5.5. Subnational level formal institutions-Policies

5.5.1. District/Municipal Medium Term Development Adaptation Plans

The District Assemblies are obliged by the National Climate Change Committee together with the National Development Planning Commission to draw their own Medium-Term Development Plans to reflect climate change adaptation based on the guidelines given by this committee. Local projects or programmes relating to the environment and water include tree planting project championed by forestry commission, sustainable land and water management-tree planting combined with cropping, Ghana social opportunity projects-rehabilitation of dams, land zoning for waste management and catchment planning-white Volta basin. The districts also prepare Strategic Environmental Assessments Plans which also capture environmental issues in general. It must be stated that climate change issues are yet to take shape in these districts. It is a fact that pockets of activities are going on which are usually donor-funded but most of these focus on tree planting.

5.5.2. Community-level Adaptation Plans

The local communities through the Town and Area Councils in the districts play a crucial role in climate change adaptation strategies. These communities are supposed to draw their own climate change adaptation plans which are then harmonized and factored into district plans. The climate change agencies at the community level are expected to make inputs which are collected, collated and then synthesised into the community level plan which is submitted to the district assembly for action. The above is the ideal situation and what is documented. However, no community in any of the study districts has such adaptation plans in place.

5.6. Subnational level formal institutions-Administrative

5.6.1. The Regional Coordinating Council (RCC)

The council is seen as an administrative rather than a political entity. The RCC is lauded with the responsibility of monitoring and evaluating climate change adaptation efforts at the district level. The council is also supposed to collaborate with the national climate change committee to

streamline climate change in a manner that will make it easier for implementation in the district. The council is also expected to constitute a Climate Change Monitoring Committee at the regional level to monitor climate change efforts at the district level. Unfortunately, no such committee existed in the Upper East Region.

5.6.2. The District/Municipal Assemblies

The District assemblies play an important role as far as the implementation of climate change adaptation measures is concerned. Climate change issues here in the district are designed in line with both local conditions and national guidelines by the District Planning and Coordinating Unit together with the budget unit of the assembly. The District Environmental Management Committee is made up of representatives from the Forestry Commission, Ghana Education Service, Community Development, Fire Service, Health and Sanitation, District Gender Desk, NGOS, chiefs, District Planning office, district coordinator directorate and the EPA. This committee together with the Water and Sanitation Management committee ensures the implementation of these climate change projects/programmes. These assemblies are assisted by NGOs, Civil society based organisation, the private sector, decentralized department and the traditional authorities.

5.6.3. Local community level

The Town and Area Council is the lead representative of the District Assembly in the local community. As a result, climate change adaptation measures are initiated and facilitated in the community by the council. The council is supported by the traditional political leaders, the Water and Sanitation Management Committees (WATSAN), women groups, youth groups, farmers Associations and others.

5.6.4. Emerging issues

From the review of the subnational institutions, the following issues are critical and worth noting:

- Firstly, apart from the Kassena Nankana East District, the other three districts within which the study communities fall have draft bye-laws. None of these three districts has been able to gazette their bylaws as at the time of the field work. This has implications for their enforcement.
- Even with the draft bye-laws, none of these has captured issues relating to water resources in general and groundwater in particular, perhaps only the Bongo District Assembly has Wetland Protection bye-law 2016. Their contents reflect a few but general environmental challenges as presented in the table above.
- Copies of these by-laws are also limited and difficult to access. The Kasena-Nankana East District could not just lay hands on a copy of its bye-laws at the time of the field work; a copy was obtained from an official of a Non-Governmental Organization (NGO) in the district who happens to be a member of the Environmental Management Committee; got a copy through his own efforts from the Local Government Secretariat in Accra. It took two weeks to get a copy of the bye-laws for the Bongo District from the District office and a month to get a hard copy of these bye-laws from the Kasena Nankana West Assembly. Only the Bolgatanga municipality was able to make copies of its by-laws available within hours.
- The contents of these by-laws are similar which should not be the case because the districts' local development challenges are different. The Kasena Nankana West Municipality which has the highest number of bye-laws among the four districts to some extent has diverse bye-laws but there still exist a lot of similarities with other districts'

bye-laws. The reason for these similarities in content is due to the fact that the District Assemblies do not have the wherewithal to prepare their own bye-laws. As a result, they tend to rely on donors for support like the Canadian International Development Agency (CIDA). This donor support, however, comes with conditionalities and this pushes local assemblies to design bye-laws that take into account these conditionalities. The lack of competent and skilful staff in these assemblies also encourages copying of bye-laws from the supposed districts endowed with better staff.

- Climate Change Committees are non-existent at the district level. The District Environmental Management Committees are saddled with the responsibilities of climate change and these committees are not well vexed with climate change issues. This is because no efforts have been made consciously to do so. Even where there is the need, such committees are usually taken through short workshops whose objectives are just to inform/update them about climate change projects in the district. This is usually done by the EPA with support from NGOs.
- The only major efforts that district assemblies are offering in line with groundwater adaption to climate change is the supervision of groundwater supply facilities, the registering of water use rights and groundwater drilling companies as mandated by legislation instruments such as the community water and sanitation Agency Regulation (2011) (L. I 2007), the Water Use Regulation, 2001 (L.I 1692) and the Drilling License and Groundwater Development Regulation 2006 (L.I 1827).
- The commonest form of climate change adaptation projects in the districts are tree planting projects, like Mango plantation projects, Rehabilitation of dams), usually supported by NGO. For instance in Bongo Municipality, tree planting has been organised by TREE AID, an NGO carried out along water bodies, Ghana Education Service also undertakes tree planting. Traditional authorities like the Bongo chief in the Bongo Municipality is championing a project called Green Bongo: a tree planting project where any child born in the hospital is given a tree seedling to go and plant and nurse it until it becomes a tree. Also as in the case of the Kasena Nankana municipality where there was the desilting of Tono and Doba dams.
- Even though community participation in the drawing up of district plans is important, challenges of inadequate funds and logistics characterising all the districts hamper this process. Again, the challenge posed by limited funds has also affected the monitoring of climate change projects in the district.
- There are little efforts at the community-level to prepare community-level adaptation plan. This is partly due to problems of funds and limited human resource from the district assembly to support these communities in this regards.

5.7. Groundwater components captured in Ghana's legal provisions

Ghana boasts of several institutions that regulate climate change adaptation in the country nonetheless, it is some that captured groundwater resources issues. It is also worth noting that modern legislation must take note of some components of groundwater as considered by Nanni et al (2003). These components as presented in Table 4 are considered important because they play an important role in efforts to boost groundwater adaptation to climate change. Note that there is currently no legal provision that takes into account the conjunctive use of groundwater and surface water.

Table 4. Institutions and groundwater components

Groundwater component	Institution	Prescription of institution
Groundwater abstraction and user rights	Water Resource Commission Act 1996 Act 522	A person may apply to the Commission in writing for the grant of water right.
	Water Use Regulations (L.I 1692) 2001	Subject to the Act, a person may obtain a permit from the Commission for: domestic water use, commercial water use, municipal water use, industrial water use, agricultural water use, power generation water use, water transportation water use, fisheries (aquaculture) water use, environmental water use, recreational water use, and under water (wood) harvesting.
	Drilling License and Groundwater Development (L.I 1827) 2006	A person shall not construct a well for the abstraction, or monitoring of groundwater or for research if that person does not have a drilling licence granted in accordance with these Regulations
Wastewater discharge licensing	The Environmental Protection Agency (EPA) Act 1994, Act 490	EPA to issue environmental permits and pollution abatement notices for controlling the volume, types, constituents and effects of waste discharges, emissions, deposits or any other source of pollutants and of substances which are hazardous or potentially dangerous to the quality of the environment or a segment of the environment. EPA to prescribe standards and guidelines relating to the pollution of air, water, land and any other forms of environmental pollution including the discharge of waste and the control of toxic substances
	Water Resource Commission Act 1996 Act 522	The commission by Legislative Instruments shall make regulations for the granting of permits to discharge waste into water bodies
Sanctions for non-compliance	Water Resource Commission Act 1996 Act 522	A person who, except in accordance with the provisions of this Act or with the approval of the Environmental Protection Agency (a) interferes with or alters the flow of, or (b) pollutes or fouls, a water resource beyond the level that the Environmental Protection Agency may prescribe, commits an offence and is liable on conviction to a tine not exceeding five hundred penalty units or to a term of imprisonment not exceeding two years or to both the fine and the imprisonment (1) Where the holder of the water right (a) fails to comply with a condition of the grant express or implied, or (b) has abstracted or used water resources for a purpose not authorised by the

Groundwater component	Institution	Prescription of institution
		grant, the Commission may by notice in writing addressed to the holder require the holder to remedy the default within the period specified in the notice. (2) If the holder fails or neglects to remedy the default within the period specified the Commission may terminate the water right and inform the holder accordingly in writing
Controlling wells construction activities	Drilling License and Groundwater Development (L.I 1827) 2006	A drilling contractor shall not construct or begin to construct a well without notice to the Commission of the intention to do so
Catchment or aquifer level resource planning	Integrated Water Resource Management (IWRM) strategy	The IWRM plan: – strengthen the regulatory and institutional framework for managing and protecting water resources for water security and enhancing resilience to climate change -enhance public awareness and interest in water resource management issues – improve access to water resources knowledge base to facilitate water resources planning and decision making
	River Basin Approach	Establishment of White Basin Boards to promote transboundary activities at the community level through multiple stakeholders participation
Land surface zoning for groundwater conservation/protection	Water Resources Commission Act 1996 Act 522	Where the Minister is satisfied that special measures are necessary for the protection of water resources in or derived from an area, the Minister may by executive instrument declare that area or a part of that area, to be a protected catchment area.
Facilitating water-user and stakeholder participation	Community Water and Sanitation Agency (CWSA) Act 564 of 1998	The Agency shall provide support to District Assemblies to enable the Assemblies encourage the active involvement of the communities, especially women, in the design, planning, construction and community management of projects related to safe water supply and related sanitation service
	Community water and Sanitation Agency Regulations (L.I 2007) 2011	A District Assembly shall establish a Water and Sanitation Management Team to manage a water or sanitation facility for the benefit of a community
Provision for groundwater monitoring	Water Resources Commission Act 1996 Act 522	The commission – shall advise pollution control agencies in Ghana on matters concerning the management and control of pollution of water resources – monitor and evaluate programmes for the operation and maintenance of water resources

6. ASSESSING INSTITUTIONS' PERFORMANCE FOR ADAPTATION

Having looked at the nature of formal government institutions in Chapter Five as those that operate at different levels with differing roles and functions, the discussion here centres on how these institutions are performing by way of enabling, doing and achieving groundwater adaption to climate impacts. This relates to the five themes given by Dillon et al. (2009) of adaptation which are discussed in turn. Drawing from the performances of these, a scale is chosen which allows for the ranking of them. The contributions of agencies outside formal government institutions in order to provide a holistic picture of efforts aim at promoting groundwater adaptation in the entire country forms the concluding part of this chapter.

Considering the performances of these institutions, the study revealed that managing groundwater demand is an area which has experienced a higher level of performance. This level of performance perhaps is due to the fact that population increase and other socio/economic factors are fueling higher groundwater consumption hence the need to manage demand.

It is further revealed that while there are groundwater instruments for managing the demand of groundwater for domestic purposes, such cannot be said of groundwater for irrigation. Nonetheless, traditional institutions define the allocation of groundwater for irrigation in the catchment which promotes organised behaviour for adaptation.

Groundwater quality showed the concentrations of nitrate, fluoride and manganese higher than the World Health Organisation (WHO) guideline levels. However, measures such as capping of boreholes, testing of water before consumption and many others have been adopted. Institutions are performing well in this regards also.

Additionally, there is the presence of about 25 monitoring wells in the northern part of the country that provide data on groundwater levels, discharge, recharge and interactions between surface and groundwater. Unfortunately, artificial recharge of groundwater performed least because it is yet to receive attention in the area as groundwater recharge remains solely natural, from rainfall hence the least scored.

To provide a holistic presentation of the situation, the study further noted that there are institutions (agencies) outside the domain of formal government that support groundwater adaptation even beyond the frontiers of Ghana. These are in the form of multilateral institutions, governments of countries, Civil Society Organisations (Non-Governmental Organisation, and Environmental Groups), universities and research institutions both locally and internationally, private companies, union governments (European Commission) and individuals. Their roles include direct research, funding, governance, information and human resources development. The ensuing discussions digest these issues in detail.

6.1. Managing groundwater recharge

Recharge of groundwater is a major area of attention as far as adaptation to climate change is concerned. This takes into account both natural and artificial processes. Therefore, examining the situation in Atankwidi is critical for adaptation.

6.1.1. Nature of groundwater recharge in the catchment

Studies of groundwater recharge in the entire Volta Basin are limited. Nonetheless, it is realised that recharge is highly variable both spatially and temporally (Kolavalli and Williams, 2016). A study by Anayah et al. (2013) about recharge for the whole Ghana revealed that average recharge rate is 23% of the mean total annual rainfall. A study of recharge in some selected areas which include the Pwalugu catchment in the Upper East Region using stream hydrograph separation and chloride mass balance gave a recharge rate between 1.7 and 4.9% (Pelig-Ba, 2004). Martin and Giesen (2005) followed up with a study on recharge for the entire Volta River basin using Linear Regression. Their study put recharge at 3.7%. Obuobie (2008) also studied recharge for the White Volta basin and came out with a value of 8.3% as the average recharge rate of total rainfall.

In the Atankwidi catchment, Martin (2006) came out with the following results of recharge (Table 5) in the catchment.

Table 5 Comparison of annual recharge rates using different methods

	mm/y		**% of Precipitation**	
	2003	2004	2003 P=1138mm	2004 P=910mm
Chloride mass balance	59 (long term average)		2.9 (long term average)	
Water table fluctuation method	20-143	13-96	1.8-12.5	1.4-10.6
Soil water balance	147	35	13	4

Source: adapted from Martin (2006)

To further this discussion, reference is made to Carrier et al. (2008) who used soil moisture method to calculate recharge for some areas in the country using meteorological data from some weather stations which includes Navrongo weather station (the nearest station to Atankwidi) as presented in Table 6.

Table 6. Summary of soil water balance results for 1971-2001 period (mm of H_20)

Station	**Navrongo**	
Region	Upper East	
Units	mm	% of precipitation
Potential evapotr. (pET)	1723	-
Precipitation (P)	987	100
Runoff (Q)	123	12.5
Actual evapotr. (aET)	798	80.9
Recharge (R)	65	6.6

Source: adapted from Carrier et al. (2008)

From the illustrations above, it can be said that some studies which have looked at groundwater recharge in the area have been conducted already and these put the value of recharge within the range between 1% and 13% of mean total annual rainfall. In Atankwidi, rainfall is a major source of water for recharge which Martin (2006) says occurred through direct infiltration or leakages from streams and rivers.

6.1.2. Institutions' performances regarding groundwater recharge

Apart from studies on groundwater recharge, methods to boost artificial recharge have not been undertaken anywhere in the country by formal government agencies. No responses from the interviews with the officials of the Water Resources Commission (WRC), the Community Water and Sanitation Agency (CWSA) and the local communities show that there is no infrastructural development undertaken anywhere in the country that aids artificial recharge of groundwater aquifers by formal institutions.

Nonetheless, a few existing projects about groundwater recharge have been initiated by agencies outside formal government agencies with the formal government institutions only collaborating. The aim of such artificial recharge projects in the northern part of the country is usually to boost dry season irrigation with none of such at the moment in the catchment. A review of some of these projects is captured in Kwoyiga and Stefan (2019).

6.2. Institutions and groundwater quality- Existing situation

Groundwater quality is generally considered suitable for consumption. However, Agyekum and Dapaah-Siakwan (2008) stated that groundwater in northeast Ghana is characterised by concentrations of nitrate, fluoride and manganese higher than the WHO guideline levels. This has been elaborated by Kolavalli and Williams (2016) who said that a major health concern of groundwater in the Volta basin is the high fluoride concentration found in the central part of the basin (Northern Ghana) where the geology is dominated by granite. According to them, this situation is more pronounced with boreholes than shallow hand-dug as shallow wells tend to have much lower fluoride concentration because of dilution by recent recharge. "Groundwater exhibits aggressive characteristics and large concentrations in some chemical species in some areas of northern Ghana. More specifically, iron, manganese, fluoride and chloride were measured in groundwater in concentrations exceeding WHO recommended guideline values. It was also reported that the quality of water generally deteriorates closer to areas where human activities take place, due in part to the occurrence of latrines, the use of manure for agriculture, or the disposal of domestic wastes" (Carrier et al., 2011:99).

The high level of fluoride present in the water has caused dental fluorosis problems among the people particularly in the Bongo District: one of the study districts of the research. The incidence of fluoride in the region is further highlighted by information for some boreholes in the Bongo District in the region (Table 7). Response from the CWSA in Bolgatanga showed that all the districts in this region have cases similar to those in the Bongo District.

An assessment of groundwater suitability for irrigation in the Atankwidi catchment was carried out by Barnie et al. (2014) based on salinity, sodium, magnesium hazards, pH and alkalinity. The results showed that groundwater is suitable for irrigational activities even though there are potential magnesium hazards and alkalinity challenges.

Table 7. Some capped boreholes in the Bongo District in 2005

No	Name of community	Borehole No	Parameter (Value mg/l) 1.5	Project under which borehole was constructed
1	Bongo Tingre	Bon 455 F-63	F(2.1)	Drilled under CWSP-2
2	Zorko Goo Kuyonko	Bon 455 B-56	F(2.2)	Drilled under CWSP-2
3	Zorko Goo Widongo	Bon 455 B-57	F(3.2)	Drilled under CWSP-2
4	Zorko Tarongo Awaa	Bon 455 E-59	F(2.18)	Drilled under CWSP-2
5	Asibigan	Bon 456A-01RB	-	Drilled under COWAP
6	Bongo Nayire	Bon 455F-18RB	F(2.6)	Drilled under COWAP
7	Bongo Tingre	Bon 455 F-20 RB	F(3.4)	Drilled under COWAP

Source: adapted from Community Water and Sanitation Agency, Bolgatanga 2017

6.2.1. Naturally occurring contaminants in groundwater-Performance

- The Ghana Standard Board (GSB) has set drinking water quality parameters with reference to the World Health Organization (WHO) (1958) standards which cover the bacteriological, physical and chemical, biological and radiological requirements. These standards guide the operations of domestic water services providers like the CWSA.
- There is in place the National Drinking Water Quality Management Framework, a recommendation by the WHO in 2004 which entails a systematic assessment of risks throughout a drinking-water supply. Specific themes like health-based target, water quality plan development and independent surveillance are discussed.
- Boreholes whose water quality does not meet the standards of the Ghana Standard Board are capped by the CWSA as shown in Table 7.
- It is also obligatory for water quality testing to be done regularly by a certified institute as contained in the Small Communities' Sector Guidelines of the CWSA by the WRC (2010). This is, however, not the case with the catchment as noted by CWSA (2016) in the last table above.
- The country also has in place the National Household Water Treatment and Safe Storage Strategy which seeks to encourage households to embrace water treatment technologies in order to improve hygiene (CWSA regulations 2007). This is an age-long practice which has been reinforced by water sector NGOs campaigns and education programmes.
- The WRC and other organisations through joint efforts have constructed 25 monitoring wells in the northern part of the country for water quality monitoring. A database through the Hydrological Assessment Project, 2008 has been created depicting groundwater quality (Carrier et al., 2011; Water Resources Commission, 2008).

It is a fact that there are measures in place with the aim of addressing chemical related pollution of groundwater in any community throughout Ghana. It is, however, needful to mention that there are some communities that still rely on dug-outs and other sources of water which do not meet the WHO standards or may have chemical problems. From the interviews with the local people, access to borehole water, especially during the dry season is sometimes difficult due to

issues of overcrowding, reliability, functionality and distance. This sometimes compels some of the local people to resort to other sources of water supply which may not be of high quality.

