PARTICIPATORY GIS FOR INLAND WATER CADASTRE:

CASE OF DENSUANO, KOFORIDUA, GHANA

BY

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DECLARATION

I hereby declare that this submission is my own work towards the award of Master of Science and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the university, except where due acknowledgement has been made in the text.

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ABSTRACT

Water bodies in Ghana are utilized for various purposes including drinking, irrigation, transportation and hydropower generation just to mention a few. Stakeholders who utilize these water bodies for different activities hold diverse rights and relating interests seen in the form of responsibilities, restrictions and privileges. In Ghana, one major challenge that threatens management and administration of these rights is the absence of a complete and comprehensive information system that records the spatial extents and terms on use rights for stakeholders who hold both statutory and customary water rights. This study aims at exploring participatory GIS tools to capture and record the various interests related to inland water resources in Ghana and to develop a prototype information system that facilitates the visualization and analysis of the identified interests. Participatory sketch mapping, interviews and focus group discussions were used to capture and record indigenous knowledge on water rights. Two participatory mapping exercises were conducted; for stakeholders at Densuano in Koforidua, a community in the Densu River Basin. The mapping exercise engaged stakeholders upstream and the other for stakeholders at the downstream portion of the water resource. A GPS survey of selected points was used to validate the accuracy of the mapping exercise. ArcGIS and Map Guide Maestro were used to develop a prototype cadastral system for the resource. The study shows that the local community members have rich knowledge in water rights. The stakeholders were able to use the participatory mapping tools after a short training and the maps produced through the participatory exercise shows that the stakeholders have varying use rights on water. Participatory mapping ensured maximum community participation and involvement, urging the various stakeholders to identify and come to a consensus on the various physical boundaries associated to particular rights and underlining responsibilities, privileges, and restrictions. The prototype created provides a good interface for visualizing the physical extent of varying customary and statutory rights and the restrictions on water usage. The interface provides users the opportunity to conduct spatial analysis and therefore can aid in the management and administration of water at Densuano.

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God Bless You!

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ACRONYMS

CTA	Technical Center for Agricultural and Rural Cooperation
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
FIG	International Federation of Surveyors
GIS	Geographical Information Systems
GIT	Geospatial Information Technologies
GPS	Global Positioning System
GUI	Graphical User Interface
GWCL	Ghana Water Company Limited
IDS	Institute of Development Studies
IIED	International Institute for Environment and Development
IK	Indigenous Knowledge
ISK	Indigenous Spatial Knowledge
IWRM	Integrated Water Resources Management
MLNR	Ministry of Lands and Natural Resources
MWRWH	Ministry of Water Resources, Works and Housing
OECD	Organisation for Economic Cooperation and Development
PLA	Participatory Learning and Action
PGIS	Participatory Geographical Information Systems
RMSE	Root Mean Square Error
SDI	Spatial Data Infrastructure

SIDA	Swedish International Development Cooperation Agency
WRC	Water Resource Commission
UNCLOS	United Nations Convention on the Law of the Sea
UN	United Nations

CHAPTER ONE

INTRODUCTION

1.1 Background

Water is very critical to the existence of man as it plays a vital role in the natural environment, serving as a habitat for animals as well as plant life (Opoku-Agyeman, 2005). Ghana is blessed with a myriad of water resources, bordered in the south by the Gulf of Guinea and possessing a number of inland water resources that cover a significant land area (MWRWH, 2007). Inland water resources are resources within the boundaries of a particular country, under the sole jurisdiction of that state (FAO,2005). In Ghana water resources comprise ground water resources and surface water found within the boundaries of Ghana (WRC, 2011). These water resources are utilized in different ways. Stakeholders hold rights to conduct activities ranging from agriculture, transportation, irrigation, damming, recreation, hydropower, underwater wood harvesting, mining and just to mention a few. The diverse and competitive nature of rights as held by different stakeholders who conduct these various activities, have facilitated the need to adopt a plan towards inland water management and administration in countries all over the world (Global Water Partnership, 2012). .

Over the years, many African countries have continuously suffered setbacks in the management of natural resources, including water resources. In Africa 48% of conflicts during the first decade of this century arose as a result of conflicts on natural resource ownership, including conflict on water resources(Wily, 2009). The immediate drivers of conflicts in natural resources are competition, tenure or ownership, and alienation or isolation from use. For example, whilst water becomes scarce in dry areas, conflicts over rights of access will arise where upstream rivers have been developed to retain, discharge or divert water and downstream communities are negatively affected (WRC, 2010). The lack of clear and stable water rights, weak regulations and enforcement has been a contributing factor to many conflicts over access and competition for water use (FIG, 2014) Water management is therefore not only important in managing and preempting future conflicts regarding the use of internal water resources but in ensuring the very existence and sustainability of these resources.

Countries like Armenia, Moldova, Azerbaijan and Uzbekistan have adopted the use of Inland Water Cadastral Systems comprising a spatial inventory on available data on water resources

as a successful tool towards the implementation of the IWRM plan (Global Water Partnership, 2012). The inland water cadastral systems have been adapted to primarily regulate activities in river basins through the capturing, recording, visualization and analyzes of various terms of interests in the basins. The "Ouagadougou Statement" expedited the need to adopt an Integrated Water Resources Management (IWRM) plan for managing water resources in West African countries (WRC, 2012). Drawing from this decision, water management and administration in Ghana has been guided by the IWRM plan. The plan primarily seeks to promote and foster water management and administration, while considering its immediate related resources. The WRC is mandated by WRC Act 552 of 1996 as the body responsible for the successful implementation of the IWRM plan. In the management and administration of water resources, the WRC asserts that one major challenge that hinders the implementation of the IWRM plan is the lack of regulation on the many activities in river basins, leading to catchment degradation and poor water quality and other related conflicts (WRC, 2012).

1.2 The Need for Inland Water Cadastre in Ghana

The term cadastre is used in land management to describe a record system which provides security of land tenure for the different classes of land right owners (FIG, 1995). Traditionally the term has not readily been used in connection with water resources (Binns et al, 2004). The diversity of the water resources, however, requires effective economic, social and environmental management and record keeping systems that is just as comprehensive as that on land (Williamson et al, 2010).

Record keeping on ownership on land in Ghana has evolved over time. Record keeping previously entailed orally passing on information regarding land ownership to interested parties. This resulted in creating a situation of "overlapping claims" and conflicts among neighbors, the underlining problems and conflicts emphasized the need for the recent phenomenon of land record keeping (Prah, 1997). Recording of rights orally in Ghana is not limited to land rights but water rights. In the oral recording of rights associated with water use there are also claims of overlapping rights. Conflicts and misunderstandings on land, which have warranted the need for the development of cadastral systems. These systems should capture the spatial extents of the rights, responsibilities, restrictions and privileges, which occur on water resources (Fowler & Treml, 2001).

Cadastres for the aquatic environments have been built due to the increasing awareness of the utility of spatial data in facilitating the management of future conflicts on aquatic resources (Williamson et al, 2010). A cadastre for aquatic environments captures the competing rights on tenure, data on boundaries of restricted zones, aquaculture farming activities and other undertakings on water resources as seen in Figure 1.

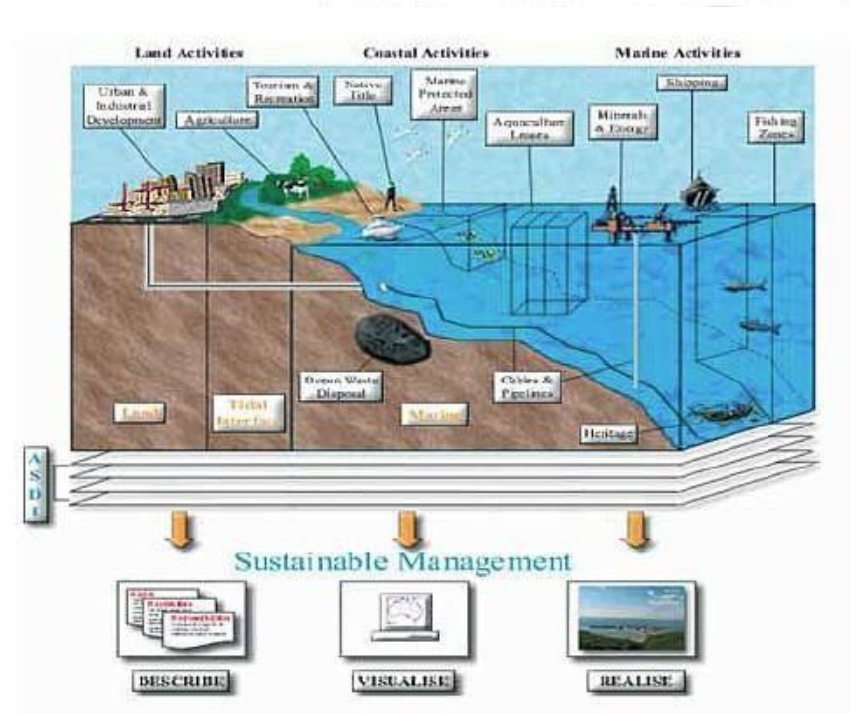


Figure 1: Cadastres for Aquatic Environments

Source: *(Williamson et al, 2010).*

As shown in Figure 1, the SDI for cadastres in aquatic environments are designed to systematically describe, visualize and realize the various right interests as captured in order to facilitate administration and management (Williamson et al, 2010). The components captured seek to allow for an orderly and comprehensive database of key attributes particular to different stakeholders in order to facilitate water administration and management and effectively represent all stakeholders (Williamson et al, 2010).

The WRC has a defined laid down process towards capturing and recording details on rights of permits as issued by the commission. However, apart from rights issued by the commission, other stakeholders hold recognized rights as approved by customary authorities. In facilitating the regulation of activities in river basins, details on permits obtained statutorily as well as those held by indigenes of a particular catchment area must all be effectively captured and recorded.

In advancing the management of Ghana's maritime waters, some attention has been paid to capturing the physical boundaries and rights regarding its use. However, with regards to inland water resources relatively less attention has been paid to the capture and record of physical boundaries and related ownership details particular to each resource (WRC, 2010). The current record keeping system allows for the rights, responsibilities, restrictions and privileges of recorded permits to be viewed in a water register published as a table (WRC 2012).The table has no link to spatial data regarding the specific boundaries on water bodies were rights are held making it increasingly difficult to enforce certain regulations. For example permits for activities such fish cage farming should not be granted if site is close to a commercial crop farming area (MWRWH, 2013). The absence of such spatial database makes it increasingly difficult to enforce such technical regulations.

It is worth noting that there are similar examples of conflicts and misunderstandings on water resources common to land resources that warrant the need for record keeping related to surveys, adjudication processes and the establishment of owner rights (Fowler & Treml, 2001). The (WRC,2012) acknowledges that a major challenge that hinders the implementation of the IWRM plan are the challenges in enforcing regulations related to the various activities in river basins leading to catchment degradation and poor water quality. Lack of a system to facilitate capturing recording, visualizing and analyzing the various ongoing activities on inland water resources makes it difficult to regulate activities taking place on water resources.

1.3 Problem Statement

The need for a comprehensive spatial and non-spatial system for capturing and recording water rights in Ghana is not a new consideration. Some research has been done in this direction. Boateng (2006) recommended that it is important, that coastal and marine space administration is given similar preference and attention received by land administration. The research laid emphasis on the need and the ensuing benefit of developing a cadastre for coastal and marine administration in Ghana, but does not delve into how to develop an inland water cadastre for the inland water management.

Dei (2011) evaluated the level of implementation and observance of regulations on water resources. The study considers the role policies and implementing institutions play in managing water resources and the adherence of stakeholders to rules and regulations associated with

water. The study recommended the development of a database of water resources with relating details of use rights of stakeholders as a facilitator of water administration.

Amamoo-Otchere (2010) also asserted that geospatial information available on inland water resources does not present spatial incongruities sufficiently, for the different and mutually opposing stakeholders of water resources to see the realities. The study maintains that community involvement through participatory mapping will contribute positively towards curbing rampant cases of encroachment, pollution and other related setbacks on water resources.

Various activities take place on inland water resources in Ghana such as fishing, transportation, damming water, drawing water for irrigation as well as tourism and recreational activities, only to mention a few. The different classes of users engaged in these activities have distinct form of rights, responsibilities, restrictions and privileges governing the use of the resource. Water rights are held either by statutory or customary authorization. Details of statutory rights like damming and hydropower generation are recorded and published in a table for viewing without spatial reference to the exact region of space where these rights are held. On the other hand, water rights held through customary practices such as drinking, fishing, washing, irrigation and religious practices are rarely captured in the water register as stakeholders are only required to voluntarily register their use of the resource with the District Assemblies. These rights are mostly stored mentally and passed on through oral narrations.

This research uses participatory GIS tools to identify and record these indigenous water rights and also creates an information system for storing, visualizing and analyzing the physical extents, rights, restrictions, responsibilities and privileges held through both statutory and customary systems.

1.4 Research Objective

This study makes use of participatory mapping methods to capture and record the various interests related to inland water resources in Ghana and to develop a prototype information system that facilitates the visualization and analysis of the identified interests.

The specific objectives are:

1. To analyse the existing system used to capture and record physical boundaries, rights, responsibilities, restrictions and privileges associated with inland water resources in Ghana.

2. To analyse whether or not participatory mapping could be used to capture and record indigenous knowledge on water rights.

3. To develop a prototype cadastral system for identifying capturing and recording interests of tenure inland water resources in Ghana.

4. To provide guidelines for implementing an inland water cadastre in Ghana.

1.5 Research Questions

1. How are physical boundaries, rights, responsibilities, restrictions and privileges associated to the use of inland water resources captured and managed in Ghana?

2. Can participatory mapping be used to record indigenous knowledge on water rights?

3. What cadastral system can be developed to define, capture and record interests of tenure governing inland water in Ghana?

4. What are the requirements for implementing inland water cadastre in Ghana?

1.6 Research Design and Methodology

This study uses a systematic approach to analyze the current system of administration and management of water rights and further investigate whether participatory mapping tools or methods can be used to capture and record water rights. The study is divided into 2 stages. In the first stage of the study, the background information is established and literature is reviewed. The second stage is a field study. The various parts of this study are segmented into chapters and are achieved in 6 steps as seen in Figure 2.

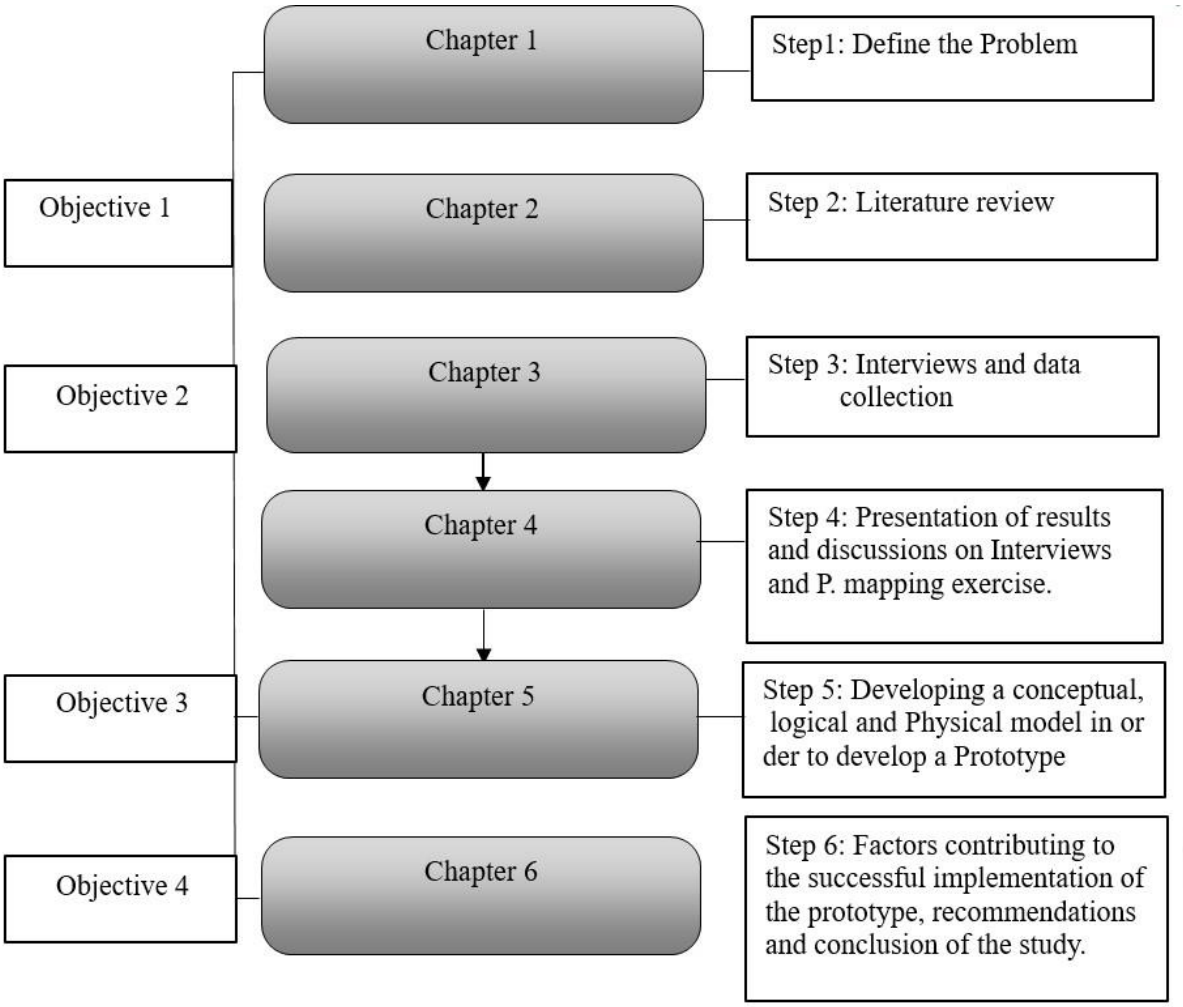


Figure 2: Research Design and Methodology

The study is developed building from the general perspective of water rights administration in Ghana and further narrowing down to the specific, using a case study. The first step of this study establishes the background of the study by making use of literature analysis. At this stage, the problem this study seeks to address is properly defined. The research aim and objectives as well as research questions are also clearly spelt out.

