Geodata Maintenance and Collaboration in GIS Implementation in Health Sector in a Developing Country Context: The Case of DHIS2 GIS in Malawi

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Submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy (PhD)

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June 2019

Series of dissertations submitted to the
Faculty of Mathematics and Natural Sciences, University of Oslo
No. 2151

ISSN 1501-7710

Cover: Hanne Baadsgaard Utigard.
Print production: Reprosentralen, University of Oslo.

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Abbreviations and Acronyms

CHAM	Christian Health Association of Malawi
CMED	Central Monitoring and Evaluation Division
CSCW	Computer-Supported Cooperative Work
DHIS2	District Health Information Software version 2
DHMT	District Health Management Team
GIS	Geographic Information System
GML	Geography Markup Language
GPS	Global Positioning System
HMIS	Health Management Information System
IT	Information Technology
JICA	Japanese International Corporation Agency
M&E	Monitoring and Evaluation
NAC	National Aids Commission
NGO	Non-Governmental Organisation
NSO	National Statistical Office
UiO	University of Oslo
UNICEF	United Nations Children's Fund
UNIMA	University of Malawi
WHO	World Health Organisation

Acknowledgement

I would like to express my sincere gratitude and appreciation to my supervisors Professor Jens Kaasbøll and Associate Professor Petter Nielsen for their guidance, encouragement and support throughout the period of my study. I would also like to extend my gratitude to Professor Brian Nicholson, Dr. Arunima Mukherjee, Professor Jørn Braa and Dr Knut Staring for comments and guidance on my work.

My thanks go to UNICEF and Ministry of Health particularly CMED managers, DHIS2 team, HMIS officers and health program coordinators at Blantyre and Mchinji DHOs for their support during my fieldwork. My thanks also go to National Health Sciences Research Committee for approving my research in the health sector in Malawi.

My special thanks to my dear wife, Loveness, and children Christina, Alexander, Charity and Patrick Junior for the encouragement and support.

I thank my colleagues at the Department of Informatics particularly Brown, Eric, Esther, Wilfred, Flora and Manya for the support.

Last but not least, my thanks go to Mozhdeh of IFI administration, Michelle and Lynn of the Norwegian State Education Loan Fund (Lånekassen) for the administrative support during my study period.

Abstract

The thesis was motivated by the underutilisation of GIS in health in developing countries due to lack of long-term maintenance of geodata. Geodata maintenance is recognised as the central component of any operational GIS for continuously meeting new user requirements. However, the explicit description on how to perform geodata maintenance is missing in GIS literature. GIS literature has not exhaustively defined key activities except geodata collection and geographic database update. The understanding is that geodata maintenance aims at meeting new user requirements. Therefore, to define the exhaustive set of activities, key actions for the requirements analysis are to be identified and defined as part of geodata maintenance. In addition, since geodata maintenance is complex and expensive while many organisations have the shortage of local GIS expertise, key decisions are to be made on when and how to collaborate with other organisations to access such expertise at a low cost. At the same time, the user organisation is to provide opportunities for external experts to impart knowledge to local users during collaboration for the continued GIS support. Therefore, this research aimed at proposing a framework for geodata maintenance in health in developing countries and investigating the contribution of collaboration towards geodata maintenance and the building of local expertise. The study was guided by three questions: (1) What are activities of geodata maintenance in health sector in a developing country setting? (2) How can collaboration assist in the maintenance of geodata in health sector? and (3) How can collaboration contribute towards the building of local expertise for geodata maintenance in health sector?

The research was qualitative, interpretive case study using the case of Ministry of Health in Malawi. It was conducted from July 2015 to January 2017. Data was collected through the participant observation, semi-structured interviews and artefact examination. The data analysis was done during the individual paper writing and thesis writing in which the following four key steps were applied – immersion in the data, coding, creating categories and identification of themes.

It has been found that for GIS applications, the user organisation needs to perform geodata maintenance when a new demand arises; by performing six administrative and technical actions. The framework suggests doing the requirements analysis through the first three actions – *identify the need, communicating the need* and *analysing the need* – to decide whether to wait, accept or reject the change. If the decision is the acceptance, geodata update is to be carried out – *edit the model, acquire the geodata* and *edit the dataset*. Due to the scarcity of in-house expertise, geodata maintenance requires collaboration in the technical actions such as *analyse the need, edit the model* and *acquire the geodata*. However, collaboration needs to be mitigated through substituting GIS experts with local expert users.

The thesis contributes to both concept and practice. The thesis explicitly describes geodata maintenance by identifying and defining its actions and elaborating the concept of geographic database update, that is, the thesis builds the rich understanding of the concept of geodata maintenance that has partially been described in GIS literature. Practically, the thesis provides the framework for geodata maintenance in health in developing countries; highlighting key decisions including when and whom to collaborate with to leverage limited resources in the user organization, who local users to substitute for GIS experts and mechanisms of building capacity to those local users.

Chapter 1: Introduction

This chapter introduces the research topic of geodata maintenance and collaboration in the implementation of Geographic Information System (GIS) in health sector in a developing country context. The first section presents the problem area; positioning geodata maintenance and collaboration in the context of GIS implementation. The second section presents the aim and questions of this research, followed by the theoretical perspective in the third section. The research approach is introduced in the fourth section. The fifth section lists papers that have been developed as part of this research, followed by the research contributions in the sixth section. This chapter ends with the structure of thesis in the seventh section.

1.1 Problem Area

A review of public articles on GIS in health from 1991 to 2011 demonstrates the growing importance of GIS in the health literature in both developed and developing countries (Lyseen et al., 2014). Despite experiencing the growth of GIS use in health, the observation is that the implementation of this technology is facing numerous challenges particularly in developing countries (Fisher and Myers, 2011; Fletcher-Lartey and Caprarelli, 2016; Lyseen et al., 2014). One limitation that contributes to the underutilisation of GIS in health in developing countries is lack of long-term maintenance of databases (Fletcher-Lartey and Caprarelli, 2016). Scholars have emphasised the importance of data maintenance in GIS implementation. Longley et al. (2015) state that in the GIS implementation, after completing basic data collection the focus should move on to data maintenance. Huisman and de By (2009) point out that one critical component for any functioning GIS is its ability to manage data that involves data storage and maintenance. However, in GIS literature, the concept of spatial data (geodata) maintenance is not explicitly described as briefly discussed in the following subsection.

1.1.1 Geodata Maintenance

The thesis uses the term *geodata* as the type of data being geographically referenced in some consistent manner using, for example, latitudes and longitudes, national coordinate grids, or postal codes (Awange and Kiema, 2013). GIS is different from other information systems because additionally GIS deals with geodata. That is, GIS is not useful without geodata (Huisman and de By, 2009; Longley et al., 2015). Geodata, as the resource, has a value that is to be maximised. In this research, the value of geodata is in the form of a solution to a GIS problem or satisfaction of a GIS need. The value of geodata is held in its properties – thematic elements (i.e. attributes), spatial elements (i.e. space or location), temporal elements (i.e. time and events), and relationships between spatial features (Longley et al., 2015) – that need to be well defined and continuously maintained in order to meet GIS needs. To achieve this, it is the issue of data maintenance. The process of data maintenance in an organisation may lead to improved and new usage of the data thereby leveraging its value. Although space is dominant, time is critical to understanding phenomena as events that appear and disappear in space over time. Attributes represent elements that are not geometrical and are used, for example, in queries, analyses and visualization of spatial data. Relationship between spatial features is also important and its degree of importance depends on an application of GIS.

Huisman and de By (2009, p. 153) defines spatial data maintenance as “the combined activities to keep the data set up-to-date and as supportive as possible to the user community.” However, literature has not exhaustively defined these activities. In literature of geodata maintenance, the focus has been on the geodata collection and update of geographic databases (Huisman and de By, 2009; Longley et al., 2015). Huisman and de By (2009) state that data maintenance deals with obtaining new data and update existing data sets to meet the requirements imposed by data users and as well as due to the real world change. Likewise, Longley et al. (2015) state that geographic database is transactional that is constantly updated as new data arrive. Two actions, geodata collection and geographic database update, have been explicitly discussed in literature (Huisman and de By, 2009; Longley et al., 2015). In order to reach a time to collect geodata and update a geographic database, firstly, the user organisation needs to get and analyse a user demand or a real world change that would guarantee a change in geodata. In addition to geodata collection and update, the thesis argues that it is important to identify and define other activities for handling new requirements in order to have a complete set of activities. These two actions (i.e. geodata collection and update) are a subset of geodata maintenance. The key challenge is that the explicit description on how to perform geodata maintenance is missing in GIS literature. Therefore, there is a need to develop a framework which can guide organisations in health on how to perform geodata maintenance. A clear and well-specified management regime is critical in the maintenance of data (IGGI Working Group, 2005).

As in any other GIS initiative, to perform activities of geodata maintenance, the user organisation requires adequate resources. In the long-run, geodata maintenance is complex and expensive (Longley et al., 2015). In developing countries, one most frequently cited concern is the shortage of local expertise in GIS implementation (Fletcher-Lartey and Caprarelli, 2016; Kim, Sarker and Vyas, 2016; Msiska, 2009; Sipe and Dale, 2003). To keep GIS sustainable, one important requirement is for the user organisation to have individuals who are committed, empowered and enthusiastic for the continued support and maintenance of data and technology (Cavric, Nedović-Budić and Ikgopoleng, 2003; Longley et al., 2015). This implies that geodata maintenance is one GIS initiative that requires adequate expertise. Thus, the following subsection briefly discusses key challenges of GIS expertise in developing countries that can lead to collaboration between organisations.

1.1.2 GIS Expertise and Collaboration

The thesis perceives *expertise* as special knowledge, skill and experiences held by a person in a specific domain (Germain and Ruiz, 2008). GIS needs people with adequate knowledge, skills and experiences. As Longley et al. (2015) point out, GIS cannot be operational without people who design, program and maintain it; who supply it with data; and who interpret its results. In organisations, knowledge and skills of employees in using computer systems have become a critical factor for successful use of information technology (IT) (Munkvold, 2003). Longley et al. (2015) argue that staff as assets should function well both individually and as well as a team; otherwise nothing of merit would be achieved.

If the user organisation lacks the needed GIS expertise, it may hire external GIS experts or collaborate with other organisations to access such expertise in order to build capacity for GIS activities

(Fletcher-Lartey and Caprarelli, 2016; Longley et al., 2015). However, hiring external GIS experts appears expensive (Cavric et al., 2003; Fletcher-Lartey and Caprarelli, 2016; Longley et al., 2015) and it is usually beyond the reach of budgets of most health departments in developing countries (Sipe and Dale, 2003). Scholars have suggested collaboration between organisations as one way of addressing the issue of limited GIS expertise in developing countries (Fletcher-Lartey and Caprarelli, 2016; Kim et al., 2016; Ramasubramanian, 1999). One reason to collaborate is to leverage limited resources of organizations (Berkowitz, 2000). Generally, the word *collaboration* means that two or more stakeholders work jointly to achieve a particular goal (Kotlarsky and Oshri, 2005).

In information systems, collaboration is not a new phenomenon. In most studies of collaborative work practices in information systems, including health information systems (Chawani, 2014; Fitzpatrick and Ellingsen, 2013; Shidende, 2015), the focus has been on the design of technologies and knowledge acquisition. In the context of GIS, apart from technology and people, data element of GIS is also important. In the context of geodata, studies have explored collaboration particularly in spatial data infrastructure (Castelein, Bregt and Grus, 2013; McDougall, 2006; Othman, Bakar and Mahamud, 2017). Especially in developing countries, existing collaboration initiatives are mostly on the geodata collection as organisations are implementing their GIS applications (Othman et al., 2017). As stated in the previous subsection, the geodata collection is just one activity of geodata maintenance; other activities may (not) need collaboration. However, the understanding is that collaboration changes overtime (Bedwell et al., 2012) while geodata maintenance is an ongoing process that will continuously need GIS expertise within the lifespan of a GIS application. The long-lived GIS applications usually require the continued administration of spatial change and the sustained availability of geodata (Huisman and de By, 2009), that is, GIS requires staff who continuously supply it with geodata (Longley et al., 2015).

Apart from the financial challenges, heavily depending on external GIS experts brings knowledge-related challenges particularly when external GIS experts go because all knowledge and high-level expertise go with them (Cavric et al., 2003; Longley et al., 2015). Hence, it is a necessity to build local expertise to continue supporting the implemented GIS. Ramasubramanian (1999) argues that it is vital to make sure that knowledge created during the GIS implementation is left behind with local users to continue using and supporting the system. Drees and Heugens (2013) emphasise on the in-house capacity building to mitigate the dependence of the user organisation on the external environment. However, to leave the created knowledge behind with local users, the user organisation needs to provide opportunities for knowledge sharing between external GIS experts and local users. For instance, Botswana government experienced problems in the GIS implementation because it heavily depended on the foreign professionals without involving local counterparts and without effective mechanisms for the transfer of skills and knowledge (Cavric et al., 2003).

In developing countries, access to training is considered as the key mechanism for building in-house expertise which is vital for sustained use and maintenance of resources including geodata (Cavric et al., 2003; Fletcher-Lartey and Caprarelli, 2016; Kim et al., 2016; Meaden, 2013). However, apart from training, there are other opportunities of sharing knowledge such as structured work teams, technology-based systems, social networks and personal relationships (Amayah, 2013; Ipe, 2003; Willem and Buelens, 2007) on which GIS literature in developing countries has limited discussions.

The thesis argues that through collaboration it is possible to build structured work teams of, social networks and personal relationships between external GIS experts and local users, which may lead to the building of local expertise.

1.1.3 DHIS2 GIS in Malawi

Since, this research has used the case of DHIS2 GIS implementation in Malawi, this subsection briefly describes the DHIS2 GIS in the context of the national health management information system (HMIS) and why geodata maintenance seems to be a necessity. The thesis also includes key GIS initiatives since 2002, when Ministry of Health had been implementing the desktop GIS as one technology for strengthening its HMIS. Some important activities related to geodata and expertise were carried out before the commencement of DHIS2 GIS implementation.

This research was conducted in the health sector in Malawi from 2015 to 2017. Collaborations in GIS implementation have been taking place at the national level. HMIS was introduced in 2002 with the primary objective of providing up-to-date information for policy makers, planners, researchers, and health program managers that would allow guidance in the planning, development, monitoring and evaluation of health. HMIS is an information system for health management at different administrative levels (Asangansi, 2012), which aims at ensuring appropriate and effective use of resources (Garrib et al., 2008). Ministry of Health is usually in collaboration with other organisations, both local and international, in the implementation of different technologies to strengthen HMIS such as DHIS2 in 2012 and DHIS2 GIS in 2015.

District health information software version 2 (DHIS2) is used as the central data repository in Malawi's HMIS. DHIS2 (www.dhis2.org) is a web-based platform for collection, validation, analysis, and presentation of aggregate and patient-based statistical data, tailored (but not limited) to integrated health information management practices. This system is used at the district and national levels. At the district level, the main users are HMIS officers (who are data managers and also provide technical support to HMIS users) and health program coordinators. At the national level, the main users are the management of Central Monitoring and Evaluation Division (CMED), health program managers and DHIS2 programmers. DHIS2 programmers are IT professionals deployed to CMED on secondment from collaborating organisations.

In 2015, Ministry of Health through CMED commenced the implementation of DHIS2 GIS (GIS as the module built in DHIS2) in collaboration with other organisations. Thus, the thesis focuses on the implementation of DHIS2 GIS as the process involving activities necessary to put the GIS technology into practice and incorporate into operations of HMIS. This GIS is not a standalone information system but embedded in another information system, i.e. DHIS2. The installed DHIS2 GIS has the geodata of about 10,000 health facilities out of which 90% are village and outreach clinics at the community level; collected in collaboration with other organisations such as ICF International and UNICEF. This means that Ministry of Health in Malawi is now the custodian of such volume of geodata that needs to be continuously maintained for supporting the DHIS2 GIS in indefinite future; that is, the ministry is responsible for the maintenance of its geodata to meet new user demands and/or real word changes when they arise. Since the DHIS2 GIS supports multiple health programs having unique requirements, Ministry of Health is expecting to collect and maintain other spatially referenced cultural, social, environmental, biological and physical data apart from those of health facilities. Ministry of Health has no any documentation to articulate how its geodata should be maintained. Therefore, there is a need to explore what key activities Ministry of Health should carry out in geodata maintenance including decisions to be made and allocation of important resources.

1.2 Research Aim and Questions

From the brief discussions in the previous section, geodata maintenance is considered as one important function in GIS implementation in health in developing countries. The key challenge is that the explicit description on how to perform geodata maintenance is missing in GIS literature. In addition, since geodata maintenance can be complex and expensive and many organisations in health sector in developing countries have the shortage of local GIS expertise, one decision that should be made is when and how to collaborate with other organisations to access GIS expertise at the low cost, on the one hand. On the other hand, during collaboration, the user organisation is to provide opportunities for external experts to impart knowledge to local users for the continued GIS support when collaboration is no longer in existence. Therefore, this research aimed at proposing a framework for geodata maintenance in health in developing countries and investigating the contribution of collaboration towards geodata maintenance and the building of local expertise. To achieve these aims, the thesis seeks to address the following three questions.

The first research question relates to the understanding of the concept of geodata maintenance; building a framework for geodata maintenance by identifying and defining its activities.

RQ1. What are activities of geodata maintenance in health sector in a developing country setting?

The second question relates to the role of collaboration in geodata maintenance; identifying which activities may require collaboration.

RQ2. How can collaboration assist in the maintenance of geodata in health sector?

The third question relates to the local expertise; exploring the role of collaboration in the local expertise building.

RQ3. How can collaboration contribute towards the building of local expertise for geodata maintenance in health sector?

1.3 Theoretical Perspective

In this thesis, resource dependence theory has been adopted in which the concept of *dependence* has been applied. This theory has been used to explain how external resources may have affected the behaviour of Ministry of Health in geodata maintenance and local GIS expertise building. In other words, resource dependence theory has guided this research in understanding how the scarcity of critical resources, that are geodata and GIS expertise, has driven Ministry of Health in Malawi to collaborate with other organisations in GIS implementation and how it has managed to build its own geodata and GIS expertise. Three concepts – resource criticality, scarcity and replaceability – were used. The *resource criticality* determines the ability of the organisation to continue functioning in the absence of the resource and in this research, it has been used to determine the importance of geodata and GIS expertise in the operational DHIS2 GIS. The *resource scarcity* is the extent of the availability of the resource and has been used to assess the shortage of geodata and GIS experts in Ministry of Health that leads to collaboration and what causes such shortage. The *resource replaceability* is the extent to which the organisation can substitute sources of the same resources. In this research, the resource replaceability has been used to identify any innovative ways that Ministry of Health has put in place to reduce dependence on the external environment to access geodata and expertise and how collaboration has contributed towards introducing those innovative ways.

1.4 Research Approach

This is the qualitative research being guided by the philosophical assumptions which relate to the underlying epistemology. The research applied the interpretive methods in order to build a rich understanding of the context of geodata maintenance and collaboration in health sector and the process whereby the geodata maintenance could influence and been influenced by the context. The research has adopted a case study strategy with the aim of investigating geodata maintenance and collaboration within the real life context. Data was collected through participant observation, interviews, and artefact examination. The unit of analysis is Ministry of Health at the national level as the focal organisation.

1.5 List of Papers

The empirical findings are presented in four papers listed below.