6.2.2. Groundwater pollution control in the catchment-Performance

To address the various human activities that generate waste in the environment which ends up contaminating groundwater, the following institutional measures have been put in place:

- By-laws which relate to environmental sanitation, wetlands protections, cemeteries planning, control of pollution, waste removal and disposal have been made.
- CWSA has designed guidelines which prohibit human activities within 50 meters radius in case of groundwater. Also, siting of latrines is supposed to be at the downstream of water sources
- According to the CWSA regulations 2009 (L.I 2007), District Assemblies must ensure the availability of facilities for the safe handling and disposal of human excreta (night soil and sewage), industrial waste, animal manure, industrial sewage and domestic or domestic/commercial wastewaters. These regulations further banned the bucket (pan) and open trench latrines and recommended the use of the water closet and septic tank system.
- By the description of the nature of the National Environmental Policy (2007) and the functions of the WRC, water pollution limits may be set which allow for the discharge of waste or sullage into water bodies when necessary before permits are issued.
- The CWSA guidelines added that contaminated groundwater sources are supposed to be monitored regularly (monthly) for at least one year which is followed by a recommended action.

As noted, Atankwidi catchment is largely rural with a few waste facilities for the collection and disposal of residential waste. Open refuse dumps are found in front of every house except in some parts of Sumbrungu and Sirigu where few modern houses built have improved sanitary facilities. There are just a few sanitary facilities like toilet facilities as most of the people defaecate in the open in the bushes nearby.

The culture of the people also allows them to own family cemeteries where they bury the dead. The bye-laws of the District Assemblies about cemeteries seem to be applicable only in urban areas or towns. Moreover, some dry season farmers use inland wells for the cultivation of vegetables in the dry season; however, some of these wells end up being abandoned. All these activities are thwarting efforts to improve or protect groundwater quality.

6.2.3. Wells Head Contamination-Performance

- A superstructure, consisting of a concrete well pad with a platform is provided with a 200 mm concrete dwarf wall. The surface of the well pad is usually sloped to ensure adequate drainage. The platform or well apron is circular (minimum diameter 2.5 m) or square/rectangular with a minimum length of 4.5 m.
- CWSA guidelines for site selection ensures that boreholes (hand pumps) are sited some meters away from latrines, refuse dams, cemeteries. For instance, a borehole is sited 50 m away from a latrine (Community Water and Sanitation Agency-Accra, Ghana, 2010).
- Siting of boreholes is supposed to be done by qualified personnel usually from the CWSA if the provider is the CWSA.
- Wells lining is to be extended a minimum of 200 mm above ground level to form a headwall. Well cover slabs minimum 75mm shall be nominally reinforced to prevent collapse during usage.

It is a fact that almost all the boreholes in the communities have in place some of these attributes that curtail wells head contamination, however, the ill performances of the Water and Sanitation Management Teams in the communities of the region was noted during the interviews. This has rendered some of the precautionary measures ineffective. For instance, from observation in the communities, there are some boreholes whose platforms have been destroyed resulting in poor drainage systems. This has caused flooding in the immediate surroundings of the boreholes. Animals too, sometimes, invade the premises of these boreholes and degrade their environment with waste.

On the part of groundwater for irrigation, all respondents admitted that no information about groundwater quality has been shared with them by any institutions. The research could not document any evidence of empirical or secondary data indicating that some measures are in place to promote groundwater quality for farming.

6.3. Managing demand for groundwater

Managing groundwater demand is critical for the overall success of climate change adaptation in the water sector. An examination of the situation in Atankwidi is important for accelerating adaptation.

6.3.1. Nature of groundwater demand

Groundwater is exploited in all districts in the northern part of the country particularly for domestic use. It can be said that there is no single community which does not have at least two boreholes and this has been confirmed by the field survey through observation and respondents' responses. Groundwater is abstracted for domestic use through hand pumps and piped water schemes in the study area. These facilities as distributed in Table 8 are provided by the CWSA, civil society based organisation and others. Water from traditional wells and hand-dug outs also support to meet domestic water needs.

Table 8. Distribution of handpump and piped scheme water services in the study area

Community	Population	Hand pump services	Functionality of hand pump services (%)	Piped Scheme Water services	Functionality of piped scheme water services (%)
Kandiga	4547	32	81	No service	-
Mirigu	4979	76	91	1	100
Sirigu	2962	40	85	1	0
Sumbrungu	14026	119	90	1	0
Yua	1069	No data	No data	No data	No data
Zorkor	13,274	67	81	1	100

Source: adapted from CWSA (2015) Bolgatanga, 2015

The demand for groundwater for irrigation activities has also been rising. Barry et al. (2010) noted that 387 hectares of land were put to use under shallow groundwater irrigation as of 2008. Groundwater is exploited usually through hand dug wells. These wells some of which are shallow while others are deep (Figure 23) are either in the riverine (shallow) or in-field (deep). The red dots indicate the infield wells while the white dots represent the riverine wells.

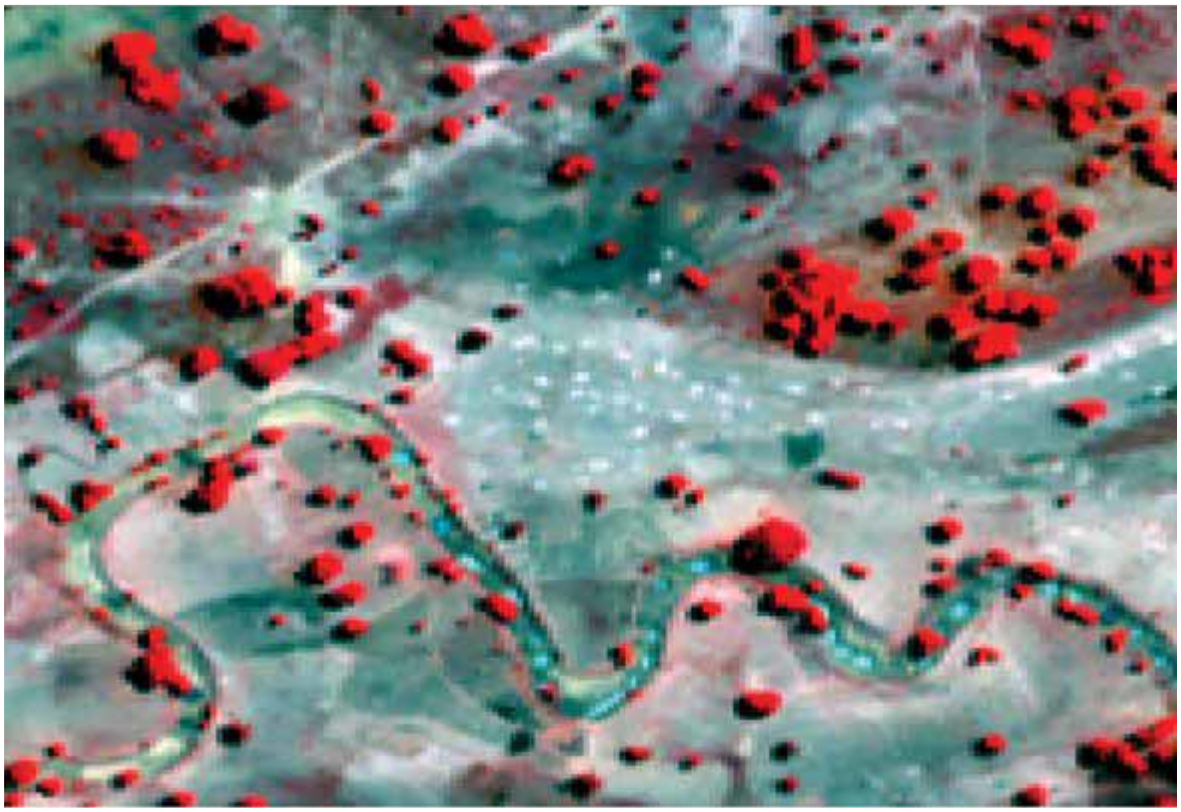


Figure 23. In-field and riverine seasonal shallow well systems

Source: Namara et al. (2011)

6.3.2. Institutions and groundwater demand management

As discussed by Dillon et al. (2009), managing groundwater is one of the areas that need attention in this era of climate change. This, according to them, should include decisions that allow for the conjunctive use of groundwater with surface water. The National Climate Change Policy has advocated for the harvesting of rainwater even though it did not explain that the reason is to ease pressure on groundwater. Other measures that address groundwater demand issues are:

- Infrastructural development is being undertaken throughout the country to boost groundwater abstraction. Any person in the community has the right to access any of the water supply facilities.
- Even though water from all hand pumps do not attract any cost, levies meant for the maintenance/repairs of the hand pumps are imposed on the local people by the Community Water Management Committees
- Water from piped scheme facilities is charged. It is spelt out in the CWSA regulations 2011 that the method of tariff collection is the *Pay As You Fetch* or what is commonly called cash and carry method at standpipes or pumps, monthly billing for individual customers and institutional customers). From the responses of the local people, most of the local users cannot afford the services of the piped scheme system hence the high level of preference for the hand pumps.
- All water facilities are being managed by the Community Water Management Committee in the study area. Traditional leaders and other opinion leaders also augment the efforts of the Community Water Management Committees.

- Hand pumps typically operate both day and night but those with taps operate only during the day.
- Irrigation using groundwater has its own rules and management practices are different. Even with the passage of WRC act 1996 which vest all water resources in the president, the people at the catchment level are yet to imbibe this. Water rights here are still part of land rights. Whoever controls the land, therefore, controls the resources above and beneath it.
- It can, therefore, be said that informal institutions like taboos and customs are very important in regulating groundwater use for irrigation.
- The customs of the people grant universal access to all persons both indigenes and aliens once the person has access to land to use groundwater resources. There are no groundwater tariffs, quotas, permits or licence. How much one can abstract depends on his physical and financial capabilities.
- Within the context of formal institutions, groundwater farmers in the catchment have been exempted from the water use regulations. This is because farmers' abstraction of groundwater is manual and their farm plots do not exceed one hectare. The process of lifting water is labourious and for that matter, farmers tend to use water efficiently. Water is applied directly to the roots of crops.

6.4. Groundwater storage

6.4.1. The existing situation

It is noted that the storage space of groundwater for both Ghana and Burkina Faso is low compared with North Africa countries like Libya even though the storage capacity is sufficient and far more than what is abstracted or stored as recharge (Namara et al., 2011). In Atankwidi catchment, Barry et al. (2010) studied the storage capacity of only the shallow aquifer (out of the three existing ones) in the catchment. According to them, the shallow underlying aquifer of the catchment varies from 2.6 to 13.7 meters with a low resistivity ranging from 3.2- 55.3 Ohm-m. It is also estimated that the volume of water that can be stored in the aquifer is approximately 3.7 x 108 m^3 which is able to meet annually the irrigation water needs of farmers both at the planting and flowing stages.

6.4.2. Institutions and groundwater storage management

A review of the formal institutions relating to climate change adaptation in the previous section shows that no significant attention has been attached to groundwater storage in this era of climate change. Studies about groundwater storage in the catchment are limited and undertaken as part of projects by individuals or external agencies on ad hoc basis. Irrigation development in the entire country is limited to the construction of surface dams and community reservoir even though researchers like Kankam-Yeboah et al. (2003) have explained the feasibility and importance of constructing underground dams.

Nonetheless, farmers at the catchment have adopted the following as ways of making groundwater available. Since groundwater irrigation is mostly done in the dry season, the rainy season, therefore, serves as a fallow period for dry season farming which then provides an opportunity for groundwater recharge and for that matter storage to take place. Also, farmers, cultivate mostly vegetables which do not require irrigation every day especially, at the planting stage.

Another strategy adopted by the farmers is with the conjunctive use of groundwater with surface water, a practice typical of the riverine irrigation farmers. The farmers at the early stages of

farming use the available surface water until exhausted before they depend on wells for groundwater. These farmers who are at the downstream have however lamented about the blockade of water in these rivers/streams by the Burkinabe government for its farmers who are in the upstream.

6.5. Managing groundwater discharge

In the Atankwidi catchment, Martin (2006) noted that groundwater tables in parts of the basin appear lower than the river bed resulting in no significant contribution from the groundwater to discharge in those portions of the basin. However, in some parts, water tables rise so high during the wet season that groundwater contributes to base flow in rivers. She concludes that "Although infiltration from streams occurs at certain locations, discharge from groundwater to streams is more frequent. Sinks of groundwater from the regolith aquifer are discharged to streams (base flow), sub-surface groundwater run-off, recharge of the fractured bedrock aquifer and evapotranspiration by trees" (Martin, 2006:47).

The study by Martin (2006) provides preliminary information about the nature of groundwater discharge in this catchment with no subsequent studies to specifically study the time, scale and the conditions under which groundwater discharge in the catchment occurs. Studies on the uptake of groundwater by deep-rooted plants and other land uses are lacking. Detail information is still lacking about whether there is a need to regulate discharge in the first place.

This notewithstanding, in terms of performances, it is noted already about the presence of 25 monitoring wells which have been installed in the northern part of the country including the catchment. Obuobie (2008) as part of his study of the White Volta basin simulated water balance in SWAT and showed that about 11 % of the annual precipitation in the White Volta Basin constitutes discharge.

6.6. Holistic analysis of formal institutions for adaptation

The radar diagram (Figure 24) depicts the level of performances of formal government institutions as far as groundwater adaptation is concerned. To represent the performances of the five themes of groundwater adaptation, a radar diagram with scores on a scale of 1-10 where 1=least and 10=highest is employed. Respondents were asked to rate the performances of these themes to show which one is performing (enabling, doing and achieving) more postively. The percentage of respondents and the scale chosen for each theme then formed the basis for drawing the radar diagram.

It is revealed that managing groundwater demand is one aspect which is performing well, as the percentage of people who chose this was the highest. This performance is perhaps due to the fact that population increase and other socio/economic factors are fueling higher groundwater consumption hence the need to manage demand. Nonetheless, demand management of groundwater for irrigation is completely ignored as it does not form part of the activities of these institutions. The existence of monitoring wells provides data on groundwater levels, discharge, recharge and interactions between surface and groundwater.

Artificial recharge of groundwater is yet to receive attention in the area as groundwater recharge remains solely natural from rainfall hence the least score. This perhaps may be due firstly to the fact that there are still no agreements regarding the results of General Circulation Models (GCM) on the impacts of climate change on groundwater in the entire basin. The second reason has to do with the fact that existing studies have shown of low extraction rate of groundwater compared to available storage in the entire Volta basin. Groundwater quality is the second best

performing area due to the measures put in place not only to control pollution but to address hydrochemistry issues. Extensive studies in the entire Volta basin have been done to cover the chemical components of groundwater. The results show the presence of high concentrations of fluoride, iron, manganese and chloride in the northern part of the Volta basin of which Atankwidi is part. Boreholes whose chemical content exceeds the WHO standards (1.5 mg/l) are capped. The least performing areas which thus need attention are storage and artificial recharge.

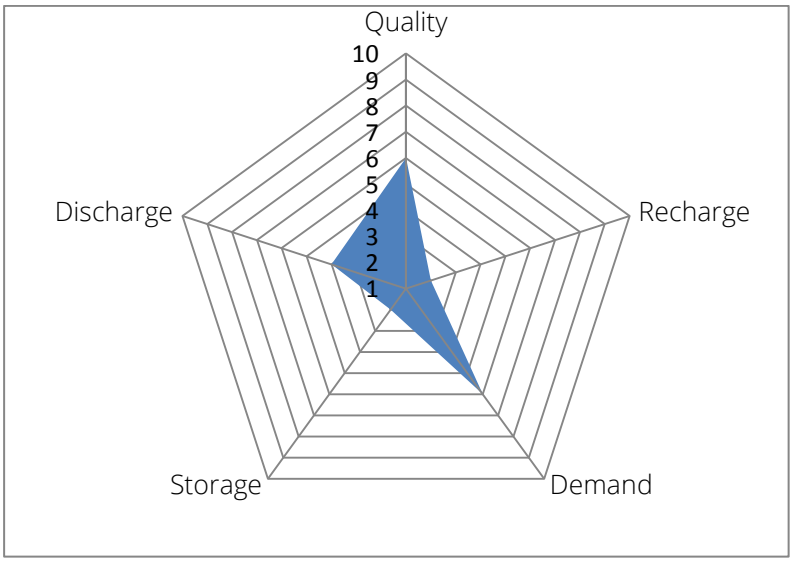


Figure 24. Radar diagram showing performances of groundwater adaptation efforts

6.7. Formal groundwater institutions within the context of theory

The argument by New Institutional Economics (NIE) for the adoption and application of formal institutions in the form of laws, policies and administration as seen in the works of Dinar and Saleth (2014) has resulted in a myriad of them in the country. These institutions permeate the various sectors of the ecomomy with some focusing on addressing environmental challenges such as climate change. Regarding groundwater adaptation, it is realised that a corpus of these institutions exist which resulted in institutional plurality, a situation attributed to the lack of specific formal institutions as rather exisiting but relevant ones are being applied in this context.

As argued by the NIE, that institutions are created for a specific purpose, one realises that within the context of groundwater adaptation, this is refuted. The situation rather depicts the argument by Critical Institutionalism (Cleaver and De Koning, 2015) that instititions are multi-purposed, as seen in the application of existing but related ones. Even with the applicable groundwater adaptation institutions, it is noted that these cover a wider spectrum of activities which sometimes do not directly target the promotion of adaptation.

The discussion also revealed the weaknesses of formal institutions as seen in the emerging issues associated with the nature of formal insittutions at both the national and sub-national levels. That is, there is the problem of poor enforcement as responsibilities between adaptation agencies at the two levels are poorly defined. Roles are also sometimes conflicting. The multiplicity of these institutions without clear cut responsibilities and functions at the two levels further create room for confusion and maneuvering.

It is realised that though some formal institutions exist for groundwater adaptation, lack of resources and expertise hinder their implementation which results in little adaptation impacts. This is common with the Disticts/Municipal Assemblies where it is noted that the challenges of

limited resources hinder the design and implementation of districts/community level adaptation plans and programmes. It can therefore be said that Ghana has in place formal institutions geared towards promoting groundwater adaptation, however, their performances are low.

6.8. Other institutions and adaptation

Assessing the performances of formal government institutions about groundwater adaptation to climate change and its impacts revealed that agencies outside the domain of these institutions form major promoters of adaptation. These agencies (Figure 25) are in the form of multilateral institutions, governments of countries, Civil Society Organisations (Non-Governmental Organisations, and Environmental Groups), universities and research institutions both locally and internationally, private companies, union governments (European Commission) and individuals. The details of the framework have been presented in the ensuing discussion.