The second step constitutes literature analysis. It highlights concepts of water rights management and tools used to record water rights, with special attention to Ghana. At this stage the second objective which seeks to analyze the existing system for capturing and recording, interests on inland water resources in Ghana is addressed.

Step 3 entails a field study. The aim of this field study is to propose and investigate a suitable process of capturing, recording, visualizing and analyzing interests (rights, responsibilities, restrictions and privileges) on water tenure as defined in Step 2. Thus an inland water resource is chosen as a case study area. In step 3, the second objective is realized which entails

investigating the use of participatory mapping methods to capture details on water rights as held by indigenes as well as stakeholders who hold statutory permits for water use. A description of how interviews and participatory mapping methods are used as a tool for capturing the identified water rights is highlighted.

In Step 4 the results obtained during the interviews and participatory mapping exercises are highlighted and discussed. Step 5 tackles the third objective which seeks to develop a prototype information system to capture, record, visualize and analyse water rights and related interests. In this step, data modeling processes, which entail conceptual, logical and physical models are developed and implemented. Drawing from the data collected in Step 3, a prototype information system is developed from the various models.

In Step 6 the necessary strategies required for the implementation of the prototype are discussed. In this step the fourth objective which entailed recommending suitable strategies for implementing a prototype inland water cadastre. Based on the steps previously undertaken a conclusive discussion is then made on the study indicating the objectives achieved and how the research questions have been answered (Step 6).

1.7 Outline of Chapters

The thesis has been organized into 6 chapters with each chapter addressing the defined steps adapted towards achieving the research objectives and answering research questions.

Chapter 1 introduces the research with a literature analysis. It gives the background of the research and defines the problem the study seeks to address. In this chapter research objectives and research questions are defined to guide the progress of the study.

Chapter 2 analyses existing literature on land and water resources tenure and cadastral systems. It also lays emphases on the existing water management frameworks which play a key role in inland water administration in Ghana. It also discusses application of PGISs (PGIS) in capturing and recording water right interests.

In Chapter 3, details on the demographical information of the case study area are discussed. A justification is given for the selection of case study area in this chapter. Details on data collecting methods including interviews, participatory mapping in capturing and recording of data, the limitations of data collection as well as data validation and processing are discussed in this chapter.

Chapter 4 presents and discusses results of data collection through interviews and participatory mapping. The results obtained from these data collection processes are discussed.

In Chapter 5 the conceptual, logical and physical models are developed. From the conceptual, logical and physical models a prototype inland water cadastre is consequently developed. The necessary legal, institutional and technical requirements needed for the successful implementation of the prototype are highlighted in this chapter.

In Chapter 6, conclusions are drawn considering how best the research objective have been achieved and how effectively research questions have been answered by the study.

Recommendations are made based on the conclusions drawn from the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The previous chapter has given the setting of the study by outlining the background of the problem this study seeks to address. It indicated the absence of a comprehensive spatial and non-spatial information system on internal water bodies that captures interests on water rights held by different categories of stakeholders which utilize water resources. It also highlighted the negative impacts this absence has on advancing inland water management. This chapter analyses existing literature available on key concepts and practices needed to be analyzed prior to the advancement of data collection processes and the information system development. Section 2.2 discusses natural resource tenure. It discusses land tenure in general and customary and statutory water rights. Section 2.3 discusses cadastral systems with special attention on cadastre in the marine environment Section 2.4 discusses water management and administration in Ghana. Section 2.5 discusses participatory GIS and its application in water management and administration.

2.2 Natural Resource Tenure

Tenure is explained as the rights that define a particular property, how it is held, and what a person or group of persons can do with this property (OECD, 2011). Natural resource tenure is one type of tenure system which refers to the nature by which legitimate access to natural resources is held and used, how benefits are shared and managed and the institutions responsible for their administration (SIDA, 2007).

2.2.1 Land Tenure

Land tenure refers to the societal institutions (organizations, rules, rights and restrictions) that control the allocation and use of land and its associated resource (Cumming & Barnes, 2007). Land tenure can be defined as the mode by which land is held or owned, or the set of relationships among people concerning the use of land and its product (Payne, 1997). It describes the legal or customary relationship, defined, among people, as individuals or groups, with respect to land (Dale & McLaughlin, 1999). Land tenure system, is based on customary

traditions and/or statutory laws and may differ from one locality to another depending on traditional practices (Arko-Adjei, 2011). It comprises of private (rights assigned to private parties), communal (rights held by members of a community), open access (rights held by all with the exclusion of no one person) and state (rights assigned to some authority in a public agency) rights (FAO, 2015). These rights are either held under freehold or leasehold systems. While freehold systems entail absolute ownership rights, leasehold systems entail rights held by a defined period of time (Larbi, 2008). Ghana operates a dual land tenure system, comprising statutory and customary tenure (Areas, 2009). Land tenure can therefore be described in terms of relationship people have on land.

2.2.2 Water Resources Tenure

Water rights are intricately linked with land rights insofar as water is found on land (Mensah, 1999). Tenure on water resources entails the nature in which legitimate access to water resources are held and used. Figure 3 shows that various countries operate laws governing the use and administration of water resources which are a cocktail of international, state, religious, local or customary laws as well as laws associated to specific projects (*Pradhan* & Meinzine-Dick, 2002).

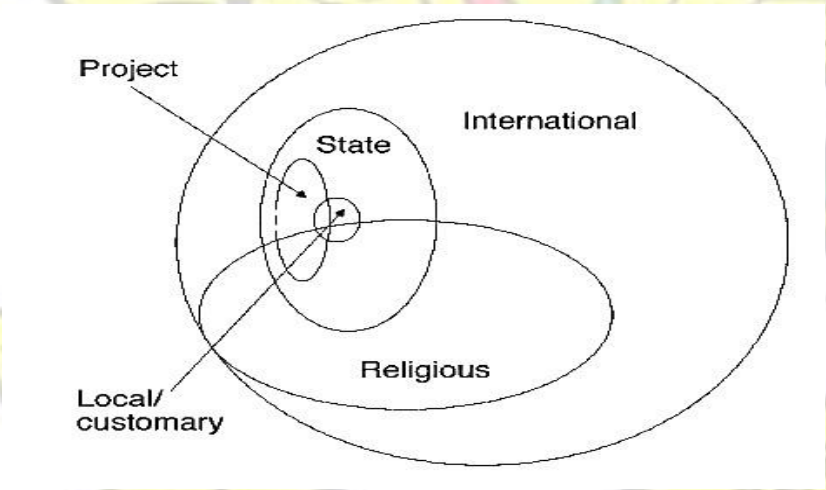


Figure 2: Overlapping Laws of Water Administration

(Source: Pradhan & Meinzine-Dick, 2002)

2.2.3 Customary Tenure on Water Rights

Customary laws on natural resources are dynamic, arising as a result of various contributing factors (Bruns & Meinzen-Dick, 2003). Different communities before statutory measures were put in place, had various customary rules concerning water use within the community and among other communities. These customary rules served as laws which governed the practices related to water use. Development and the evolving trends of water use by the state have however made it prudent for introduction of legislation and other policy measures by the state (Ramazzotti, 2008).

According to the customary law regarding the use of water in Ghana, ownership is vested in stools, communities and families (Sarpong, 2005; Ramazzotti, 2008). Such rights as vested in customarily recognized authorities and are likened to allodial rights. Inhabitants also enjoy usufruct rights over water. Usufruct rights are embodied in the *Riparian doctrine* which particularly allows for landowners with water bodies located on or next to the land on which a water body is found to use the resource for domestic purposes (Eguaven, 2008). Generally, customary law asserts that household water is a common good, not belonging to any particular individual (Sarpong, 2005). In Ghana, for example, there have been cases however in the past where Adagme and Ga-speaking societies had rules for private ownership and privileges related to water resource use (Ramazzotti, 2008). That notwithstanding, customary law in most communities in Ghana assert that rights related to use of water resources cannot be sold as a freehold to any private individuals or stakeholders (Mensah, 1999).

Many communities have different ethnic groups living side by side and using the same water, but having different traditions regarding its use (Meinzen-Dick & Nkonya, 2007). In cases where a water body is shared, verbal agreements are made on general guidelines governing water use. For example, abstraction of water from small water sources such as springs and streams on family land requires the head of the family's permission (Tarkang, 2012). In such cases agreeing on practices accepted by each group of people, provides guidelines to govern the use of a water resource.

Customary water rights, generally do not state the amount or quantity of water each stakeholder is entitled to (Ramazzotti, 2008). Users of water bodies are thus expected to use their discretion to considerately withdraw water leaving enough behind for the use of others. Each stakeholder is responsible for ensuring that continuous sustenance and maintenance of the water body is prioritized at all times and must be ready to face appropriate sanctions if he conducts himself

in a manner that contradicts this. Record keeping on customary tenancies on water is mostly verbal. The priority given to water for domestic use, is a common feature of customary law regarding water throughout Ghana (Dei, 2011).

2.2.4 Statutory Tenure on Water Rights

The UNCLOS places the management of rivers, streams, deltas, mangroves, underground water systems, and other inland waters under the sole jurisdiction of the state in which they are found (Williamson et al, 2010). The laws regarding water rights in various parts of Africa are heavily influenced by European concepts and principles as well as Islamic law, not forgetting national constitutions, statutes, regulations, orders, and other administrative sources (Pradhan & Meinzine-Dick, 2002).

In Ghana, the Water Resources Commission Act, 1996 (Act 552) is an amendment to the pre1996 customary regime for ownership of water which solely resided in stools, communities, families and individuals. This Act confers ownership and control of all water resources on the President on behalf of the people. Thus the state now claims ownership over water bodies through a multifaceted institutional approach (Sarpong, 2005). Statutory guidelines stipulated in the constitution to regulate water use is captioned under the Water Use Regulation 2001 of L.I. 1692 which provides procedures for allocating permits for the different uses of water. This includes the domestic, municipal, industrial, agricultural, power generation, water transportation, (aquaculture), recreational and under water (wood) harvesting (MWRWH, 2007).

Under statutory tenure, water resources may not be privately owned under any circumstance. This is consistent with general natural resource management as stipulated in the Ghanaian 1992 Constitution (Article 268 and 269). Thus, interested stakeholders who require rights towards water use seek permission for use from the WRC. Riparian rights are, however, given to land owners which share boundaries with water bodies.

2.3 Cadastral Systems

The term *cadastre* is commonly used as applied to land administration and is traditionally adopted to describe a system of records employed towards tenure security for land right owners or users (FIG, 2014). Cadastre traditionally is a land administration tool which provides unique identification of land parcels as well as their relationship to man (Williamson et al, 2010). Cadastral systems have evolved over the years with evolving relationship between man and his

environment. Due to these evolving trends, the traditional meaning of the term cadastre which was solely related to land (the solid part of the earth's surface) management and administration has evolved to include using it as a tool to manage and administer other resources.

2.3.1 Types of Cadastral Systems

Cadastral systems may be described as legal, fiscal or multipurpose. The legal cadastre focuses on parcel based description of the rights or interests in real property and places emphasis on the titles or deeds and registry in order to ensure tenure security (Ventura, 1998). Fiscal cadastre dates back to the 18th century and places emphasis on mapping out land parcels for the main purpose of taxing particular uses of land (Larsson, 1991).

In some European countries like Germany, the idea of using maps and records for further purposes of governmental activities was implemented in the cadastral systems from the beginning (Hawerk, 1996). Over time a cadastral system that could be used for the purposes of legal tenure security, taxation and adopted for management was considered (Williamson et al, 2010). In 1995 a concept of a multipurpose cadastre was articulated as being a parcelbased up-to-date land information system, capturing the nature and interests of land established for fiscal, legal and other management purposes (FIG, 1995).

The evolving relationship between man and his environment however requires the development of other cadastral systems in order to capture the *bundle of rights* held by man on other resources. These rights may include or preclude surface rights, subsurface mineral rights, aquifer use rights, air rights and other rights related to a particular location (Henry George Institute, 2015) as seen in Figure 4.

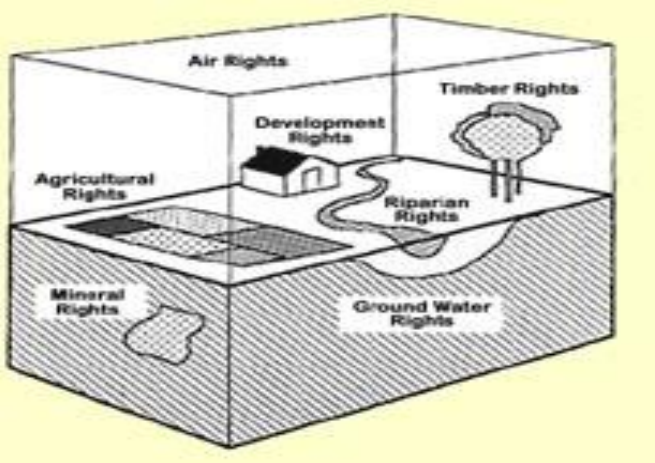


Figure 3: "Bundle of Rights" as Present at a Particular Location

(Source: Henry George Institute, 2015)

In order to register and give insights to interests of tenure on 3-dimentional property units, which entail details above and below the 2D earth's surface, studies are being conducted on the concept of a 3D cadastral system (Stoter, 2004). In Ghana, cases requiring a 3D cadastre include complex situation of ownership where rights and interests differ with increase or decrease of the dimension of height (Akoto & Godwyll, 2012). A demonstration of such a case is seen in Figure 4 where ownership interests differ with increasing height.

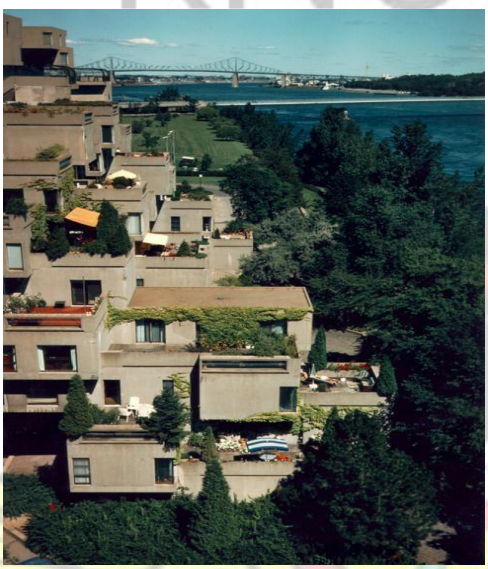


Figure 4: Case Requiring a 3D cadastre; Habitat 67, Montreal- Canada (Source-Canadian Architecture Collection, McGill University, 2001)

The marine cadastral system is also another developing cadastral system. It is described as a system which enables the boundaries of maritime rights and interests to be captured, spatially managed and physically defined in relation to other such boundaries with underlying rights and interests (Robertson et al, 1999). Cadastre in the marine environment is discussed in detail in the ensuing paragraphs.

2.3.2 Cadastral Systems in Marine Environment

The interests of coastal nations do not end at the land sea interface but continue into the marine environment. UNCLOS provides guiding principles for stipulated marine zones of marine administration, for UN member states who have adapted it as a working document. These guidelines together with local, state and national maritime practices are major determining

factors of consideration in the development of a marine cadastral system in concerned coastal states (Williamson et al, 2010).

In Africa, discussions and research have been undertaken among countries like South Africa, Angola and Namibia into the development and operationalization of marine cadastres (Attwood, 2013). One issue common to these discussions is the need for water rights and interests in the marine environments to be clearly identified Reddy et al. (2014) maintain that management policies towards marine administration will only be partially implemented if stakeholders are ignorant about their rights, responsibilities and restrictions on water. The primary aim of the marine cadastre is to allow its users and various stakeholders to clearly describe, identify and realize spatial information in the marine environment and to avoid future conflicts that may arise in the marine environment (Todd, 2001).