Paper 1: Chikumba, P. A. and Chisakasa, G. (2018) Towards Geodata Maintenance: A Case of DHIS2 GIS Implementation in Malawi. *Journal of Health Informatics in Development Countries,* Vol. 12, No. 2

Paper 2: Chikumba, P. A. Acquiring Geodata and Expertise in GIS Implementation for Health Management in Malawi: The Role of Collaboration. *Under review in Journal of Information Systems and Technology Management*

Paper 3: Chikumba, P. A. (2017) Exploring Integrative Approach of GIS Implementation: The Case of GIS in Health Management in Malawi. Paul Cunningham and Miriam Cunningham (Eds): IST-Africa 2017 Conference Proceedings, IIMC International Information Management Corporation

Paper 4: Chikumba, P. A. and Naphini, P. (2018) GIS Initiatives in Health Management in Malawi: Opportunities to Share Knowledge. T.F. Bissyande and O. Sie (Eds.): *AFRICOMM 2016*, *LNICST 208*, pp. 263–272, https://doi.org/10.1007/978-3-319-66742-3_25

1.6 Research Contributions

The thesis contributes to both the concept and practice of geodata maintenance in health in developing countries. The thesis builds the rich understanding of the concept of geodata maintenance that has partially been described in the work of Huisman and de By (2009) and Longley et al. (2015) by explicitly identifying and defining its actions. The thesis has identified and articulated three administrative actions (*identify the need, communicate the need, analyse the need*) and three technical actions (*edit the model, acquire the geodata, and edit the dataset*). In addition, the technical actions were derived from the concepts of geodata capture (i.e. *acquire the geodata)* and geographic update (i.e. *edit the model* and *edit the dataset*); however, action of *edit the model* has been extended by incorporating software customisation.

Practically, the thesis provides the framework for geodata maintenance in health in developing countries; highlighting key decisions including when and whom to collaborate with to leverage limited resources in the user organization and also which local users to substitute for GIS experts and mechanisms of building capacity to those local users.

1.7 Structure of Thesis

The rest of the thesis is as follows. Chapter 2 discusses the related literature on geodata and expertise as resources and collaboration. The chapter also draws the theoretical framework from resource dependence theory. The context in which the study was conducted is described in Chapter 3. Chapter 4 discusses the research methodology including data collection and analysis techniques. The research findings are presented in Chapter 5. Chapter 6 contains discussions. The thesis ends with contributions and conclusions in Chapter 7.

"Getting GIS properly implemented is an extremely important part of the total GIS adoption process" (Meaden, 2013, p. 81). Sieber (2000) states that GIS implementation involves activities necessary to put GIS into practice and incorporate into existing and developing operations of an organisation. Since there are different thematic areas for GIS and organisations of different sizes or purposes, different organisations have different GIS implementation strategies or approaches (Meaden, 2013); ranging from the large, complex, highly coordinated enterprise-wide efforts of many local governments to the small, independent GIS implementations found in some areas of companies (Somers, 2008). Regardless of a strategy the user organisation can decide, every GIS is structured around five fundamental components – data, people, hardware, software and procedures (Fletcher-Lartey and Caprarelli, 2016; Huisman and de By, 2009; Longley et al., 2015). However, as mentioned in Chapter 1, the emphasis of this thesis is on geodata and expertise as they are more of an impediment to GIS implementation than technical constraints (Dawes and Eglene, 2008; Meaden, 2013; Ramasubramanian, 1999). Convey and Dewey (2008) argue that simply acquiring a GIS system cannot automatically guarantee its successful implementation in an organisation. Meaden (2013) points out that the failure of GIS implementation is mainly due to non-technological factors. Therefore, in the context of health sector in developing countries, this chapter discusses geodata and expertise as important resources; and the debate on important challenges of accessing such resources in the first and second sections. Collaboration as one way of mitigating the scarcity of resources has been discussed in the third section. The fourth section presents the concept of *dependence* that has been used to conceptualise collaboration.

2.1 Geodata as the Important Resource

GIS literature emphasises that geodata are fundamental to any community that uses GIS, that is, GIS is not useful without geodata (Huisman and de By, 2009; Longley et al., 2015). GIS is different from other information systems because additionally GIS deals with geodata. Geodata determine types of questions or problems that may be answered or solved by GIS. Thus, for successful operational GIS, an organisation must have the access to geodata. At the beginning of a GIS project, one important task is the initial data collection using techniques such as data transfer, sharing and capture as discussed in the following subsection.

2.1.1 Geodata Acquisition

Longley et al. (2015) point out that at the start of GIS implementation, one major decision must be made; whether to build a database from primary and secondary sources (data capture) or buy part or all of a database (data transfer). However, some data sets are freely available as part of national and global spatial data infrastructures (SDI). Despite its importance, geodata capture is one of the most time-consuming and expensive tasks whose costs can go up to 85% of the cost of GIS implementation (Longley et al., 2015). Hence, in developing countries, many organisations prefer data transfer or sharing to data capture due to their limited local capacities as frequently cited in GIS literature (Cavric et al., 2003; Fletcher-Lartey and Caprarelli, 2016; Kim et al., 2016; Ramasubramanian, 1999).

Data transfer or sharing – This is to obtain the geodata from external sources, which may be less time-consuming and less risky than the data capture. As Awange and Kiema (2013, p. 22) point out, "Geodata may be collected by both government organisations as well as private agencies … be shared and re-used by different users and applications." One preferable way to find geodata is to search the Internet using geoportals or specialist geo-libraries (Longley et al., 2015). However, this method faces challenges such as some datasets having service copyright restrictions placed on their use; not fitting for the purpose; and incompatibility among others (Gelagay, 2017; Huisman and de By, 2009; Longley et al., 2015). In the health, Fletcher-Lartey and Caprarelli (2016) emphasise that the availability of good quality data is an essential consideration for the use of GIS applications to ensure that policies and practices are informed by the best available evidence. If shared geodata are not of good quality, they are likely not be used in a GIS application and thus, this forces the user organisation to capture required geodata in-house through the use of primary and/or secondary data capture techniques.

Primary data capture – This involves the collection of geodata in digital format through, for example, the use of global positioning system (GPS), ground surveying and remote sensing from satellite; specifically for the use in a GIS project. This is the direct measurement of objects that can either be input directly into the geographic database or reside in a temporary file prior to input. Longley et al. (2015) argues that although the option of direct input is preferable because it minimizes the amount of time and possibility of errors, the close coupling of data collection devices and geographic databases is not always possible. Thus, geodata require to be converted to the format suitable for entry into a GIS application (Barrington et al., 1994; Huisman and de By, 2009). For instance, GPS data are usually transferred from GPS gadgets to a certain software application such as Excel before inputting into the geographic database. This temporary file can also be used for sharing geodata.

Secondary data capture – This is the conversion of digital and analogue datasets that were originally captured for another purpose into a suitable digital format for the use in a GIS project through scanning for raster data and digitizing for vector data (Longley et al., 2015). Despite the significant increase in the availability and sharing of digital data sets, in some cases, real data objects of interests in a GIS application are to be constructed out of the captured data (Huisman and de By, 2009). Once geographic data is in the digital format, it becomes powerful resource and its use may go beyond the original purpose.

Capturing attribute data – Geodata have thematic elements (attribute data) that need to be captured, which is usually straightforward process than capturing spatial elements. Longley et al. (2015) argue that although attributes can be collected at the same time as spatial elements, it is usually more cost-effective to capture attributes separately because attribute data capture is relatively simple task that does not require expensive hardware and software systems and can be undertaken by lower-cost clerical staff.

After completing the initial data collection, the focus should move on to data maintenance (Longley et al., 2015), particularly for long-lived GIS applications that usually require the continued administration of spatial change and the sustained availability of geodata (Huisman and de By, 2009). Therefore, the next subsection discusses the concept of geodata maintenance.

2.1.2 Geodata Maintenance as Central Component of GIS

Huisman and de By (2009) suggest four functional components of a GIS application namely data capture and preparation, storage and maintenance, manipulation and analysis, and data presentation. They argue that "the system should not be called a geographic information system if any one of these components is missing" (Huisman and de By, 2009, p. 144). As illustrated in Figure 2-1, data storage and maintenance are perceived as the central component of a GIS application upon which data manipulation, analysis and presentation depend. A geographic database is used to store data in a GIS application, which Longley et al. (2015) define as any database that contains geographic data for a particular area or subject. Puri (2003) considers GIS as both a database system with specific capabilities for spatially referenced data and a set of operations for working with this data. The function of GIS is based on a database that different users use to meet various information needs (Fradelos et al., 2014), that is, the database forms the basis for all query, analysis, and decision-making activities (Longley et al., 2015).

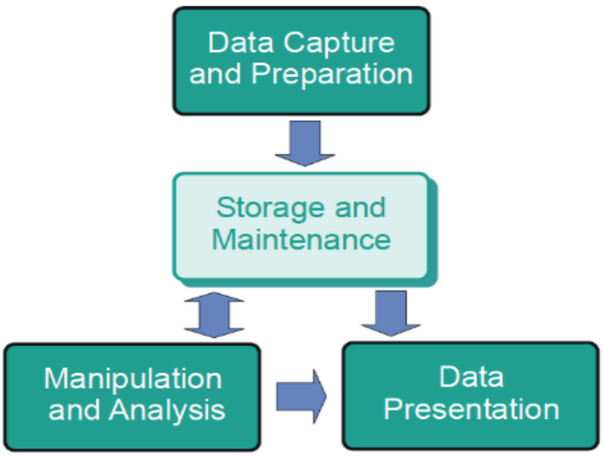

Figure 2-1: Functional Components of GIS
(Source: Huisman and de By, 2009, p. 145) – Arrows indicate the data flow in the system

The geographic database should be continuously maintained during the life-time of a GIS application so that data quality is not diminished. As stated in Chapter 1, the geodata maintenance is perceived as a set of combined activities for keeping the data set up-to-date and as supportive as possible to the user community (Huisman and de By, 2009). In literature of geodata maintenance, the emphasis has been on the geodata acquisition and update of geographic databases. The geographic database is usually updated once geodata is acquired. Cavric et al. (2003) point out that some critical aspects of the GIS implementation process are development of base data and application of affordable methods for database update. Geodata maintenance deals with obtaining new data and entering them into a database (Huisman and de By, 2009). Longley et al. (2015) state that a geographic database is transactional that is constantly updated as new data arrive.

According to Longley et al. (2015), *geographic database update* is taken as any change to geometry (i.e. spatial elements), attributes (i.e. thematic elements), object relationships, or database schema.

Two main types of database schema are logical database schema that conveys the logical constraints to the stored data and physical database schema that lays out how data is physically stored. The physical database schema is a collection of database tables for holding data values and relationships between them, which is usually created using the data definition language of database management system (DBMS) software; in most cases, structured query language (SQL) with geographic extension (Longley et al., 2015).

In the health sector in developing countries, with the availability of cheaper and more user friendly GIS technology, regular updating of data has now become broad practice in many organisations (Fletcher-Lartey and Caprarelli, 2016) since these organisations are custodians of geodata. However, any update on the geographic database is for addressing a particular requirement that the data users impose or due to the real world change (Huisman and de By, 2009). In practice, some requirements are hardly implemented due to factors mainly related to the scarcity of resources. This implies that the requirements analysis is vital to determine the feasibility of geodata maintenance. It is important for the user organisation to decide how user needs should be efficiently and effectively implemented and sustained. In GIS, as in any other information system, the requirements analysis provides the detailed information necessary for the implementation of user needs, including the examination of future uses of the system, work processes and information technology environment (Meaden, 2013; Somers, 2008). Thus, the thesis argues that apart from the geodata acquisition and geographic database update, geodata maintenance requires other activities related to the requirements analysis. However, a framework explicitly stating key actions and how they should be carried out to guide organisations in health on performing geodata maintenance is missing in GIS literature.

According to British Standards Institution (2010), *maintenance* is the combination of technical, administrative and managerial actions aimed at retaining an item in a state in which it can perform a required function. Hence, the thesis perceives the combined activities stated in the definition of geodata maintenance (Huisman and de By, 2009) as the combined technical and administrative actions for keeping the data set up-to-date and as supportive as possible to users of a particular GIS application in which the data set is (to be) used. In this research, technical actions are taken as actions that need GIS specific knowledge while administrative actions do not necessarily need that type of knowledge. GIS specific knowledge is scientific knowledge inscribed in GIS including database system with specific capabilities for managing spatially referenced data and a set of operations for working with this data (Puri, 2007). The geographic database update and geodata acquisition are taken as technical actions because they need the scientific knowledge of database systems and geodata together with its related technologies. Hence, the thesis considers geographic database update and geodata acquisition as the subset of geodata maintenance.

To build the rich understanding of geodata maintenance, the thesis has applied the concept of geodata completeness which is one of properties of data quality. Therefore, the next subsection describes the concept of geodata completeness and how it has been used to understand geodata maintenance.

2.1.3 Geodata Completeness: Conceptualising Geodata Maintenance

Geodata for a particular GIS application require being complete and well matched with existing data so that they can be properly integrated. The concept of *geodata completeness* refers to the exhaustiveness of set of spatial features and their attributes in the geographic database with the relation to the universe of all objects (real world) (Jackson et al., 2013; Yang, 2007). When geodata are not complete, (i.e. there exist either omissions or commissions), geodata maintenance is probably required. Basically, *omission* means that some required spatial features and/or their attributes are not included in the geographic database while *commission* means that extra spatial features and/or their attributes, which are not necessarily required, are included in the geographic database (Yang, 2007). Omission and commission are referred to as under-representation and over-representation of the reality respectively (Jackson et al., 2013). The reality is made up of real world phenomena.

The completeness of geodata is generally assessed at two levels: model and data completeness (Joksic and Bajat, 2004; Yang, 2007). According to Yang (2007), *model completeness* is the commission or omission relationship between the spatial features in the model world and those in the reality. Huisman and de By (2009) refer to *model* as a representation of some part of the real world and geographic databases are one important class of models. The thesis perceives the geographic data modelling as a way of achieving the model completeness. The geographic data modelling is taken as the process of abstracting or simplifying the real world phenomena (Huisman and de By, 2009; Longley et al., 2015). According to Longley et al. (2015), a data model is a set of constructs for representing objects and processes in the computer and it is an essential element of any operational GIS. Since different people use GIS for different purposes and the phenomena they study have different characteristics, right decisions should be made about what features should be modelled and how they should be presented in GIS (Longley et al., 2015). The model completeness is application dependent in the sense that the model world is created for a particular GIS application (Yang, 2007) and therefore, it is an aspect of the fitness-for-use (Joksic and Bajat, 2004). This implies that this type of completeness is achieved if user requirements are properly analysed or problems to be solved are clarified. This can be possible through data modelling in which both users and system developers participate in the process leading to a common understanding of the requirements (Longley et al., 2015). The clarity in problem definition is critical in GIS implementation (Ramasubramanian, 1999).

In the context of geographic database update, the update on models can be taken as any changes to database schema and object relationships. These changes usually influence the data manipulation, analysis and presentation (see Figure 2-1). Hence, decisions on data model to be adopted are vital in GIS implementation because the way the real world is modelled has a strong influence on the types of analyses that can be undertaken (Longley et al., 2015). Due to advances in GIS software, the concern of editing database schema is taken care of, for example in DHIS2 GIS. Since GIS is inbuilt in DHIS2, the deployment of GIS is completely within the architecture of DHIS2 in terms of database and tools for integration, analysis and visualisation. DHIS2 GIS allows the integration of health data collected in DHIS2 with geodata stored in the same database and the setting up of DHIS2 GIS is basically a matter of populating coordinates of the organisation units in the database and immediately maps are available in the GIS module (Braa and Sahay, 2012).

Once required spatial features have been modelled, the user organisation is expected to acquire required geodata and capture into the geographic database. At this stage, the data completeness is to be assessed in order to determine which geodata is to be acquired. According to Yang (2007), *data completeness* refers to the commission or omission relationship between datasets and their attributes defined in the model world and those available in the digital data or geographic database. The assessment of data completeness influences the geodata acquisition and changes on spatial and thematic elements in the geographic database in response to reported problems or demands. Data completeness is application independent, and hence, digital data can be shared and re-used in various contexts. Taking the study of Saugene and Sahay (2011) in Malawi as an example, there was an omission of geodata for some health districts in the geographic database. The health system in Malawi has twenty-nine health districts but the geodata used in that study had only twenty-five health districts in the geographic database although the missing four were required. The health district as the spatial feature was modelled but its digital data was not complete.

From the perspective of geodata completeness, the thesis has applied three aspects – the reality, the model world, and the digital data – to understand the geodata maintenance. The reality assists in the definition of an application domain of GIS through identifications of essential spatial features and their relationships based on given GIS user needs. Requirements imposed by users or the real world change that guarantee geodata maintenance are within a particular application domain. As Puri (2007) points out, any given information system is designed for a particular application. The model world helps in identifying thematic and spatial elements of the spatial features for a GIS application. The thesis perceives the process of creating the model world to achieve the model completeness as the requirements analysis. The implementation of the model world is through the action of changing object relationships and/or database schema as the part of geographic database update. The aspect of digital data is for defining the actual geodata for the GIS implementation and two actions of geodata acquisition and of changing spatial and/or thematic elements as the part of geographic database update are carried out.

In summary, this section has discussed geodata maintenance as the central component of GIS for meeting new user requirements, which is the set of combined actions for keeping the data set up-to-date. However, GIS literature has not exhaustively defined these actions except geodata collection and geographic database update. In this section, requirements analysis has been recognised as one key component of geodata maintenance that thesis aims to discuss.

Geodata maintenance as the combination of technical and administrative actions requires people with different expertise. Hence, the next section discusses GIS expertise as the important resource particularly knowledge domains and shortage of GIS experts in developing countries.

2.2 GIS Expertise as Important Resource

People are the most important part of GIS who overcome shortcoming of the other fundamental elements of GIS – data, hardware, software and procedures – and therefore, they need adequate knowledge and skills in order to manage these elements. GIS, as any other information systems, requires committed, empowered and enthusiastic staff and users for the continued support and maintenance of data and technology (Cavric et al., 2003; Longley et al., 2015). People require certain knowledge and skills in order to use and apply GIS properly to solve real world problems (Campbell and Shin, 2011; Longley et al., 2015). Longley et al. (2015) suggest three key groups of people who are typically involved in day-to-day GIS operations as briefly described below.

- The GIS team – This team comprises of the dedicated GIS staff with a GIS manager as the team leader. The team leader needs to have understanding of GIS technology and the organisation business to handle liaisons involved.
- The GIS users – Typically, these users include professional users who utilise output from the GIS for their professional work; clerical and technical users who perform tasks such as data collection, map creation, routing and service call response.
- The external consultants – These include strategic advisors, project managers and technical consultants to supplement the available staffing.

However, most government agencies in developing countries are unable to recruit the dedicated GIS staff due to various factors, one of which is the lack of finances. In literature of GIS in developing countries, identifying a 'champion' within the organisation is considered as the most significant step a government agency can take to implement effective GIS (Convey and Dewey, 2008). Champions are not necessarily experts in GIS but they understand potential benefits and capabilities of GIS; that is, according to Meaden (2013), champions in some way pursue the use and adoption of GIS and foster its growth and development within their respective organisations. Hence, organisations need to hire services of GIS experts from somewhere else, that is, hiring the external consultants. For example, in the study by Convey and Dewey (2008), they found out that GIS implementation in Pennsylvania Local Governments was championed by township managers but the actual work was managed by the hired GIS engineers who served as the GIS managers.

Since GIS is a special case of information systems, special knowledge and skills are necessary that may be referred to as GIS expertise. However, "there is more to expertise that just acquiring the right knowledge and skills" (Bourne, Kole and Healy, 2014, p. 2). Germain and Ruiz (2008) recognise four dimensions of expertise: knowledge, skills (including critical and problem solving skills), experience, and domain specificity. From this perspective, Germain and Ruiz (2008) perceive expertise as the combination of knowledge, skills and experience held by a person in a specific domain. Thus, in this thesis, *GIS expertise* is taken as the combination of knowledge, skills, and experiences required by people, to perform different tasks of geodata maintenance effectively and efficiently in health sector. To build the understanding of GIS expertise, the following subsection discusses knowledge domains in GIS implementation, followed by discussions on ways of mitigating the shortage of GIS expertise in developing countries.