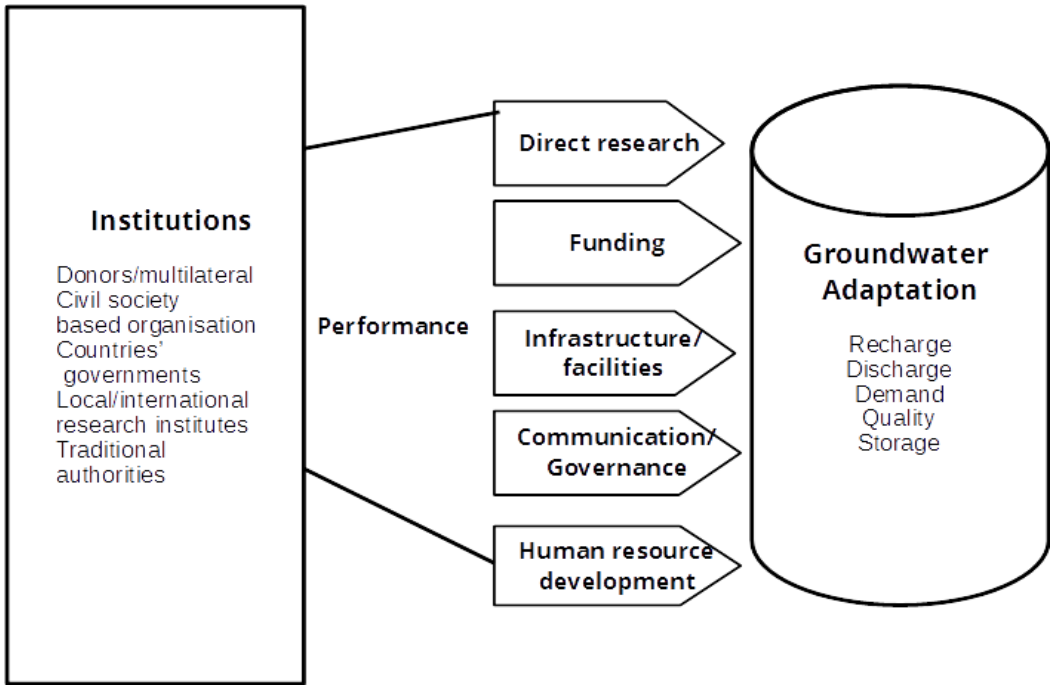


Figure 25. Nature of agencies outside formal government institutions

Within the domain of water resources, the contributions of these agencies to water resources in general and groundwater in particular have been tremendous. Firstly, these institutions provide funds/donations for programmes. These programmes sometimes go beyond the frontiers of Ghana to cover other countries. For instance, projects that cover the entire Volta Basin are usually of this nature. The GLOWA programme which started in 2000 is widely acclaimed for its extensive coverage of the Volta Basin (Kasei, 2009; Martin, 2006; Obuobie, 2008).

Collaboration in executing groundwater programmes/projects in Ghana is another activity often embarked on by these agencies. Administrative institutions of government like the CSIR, WRC and, ministries and departments jointly execute groundwater projects with these institutions. International institutions which are locally based like the International Water Management Institute (office in Accra) have been implementing some of these projects in collaboration with the country's formal government institutions like the CSIR, Water Resources Commission and other civil society organisations.

The provision of infrastructure or facilities in the form of research centres and institutes forms part of the roles being played by these agencies in the area of groundwater resources development. An example in this regard is the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) built with financial support from the Federal Government of Germany.

These agencies also provide research facilities or resources/equipment for studying and monitoring of groundwater resources in the country. The Hydrological Assessment Project (HAP) funded by the Canadian International Development Agency (CIDA) is noted in recent times particularly for its contribution to groundwater studies in northern Ghana. The CIDA came in 2005 to support a project initiated already by the WRC of Ghana through the Danish International Development Agency (DANIDA) assistance and this resulted in the construction of 12 new dedicated monitoring wells in the three (3) northern regions of the country for the analysis of water quality. This project has resulted in a database which covers all available groundwater information in the country (Carrier et al., 2011).

Some of these institutions also initiate platforms or fora for discussing transboundary water management and governance in the Volta Basin among the various riparian countries. For instance, the Unnited Nations Environment Programme (UNEP) and Global Environmental Facility (GEF) supported a project in 1999 on the Volta Basin with the aim of promoting a regional institutional framework for the effective management of the Volta Basin. It brought together representatives from the six (6) riparian countries in Accra to dialogue on transboundary concerns of the Volta Basin. The International Union for Conservation of Nature (IUNC) facilitated in 2005, the formation of the Volta Basin Authority (2005) and the passage of the Volta Basin Convention in 2009 (Opoku-Ankomah et al 2006).

Regarding human resource development, workshops to train and boost the capacity of personnel in groundwater issues are sometimes organised by these agencies. Scholarships for research and studies relating to groundwater adaptation are being offered for graduate studies. Countries like Japan, Canada, the USA, Germany, Australia, Norway, Denmark and others do not only give financial support to graduate students but also serve sometimes as the destinations for such studies. Examples of such packages include the DAAD (Germany).

Traditional/local institutions also play a key role as far issues about groundwater are concerned. Their role centres on governance: water rights, ownership, and conflict resolution among others. They form part of the Volta Basin Boards and constitute the first point of contact to both government and non-governmental agencies who intend entering into the catchment community. It can be said that these agencies are inevitably influenced by the guidelines and operational activities of the formal government institutions (Figure 26).

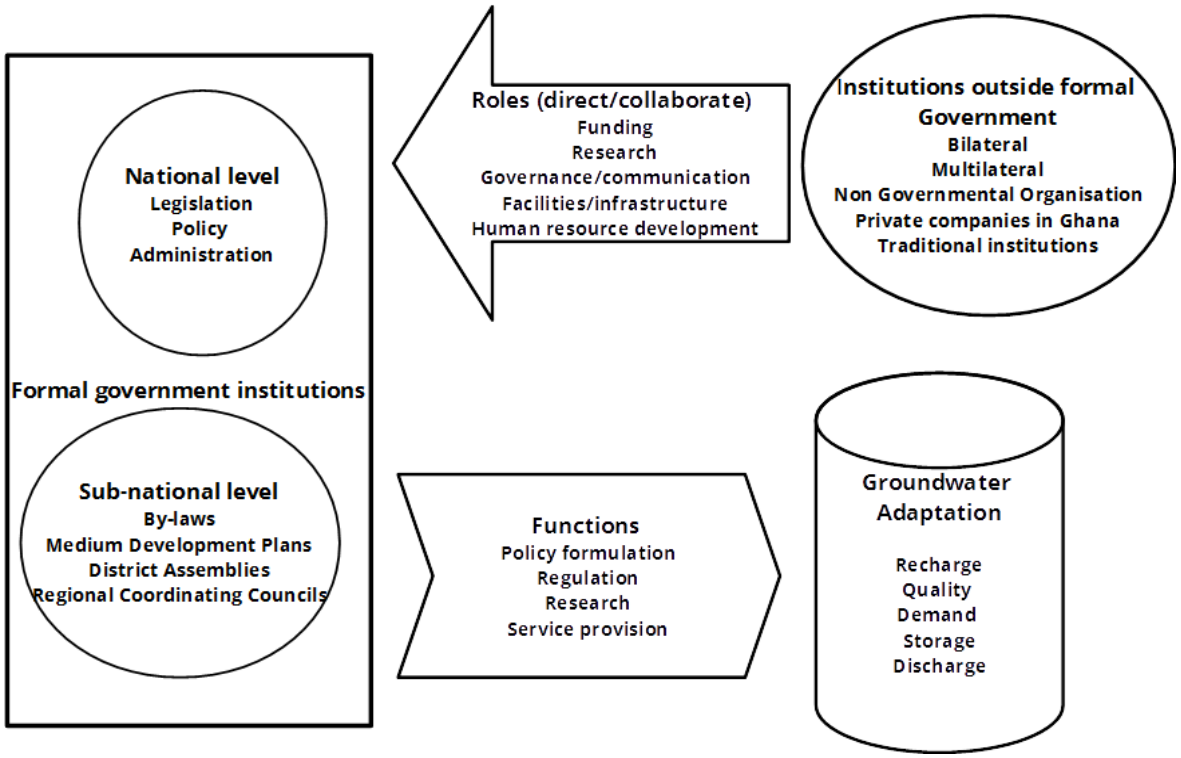


Figure 26. Composition of all institutions promoting groundwater adaptation

With groundwater adaptation at the centre, the Figure 26 indicates that agencies outside formal government institutions relate with formal institutions (at the two levels) as seen in their roles discussed above. It is then expected that the results of the relationship between formal government institutions and those outside the domain of these institutions will manifest in policy formulation activities among other things geared towards groundwater adaptation in the country in general and in Atankwidi catchment in particular.

7. LOCAL KNOWLEDGE FOR GROUNDWATER IRRIGATION

This chapter looks at the place of local knowledge for groundwater development for irrigational purposes only. The weaknesses of this knowledge as far as adaptation is concerned are then discussed, highlighting the various aspects of this knowledge which are limited through ranking. Formal government institutions' support to enhance the scope of this knowledge is thus canvased by suggesting ways of doing so.

The results revealed that, in the catchment, local knowledge has served as an age-long store of knowledge for the people which enabled them to develop and use groundwater resources for different purposes in the catchment. Just like small islands communities and their understanding of climate changes using local knowledge (Hiwasaki et al., 2014), the people of the Atankwidi catchment equally apply local knowledge to understand climate change and how this affects groundwater resources.

Like the Inuit in the Canadian Arctic (Pearce et al., 2015), the people of Atankwidi have also identified methods of adapting through deepening the depth of groundwater wells, increasing the number of wells per crop area, conjunctive use of ground and surface water and many others.

However, the scope of local knowledge in some aspects is limited. This is because this knowledge only provides short term adaptation measures. It is also unable to identify methods that purposely but artificially boost groundwater recharge. Therefore, formal government institutions can broaden this knowledge through capacity building and updating local knowledge holders with integrated/hybrid knowledge that encompasses both local and scientific knowledge about groundwater resources.

Climate change policies should include programmes relating to artificial methods of groundwater recharge/storage. However, such programmes should be anchored on local knowledge. A broader picture of these issues is provided below.

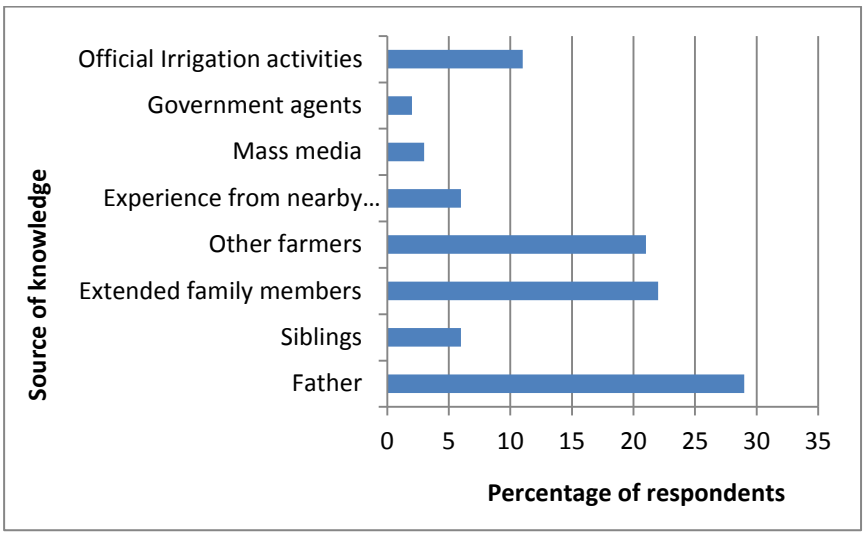
Reference to Kwoyiga and Stefan (2018: 2019) revealed that land and groundwater are inseparable. Though ownership of these two resources in the northern part of the country was initially defined jointly by the country's 1992 constitutions, the passage of the Water Resources Commission Act 1996 made a separation. Even though land in the catchment is considered skin land and still owned by the local people, groundwater resources like other natural resources are owned by the state. However, it is common to find wells in the catchment constructed by individuals to exploit groundwater for irrigation.

7.1. Local knowledge for dry season groundwater farming

Detailed discussion of local knowledge about groundwater irrigation is found in Kwoyiga and Stefan (2018). Nonetheless, it is realised that local knowledge as understood by the people of Atankwidi permeates every part of their day to day activities including their livelihood strategies. It is knowledge that has been accumulated over time through observation, experiences and participation. It is not documented but passes on generationally through oral tradition. This knowledge for irrigation emanates from multiple sources.

The percentage of responses from farmers (Figure 27) showed that fathers (29%) and extended family members (22%) constituted the major sources of this knowledge. Only 3% of the responses mentioned that this knowledge sometimes comes from government agencies. It was revealed that in this era of science and technology coupled with improved communication

network like the mass media; new knowledge is being diffused into the existing ones regularly. Thus this knowledge is not static as it is being refined over time.

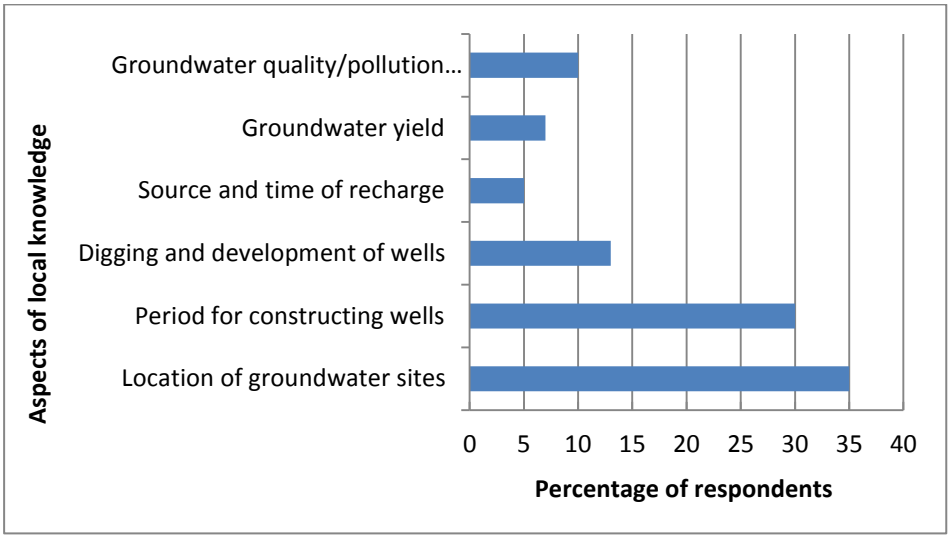


Note: Population of respondents (n)=210, multiple responses were possible

Figure 27. Source of local knowledge

The value of local knowledge for groundwater development and use for irrigation can be summarised (Kwoyiga and Stefan, 2018) in the following areas: location of groundwater sites, source and time of recharge, period for constructing wells, groundwater yield, well construction and development, groundwater quality protection and pollution control mechanism (Figure 28).

A dichotomy of local knowledge for groundwater development showed that majority of the irrigators (35%) are familiar with where to dig and hit the water-bearing table. This is largely attributed to the fact that most of these farmers also serve as well drillers or participate in the digging, so have accumulated enough knowledge and experiences over time. Also, 30 % of the farmers are knowledgeable about the period to dig these wells. This is because, irrigators farm in the rainy season too and apart from the fact that digging wells in the dry season is safe, activities in the rainy season may not permit them to construct such wells at any other time apart from the dry season. Farmers are thus familiar with both dry and wet season calendar, this is to avoid their activities clashing.



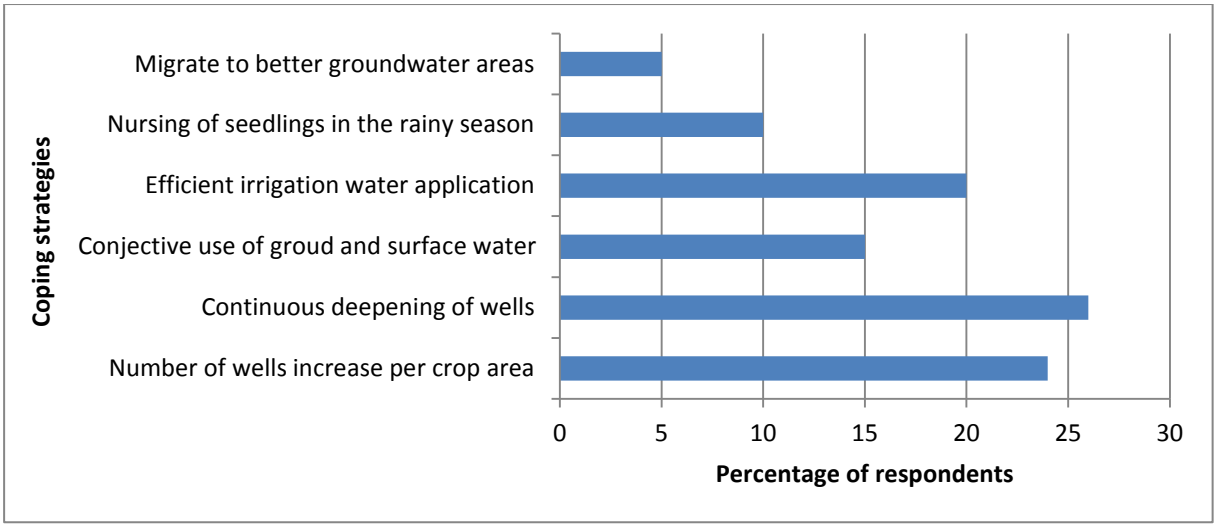
Note: Population of respondents (n)=210, multiple responses were possible

Figure 28. Aspects of local knowledge in relation to groundwater development

7.2. Coping with/adapting to limited groundwater situation

Confronted with limited groundwater for irrigation as noted in Chapter Four and in Kwoyiga and Stefan (2019), farmers have adopted the following means to adapt to the situation. These include increasing the number of wells per crop area (new wells and reopening of old wells), continuous deepening of wells depth, migrate in search of groundwater resources endowed areas, conjunctive use of surface and groundwater, nursing of seedling in the rainy season, change in crop types and others (Figure 29).

The composition of farmers opting for these adaptive strategies showed that 26% of the farmers prefer deepening their wells, especially in the dry season in order to secure sufficient water to other options because it is cheaper. However, 24% of them chose to increase the number of wells as a way of coping with insufficient groundwater. This is mostly practised by riverine farmers who use pumping machines coupled with the fact that wells in this category are shallow dug out and easy to dig. Migration (5%) scored the least because it was only Yua that this practice is going on. It must be stated that farmers adopted more than one of these coping strategies.



Note: Population of respondents (n)=210, multiple responses were possible

Figure 29. Ways by which irrigators cope with inadequate groundwater

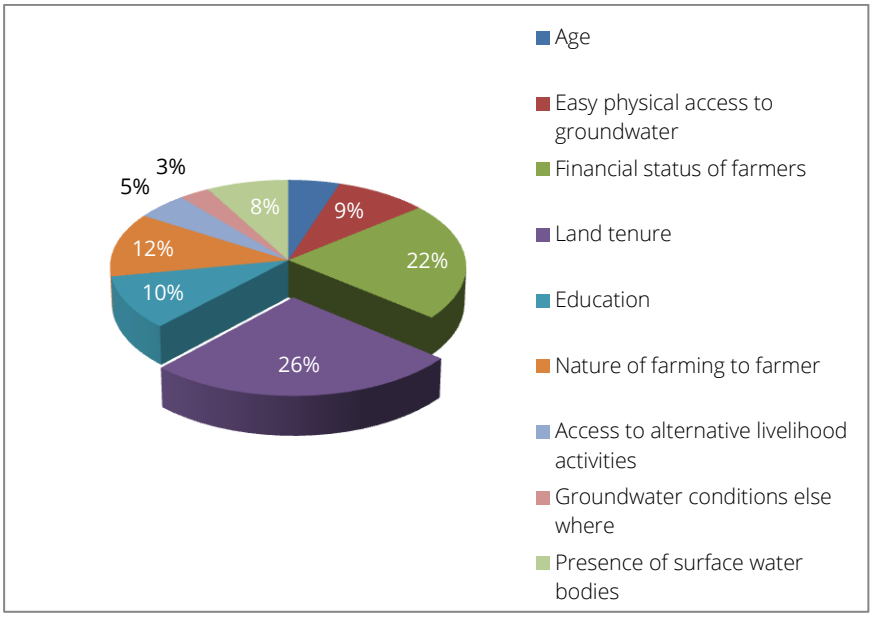
7.3. Determinants of coping/adaptation strategies

For farmers to adopt some of these strategies which are multiple sometimes, some factors have necessitated their decisions (Figure 30) which includes the following:

- Age: farmers who engage in dry season farming fall between the age cohort of 20 and 50 years. Those who are between 25 and 40 years are the majority while those approaching 50 years are fewer. Farmers who are older prefer to dig new wells, deepen the depth of existing ones and continuously maintain them. This is more characteristics of infield wells in Zorkpo.
- Physical access to water resource: farmers who dig wells easily and get water are reluctant to adopt other adaptation methods.