The underlining issues that have warranted the consideration of marine cadastral systems have parallels in the inland water resources environment. However, the marine zones covered under UNCLOS do not include rivers, streams, deltas, mangroves and underground water systems. All such inland waters fall totally within the jurisdiction of the nation in which they are found (Williamson et al, 2010). In a country like Ghana, the WRC envisages that, considering the possible effects of climate change, internal water conflicts might be an even more conflict prone hotspot in comparison with conflicts that may arise from oil and mineral exploration (WRC, 2010). This is evidenced by the constant reports of conflicts arising where stakeholders who utilize water for drinking purposes are in constant disagreements with users who utilize water source as a means of washing mined minerals like gold.

In a bid to manage their internal water resources, countries like Armenia, Moldova, Azerbaijan and Uzbekistan, have championed the operation of a state water cadastre under the Water Resource Management Agency. The state water cadastre serves among other things as a record base to record water users and water system use permits (Global Water Partnership, 2012) Through the State Water Cadastre, implementation data related to water resources in these countries is much easier to attain and this has fuelled accurate response to environmental challenges (Global Water Partnership, 2012).

2.4 Water Management and Administration in Ghana

Surface water resources in Ghana comprise the Volta, Southwestern, and Coastal systems, which are comprised of the Oti river, the Red, Black and White Volta rivers, the Bia, Ankobra

and Pra rivers and the Todzei/Aka, Densu, Ayensu, Ochi-Nakwa Ochi-Amissah rivers respectively (MWRWH, 2007). A framework for successful administration and management of the above mentioned water resources in Ghana is provided in legal, institutional, and technical provisions as discuss below. .

2.4.1 Legislative Framework

Similar to laws governing land in Ghana, the laws governing rights, responsibilities, restrictions and privileges associated with tenure on water resources also operate in a legally pluralistic state of statutory and customary law (Mensah, 1999). The WRC, is statutorily mandated by the WRC Act 1996 (Act 552) as the overall body responsible for the management and administration of water resources in Ghana. This however does not disregard the enforcement of customary laws regarding water rights and interests. Customary law is defined under Article 11(2) and (3) in the Ghanaian constitution under common laws and asserts that common laws are specific and unique to explicit communities. Thus despite the unwritten nature of customary laws, the constitution still raises customary law to a high pedestal, although in terms of hierarchy, customary law rules are subordinated to statutory enactments (Sarpong, 2005). The two laws are thus operated side by side.

The WRC Act 1996 (Act 552) requires that , stakeholders who desire to access rights to use water bodies for domestic, industrial, agricultural, power generation, water transportation, (aquaculture), environmental, recreational and under water (wood) harvesting, must apply to be granted those specific rights (WRC, 2011). Applicants, applying for water use permits are required to file an application with the WRC. Completed applications shall be accompanied by processing fees as directed. The payment charges vary, based on the kind of right being sort for and the duration for which it is being sort. The application highlights information regarding the name and address of applicant, category and level of water use, water body or stream affected, and the location.

Stakeholders seeking specific usufructory rights are exempted from applying for permits from the WRC. These stakeholders are however mandated by customary law to seek approval for any such use from the recognized customary authority specific to the community where river body is found (Sarpong, 2005). They are also required to register the rights they hold with the District Assemblies (WRC, 2011).

There are cases where the rights stakeholders seek is a hybrid between the land and inland water interface. Clear examples of such cases is seen when water is abstracted from a source for the

purposes of washing mineral deposits found on land during small scale mining processes as well as purposes of filtered water production processes. In such cases, a site plan is required as a supplementary document to complete application for water right interest. The production of these site plans is the mandated responsibility of the Survey and Mapping Division of the Lands Commission. The site plan showcases the boundaries of the landed area where production activity takes place with an insert showing the water resource from which water is abstracted as seen in Figure 6.

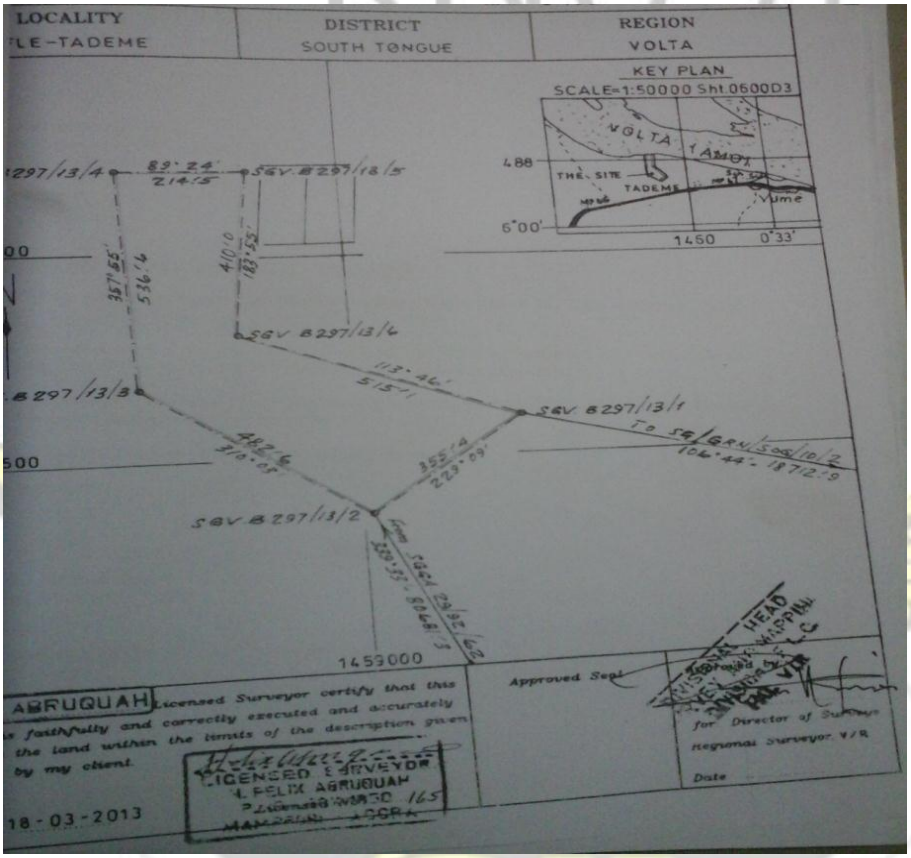


Figure 5: Site Plan showing Water Processing Site

(Source Photograph taken of Site Plan document at the Water Resources Commission)

2.4.2 Institutional Framework

In Ghana the Integrated Water Resource Management (IWRM) plan which serves as the working document for management of water resources has led to the introduction of an enabling institutional framework that engages a number of interrelating agencies providing information services, administration and regulation of water rights (WRC, 2012). The Densu River Basin has been chosen as the first river basin for the implementation of the IWRM plan because of a

number of factors that include occasional water shortages in an otherwise perennial river system as well as the rapid population increase of the Accra metropolitan area and other urban centers within the basin. (WRC, 2007).

A demonstration of the institutional framework for managing water resources is captured in Figure 7. The framework captures the agencies and bodies that play central roles in water administration and management. It also captures the agencies responsible for the provision of regulatory and information services and how they relate with the central agencies.

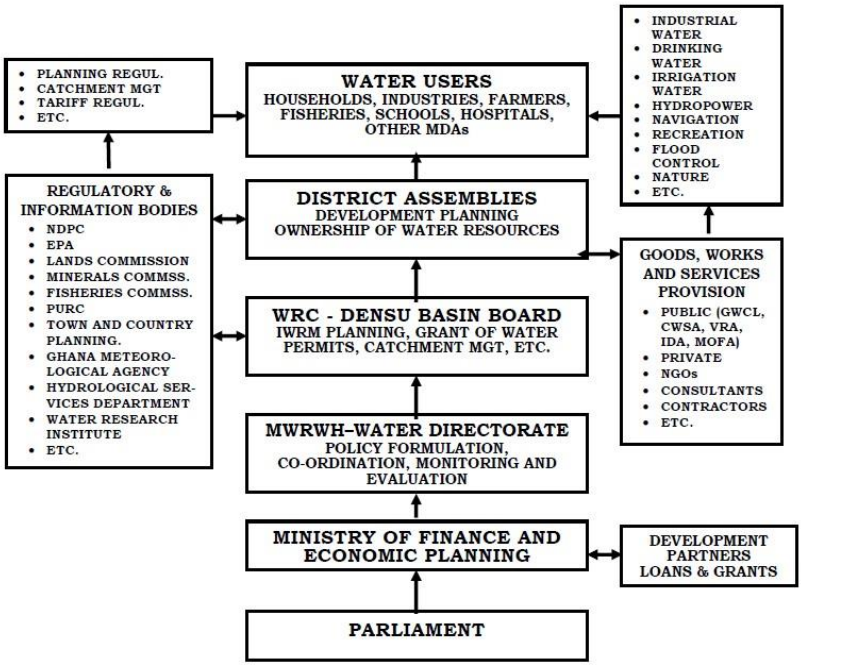


Figure 6: Institutional Framework for Densu Basin

(Source WRC, 2007)

The central bodies and agencies in the institutional framework are categorized into 3 levels namely policy, organizational and operational levels as seen in Table 1.

Table 1: Functional Roles of Central Agencies for Water Resource Management

Policy Level	Organizational Level	Operational Level
Ministry of Local Government and Rural Development	WRC	Water Supply and Sanitation Committee
Ministry of Finance and Economic Planning	Community Water and Sanitation Agency	Water Supply and Sanitation Development Board
Ministry of Water Resources, Works and Housing	Ghana Water Company Ltd.	Communities
Water Directorate	River Basin Boards	Customers

	Regional Offices	Private Sector +NGOs + CBOs
	Local Government Service Commission	
	Environmental Health and Sanitation Directorate	

(Source WRC, 2007)

The institutionalized process for acquiring water rights begins with the stakeholder or water user who desires to acquire water rights. In the institutional structure, the WRC serves as the foremost agency through which stakeholder acquire water use permits. Water Basin Boards are boards that serve under the WRC and comprise government agencies, religious groups, non-governmental organizations, customary rulers, Water Research Institute and others as the commission may deem fit. The board supports the commission in the administration and management of water (Water Resource Commission, 2012).

As per the consideration of the WRC, the EPA is consulted on proposed water permit application in cases that require environmental impact assessment. The Environmental Protection Agency may propose an environmental management plan in cases where use may have a direct or indirect adverse effect on the existence and sustainability of the water resource (WRC, 2011). The Survey and Mapping Division of Lands Commission, requested to provide the required spatial data in order to implement certain environment conscious policies like the buffer zone policy (MWRWH, 2013).

There are categories of rights for which stakeholders seeking interests are exempted from applying to WRC. These categories include the manual abstraction of water for use for domestic purposes, the use of water to fight fires, water abstracted by mechanical means for any purpose where abstraction level does not exceed 5 liters per second. The exempted uses include the use of water for subsistence agriculture for farming area less than 1 hectare and manual fishing with nets. These rights must however be approved by customary authorities. The District Assembly is required to furnish the WRC quarterly with registered water uses. The WRC in turn must enter the particulars of the approved water right holders in the Water Register and publish annually water uses registered. Figure 8 shows the institutionalized procedure for acquiring water rights. This emphasizes the need for community engagement and participation in identifying and recording these diverse rights in order to avoid marginalizing locals and communities. The registration of land and natural resource rights is critical to providing security to people especially in rural areas and to enable them to negotiate from a better position (FIG, 2014).

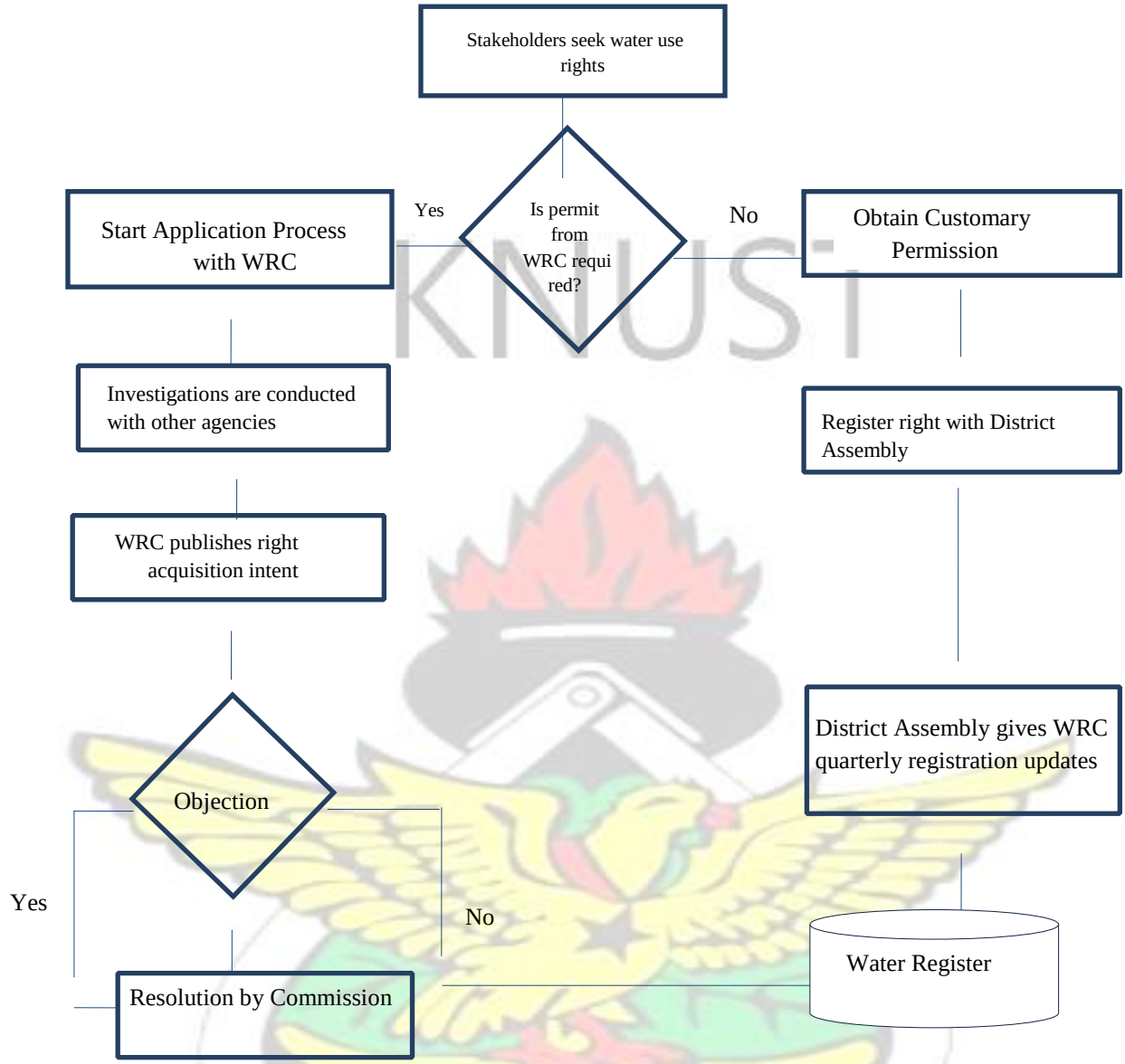


Figure 7: Institutionalized Process of Acquiring Rights for Various Water Interests

(Source WRC, 2012)

2.4.3 Technical Framework

In granting rights, the WRC makes decisions bordering on technical data (WRC, 2011). This includes the determination of boundaries on water bodies related to each proposed activity. Locating the area of the proposed water usage is a key technical data that serves as a basis for granting or refusal of water permit. The data required may differ depending on the type of right

being administered. The WRC thus works with other agencies in areas of boundaries on water resources.

For purposes that require data which is 2 dimensional in nature, officers of the WRC conduct surveys with hand held GPS. One northing and easting coordinates of the point at the site where proposed activity is to occur is chosen and recorded to serve as a reference. The Survey and Mapping Division is responsible for directing and supervising all surveys including hydrographic surveys as mandated by section 20 of the Lands Commission Act (Act 767). Hydrographic surveyors under the Survey and Mapping Division of the Land Commission provide complete surveying service for water bodies. They collect and compile hydrographic data for various applications and purposes notable among them is for water inventory.

A variety of approaches may be used to capture the relevant data on tenure on water resources. In cases where permit is being sought for the purposes of fish cage farming and under water wood harvesting, the dimension of the data set needed in order to make informed decisions on granting a permit is 3-dimensional in nature. This comprises horizontal northing and easting coordinates as well as the depth profile of the specified area. In cases where the plan and profile shows that the proposed location is unsuitable, and poses a threat to the sustainable use of the water, objections are raised based on conflicting claims of interest (WRC, 2011). For example, permits for activities such fish cage farming would not be granted if site is close to a commercial crop farming area or the depth at the proposed location would not allow for a space of more than 2m between the bottom of the cage and the bottom of the water body (WRC, 2013).

Data regarding the details of rights and interests held on water resources in Ghana are published in a water register. The register shows a tabular list with columns to show various properties including the name of the right holder, name of district where resource is located, the point of use, type of source, water use activity, primary purpose and expiry date as seen Appendix 1. The water register does not include information on the actual boundaries on water bodies where the permitted activity takes place. This makes it increasingly difficult to conduct spatial analyses on the areas where specific activities on water take place and the immediate land interface. Such analyses will be necessary in other to facilitate the implementation of some regulations like the “Buffer Zone Policy”.