2.2.1 Knowledge Domains in GIS Implementation

Several analytical techniques in the application of GIS require from basic to advanced skills (Fletcher-Lartey and Caprarelli, 2016) and people have various skills depending on the roles they perform in GIS (Longley et al., 2015). Basically, all GIS applications have basic mapping and spatial analysis tools that can be mastered even by users with no programming skills (Fletcher-Lartey and Caprarelli, 2016). Some people are responsible for providing the user/customer support while others provide the support on operations, data management and application development (Longley et al., 2015). Hence, these people may require different knowledge and skills depending on specific roles they play. According to Longley et al. (2015), in the user support provision, key tasks include technical support and problem logging that require the support staff to have both GIS system analyst and administrative skills. In the case of the operations support, the system administration is involved that is a highly technical and mission-critical task requiring dedicated, properly trained and paid people (Longley et al., 2015). Longley et al. (2015) state that people involved in the data management are responsible for ensuring that all data meet all standards of accuracy, integrity, and compatibility required by the organisation as well as planning future data resource. Application developers are also needed in GIS to enhance existing applications as well as developing new ones for new users and new project areas starting to adopt GIS (Longley et al., 2015). Knowledge required in GIS projects can be in four domains – technology, application, implementation, and community specific knowledge (Puri, 2007) – and their key characteristics are briefly described below.

Technology specific knowledge – This is the case of scientific knowledge inscribed in information systems. Software development is based on scientific and technical rationalities and in the case of GIS, its roots are in the scientific principles of cartography and mathematics (Puri, 2007). Arising from the fact that GIS is designed to work with geodata, it is both database system with specific capabilities for managing spatially referenced data and a set of operations for working with this data (Puri, 2007). Campbell and Shin (2011) state that GIS software is the special type of computer program that is capable for storing, editing, processing, and presenting information as maps. GIS needs also special peripherals for data input and (e.g. scanners, digitizers, global positioning system (GPS)), data output (e.g. plotters), data storage and processing (Huisman and de By, 2009; Longley et al., 2015). According to Puri (2007), technology specific knowledge is explicit, considered universally applicable, rational, analytical objective, codifiable, and hence transferable.

Application specific knowledge – This is the knowledge specific to any particular application since any given information system is designed for a particular application (Puri, 2007). GIS requires an organisation that defines the context and all necessary procedures of managing the system (Huisman and de By, 2009; Longley et al., 2015). In this thesis, the application domain is the health management in developing countries and application specific knowledge derives from specific parameters relating to health management including knowledge related to GIS. Application specific knowledge requires input of relevant knowledge from potential users. As in the participatory design, users are expected to be involved in the information system design (Chawani, 2014) with the aim of mutual-learning between designers and users. Particularly, in GIS implementation, both potential users and system developers participate in the process of spatial data modelling leading to a common understanding of the requirements (Longley et al., 2015). Puri (2007) states that application specific knowledge is needed to identify relevant spatial and non-spatial data required to address the application domain, which is drawn on the accumulated experience of prior scientific work in similar applications.

Implementation specific knowledge – This is the case of the resource manager's knowledge. Puri (2007) perceives resource managers as the group of people responsible for the introduction of new technologies. Puri (2007) gives an example of the staff of government-supported projects as resource managers who are responsible for liaison between the scientists/technologists and the community responsible for the resources, the use of which is being addressed through the new technology. This type of knowledge is built upon bureaucratic rules, guidelines, and financial norms prescribed by government and/or international donor agencies (Puri, 2007).

Community specific knowledge – This is the case of indigenous knowledge that is acquired by local communities through the accumulation of experiences, informal experiments, and intimate understanding of the environment in a given culture (Puri, 2007). It is context-specific and embedded in everyday practices of members of the community. Developing indigenous knowledge is recognised as one characteristic of the successful GIS implementation in developing countries. Ramasubramanian (1999, p. 375) notes that "the development of local, context-specific knowledge about the theory and practice of GIS is vital to successful GIS implementation."

As discussed above, geodata maintenance involves both administrative and technical actions, which may require these four types of knowledge. GIS technology specific knowledge is highly required in the technical actions of geodata collection and geographic database update. Even in GIS software application modifications to support new spatial data models, such type of knowledge is essential. In the case of requirements analysis, the involvement of potential users may lead to the generation of application and implementation specific knowledge. Even local communities may be involved in some cases that generate community specific knowledge, because events from which health data is recorded happen in local communities.

2.2.2 Mitigating Shortage of GIS Expertise in Developing Countries

In developing countries, one of the most frequently cited concerns is the shortage of local GIS experts for the successful GIS implementation in various sectors (Cavric et al., 2003; Kim et al., 2016; Ramasubramanian, 1999) including the health sector (Fletcher-Lartey and Caprarelli, 2016; Msiska, 2009; Sipe and Dale, 2003). The shortage of local experts has resulted in organisations to depend on the external consultants. The external consultants are brought in as a valuable addition to GIS projects since they are often well trained and highly focused (Fletcher-Lartey and Caprarelli, 2016; Longley et al., 2015). However, these external consultants appear expensive (Fletcher-Lartey and Caprarelli, 2016; Longley et al., 2015). As Sipe and Dale (2003) point out, the shortage of local GIS experts can be due to the fact that they are beyond the reach of budgets of most health departments.

Scholars have suggested the local capacity building as one way of mitigating the shortage of local GIS experts. Although in developing countries organisations can have access to the external GIS experts, the extensive reliance on them can create problems in the long-run (Cavric et al., 2003) particularly when they go because all knowledge and high-level expertise go with them (Longley et al., 2015). Therefore, it is vital to make sure that knowledge created during the GIS implementation is left behind with local users to continue using and supporting the system (Ramasubramanian, 1999). For example, Botswana government experienced problems in the GIS diffusion because it heavily depended on the foreign professionals without involving local counterparts and without effective mechanisms for the transfer of skills and knowledge (Cavric et al., 2003).

Access to training is considered as the key to building in-house expertise (Cavric et al., 2003), which is vital for sustained use and maintenance of resources (Fletcher-Lartey and Caprarelli, 2016). It is a requirement of keeping GIS users up to date with progress and developments in GIS and knowing where they can return to for help and guidance (Meaden, 2013), which can be met through continuous user training. Fletcher-Lartey and Caprarelli (2016) point out that both persons and sources of training are crucial in the identification of training capacity.

According to Meaden (2013) training can be basically thought of in terms of four main perspectives:

1) *needs for training* – the purpose of training that may involve GIS users building or expanding the range of GIS-based knowledge and skills;
2) *sources of training* – the types of organisations and individuals who are in a position to deliver training;
3) *medium of delivering training* – how training is to be provided or given, for example, via manuals, the Internet or in person;
4) *types of training* – in-house training, training organised by other organisations; short courses or long-term training like university degrees. Where training cannot be conducted locally or in-house, a suitable and sustainable alternative should be identified that may require strong links and collaboration with academic institutions and industrial partners (Fletcher-Lartey and Caprarelli, 2016).

Apart from formal training programmes, there are other formal and informal opportunities to share knowledge among individuals and groups leading to the building of in-house expertise. On the one hand, formal opportunities, also known as 'formal interactions' or 'purposive learning channels', are designed to explicitly acquire and disseminate knowledge, which include training programs, structured work teams, and technology-based systems (Ipe, 2003). Willem and Buelens (2007) further group formal opportunities into formal systems and lateral coordination. Formal systems are any kind of coordination that is planned and formally established, such as formal procedures, rules, manuals, and formal processes while lateral coordination is not planned in advance, for example, teamwork, liaison roles, task groups, and mutual adjustments. According to Willem and Buelens (2007), lateral coordination may be more flexible and timely knowledge sharing than the formal system that has limited potential for enhancing knowledge sharing although it is considered to have a low cost. Generally, formal opportunities are able to connect a large number of individuals and allow for the speedy dissemination of shared knowledge, especially through electronic networks and other technology-based systems (Ipe, 2003).

On the other hand, informal opportunities include personal relationships and social networks that facilitate learning and sharing of knowledge and even help individuals develop respect and friendship that may influence their behaviour (Ipe, 2003). In public organisations, according to Willem and Buelens (2007), there is a need for voluntary, natural, and spontaneous personal networks with high levels of personal connectivity and social identity and low levels of management control to allow knowledge sharing. Ipe (2003) points out that the most amount of knowledge is shared in informal settings, that is, through the relational learning channels.

From discussions above, apart from training, there are other opportunities of sharing knowledge such as structured work teams, technology-based systems, social networks and personal relationships on which GIS literature in developing countries has limited discussions. The understanding is that when external consultants are available during the GIS implementation it is possible to build structured work teams of, and social networks and personal relationships between external GIS experts and local users, which may lead to the building of local expertise. Ramasubramanian (1999) emphasises on making sure that knowledge created during the GIS implementation is left behind with local users. However, possibly not all actions of geodata maintenance can be carried out by local non-GIS experts, particularly technical actions that require advanced GIS technology specific knowledge. Hence, external GIS experts are still needed and this leads the organisation to go into collaboration with other organisations in order to access necessary expertise since most organisations in developing countries are unable to recruit their own GIS experts due to financial constraints, for example. Sirmon, Hitt and Ireland (2007) state that forming strategic alliances with organisations having the desired knowledge can be valuable to the user organisation for learning new knowledge. Hence, the next section builds the understanding of collaboration and how it is conceptualised in this thesis.

2.3 Understanding Collaboration

According to Thomson and Perry (2006), collaboration can be viewed from two different perspectives: (1) as a process that aggregates private preferences into collective choices through self-interested bargaining, that is, organisations enter into collaborative agreements to achieve their own goals; and (2) as a process that treats differences as the basis for deliberation with the aim of building mutual-understanding, a collective will, trust, sympathy and the implementation of shared preferences. The later perspective is the focus in this thesis.

2.3.1 The 4 Cs – Communication, Cooperation, Coordination and Collaboration

Before defining *collaboration*, this subsection differentiates between collaboration and other related concepts – communication, cooperation and coordination. Bedwell et al. (2012, p. 134) point out that “Unpacking what constitutes collaboration requires clear articulation of how it is distinct from other commonly used terms.” Communication, cooperation and coordination cannot be ignored when discussing collaboration, that is, collaboration involves communication, cooperation and coordination. Bedwell et al. (2012) mention the teamwork as another related term to collaboration.

Communication – Martin, Nolte and Vitolo (2016) state that communication is critical ingredient of collective action in which messages are transmitted from one organisation to another or part of organisation. Communication is a process by which information is exchanged between individuals promoting the sharing of knowledge. This may result in building necessary expertise for GIS implementation, for example. For the effective communication, information should be collected and shared in a usable way (Martin et al., 2016).

Teamwork – Bedwell et al. (2012) differentiate between teamwork and collaboration in terms of the level of analysis; that is, teamwork exclusively involves individuals within one team while collaboration can involve individuals, groups, units and organisations. They argue that collaboration can exist at a level beyond a team, which means that not all collaborative activities can be classified as teamwork.

Cooperation and coordination – Both represent inter-organisational relationships. However, they have different characteristics and are applied differently (McDougall, 2006; Sowa, 2008; Thomson and Perry, 2006). Sowa (2008) states that cooperation involves personal relationships between management and staff in different organisations with informality and lack of formal structure while coordination involves independent multiple organisations working together to coordinate their services, yet remain fundamentally independent from each other. Bedwell et al. (2012) emphasise that coordination does require reciprocity as in collaboration. They state that cooperation is somehow hard to fully separate from collaboration as compared to coordination; however, they consider cooperation as an attitudinal construct that helps to facilitate the process of collaboration. (McDougall, 2006, p. 59) concludes that "collaboration between organisations may be seen as an extension and/or the inclusion of both cooperation and coordination."

Table 2-1 illustrates differences between collaboration and other related constructs.

Table 2-1: Differences between Collaboration, Teamwork, Cooperation and Coordination (source: Bedwell et al., 2012, p. 135)

Constructs	**Level of analysis**	**Evolving**	**Process**	**2 or more social entities**	**Actively and reciprocally participate**	**Achieving at least one shared goal**
Collaboration	Multiple	√	√	√	√	√
Teamwork	Team only	√	√	√	√	√
Coordination	Multiple	√	√			√
Cooperation	Multiple	√			√	√

2.3.2 Definition of Collaboration

Different researchers have defined collaboration differently.

Wood and Gray (1991) provide clarity towards understanding of collaboration and they state that "collaboration occurs when a group of autonomous stakeholders of a problem domain engage in an interactive process, using shared rules, norms, and structures, to act or decide on issues related to that domain" (p. 146). According to Wood and Gray (1991), stakeholders of a problem domain consists of the groups of organisations having an interest in the problem domain.

As expansion to Wood and Gray's definition of collaboration, Thomson, Perry and Miller (2007, p. 25) define collaboration as "a process in which autonomous or semi-autonomous actors interact through formal and informal negotiation, jointly creating rules and structures governing their relationships and ways to act or decide on the issues that brought them together; it is a process involving shared norms and mutually beneficial interactions." Thomson et al. (2007) perceive collaboration as a multidimensional, variable construct composed of structural dimensions (governance and administration), social capital dimensions (mutuality and norms), and one involving agency (organizational autonomy).

However, the thesis has adopted the definition of Bedwell et al. (2012) who refer to collaboration as

> "an evolving process whereby two or more social entities actively and reciprocally engage in joint activities aimed at achieving at least one shared goal" (p. 130).

From this definition, Bedwell et al. (2012) suggest five characteristics of collaboration as briefly described below.

- *Evolving process* – Bedwell et al. (2012) take collaboration as active process that can improve and change over the course of its life cycle; that is, it involves interpersonal interactions and relationships that change overtime.
- *Involving two or more social entities* – Social entities include individuals, groups, organisations, or even societies (Bedwell et al., 2012), which can also be referred to as stakeholders (Wood and Gray, 1991) or actors (Thomson et al., 2007). In this research, the focus is on collaboration between organisations as stakeholders of a particular problem domain (Wood and Gray, 1991).
- *Reciprocity* – All involved entities should work interdependently and contribute sufficiently towards reaching their joint aims (Bedwell et al., 2012). Collaboration is accomplished through voluntary agreements and mutual adjustments between organisations and it is based on a need for and willingness to work together (Axelsson and Axelsson, 2006). In collaboration, it is assumed that there will be balance, harmony, equity and mutual support and benefits of forming a linkage far exceed its disadvantages (Oliver, 1990).
- *Participation in joint activities* – Collaboration is considered as an approach for sharing resources and solving problems and associated with action-oriented or execution task activities (Bedwell et al., 2012). Collaboration should have agreed-upon standards of action and shared rules and norms between the organisations working together, which govern how the joint activity will progress over time Sowa (2008). Collaboration requires clear understanding of roles and responsibilities of each participating organisation (Fraser et al., 2015).
- *Shared goal* – One key element of collaboration is the existence of a shared goal (Bedwell et al., 2012). Collaboration requires common and unique purpose (Fraser et al., 2015). In collaboration, organisations pursue common or mutually beneficial goals (Dedekorkut, 2004).

There are at least three critical issues to be addressed in collaboration: the preconditions that make collaboration possible and motivate stakeholders to participate; the process through which collaboration occurs; and the outcomes of the collaboration (Wood and Gray, 1991). In this thesis, the interest is on the determinants of collaboration as the preconditions to identify reasons for depending on other organisations and the capacity building as one positive outcome of collaboration since one concern is to mitigate the shortage of in-house expertise.

2.3.3 Determinants of Collaboration

The preconditions of inter-organisational relationships are reasons (or causes) and conditions including environmental and organisational factors that influence establishment of linkages or exchanges between organisations. Based on the integration of literature on organisational relationships from 1960 to 1990, Oliver (1990) proposes necessity, asymmetry, reciprocity, efficiency, stability, and legitimacy as critical contingencies of relationship formation. Dedekorkut (2004) also suggests factors that motivate inter-organisational collaboration as organisational goals, environmental uncertainty, mutual interdependence, legitimacy, fragmented jurisdictional structure, legal or regulatory requirements, and resource scarcity of which most factors are similar to those proposed by Oliver (1990). Oliver (1990) argues that the decision to collaborate is usually based on multiple contingencies or factors, despite each being a separate and sufficient cause of collaboration. Since this thesis takes collaboration as the reciprocal and voluntary support between organisations, the following determinants of collaboration have been briefly described.

Organisational goals (reciprocity contingency) – Organisations can collaborate in order to pursue common or mutually beneficial goals and interests (Dedekorkut, 2004). As reciprocity contingency, it is assumed that there will be balance, harmony, equity and mutual support and benefits of forming a linkage far exceed its disadvantages, for example the loss of decision-making latitude and cost of managing the linkage (Oliver, 1990).

Environmental uncertainty (stability contingency) – There are several conditions that result in environment uncertainty, which can be reduced through collaboration; for example, resource scarcity, lack of perfect knowledge about environmental fluctuations, and availability of exchange partners in an organisational field. According to Oliver (1990, p. 246) “the formation of relations often has been characterized as an adaptive response to environmental uncertainty” by achieving stability, predictability, and dependability in relations of organisations with others.

Resource scarcity (asymmetry contingency) – Organisations will voluntarily collaborate when they are faced with the threat of resource loss or they want to expand in terms of resources, power and task domains in order to prevent future crises (Dedekorkut, 2004). However, instead of forming expected collaboration, resource scarcity may result in organisations trying to exert power over other organisations that control the required scarce resources, which Oliver (1990) refers to as asymmetry contingency.

Mutual interdependence – In some cases, organisations collaborate in order to build a collective capacity to reduce unintended consequences due to turbulent conditions and they have realized the interdependence of their goals and interests (Dedekorkut, 2004). In government setting, agencies are dependent on each other for information, resources, and policy decisions (McDougall, 2006).

Fragmented jurisdictional structure – Division of responsibilities among multiple, separate agencies, each having a unique purpose, but lacking a coherent policy or integrated policy has resulted in a fragmented service system particularly in government (Dedekorkut, 2004), which is a barrier in government service efficiency, responsiveness and use of scarce resources (McDougall, 2006). Jurisdictions may seek much cohesive structures through collaboration (McDougall, 2006).

2.3.4 Collaboration and Capacity Building

Researchers have suggested different criteria for judging success of collaboration. Gray (1989), as cited in Dedekorkut (2004), states that success of collaboration is assessed through the objective and subjective criteria. The objective criteria focus on reaching and implementing agreements while the subjective criteria involve the satisfaction of participants on collaboration. Similarly, success of collaboration can be assessed in terms of outcome and process criteria. Outcome criteria assess whether collaborating partners are approaching their goals as expected while process criteria assess whether collaborating partners are satisfied with the collaboration process (Dedekorkut, 2004).

From organisational literature, the benefits (or simply positive outcomes) of inter-organisational collaboration include acquiring and accumulating competencies; gaining resources such as time, money, information and legitimacy; shared risk; gaining influence over the domain rather than a loss of autonomy; ability to manage uncertainty; combined effort to solve problems rapidly and efficiently (McDougall, 2006). This thesis focuses on the capacity building, which is identified as a successful outcome measure of collaboration (Dedekorkut, 2004) with the aim of understanding the contribution of collaboration towards geodata maintenance and GIS expertise building.