- Groundwater conditions elsewhere: the availability of groundwater resources in nearby communities influences farmers' decisions as to whether to remain stationary or not in their original farmlands. This factor influences the decision of farmers in Yua in particular because they are surrounded by communities endowed with groundwater resources.
- Farmer level of education: farmers who are well educated easily adopt multiple adaptation measures like buying pumping machines to draw water from wells and surface water bodies. This is common among farmers in Sirigu, Kandiga and Mirigu. Most of the farmers here are young and literates who are open to other knowledge sources.
- Presence of surface water bodies: Farmers in Sumbrungu, Mirigu and Kandiga are surrounded by ephemeral rivers. They, therefore, use both surface and groundwater conjunctively in farming. They tend to invest more in both their wells and also in buying equipment like pumping machines.
- Land tenure system: farmers who own the land for constructing wells and farming tend to invest more in digging and deepening wells. They build and maintain their wells regularly. Farmers who acquire land through lease do not invest so much on such wells. This is common with farmers at Sumbrungu, Mirigu, Zorkpo and Kandiga.
- Available alternative livelihood activities: farmers who have access to other livelihood activities tend to give less attention to constructing and maintaining wells. it can be said that most of the farmers in Yua, Mirigu, Kandiga and Sumbrungu focus more on irrigation.
- Farmer financial status: farmers who have financial capacity invest more in water resource development. This is a major factor influencing adaptation and most of the farmers strive to acquire financial support from available sources to enable them to meet the cost of farming.
- Nature of farming activity: farmers who depend largely on dry season farming invest more on the development of groundwater resources. Communities like Mirigu, Yua and Sumbrungu become empty during the period of dry season farming as farmers often stay on their farms until the farming season is over.

The composition of farmers influenced by these determinants shows that about 26% of them consider land tenure as having an impact on farmers' decisions of how to adapt to groundwater scarcity. Only 5% of the farmers are influenced by age, this is because as noted already, the majority of these farmers are young.



Note: Population of respondents (n)=210, multiple responses were possible

Figure 30. Factors that influence irrigators' choice of coping strategies

In order to understand the level of influence of these determinants in each community, a scale of **1-3** where **1=Low, 2=moderate and 3=high** was applied. The results are thus presented in Table 9:

Table 9. Factors that influence farmers' choice of coping strategies by communities

Determinant	**Community**					
	Kandiga	**Mirigu**	**Sirigu**	**Sumbrungu**	**Yua**	**Zorkpo**
Age	1	2	2	2	1	3
Physical access to water resource	2	2	2	2	2	3
Groundwater conditions elsewhere	2	2	1	2	3	1
Farmer level of education	3	3	3	2	2	1
Presence of surface water bodies	2	2	2	2	2	1
Land tenure system	3	3	3	3	3	3
Available alternative livelihood	2	2	2	2	2	2
Financial status	3	3	3	3	3	3
Nature of farming activity	2	2	2	2	2	2

Note: Multiple responses were possible

7.4. Limitations of local knowledge for adaptation

Despite the ability of the people of Atankwidi to develop groundwater to irrigate and also adjust to climate change impacts, this knowledge to some extent has limitations which need consideration.

7.4.1. Depth and distribution of local knowledge

The scope of local knowledge about groundwater resources is limited. Due to the invisible nature of groundwater resources, local knowledge is not able to offer deeper explanations of this

resource and how it forms part of the hydrological cycle. It is a fact that local knowledge tells the people that there is water beneath the ground, but its quantity, quality, physical distribution and how to explore them in a better way remain areas outside the domain of local knowledge.

Associated with the depth of this knowledge is the skewed distribution of it among the population. It is worth noting that unlike scientific knowledge; local knowledge about groundwater is not universally distributed among the population. Women and children often possess less of this knowledge. This knowledge appears to be wielded mostly by men and older people.

7.4.2. Local knowledge and the development/use of groundwater resources

It is a fact that the Atankwidi catchment is endowed with groundwater resources. However, apart from the use of simple tools based on local knowledge to abstract these resources, no efforts have been made to promote better understanding and utilization of these resources. It is, therefore, not surprising that Barry et al. (2011) noted that better technology is required for farmers to exploit water at deeper depth. Local knowledge is limited in its application to protect groundwater from sources of pollution. This knowledge does not also allow for proper mapping of the groundwater resources.

7.4.3. Discussing the linkage between groundwater and climate change

Just as it is difficult to determine scientifically the impact of climate change on groundwater as documented in Chapter Two, the use of local knowledge to explain the linkage between groundwater and climate change remains a challenge. While it is easy to do so regarding groundwater quantity, it is difficult to explain how climate change, affects groundwater quality. With reference to Chapter Four, the responses of groundwater farmers with regard to climate change impacts on groundwater quantity and quality revealed that farmers understood quickly through observation and experiences over time how climate change affected groundwater quantity but it was difficult for them to interpret groundwater quality under climate change. This perhaps might have influenced the few responses given to groundwater quality.

7.4.4. Local knowledge is only about coping and not adaptation

Local knowledge supporting methods only offer farmers short term remedies to water scarcity. These remedies focus on abstraction and not recharge. Also, managing groundwater demand for irrigation at the moment involves only the application of informal institutions which also have some limitations considering the fact that demand is ever increasing while recharge is largely through rainfall infiltration. Farmers lack knowledge about how to enhance groundwater recharge, quality and storage.

7.4.5. Future research about groundwater under changing global conditions

Local knowledge as it is only allows for its applicants to use groundwater resources and cope with climate change impacts. Unlike scientific knowledge where models are designed to study past climates and future scenarios of climate change vis a vis resources like groundwater, local knowledge by its nature offers only explanations to past and perhaps present climate conditions. Local knowledge is not able to predict what climate change may look like in the future and its influence on groundwater resources. One may say that within the Atankwidi catchment, the *tindaanma* and other spiritualists perform similar roles even though activities are characterised by rituals, sacrifices and spiritualism. Their activities do not create platforms for people to question their findings and perhaps try to replicate them: findings are usually shrouded in secrecy. Local knowledge in this regards limits popular participation in addressing natural

occurrences because of limited information and its distribution as is the case of scientific knowledge.

In the light of these limitations, the radar diagram (Figure 31) below provides a broader picture of the levels of the various aspects of this knowledge possessed by groundwater farmers on a scale of **1=Least understood and 10=Highest understood** displayed. The percentage of respondents with knowledge about the given local knowledge aspect is considered in drawing the diagram

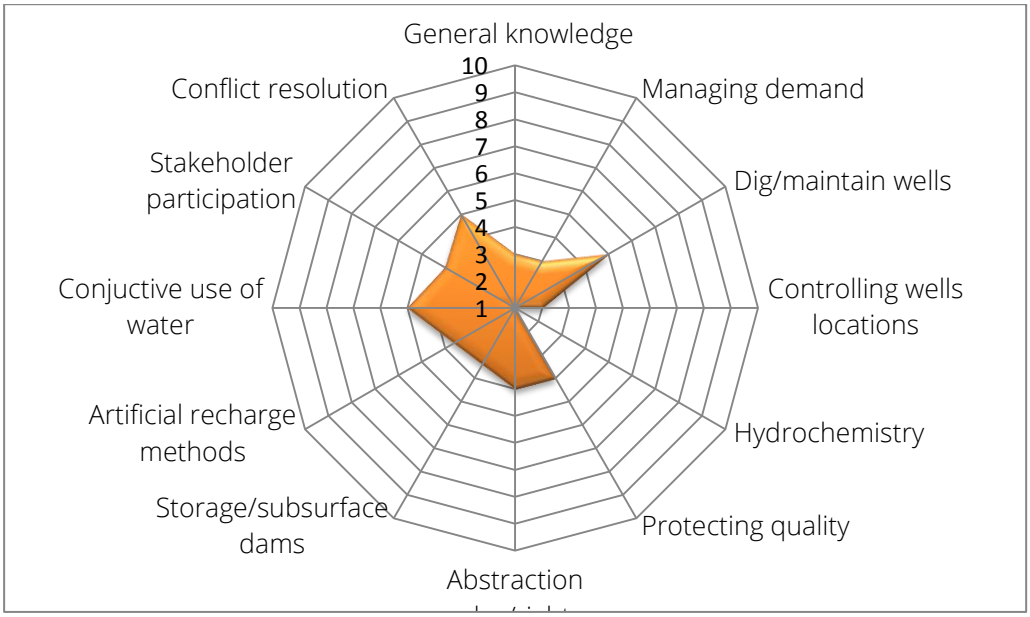


Figure 31. Aspects of local knowledge for groundwater development

It is realised that the existing local knowledge about groundwater storage, hydrochemistry and artificial recharge were aspects which were least or poorly understood as far as adaptation is concerned. Groundwater farmers though major users of groundwater lacked opportunities in participate in formal discussions. Application of formal groundwater allocation mechanisms at the moment is absent. Farmers are performing well in terms of resolution/management as conflicts hardly occur among them. Wells construction both infield and in riverine is more familiar with farmers. The presence of ephemeral rivers like rivers Atankwidi and Anayire coupled with periodic water challenges have prompted farmers to conjunctively use surface water and groundwater. General knowledge about climate change and its impacts, however, remain limited.

7.5. Enhancing local knowledge through formal institutions

Though local knowledge proves valuable in the catchment, its limitations may not permit its full effectiveness in promoting climate change adaptation. Therefore, there is the need to broaden the scope of it in terms of content and application with the help of formal government institutions.

7.5.1. Legislation

Legislation at the catchment level in the form of bye-laws should incorporate local knowledge of groundwater resources. Mainstreaming relevant local norms and taboos into by-laws will not only increase their relevance because of their familiarity but portrays an endorsement of them by

formal government institutions which will serve as a catalyst for achieving adaptation. This will contribute to enhancing its acceptance and application as an adaptation strategy.

Copies of the bye-laws should then be easily accessed by everyone or made available to the Unit Committee/Area Council members who live close to the local people. Community platforms can also be created to disseminate and update the content of the bye-laws to the local people. The information can also be passed on to the local people through the mass media in the form of talk shows, drama, advertisements among others.

7.5.2. Policies

Policy documents on climate change adaptation are usually designed at the national level almost in the form of scientific knowledge/information. It is realised in Chapter Four that local people have some level of knowledge about climate change and adaptation, therefore, harnessing, validating and documenting local knowledge is the first step to adaptation, which should be captured in policy documents.

Joint analysis of climate change adaptation policies/programmes involving both local knowledge and scientific knowledge holders, and outcomes about groundwater adaption should reflect both pieces of knowledge. This is because, during the interviews, it was realised that just as local methods on climate change adaptation are too weak to stand on their own, scientific measures appear too abstract and lack local outlook. Reconciling both pieces of knowledge can boost adaptation as these weaknesses will fizzle out. This will create room for the application of knowledge which is integrated hence overcomes the weakness of the sole application of local knowledge in groundwater adaptation as it is the case in the catchment. This will further promote effective management, sustainability, acceptability and even reduce the cost of adaptation.

The adoption of artificial methods that boost groundwater availability like Managed Aquifer Recharge (MAR) and other technologically advanced methods should be captured deliberately in adaptation policies. However, such programmes should be anchored on local knowledge. This is to enable local knowledge holders to apply what is known already by them and gradually learning to imbibe the associating scientific methods of augmenting groundwater availability.

7.5.3. Administration

The presence of local groundwater bodies/associations will help expedite action, particularly on groundwater resources. Just like the Volta Basin Board, the Water Resources Commission (WRC) should create Aquifer Management Organisations (AMOR) in Atankwidi where groundwater resources play multiple roles. This is because it has been established that River Basin Boards are more concerned about surface water rather groundwater resources. Therefore, a formation of AMOR at the catchment could create an opportunity for more stakeholders' participation (especially farmers) in managing these resources. This will contribute to increasing knowledge and awareness about groundwater resources and climate change.

Similar to the above, detail mapping of groundwater users and their functions should be undertaken. This does not only create a sense of responsibility for all but allows stakeholders to update their knowledge about the prevailing environmental conditions (like climate change) that may shape their roles. Stakeholder consultative platforms/workshops should be organised to give knowledge holders the opportunity to jointly engage in knowledge production pertinent to groundwater adaptation.

The formation of effective groundwater farmer associations or organisations should be encouraged. Groundwater dependent farmers are major users of groundwater but they are not

well organised into associations or organisations. Associations of this sort at the catchment will not only enable these farmers to present their interests and concerns but also galvanise their support for any adaptative actions that have to do with groundwater resources.

Workshops, community durbars and other community-based knowledge improvement platforms should be organised by the WRC and the EPA at the catchment level to build capacities of all catchment dwellers on the sustainability of groundwater projects such as MAR.

Awareness creation and education are key components of the climate change adaptation strategies; however, there are no specified numbers of times these campaigns are organized in the country. These activities should be time specific with some milestones set to measure success, periodically. Catchment-level information platforms should be created for disseminating information especially regarding climate change and other environmental problems bedevilling the catchment.

Drawing from the ways of enhancing or strengthening local knowledge through formal institutions, it can be said that such efforts will contribute to strengthening the existing local knowledge (Figure 31), as this knowledge will be broadened to the desired limit (Figure 32). Guided by the information about Figure 31, the author based on the role of institutiions in enhancing local knowledge exercised discretion based on the importance of the various aspects. The author hope that when local knowledge is enhanced, it is possible to to increase the exisiting knowledge levels to desired levels as this will manifest in the increased length of the antenae/tentacles) Forinstance, hydrochemistry though important, appeared least (level 1) understood by farmers as far as the application of knowledge is concenrned. Through formal institutions, it is presented that the knolwedge level of farmers will increase to level 8.

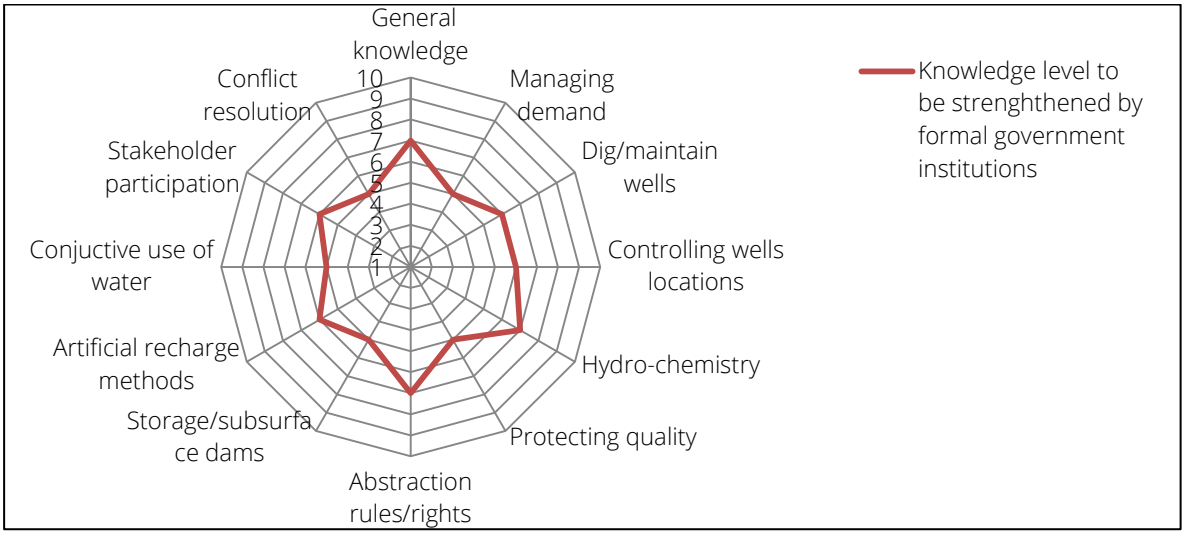


Figure 32. Aspects of local knowledge for groundwater adaptation

8. FEASIBILITY OF MANAGED AQUIFER RECHARGE TO AUGMENT GROUNDWATER AVAILABILITY

Guided by the results of Chapter Four and the reviewed literature in Chapter Two which showed that climate change is affecting rainfall and temperature with corresponding impacts on groundwater availability with more impacts anticipated, this chapter assesses the ways of boosting groundwater availability for dry season farming through artificial methods. The chapter touches on the nature of both formal government and catchment level informal institutions as contained in Kwoyiga and Stefan (2019) and their feasibility for Managed Aquifer Recharge (MAR) in the catchment. The concluding part of the chapter as a way of suggesting any MAR methods reviews the prospects of constructing a subsurface dam as a means of securing groundwater for irrigation use particularly in the dry season.

Drawing from the results, it is noted that formal institutions like legislations provide some guidelines for artificial groundwater recharge even though the quality of water for recharge is not captured. It is realised again that formal government organisations may experience some challenges regarding the planning and implementation of MAR projects since their expertise/functions are only to regulate rather than develop. Additionally, climate change policy documents may negatively affect the adoption of MAR because they failed to capture artificial methods of boosting groundwater resources in them.

Nonetheless, catchment-level institutions which are largely informal in nature in the form of taboos, norms and practices to a large extent are important for planning and implementing MAR projects. Furthermore, local knowledge possessed by farmers may support the operations and maintenance of MAR projects. Therefore, the construction of a subsurface dam may be a solution to make groundwater available for irrigation use because of the numerous benefits *inter alia* as it caters for water losses due to evaporation which is a problem in Atankwidi. The discussions below throw more light on the situation.

8.1. Institutions and MAR in Atankwidi catchment

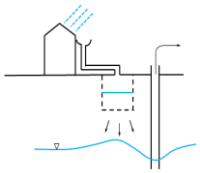
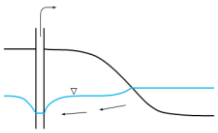
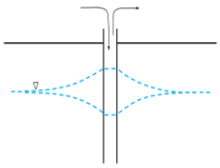
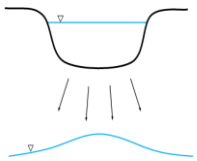
With reference to Kwoyiga and Stefan (2019), it is realised that both formal government institutions and catchment level institutions can influence the feasibility of MAR in Atankwidi. Focusing on the formal government institutions, it is established that legislation/legal provisions do not prohibit MAR schemes in the country. However, there are no guidelines at the moment on the quality of water that should be used for recharge. On the part of policies and administration, MAR schemes may be negatively affected during design, implementation and management. For instance, the country's policies lend no attention to groundwater recharge through artificial means.

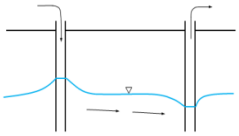
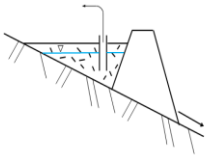
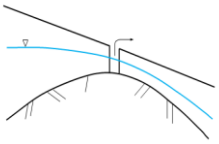
Also, there are no formal government organisations whose area of focus is on managing groundwater projects relating to artificial recharge. Experts in the country's Water Resources Commission are concerned more about regulation rather than development. The Ghana Irrigation Development Authority which is responsible for irrigational activities in the country does not cover the activities of groundwater irrigation and for that matter developing groundwater for irrigation.

Regarding catchment level institutions, Kwoyiga and Stefan (2019) brought to the fore that these were largely informal in nature in the form of rules, norms, taboos and practices. Traditional leaders formed the primary agency of these institutions. These institutions are important

especially regarding the planning and selection of MAR sites. Traditional leaders and farmers possess a wealth of knowledge about groundwater which may support MAR projects and their operations. A summary of some of the existing institutions and the corresponding MAR types is shown in Table 10.