2.5 Participatory Geographic Information Systems (PGIS)

Participatory mapping also known as community based mapping is a term that describes the use of a combination of cartographic processes together with participatory methods to effectively represent spatial knowledge as held by local communities (IDS, 2015). Access to and the understanding of advanced spatial technologies notable among them being GIS, Global Positioning Systems and Remote Sensing Technologies to mention a few, gives a great advantage to those empowered to make use of such technologies, often to the marginalization and disadvantage of communities and local folk (IDS, 2015). By combining modern cartographic principles and indigenous knowledge held by local communities, PGIS empowers minority groups and sectors of the society who are traditionally disenfranchised giving them an opportunity to be a part of the decision making process (Jankowski, 2009). PGIS has become synonymous with eliciting IK with participatory approaches including face-to-face (traditional meeting format) and distributed (on-line) and GIT. McCall (2003) stated that using PGIS with communities can add value to ISK by helping in the creation of more reliable data outputs and encouraging capacity building and learning processes. Wang et al.(2008) indicate that PGIS approach is designed to reflect the local people's spatial knowledge.

2.5.1 Indigenous Knowledge (IK)

Warren (1992) describes indigenous knowledge (IK) as local knowledge specific to each community that often serves as a basis for decision making regarding agriculture, health care, food preparation, education, natural-resource management and other activities at the local level. Indigenous Knowledge may be technical or spatial. Indigenous technical knowledge is described as embodied knowledge that is a local resource specific to local and urban people as an individual as well as communal resource. Indigenous spatial knowledge is specific and ongoing knowledge about the resource related to terms like the location and management of the resource (McCall, 2003).

The emphasis placed on community participation has greatly highlighted a preference and focus on indigenous knowledge in modern times. Sillitoe (1998) asserts that the new focus on IK gives an indication of the next revolution of methods in conducting researches as it encourages collaboration among informants and serves as a good basis for development for the people by first engaging them in novel ways. This assertion is confirmed by the Kimberly

Declaration (2002) which affirmed the desire of indigenous people to own, control and manage ancestral lands and territories, waters and other resources.

There are however limitations regarding Indigenous knowledge which render challenges in using it as a source of information Minang & McCall, (2006) affirm this stating that limitations regarding the use of IK include the limitations of how information is stored and passed on, the inability of informants to predict the effect of changes over time to come, and the difficulty in performing analyses on information often due to the nature in which it is quantified.

2.5.2 PGIS Tools and Methods

PGIS combines Participatory Learning and Action Methods (PLA) together with geo-spatial information management tools and methods such as sketch maps, participatory 3D models, aerial photographs, satellite imagery, Global Positioning Systems (GPS) and Geographic Information Systems (GIS) to produce virtual or physical models for interactive discussions and decision making (CTA, 2015).

The PGIS process can be divided into two broad steps namely; map production which involves engaging a cross section of community members to successfully produce maps capturing the details of interest and map utilization which involves the effective use of the produced map towards decision making processes (Kolagani et al, 2012).

Many tools and methods maybe employed; namely ephemeral maps (drawn on the ground in sand), sketch maps (drawing mental maps), scale mapping (overlay drawing on base maps) (IIED, 2009). In modern times, mapping is combined with video production to support the call for action and advocacy work (IDS, 2015). Rambaldi (2005) asserts that participatory mapping has become a popular form of counter mapping allowing indigenes to have a say in building models or drawing maps that depict situations as seen from their perspectives.

Participatory GIS methods if adopted effectively can be used as a useful tool for empowering rural communities to view and understand the different problems they face and the solutions thereof allowing for community participation and GIS technologies (Kolagani et al, 2012). Rambaldi (2005) outlines applications of PGIS to include protecting ancestral lands and resource rights; management and resolution of conflicts over natural resources; collaborative resource use planning and management just to mention a few. In mapping indigenous knowledge in land tenure dynamics in a peri-urban community in Northern Ghana Lamptey (2009) confirms the usefulness of using participatory mapping methods as an effective tool that

encourages maximum participation among informants, allowing for all indigenes irrespective of their backgrounds to get involved.

2.5.3 PGIS in Water Management

FAO (2006) asserts that stakeholders with various interests in water can be supported to manage water when they are guided to make decisions and reach a consensus regarding sharing and allocating water related goods and services. In guiding stakeholders with water interests to make the rights decisions, Bruns & Meinzen-Dick (2003) maintain that the application of participatory approaches for improving basin-scale water governance should be considered in light of critical analysis of community-based natural resources management and institutional design principles for common-property resources management.

Ramsey et al (2003) argue that the increasing involvement of stakeholders and use of scientific data in water resource management has created a need for participatory GIS (PGIS) technologies capable of supporting collaborative spatial decision-making. A study conducted in Tanzania on agricultural water management solution employed the use of PGIS in order to vividly describe the effects of agricultural practices on the watershed under study (Cinderby et al, 2010).

2.6 Concluding Remarks

This chapter sought to review literature on natural resource tenure, cadastral systems, water management and administration in Ghana and PGISs (PGIS). The need for a tool to record indigenous water use rights and also a system to record these rights for decision-making have been emphasized. The next chapter focuses on the methods adopted in capturing spatial and non-spatial data on water rights and use by various right holders using a case study.

CHAPTER THREE

STUDY AREA AND RESEARCH METHODS

3.1 Introduction

In Chapter two, concepts of water resource tenure, cadastre and participatory GIS were discussed. This chapter describes the methods used to collect empirical data to answer the

research questions. Sections 3.2 describes and justify the study area chosen for the purpose of researching into developing an inland water cadastral system. Section 3.3 describes the data and used for the study. Sections 3.4, 3.5 and 3.6 describe the methods used for collecting the empirical data for the study. Since the main research seeks to employ participatory mapping for identifying and mapping indigenous water rights, Section 3.5 is devoted for the participatory mapping techniques enrolled in the research. Sections 3.7 describes the GPS Survey. The chapter ends with the limitations on the data collection procedures.

3.2 Study Area

3.2.1 Criteria for the Selection of the Study Area

The portion of the Densu River bounded by the Densuano community was chosen to provide empirical evidence for the study. The Densu Basin is the foremost basin chosen by the WRC to implement the IWRM plan (WRC, 2007). The area plays various prominent roles and showcases various examples use rights. The shared nature of rights existing on the water space at Densuano presents a clear case where there is an urgent need to identify major stakeholders and define spatial extents of boundaries on the water in order to indicate the extent of access to each of the various stakeholders with statutory and customary permits. The area also provides a clear situation where there is the need to capture spatial data in order to allow for the implementation of the buffer zone policy. This is necessary considering the obvious need to clearly define the zone along the river bank that should not be encroached upon in order to ensure that the quality and quantity of water is not compromised.

3.2.2 Demographical Information

Densuano is one of the 200 settlements along the Densu river basin (WRC, 2007). The Densu river basin has an average population of 240 persons per km squared (Ghana Statistical Service, 2010). The Densu River is located in the New Juabeng Municipal area, Koforidua in the Eastern Region (Figure 9). The portion of the basin used for the study lies between latitudes O◦ 17’ 36’’ W and 0◦ 17’ 38’’ W and longitudes 6◦ 4’ 10’’ N and 6◦ 4’ 3’’ N. The basin also hosts the Densuano dam. The dam serves water to the Koforidua Township and its surrounding communities and is under the management of GWCL. The resource thus serves as the main source of drinking water to some communities in Koforidua. The site serves as a source of livelihood for the inhabitants of Densuano who are mostly farmers and fishermen.

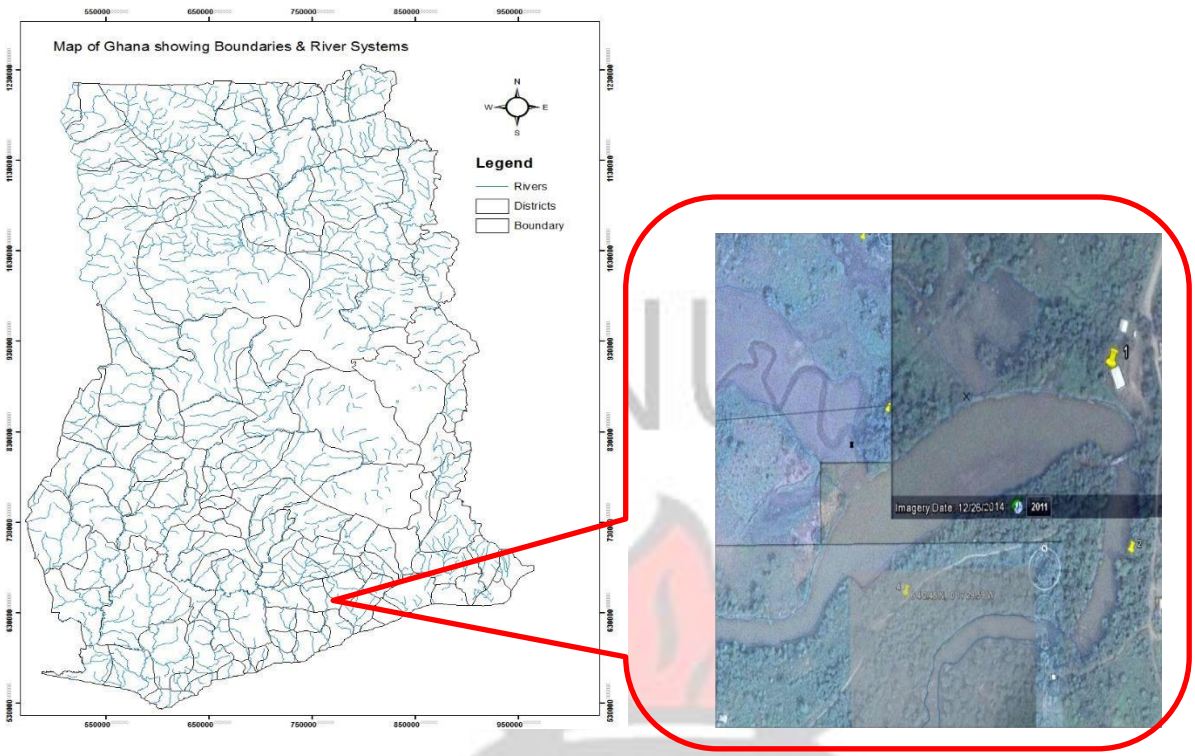


Figure 8: Location of Study Area

(Source Ghana Map showing Rivers created by Godwyll, Satellite Image of Study Area Google Maps 2015)

Fishing on the upstream portion of the study area is mostly seasonal and largely depends on the activities of the GWCL. According to GWCL officials in charge of the dam, when water is dammed up to the level of 14ft and above enough water extends to cover more areas upstream and facilitates fishing. Water from the river is used as a source of irrigation. Other portions of the river are also used for other domestic purposes like drinking and recreation. Indigenes of Densuano are mostly Christians and African Traditionalists with the minority being Moslems. The resource is thus used for religious purposes like baptism, rituals and festive celebrations.

3.2.3 Land Tenure

Land tenure in the study area is vested in families and stools. The family land is vested in indigenous families at Densuano while the stool land is vested in the New Juabeng Traditional area. The New Juabeng Traditional Area is represented by the Odikro of Densuano, who serves as a traditional head and a caretaker chief for the stool. The Odikro represents the paramount

chief of New Juabeng in the management of land as well as the water resource at Densuano. For the family lands, the management is vested in the family heads.

The Odikro serves as an initiator of negotiations regarding interest in acquiring land and may lead interested parties to the appropriate quarters. Currently rights to land at the Densuano community are mostly held by subsistence farmers who are indigenes of Densuano and have usufructory rights to farm on approved plots of land. There are also designated areas approved for settlements. The government and citizens who are interested in acquiring rights to designated areas contact either the Odikro or family heads depending on the land for which rights are being sought, to initiate the process of acquiring rights towards land use.

Rights of use along the Densu river basin are vested in the State and the New Juabeng Traditional area which hold the water resource in trust of the people. The New Juabeng Traditional authority holds user rights which is transferred to indigenes of Densuano and regulated by the Densu Basin secretariat. The Densu River Basin Secretariat is the institution mandated by the state to manage the issuance of rights, responsibilities, restrictions and privileges relating to the use of the resource.

3.3 Data

Both qualitative and quantitative data from primary and secondary data sources were used. The primary data was obtained through interviews, feedback forum and validation workshop. Secondary data was gathered from literature study. Other sources of data were December 2014 Digital Globe Quick Bird Satellite Image with a 0.5 m resolution from Google Earth platform.

3.4 Interviews

Interviews were conducted with major stakeholders who comprised indigenes at Densuano and GWCL. Other respondents were water rights managers and administrators made up of officials from the WRC and members of the traditional council at Densuano. Surveyors from the Survey and Mapping Division of the Lands Commission were also interviewed.

The main questions centered on: which stakeholders hold statutory and customary permits to conduct activities on the resource; the nature of the rights, responsibilities and restrictions held by these stakeholders; whether the boundaries associated to each right of use are known and how are they recorded; whether customary rights to water use are recognized and upheld; whether there is cordial coexistence between the GWCL and other stakeholders; and whether

surveys or other procedures are conducted to determine boundaries associated to the various activities on water resources?

A total number of eight (8) respondents were engaged comprising four (4) indigenes from Densuano, one supervising officer from the GWCL, the traditional head of Densuano, one officer from the WRC and two(2) surveyors from the Survey and mapping division. Figure 10 shows the interview with officials at GWCL, Indigenes and the Odikro of Densuano

(a)  (b)  (c) 

Figure 9: Interviews

(a) Interview *with GWCL officer in charge of the Densuano dam (b) Interview with Odikro of Densuano Traditional Area (c) Interviews with Indigenes of Densuano*

(Source Picture taken by Godwyll at Densuano)

3.5 Participatory Mapping

3.5.1 Preparatory work

The Digital Globe Quick Bird Image with a 0.5 m resolution obtained from the Google Earth platform downloaded as a TIFF image was imported into the Arc Map environment and georeferenced using the WGS84 UTM zone 30 projected coordinate system. The georeferenced image was set to a scale of 1:1000 as this was realized to be an appreciable scale at which details could be clearly identified. A photomap of scale 1:1000 was printed out in A2 size format.

3.5.2 Community Entry and Awareness Creation

Various stakeholders holding rights on the water resource gathered at a communicated location. The stakeholders were addressed and briefed on the purpose and objectives of the research. The photomap map of the study area was displayed to the view of the various stakeholders present as shown in Figure 11.

(a)  (b) 

Figure 11 Community entry and awareness creation

(a) Members *of the community briefed on research objectives*

(b) Photomaps *displayed to community members*

(Source Picture taken by Godwyll at Densuano)

3.5.3 Selection of Key Informants and Training

The key stakeholders of the water resource at Densuano community were represented during the meeting. These comprised 10 fishermen, 7 farmers, 3 representatives of GWCL as well as 8 domestic users. All the stakeholders were trained to identify key structures on the map in order to properly orient themselves to the details shown on the map as shown in Figure 12. Stakeholders then engaged a feature identification exercise without guidance to investigate their ability to properly orient themselves with map and identify features on the map. The identified features were noted.

(a)  (b) 

Figure 12: Training of Stakeholders

(a) Stakeholder observing the photomap (b) pointing to identified location on the photomap

(Source Picture taken by Godwyll at Densuano)

3.5.4 Participatory Mapping Exercise

A board, paper tape, tracing sheet and stationary like pencils and erasers as well as different colored roller tip pens were utilized in the mapping exercise. Shown in Figure 13, two mapping exercises were conducted; one for stakeholders at the upstream and the other for stakeholders at the downstream portion of the resource.

Figure 13: Participatory Mapping by at Upstream and Downstream Dwellers at Densuano

(Source Picture taken by Godwyll at Densuano)

Upstream water dwellers were first engaged in the mapping exercise. A tracing paper was placed on one of the photomaps and secured unto the board. To aid in georeferencing, ticks were marked out showing grid intersections. The second photomap was mounted on the side to serve as an extra reference guide. The stakeholders identified the boundaries around portion used for fishing, domestic water abstraction, restricted access, and that for recreational and religious activities. These areas were transposed unto the tracing paper using pencils and colored roller tip pens. The boundary of fishing area was indicated by blue. The dam area with restricted access was indicated by red. Portions where water is drawn for domestic purposes and irrigation were indicated by green darts. The portion of the study area where baptism, religious and other recreational activities take place was indicated by green bold lines.

Similar exercise was conducted for stakeholders at downstream. The same color indicators as used by downstream dwellers were used by upstream dwellers. A red boundary outline was

used to represent the identified portion of the water with restricted access belonging to the GWCL. The zones where fishing takes place were also marked out using blue. Portions along the resource were water is drawn for domestic use was earmarked by green darts and the portion for domestic and recreational activities was marked with green bold lines. Figure 13 shows the participatory mapping exercise.

3.6 GPS Survey

A GPS survey was conducted to validate and test the ability of the participants of the pmapping to correctly identify features on the photomap. With the help of a boat rider, transect was designed for some of the boundaries identified during the p-mapping exercise (Figure 14). A Garmin GPS of 3m accuracy was used to record points of some of the boundaries identified and drawn on the sketch maps. A total of 20 identified points were surveyed. In order to compare the two datasets the Root Mean Square Error (RMSE) was computed. The RMSE measures how much error there is between two datasets, it usually compares a predicted value and an observed value (Ross, 2004).