Capacity building has been conceptualized in many ways and associated with different meanings (Crisp, Swerissen and Duckett, 2000) and frequently discussed in the development literature (Adam and Urquhart, 2007). *Capacity building* is referred to as a process of strengthening the abilities of an organisation, its people and systems to perform core functions effectively, efficiently and sustainably with the aim of achieving objectives and fulfilling mission of the organisation (CIPP, 2015; PEPFAR, 2012). Crisp et al. (2000) state that capacity building involves the provision of financial and other resources to organisations from external sources with the aim of increasing the self-sustaining ability of people to recognize, analyse and solve their problems by effectively controlling and using resources.

Capacity building can be viewed from different perspectives, which PEPFAR (2012) perceive as individual/workforce, organisational and system/policy level capacity building. At the individual level, capacity building activities are to improve the performance of staff according to defined competencies and job requirements through, for example, training and education, that is, generally through knowledge sharing. The organisational level capacity building involves the strengthening of internal organisational structures, administrative systems and processes, and resource mobilization in order to improve the ability of organisation to finance, plan, manage, implement and monitor core functions and services. Capacity building activities at the systems and policy level focus on the external environment in which organisations and individuals function. Therefore, capacity building can be assessed in different ways and at different levels in different contexts. For example, in the study of Dedekorkut (2004, p. 45), capacity building was assessed "through acquisition of new resources (technology, labour, funds, or equipment), acquisition of knowledge, information, or expertise, and acquisition of knowledge that results in new decision-making structures and/or processes."

The thesis has adopted individual and organisational capacity building in regards of the maintenance of geodata and building of local expertise through collaboration. Availability and accessibility of IT capacity for technology implementation, use and maintenance is one of concerns for long-term sustainability of health information systems in developing countries (Manda, 2015). Manda (2015) argues that without the right capacity at both individual and organisational levels, it is hard to take advantage of implemented technological solutions and maintain them over time. Particularly in health, collaboration between organisations is a fundamental component of an effective capacity building strategy through which the resources required to plan and implement various activities may emerge (Crisp et al., 2000).

2.3.5 Involvement in Collaboration

To identity roles and responsibilities of collaborating partners in geodata maintenance, the thesis has applied *involvement in collaboration* that, according to Lawrence, Hardy and Phillips (2002), focuses on the internal dynamics of the collaboration; the ways in which the collaborating organisations relate to each other. Lawrence et al. (2002) suggest three dimensions of examining the involvement of organisation in collaboration: (1) the pattern of interactions among collaborating organisations, (2) the structure of the coalition formed by collaborating partners, and (3) the pattern of information sharing among collaborating partners. Lawrence et al. (2002) have developed these three dimensions through the application of the work on structuration of DiMaggio and Powell (1983). Although these dimensions are interdependent, each captures an important characteristic of the collaborative relationship. The brief description of each dimension is presented below.

The pattern of interactions – This is in two dimensions – the depth and the scope of interactions (Lawrence et al., 2002). The depth of interactions involves only the focal organisation and its collaborating organisations, which ranges from shallow (i.e. interactions restricted to the top level management of the focal organisation to its counterpart at another organisation) to deep (i.e. interactions extended to other personnel from the focal organisation and the collaborating organisation). The scope of interactions includes the third parties, which ranges from narrow (i.e. the focal organisation interacts with only its collaborating organisations) to broad (i.e. the focal organisation also interacts with third parties during the collaboration). A third party can be seen as an organisation that is not directly involved in collaboration but it has some contributions towards collaboration through a collaborating organisation. For instance, organisation A and organisation B are in collaboration to carry out a particular project and organisation B has sourced funds for the project from organisation C. In this context, organisation C is taken as the third party.

The structure of coalition - Lawrence et al. (2002) have identified three distinct structures – donations, partnerships and representation. In the case of donation, the focal organisation receives funds or other forms of help from collaborating organisations in aid of particular activities; in partnerships, the collaboration is characterized by a new coalition in which the focal organisation and its collaborating organisations work together to carry out particular activities while in representation, the coalition involves collaborating organisations representing each other's interests to outside parties (Lawrence et al., 2002). The partnership is one form of collaborative arrangement that relies on the participation of parties with the purpose to work toward shared goals through the agreed division of labour and it is often formalised. As McDougall (2006) puts it, partnerships are generally at the higher end of the collaboration continuum, which usually operate through formal agreements and have specific goals. Carnwell and Carson (2005, p. 6) perceive a partnership as "a shared commitment, where all partners have a right and an obligation to participate and will be affected equally by the benefits and disadvantages arising from the partnership."

Information sharing – In collaboration, collaborating organisations expect to learn from each other in one way or another. Lawrence et al. (2002) have identified three patterns of information flow – unidirectional, bidirectional and multidirectional. According to Lawrence et al. (2002), in the unidirectional information flow, one collaborating organisation learn from the other; in the bidirectional information flow, all collaborating organisations learn from each other while in the multidirectional information flow, collaborating organisations and third parties learn from each other.

2.3.6 Collaboration in Information Systems Development

As pointed out in Chapter 1, in information systems development and implementation projects, collaborations between stakeholders always exist. Users, designers and developers, with their own unique group and individual perspectives, need to interact in order to understand how the information system being developed will co-exist with, and ideally support patterns of work activities, social groups, and personal beliefs (Sonnenwald, 1995). Initially, the information systems staff and the user community each have a knowledge base not well known to the other (Abdelhak, Grostick and Hanken, 2014). According to Sonnenwald (1995), in collaboration between designers and users, designers may learn about user work domains while users may discover the possible implications of emerging technology in their work domains. Likewise, users and developers may collaborate to determine how the new information system is to be implemented (Sonnenwald, 1995). When designing and implementing a new information system, it is important to speak common language with users and other stakeholders (Halonen, 2004). The understanding is that information systems development and implementation are fundamentally interactive processes that require communication among stakeholders or participants such as users, designers and developers (Sonnenwald, 1995). This aims to learn from each other, that is, *mutual learning*. Shidende (2015, p. 46) states that the aim of mutual learning is to create "shared understanding between practitioners and designers in organized settings of collaboration, whereby practitioners try to learn technological features and IT professionals strive to learn about users' work practices." Users and developers or designers are expected to work as full partners in the system design processes (Chawani, 2014).

In the context of health information systems development and implementation, a number of studies have examined collaboration between users and implementers or between different software developers who could be in different geographical locations (Shidende, 2015). Abdelhak et al. (2014) point out that dependence exists between users and IT professionals in the pursuit of definition, design, development, purchase, implementation and use of health information systems. As Kimaro (2006) and Saugene (2013) point out, in the development and implementation of health information systems, one importance of collaboration between developers and users is the assurance of knowledge sharing, which may result in some users to becoming local experts. Shidende (2015) recognizes the importance of collaboration between practitioners and IT professionals in the design and implementation of patient-care information systems for successful operation of support healthcare services.

However, on the one hand, commonly in the distributed information systems development, users and developers or designers may unable to meet and instead representatives serve in decision-making committees (i.e. indirect involvement) who mediate requirements between users and developers (Chawani, 2014). In this research, these representatives are referred to as *GIS* *implementers*. On the other hand, information systems development and implementation may involve the diversity of stakeholders participating in the processes. In the system design processes, Chawani (2014) states that stakeholders can be those on the organisational side who are usually referred to as users, those on the development side who are designers and developers, and those external to the boundaries of the organisation, for example, customers, sponsors, shareholders and even society. As stated in Chapter 1, in the case of GIS implementation, other stakeholders specialized in geodata can participate in collaboration. There is also a possibility of some stakeholders who are neither implementers nor users participating in collaboration with different roles, for example, as donors.

2.4 The Concept of Dependence

Different theories have been applied to understand collaboration in various contexts, which include transaction cost theory, resource dependence theory, institutional theory, and network theory (Delke, 2015; Klein and Pereira, 2016; Philips, Lawrence and Hardy, 2000; Røiseland, 2011; Sharfman, Gray and Yan, 1991; Walter, 2005). This research has adopted resource dependence theory to explore collaboration in geodata maintenance in health sector. Resource dependence theory gained public awareness through the book by Jeffrey Pfeffer and Gerald Salancik (1978) "The External Control of Organisations. A Resource Dependence Perspective" (Nienhüser, 2008) and the authors codified and integrated many pre-existing ideas about the management of inter-organisational interdependencies (Drees and Heugens, 2013). Since then, resource dependence theory has become one of the most important theories in organisation and management studies (Hillman, Withers and Collins, 2009) and recently, in information system research (Tsai, Lin and Fang, 2010).

A fundamental assumption of resource dependence theory is that dependence on critical resources influences the behaviour of organisation (Nienhüser, 2008). According to Peters (2014), resource dependence theory can be defined as an explanation of how the external resources affect the behaviour of an organisation. Basically, behaviour includes actions taken and decisions made and their outcomes (Nienhüser, 2008). The survival of organisations depends on their abilities to acquire and maintain critical resources from external environment (Klein and Pereira, 2016; Rossignoli, 2015). Scholars argue that organisations have to exchange with environment to acquire critical resources since no organisation is self-contained or self-sufficient (Cao and Zhang, 2013; Pfeffer and Salancik, 1978). One way to achieve this is through collaboration. Literature has demonstrated that resource dependencies indeed tend to result in the formation of inter-organisational arrangements (Drees and Heugens, 2013). Since collaboration aims at resource exchange and sharing (Bazzoli et al., 1997; Berkowitz, 2000; Rossignoli, 2015), resource dependence theory has guided this research in understanding how the scarcities of critical resources, that are geodata and GIS expertise, have forced Ministry of Health in Malawi to collaborate with other organisations in GIS implementation and how the ministry has managed to build its own geodata and GIS expertise. Tsai et al. (2010, p. 189) argue that "a variety of resources taken from the environment of an organisation must be put to best use in order for the organisation to survive in a demanding and changing environment." Resource dependence theory describes how resource scarcities force organisations to look for new innovations that use alternative resources (Hessels and Terjesen, 2010).

2.4.1 Determinants of Dependence

As mentioned in Chapter 1, the thesis has adopted the concept of *dependence*, which assesses "the potency of the external organisations or groups in the given organisation's environment" (Pfeffer and Salancik, 1978, p. 52), that is, the extent to which an organisation needs another in relation to a given resource (Klein and Pereira, 2016). Pfeffer and Salancik (1978) suggest three critical factors through which the dependence of one organisation on another can be determined: resource importance, discretion over resource allocation and use, and concentration of resource control. They refer to *dependence* as the product of the importance of a given resource to the organisation and the extent to which it is controlled by relatively few organisations.

Importance of the resource – The importance of the resource can be determined by the criticality of the resource. In resource dependence theory, criticality determines the ability of the organisation to continue functioning in the absence of the resource (Pfeffer and Salancik, 1978). However, it is important to assess the scarcity of the critical resource, which is the extent of the availability of the resource (Pawlowski and Datta, 2001). Hessels and Terjesen (2010) state that the major tenet of resource dependence theory is the resource scarcity; resulting in multiple organisations competing for the same or similar sets of scarce resources. The criticality and scarcity of the resource may vary from time to time according to environmental changes.

Discretion over allocation and use of the resource – Pfeffer and Salancik (1978, p. 48) argue that "discretion is a source of power and is more important when the resource is more scarce." This is the capacity to determine the allocation and use of the resource possessed by another social actor. Various forms of discretion over a resource exist including:-

- Possession of the resource – An example is knowledge, which is controlled in this fashion. Pfeffer and Salancik (1978) illustrate by giving example of professionals such as doctors, lawyers, and engineers whose power, with respect to their clients, lies in the access to knowledge and information. Ipe (2003) argues that particularly when individuals who possess it perceive knowledge as a valuable commodity, knowledge sharing becomes a process mediated by decisions about what knowledge to share, when to share, and who to share with.
- Access to the resource – This can be possibly regulated without owning it. For instance, a secretary can determine who is permitted to have access to the boss. This example demonstrates that any access that affects the allocation of the resource provides some degree of control over it (Pfeffer and Salancik, 1978).
- The actual use of the resource and who controls its use – This is another basis of control over the resource. Apart from its owner, a resource can be used by other users who have some measure of control over it (Pfeffer and Salancik, 1978).

Concentration of control of the resource – This determinant is the extent to which the focal organisation can substitute sources of the same resources (Pfeffer and Salancik, 1978), which can also be referred to as resource replaceability (Chatterjee and Ravichandran, 2013) or resource substitutability (Straub, Weill and Schwaig, 2008). Pawlowski and Datta (2001) point out that identifying substitutes for the resource and establishing multiple sources of supply are some strategies of avoiding or reducing dependencies. Apart from the relative number of alternatives available, the importance of these alternatives has consequences for the extent to which organisational behaviour is constrained (Pfeffer and Salancik, 1978). In some cases, despite the focal organisation having alternative sources for its resources, rules and regulations are formulated to restrict access to those alternatives. “Any system that regulates resources and their exchanges, in effect, concentrates influence over those resources” (Pfeffer and Salancik, 1978, p. 51).

2.4.2 Resource Dependence Perspective in Information System Research

Information technology (IT) resource plays an increasing critical role in organisations and much have been written about its strategic role (Straub et al., 2008). IT resources include hardware, software, IT applications, communications, IT personnel, routines and procedures. Ulbrich and Borman (2013) state that the IT resources required may not always be available in-house, can be of poor quality, or complement existing ones, which forces the organisations to enter into relationships with one another to gain access to specific resources. Tsai et al. (2010) note that resource dependence perspective is increasingly applied in information systems research because governance of information systems and related organisational activities is deeply involved with resource generation, seeking, planning and coordination for power and dependencies. They further argue that investigating the nature of information systems and resource coordination under the resource dependence perspective becomes crucial when viewing information systems as they organize the complex, multiple parties of constituents including human beings, processes, technologies and designs. Below are some examples of information systems studies in which resource dependence perspective was adopted.

1. Mwai, Kiplang’at and Gichoya (2014) sought to establish how resource dependence theory could inform decisions to outsource ICT services by public university libraries in Kenya. They found out that libraries had internal and external coalitions from the environment that emerge from social exchanges that were formed to influence and control behaviour; that is, the environment had scarce and valuable resources essential to the survival of public university libraries in Kenya. They observed that librarians used different factors including need for knowledge and technology transfer, risk reduction and a faster way of doing things, to determine the critical resources to acquire. Decision of outsourcing some of library functions was made when the libraries had understood and clarified which resources were critical to their functions.
2. Chatterjee and Ravichandran (2013) adopted resource dependence theory in their study of governance of inter-organisational information systems (IOS). They applied the constructs of resource criticality and replaceability to examine how the external dependencies that arise due to resource dependencies influenced the extent of inter-firm operational integration. They found out that the resource criticality increases operational integration while resource replaceability decreases it, which result in increasing and decreasing respectively the extent of transactional and financial IOS governance exercised by firms.
3. Straub et al. (2008, p. 196) adopted resource dependence theory to answer the following question: “To what extent does the degree of dependency that results from outsourcing various IT resources affect firm performance?” They strongly supported “a selective approach to outsourcing based on strategic control of key IT assets and the core competencies of the organisation”; that is, “Managers in the position to influence key outsourcing decisions should

think about the need to strategically control each IT activity and make their decisions accordingly" (p. 202).

4. Using the example of ERP system implementation, Pawlowski and Datta (2001) used resource dependence theory as the conceptual foundation to develop broader perspectives on organisational responses to the shortage of IT professionals. They suggested three basic steps to understand the organisation's dependence on ERP professionals and the management strategies available for coping with such dependence – assessing resource criticality and scarcity, assessing the environment, and identifying strategies for avoiding or reducing dependencies. They further identified four strategic responses to the shortage of IT professionals that are determined by IT function resource criticality and volatility: (1) reduce dependencies on IT function by automating the process or finding non-IT replacements for its operations if IT function is not critical resource and less volatile to environmental changes; (2) train existing workforce if IT professionals are critical even though the IT function is not volatile to environmental changes; (3) create strategic alliances if the IT function is critical and also volatile; and (4) outsource if the IT function is not critical but volatile to environmental changes.

From these examples, it is observed that resource dependence perspective has been applied in the management of IT resource shortage particularly technological and human resources. As pointed out earlier, GIS needs geodata as another critical resource. Therefore, apart from GIS expertise, the thesis intends to apply resource dependence perspective to understand how the user can manage the shortage of geodata.

2.4.3 Limitations of Resource Dependence Theory

As any other theory, the thesis has recognised limitations of resource dependence theory. Shehada (2010) states that since resource dependence theory focuses on transactional interdependence, it overlooks other important processes on organisations that must respond to a variety of institutional demands being embodied in regulations, norms, laws and social expectations. Hillman et al. (2009) argue that the interaction of interdependent organisations and their environment requires robust perspectives that can explain a broad range of outcomes, since it is a dynamic and complex process. That is, resource dependence theory looks at organisations from the external perspective; ignoring the internal dynamics of organisations that contribute to their relationships with the external environment. To offer new insights into the relationship between organisations and their environments, scholars have suggested to integrate resource dependence theory with other theoretical lenses such as institutional theory (Hessels and Terjesen, 2010; Lipnicka and Verhoeven, 2014; Shehada, 2010), resource-based view, stakeholder theory and contingency theory, among others (Hillman et al., 2009). However, in this thesis, the focus is on the resource that, according to Altholz (2010), is the important feature of resource dependence theory within the context of the formulation and implementation of corporate strategy. Specifically, the thesis has adopted resource dependence theory to describe how geodata and expertise resource scarcities have forced Ministry of Health to pursue new innovations to address the pressure, and ensure stable flows of these resources.

2.4.4 Selected Concepts guiding the Research

This research has been guided by the following concepts drawn from the discussions on collaboration and dependence above.

- *Resource criticality and scarcity* – To understand the importance of geodata and GIS expertise, the thesis has applied both the *criticality* and *scarcity* of each resource. Particularly, the resource criticality has been applied to determine the possibility of having the operational DHIS2 GIS without either of them while the resource scarcity has been used to assess the shortage of geodata and GIS expertise in Ministry of Health that leads to collaboration and what causes such shortage. When the organisation cannot manage to continue functioning in the absence of the resource (Pfeffer and Salancik, 1978), it may voluntarily opt for collaboration in order to access that critical resource. As mentioned earlier, the resource scarcity is one determinant of collaboration (Dedekorkut, 2004; Oliver, 1990).
- *Resource replaceability* – This has been used to identify any innovative ways that Ministry of Health has put in place to reduce the geodata and expertise resource scarcities and how collaboration has contributed towards those innovative ways, that is, the extent to which Ministry of Health could substitute sources of geodata and GIS expertise. According to Pawlowski and Datta (2001), to reduce dependencies, the organisation is to identify substitutes for the resource and establish multiple source of supply.
- *Problem domain and stakeholders* – In collaboration, the focal organisation depends on other organisations (i.e. stakeholders or social actors) to address a problem or achieve a shared goal in the particular domain. Since not all stakeholders of the problem domain are involved in collaboration (Wood and Gray, 1991), these stakeholders are only organisations engaging in resource exchange relationships with Ministry of Health. Thus, the stakeholder has been adopted to identify external environment which the ministry depends on to address shortage of geodata and GIS expertise in GIS implementation as the problem domain.
- *Structure of coalition* – Since collaboration requires clear understanding of roles and responsibilities of collaborating organisations (Fraser et al., 2015) and having agreed-upon standards of actions and shared rules and norms (Sowa, 2008), the *structure of coalition* has been adopted to understand roles of the external environment in addressing shortage of geodata and GIS expertise; that is, to determine the participation of external organisations in joint activities.

Therefore, in the context of resource dependence, the thesis perceives collaboration as *dependence* of the user organisation on other stakeholders having shared goals in GIS implementation in health sector as the problem domain to obtain geodata and expertise as critical and scarce resources that cannot be easily replaced or substituted.