Table 10. Matching institutions with MAR in Ghana (adapted from MAR portal 2018)

Classification of Managed Aquifer Recharge		**Institutions/provision**
	Roof top Harvesting Outlet pipe from a guttered roof-top to divert rainwater to either existing wells is constructed. Water can then be collected from a well or borehole.	– Environmental Assessment Regulations 1999 – Drilling Licence and Groundwater Development Legislative Instrument (L.I) 1827 – Catchment level informal institutions – National Rainwater Harvesting Strategy – National Water Policy 2007 – Climate change Adaptation Strategy – National Climate Change Policy – Water Resources Commission, EPA, WRI, River Basin Management Board, DA, traditional leaders catchment community
	River Bank Infiltration River bank infiltration schemes commonly consist of a gallery or a line of boreholes at a short distance from, and parallel to the bank of a surface water body. Pumping of the boreholes lowers the water table adjacent to the river or lake, inducing river water to enter the aquifer system.	– Rivers Act 1903 – Drilling Licence and Groundwater Development Legislative Instrument (L.I) 1827 – Catchment level informal institutions – Environmental Assessment Regulations 1999 – National Water Policy 2007 – Climate change Adaptation Strategy – National Climate Change Policy – Water Resources Commission, EPA, WRI, River Basin Management Board, DA, traditional leaders catchment community
	Aquifer Storage and Recovery (ASR) Water is injected into boreholes for storage and the water is recovered from the same well.	– Drilling Licence and Groundwater Development Legislative Instrument (L.I) 1827 – Catchment level informal institutions – Environmental Assessment Regulations 1999 – National Water Policy 2007 – Climate change Adaptation Strategy – National Climate Change Policy – Water Resources Commission, EPA, WRI, River Basin Management Board, DA, traditional leaders catchment community
	Infiltration Pond Ponds are constructed off stream to allow for the diversion of surface water. This water then infiltrates through an unsaturated zone to the underlying unconfined aquifer.	– Environmental Assessment Regulations 1999 – Drilling Licence and Groundwater Development Legislative Instrument (L.I) 1827 – Catchment level informal institutions – National Water Policy 2007 – Climate change Adaptation Strategy – Water Resources Commission, EPA, WRI, River Basin Management Board, DA,

Classification of Managed Aquifer Recharge		Institutions/provision
		traditional leaders catchment community
	Aquifer Storage Transfer and Recovery Water is injected into one borehole for storage and is recovered in another borehole.	– Drilling Licence and Groundwater Development Legislative Instrument (L.I) 1827 – Catchment level informal institutions – Environmental Assessment Regulations 1999 – Climate change Adaptation Strategy – National Climate Change Policy – Water Resources Commission, EPA, WRI, River Basin Management Board, DA, traditional leaders catchment community
	Sand Dam It is usually built in ephemeral streams on low permeability lithology. Sediments are trapped during flash floods when flow events. Coarser materials settle out and accumulate upstream the dam wall to create an aquifer.	– Dam Safety Regulations 2016 – Environmental Assessment Regulations 1999 – Climate change Adaptation Strategy – Catchment level informal institutions – National Climate Change Policy – Water Resources Commission, EPA, WRI, River Basin Management Board, DA, traditional leaders catchment community
	Subsurface/Underground Dam Dams may be used to detain water in alluvial aquifers. In ephemeral streams where basement highs constrict flow, a trench is constructed across the streambed keyed into the basement rocks and backfilled with low permeability material to constrain groundwater flow.	– Drilling Licence and Groundwater Development Legislative Instrument (L.I) 1827 – Dam Safety Regulations 2016 – Catchment level informal institutions – Environmental Assessment Regulations 1999 – Climate change Adaptation Strategy – National Climate Change Policy – Water Resources Commission, EPA, WRI, River Basin Management Board, DA, traditional leaders, catchment community

8.2. Proposed sub-surface dam for irrigation

MAR methods are many as indicated in Table 11. It is realised that apart from the institutional provisions, geophysical, hydrogeological and even economic factors play major roles in determining the suitability and hence adoption of any of these. A rural catchment where the housing structures do not facilitate rooftop rain water harvesting may not support any MAR method that relates to rooftop rainwater harvesting especially at the household level. Also, the catchment is located in the region considered to be among the poorest in Ghana. This means that the economic/financial component of MAR projects (as are usually expensive) may be beyond the financial capacity of the catchment dwellers.

Additionally, considering the transboundary nature of the catchment as characterised by the presence of the Atankwidi River which flows from Burkina Faso to Ghana, attempts at modifying the channel to trap water may require broad consultations/negotiations between the riparian

countries as there are already issues regarding the use of the water in the river already. This may be time consuming and expensive as in a situation where such consultations have to be undertaken. The Rivers Act 1903 mandates that all water in surface water bodies like rivers should flow freely without interruption into the Akosombo Dam to generate Hydro electricity. This notewithstanding, a permit is needed to divert or modify such water courses/bodies which in some instances may take a longer time. It is in the light of some of these challenges that the construction of subsurface dams have been proposed. This lends support to the work of Kankam-Yeboah et al. (2003), *The hydrological settings of Ghana and the potential for underground dams* where it is argued for the constructions of such dams in some part fo the country.

8.2.1. Issues to be addressed through a sub-surface dam

Guided by the interviews, community discussions, observation, policy document analysis, informal discussions and conversations, the thesis proposes for the constructions of subsurface dams. The construction of subsurface dams will boost groundwater availability and reduce pressure on groundwater sources as groundwater farmers will be weaned off from shared groundwater sources. This is because the Atankwidi catchment is located in a region characterised by highest groundwater exploitation as noted already, with the incidence of falling groundwater levels and drying up of wells, with fears that current groundwater extractions already exceeded sustainable levels (Martin, 2006). It is therefore not surprising that there is competition for groundwater among users.

The catchment is characterised by a mono-modal rainfall pattern where it rains only for five months. Analysis of the trend of total annual rainfall for the 30 year period shows no significant change. Furthermore, there are wide rainfall variabilities in the catchment in terms of onset and offset of rainfall, the volume of rainfall, and many others. Some years have also been driest while others wettest. However, temperatures are increasing. Coupled with these changes are the occurrences in recent time of floods (2007) and drought (2006) in the catchment. Nonetheless, potential evapotranspiration rises to the highest level of 10 mm/d usually in the dry season (Martin, 2006) as there is also no rainfall. The picture painted, therefore, provides an opportunity to harvest rainwater when it is available and store in the ground for later use. The outcome is the improvement of groundwater availability for use particularly in the dry season when rainfall is absent.

In the Atankwidi catchment, groundwater location by farmers is sometimes trial and error which sometimes results in a fruitless search for groundwater. This increases the initial costs of farming in terms of time and energy spent to get water. The construction of a subsurface dam will provide farmers with water at specific points in an organised manner for use in the dry season hence safe farmers' time, and energy. This has the tendency of increasing sizes of cropland and granting farmers the freedom to search for better crop lands instead of being tied to alluvial areas and other low-lying areas due to groundwater availability.

This dam will further offer farmers the opportunity to rely on better methods of groundwater harvesting and distribution during irrigation by moving away from the "bucket and calabash" system of irrigation which is a characteristic of groundwater farmers in the Upper East Region. As noted of the ASR and pit infiltration projects above which come with better ways of water recovery and distribution, farmers in the catchment may also benefit in this regard.

Dotting the area with wells particularly in the riverine in the quest for groundwater may be curtailed as this is contributing in no small way to environmental degradation in the form of erosion, deforestation and siltation of surface water bodies in the area. The threats of these activities near surface water bodies have influenced the documentation of the Riparian Buffer Zone, 2011as a way of promoting vegetation buffers to preserve and support the functioning of

all water bodies and ecosystems in Ghana. This policy intends to become a Legislation Instrument (LI) and when it is fully implemented, this will imply that riverine farmers in particular will have to lose their farming jobs or will have to invest more resources in tapping groundwater for irrigation. The construction of this dam will move farmers away from the riverine and other low lying areas and create room for the successful implementation of the buffer zone policy. Such farmers will also continue with their irrigation activities.

8.2.2. Merits of a sub-surface dam

It is recognised that subsurface dams have been in existence for the past several years. Historical accounts given by Hanson and Nilsson (1986) showed that such dams were constructed on Sardinia in Roman times and associated with ancient civilizations in North Africa with these dams existing in southern and East Africa in recent times. According to Foster and Tuinhof (2004), they are found in semi-arid regions and efficient for conserving groundwater. Countries like Kenya, Ethiopia, Namibia and Japan are noted for the presence of these dams (Murray, 2017).

For instance, in Japan, the Miyakojima subsurface dams store 20 million m^3 of groundwater with installed 147 tubewells which draw up to 50000 m^3 of water per day for irrigation with plans to construct similar ones in Ryukyu and Amami islands in southwest Japan (Ishida et al., 2003). According to Raju et al. (2006) in their study *Subsurface dams to harvest rainwater— a case study of the Swarnamukhi River basin, Southern India*, the construction of the subsurface dam has contributed to groundwater storage and increase in land productivity.

Acccording to (Kankam-Yeboah et al., 2003), " a sub-surfface dam is aconstructed to the underlying impervious materials with its crest a desired depth below the ground level. By this this means, groundwater flow in the natural aquifer is arrested and can thus be pumped"Considered "a facility that stores groundwater in the pores of strata and uses groundwater in a sustainable way", it is realised that such dams are not associated with land subsidence and are constructed in regions where geological conditions do not permit the construction of a surface dam (Ishida et al., 2011:51). According to Hanson and Nilson (1986:217) by storing water behind subsurface dams in natural aquifers or in the sand accumulated in sand storage dams, the disadvantages of conventional surface storage, such as high evaporation rates, pollution, siltation, and health hazards, may be avoided. Another advantage of subsurface dams is that they are simpler and cheaper to design and construct. Also, they do not require any maintenance or repairs at all (Nissen-Petersen, 2013). Peruse of literature further provides the importance of subsurface dam which Baurne (1984) noted to include the following:

- It is realised that the construction of a subsurface dam will secure groundwater at all times and improve storage. This is because; these dams are noted for having the potentials of curtailing water losses due to evaporation.
- The storage capacity of such dams hardly reduces because there is the absence of siltation resulting from the accumulation of sediments.
- Due to the fact that water stored in the ground is not exposed to the earth surface, it is difficult for such water to be contaminated.
- Health concerns relating to Malaria caused by the breeding of mosquitos as is the case of surface water bodies are taken care of.
- Land submergence is avoided when subsurfaces are chosen as it is the case with surface dams
- The challenges of relocating people in order to have more land available for construction become less with subsurface dams
- The tendency of such dams being destroyed by floods is low.

Putting Atankwidi within the context of the aforementioned points, it is realised that the catchment is situated in an area where temperatures are usually high in the dry season causing high evaporation. The catchment is environmentally degraded as the vegetation cover here is poor; characterised by short grasses, few stunted trees and usually bear soils in the dry season coupled with poor waste management which cause water pollution. Also, the poor vegetation cover accelerates erosion which is contributing to the siltation of the existing surface water bodies like the Atankwidi River.

A nearby surface water dam to Atankwidi (Zorkpo) is the Vea dam in Bolgatanga which brought about the incidence of Malaria caused by the breeding of mosquitoes. Health hazards of this nature are therefore avoided when subsurface dams are constructed.

Administratively, the Upper East Region is the most densely populated region in Ghana and the smallest in terms of land size. The region has already two large surface dams with one of them being the largest in West Africa: Tono Dam. Apart from these, there are also several surface water reservoirs in the region. This implies that with the growing population coupled with the degree to which land in the area has already been put to use, the construction of any surface dam may not be feasible.

Comparing the benefits of a subsurface dam with the existing characteristics of the catchment, it can be said that constructing a subsurface dam to boost groundwater storage will be more useful than other alternatives as indicated in Table 10. The call for consideration of subsurface dams in Ghana has therefore been long argued by Kankam-Yeboah et al. (2002).

8.2.3. Existing conditions supporting the construction of the dam

Though this discussion offers a general insight into the situation of which detail studies may be required, it is realised that for the construction of a subsurface dam to be possible, some conditions have to be met (A manual on SubSurface Dams constructionbased on an experience of Vétérinaires Sans Frontièresin Turkana District (Kenya), 2006) . For instance, the rocks in the area must be solid (metamorphic or volcanic) to serve as a foundation. Fortunately, the Atankwidi catchment is endowed with Granitoids, Intrusive Bongo granite and Birimian meta-sediments (Martin, 2006).

It is also recommended that the soil type in the area should have large porosity. A study of soils in the Upper East Region which includes the catchment by the Soil Research Institute shows that Leptosols, Fluvisols and Lixisols exist. This has been confirmed in the catchment by Martin (2006).

The construction of subsurface dam may require the use of pumping machines to draw water (Bancy Mati, n.d.). This is not new to farmers in the catchment as most of the riverine farmers already possess them. As noted in Chapter Seven, farmers have a store of local knowledge which is being applied throughout their activities and this knowledge supports in the management and maintenance of a subsurface dam.

There are available local construction materials in the catchment like clay and stone masonry, which may be needed in the process. (Onder & Yilmaz, 2005) note that such materials serve as impermeable barriers. The presence of clay is evident in the North-East part of the catchment which causes flooding due to poor infiltration (Martin, 2006). There have been extensive studies already on the geological and hydrological studies some of which have been reviewed in the study area. Therefore, background information on this already exists. Additionally, an assessment of the institutional support revealed the feasibility of MAR methods in general. It is, therefore, advocated that a subsurface dam should be constructed in Atankwidi to boost groundwater availability for irrigation.

9. GENERAL CONCLUSIONS AND RECOMMENDATIONS

In the face of climate change where all environmental resources are impacted, adaptation is one option to address these impacts. In order to realise the goals of adaptation, institutions are crafted to regulate the process. This study analysed how formal institutions promote groundwater adaptation to climate change in Ghana. It looked at the nature of formal government (state) institutions in particular at both the national and subnational (district/municipal) levels. Knowledge is an important tool for adaptation, as such the study also looked at how formal government institutions could enhance or strengthen this knowledge for adaption as it is considered weak. Groundwater adaptation measures include giving attention to artificial methods of boosting groundwater availability through recharge/storage. As a result, the study crowned the discussion by looking at the institutional feasibility of Managed Aquifer methods in Atankwidi.

Regarding the nature of formal institutions for adaptation, the following are noted:

- There exist various institutions that regulate groundwater adaptation in Ghana. They brought to the fore a myriad of laws, policies and administration at national and subnational levels. In terms of laws at the national level, there is a multiplicity of them resulting in pluralism.
- However, issues of water resources in general at the subnational level are skeletally captured by the bye-laws.
- There are a number of policies in the country that relate to climate change, however, little information is captured in them about how to promote groundwater adaptation as more attention is shifted towards surface water resources.
- Administrative structures also exist that are concerned about groundwater adaptation even though their efforts or areas of focus appear limited. In terms of development and management, attention is more on groundwater for domestic purposes rather than groundwater for irrigation. Also, regulation is concerned more about surface water rather than groundwater.
- There is still much to be done as far as the definition of roles is concerned especially at the local level.
- Nonetheless, the existence of these institutions is the first step to achieving adaptation to climate change.

In looking at how these institutions are performing by way of enabling, doing and achieving groundwater adaption to climate impacts, the following issues emerged:

- The study revealed that managing groundwater demand is performing credibly.
- However, while there are groundwater instruments for managing the demand of groundwater for domestic purposes, such cannot be said of groundwater for irrigation. Traditional institutions define the allocation of groundwater for irrigation in the catchment which promotes organised behaviour for adaptation.
- There is the presence of about 25 monitoring wells in the northern part of the country that provide data on groundwater levels, discharge, recharge and interactions between surface and groundwater.
- Artificial recharge of groundwater is lagging behind as it has received limited attention. Recharge is solely natural, from rainfall hence the least scored.
- It can be said that in terms of performance, institutional efforts for groundwater adaptation are yet to gain momentum.

Local knowledge has enabled the people of Atankwidi to develop and use groundwater resources for different purposes in the catchment. The following are however the limitations of it:

- It is more about coping rather than adaptation.
- This knowledge is unable to comprehensively explain the linkages between climate change and groundwater resources.
- This knowledge is also skewed distributed as it is found mostly with men.
- This knowledge is not able to provide sufficient information regarding the aspects of quality, recharge, storage and discharge.
- Therefore, formal government institutions can broaden the scope of this knowledge to increase adaptation efforts. This can be done through building capacity and updating local knowledge holders with integrated/hybrid knowledge that encompasses both local and scientific knowledge about groundwater resources.
- Climate change policies should include programmes relating to artificial methods of groundwater recharge/storage. However, such programmes should be anchored on local knowledge.

Guided by the fact that climate change is affecting groundwater resources for irrigation, the search for methods to promote recharge/storage revealed the existence of some MAR schemes such as ASR and Pit Infiltration for agricultural purposes in the northern part of Ghana. Inspired by the presence of these schemes, institutional feasibility for the adoption of such in Atankwidi brought to the limelight the following:

- Formal institutions like legislations provide some guidelines even though the quality of water for recharge is not captured.
- Catchment-level institutions largely favour the adoption of MAR as they can effectively contribute to the planning and implementation of MAR projects.
- Local knowledge possessed by farmers may support the operations and maintenance of MAR projects
- Therefore, it can be said that in the Atankwidi catchment, the adoption of MAR schemes is feasible.
- This may, therefore, accelerate the construction of a subsurface dam as a way of making groundwater available for dry season irrigation.
- The construction of a sub-surface dam will address issues of water loss through evaporation considering the higher temperatures in the catchment. Issues of malaria, water pollution and displacement of people in the area will also be avoided.
- Other existing conditions in the catchment like local materials (clay) and available information about the geography and hydrogeology may support the construction of a sub-surface dam.

Drawing from the results of the study, it is realised that, though the institutional arrangements are enabling, doing and achieving some successes as far as groundwater adaptation to climate change is concerned, there still exist some inadequacies, challenges and issues that need to be addressed. The following recommendations, therefore, intend to contribute to tackling some of these.

Firstly, it is a fact that in terms of laws, there exist a myriad of them that relate to climate change, however, their multiplicity creates pluralism. The plurality of these institutions sometimes creates conflicting or overlapping situations with instances of lack of clear definition of roles especially at the District/Municipal level. It is, therefore, recommended that there should be a clear definition of roles and responsibilities by the Ministry of Environment, Science, Technology and Innovation to enable the responsible agencies to perform effectively. In line with this, the content of the

country's climate change policies regarding adaptation should give maximum attention to groundwater resources just like surface water resources.

Secondly, it is recommended that groundwater studies on groundwater storage covering all the aquifer system in Atankwidi should be undertaken. This will contribute to understanding better the sustainable yield of groundwater in the catchment as it will guide to address issues of fallen groundwater tables in the catchment. This information is also relevant for adopting the appropriate MAR schemes in the catchment.

Institutional support should be given to the promotion of artificial groundwater recharge both scientifically and through the application of local knowledge. Stakeholder participation is important for achieving effective governance and management of water resources. As a result, it is recommended for a comprehensive study of all relevant groundwater stakeholders in the Atankwidi and their integration in formal decision-making processes. Local knowledge is the foundation of adaptation especially among most farmers in the catchment. As such, such knowledge should be harnessed and documented and recognised an effective tool for adaptation. Integrating this knowledge with scientific knowledge will make the latter more concrete for adaptation. Climate change projects about groundwater adaptation should be local in nature and built upon local knowledge to promote easy adaption and management.

Lastly, boosting groundwater availability is very crucial especially to promote the sustainability of livelihood activities in the dry season in the catchment. The thesis, therefore, recommends the adoption of MAR schemes like the suggested sub-surface dam. The Government of Ghana is currently rolling out a strategy called *One District One Dam* which aims at providing districts and villages with dams. It is, therefore, recommended that such dams should take the form of sub-surface dams and not surface dams like the existing ones, considering the significance of sub-surface dams as discussed already.

10. REFERENCES

A manual on SubSurface Dams constructionbased on an experience of Vétérinaires Sans Frontièresin Turkana District (Kenya). (2006). *SubSurface Dams :a simple, safe and affordabletechnology for pastoralists*. Retrieved from https://www.samsamwater.com/library/Sub_surface_dams_-_a_simple_safe_and_affordable_technology_for_pastoralists.pdf

Agrawal, A., McSweeney, C., & Perrin, N. (2008). The social Dimension of Climate Change. Retrieved 9 October 2017, from https://openknowledge.worldbank.org/bitstream/handle/10986/11145/4489100BRI0Box31te0Change0Adaptation.pdf?sequence=1&isAllowed=y

Agyekum, W., & Dapaah-Siakwan, S. (2008). The occurrence of groundwater in northeastern Ghana. *Applied Groundwater Studies in Africa, IAH Selected Papers on Hydrogeology*, *13*.