Figure14: GPS Survey of Identified Points

(a), (b),(c) Survey of identified *points taken at banks of the river*

(d) Boundary pillar where exclusive *rights of GWCL ends* (*e) GPS survey of the position of the pillar* (*f) Waypoint taken where dam is located on the water resource.*

(Source Picture taken by Godwyll at Densuano)

3.7 Data Processing

The sketch maps produced from the p-mapping exercise were scanned. The scanned images were imported to ARC Map version 10.2.1. Tick marks were used as a guideline to georeference using the WGS84 UTM Zone 30 N. Both photomaps were added as a layer in Arc Map. The transparency of each of the scaled map was set to 70% to allow easy visibility between the photomap and the sketch maps. The GPS surveyed waypoints were also plotted on the map of the study area.

3.8 Feedback and Validation Forum

A feedback and validation forum was undertaken at Densuano. A section of the community members were available for this function. Two (2) officials from the GWCL, the Odikro of the Densuano community together with six (6) indigenes comprising 4 fishermen, 1 farmer and 1 domestic user were present for the exercise (Figure 15). The validation exercise sought to find out whether the PGIS map produced correctly represented the physical boundaries where the identified rights were being held. It also investigated the ability of stakeholders to identify and confirm zones where they held user rights. The output maps of the p-mapping exercise were displayed to the people present for scrutiny. The details in the sketch maps were verified.

Figure15: Feedback and Validation of Sketch Maps

(Source Picture taken by Godwyll, 2015 in the course of this research)

3.8 Limitations of Data Collection

Stakeholders who participated in the P-mapping exercise could not readily provide information regarding the extent of their rights in terms of a vertical sense. This was due to the highly dynamic nature of water levels which fluctuates when dammed water is released. The vertical dimension of their rights may vary as often as each and every passing day. Stakeholders thus only related with the properties of the resource and rights vary solely based on horizontal extents.

3.9 Concluding Remarks

This chapter has outlined the characteristic of the study area. It has also described how Pmapping was used to solicit indigenes knowledge and map water rights. This information will serve as an input in the design of water cadastre in Chapter 5. The chapter has also outlined the limitation of the study. In the next chapter, the results of the interviews, participatory mapping exercise, and GPS survey will be discussed as a basis for design of the cadastral database which will be presented in Chapter 5.

CHAPTER FOUR

ANALYSIS OF TENURE AND MAPPING WATER RIGHTS

4.1 Introduction

This chapter presents the results of data collection procedures. This chapter aims at investigating and visualizing ownership, responsibilities and restrictions associated with the use of water along the Densuano basin. The chapter begins by analyzing land tenure and water rights captured through interviews and focus group discussions. Next the chapter discusses the spatial representation of water rights, responsibilities and restrictions captured through p-mapping activities and the results from the GPS transit survey..

4.2 Land Tenure and Water Rights

Interviews conducted provided information on tenure which includes rights, responsibilities, restrictions and privileges associated to each stakeholder, existing methods for identifying and recording water rights and the management of water rights at the Densuano community.

Results from the study indicate that the GWCL holds rights to dam the Densu River in order to abstract water. These rights had been issued by the WRC. As a holder of the right to dam, the GWCL has the responsibility of monitoring and managing the dam water levels in order to prevent possible flooding of the neighboring community. The institution also holds the responsibility of ensuring the quality and safety of the water pumped out as well as the overall sustainability of the resource. The GWCL is permitted to conduct its activities within a bounded region of space marked by a pillar. Other water users are restricted to conduct activities like fishing and extraction for domestic water within the restricted boundary.

Customary rights of use over the resource are vested in the stool. These rights are transferred to indigenes of the Densuano community for the purposes of domestic, irrigation, religious, fishing and recreational use. Individuals or groups seeking such usufruct rights who are not indigenes must seek permission from the traditional authorities before they conduct any activity. According to customary belief the Densu River is believed to be a god and the Densuano community has a resident priest who plays a major role in managing the components of tenure on the resource. Rights of use of the Densu River and restrictions are passed down through generations by oral traditions. Indigenes and strangers who use the water resource

have the responsibility of maintaining the safety and quality of the water at all times. The priest who worships at the Densu shrine has the responsibility of ensuring that restrictions concerning the use of the water resource are adhered to and the related punishments applied when defaulted. Fishing activities and farming at Densuano are prohibited on Thursdays, the reason is that the Densu god is believed to be a Thursday born and thus would be resting on Thursday. Fishermen who fish on the river the resource are prohibited to use chemical for fishing. Farmers who farm close to the river bank are prohibited from weeding close to the water resource. Users who fetch water from the resource are not supposed to use utensils covered with soot to fetch water from the resource. Swimming in the resource is also prohibited.

Drawing from interviews with customary right holders, the customary sanctions regarding the inappropriate use of the resource remain potent even though not as stringent as in the past. There is however a lot of reverence still given to the "Densuano" shrine and the attending priest gives out sanctions to those who do not obey these customary restrictions on water usage. This is a key contributor to why the resource is kept in its clean and safe state.

The boundary of the dam is not known. Results from the interview revealed that surveys are conducted to determine boundaries on water for some activities like fish farming and aquaculture. Aside that, hydrological surveys conducted are done to establish water profiles for research and studies as specified by the customer. In determining boundaries for fish farming and aquaculture, a GPS survey is used, while echo sounding is used to determine the depth at various points. More often than not, surveyors contracted for such jobs are contracted privately and output for such surveys is produced as a map. The study revealed that there is a gap between surveys conducted and record keeping on such surveys by the Hydrological Department.

Findings of the research found a perfect harmony between statutory and customary rights and their implementation agencies regarding water use at Densuano. Meetings between GWCL and the customary authorities at Densuano to discuss general practices in maintaining water quality are held when necessary. The Customary authorities of the New Juabeng Traditional Area are represented on the Densu Basin Board. It was revealed that though customary rights for the use of water are recognized by the WRC, none of the indigenous stakeholders had voluntarily registered their use rights with the District Assembly.

4.3 Participatory mapping

The results of the sketch mapping exercise are shown in Figures 16.

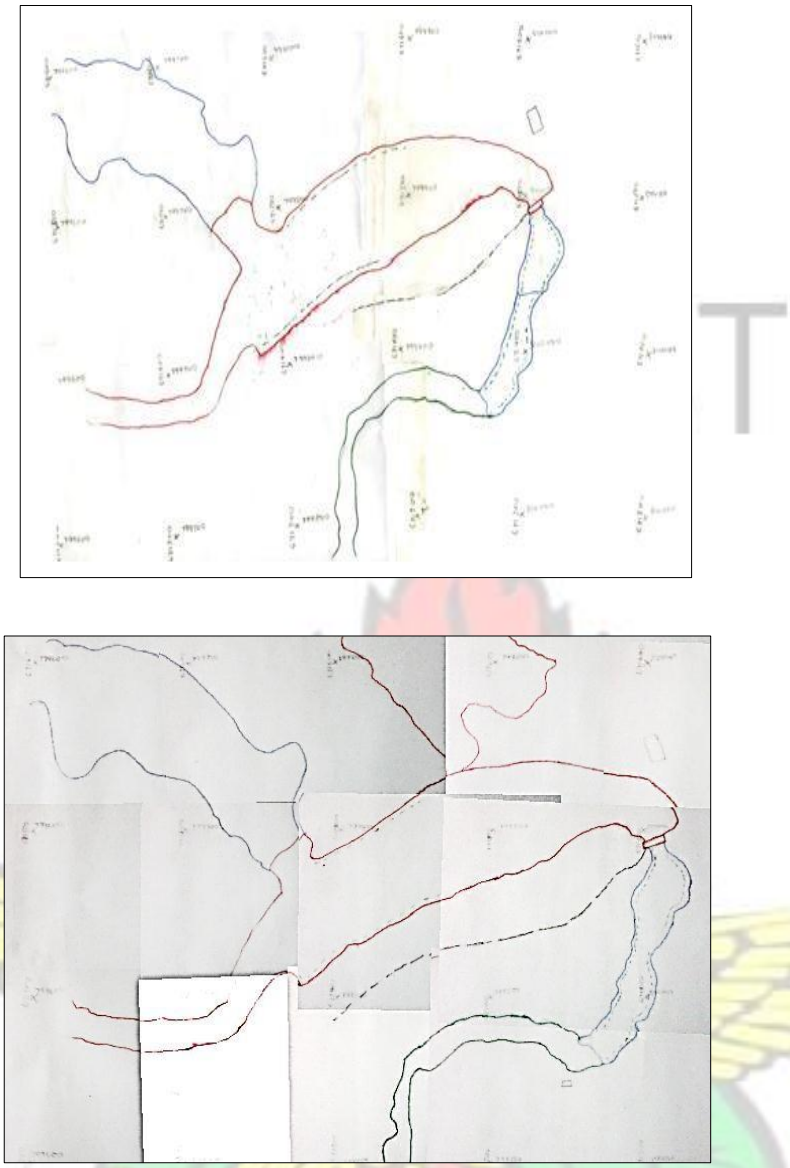


Figure 16: Scale Maps Produced from the P-Mapping Exercise

Top: Upstream

Bottom: Downstream

(Source Scale Maps drawn by Upstream and Downstream dwellers at Densuano)

Boundaries of four major activities that take place on the water body were identified and grouped into zones. Various usufruct rights were identified as being held over the various zones, namely rights to fish, rights to domestic use and religious activities, rights to use resource for recreational purposes and rights to dam a portion of the water resource. Figure 17 shows the processed sketch map in GIS.

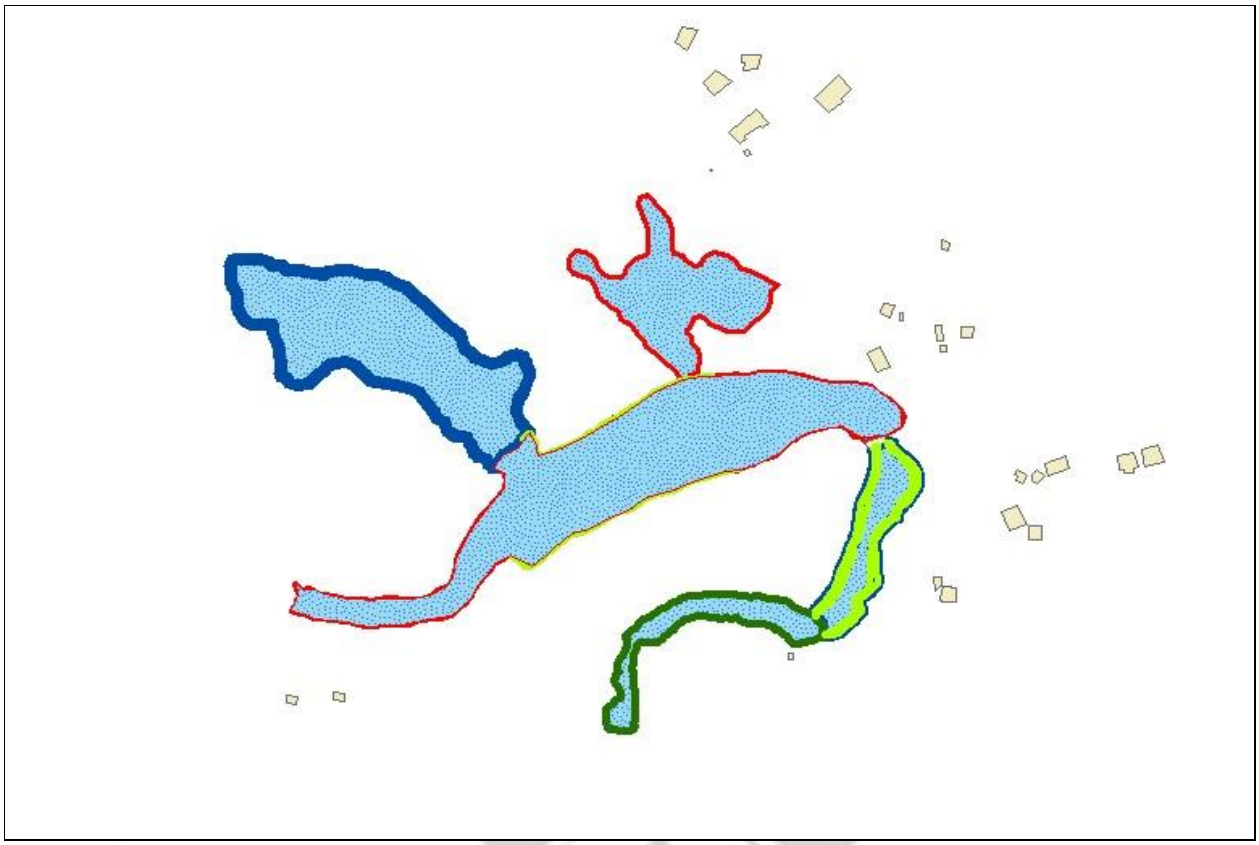


Figure 17: Sketch Map Processed in GIS Environment

Both upstream and downstream dwellers demonstrated similar views on physical boundaries extents and the associated characteristics of tenure on these boundaries. There appeared to be the general awareness of the rights and interests associated to the use of each zone as users gave similar information regarding the terms of use of the resource. For example all users were aware that it was prohibited to use the resource on Thursdays and it was forbidden to swim in the resource.

Participatory mapping ensured maximum community participation and involvement, urging the various stakeholders to identify and come to a consensus on the various physical boundaries associated to particular rights and underlining responsibilities, privileges, and restrictions. During the Participatory mapping it was revealed that there are instances where some fishermen cross the designated zone and attempt to fish in the restricted zone. Participatory mapping thus created a general sense of community awareness of the extent, rights, responsibilities, restrictions and privileges associated to each stakeholder. This observation has been made in other studies (Lamptey, 2009; Arko-Adjei, 2011)

4.4 GPS Validation Survey

The surveyed waypoints of selected boundary points were overlaid on maps produced from the p-mapping exercise. Data recorded form GPS technology are frequently used to add accuracy to information obtained from sketch maps and other less rich technology mapping tools (Rambaldi, 2005) . In order to compare the two datasets the Root Mean Square Error (RMSE) was computed. The RMSE of the observations are 6.233 in the Northerns and 5.993 in the Easterns. The residual GPS points are shown in Appendix 3.

To be able to visualize the closeness of the surveyed GPS points to the sketched boundaries, the GPS points were superimposed and the processed sketched maps in GIS environment as shown in Figure 18.

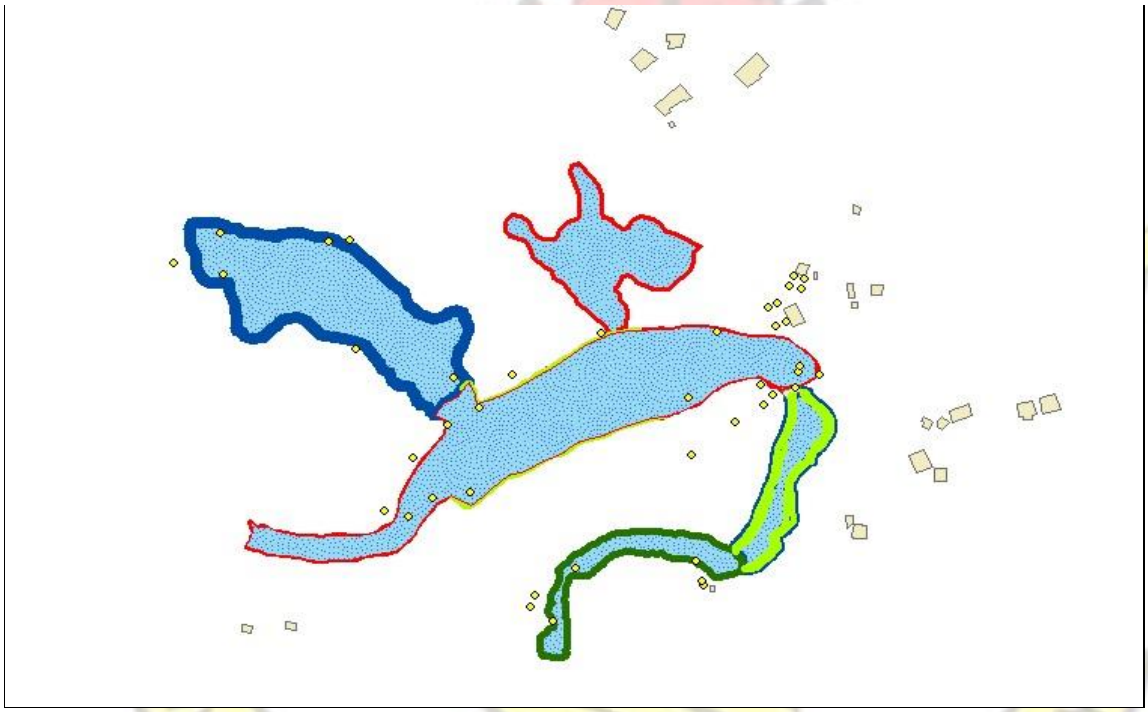


Figure 18: GPS Points Plotted on Identified Boundaries on Sketch Maps

Figure 17 shows that most the GPS points coincide with their corresponding boundaries on the sketch maps. This indicates that stakeholders were able to effectively identify the various activity boundaries on the photomaps.