Chapter Summary

Geodata maintenance is recognised as the central component of any operational GIS for continuously meeting new user requirements. Lack of geodata maintenance may result in underutilisation of GIS in health in developing countries particularly for the long-lived GIS applications. Although data maintenance is defined as the set of combined activities for keeping the data set up-to-date, GIS literature has not exhaustively defined these activities except geodata collection and geographic database update. Requirements analysis is recognised as one key component of geodata maintenance that needs to the clarity. Therefore, the thesis aims at identifying and defining key actions for the requirements analysis as part of geodata maintenance in order to define the exhaustive set of combined activities.

In developing countries, geodata maintenance is likely to bring the extra work to the user organisation that is already resource constraint. Hence, in geodata maintenance the user organisation is likely to go into collaboration with other organisations to access necessary GIS expertise. However, the extensive reliance on external GIS experts can create financial and knowledge problems in the long-run because they appear expensive and when they go, all knowledge and high-level expertise go with them. Scholars have suggested making sure that knowledge created during the GIS implementation is left behind with local users for continuity. Debate on how collaboration can be utilised to achieve this is limited in GIS literature. Therefore, the thesis also aims at discussing how collaboration can contribute towards the building of in-house expertise for geodata maintenance. To understand geodata maintenance and collaboration, the thesis has adopted resource dependence theory. Specifically, the thesis has adopted the concept of *dependence* to understand how geodata and expertise resource scarcities can force the user organisation to pursue new innovations for addressing the pressure of ensuring stable flows of these resources in geodata maintenance.

The next chapter describes the research context including the country profile, health system including HMIS, the maturity of GIS and key partners' profiles.

Chapter 3: Research Context

This chapter presents the context in which the research was conducted. The first section briefly describes the country profile. The health system in Malawi is presented in the second section. This is followed by the description of health management information system (HMIS), in the third section, in which the GIS implementation has been taking place. The fourth section presents the maturity of GIS Malawi's HMIS. The fifth section summarises key partners' profiles.

3.1 Malawi Country Profile

Malawi is a country in sub-Saharan Africa, which is bordered by Tanzania to the north and northeast, Zambia to the west and northwest, and Mozambique to the east, south and southwest (see Figure 3-1). The country covers total area of approximately 118,484 square kilometres of which 24,208 square kilometres is water including Lake Malawi. Administratively, Malawi is divided into three regions namely north, centre and south, which are divided further into twenty-eight districts: six in the northern region, nine in the central region, and thirteen in the southern region. The districts are subdivided into traditional authorities and each traditional authority is composed of villages that are the lowest administrative units. In Malawi, there are four cities namely Blantyre, Lilongwe, Mzuzu and Zomba with Lilongwe as the capital city. As mentioned in Chapter 1 and shown in Figure 3-1, this research was conducted at the national level involving Central Monitoring and Evaluation Division (CMED) and UNICEF, and the district level involving Blantyre and Mchinji district health offices.

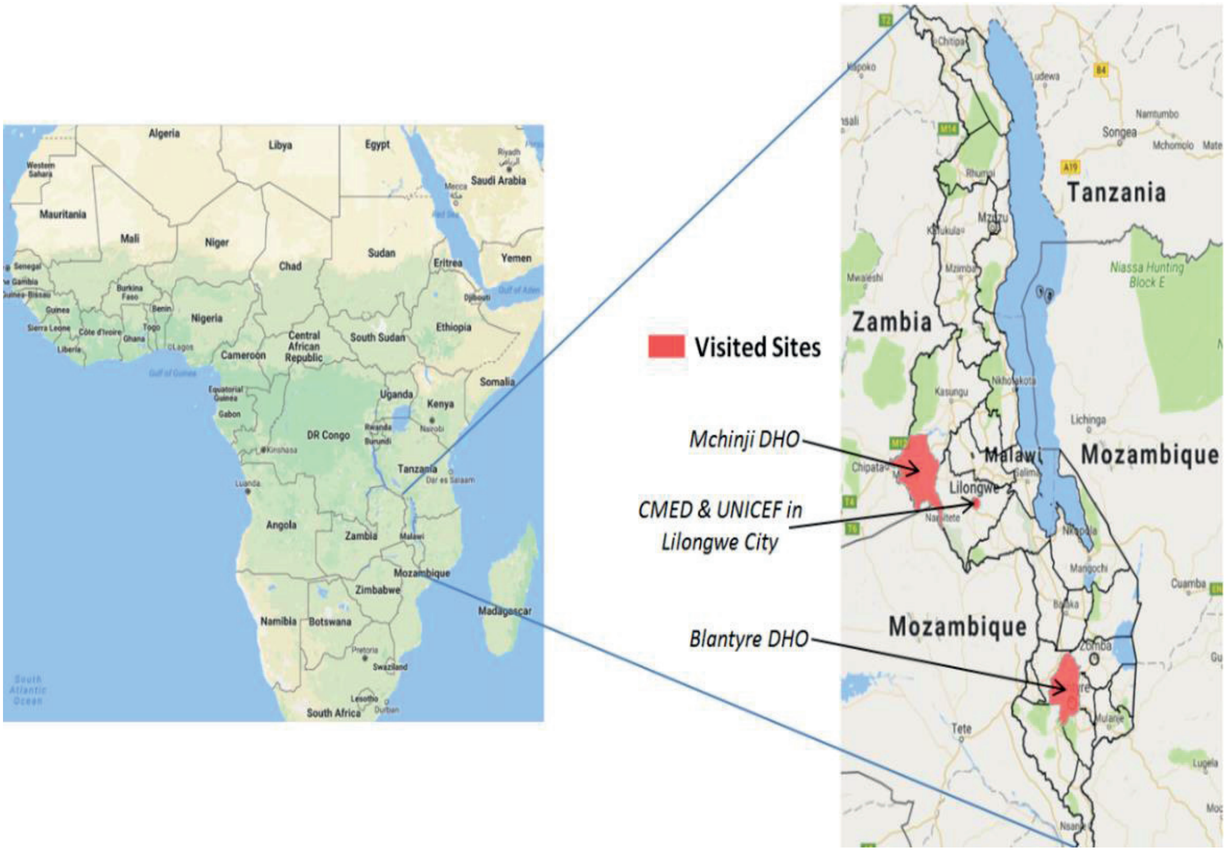

Figure 3-1: Map of Malawi and visited sites

According to the preliminary results for the 2018 Population and Housing Census, the total population is 17.5 million people and about 49 percent are males and 51 percent are females (National Statistical Office, 2018). Fifty-one percent of the total population is under the age of 18 years (National Statistical Office, 2018). Malawi is one of the most densely populated countries in Africa and amongst the poorest countries in the world. About 84 percent of the total population live in rural areas (National Statistical Office, 2018) and depend on subsistence farming for their livelihoods (ICEIDA, 2012).

3.2 Malawi Healthcare System

In Malawi, the public health system is divided into five zones, which are further divided into 29 health districts. Individual health districts are divided into catchment areas for health facilities within which there are communities being composed of villages. Thus, the healthcare system has five administrative levels: nation, zone, district, facility and community (see Table 3-1). The health zone is a catchment area consisting of health districts within an administrative region. Ideally, each administrative district is taken as a catchment area for the health district. However, in one case, one administrative district (Mzimba) has two health districts, which has resulted in having 29 health districts against 28 administrative districts.

Table 3-1: Malawi Healthcare System

Levels	Healthcare Services	Health Facilities
Nation	Tertiary	Central Hospitals
Zone		
District	Secondary	District Hospitals
Facility	Primary	Community/Rural Hospitals down to Health Posts
Community		Village & Outreach Clinics

The government is the main provider of healthcare services through Ministry of Health, which sets the agenda for healthcare in collaboration with non-governmental organisations (NGOs) among others. Ministry of Health provides 60 percent of the health services; 37 percent is provided by Christian Health Association of Malawi (CHAM); one percent is from the Ministry of Local Government and Rural Development; and private practitioners, commercial companies, army, and police cover two percent (ONSD, 2005). CHAM is composed of independent church-related and other private voluntary agency facilities, and also provides training for nurses and other health personnel.

Ministry of Health is responsible for the development of health and related policies, norms, standards and management protocols; their implementation and support at all levels including the private health sector; and monitoring and evaluation. Health zones provide technical support to health districts in planning, delivery and monitoring of health services. At district, facility and community levels, there are committees responsible for managing health and related activities. District health committee responds to health needs for the district; hospital management committee oversees planning and implementation of health services at the facility level; and village health committee promotes the primary healthcare activities through community participation and works with community health workers (Ministry of Health and ICF International, 2014).

In Malawi, as in other developing countries, a District Health Management Team (DHMT) manages health services at the district level. DHMT is defined as a group of technical persons with background of different professional disciplines working together to guide, oversee and coordinate health care services with the aim of achieving better health for people in the district (Chatora and Tumusiime, 2004). The role of DHMT is to allocate available resources in the best possible way to meet the basic health needs with the aim of improving the health status of communities (Engelbrecht et al., 2002).

Healthcare services are delivered in three levels: primary, secondary and tertiary (see Table 3-1). Primary healthcare is the first contact for healthcare services, which are provided at the facility and community levels by community/rural hospitals down to village and outreach clinics. At the community level, the delivery of services is done by community health workers with the support of village health committees; including promotive, preventable and some curative services. Secondary healthcare services are provided at the district level by district hospitals as referral facilities for the primary healthcare and provide both inpatient and outpatient services for their target populations. Each health district is expected to have a district hospital, although some do not have. Tertiary services are provided at the national level by central hospitals (as the referral hospitals for the secondary healthcare) having departments that provide specialized health services. There are four central hospitals, one in each city (i.e. Blantyre, Lilongwe, Mzuzu and Zomba), which have also the mandate to offer professional training, conduct research, and provide support to the districts. In health districts, secondary and primary health services are delivered under the management of DHMT.

Health facilities provide various health services to the population in their respective catchment areas. In this thesis, the health facility is taken as any place where people can go and get required health services, which are provided by a healthcare agency. WHO (2004) defines the catchment area as a geographic area served by a health program or institution and it is delineated on the basic of such factors as population distribution, natural geographic boundaries and transportation accessibility. All health facilities from the central hospitals down to health posts have permanent structures while village and outreach clinics have temporary structures. In the case of village clinics, houses of community health workers or small huts constructed by the community can be used to deliver health services. In case of outreach clinics, health services are usually provided next to a community facility.

3.3 Health Management Information System (HMIS)

The year 1999 is remarkable in the health sector in Malawi when the restructuring of the health information system (HIS) started. This was in line with the restructuring of HIS in developing countries since the adoption of primary health for achieving the goals of 'health for all' (Chaulagai et al., 2005). The Malawi National Health Plan of 1999-2004 emphasized on health sector reforms and restructuring of HIS was part of it. This exercise of restructuring HIS was essential because its outcomes have been fruitful; for example, commissioning various technologies and data integration from various health programs to enhance the flow of data in the health system. Information systems are important for measuring and improving the quality and coverage of health services (Chaulagai et al., 2005).

In order to have a continuous routine reporting of data from all health facilities, Ministry of Health introduced a comprehensive but simple and manageable HMIS in 2002 (Chaulagai et al., 2005) and in the same year, the ministry witnessed the 'birth' of two systems, district health information software (DHIS) and Geographic Information System (GIS). For details about GIS, refer to Section 3.4. The catchment areas for health facilities and districts were defined and the catchment area maps were created showing essential features that affect health of the population (Chaulagai et al., 2005). DHIS1.3, as a digital HMIS solution, was introduced at district health offices, central hospitals and CMED to aid routine health data storage, analysis and presentation at the district and national levels. Between 2009 and 2012, DHIS1.3 (the desktop solution) was upgraded to DHIS2 (the web-based solution) to enhance HMIS towards integration of various health programs and the introduction of a national integrated platform.

By 2002, in order to provide continued technical support to HMIS users, Ministry of Health established a new post for the assistant statistician (now called HMIS officer) at each district health office and central hospital to assist with computerized data processing. At the national level, the ministry established a Health Management Information Unit (now called CMED) with "the responsibility of coordinating information collection functions; compiling complete health information from internal, external, primary and secondary sources; analysing, interpreting and storing information in appropriate formats; generating reports in different ready-to-use formats; and disseminating information to all relevant stakeholders" (Chaulagai et al., 2005, p. 380).

In Malawi HMIS, data is collected and aggregated at the facility level, and then integrated and analysed at the district level. In Malawi, as in other developing countries for example Tanzania (Smith et al., 2008), the district is identified as a focal geographic unit for integrating multiple health programs and information systems. The integration and analysis are done through the computerised system, DHIS2. Officers at the zonal and national levels rely heavily on health districts in terms of data availability. DHIS2 is used in data analysis, reporting, presentation, interpretation and even sharing. Since DHIS2 is a web-based system, users can access it at all levels provided they have the Internet access. In Malawi, Ministry of Health is promoting the use of DHIS2 as a central data repository. The key DHIS2 users are Economists, Statisticians, M&E officers, HMIS Officers, health program managers and coordinators (see Figure 3-2).

In the process of restructuring and enhancement of HMIS, Ministry of Health has been working in collaboration with various organisations including government agencies, non-governmental organisations (NGOs) and universities. Specifically, in the development and implementation of technologies in HMIS (for example, DHIS2, DHIS2 GIS and DHIS2 mobile), Ministry of Health has been collaborating with other organisations such as University of Oslo, HISP Malawi, University of Malawi, Baobab Trust, UNICEF, International Training and Education Centre for Health (I_TECH), the Centres for Disease Control and Prevention (CDC), the Global Fund, eGovernment Department and National Statistical Office (NSO) among others.

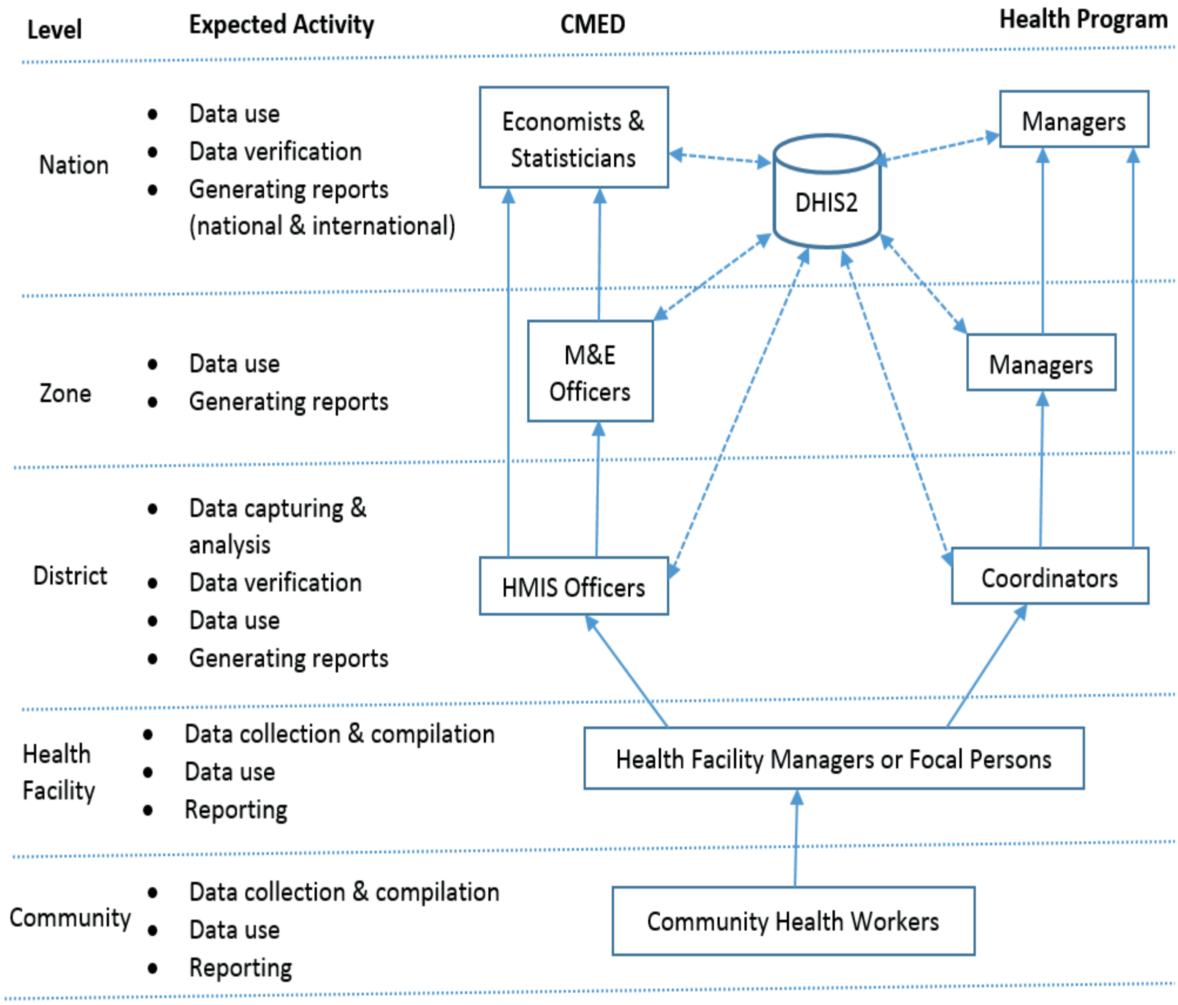

Figure 3-2: Key Users of DHIS2

3.4 The Birth of GIS and its maturity in HMIS

Several initiatives towards GIS implementation have been taking place since 2002, which involve the policy formulation, user training, producing static maps, geodata capture, and deployment of DHIS2 GIS. The journey of GIS implementation in health management started with the definition of catchment areas and population for the health facilities and health districts. According to Chaulagai et al. (2005), this definition has enabled health facilities to monitor coverage, organize outreach clinics and plan community health development activities in collaboration with communities themselves. Chaulagai et al. (2005) further emphasize that the catchment areas compel health managers to think about the equity in resource distribution and universal access to basic health services. Figure 3-3 is one of the initiatives of producing maps for health districts. The map shows cases treated for malaria in 2002-2003 in Mchinji health district. The researcher found this map on the wall in the HMIS office during the visit to Mchinji district health office in January 2017.

Figure 3-3: Cases treated for malaria in 2002-2003 in Mchinji
(**Source:** Mchinji HMIS Office)

In 2002-2003, the department of Planning and Policy Development in Ministry of Health carried out the exercise of mapping public and CHAM health facilities across the country with the GIS expertise from Japanese International Corporation Agency (JICA) and the department of Surveys. The maps were distributed in Compact Disks (CDs) to stakeholders at district and national levels. During this study, the researcher did not find even a single CD of those maps.

> One manager at CMED said: “We used to have CDs containing maps of health facilities in each health district which were categorized by facility type and ownership. People were coming to CMED to borrow the CDs but they failed to return them. As a result, we do not have even one CD that we can share with you.”

However, another manager at CMED provided the researcher with digital datasets of health facilities and their catchment areas in all health districts in Malawi, which were created in 2003. Figure 3-4 shows the health facilities and their catchment areas in Mchinji health district, as an example. The researcher generated this map from the digital datasets of 2003 using ArcGIS 10.2.