Amadou, M., Villamor, G., Attua, E., & Traoré, S. (2015). Comparing farmers' perception of climate change and variability with historical climate data in the Upper East Region of Ghana. *Ghana Journal of Geography*, *7*(1), 47–74.

Anayah, F. M., Kaluarachchi, J. J., Pavelic, P., & Smakhtin, V. (2013). Predicting groundwater recharge in Ghana by estimating evapotranspiration. *Water International*, *38*(4), 408–432.

Andah, W. E., van de Giesen, N., & Biney, C. A. (2003). Water, climate, food, and environment in the Volta Basin. *Contribution to the Project ADAPT. Adaptation Strategies to Changing Environments*.

Bancy Mati. (n.d.). *Subsurface dams: A training note*. Retrieved from http://www.jkuat.ac.ke/departments/warrec/wp-content/uploads/2016/07/SUBSURFACE-DAM.pdf

Bandaragoda, D. J. (2000). *A framework for institutional analysis for water resources management in a river basin context* (Vol. 5). Colombo, Sri Lanka: IWMI.

Barnie, S., Anornu, G., & Kortatsi, B. (2014). Assessment of the Quality of Shallow Groundwater for Irrigation in the Atankwidi Sub-Basin of the White Volta Basin, Ghana. *Journal of Natural Sciences Research*, *4*(15), 1–11.

Barry, B., Kortatsi, B., Forkuor, G., Gumma, M. K., Namara, R. E., Rebelo, L.-M., … Laube, W. (2010). *Shallow groundwater in the Atankwidi Catchment of the White Volta Basin: Current status and future sustainability* (Vol. 139). Colombo, Sri Lanka: IWMI.

Bates, B., Kundzewicz, Z., Wu, S., & Palutikof, J. (2008). Climate change and water. Technical paper of the intergovernmental panel on climate change. *Climate Change Policy with a Renewed Environmental Ethic*, *21*, 85–101.

Baurne, G. (1984). "Trap-dams": Artificial Subsurface Storage of Water. *Water International*, *9*(1), 2–9.

Baxter, P., & Jack, S. (2008). Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. *The Qualitative Report*, *13*(4), 544–559.

Bernstein, B. P., Canziani, O., & others. (2007). *Intergovernmental panel on climate change, fourth assessment report: Climate Change 2007, Synthesis Report.* Retrieved from IPCC website: http://www.un-documents.net/ipcc-ar4/syr.pdf

Calow, R., & MacDonald, A. (2009). What will climate change mean for groundwater supply in Africa. *Overseas Development Institute (ODI) Background Note*.

Carrier, M.-A., Boyaud, C., Lefebvre, R., & Asare, E. (2011). *Hydrogeological Assessment Project of the Northern Regions of Ghana (HAP): Final technical report: Hydrogeological Assessment of the Northern Regions of Ghana.* Québec, Canada: INRS, Centre Eau, Terre et Environnement.

Chhetri, N., Chaudhary, P., Tiwari, P. R., & Yadaw, R. B. (2012). Institutional and technological innovation: Understanding agricultural adaptation to climate change in Nepal. *Applied Geography*, *33*, 142–150.

Cleaver, F. (2017). *Development through bricolage: Rethinking institutions for natural resource management*. New York: Routledge.

Cleaver, F. D., & De Koning, J. (2015). Furthering critical institutionalism. *International Journal of the Commons*, *9*(1), 1–18.

Clifton, C., Evans, R., Hayes, S., Hirji, R., Puz, G., & Pizarro, C. (2010). *Water and climate change: Impacts on groundwater resources and adaptation options* (WB Working Note No. 25.). Washington, DC: World Bank.

Coase, R. (1998). The New Institutional Economics. *The American Economic Review*, *88*(2), 72–74.

Colding, J., Elmqvist, T., & Olsson, P. (2003). Living with disturbance: Building resilience in social-ecological systems. In F. Berkes, J. Colding, & C. Folke (Eds.), *Navigating social-ecological systems: Building resilience for complexity and change* (pp. 163–185). Cambridge, UK: Cambridge University Press, UK.

Community Water and Sanitation Agency-Accra, Ghana. (2010). *Small communities sector guidelines: Design guidelines*. Retrieved from https://www.ircwash.org/sites/default/files/cwsa-2010-small_design.pdf

De Koning, J. (2011). *Reshaping institutions: Bricolage processes in smallholder forestry in the Amazon* (PhD Thesis). Wageningen University, Wageningen, the Netherlands.

Derbile, E. K. (2010). *Local knowledge and livelihood sustainability under environmental change in Northern Ghana* (PhD Thesis). Rheinischen Friedrich - Wilhelms - Universität zu Bonn, Bonn, Germany.

Dillon, P., Pavelic, P., Page, D., Beringen, H., & Ward, J. (2009). Managed aquifer recharge: An introduction. *Waterlines Report Series*, (13), 86.

Döll, P. (2009). Vulnerability to the impact of climate change on renewable groundwater resources: A global-scale assessment. *Environmental Research Letters*, *4*(3), 035006.

Food and Agriculture Organization of the United Nations. (2016). Global framework for action to achieve the vision on groundwater governance. Retrieved 6 January 2018, from http://www.fao.org/3/a-i5705e.pdf

Foster, S., & Tuinhof, A. (2004). Brazil, Kenya: Subsurface dams to augment groundwater storage in basement terrain for human subsistence. *World Bank Sustainable Groundwater Management Lessons from Practice*, 1–8.

Fukuyama, F. (2006). Do defective institutions explain the gap between the United States and Latin America? *The American Interest*, *2*(2), 1–39.

Ghana Statistical Service. (2012). *2010 Population and Housing Census: Summary Report of Final Results*. Accra: GSS, Government of Ghana.

Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., van den Brink, M., Jong, P., & Nooteboom, S. (2010). *Institutions for climate change: A method to assess the inherent characteristics of institutions to enable the adaptive capacity of society*. Amsterdam, Netherland: IVM: Institute for Environmental Studies Vrije Universiteit.

Gupta, S. K. (2011). *Modern hydrology and sustainable water development*. Chicester, United Kingdom: John Wiley & Sons.

Hall, P. A., & Soskice, D. (2001). *Varieties of Capitalism: The Institutional Foundations of Comparative Advantage*. New York: Oxford University Press.

Hanson, G., & Nilsson, \AAke. (1986). Ground-Water Dams for Rural-Water Supplies in Developing Countries. *Groundwater*, *24*(4), 497–506.

Hart, O. (2001). *Norms and the Theory of the Firm* (Working Paper No. 8286). https://doi.org/10.3386/w8286

Helmke, G., & Levitsky, S. (2004). Informal institutions and comparative politics: A research agenda. *Perspectives on Politics*, *2*(4), 725–740.

Hiwasaki, L., Luna, E., Shaw, R., & others. (2014). Process for integrating local and indigenous knowledge with science for hydro-meteorological disaster risk reduction and climate change adaptation in coastal and small island communities. *International Journal of Disaster Risk Reduction*, *10*, 15–27.

Hodgson, G. M. (2006). What Are Institutions? *Journal of Economic Issues*, *40*(1), 1–25. https://doi.org/10.1080/00213624.2006.11506879

IPCC. (2014). Summary for policy makers. In Field et al. (Ed.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Ishida, S., Kotoku, M., Abe, E., Fazal, M. A., Tsuchihara, T., & Imaizumi, M. (2003). Construction of subsurface dams and their impact on the environment. *Materials and Geoenvironment*, *50*, 149–152.

Ishida, S., Tsuchihara, T., Yoshimoto, S., & Imaizumi, M. (2011). Sustainable use of groundwater with underground dams. *Japan Agricultural Research Quarterly: JARQ*, *45*(1), 51–61.

Job, C. A. (2010). *Groundwater economics*. London, UK: CRC Press.

Johnston, R. M., & McCartney, M. (2010). *Inventory of water storage types in the Blue Nile and Volta river basins*. Retrieved from http://dx.doi.org/10.5337/2010.214

Jung, G. (2006). *Regional climate change and the impact on hydrology in the Volta Basin of West Africa.* (PhD Thesis). University of Augsburg, Augsburg, Germany.

Kankam-Yeboah, K., Dapaah-Siakwan, S., Nishigaki, M., & Komatsu, M. (2003). The hydrogeological setting of Ghana and the potential for underground dams. 岡山大学環境理工学部研究報告, *8*(1), 39–52.

Kankam-Yeboah, K, Obuobie, E., & Amisigo, B. (2009). Climate Change Impacts on Water Resources in Ghana. *Ghana National Commission for UNESCO*, 65–69.

Kasei, R. A. (2009). *Modelling impacts of climate change on water resources in the Volta Basin, West Africa* (PhD Thesis). Rheinischen Friedrich-Wilhelms-Universität Bonn, Bonn, German.

Kemper, K. E. (2007). Instruments and institutions for groundwater management. In M. Giordano & K. G. Villholth (Eds.), *The agricultural groundwater revolution: Opportunities and threats to development* (pp. 153–172). London, UK: CAB International.

Kimmerer, R. W. (2002). Weaving traditional ecological knowledge into biological education: A call to action. *AIBS Bulletin*, *52*(5), 432–438.

Kolavalli, S., & Williams, T. O. (2016). Socioeconomic trends and drivers of change. In T. Williams, M. Mul, C. A. Biney, & V. Smakhtin (Eds.), *The Volta Basin: Water for food, economic growth and environment*. Oxon, Uk: Earthscan.

Kortatsi, B. (1994). Groundwater utilization in Ghana. *IAHS Publications-Series of Proceedings and Reports-Intern Assoc Hydrological Sciences*, *222*, 149–156.

Kumar, P.C. (2012). Climate change and its impact on groundwater resources. *International Journal of Engineering and Science*, *1*(5), 43–60.

Kwoyiga, L., & Stefan, C. (2018). Groundwater Development for Dry Season Irrigation in North East Ghana: The Place of Local Knowledge. *Water*, *10*(12), 1724. https://doi.org/10.3390/w10121724

Kwoyiga, L., & Stefan, C. (2019). Institutional Feasibility of Managed Aquifer Recharge in Northeast Ghana. *Sustainability, MDPI*, *11*(2), 378.

Livingston, M. L. (2008). Evaluating Institutional Performance: An Ex Post Analysis of Water Law in Colombia. *Acta Oeconomica Pragensia*, *2008*(3), 70–79.

Madzwamuse, M. (2011). *Climate Governance in Africa-adaptation strategies and institutions*. Retrieved from Heinrich Boell Foundation website: https://www.boell.de/sites/default/files/assets/boell.de/images/download_de/Climate_Governance_in_Africa.pdf

Maharjan, S. K., & Maharjan, K. L. (2017). Review of climate policies and roles of institutions in the policy formulation and implementation of adaptation plans and strategies in Nepal. *Journal of International Development and Cooperation*, *23*(1–2).

Martin, N. (2006). *Development of a water balance for the Atankwidi catchment, West Africa: A case study of groundwater recharge in a semi-arid climate* (PhD Thesis). University of Goettingen, Goettingen, Germany.

Martin, N., & Giesen, N. van de. (2005). Spatial Distribution of Groundwater Production and Development Potential in the Volta River basin of Ghana and Burkina Faso. *Water International*, *30*(2), 239–249. https://doi.org/10.1080/02508060508691852

MAXQDA. (2018). *MAXQDA 2018 Manual*. Retrieved from https://www.maxqda.com/download/Online-Manual-Complete-Englisch.pdf

McSweeney, C., New, M., Lizcano, G., & Lu, X. (2010). The UNDP Climate Change Country Profiles: Improving the accessibility of observed and projected climate information for studies of climate change in developing countries. *Bulletin of the American Meteorological Society*, *91*(2), 157–166. https://doi.org/0.1175/2009BAMS2826.1

Ministry of Environment, Science and Technology. (2013). *Ghana National Climate Change Policy*. Retrieved from http://www.un-page.org/files/public/ghanaclimatechangepolicy.pdf

Mubaya, C. P., & Mafongoya, P. (2017). The role of institutions in managing local level climate change adaptation in semi-arid Zimbabwe. *Climate Risk Management*, *16*, 93–105.

Mul, M., Obuobie, E., Appoh, R., Kankam-Yeboah, K., Bekoe-Obeng, E., Amisigo, B., … McCartney, M. (2015). *Water resources assessment of the Volta River Basin* (Vol. 166). Colombo, Sri Lanka: International Water Management Institute (IWMI).

Murray, R. (2017, March). Managed Aquifer Recharge: An introductory guide for the SADC. Groundwater Management Institute including the Windhoek case study. Retrieved 20 January 2018, from http://sadc-gmi.org/wp-content/uploads/2017/03/Booklet_GMI_24022017.pdf

Namara, R. E., Horowitz, L., Kolavalli, S., Kranjac-Berisavljevic, G., Dawuni, B. N., Barry, B., & Giordano, M. (2011). *Typology of irrigation systems in Ghana* (Vol. 142). Colombo, Sri Lanka: IWMI.

Namara, R. E., Horowitz, L., Nyamadi, B., & Barry, B. (2011). *Irrigation development in Ghana: Past experiences, emerging opportunities, and future directions* (No. 27). Accra, Ghana: International Food Policy Research Institute.

Nanni, M., Foster, S. S., Dumars, C., Garduño, H., Kemper, K., & Tuinhof, A. (2004). Groundwater legislation & regulatory provision: From customary rules to integrated catchment planning. In *GW-MATE Briefing Note Series* (Vol. 4). Banco Mundial.

Niang, I., Ruppel, O. C., Abdrabo, M. A., Essel, A., Lennard, C., Padgham, J., & Urquhart, P. (2015). Africa. In Barros et al. (Ed.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Nissen-Petersen, E. (2013). Subsurface dams for water storage in dry riverbeds. *ASAL Consultants Limited*. Retrieved from http://www.waterforaridland.com/Books/Subsurface%20dams%20for%20water%20storage.pdf

North, D. (1990). *Institutions, Institutional Change and Economic Performance*. Cambridge: Cambridge University Press.

Obuobie, E. (2008). *Estimation of groundwater recharge in the context of future climate change in the White Volta River Basin, West Africa* (PhD Thesis). Rheinischen Friedrich-Wilhelms-Universität Bonn, Bonn, Germany.

Ofosu-Addo, D., Jianmei, C., & Dong, S. (2008). Groundwater Development and Evaluation of the White Volta Basin (Ghana) using numerical Simulation. *The Journal of American Science*, *4*(4), 1545–1003.

Onder, H., & Yilmaz, M. (2005). *Underground Dams. A Tool of Sustainable Development and Management of Groundwater Resources*. 11.

O'Riordan, T., & Jordan, A. (1999). Institutions, climate change and cultural theory: Towards a common analytical framework. *Global Environmental Change*, *9*(2), 81–93.

Ostrom, E. (2010). Institutional analysis and development: Elements of the framework in historical perspective. *Historical Developments and Theoretical Approaches in Sociology*, *2*, 261–288.

Owusu, K., & Waylen, P. (2009). Trends in spatio-temporal variability in annual rainfall in Ghana (1951-2000). *Weather*, *64*(5), 115–120.

Oyebande, L., & Odunuga, S. (2010). Climate change impact on water resources at the transboundary level in West Africa: The cases of the Senegal, Niger and Volta Basins. *Open Hydrology Journal*, *4*(1), 163–172.

Page, G. (1987). Water and health. *Public Health and the Environment*, 105–138.

Paradis, E. (2002). *R for Beginners*. Retrieved from https://cran.r-project.org/doc/contrib/Paradis-rdebuts_en.pdf

Pearce, T., Ford, J., Willox, A. C., & Smit, B. (2015). Inuit traditional ecological knowledge (TEK), subsistence hunting and adaptation to climate change in the Canadian Arctic. *Arctic*, 233–245.

Pelig-Ba, K. B. (2004). Estimation of water balance in the Northern Region of Ghana. *Ghana Journal of Development Studies*, *1*(2), 118–141.

Pinto, A. de, Demirag, U., Haruna, A., Koo, J., & Asamoah, M. (2012). *Climate change, agriculture, and food-crop production in Ghana*. Retrieved from https://www.researchgate.net/publication/232253127_CLIMATE_CHANGE_AGRICULTURE_AND_FOODCROP_PRODUCTION_IN_GHANA

Polski, M. M., & Ostrom, E. (1999). *An institutional framework for policy analysis and design*. Retrieved from http://www.atelierpolitique.fr/wp-content/uploads/2013/09/Article-PolskiOstromIAD.pdf

Raju, N. J., Reddy, T. V. K., & Munirathnam, P. (2006). Subsurface dams to harvest rainwater—a case study of the Swarnamukhi River basin, Southern India. *Hydrogeology Journal*, *14*(4), 526–531.

Rauf, M. (2009). Innovations and informal institutions: An institutionalist approach to the role of social capital for innovation. *Journal of Academic Research in Economics*, *1*(1), 25–33.

Raven, P., Hassenzahl, D., & Berg, L. (2013). Environment: International student version (eight ed). *Singapura: John Wiley & Son*.

Richter, R. (2005). The New Institutional Economics: Its Start, its Meaning, its Prospects. *European Business Organization Law Review (EBOR)*, *6*(2), 161–200. https://doi.org/10.1017/S1566752905001618

Roggero, M., Villamayor-Tomas, S., Oberlack, C., Eisenack, K., Bisaro, A., Hinkel, J., & Thiel, A. (2018). Introduction to the special issue on adapting institutions to climate change. *Journal of Institutional Economics*, *14*(3), 409–422.

Saleth, R. M. (2006). Understanding water institutions: Structure, environment and change process. In S. Perret, S. Farolfi, & R. Hassan (Eds.), *Water governance for sustainable development.* Retrieved from https://cgspace.cgiar.org/handle/10568/37398

Saleth, R. M., & Dinar, A. (2004). *The Institutional Economics of Water: A cross country analysis of institutions and performance*. Cheltenham, Uk: Edward Elgar.

Salick, J., & Byg, A. (2007). *Indigenous Knowledge and Climate Change.* Retrieved from https://archive.org/details/fs_cc_Indigenous_Peoples_and_Climate_Change/page/n1

Salifu, T., & Agyare, W. A. (2012). Distinguishing different land use types using surface albedo and normalized difference vegetation index derived from the SEBAL for the Atankwidi and a farm sub catchments in Ghana. *J. Eng. Appl. Sci*, *7*(1), 69–80.

Stefan, C., & Ansems, N. (2018). Web-based global inventory of managed aquifer recharge applications. *Sustainable Water Resources Management*, *4*(2), 153–162. https://doi.org/10.1007/s40899-017-0212-6

Taylor, P., Owen, R., Mirghani, M., Diene, M., & Tuinhof, A. (2010). Groundwater Management in IWRM: Training Manual. *Cap-Net, Africa Groundwater Network (AGW-Net) and Ground Water*

Management Advisory Team (GWMATE). Available Online at: Www. Cap-Net. Org/Sites/Cap-Net. Org/Files/Cap-Net% 20Groundwater, *20*.

Tellis, W. M. (1997). Application of a case study methodology. *The Qualitative Report*, *3*(3), 1–19.

University of Notre Dame. (2015). Country Index. Retrieved 10 October 2016, from The Notre Dame Global Adaptation Initiative (ND-GAIN) website: https://gain.nd.edu/our-work/country-index/

Vaessen, V., & Brentführer, R. (2015). Integration of Groundwater Management into Transboundary Basin Organizations in Africaâ□"A Training Manual by AGW-Net, BGR, IWMI, CapNet, ANBO, & IGRAC". Retrieved 3 May 2017, from https://cgspace.cgiar.org/bitstream/handle/10568/77070/00_Training_Manual_Intro_en.pdf?sequence=1

van Drunen, M. A., Lasage, R., Dorland, C., & others. (2006). *Climate change in developing countries: Results from the Netherlands Climate Change Studies Assistance Programme*. Oxfordshire, Cambridge: CAB International.