4.5 Concluding remarks

This chapter discussed the results of the interviews, the PGIS exercise as well as the GPS survey. The chapter shows that there are different use rights for the various stakeholders.

Stakeholders at Densuano are permitted to use the river basin through customary practices and statutory provisions. The use of PGIS process has helped in the identification and mapping of the varying water rights and restrictions. This information is key for the design of inland cadastre for Densuano. The proceeding chapter will demonstrate the building and implementation of a prototype inland water cadastral system and the necessary requirements needed for its successful implementation.

CHAPTER FIVE

DESIGN OF PROPOSED INLAND WATER CADASTRE FOR DENSUANO

5.1 Introduction

In the preceding chapter, land tenure system and water rights was identified and described using interviews and participatory mapping. This chapter discusses how to use this information to develop a prototype inland water cadastral system. Section 5.2 describes the conceptual, logical and physical models of the inland water cadastre. It distinguishes between the spatial and non-spatial modeling process Section 5.3 presents the prototype inland water cadastre. Section 5.4 analyzes the technical, institutional and organizational requirements for a successful implementation of the prototype cadastre.

5.2 Designing the Inland Water Cadastre

In order to create the prototype various data modeling processes were employed. The conceptual, logical and physical models were created in order to model out the data. The conceptual models are designed to capture entities and the highest level of relationships between them, logical models which give further details to data without considering how they will be physically implemented in the database, and physical models show how the model will be built in a database (One Key Data, 2015)

5.2.1 Non-spatial Data Modeling

A conceptual model was developed by identifying the main entities involved namely Water Resource Commission, User, Water Resource and Customary Authority. The entities and attributes as well as relationships between the entities are as shown in the entity-relationship diagram in Figure 19.

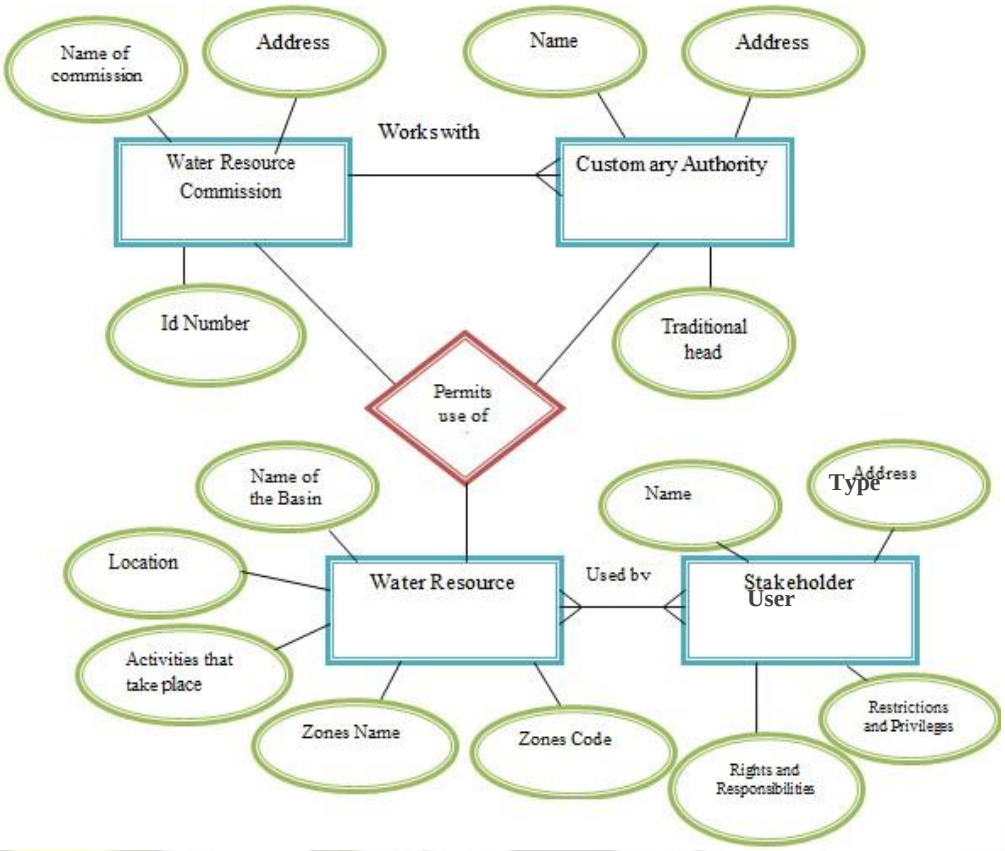


Figure 19: Entity Relationship Diagram of Water Cadastre for Densuano Community

(Source: drawn by Godwyll, 2015)

To be able to map the identified entities into the database, the relationship between the entities need to be normalized, by eliminating data redundancies. The logical data model restructures the conceptual data model in a way that can logically be accepted by the database. The logical data model for proposed inland water cadastre is shown in Figure 20. The corresponding skeleton table is shown in Appendix 4.

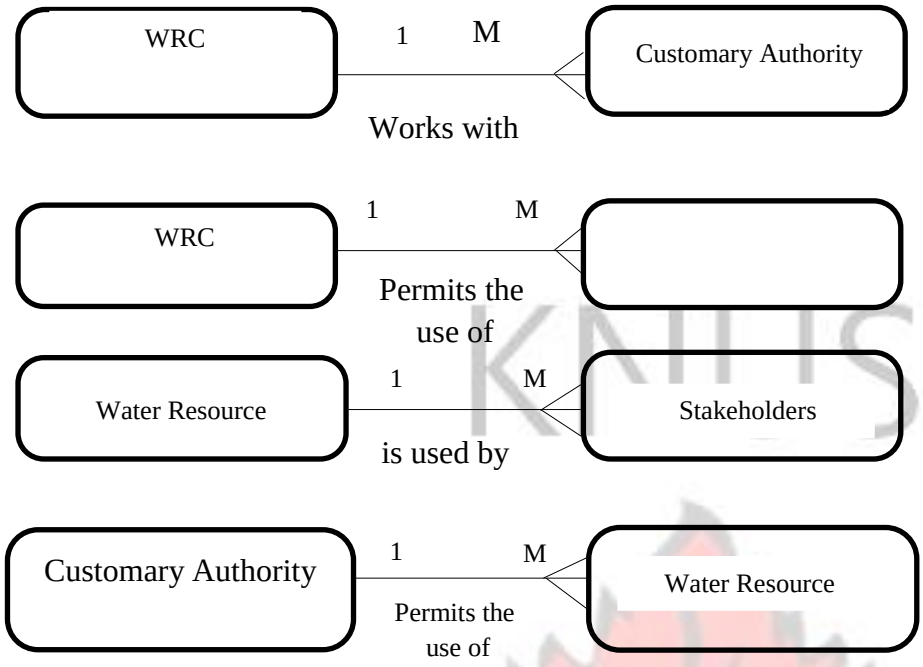
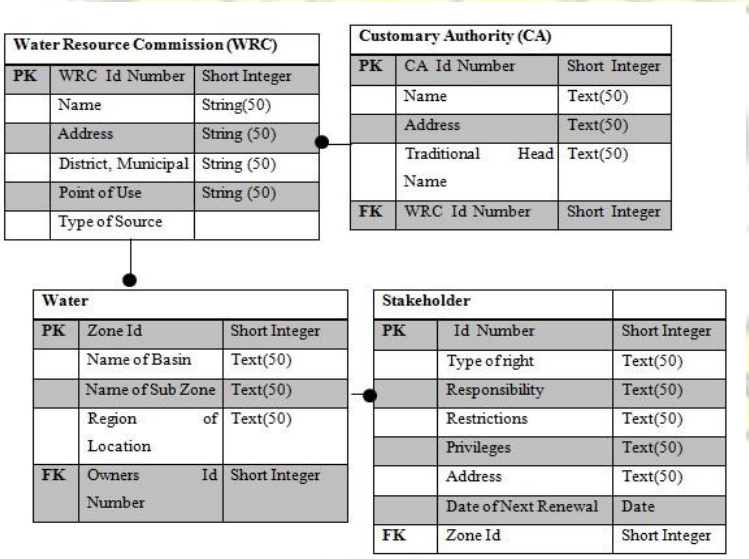


Figure 20: Logical data Model of Inland Water Cadastre

(Source drawn by Godwyll, 2015)

A logical model shows how the logical models are converted into tables. Physical model was created by taking into account the nature of data types and constraints that would represent the cadastre at Densuano as shown in Figure 21.



Water Resource Commission (WRC)

PK	WRC Id Number	Short Integer
	Name	String(50)
	Address	String (50)
	District, Municipal	String (50)
	Point of Use	String (50)
	Type of Source	

Customary Authority (CA)

PK	CA Id Number	Short Integer
	Name	Text(50)
	Address	Text(50)
	Traditional Head Name	Text(50)
FK	WRC Id Number	Short Integer

Water

PK	Zone Id	Short Integer
	Name of Basin	Text(50)
	Name of Sub Zone	Text(50)
	Region of Location	Text(50)
FK	Owners Id Number	Short Integer

Stakeholder

PK	Id Number	Short Integer
	Type of right	Text(50)
	Responsibility	Text(50)
	Restrictions	Text(50)
	Privileges	Text(50)
	Address	Text(50)
	Date of Next Renewal	Date
FK	Zone Id	Short Integer

Figure21: Physical Model of Inland Water Cadastre

5.2.2 Spatial Data Modeling

The procedure used to design the spatial data base is described in the paragraphs below.

A personal geodatabase was created in Arc Catalog and named “Water Cadastre”. In “Water Cadastre” geodatabase a feature geodataset named “Water Resource” was created. In the feature geodataset, four (4) feature classes were created with the names Fishing Zone, Restricted Zone, Domestic and Recreational Zone, and Hand Drawn Zone. These feature classes were added to ArcMap. The zones as drawn on the sketch maps were digitized into their corresponding feature class zones. Feature classes for other identified features such as the Dam, Water Pumping Station, Shrine, Farm Plots and Build Structures, were also created in Arc Catalog and digitized respectively as shown in Figure 22.

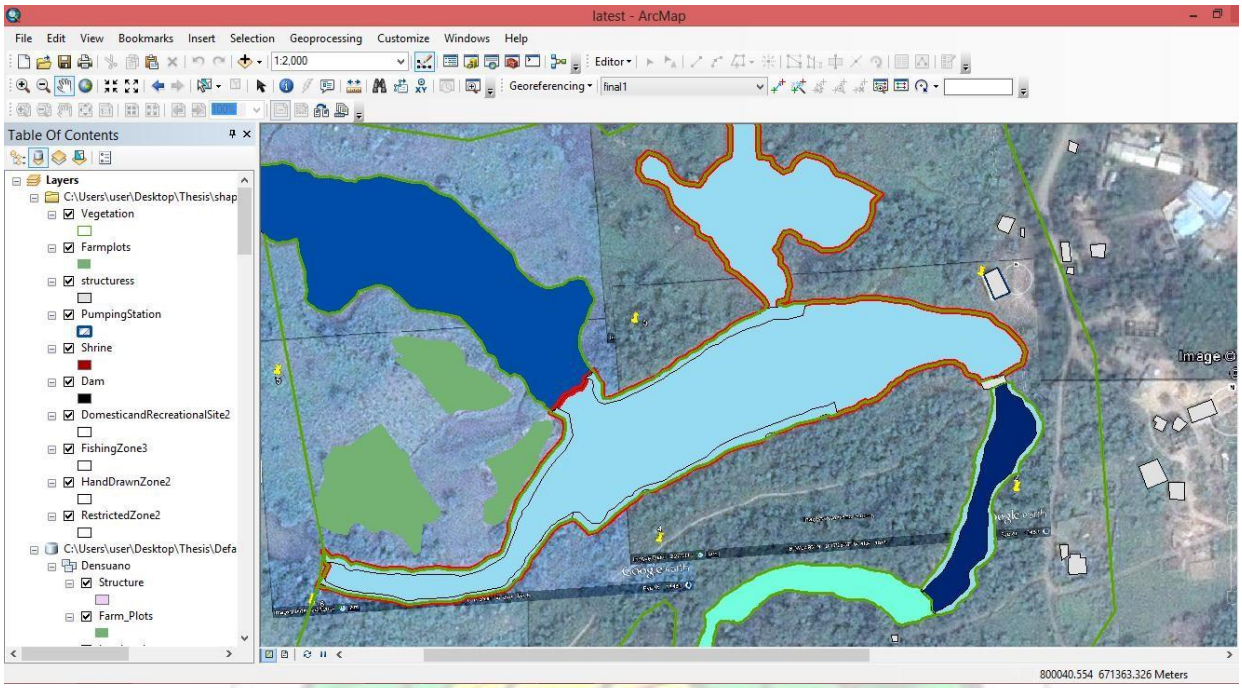


Figure22: Digitizing the Various Zones into the Created Feature Classes

Other attributes were added to the Water Resource attribute table to capture the attributes as highlighted in the physical model. A join operation was performed to link relations of “Water Resource” and that of “Stakeholder”. This provided a view that showed a relationship between each stakeholder and a designated zone. An application system was developed in order to provide an accessible Graphical User Interface (GUI) for viewing information in the geographical database created in Arc GIS. The system was designed to make use of a local server to show information about the spatial extent of the boundaries and various rights, responsibilities, restrictions and privileges related to their use. Map Guide Server is used in the development of the application system. The computer settings were adjusted in order to recognize Map Guide Server as a local host as shown in Table 2.

Table 2: Settings allowing computer to recognize Map Guide Server as Local Host

Description	Detail
Admin connection port	2810
Site connection port	2811
Web connection port	2812
Developing environment	PHP
Server site server IP address	127.0.0.1

To start the server "localhost: 8008" was selected as the server address. "Administrator" was typed in as "User name" and the "admin" was typed in as "Password" (see Figure 23).

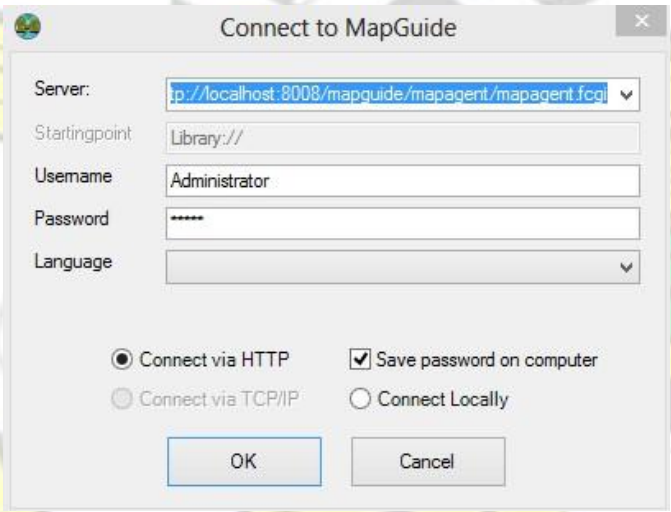


Figure 23: Login Page to Map Guide

Upon running Map Guide Maestro a folder Named "Inland Water Cadastre" was created and subsequent folders were automatically added. The sub folders added included "Data", "Layers", "Layouts", "Maps" and "Symbols".

The shapefiles of the zones representing the water rights were added as a new resource to the "Layer" sub folder. The transformational parameters were set to UTM Zone 30 N. In the "Map" sub folder a new resource named "Internal Water Cadastre" was created and the various layers

in the “Layer” sub folder were added. In the “Layout” sub folder a new resource “Application Definition” was selected and the template called Slate was chosen for viewing as shown in Figure 24.