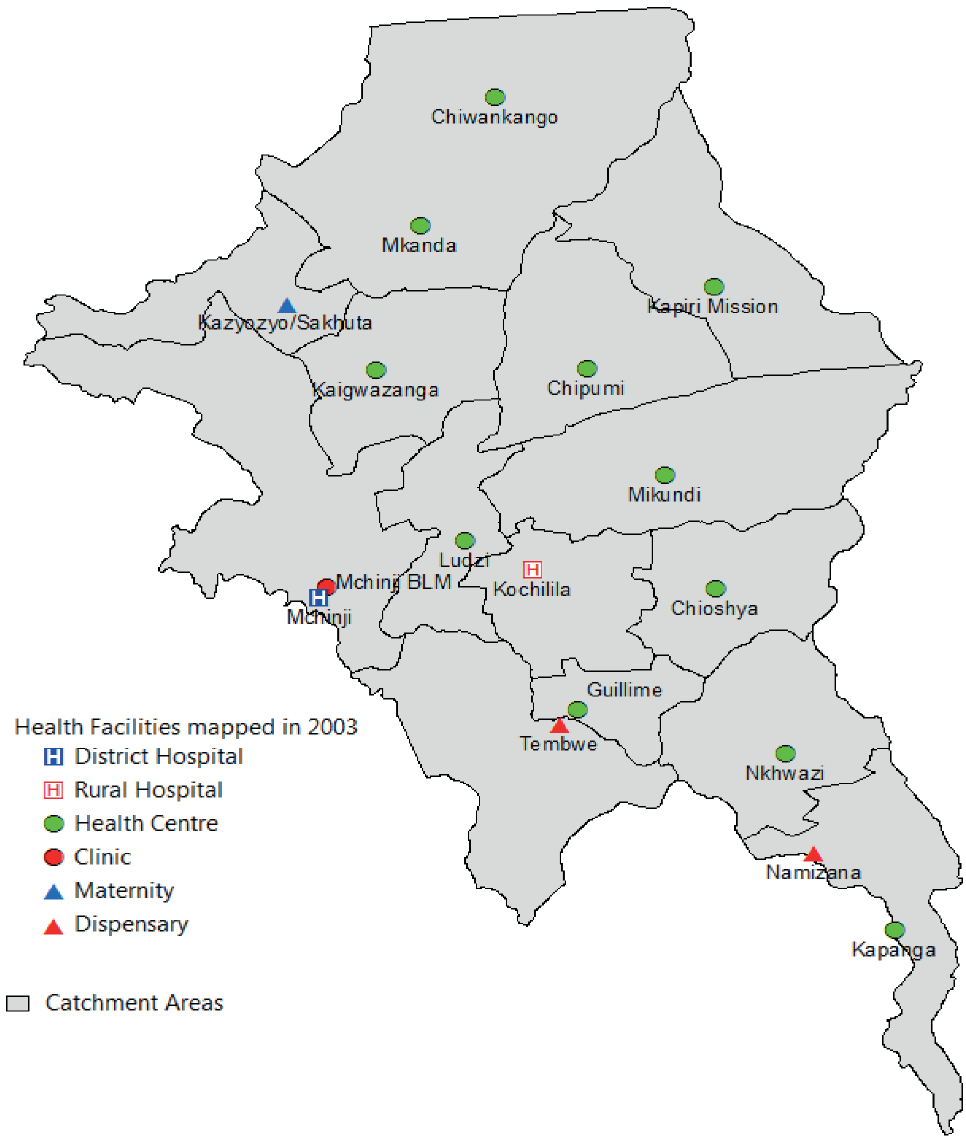

Figure 3-4: Health facilities of 2003 and their catchment areas in Mchinji health district

In 2011, the department of Planning and Policy Development updated the maps of 2003 with the support from the same JICA and the department of Surveys. Fortunately, the researcher had access to the maps from another manager at CMED and Figure 3-5 shows the health facilities of 2011 in Mchinji health district.

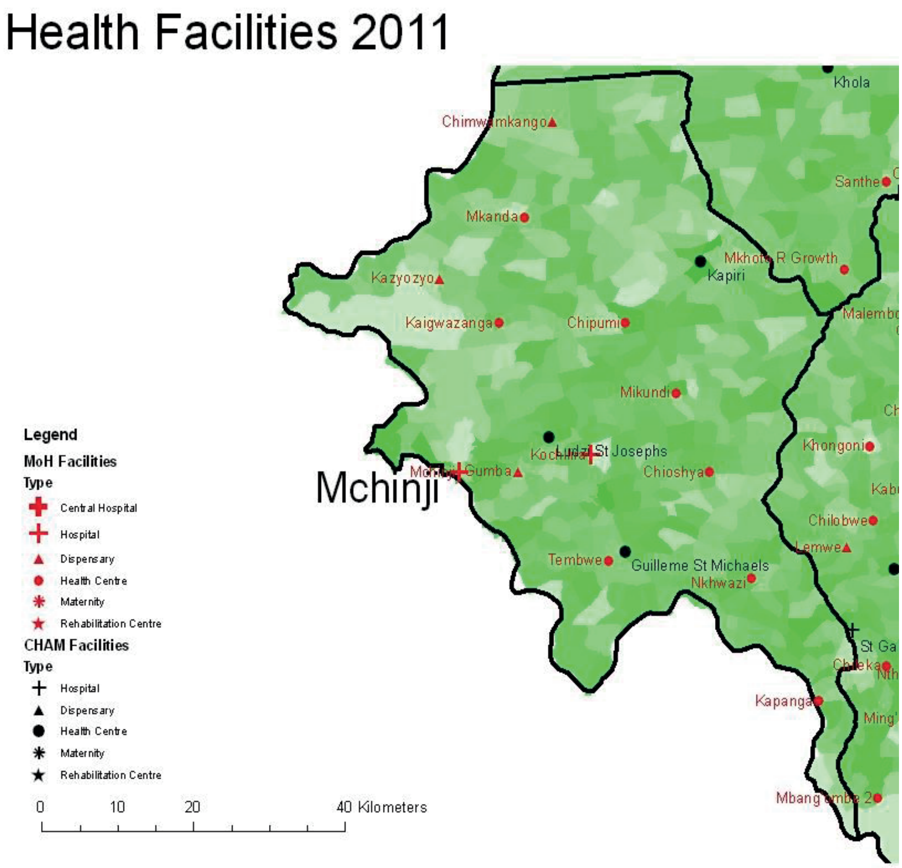

Figure 3-5: Health facilities of 2011 in Mchinji health district

To demonstrate its commitment towards the GIS application in health management, Ministry of Health considers GIS as one component in its socio-economic policies. In HIS policy and strategy of 2003, Ministry of Health recommends the application of GIS as a powerful visual tool for planning and monitoring of health services (Ministry of Health and Population, 2003). The policy emphasis is on geographical variations in types and magnitude of problems, and equity in distribution of health services. Even in the revised HIS policy of 2015 (Ministry of Health, 2015), although it has not directly included GIS, it has statements which can influence the use of GIS; for example, equitable coverage. Apart from these policies, strategic plans and program documents emphasize on the inclusion of spatial dimension in data analysis and importance of incorporating geographic information into the demographic and health surveys (for example: ICF International, 2013; Ministry of Health, 2013).

The issue of policies and strategies is just one part of GIS implementation. Since GIS also needs people, technology and data, Ministry of Health in collaboration with other organisations has been training HMIS officers, capturing geodata and providing necessary technologies. In 2005, Ministry of Health bought global positioning systems (GPS) for HMIS officers in district health offices and central hospitals and then trained them in GIS. Ministry of Health has put much effort on HMIS officers at the district level by imparting them with GIS knowledge through training. In-house trainings involving these HMIS officers were conducted in 2009, 2010, and 2013, which covered areas such as how GIS works, geodata capture using GPS, data analysis and map generation. In these trainings, facilitators were from the government agencies: the department of Surveys, National Aids Commission (NAC), National Statistical Office (NSO) and the department of Lands. Although the trainings were conducted, there has not been any GIS application for use till the introduction of DHIS2 GIS in 2017. In April 2017, there was training on the new instance of DHIS2, including DHIS2 GIS, to HMIS officers and facilitators were from CMED.

The maps of 2003 and 2011 are static, such that it is difficult to share and update them. Hence, Ministry of Health has decided to introduce an operational GIS using DHIS2 GIS aiming at simplifying the access, update and integration with health data. In order to achieve this, there have been initiatives in the geodata capture for health facilities in 2013, 2015 and 2016; and also the deployment of DHIS2 GIS from 2015 to 2017 in which the researcher participated. The researcher's role in the deployment of DHIS2 GIS is described in detail in Chapter 4 (Research Methodology).

Two major exercises of capturing geodata were executed. In 2013, Ministry of Health and ICF International collaboratively captured coordinates of public and CHAM health facilities (central hospitals down to health posts) and some private facilities while carrying out the service provision assessment. ICF International coordinated the exercise and provided financial and material support, and trained health personnel on the use of GPS. Ministry of Health provided the technical team, comprising of medical assistants and nurses from health facilities. From this exercise, geodata for 997 health facilities were captured. The second exercise of geodata capture was done by UNICEF in 2015 and 2016 in which 9498 public and CHAM health facilities including village and outreach clinics were involved. In this exercise, UNICEF was the funder and facilitator; Ministry of Health provided health personnel whereas the GIS expertise was from the department of Lands. One of the objectives of capturing these coordinates is to generate evidence for future planning activities; for example, conducting gap analysis aiming at revealing the population living in depreciation (Jacobs, 2016).

In 2015, Ministry of Health decided to adopt DHIS2 GIS for the GIS application at the district and national levels. The deployment of DHIS2 GIS was one of the activities of 'reconfiguring' DHIS2. The setting up of DHIS2 GIS is basically a matter of populating coordinates of the organisation units in the database and immediately maps are available in the GIS module (Braa and Sahay, 2012). However, as experienced in this research, the exercise is not easy as it sounds. A number of activities were performed from 2015 to 2017 as elaborated in Chapter 4 (Research Methodology).

3.5 Key Partners in GIS Implementation

As mentioned above, Ministry of Health has been receiving different forms of support in DHIS2 GIS implementation from various organisations and the key organisations are briefly summarised below.

National Statistical Office (NSO) – NSO is the main government department responsible for the collection and dissemination of official statistics including the demographic and health survey in which Ministry of Health participates. In addition, in its works, NSO also generates geodata particularly for administrative boundaries including villages, which is used in a number of demographic and social surveys. Ministry of Health is able to access such geodata and GIS expertise from NSO.

Department of Surveys – This is the government agency on all matters of land surveying and mapping and the national point for GIS and remote sensing. Its strategic outcome is the improved provision of geospatial information in the country. As part of computerisation of records and spatial data sharing, there are efforts to institutionalise a Malawi Geographic Information Council (MAGIC) and a National Spatial Data Centre (NSDC) in the country to coordinate acquisition and sharing of geo-information among producers and users and encourage, which will assist in the development of National Spatial Data Infrastructure (NSDI). NSDC has the capacity to develop complete GIS related applications for users through joint ventures projects and it shares data through its web portal known as Malawi Spatial Data Portal (MASDAP) (http://www.masdap.mw/). Ministry of Health is able to access the geodata and GIS expertise from the department of Surveys.

UNICEF – Operations of UNICEF in Malawi started in 1964 when Malawi got its independence from Britain and the current country programme aims to support national efforts to progressively realise the rights of children and women through improved child survival, development, protection and participation. UNICEF works with the Government through line ministries and institutions at the national and district levels for coordination of the implementation of the country programme and Ministry of Health is one of them. The health programme has the overall goal of contributing to the improvement of maternal, new born and child health through strengthening of national and district-level systems. To support the improvement of management, planning and situation analyses among others, health managers need adequate information including spatial information. However, although there are organisations that had collected spatial data in Malawi, most datasets were incomplete, of poor quality or outdated (Jacobs, 2016). This prompted UNICEF Malawi in collaboration with Ministry of Health to collect geodata of all health facilities that provide free health services in Malawi, including village and outreach clinics. This geodata is being used in DHIS2 GIS.

Jhpiego – Jhpiego is an international, non-profit health organisation affiliated with The Johns Hopkins University, which works with health experts, governments and community leaders to provide high-quality healthcare for specifically women and children in over 155 countries. Jhpiego helps countries care for themselves by training competent healthcare workers, strengthening health systems and improving delivery of care. Jhpiego designs innovative, effective and low-cost healthcare solutions to ensure a level of care for people and currently, it is implementing digital health interventions in over twenty countries in Africa and Asia. In Malawi, Jhpiego works with CMED in strengthening the national HMIS and one of the areas is DHIS2 GIS. Jhpiego has been using DHIS2 GIS for over five years and hence, it is able to provide GIS expertise to Ministry of Health.

Universities of Oslo and Malawi – Ministry of Health has been working with University of Oslo (UiO) and University of Malawi (UNIMA) in DHIS2 GIS implementation. Through Department of Informatics, UiO is in collaboration with Ministry of Health and UNIMA in the strengthening of HMIS. Two key activities are the development and implementation of various digital health solutions and human capacity building through the postgraduate training and research. In the case of DHIS2 GIS, the universities provided GIS professionals as researchers. UiO is also the developer of DHIS2 through HISP Oslo.

Chapter Summary

This chapter has presented the context of the research, which is the Malawi's national health management information system (HMIS). The research was conducted at the national level involving Ministry of Health and UNICEF and two district health offices. GIS application in HMIS was introduced in 2002 with the static maps until 2015 when the ministry decided to implement the operational GIS using DHIS2 GIS. All health facilities, from the central hospitals down to village and outreach clinics, have been included in DHIS2 GIS. The GIS implementation in Malawi's HMIS has been possible due to the support of other organisations, particularly National Statistical Office (NSO), department of Surveys, UNICEF, Jhpiego, Universities of Oslo and Malawi.

The next chapter presents the research philosophy, strategy, and how the data was collected and analysed.

Chapter 4: Research Methodology

This chapter presents the account of how and when the research was conducted. The first section discusses the philosophical assumptions that guided the study. This is followed by the research strategy that was adopted in the second section. The third section describes how I gained and maintained access to the research site, including my role as the researcher. The fourth section describes how the data was collected. The fifth section presents how the data was analysed.

4.1 Research Philosophy

Every research, whether qualitative or quantitative, is based on some underlying assumptions, which are typically ways of thinking about the nature of being (ontology) and ways of acquiring knowledge (epistemology) (Gonzalez and Dahanayake, 2007; Myers, 1997; Saunders, Lewis and Thornh, 2009). Ontology is the study of "the nature of existence and what constitutes reality" while epistemology "provides a philosophical background for deciding what kinds of knowledge are legitimate and accurate" (Gray, 2014, p. 19). As Orlikowski and Baroudi (1991) put it, the empirical world can be objective – being independent of humans, or subjective – being created and recreated by humans. This research was guided by the philosophical assumptions which relate to the underlying epistemology. GIS, as the information system, is composed of both technical and social elements. Information systems cannot be independent of people around them because, for example, their individual motivations, practices, values and interests influence their use of information technologies. The understanding of information system as a socio-technical field has influenced researchers to apply multiple approaches to information systems research (Gonzalez and Dahanayake, 2007). Literature suggests three underlying epistemologies in information systems research: positivist, interpretive, and critical (Gonzalez and Dahanayake, 2007; Myers, 1997).

In social sciences, positivism was the dominant epistemological paradigm between 1930s and 1960s (Gray, 2014) and this has also been observed in information systems research. In their examination of 155 information systems research articles published from 1983 to 1988, Orlikowski and Baroudi (1991) found out that positivism was the dominant epistemology. In positivist studies, the core argument is that the reality is objectively given and exists independent of human (Gray, 2014; Myers, 1997; Orlikowski and Baroudi, 1991). A positivist researcher is seen to be external to the process of data collection, that is, he or she is expected not to intervene in the phenomenon of interest. However, positivism may not offer powerful insights to studies of information systems phenomena. Orlikowski and Baroudi (1991, p. 12) argue that "The quest for universal laws leads to a disregard for historical and contextual conditions as possible triggers of events or influences on human action."

For better understanding of information systems development, implementation and use, it is important to analyse social practices and organisational culture in which people are engaged (Mukama, Kimaro and Gregory, 2005). Gonzalez and Dahanayake (2007) note that information systems researchers advocate interpretivism as the most appropriate for information systems interventions. Interpretivism addresses some limitations of positivism. Interpretive researchers assume that people create and associate their own subjective meanings as they interact with the world around them (Orlikowski and Baroudi, 1991) and they attempt to understand the complexities of the social work, particularly each individual's interpretation of the world (Jabar et al., 2009). Hence, this research applied the interpretive methods in order to build a rich understanding of the context of GIS implementation for health management and the process whereby the implementation process has influenced and been influenced by the context (Jabar et al., 2009; Myers, 1997). The understanding is that "The design and use of information technology in organisations, in particular, is intrinsically embedded in social contexts, marked by time, locale, politics, and culture" (Orlikowski and Baroudi, 1991, p. 12).

The third epistemological paradigm in information systems research is the critical research, which is different from other two paradigms due to its evaluative dimension. The two perspectives, positivism and interpretivism, focus in predicting or explaining the status quo while the critical perspective is for "critiquing existing social systems and revealing any contradictions and conflicts that may inhere within their structures" (Orlikowski and Baroudi, 1991, p. 19), that is, the critical research "questions currently held values and assumptions and challenges conventional social structures" (Gray, 2014, p. 27). This research focused on the interpretation of the context of geodata maintenance and collaboration in GIS implementation in health sector and not necessarily seeking to change it.

4.2 Research Strategy: Case Study

Within information systems research, the increasing interest in organisational and social issues associated with the development and implementation of information systems has influenced researchers to adopt research strategies such as action research, case study, and ethnography. To understand the natural setting and cultural context of geodata maintenance and collaboration in GIS implementation in health sector, this research adopted the case study strategy. Yin (2003, p. 13) defines a case study as "an inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident." Cavaye (1996) points out that case study researchers aim for in-depth understanding of the context of a phenomenon and studying a large number of variables and different aspects of the phenomenon. However, case studies do not involve explicit control or manipulation of variables (Rose, Spinks and Canhoto, 2015) that need not be determined in advance (Cavaye, 1996). The choice of case study as a research strategy was done with considerations of, particularly, generalisability, the access to research sites, data collection (sources of evidence), data analysis and reporting, and the role of the researcher, which have been elaborated in the next sections.

This research adopted a single case study design for investigating geodata maintenance and collaboration in GIS implementation in health sector and used Ministry of Health in Malawi as a case. As stated earlier, Ministry of Health has been implementing GIS since 2002 as part of strengthening its national health management information system (HMIS). Ministry of Health was taken as an appropriate organisation for this case study particularly because the research focused on public health management setting and the ministry had been implementing GIS for some time covering all health districts and a number of health programs. In addition, Ministry of Health has been collaborating with other organisations in its GIS initiatives. Figure 4-1 illustrates the steps that were taken in this case study.