Vatn, A. (2005). *Institutions and the Environment*. Cheltenham, Uk: Edward Elgar Publishing.

Vaux, H. (2011). Groundwater under stress: The importance of management. *Environmental Earth Sciences*, *62*(1), 19–23. https://doi.org/10.1007/s12665-010-0490-x

Vinyeta, K., & Lynn, K. (2013). Exploring the role of traditional ecological knowledge in climate change initiatives. *Gen. Tech. Rep. PNW-GTR-879. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. 37 p.*, *879*.

Walter, H., & Lieth, H. (1967). Klimadiagramm-Weltatlas: VEB Gustav Fischer Verlag. *Jena, Germany*.

Water Resources Commission. (2008). White Volta River Basinâ□"Integrated Water Resources Management Plan. Retrieved 20 March 2016, from WHITE VOLTA RIVER BASIN - Integrated Water Resources Management Plan website: http://webcache.googleusercontent.com/search?q=cache:vkxrZJOB6eIJ:www.wrc-gh.org/dmsdocument/19+&cd=2&hl=en&ct=clnk&gl=de

Williamson, O. E. (1996). Efficiency, Power, Authority and Economic Organization. In J. Groenewegen (Ed.), *Transaction Cost Economics and Beyond* (pp. 11–42). https://doi.org/10.1007/978-94-009-1800-9_2

Williamson, O. E. (2000). The New Institutional Economics: Taking Stock, Looking Ahead. *Journal of Economic Literature*, *38*(3), 595–613. Retrieved from JSTOR.

Yin, R. K. (2014). *Case study research: Design and methods (Fifth)*. London, UK: SAGE Publications Ltd.

APPENDICES

APPENDIX A

ATANKWIDI COMMUNITY INTERVIEW GUIDES

1. **THIS INFORMATION/QUESTIONNAIRES/INTERVIEW GUIDE BELOW IS MEANT TO PROVIDE INFORMATION FOR THE STUDY OF THE TOPIC:INSTITUTIONS, GROUNDWATER RESOURCES AND CLIMATE CHANGE ADAPTATION IN NORTHERN GHANA. THIS IS PART OF A DOCTORAL RESEARCH BY**

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Profile of Groundwater and climate change

1. Do you think rainfall has decreased, increased or remained the same for the past 30 years?
2. If there are changes with rainfall for the past 30 years, describe these changes you have observed.
3. If there are changes in temperature for the past 30 years, describe these changes you have observed.
4. What surface water bodies do you have in your community?
5. Do you have groundwater resources in your community?
6. What are the ways by which you get the water pumped out from the ground?
7. Name the activities that you use the groundwater for?

Effects of climate change on groundwater dependent activities particularly dry season farming

1 How has the change in groundwater resources affected the number of plots of land that you farm?
2 Explain what your dry season farming calendar was like 20 to 30 years ago.
3 How have the changes in groundwater resources affected your dry season farming calendar now?
4 How have the changes in groundwater resources influenced the types of crops to cultivate now?
5 How have the changes in groundwater resources influenced the cost digging wells for dry season farming now?
6 How have the changes in groundwater resources affected the quality of crops you cultivate now?

7 How have the changes in groundwater resources affected the quality of crops you cultivate now
8 How have the changes in groundwater resources affected animal rearing?
9 How have the changes in groundwater resources affected domestic water supply?
10 How have these changes affected pito brewing?
11 How have these changes affected basket weaving?
12 How have these changes affected pottery?
13 How have these changes affected Shea butter production?
14 Coping/Adaptation
15 Describe the ways by which you are coping with the changes in groundwater resources in terms of quantity for dry season farming
16 Describe the ways by which you are coping with the changes in groundwater resources in terms of quality for dry season farming
17 Describe the ways by which you are coping with the changes in groundwater resources in terms of storage for dry season farming
18 Describe the ways by which you are coping with the changes in groundwater resources (quantity, quality and storage) for dry animal rearing season farming
19 Describe the ways by which you are coping with the changes in groundwater resources (quantity, quality and storage) for pito brewing
20 Describe the ways by which you are coping with the changes in groundwater resources (quantity, quality and storage) for pottery
21 Describe the ways by which you are coping with the changes in groundwater resources (quantity, quality and storage) for shea butter production
22 Describe the ways by which you are coping with the changes in groundwater resources (quantity, quality and storage) for basketry
23 What measures have been put in place by the community to address the challenges associated with groundwater resources
24 What measures have been introduced by the government to address the challenges associated with groundwater resources
25 What measures have been introduced by the civil society organizations to address the challenges associated with groundwater resources

Issues with regards to water for drinking purposes

Local situation	**Explanation**
Number of boreholes in the community now compared to the past	
How reliable/functional are these boreholes in your community	
Are there some boreholes that dry up now which used not to dry up in the past	
Are the boreholes usually crowded	
Quantity of water you use in a day (number of buckets, basin or jerry cans	
Minutes do you spend to get to the source of water	
Distance covered influence your use of water	
Factors that influence the quantity of water used per day/week	
Describe the quantity of water used in the dry season	
Changes in the ease with which water is pumped manually now and in 30 years ago	

Local situation	Explanation
Changes in the ease with which water is pumped manually in the dry season and in the rainy season	
Reasons for the changes in seasonal pumping out of water	
Changes in the quality of water from boreholes for the past 30 years	

2. **THIS INFORMATION/QUESTIONNAIRES/INTERVIEW GUIDE BELOW IS MEANT TO PROVIDE INFORMATION FOR THE STUDY OF THE TOPIC:INSTITUTIONS, GROUNDWATER RESOURCES AND CLIMATE CHANGE ADAPTATION IN NORTHERN GHANA. THIS IS PART OF A DOCTORAL RESEARCH BY**

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Institutions and their nature

Laws

1 Mention any national (government) laws that regulate the groundwater
2 How did you get to know about these laws?
3 What specific areas of groundwater resource do these laws talk about?
4 Which specific national law on (ground) water talks about climate change and adaptation?
5 What key areas of climate change adaptation (recharge, discharge, demand, storage, quality) are considered in this law?
6 What laws from the district assembly or the regional council do you know that regulate the groundwater that you use?
7 How did you get to know about these laws?
8 What specific areas of groundwater do these local or by-laws talk about (recharge, discharge, demand, storage, quality)?

Policies

1. What national policy do you know about the groundwater in your community
2. What key areas of groundwater does this policy address?
3. What climate change adaptation options (discharge, quality, demand, storage and abstract) are considered in this policy regarding groundwater?
4. What projects from the district assembly exist in your community about groundwater for drinking?
5. Do these projects on groundwater relate to climate change adaptation in the areas of discharge?
6. Do these projects on groundwater relate to climate change adaptation in the areas of quality?
7. Do these projects on groundwater relate to climate change adaptation in the areas of abstraction?
8. Do these projects on groundwater relate to climate change adaptation in the areas of demand?

9. Do these projects on groundwater relate to climate change adaptation in the areas of storage?
10. What projects from the district assembly exist in your community about groundwater for irrigation?
11. Which aspect of irrigation do these projects address?
12. What projects of NGOs do you see in your community that has to do with groundwater for drinking?
13. What projects from the NGOs do you see in your community that has to do with groundwater for irrigation?
9 Which aspect of irrigation do these project focus on?

Administration

1 Do you receive officials from the national level who come to the community regarding the groundwater?
2 Do you receive officials from the regional council or district assembly who come to the community regarding the groundwater?
3 What work do they exactly come to do?
4 Do you have water users association in your community?
5 Do you have groups like WATSAN in the community?
6 Is there an association for those who go into dry season farming?
7 Informal law (customary arrangement)
8 Who owns the groundwater in the community?
9 Can anybody use the groundwater in the community?
10 What are the ways by which you can get land to drill for groundwater?
11 What process do you need to go through before you start digging for water and then farm?
12 Is there a guide that determine the location of wells or boreholes
13 Mention any taboos about groundwater?
14 Mention any norms about groundwater?
15 What punishment is given to people who disobey customs about groundwater use
16 Who take decisions about the use of groundwater in the community and who participate in making those decisions?
17 Who monitor the use of groundwater in the community?
18 What environmental practices are undertaken to conserve/keep the groundwater?
19 What environmental practices are undertaken to protect the groundwater?
20 How do you protect the vegetation or trees near the groundwater source?
21 How do you clear the land near these places
22 How to you dispose waste in these places near groundwater
23 Mention any associations or committees in this community that are formed to monitor and activities relating to the use of groundwater
24 What are the various functions of these associations or committees?

Institutional Performances

Quality

1. Describe the quality of the groundwater you use for cooking, drinking and washing?
2. Do you feel sick after drinking water?
3. Describe the quality of the groundwater that you use for irrigation.

4. Does the quality of the water affect the growth and taste of your vegetables?
5. What practices have you adopted to protect groundwater areas in the community?
6. How do you manage domestic waste near groundwater sources?
7. How do you manage agricultural waste near groundwater sources?
8. Do you burn bush near groundwater sources?
9. Do you cut down trees near groundwater sources?
10. Do you intentionally plant trees near surface/groundwater sources?
11. Are there taboos, norms that talk about waste treatment near water bodies?
12. Are there taboos that talk about how groundwater should be protected?
13. Are there taboos that forbid bush burning or felling of trees near groundwater sources?

Recharge

1. Where do you think the water in the ground comes from?
2. Are the measures or projects that deliberately increase the level of groundwater?

Storage

1 By what means are you able to tell the quantity of water stored beneath the ground as groundwater?
2 Do you think the taboos, norms, customary laws are able to regulate the supply and use of groundwater?
3 What are the gaps or the things that these taboos, norms and customary laws are not able to do?

Discharge

1 Do you think the groundwater contribute to the water in the Atankwidi river?
2 Do you think the Atankwidi river supply the ground with water

Demand

1 How much do you pay for the water at the boreholes and wells for use at home?
2 How much do you pay for the water at the boreholes and wells for dry season farming?
3 Is there any law or taboo that dictates how much groundwater you can fetch from any groundwater source for domestic use?
4 Is there any law or taboo that dictates how much groundwater you can fetch from any groundwater source for dry season farming?
5 Is there any law that spells how that you must use both groundwater and surface water at the same time?

Catchment or community/village

1. When a new policy or project about groundwater resources focusing on climate change adaptation is introduced, what challenges does it encounter?
2. What challenges do the laws face in their quest to regulate climate change adaptation especially in the water sector?
3. What administrative hiccups exist in attempt to regulate climate change adaptation especially in the water sector
4. What challenges do the local customs face in regulating climate change adaptation in the country especially in the water sector?

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Groundwater resources/governance

Key informants (Chiefs, elders, well drillers)

1. Do you have groundwater resources in your community (Atankwidi)?
2. What is the geographic boundary of the groundwater in your community?
3. What criteria do you use to delineate the groundwater boundary?
4. What indicators or landmarks define the groundwater boundaries?
5. Can families or clans own groundwater resources?
6. Are the groundwater resources communally own?
7. What are the resource units (things that sit on the ground above) of the groundwater?
8. How often are these resource units replaced or what are is the growth rate of these?
9. What economic value do these resource units offer to the community?
10. Mention the rules that govern the groundwater resources.
11. Can individuals who use the groundwater make their own rules and if so what are these rules?
12. Are there government organisations that work with you regarding the use of the groundwater resources?
13. Are there government organisations that work with you regarding the use of the groundwater resources?
14. Describe the network structure among the users of the groundwater resources
15. Is there any specific time when users can use the groundwater and the associated resource units?
16. What rules define the specific place where groundwater and other resource units can be extracted?
17. Is there any rule that defines the type of technology to use in abstracting the water and the resource units?
18. Who makes the rules concerning the groundwater?
19. Is there an association or club that manages the groundwater?
20. In what ways do the users of the water contribute to changing the rules?
21. Who monitors the groundwater resources?
22. In what ways are the monitors accountable to the appropriators of the water at catchment?
23. What sanctions are used against violators of the use of the water?
24. In what ways are groundwater conflicts resolved in the community (individual, chief palace or court)?
25. Is there any influence from the national government or government water agencies on the institutions created by appropriators?

26. Are the appropriators of groundwater put into sections/groups?
27. Is there an over aching organisation for managing groundwater use in the catchment?
28. How many people use the groundwater resources?
29. What are the socioeconomic attributes of the users?
30. Give the history about the use of groundwater in this community
31. How is information shared among the users groundwater resources
32. Describe how issues regarding groundwater resources are deliberated upon.
33. What are the ways by which the people have invested in the groundwater resources
34. How do users of groundwater resources self organise themselves?
35. What kind of activities promote network among users of groundwater resources
36. How can users of groundwater lobby for these resources?

APPENDIX B

COMMUNITY WATER AND SANITATION AGENCY (CWSA) INTERVIEW GUIDE

4. **THIS INFORMATION/QUESTIONNAIRES/INTERVIEW GUIDE BELOW IS MEANT TO PROVIDE INFORMATION FOR THE STUDY OF THE TOPIC:INSTITUTIONS, GROUNDWATER RESOURCES AND CLIMATE CHANGE ADAPTATION IN NORTHERN GHANA. THIS IS PART OF A DOCTORAL RESEARCH BY**

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Quality

1. Explain the quality (nature) of the groundwater for domestic use?
2. Are there changes in the age and origin of groundwater at specific locations within the catchment?
3. What measures have been put in place for the assessment of aquifer pollution vulnerability?
4. What practices have you adopted to protect groundwater areas in the local communities?
5. How is domestic and agricultural waste near groundwater sources being managed in the communities?
6. Are there measures that promote the planting of trees near surface/groundwater sources?
7. Are there taboos that talk about how groundwater should be protected?
8. Are there taboos that forbid bush burning or felling of trees near groundwater sources?

Recharge

1 What are the sources of recharge for the aquifers in the Atankwidi catchment
2 Which areas within the catchment are important for groundwater supply?
3 What infrastructure development or landscape modification have been intentionally undertaken to enhance groundwater recharge?

Hand pump service level indicators (National Standards)

Local situation	**Explanation**
Number of boreholes in the community now compared to the past	
How reliable/functional are these boreholes in your community	
Are there some boreholes that dry up now which used not to dry up in the past	
Are the boreholes usually crowded	
Quantity of water you use in a day (number of buckets, basin or jerry cans	

11. Appendixes

Local situation	Explanation
Minutes do you spend to get to the source of water	
Distance covered influence your use of water	
Factors that influence the quantity of water used per day/week	
What is the quantity of water used during the season	

Demand

1. Are there groundwater extraction charges in the catchment?
2. What measures have been put in place to ensure the management of groundwater in conjunction with surface water?
3. For instance are there measures that allow the use of groundwater reservoirs as storage space for surplus surface water flows during periods of abundant supply for use during periods of surface water scarcity?
4. To what extent have the water laws promoted the management of groundwater demand in the wake of climate change
5. To what extent have the water policies promoted the management of groundwater demand in the wake of climate change
6. To what extent have water administrators promoted the management of groundwater demand in the wake of climate cha

APPENDIX C

THE FOUR DISTRICTS/MUNICIPAL ASSEMBLIES

5. **THIS INFORMATION/QUESTIONNAIRES/INTERVIEW GUIDE BELOW IS MEANT TO PROVIDE INFORMATION FOR THE STUDY OF THE TOPIC: INSTITUTIONS, GROUNDWATER RESOURCES AND CLIMATE CHANGE ADAPTATION IN NORTHERN GHANA. THIS IS PART OF A DOCTORAL RESEARCH BY**

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Institutions and their nature

Laws

1. In what capacity has the District Assembly to make their own climate change by-laws regarding (groundwater) resources?
2. What is the source of authority or power of the District Assembly to execute such functions?
3. Who make such climate change adaptation by-laws at the District level?
4. Mention some of these by-laws that deal with climate change and (ground) water resources.
5. How are these laws implemented at the District level?
6. How are these laws implemented at the community/catchment level?
7. Describe the ways by which these laws regarding climate change adaptation of groundwater focus on recharge?
8. Describe the ways by which these laws regarding climate change adaptation of groundwater focus on quality?
9. Describe the ways by which these laws regarding climate change adaptation of groundwater focus on discharge?
10. Describe the ways by which these laws regarding climate change adaptation of groundwater focus on the demand?
11. Describe the ways by which these laws regarding climate change adaptation of groundwater focus on the storage?
12. What relevant or relating laws at the district level help address climate change and water resources?
13. How are national laws about climate change implemented at the district level?

Policies

1. Mention some climate change projects/policies relating to water resources at the district level?

2. What specific components of (ground-user rights, waste discharge licensing, sanctions, catchment planning, land zoning, monitoring etc.) water resources do these project/policies address?
3. How do these policies regarding climate change adaptation of groundwater focus on recharge
4. How do these policies regarding climate change adaptation of groundwater focus on discharge?
5. How these policies regarding climate change adaptation of groundwater focus on quality
6. How do these policies regarding climate change adaptation of groundwater focus on storage?
7. How do these policies regarding climate change adaptation of groundwater focus on demand?
8. What are the ways by which these policies are implemented in at the community/catchment level?
9. What nature do they take when they are being implemented at the community/catchment level?
10. What is done to ensure that these laws are actually implemented at the local level?

Administration

1. Which section in the District Assembly is responsible for climate change issues especially those relating to ground(water) resources
2. What is the composition of this section or unit?
3. What are the functions of these personnel?
4. In what form do climate change issues at the district level handled/administered?
5. What avenues are created for the personnel in charge of climate change to meet with the local people regarding climate change?
6. What is the level of local people participation in climate change issues at both the district and community levels
7. How often do these climate change personnel at the district level meet with the local people to discuss climate change issues?

Informal Customary law

1. In what ways does the District Assembly recognise the place of local customs regarding climate change and adaptation at the district level?
2. How these local customs are captured in climate change issues at the district level?
3. Mention some of these local customs that support climate change adaptation efforts?
4. What supporting role does the district assembly give to these local customs at the community/catchment level?
5. How does the district assembly work with the enforcers of these norms at the community level?
6. What is the relationship between the local customs and the district bye-laws?
7. What is being done to maintain local customs/laws in relation to climate change adaptation?

Relationship between the institutions at the national level and those at the local level levels

1. How do local institutions influence national institutions regarding groundwater adaptation to climate change?
2. How do national institutions influence local institutions regarding groundwater adaptation to climate change?
3. Under what circumstances can institutions at both levels come into existence at the same time regarding climate change adaptation with respect to groundwater resources?

4. How much power/authority do the institutions at both local level and national level in the area of groundwater resources adaptation to climate change?
5. In terms of hierarchy, are the institutions at the national level necessarily at the top?

APPENDIX D

ENVIRONMENTAL PROTECTION AGENCY (EPA)

6. THIS INFORMATION/QUESTIONNAIRES/INTERVIEW GUIDE BELOW IS MEANT TO PROVIDE INFORMATION FOR THE STUDY OF THE TOPIC:INSTITUTIONS, GROUNDWATER RESOURCES AND CLIMATE CHANGE ADAPTATION IN NORTHERN GHANA. THIS IS PART OF A DOCTORAL RESEARCH BY

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Collaborative definition of climate change stakeholders, climate change scenarios and adaptation measures

1. Who constitute climate change experts or knowledge holders in Ghana?
2. Which group of scientific (social and natural) experts produced the national documents on climate change?
3. Which group of local/community level experts participated in the production of the national climate change documents?
4. What criteria were used to define these experts?
5. What measures were adopted to promote collaboration among these experts in defining climate change scenarios in Ghana?
6. What collaborative measures were carried out among these experts in the process of defining climate change adaptation measures?

Climate knowledge co-production (content)

1. How much of natural science knowledge is captured in the national climate change adaptation documents?
2. How much of social science knowledge is captured in the national climate change adaptation documents
3. How much of local knowledge/traditional knowledge/indigenous knowledge is captured in the national climate change adaptation document?
4. What is done to validate local knowledge in order to make it generally acceptable in the country?
5. What conscious efforts are being carried out to synthesize all knowledges about climate change as part of national climate adaptation efforts?
6. What knowledge platforms exist in the country for the mobilization of both local and scientific knowledge about climate change/adaptation?