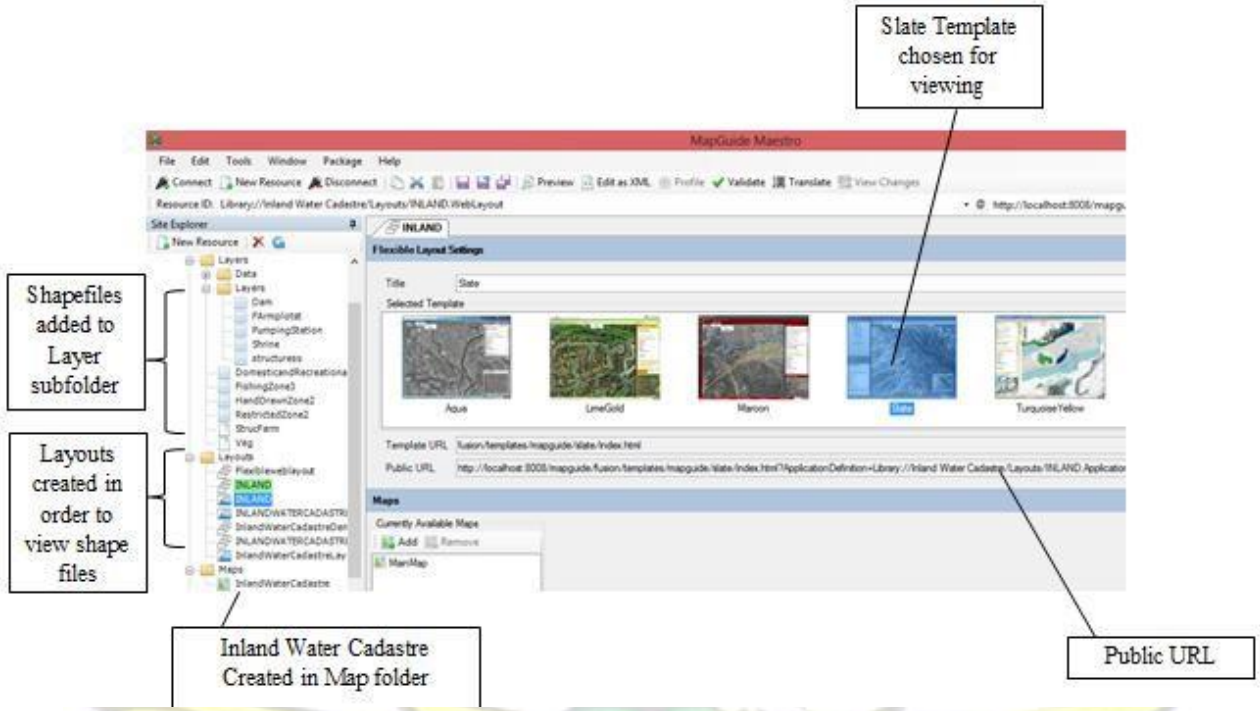


Figure 24: Map Guide Input Interface

5.3 Prototype Inland Water Cadastre

5.3.1 User interface

The user interfaces grants access to three (3) important datasets stored in the cadastral system (Figure 25). The datasets that can be accessed included general information about the Densu River Basin. Attribute information about the terms of water rights as held by different stakeholders is also accessible via the interface. The interface also provides access to shapefiles of the zones at Densuano and the immediate surrounding areas on land close to water interface.

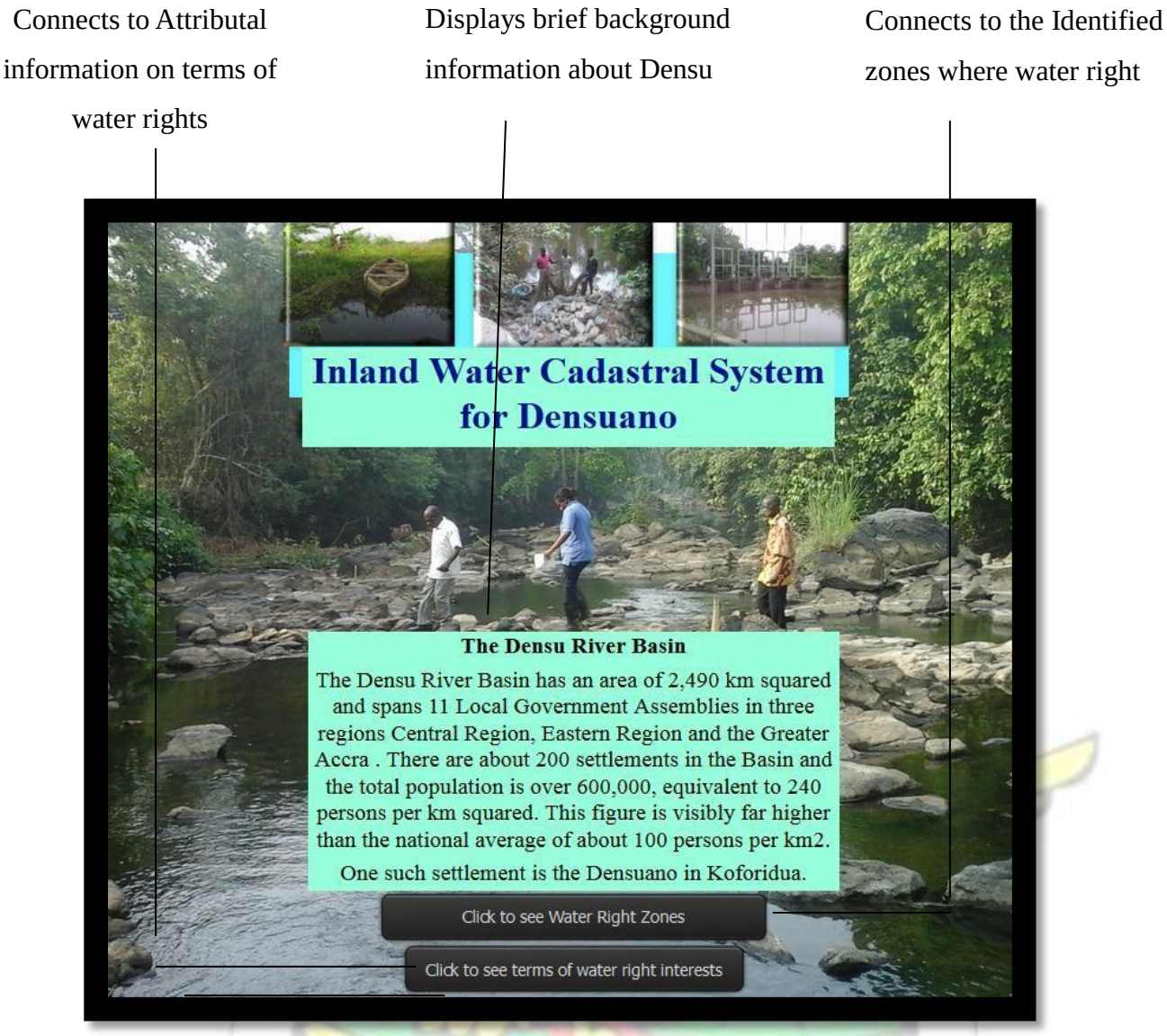


Figure25: User Interface of Inland Water Cadastre

The brief background information on Densu River Basin allows user to prior information on the characteristics of the basin under consideration. Attributal information on right holding stakeholders allows user to view the type of right being held and the underlining responsibilities, restrictions and privileges associated with the right. Dataset on the various zones where rights are held and on land use information at the water land interface allows the user to view the different zones where specific rights are held at Densuano and to examine the relationships between activities on the land water interface facilitating further spatial analysis.

5.3.2 Selection of Zones and Water rights

This application allows viewers to select a particular zone to view stakeholders and corresponding rights, responsibilities, privileges and restrictions as shown in Figure 26. The user can perform this by using spatial selection or attribute selection.

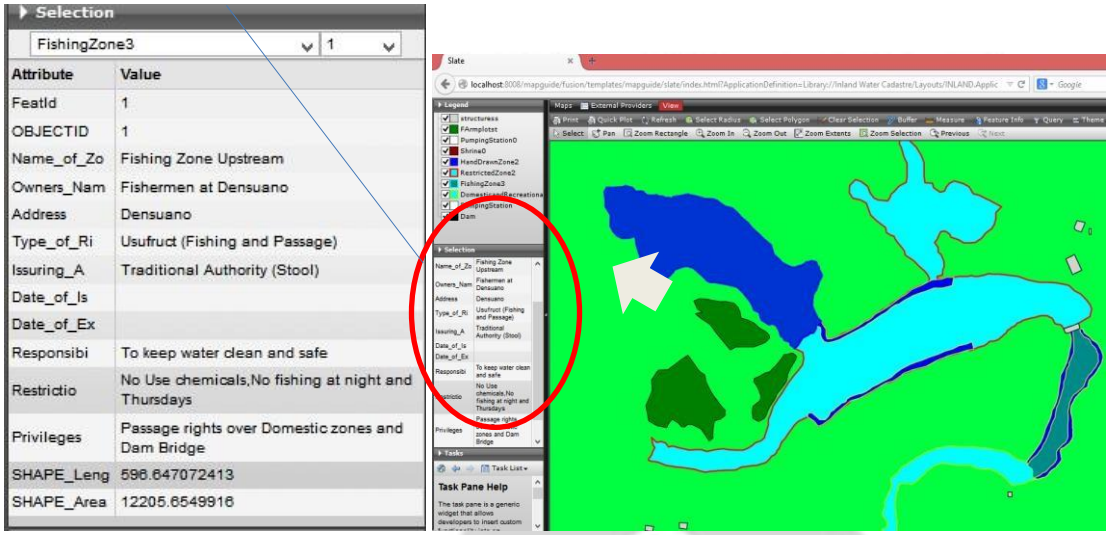


Figure 26: Selection of Zones and their Corresponding Water Rights

The cadastral system also allows smooth transition between attribute data and geographical data, giving users of the platform the opportunity to interact with the interface as shown in Figure 26.

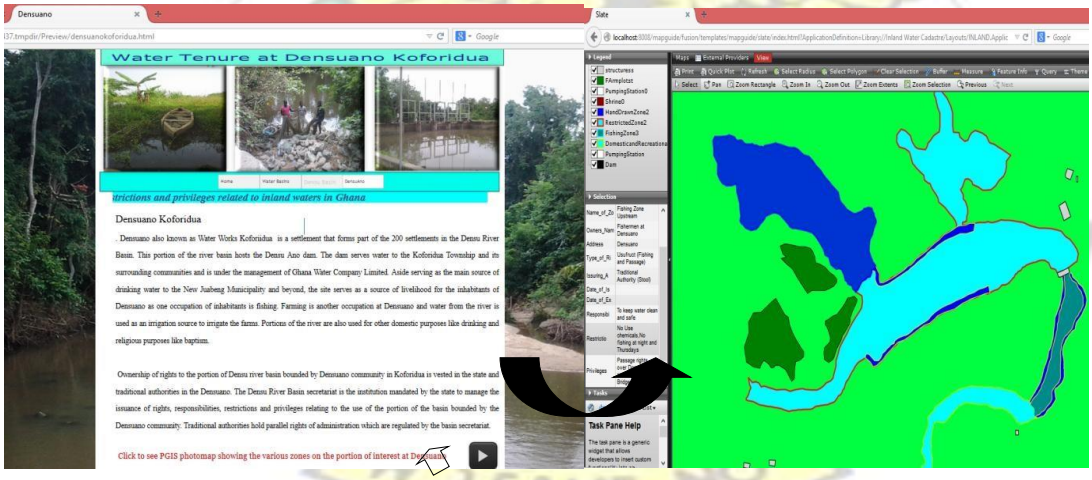


Figure 27: Transition between Attribute Information and Geographical Interactive Interface

This interface allows the descriptive and historical information about the zones to be retrieved and analyzed.

5.3.3 Buffer Analysis

The system also allows for a buffer zone of specified distance to be created around specified zones. The buffer zone policy seeks to incorporate the application of GIS to improve buffer zone management through the use of geo-referenced maps (WRC, 2013). This procedure helps to define areas restricted to certain activities. For example, Figure 28 shows farm plots as well as built structures that fall within the specified buffer zone of 15m activity free zone around a dam or reservoir.

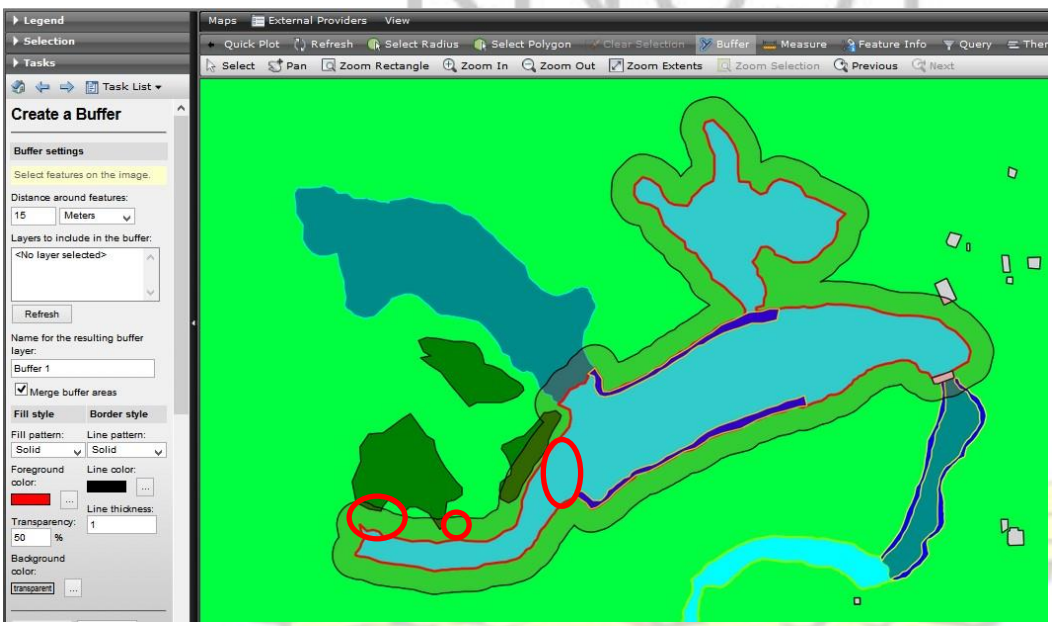


Figure 28: Buffer Analysis showing Farm Plots within 15m Restriction

Figure 29 illustrates a buffer showing a 300m restriction placed by the Town and Country Planning Department on settlements along water bodies (WRC, 2013). Performing a buffer around the area of study shows that a number of buildings are within the restricted area.

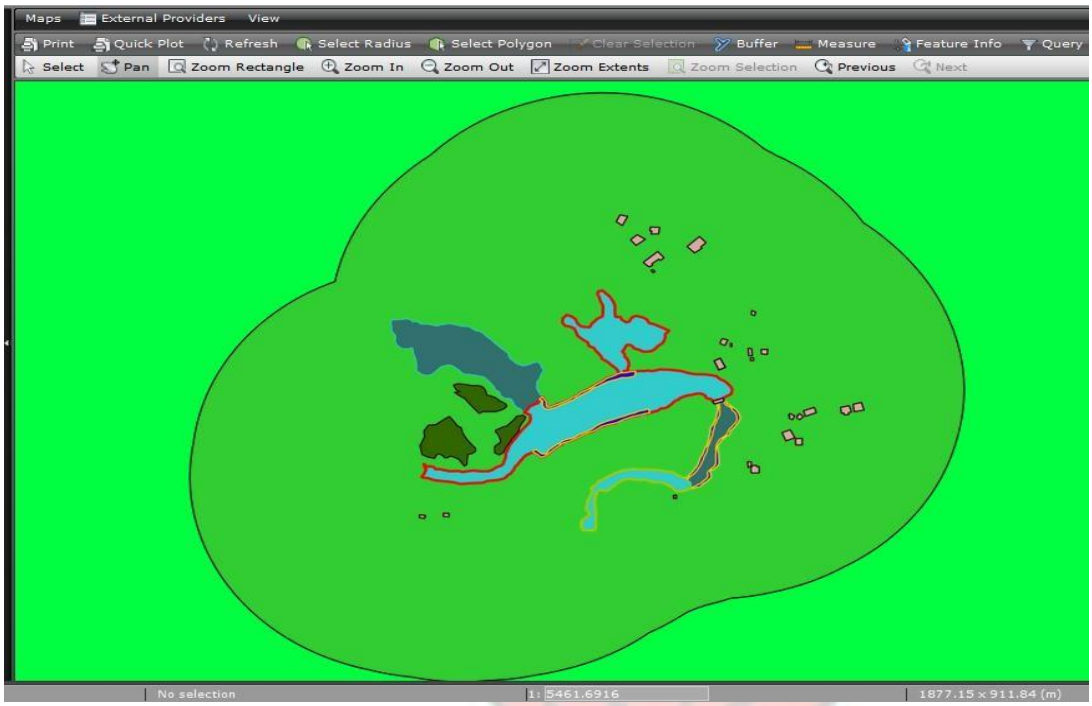


Figure29: Buildings and Settlements within the 300m Restriction Buffer

5.3.4 Maintenance of the System

The hydrological functions of the Survey and Mapping division which includes the conduction of Hydrological related surveys is mandated to champion data collection with regards to boundaries on water resources. As data managers, persons in charge must be given access rights privileges to manage and maintain shapefiles which show boundaries on water resources, and updating such information periodically as at when necessary.

5.4 Implementation Guidelines for the proposed inland Water Cadastre

The successful creation and utility of a comprehensive cadastral information system is highly dependent on technical, legal and institutional requirements as discussed below.

5.4.1 Technical Requirements

The successful implementation of the proposed inland water cadastre requires wellestablished technical requirements which include hardware and software requirements. A network of computers that would allow data sharing among information agencies and implementation agencies is required. A central server computer will be needed to serve as the point where cadastral data is stored. Client computers will also be needed nationwide in the various WRC

basin offices in order to facilitate the viewing and analysis of database. Using Internet or Intranet sites will facilitate the sharing of the data from the central server to the various client computers.

The performance of the proposed cadastre is greatly influenced by the choice of hardware and software. This is because they dictate the mode of data acquisition, data entry, data manipulation and the creation of databases. The IT market have several G.I.S software and hardware but their choice should be considered on the basis of the business processes and other issues such as data security, storage volume, complexity of data. Software would be required in order to convert the hand drawn scale maps from participatory mapping into georeferenced digital format and to update the database with attribute information. An interactive easy to use software that allows for the spatial database shared between the Central server computer and the client computers to be easily viewed and analyzed must be set in place.