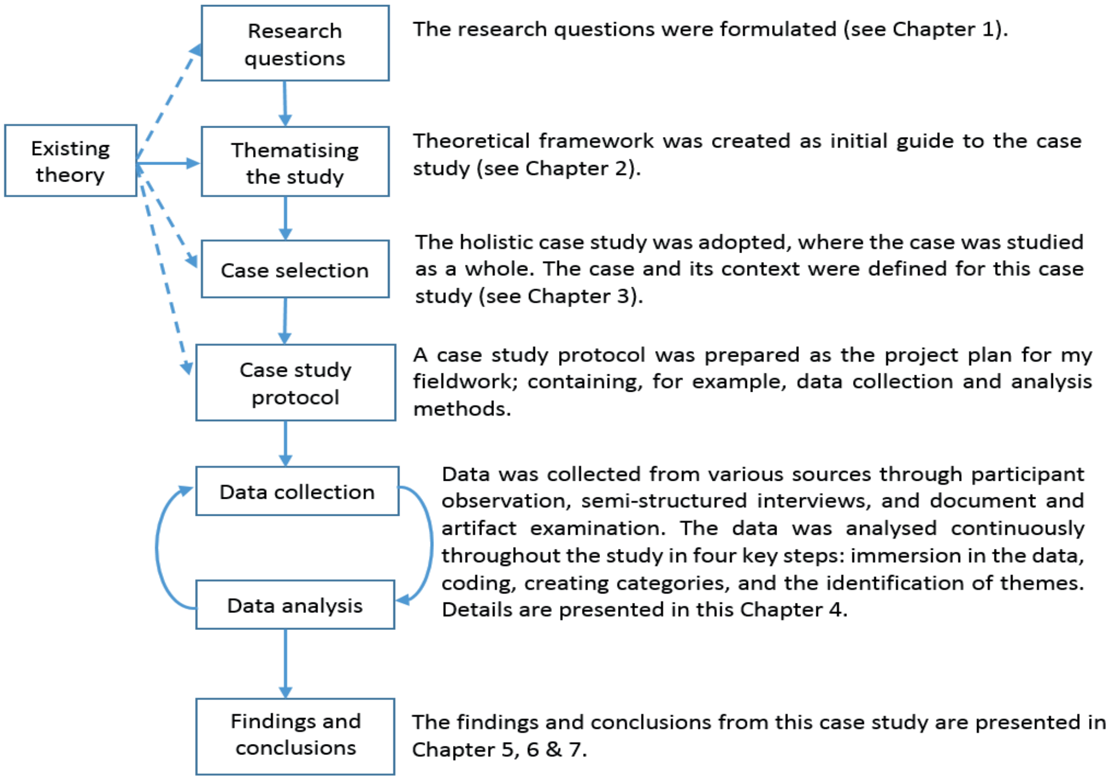

Figure 4-1: The steps taken in this single case study
(adapted from Rose et al., 2015)

One concern in the case study is the generalisability of the research. In the context of interpretive case study, four types of generalisation have been suggested that are not mutually exclusive – the development of concepts, the generation of theory, the drawing of specific implications, and the contribution of rich insight (Walsham, 1995, 2006). Hence, the thesis has mainly contributed rich insights on the concept of geodata maintenance in health sector in developing countries. The thesis has explicitly described how to perform geodata maintenance. The thesis has also drawn specific implications on understanding geodata maintenance. The thesis views geodata maintenance as the part of the maintenance of an installed GIS in which users are to maintain data and system to cope with changes. Details on the contributions and implications are presented in Chapter 6 and Chapter 7.

4.3 Gaining Access to Ministry of Health

In interpretive case studies, Walsham (2006) emphasises on the need to gain and maintain good access to appropriate organisations for the fieldwork. In the following section, therefore, I describe how I got and maintained the access to Ministry of Health as my research site, the period of my fieldwork and the role I played as the researcher.

4.3.1 Ethical Clearance

The researchers need to obtain an authorisation from the field organisation in order to have access to data sources in that organisation. Hence, first, I obtained the introductory letter from University of

Oslo (see Appendix 2.1), which supported my research interest. This introductory letter was also used as a supporting document to my application for the ethical clearance in Malawi. Second, I obtained the ethical clearance from National Health Sciences Research Committee (see Appendix 2.2), which enabled me to conduct the research in Ministry of Health. Third, in order to visit HMIS officers and health program coordinators at the district level, I obtained the introductory letter from the Deputy Director of Central Monitoring and Evaluation Division (CMED) (see Appendix 2.3). At the individual level, the consent was obtained from each participant (see Appendix 2.4). The privacy and confidentiality of the participants were also considered in all stages of my research – data collection, storage, reporting, and publications – in which the data was made anonymous.

4.3.2 My Fieldwork

The fieldwork started in July 2015 and ended in January 2017. In July 2015, I introduced my research interest to the Deputy Director of CMED. As earlier stated, CMED is the custodian of HMIS. In response, I was asked to join a team that is particularly responsible for DHIS2 in Ministry of Health; referred to as the DHIS2 team. The office of the DHIS2 team was located next to the Deputy Director's office to which I was granted the access whenever I wanted to work at CMED. This office was used by one CMED manager, two DHIS2 programmers, and one Technical Assistant from a collaborating organisation who was responsible for health information systems. I was in contact with the DHIS2 team members and other participants for 14 months. Table 4-1 summarises my field visits in Malawi. Details about interviews and participation are presented in Section 4.4 – Data Collection.

Table 4-1: My field visits in Malawi

Visits	Period	Activity
First visit	Jul. 2015	- Introducing my research interest to CMED
	Aug. 2015	- Interviews: CMED management and DHIS2 programmers
Second visit	Oct. 2015 to Jan. 2016	- Interviews: UNICEF health management, HMIS officers and health program coordinators in Blantyre district, and Jhpiego ICT officers - Participation: checking for the completeness of geodata for DHIS2 GIS
Third visit	Jun. 2016	- Participation: attending the meeting of DHIS2 team and UNICEF on GIS
	Jul. 2016	- Participation: attending the training to DHIS2 team on DHIS2 GIS by Jhpiego; and developing geodata internally - Interview: UNICEF health management
	Aug. 2016	- Participation: attending the stakeholder meeting and preprocessing geodata
	Sep. & Oct. 2016	- Participation: setting up and testing DHIS2 GIS with assistance of HMIS officers in health districts; and attending the stakeholder meeting
	Nov. 2016	- Online interviews: HMIS officers in all district health offices - Participation: demonstrating DHIS2 GIS to CMED management
	Dec. 2016	- Participation: demonstrating DHIS2 GIS to HMIS officers and health program coordinators in Blantyre district
	Jan. 2017	- Participation: demonstrating DHIS2 GIS to HMIS officers and health program coordinators in Mchinji district - Interviews: DHIS2 programmers and CMED management

During the time of my fieldwork, CMED was carrying out a major reform on DHIS2 – i.e. the reconfiguration of DHIS2 – in which the deployment of GIS was one of its milestones. The DHIS2 reconfiguration project was from March 2016 to May 2017 with four objectives. First, Ministry of Health wanted to rebuild DHIS2 towards the integrated national HMIS; that is, making DHIS2 as the central data repository for health programs. Second, Ministry of Health wanted to restructure the DHIS2 database for easily integrating with other health information systems. Third, Ministry of Health wanted to remove duplicates in DHIS2. Four, for the effective coordination of integrating systems, Ministry of Health decided to host DHIS2 close to other government health information systems and it is being hosted by the department of HIV. Previously, DHIS2 was hosted by University of Malawi – College of Medicine, as the collaborating organisation.

4.3.3 My Role as the Researcher

Apart from gaining access to research sites, Walsham (1995) also recommends interpretive researchers to have a view of their roles that can be identified as that of the outside observer and involved researcher. These roles aid to elaborate the relationship between the researcher and the phenomena under study, which, according to Nandhakumar and Jones (1997), may be argued as central to the interpretive endeavour. According to Walsham (1995), the outside researcher is not seen as a member of the field group or organisation while the involved researcher is a member of the field group or organisation or temporary member for some period of time. In this research, I perceived myself as the involved researcher because I became the temporary member of CMED belonging to the DHIS2 team responsible for the DHIS2 GIS deployment throughout my research period. My involvement was only during the set-up of DHIS2 GIS after planning and the initial geodata collection were done.

The DHIS2 GIS deployment team consisted of myself from University of Oslo as the leading member, one master student from University of Malawi, one member from Jhpiego and two members from UNICEF. University of Oslo, University of Malawi, UNICEF and Jhpiego are some organisations, which have been collaborating with Ministry of Health in DHIS2 implementation and support. Nandhakumar and Jones (1997) note that in information systems research, participant observation might mean working as an information systems developer or as a member of a strategy group. However, in the deployment of DHIS2 GIS, I played the role of the implementer. That is, the master student and I were the main implementers of DHIS2 GIS; carrying out the technical work while other members provided the technical support and advice. For example, the member from Jhpiego trained the DHIS2 team on DHIS2 GIS including the master student and myself. Two members from UNICEF coordinated the collection of geodata of health facilities across the country as the project of UNICEF. As the implementer, I participated in various activities during the deployment of DHIS2 GIS, which included preparing and processing geodata, setting up DHIS2 GIS, testing and demonstration. Details of these activities are presented in Section 4.4.1 – Participant Observation.

Although I was leading the DHIS2 GIS deployment team, I had no much authority over other members, that is, I sought to behave like any other members of the DHIS2 team. Decisions on different activities of the DHIS2 GIS deployment were made collectively in line with DHIS2 reconfiguration plans. The DHIS2 team had the leading member whom the DHIS2 GIS deployment members equally reported to. This leading DHIS2 member acted usually as an interface between the DHIS2 team and CMED management.

In the context of collaboration, I had two personalities. First, I represented University of Oslo as one of collaborating organisations to CMED and UNICEF in which the participants expected me to contribute to the deployment of DHIS2 GIS. I was deployed to CMED as the GIS technical assistant. Second, I was CMED member particularly when I was interacting with stakeholders at the district level in which the participants expected me to present the interests of CMED in the DHIS2 GIS deployment. In this context, although I disclosed my role as the researcher to the participants, I received complaints and enquiries from HMIS officers and health program coordinators. Some participants expected me to respond to some of their complaints or enquiries on behalf of CMED, which I avoided as much as possible by promising them that I would report to the authority for actions and I did.

This role of the involved researcher gave me access to the inner workings of the DHIS2 GIS deployment project in the way that might not easily be achieved from the position of an external researcher. Nandhakumar and Jones (1997) state that to understand a social process, the researcher must get inside the world of those generating it. However, apart from the access one gets as an insider, it is also important to know how one engages this insider position (Geirbo, 2017). Hence, I saw my insider position as the participant-as-observer that allowed me to participate and observe at the same time and my position was disclosed to all participants of this case study. In addition, sometimes I was able to observe formally and in other times I observed informally. My observations were recorded by the note-taking technique.

By behaving like any other members of the DHIS2 team, I was seen as the 'normal' member and as such I was expected to participate fully in the deployment of DHIS2 GIS. In this context, I claim that my presence had some effect on other team members. When the researcher plays a full part of the team's activities, he or she has an unavoidable influence on aspects of the phenomena he or she is seeking to observe through, for example, his or her contributions to the team's productivity (Nandhakumar and Jones, 1997). My contribution to the DHIS2 GIS deployment reflected my particular skills and experiences that could be different from those of another researcher. Therefore, in the same context, a different researcher would have a different effect. In this case, I took myself as the participant, which enabled me to observe and reflect on my own practice as the implementer. Geirbo (2017) states that participant observation enables an insider researcher to reflect on his or her practice with an outside perspective.

4.4 Data Collection

One strength of the case study is its ability to employ multiple sources of evidence, which allow triangulation of findings (Rose et al., 2015). Yin, as cited in Walsham (1995), proposes six sources of evidence for case studies namely documents, archival records, physical artefacts, interviews, direct observation, and participant observation. In this research, I applied the participant observation, interviews, and examination of artefacts including documents as the data collection methods. Through these data collection methods, I managed to get in-depth information on participants' opinions, thoughts, experiences, perceptions and feelings since these are the primary data of qualitative, interpretive research (Bolderston, 2012). In this section, I describe how the evidence for this case study was obtained by the data collection methods mentioned above.

4.4.1 *Participant Observation*

In the qualitative research, participant observation has been used in different disciplines (Kawulich, 2005), including information systems (Nandhakumar and Jones, 2002) for collecting data about people, processes, and cultures, among others. As stated earlier, participant observation allowed me to observe and participate at the same time and my position was disclosed to all participants of this case study. Participant observations were done in different stages in the DHIS2 GIS implementation as presented below.

Acquiring and Preprocessing Geodata – Geodata was of health facilities and health catchment areas (i.e. health districts and zones), which were acquired from various sources. CMED and UNICEF captured geodata of health facilities while geodata of health districts was obtained from National Statistical Office (NSO). Then, the geodata was checked for completeness to make sure that organisation units required in DHIS2 had corresponding coordinates. During the assessment of geodata completeness, the DHIS2 GIS deployment team managed to identify gaps, particularly, the missing geodata of zones, two health districts (Mzimba South and North) and a referral hospital (Zomba mental hospital). These missing datasets were generated internally by the DHIS2 GIS deployment team. For the mental hospital, its coordinates were captured from the Google map. For zones and two health districts, their datasets were generated through the 'dissolve' process using ArcGIS 10.2 in which boundary data of administrative districts were merged to generate zonal boundaries; and that of catchment areas of health facilities in Mzimba district were dissolved to generate the health district boundaries of Mzimba North and South. Before geodata can be uploaded into a GIS application, it requires to be in a suitable format. This is referred to as preprocessing. In DHIS2 GIS, geodata needs to be converted into GML (Geography Markup Language) format before being imported into the geographic database. GML is the XML grammar which serves as a modelling language for geographic systems and also as an open interchange format for geographic transactions on the Internet. Thus, I participated in the preprocessing of datasets of about 10,000 health facilities (including central hospitals down to village and outreach clinics), five health zones and twenty-nine health districts.

Setting up and testing of DHIS2 GIS – The set up involved creating new organisation units, editing existing ones and uploading GML files while the testing was mainly to verify the inclusion of health facilities in DHIS2 GIS and the functionality of basic features. The setting up and testing of DHIS2 GIS were carried out simultaneously in three steps. The first step was to upload coordinates of only available health facilities in DHIS2 GIS excluding village and outreach clinics. Then, the communication was made to HMIS officers in all health districts through emails to test the GIS module and provide feedback. They were provided with instructions on how to access and test DHIS2 GIS. The communication was also a means of providing the awareness of the operational DHIS2 GIS to HMIS officers. The second step was to add village and outreach clinics in two health districts – Blantyre and Mchinji, as the pilot sites. The testing of village and outreach clinics in DHIS2 GIS was done at the national level by the DHIS2 team. The third step was to add missing health facilities including village and outreach clinics of the remaining twenty-seven health districts and communications were also made to HMIS officers to verify their respective health facilities in DHIS2 GIS.

Demonstration of DHIS2 GIS – Before being rolled out, the DHIS2 GIS was demonstrated to some stakeholders at CMED and the health districts of Blantyre and Mchinji. Demonstrations were done at individual participants' workplaces and mainly involved the spatial analysis. In each demonstration, the choice of data to be included in the spatial analysis was done by participants themselves. At the end of each demonstration, there were discussions that allowed participants to express their expectations about the DHIS2 GIS. At CMED, two managers and one technical assistant responsible for health information system as users of DHIS2 were the participants in the demonstrations, which were done to each of them separately. Similarly, in Blantyre, the demonstrations were also done to each of four participants (one HMIS officer at Queen Elizabeth central hospital, one HMIS officer and two health program coordinators at Blantyre DHO) separately. It was difficult to have one demonstration due to availability of participants; they were available at different times. In Mchinji, there was only one demonstration in which four participants were present, and consisted of one HMIS officer and three health program coordinators.

Meetings and Training – As the temporary member of CMED and DHIS2 team, I had the opportunity to participate in meetings and training. During my fieldwork, I attended three meetings in which I was a passive participant and one training as a trainee. The first meeting was between the DHIS2 team and UNICEF in June 2016 discussing on GIS needs. The last two meetings (one in August and another in October 2016) were stakeholder meetings involving issues relating to technologies being implemented in HMIS including GIS. These stakeholder meetings were participated by development partners and some government agencies, which were working together with Ministry of Health in different technology implementation projects. I also participated in half-day DHIS2 GIS training to the DHIS2 team. The trainer was from Jhpiego as the collaborating organisation, which has been using DHIS2 GIS for some time.

4.4.2 Interviews

In information systems research, the interview has extensively been used (Schultze and Avital, 2011) and it is the important data source (Walsham, 1995). As the participant observer, interviews enabled me to step back and examine the interpretations of my fellow participants in some details (Walsham, 1995). As shown in Table 4-2, I conducted twenty-seven semi-structured interviews in total with different participants at both national and district levels. These interviews were conducted at different times (see Table 4-1) and in some cases, I had to interview one participant twice or more, which provided opportunities to confirm, verify and even build on information from previous interviews (Bolderston, 2012).

At the national level, I conducted seventeen semi-structured interviews with four CMED managers, three DHIS2 programmers, and four officers from two collaborating partners – Jhpiego and UNICEF. At the district level, I conducted ten semi-structured interviews with four HMIS officers and five health program coordinators in Blantyre and Mchinji health districts. I interviewed different participants from different roles in HMIS with the aim of trying "not to force one voice to emerge" (Myers and Newman, 2007, p. 17). Two out of the five health districts were randomly chosen as pilot sites for the deployment of DHIS2 GIS whose geodata for health facilities including village and outreach clinics were available by the time I started the fieldwork.

Table 4-2: Number of face-to-face interviews

Level	Interviewees	Number of participants	Number of interviews
National Level	CMED managers	4	7
	DHIS2 programmers	3	6
	Officers from Jhpiego and UNICEF	4	4
District Level	HMIS officers	4	4
	Health program coordinators	5	6
	Total	**20**	**27**

Purposive sampling was used to select health programs and participants at the national level and in two health districts. I chose three health programs for piloting namely malaria, nutrition, and family planning, which had been fully implemented in DHIS2 in the time of my fieldwork. Three CMED managers were chosen because they had been participating in various projects of strengthening HMIS including GIS implementation. Health program coordinators were from three chosen health programs. HMIS officers are the data managers and also provide the technical support to HMIS users in their respective health districts. They work closely with health program coordinators.

To each participant at the national level, an initial contact was done in person while at the district level, it was by telephone. This was because I was close to the participants at the national level as compared to those in the two health districts. The initial contacts were introducing myself to the participants and for finding out if they were willing to be interviewed and asking them for convenient time and place of interviews. All semi-structured interviews were conducted at the individual participant's workplace being guided by the interview questions that were prepared in advance. The interview questions were grouped per the category of interviewees as CMED managers (see Appendix 3.1), DHIS2 programmers (see Appendix 3.2), collaborating organisations (see Appendix 3.3), HMIS officers (see Appendix 3.4) and health program coordinators (see Appendix 3.5). On average, each semi-structured interview took 45 to 60 minutes. During interviewing, I used the note-taking technique to record responses in which rough but extensive notes were made. Immediately after the individual interview, I wrote my notes up in full.

Apart from the face-to-face interviews, I utilized the e-mail interview method to gather some data, taking the advantage of 'the ability to reach remote participants" (Bolderston, 2012, p. 73). I applied this method in two occasions; first, to ask follow up questions to the face-to-face interviews for clarification, and second, to gather general view of GIS use in health districts. I had two e-mail semi-structured interviews with one CMED manager and one health program coordinator after the initial individual face-to-face interviews. At first, I phoned the individual participant to introduce the theme of the email interview and agree when I expected to get the response; it took within seven days to get the responses. Both email interviews were asynchronous and text-based.

In order to get a broad view on GIS initiatives and basic GIS knowledge and skills at the district level, I organized online semi-structured interviews with HMIS officers in twenty-nine health districts and four central hospitals to gather basic information on the role of HMIS officers in DHIS2, their experiences in GIS and expectations in DHIS2 GIS (see Appendix 4). I managed to contact thirty-one out of thirty-three HMIS officers because I could not find the contacts of two HMIS officers. Their contacts were obtained from CMED. Out of thirty-one contacted, nineteen HMIS officers participated.

All interviews were asynchronous and text-based (prepared in Microsoft Word). I tried to contact twelve HMIS officers who had not responded through phone calls. Some phone calls did not go through while others promised to come back to me but they did not.