Joint analysis and evaluation of knowledges (local, social and natural sciences)

1. What platforms are created to jointly analyse all knowledges about climate change adaptation in Ghana?
2. Who participate in the process of analysing and evaluating these knowledges?
3. What criteria guide in the
4. At what level of decision making are the analysis and evaluation of climate change knowledge about adaptation undertaken?

Climate knowledge distribution/dissemination/consumption (media)

1. How frequent are climate change awareness campaigns carried out throughout the country?
2. What form do these campaigns take (durbars/ seminars/workshops/conferences)?
3. What are the media (radio, TV, informal education programmes etc.) through which climate change adaptation information in the country is disseminated?
4. What other platforms are created for the dissemination of this information?
5. What languages are used to communicate this information?
6. How much of local knowledge about climate change is included in the school curriculum and non-formal training programmes?

Composition of educators or awareness creators

1. Who are the carriers or conveyers of this information?
2. How will you grade the level of knowledge of these educators about both scientific and local knowledge of climate change?

Low	Average	High

3. Have they been trained on how to blend both knowledges in climate change awareness creation?

3b. Impact of weak relationship

1. In what ways is this weak relationship between both knowledges affecting climate change awareness creation in the water sector?
2. How has this relationship affected groundwater resources in particular in these areas?
    - Groundwater recharge
    - Discharge
    - Storage
    - Demand
    - Quality

Way forward

In what ways can climate change/water laws contribute to the promoting the following?

1. Collaborative definition of climate change stakeholders, climate change scenarios and adaptation measures?
2. Climate knowledge co-production (content)?
3. Joint analysis and evaluation of knowledges (local, social and natural sciences?
4. Climate knowledge distribution/dissemination/consumption (media)?

In what ways can climate change policies or projects/water laws contribute to the promoting the following:

1. Collaborative definition of climate change stakeholders, climate change scenarios and adaptation measures?
2. Climate knowledge co-production (content)?
3. Joint analysis and evaluation of knowledges (local, social and natural sciences?
4. Climate knowledge distribution/dissemination/consumption (media)?

In what ways can climate agencies, bodies or administrators contribute to the promoting the following?

1. Collaborative definition of climate change stakeholders, climate change scenarios and adaptation measures
2. Climate knowledge co-production (content)
3. Joint analysis and evaluation of knowledges (local, social and natural sciences
4. Climate knowledge distribution/dissemination/consumption (media)

In what ways can local norms and taboos contribute to promoting the following?

1. Collaborative definition of climate change stakeholders, climate change scenarios and adaptation measures?
2. Climate knowledge co-production (content)?
3. Joint analysis and evaluation of knowledges (local, social and natural sciences?
4. Climate knowledge distribution/dissemination/consumption (media)?

APPENDIX E

WATER RESOURCES COMMISSION(WRC)

7. **THIS INFORMATION/QUESTIONNAIRES/INTERVIEW GUIDE BELOW IS MEANT TO PROVIDE INFORMATION FOR THE STUDY OF THE TOPIC:INSTITUTIONS, GROUNDWATER RESOURCES AND CLIMATE CHANGE ADAPTATION IN NORTHERN. THIS IS PART OF A DOCTORAL RESEARCH BY**

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Groundwater recharge

1. What are the sources of recharge for the aquifers in the Atankwidi catchment
2. Which areas within the catchment are important for groundwater supply?
3. What infrastructure development or landscape modification have been intentionally undertaken to enhance groundwater recharge?
4. How much of groundwater recharge issues have been captured in the country's climate change adaptation policies?
5. To what extent have the water laws regulated groundwater recharge?

Quality

1. Explain the quality (nature) of the groundwater for domestic use?
2. Explain the quality (nature) of the groundwater for irrigational purpose?
3. Which aquifers within the catchment are more vulnerable hydro/geologically?
4. Are there issues of land subsidence in the catchment?
5. Are there changes in the age and origin of groundwater at specific locations within the catchment?
6. What measures have been put in place for the assessment of aquifer pollution vulnerability?
7. What measures have been put in place for the mapping of groundwater pollution hazards?
8. What environmental practices have been adopted at the catchment level to protect groundwater quality?
9. What is the level of influence of water laws on groundwater quality in the wake of climate change?
10. What is the level of influence of water administrators on groundwater quality in the wake of climate change
11. What is the level of influence of water policies on groundwater quality in the wake of climate change

Discharge

1. Do the aquifer systems discharge water to the land surface, rivers, lakes, wetlands?
2. At what time in the does this happen?
3. What changes exist about the base flow?

4. What efforts are being made to increase groundwater availability through the control of discharge?
5. To what extent have the water laws, policies and administration regulated the discharge of groundwater in the wake of climate change

Demand

1. What constitute the bulk of demand for groundwater in the catchment?
2. Are there groundwater extraction charges in the catchment?
3. What measures have been put in place to ensure the management of groundwater in conjunction with surface water?
4. For instance are there measures that allow the use of groundwater reservoirs as storage space for surplus surface water flows during periods of abundant supply for use during periods of surface water scarcity?
5. To what extent have the water laws promoted the management of groundwater demand in the wake of climate change
6. To what extent have the water policies promoted the management of groundwater demand in the wake of climate change
7. To what extent have water administrators promoted the management of groundwater demand in the wake of climate change?

Storage

1 Are there monitoring network of wells in the catchment for defining groundwater levels?
2 What is being done to allow for the calculation of the approximate amount of water stored in the catchment at the end of the water year?
3 To what extent has the water laws ensured that groundwater is properly stored as part of climate change adaptation measures?
4 To what extent has the water policies ensured that groundwater is properly stored as part of climate change adaptation measures
5 To what extent have the water administrators ensured that groundwater is properly stored as part of climate change adaptation measures

Challenges

1. What policy challenges exist in regulating climate change adaptation in the country especially in the water sector?
2. What challenges do the laws face in their quest to regulate climate change adaptation especially in the water sector?
3. What administrative hiccups exist in attempt to regulate climate change adaptation especially in the water sector
4. What challenges do the local customs face in regulating climate change adaptation in the country especially in the water sector?

APPENDIX F

LECTURERS: UNIVERSITY FOR DEVELOPMENT STUDIES

8. THIS INFORMATION/QUESTIONNAIRES/INTERVIEW GUIDE BELOW IS MEANT TO PROVIDE INFORMATION FOR THE STUDY OF THE TOPIC: INSTITUTIONS, GROUNDWATER RESOURCES AND CLIMATE CHANGE ADAPTATION IN NORTHERN GHANA. THIS IS PART OF A DOCTORAL RESEARCH BY

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Local knowledge and climate change awareness

1 Who constitute climate change experts or knowledge holders in Ghana?
2 Which group of scientific (social and natural) experts produced the national documents on climate change?
3 Which group of local/community level experts participated in the production of the national climate change documents?
4 What criteria were used to define these experts?
5 What measures were adopted to promote collaboration among these experts in defining climate change scenarios in Ghana?
6 What collaborative measures were carried out among these experts in the process of defining climate change adaptation measures?

Climate knowledge co-production (content)

1 How much of natural science knowledge is captured in the national climate change adaptation documents?
2 How much of social science knowledge is captured in the national climate change adaptation documents
3 How much of local knowledge/traditional knowledge/indigenous knowledge is captured in the national climate change adaptation document?
4 What is done to validate local knowledge in order to make it generally acceptable in the country?
5 What conscious efforts are being carried out to synthesize all knowledges about climate change as part of national climate adaptation efforts?
6 What knowledge platforms exist in the country for the mobilization of both local and scientific knowledge about climate change/adaptation?

Joint analysis and evaluation of knowledges (local, social and natural sciences)

1 What platforms are created to jointly analyse all knowledges about climate change adaptation in Ghana?
2 Who participate in the process of analysing and evaluating these knowledges?
3 What criteria guide in the
4 At what level of decision making are the analysis and evaluation of climate change knowledge about adaptation undertaken?
5 Climate knowledge distribution/dissemination/consumption (media)

6 How frequent are climate change awareness campaigns carried out throughout the country?
7 What form do these campaigns take (durbars/ seminars/workshops/conferences)?
7 What are the media (radio, TV, informal education programmes etc.) through which climate change adaptation information in the country is disseminated?
8 What other platforms are created for the dissemination of this information?
9 What languages are used to communicate this information?
10 How much of local knowledge about climate change is included in the school curriculum and non-formal training programmes?

Composition of educators or awareness creators

1 Who are the carriers or conveyers of this information?
2 How will you grade the level of knowledge of these educators about both scientific and local knowledge of climate change?

11 Low	12 Average	13 High

3 Have they been trained on how to blend both knowledges in climate change awareness creation?
4 Impact of weak relationship
5 In what ways is this weak relationship between both knowledges affecting climate change awareness creation in the water sector?
6 How has this relationship affected groundwater resources in particular in these areas?
- Groundwater recharge
- Discharge
- Storage
- Demand
- Quality

Way forward

In what ways can climate change/water laws contribute to the promoting the following?

1 Collaborative definition of climate change stakeholders, climate change scenarios and adaptation measures?
2 Climate knowledge co-production (content)?
3 Joint analysis and evaluation of knowledges (local, social and natural sciences?
4 Climate knowledge distribution/dissemination/consumption (media)?

In what ways can climate change policies or projects/water laws contribute to the promoting the following:

1 Collaborative definition of climate change stakeholders, climate change scenarios and adaptation measures?
2 Climate knowledge co-production (content)?
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4 Climate knowledge distribution/dissemination/consumption (media)?

In what ways can climate agencies, bodies or administrators contribute to the promoting the following?

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In what ways can local norms and taboos contribute to promoting the following?

1. Collaborative definition of climate change stakeholders, climate change scenarios and adaptation measures?
2. Climate knowledge co-production (content)?
3. Joint analysis and evaluation of knowledges (local, social and natural sciences?
4. Climate knowledge distribution/dissemination/consumption (media)?

APPENDIX G

SAVANNA RESEARCH INSTITUTE (SARI)

9. THIS INFORMATION/QUESTIONNAIRES/INTERVIEW GUIDE BELOW IS MEANT TO PROVIDE INFORMATION FOR THE STUDY OF THE TOPIC:INSTITUTIONS, GROUNDWATER RESOURCES AND CLIMATE CHANGE ADAPTATION IN NORTHERN GHANA. THIS IS PART OF A DOCTORAL RESEARCH BY

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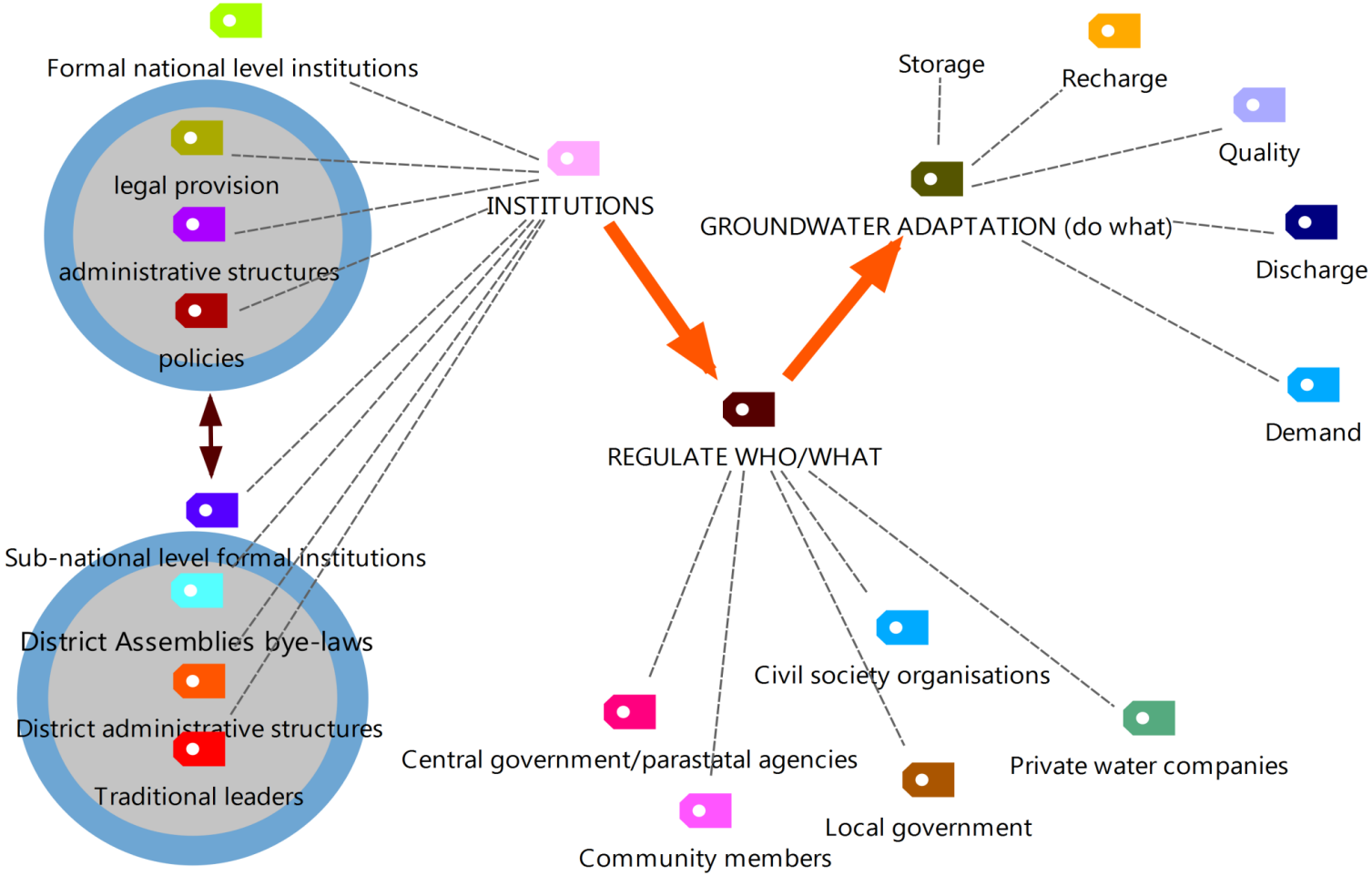
Climate change impacts on livelihood activities

1 For the past 20 to 30 years, did you notice any changes in the pattern of rainfall the Atankwidi catchment?
2 Describe the changes you have observed with regards to the change in pattern of rainfall.
3 For the past 20 to 30 years, did you notice any changes in temperature in this catchment?
4 Describe the changes you observed regarding this changes in this time period.
5 Name the activities that depend on groundwater resources in the Atankwidi catchment?
6 How has the change in rainfall pattern affected the availability of groundwater?
7 How has the situation in question 6 influenced the following the following in recent time?
   - Depth of wells
   - Number of minutes used to draw water to irrigate
   - Number of distance covered to get this water
   - Number of wells needed to irrigate a given plot of land
8 How has the change in rainfall pattern affected water quality for irrigational activities?
9 What limitations have the available quantity of water posed to other livelihood activities in the catchment?
10 Are there some locations in the past with wells yielding water and are now dry even though the depths of these wells remain the same? What are the reasons for this situation?
11 Do you think the people have over pumped the water or the water underground
12 Do you think the change in rainfall has affected recharge resulting in the situation in question 10?
13 Quality of water
14 Quantity of water

APPENDIX H

Other Supplementary texts/ materials



Mapping groundwater institutions and their functions for adaptation

In der Schriftenreihe „Beiträge zu Abfallwirtschaft/Altlasten“ des Institutes für Abfall- und Kreislaufwirtschaft sind folgende Bände erschienen:

		Preis EUR zzgl. Porto und Versand
	Erstes Abfall- und Altlastenkolloquium – Altholzseminar	vergriffen
Band 1	Möglichkeiten und Grenzen der Verbrennung von landwirtschaft-lichen Reststoffen und Nebenprodukten für die Kalkproduktion	vergriffen
Band 2	Steuerungsmöglichkeiten abfallwirtschaftlicher Gebühren	vergriffen
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Band 13	Stoffstrommanagement für Abfälle aus Haushalten	vergriffen
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Band 19	Anaerobe biologische Abfallbehandlung Grundlagen – Probleme – Kosten	begrenzt kostenlos
Band 20	Thermische Abfallbehandlung 2002	vergriffen
Band 21	Einfluss der getrennten Sammlung von graphischem und Verpackungspapier auf den Schadstoffgehalt im Altpapier am Beispiel von Pentachlorphenol und Polycyclischen Aromatischen Kohlenwasserstoffen	vergriffen
Band 22	Die „ökologische Wertigkeit der Entsorgung“ unter Berücksichtigung des Transportaspektes am Beispiel Altkühlgeräte im Land Brandenburg	vergriffen
Band 23	Endokrin wirksame Substanzen in Abwasser und Klärschlamm Neueste Ergebnisse aus Wissenschaft und Technik	begrenzt kostenlos
Band 24	Ökologische Bilanzierung von Verwertungsverfahren für Trockenbatterien	vergriffen
Band 25	Untersuchungen zur Verdichtung von Restabfall mittels Kompaktoren	vergriffen
Band 26	Ein neues Probenahmemodell für heterogene Stoffsysteme	begrenzt kostenlos
Band 27	Schwermetalle in Haushaltsabfällen – Potenzial, Verteilung und Steuerungsmöglichkeiten durch Aufbereitung	vergriffen
Band 28	Third International Conference on Water Resources and Environment Research (3 Bände)	vergriffen
Band 29	Mikrobielles Abbaupotential im Untergrund	begrenzt kostenlos
Band 30	Endokrin aktive Stoffe im Klärschlamm	begrenzt kostenlos
Band 31	First European Conference on MTBE	vergriffen
Band 32	Anaerobe biologische Abfallbehandlung – Neue Entwicklungen –	vergriffen
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Band 34	Verhalten der endokrin wirksamen Substanz Bisphenol A bei der kommunalen Abwasserentsorgung	26,00
Band 35	Trockene Tonne – Neue Wege und Chancen einer gezielten stofflichen Verwertung	15,00
Band 36	Comparative Evaluation of Life Cycle	10,00

	Assessment Models for Solid Waste Management	
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Band 57	Anaerobe biologische Abfallbehandlung -Neue Tendenzen in der Biogastechnologie	30,00
Band 58	Leitfaden Natürliche Schadstoffminderung bei Teerölaltlasten. KORA-Themenverbund 2	begrenzt kostenfrei
Band 59	VON NANO-TECH BIS MEGA SITES. Forschung am IAA	30,00
Band 60	II. EBS – Analytik Workshop - Qualitätssicherung und Inputkontrolle -	30,00
Band 61	4. Symposium Endokrin aktive Stoffe in Abwasser, Klärschlamm und Abfällen	30,00
Band 62	Brennpunkt ElektroG Umsetzung - Defizite - Notwendigkeiten	30,00
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Band 64	Untersuchungen zur Quellstärke verschiedener Abfallstoffe	30,00
Band 65	15. Fachtagung Thermische Abfallbehandlung 2010	39,00
Band 66	III. EBS – Analytik Workshop	30,00
Band 67	Anaerobe biologische Abfallbehandlung - Aktuelle Tendenzen, Co-Vergärung und Wirtschaftlichkeit -	30,00
Band 68	Untersuchungen zum anaeroben Abbau proteinreicher Reststoffe	30,00
Band 69	Schwermetalle aus Elektroaltgeräten und Batterien im kommunalen Restabfall	30,00
Band 70	German-Vietnamese Platform for Efficient Urban Water Management	kostenlos als CD erhältlich
Band 71	Siloxane in mechanisch-biologischen Abfallbehandlungsanlagen	30,00
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Band 75	Bereitstellung von bioabfall für die BtL-Produktion duch eine nassmechanische Aufbereitung	30,00

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Band 80	SILOXANE - Siliziumorganische Verbindungen in der Abfallwirtschaft	30,00
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Bestelladresse: **Forum für Abfallwirtschaft und Altlasten e. V.**

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