The technical requirements also entail how the system will be maintained. The system must continuously be maintained and record kept up-to-date at all times to reflect the current situation. Maintenance in this case does not refer to only the content of the information in the system but also the possibility for the system to manage the changes that might occur. The security of the system is ensured by the different levels of access granted. Users at the central server are granted access to the password information to allow for updates and editing information in the database. Users at the client computers are granted only viewing access via through the WRC websites.

5.4.2 Legal Requirements

One major reason for the absence of a geographical database that shows physical extents on water bodies and corresponding rights is the absence of regulation that obligates all such surveys conducted to be copied to the Survey and Mapping Division for checks and also for record keeping. In order to implement the inland water cadastre, the legal framework must obligate all such surveys conducted to be copied to the Survey and Mapping Division. There is also the need to modify or provide legislations that will allow the use of sketch maps acquired using participatory mapping as an accepted data source for populating an inland water cadastre.

5.4.3 Institutional Requirements

For the proposed inland water cadastre to be implemented successfully, various institutions need to be structured and reformed. The collaboration between customary and statutory institutions is crucial. The existing procedure for acquiring water rights and storing cadastral data must be improved. Institutional collaborations are necessary to ensure effective interoperability.

Figure30 shows the institutional framework for the proposed inland water cadastre.

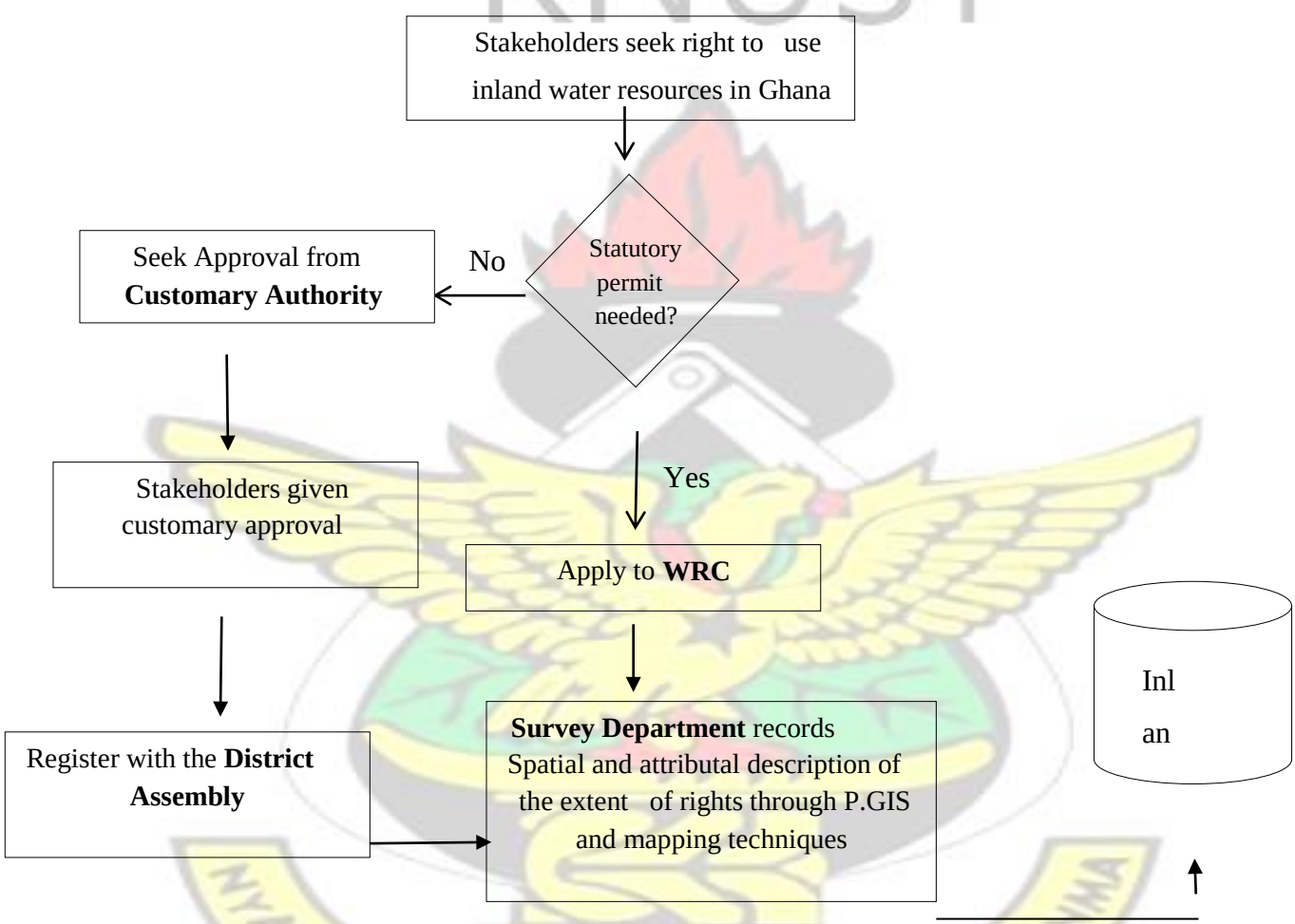


Figure 30: Institutional Framework of the proposed Inland Water Cadastre

(Source Drawn by Godwyll, 2015)

5.5 Concluding Remarks

In this chapter, the data modeling process involving, conceptual, logical and physical models were developed and implemented by developing a prototype. The functionalities of the

implemented prototype were also outlined. The technical, organizational and legal requirements needed to implement the inland water cadastre have also been discussed. These requirements must allow for the use of participatory mapping methods to collect spatial information of the water rights. The proceeding chapter concludes the research and makes recommendations for further research.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

In the introduction to this thesis, it was discussed that lack of recorded information on rights associated with use of internal water poses challenge to effective management of inland water in Ghana. The primary aim of this study is to make use of participatory mapping methods to capture and record the interests (boundaries, rights, responsibilities, restrictions and privileges) related to use of inland water resources and to use the information to develop a prototype cadastre for inland water in Ghana. The main objective was divided into four (4) specific objectives and corresponding research questions. (1) To analyse the existing system used to capture and record physical boundaries, rights, responsibilities, restrictions and privileges associated with inland water resources in Ghana. (2)To analyse whether or not participatory mapping could be used to capture and record indigenous knowledge on water rights. (3)To develop a prototype cadastral system for identifying capturing and recording interests of tenure inland water resources in Ghana. (4)To provide guidelines for implementing an inland water cadastre in Ghana.

The conclusions of the study is presented with respect to the research questions:

6.2 Conclusions

How are physical boundaries, rights, responsibilities, restrictions and privileges associated to the use of inland water resources captured and managed in Ghana?

The legal framework places priority on recording statutory rights acquired for water use and mandates all users who desire statutory rights to apply to the WRC in order to access such rights. Users who hold customary rights over water are not obliged to register their rights but are encouraged to register their rights voluntarily. This leaves a gap in information collected on water uses. Institutionally there is general lack of interoperability on data on boundaries of ownership, since information on water bodies is not referenced to the Hydrographic Department of the Survey and Mapping Division in Ghana.

Technical regulations regarding capture and record keeping of boundaries and tenure on water bodies currently differs based on the nature of the right being sort. In cases where rights are sought for various purposes, the current practice allows officials of the WRC to collect data of the point using a handheld GPS. The water register however does not display or provide information about the geographical extents of rights held by the various stakeholders.

Can participatory mapping be used to record indigenous knowledge on water rights?

The research successfully employed participatory mapping as a tool for mapping and recording indigenous knowledge on water rights. This tool ensured community participation in identifying the various zones on the water resource where various rights are held. This consequently allowed for interaction among the various water right holders and the reaching of consensus with regards to the extent of use related to rights, responsibilities, restrictions and privileges particular to each stakeholder. The locals are able to use the PGIS without any difficulty. The sketch maps represented a good reflection of how water rights are currently being held.

What cadastral system can be developed to define, capture and record interests of tenure governing inland water in Ghana?

The study confirms that there is a clear need for the development of a cadastral system that captures the various stakeholders and their corresponding interests associated with inland water bodies. The functionalities and applications of the cadastral system provide a clear picture of the various activities on water bodies and adjoining land. The system provides relevant information towards the sustainability of water resources allowing for interactive selection of specific zones and buffering operations to check for illegal structures and activities as present at adjoining land-water interface. Cadastral system needed for an inland water must be able capture the spatial extent of zones assessed and used by the various stakeholders and also record and display rights and responsibilities associated with these areas. The system developed adapts a community aided approach to effectively capture details of water tenure at the study area. The geographical and attribute data was captured by PGIS methods engaging the various stakeholders in the community practicing various rights as associated to the use of the water body. The prototype developed allows for l display of the various boundaries where activities take place on the water resource and at the same time provides an interface that allows users to interact and investigate details on ownership and use rights.

What are the requirements for implementing inland water cadastre in Ghana?

The requirements needed to support and implement inland water cadastre in Ghana has been discussed under legal, organizational and technical primitives.

A legal guideline must be capable of adapting the use of participatory methods as a tool to foster record keeping of interests associated to diverse stakeholder's rights towards water use. This will considerably prevent the gaps of information that exist on the various users and extents of rights on inland water bodies in Ghana. Proper interrelation and information flow among the various institutions associated to providing necessary information towards granting rights and record keeping must be encouraged in order to facilitate the update and relevance of the database. There must be clear technical guidelines relating to the capture and recording of information on tenure relating to rights and extents of water body usage. These technical guidelines must ensure good data maintenance and integrity, interoperability and data sharing.

Overall Conclusions

The study confirms that there is a clear need for a system that able to capture and record water rights. The study has demonstrated how participatory mapping can be used to identify and record indigenous knowledge on inland water. This information can act as a main input in developing an inland water cadastre.

6.3 Recommendations

The study focuses on participatory mapping of water usage as practiced by stakeholders in one community. The study however did not consider mapping the shared nature and rights among adjacent communities. It is recommended that the further study be conducted to identify the various physical boundaries and rights as held and administered among adjacent communities.

To further advance the functionality of the cadastral system developed it is recommended that other details such as hydrology, PH value and water profile may be added to further improve the systems multipurpose application.

The study area did not present the need to capture depth, as predominant rights of the area of interest differed only based on horizontal extents. That is to say rights did not vary based on different depths on the same surface area. Further studies may be conducted at areas which

present clear situations where rights vary based on depth in order to present a different perspective of recording such rights.

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APPENDICES

Appendix 1: Water Use Register

WATER RESOURCES COMMISSION

WATER USE REGISTER – 2013

In pursuance of Regulation 13 (6) (a) (b) of Legislative Instrument (L.I.) 1692, Water Use Regulation 2001, the Water Resources Commission hereby publishes the list of Water Rights Permit Holders, whose particulars are entered into the Water Resources Commission's Water Register as at 31st December, 2013.

No	User Name	District/Municipal/Metro	Point of Use	Type of Source	Water Use Activity	Primary Purpose	Expiry date
1	A & O Scale Limited	Dangme East	Volivo	Groundwater	Abstraction	Dredging	31-Dec-16
2	A & O Way Limited	Shama	Atwereboanda	Groundwater	Abstraction	Dredging	26-Nov-16
3	Abosso Goldfields Limited	Prestea Huni-Valley	Damang	Stream	Diversion	Mining	1-Jan-13
4	Abosso Goldfields Limited	Prestea Huni Valley	Damang	Tamang Dam	Abstraction	Mining	31-Dec-15
5	Abosso Goldfields Limited	Prestea Huni Valley	Damang	Groundwater	Abstraction	Mining	31-Dec-15
6	Abosso Goldfields Limited	Prestea Huni Valley	Damang	Groundwater	Abstraction	Mining	31-Dec-15
7	Adamus Resources Limited	Ellembelle	Nzema Gold Plant	River Ankobra	Abstraction	Mining	1-Oct-13
8	Adamus Resources Limited	Ellembelle	Salman	Bangara stream	Spillage	Mining	31-Mar-16
9	Adamus Resources Limited	Ellembelle	Salman	Groundwater	Abstraction	Mining	31-Mar-16
10	Adamus Resources Limited	Ellembelle	Salman	Groundwater	Abstraction	Mining	28-Feb-14
11	Adansi Gold Company (Gh) Limited	Amansie West	Manso Nkran	Groundwater	Abstraction	Mining	31-Oct-16
12	ADM Cocoa Ghana Limited	Kumasi Metropolitan	Kaase	Groundwater	Abstraction	Industrial	1-Jan-15
13	African Plantation for Sustainable Development	Sene	Bantama-Lailai	Groundwater	Abstraction	Irrigation/Construction/Domestic	31-Dec-15
14	Akoduro Company Limited	North Tongu	Aveyime	Groundwater	Abstraction	Dredging	31-Dec-16
15	Akosombo Textiles Limited	Asuogyaman	Akosombo	Groundwater	Abstraction	Industrial	31-Dec-15
16	AngloGold Ashanti	Obuasi Municipality	Akrofuom, Obuasi	Jimi River	Abstraction	Mining	1-Jan-14
17	AngloGold Ashanti	Wassa West	Iduapriem	Groundwater	Damming	Mining	1-Jan-13

Appendix

2: Scaled Points and Surveyed GPS Points

Description	Scaled Point from identified features on Photo Map (Northerns)	Scaled Point from identified features on Photo Map (Eastings)	GPS Surveyed Point of identified features (Northerns)	GPS Surveyed Point of identified features (Eastings)
Point 1 Tree	799688.161	671609.044	799695.288	671602.459
Point 2 Turn	799792.407	671486.277	799785.528	671479.292
Point 3 Turn	799763.832	671458.231	799763.302	671467.65
Point 4 Pump St.	799999.311	671552.423	799988.728	671553.905
Point 5 Pump St.	800007.778	671556.127	799995.607	671557.08
Point 6 Pump St.	800014.128	671542.898	800001.428	671543.851
Point 7 Pump St.	800005.661	671539.194	799994.549	671540.676
Point 8 **Middle of Dam**	800008.836	671491.569	800008.307	671495.167
Point 9 **Turn Upstream**	799780.765	671405.844	799779.707	671416.85
Point 10 **Turn Upstream**	799756.423	671407.431	799752.19	671413.146
Point 11 **Shrub on Farm**	799738.961	671442.356	799718.323	671403.621
Point 12 **Shrub on Farm**	799949.04	671348.694	799738.961	671442.25
Point 13 Shrine Pt.	799950.628	671343.402	799943.219	671348.164
Point 14 House Pt1	800008.307	671579.94	800004.074	6715669.886
Point 15 House Pt2	80014.128	671578.352	800011.482	671567.769
Point 16 House Pt3	800015.715	671586.29	800013.599	671575.707
Description	Scaled Point from identified features on Photo Map (Northerns)	Scaled Point from identified features on Photo Map (Eastings)	GPS Surveyed Point of identified features (Northerns)	GPS Surveyed Point of identified features (Eastings)
Point 17 House Pt4	800009.895	671587.348	800006.72	671577.294
Point 18 Dam edge	800022.065	671497.39	800024.711	671503.74
Point 19 Dam Edge	800003.015	671489.452	799992.432	671489.452

Appendix

Point 20 Turn	799639.594	671526.747	799641.291	671531.838

3: Residuals of GPS Surveyed Points

Description	y-y	x-x
Point 1 Tree	2.873	2.585
Point 2 Turn	-3.121	-3.015
Point 3 Turn	1.53	2.581
Point 4 Pump St.	1.183	-3.482
Point 5 Pump St.	-3.829	-3.953
Point 6 Pump St.	2.7	-2.953
Point 7 Pump St.	-1.888	-1.482
Point 8 Middle of Dam	1.529	-3.598
Point 9 Turn Upstream	1.058	-1.006
Point 10 Turn Upstream	2.233	-1.715
Point 11 Shrub on Farm	2.638	-1.265
Point 12 Shrub on Farm	3.079	4.444
Point 13 Shrine Pt.	1.409	-4.762
Point 14 House Pt1	4.233	1.054
Point 15 House Pt2	2.646	-2.417
Point 16 House Pt3	2.116	2.583
Point 17 House Pt4	3.175	-1.946
Point 18 Dam edge	-2.646	-6.35

Appendix

Point 19 Dam Edge	7.583	1.911
Point 20 Turn	-1.697	-5.091

RMSE in Northerns = 5.993 RMSE in Easterns = 6.233 4: Logical Models (Skeleton table) of Inland Water Cadastre

WRC (WRC Id , Name, Address)

Customary Authority (Customary Authority Id, Name, Traditional Head, Address, Water Resource Id Number)

WRC (WRC Id , Name, Region Address)

Water Resource (Zone Id, Name of Zone, WRC Id Number)

Water Resource (Zone Id, Name of Zone, Owners Id)

Stakeholder (Owners Id, Address , Rights, Responsibilities, Restrictions, Privileges, Date of next renewal, Zone Id)

Customary Authority(Customary Authority Id Number, Name, Sub Community, Traditional Head, Address)

Water Resources (Zone Id, Name of Zone, Name of Basin, Region of Location)