4.4.3 Artefacts Examination

The examination of artefacts provided me with the avenue of gathering data apart from the participant observation and interviews. Norum (2008, p. 25) refers to artefacts as "things that societies and cultures make for their own use" including written texts (e.g. documents, diaries, memos, letters), archival records, and those in the form of film, television, and music. I examined different artefacts to mainly build the understanding of GIS implementation initiatives from 2002 to 2017 and who participated in those initiatives. Table 4-3 lists the examined artefacts including policies, strategies, plans, program documents, data entry forms, geodata, maps, reports, and minutes. All those artefacts were produced without my intervention, and shared and used in socially organized way.

Table 4-3: List of examined artefacts

No.	Artefacts
1	Health Information System policy and strategy of 2003 (Ministry of Health and Population, 2003)
2	Report on the introduction to ArcGIS for health in Malawi in November 2008
3	Report on DHIS and GIS training workshop in February 2009
4	Emails exchanged between CMED management and stakeholders, including development partners, in September 2009 and January/February 2010
5	Maps of health districts with health facilities of 2011
6	Resource mobilization strategy for DHIS2 national implementation (Ministry of Health, 2011)
7	Malawi health sector strategic plan of 2011 – 2016 (Ministry of Health, 2013)
8	The Malawi national eHealth strategy of 2011 – 2016 (Ministry of Health, 2014)
9	Malawi service provision assessment (Ministry of Health and ICF International, 2014)
10	Geodata of health facilities and their catchment areas of 2003, health facilities of 2013, health facilities of 2015-16, and administrative districts
11	Minutes of GIS mapping meeting held on 15th October, 2015
12	Revised Health Information System policy of 2015 (Ministry of Health, 2015)
13	Brief history of DHIS implementation in Malawi (Moyo, 2016)
14	Data entry forms of nutrition, family planning, and malaria programs in DHIS2
15	Report on the new DHIS2 training in June 2017

I used these artefacts in three different ways. First, since the GIS initiatives started as early as 2002, the artefacts provided the background information; that is, bearing witness of past events. Second, this background information helped me to identify some areas that needed to be further investigated through interviews and/or participant observation. Third, the artefacts, particularly geodata, maps, reports, minutes, and HIS policies, provided a means of tracking changes and development in the GIS implementation for health management in Malawi.

4.5 Data Analysis

This interpretive information systems research focused on discovering patterns within the collected data with the aim of producing an understanding of the context of collaboration and geodata maintenance in GIS implementation in health sector in Malawi. The data analysis involved the explanation of the phenomenon based on the interpretation of case study data (Darke, Shanks and Broadbent, 1998) by examining and transforming the data into a coherent account of what was found (Green et al., 2007), that is, keeping a clear chain of evidence (Runeson and Host, 2009).

The data was analysed continuously throughout the study being guided by the theoretical framework discussed in Chapter 2 – resource criticality, scarcity and replaceability for understanding geodata and expertise resource dependencies and the role of collaboration in geodata maintenance. The data collection and analysis were carried out concurrently (see Figure 4-1). This allowed me to remain open to new ideas or insights that emerged during the analysis, which resulted in refining the focus of the study. The overlap between the data collection and analysis allow flexibility in data collection procedures (Darke et al., 1998) since new insights are found during analysis (Runeson and Host, 2009). To achieve this, the data analysis was done in two stages:–

1. *The individual paper writing* – At this stage, the data was analysed in order to answer the specific research questions in those papers. In addition, I participated in conferences (e.g. IST Africa 2017) and workshops (e.g. DHIS2 Academy 2017 and PhD Days at University of Oslo) during my study period where I presented some of my work. Feedback from reviewers and also my supervisors on those papers, and workshop participants sharpened my understanding on the case study data.
2. *The thesis writing* – At this stage, the data was analysed to address the three research questions specified in Chapter 1.

In both the individual paper and thesis writings, the data was analysed through four key steps – immersion in the data, coding, creating categories and identification of themes (Green et al., 2007). However, these steps were not done in a linear fashion; rather I moved back and forth through the processes in order to make sense of the whole dataset. This allowed me to systematically integrate new data into the analysis and assess the relevance of the chosen theoretical concepts as the data analysis proceeded (Green et al., 2007).

In the first step, *immersion in the data*, I familiarised myself with the data by reading and re-reading for several times. This process started as early as the commencement of the data collection. The data was in three forms: transcripts of interviews, field notes from the participant observation, and artefacts (including documents). The fieldwork was conducted by the master student of University of Malawi and myself. At the end of each day, we had reviews on our transcripts and/or field notes to have a common understanding on the data and, where necessary, expanded with relevant information from analysed artefacts. For example, to describe the *structure of coalition* in GIS implementation, I transcribed the interviews on interactions between Ministry of Health and other organisations. The first part of Table 4-4 demonstrates a part of transcript from the interviews and the data was organised per organisations.

In the second step, *data coding*, I examined and organised the data into significant groups and applied descriptive labels to data segments. As more data was collected, I worked through the whole data which resulted in adding new codes and refining meanings of some codes. The second part of Table 4-4 demonstrates the codes generated from the part of transcript.

Table 4-4: Part of transcript of from the interviews on interactions between organisations

Part of transcript from the interviews	Codes
HISP Malawi has two programmers who are on the secondment to CMED to manage DHIS2 and facilitate activities such as DHIS2 training, configurations, maintenance, and user support.	• Deploying programmers - HISP Malawi
UNIMA provides programmers and researchers to CMED in various projects. It has introduced DHIS2 training as part of its post-graduate programs in health.	• Deploying programmers and researchers – UNIMA • Training health students on DHIS2 - UNIMA
In the case of GIS implementation, UNICEF has worked with CMED aiming at improving analysis, integration and presentation of data to various stakeholders at the national and district levels. One activity was the collection of coordinates of health facilities, which UNICEF financed and facilitated.	• Financing GIS initiatives – UNICEF • Facilitating GIS initiatives – UNICEF
UiO has provided PhD and master students to work with DHIS2 team in Malawi in various projects as part of their research fieldwork. UiO sourced funds from the Global Fund to support the two programmers from HISP Malawi.	• Deploying researchers – UiO
In 2013, ICF International sourced funds from USAID for the service provision assessment in public health facilities in which spatial data for those facilities were collected. It also provided materials and training to MoH during the exercise. GPS used in the exercise were donated to CMED.	• Sourcing funds – ICF International • Proving GPS – ICF International
Baobab Health Trust (BHT) works with CMED in developing and implementing HIS in health facilities across the country particularly hospitals and health centres. During the deployment of DHIS2 GIS, two officers from Baobab Health Trust have been working with CMED as members of DHIS2 team.	• Deploying programmers – BHT
In 2002 and 2011, JICA provided consultants to MoH to facilitate the mapping of health facilities in Malawi. JICA also provided GIS software, ArcGIS.	• Deploying consultants – JICA • Providing GIS software – JICA
During the deployment of DHIS2 GIS, Jhpiego trained DHIS2 team on how to set up the system. It also provided spatial data for administrative district boundaries.	• Training DHIS2 users – Jhpiego • Providing geodata – Jhpiego
The department of Lands, the department of Surveys and NSO have also trained CMED officers on GIS. The department of Surveys and NSO also provide technical expertise and geodata in GIS projects.	• Training GIS users – Dept. of Lands, Dept. of Surveys and NSO • Deploying experts – Dept. of Lands, Dept. of Surveys and NSO • Providing geodata – Dept. of Surveys and NSO

In the third step, *creating categories,* I gradually brought similar codes under a set to create coherent categories. For example, from Table 4-4, codes were categorised into the external experts, training support, facilitation, financial support and material support as illustrated in Figure 4-2. Finally, in the fourth step, I identified themes from the categories guided by the selected concepts presented in Section 2.3.4, which involved explanations or interpretations of issues under investigation. As illustrated in Figure 4-2, for example, Ministry of Health is able to access external experts and support on training and facilitation due to *partnerships* with other organisations while financial and material supports are in terms of *donations*. Thus themes 'partnership' and 'donation' were identified and they are two dimensions of *structure of coalition.* In some individual papers, the identification of themes was guided by other concepts that were used to elaborate some selected concepts particularly the resource scarcity and replaceability. In Paper 1, *geodata completeness* was used to elaborate the geodata resource scarcity and identify actions for geodata maintenance. In Paper 3, *integrative approach* of GIS implementation was identified as one strategy for GIS expertise resource replaceability; that is, identifying substitutes for GIS professionals. In Paper 4, *knowledge sharing* was identified as part of building local capacity to enhance GIS expertise resource replaceability.

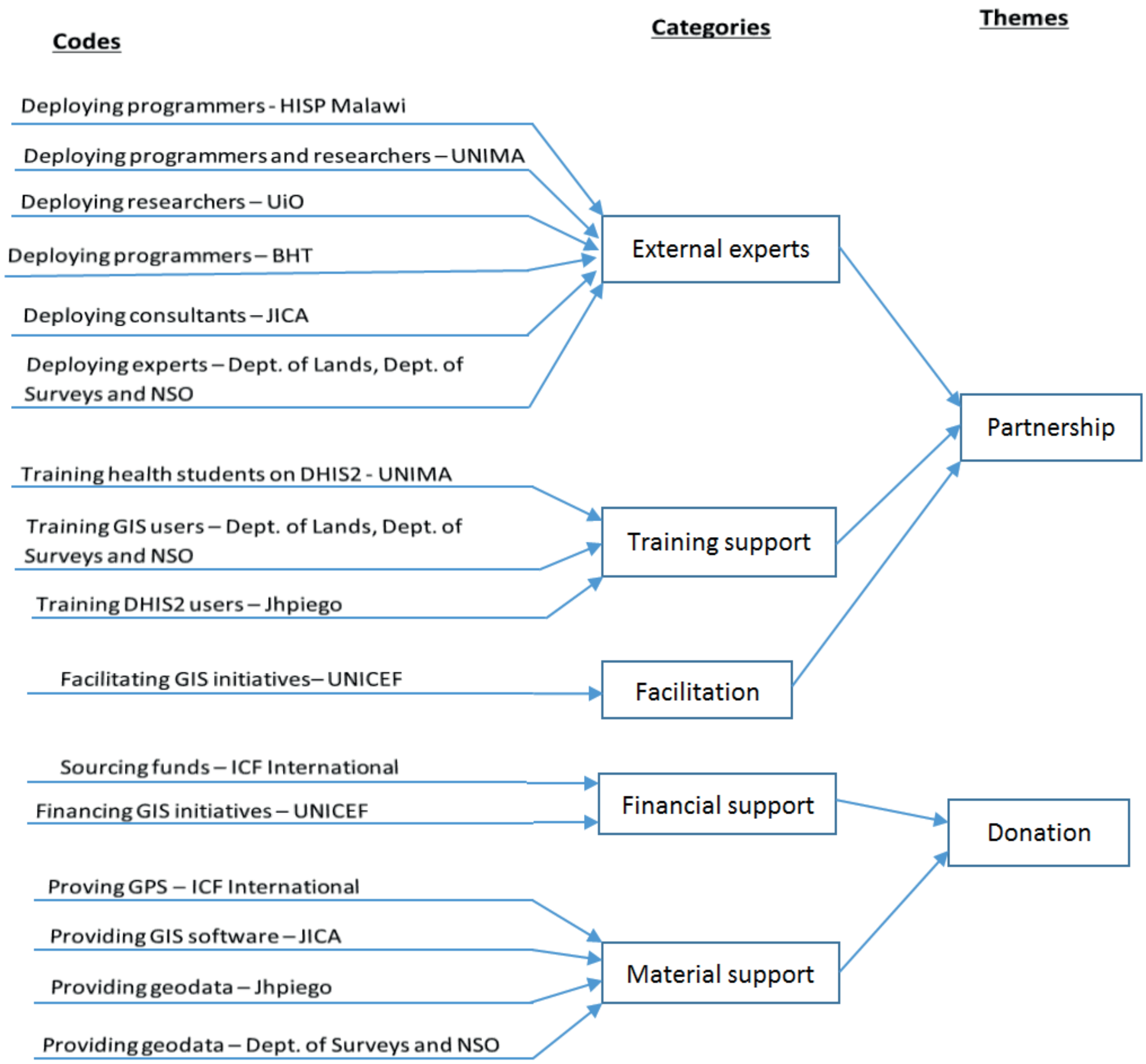

Figure 4-2: Creating Categories and Identifying Themes
(adopted from Green et al., 2007, p. 547)

Chapter Summary

This research was qualitative, interpretive case study using the case of Ministry of Health in Malawi. Data was collected through the participant observation, semi-structured interviews and artefact examination. The data analysis was done in two stages – during the individual paper and thesis writing – and through four key steps, which were applied – immersion in the data, coding, creating categories and identification of themes. The next chapter presents the key research findings.

Chapter 5: Findings

This chapter summarises the research findings through four papers that were developed as part of this thesis. The first section presents the individual papers and the role of authors. This is followed by the presentation of main findings from each paper and its contribution to the study in the second section. The third section summarises contributions of the individual papers to the research questions.

5.1 Individual Papers

The individual papers are:

Paper 1: Chikumba, P. A. and Chisakasa, G. (2018) Towards Geodata Maintenance: A Case of DHIS2 GIS Implementation in Malawi. *Journal of Health Informatics in Development Countries,* Vol. 12, No. 2

Paper 2: Chikumba, P. A. Acquiring Geodata and Expertise in GIS Implementation for Health Management in Malawi: The Role of Collaboration. *Under review in Journal of Information Systems and Technology Management*

Paper 3: Chikumba, P. A. (2017) Exploring Integrative Approach of GIS Implementation: The Case of GIS in Health Management in Malawi. Paul Cunningham and Miriam Cunningham (Eds): IST-Africa 2017 Conference Proceedings, IIMC International Information Management Corporation

Paper 4: Chikumba, P. A. and Naphini, P. (2018) GIS Initiatives in Health Management in Malawi: Opportunities to Share Knowledge. T.F. Bissyande and O. Sie (Eds.): *AFRICOMM 2016*, *LNICST 208*, pp. 263–272, https://doi.org/10.1007/978-3-319-66742-3_25

All journal and conference papers have been peer reviewed. In all four papers, I was the primary and corresponding author and I was involved in the design, data collection, data analysis, and writing of the papers. The co-authors of two papers, Paper 1 and Paper 4, were mainly involved in the data collection and analysis.

5.2 Findings from Individual Papers

This section presents the summary of findings from individual papers.

5.2.1 Towards Geodata Maintenance: A Case of DHIS2 GIS Implementation in Malawi

Purpose

The paper elaborates the concept of *geodata maintenance* in the context of health in which GIS is becoming popular by proposing the combination of six administrative and technical actions. In literature of geodata maintenance, the focus has been on geodata collection and geographic database update that this paper has identified as the subset of geodata maintenance. This translates that in addition to geodata collection and geographic database update, there are other actions to be performed in the geodata maintenance. The paper also provides the rich understanding of the context of DHIS2 GIS implementation in Malawi.

The paper adopts the concept of *geodata completeness* with the focus on the reality, the model world (for model completeness), and the digital data (for data completeness) (Veregin, 1999; Yang, 2007). The reality has helped in the identification of necessary spatial features and their relationships as an application domain of DHIS2 GIS. The model world has assisted in understanding thematic and spatial elements of the spatial features for DHIS2 GIS database. The aspect of digital data has defined the geodata for DHIS2 GIS implementation. The assessment of geodata completeness has led to the identification and definition of administrative and technical actions in the geodata maintenance.

Findings

This paper has identified three basic spatial features namely health facilities, health catchment areas, and population distribution, which are needed by the majority of health programs and services in DHIS2. Health facilities include central hospitals down to village and outreach clinics, which provide health services to the population in their respective catchment areas. Spatial datasets for these spatial features need to be updated at a certain time. The key observation is that before the geographic database is updated, certain actions should be performed to generate required new data. Thus, this paper proposes these actions (see Figure 5-1 and Table 5-1).

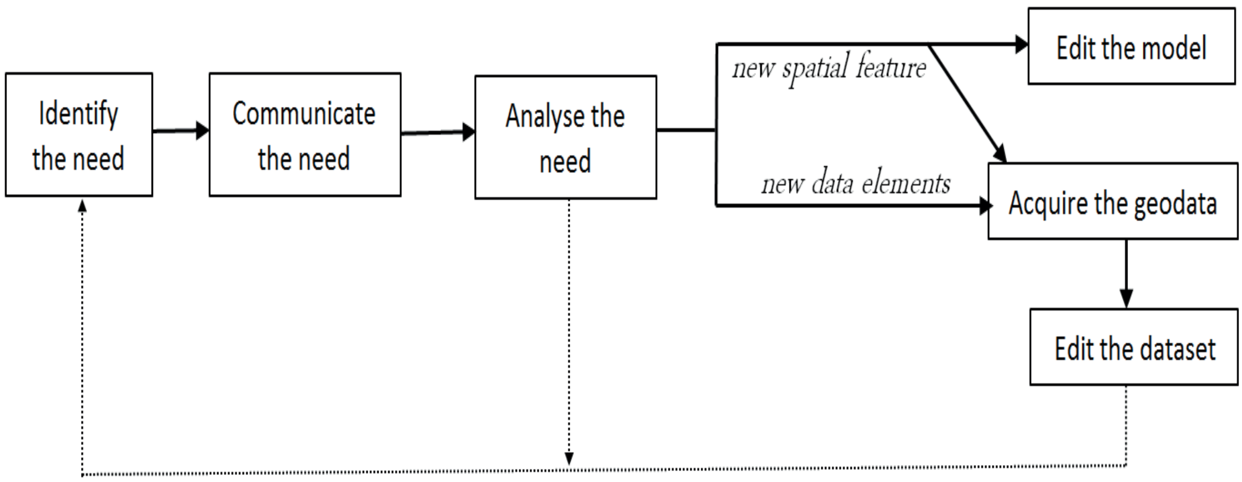

Figure 5-1: Proposed Actions for Geodata Maintenance

The process of maintaining geodata is initiated by a need that is imposed by a data user or due to a real world change. This need is to be communicated to an agency that assesses the need for its feasibility. If it is feasible to implement the change, the acquisition of geodata and geographic database update are expected to take place and the reporting agency and other stakeholders are to be communicated accordingly; otherwise the change is not to take place. The type of change is either a new spatial feature or new data elements whose geodata are acquired. If a new spatial feature is demanded, a geographic database schema (the model) may be modified to integrate the new feature with existing ones. After the geodata acquisition, the dataset is edited to be ready for use.

Table 5-1: Categories and Descriptions of Proposed Actions

Action	Category	Description	People involved
Identify the need	Administrative action	A new demand can come from any level in HMIS (nation, zone, district, facility, or community) that influences some changes in GIS including geodata as one important resource in meeting user needs.	Any stakeholder in the GIS application domain can identify the need; including health personnel.
Communicate the need	Administrative action	The identified demands are to be reported to the authority for assessment. The reported demand is to be documented for referencing.	A HMIS officer is for handling demands within his/her district while CMED management is for demands at national level.
Analyse the need	Administrative/ Technical action	A change on geodata should carefully be assessed to determine the complexity and required resources for its implementation. The assessment involves the level of change (i.e. database model or spatial and thematic elements), when to implement the change, responsible personnel and required competence, and expect effects on GIS technology and related systems.	HMIS officers and CMED management with basic knowledge of geodata and GIS can assess the need. If the need is complex and requires high competence, other organisations can be consulted for support.
Edit the model	Technical action	This is the process of making changes to a geographic database schema in order to integrate new spatial features with existing ones so that they can easily be analysed, presented and visualized.	This requires people with knowledge of GIS software in use including database management who are usually developers or implementers
Acquire the geodata	Technical action	Geodata can be acquired through three ways: data sharing, captured in the field (primary data capture), or internally developed (secondary data capture)	This needs people with knowledge of geodata capturing using at least GPS and coordinate systems
Edit the dataset	Technical action	This involves changes on spatial and/or thematic elements; add new contents or replacing outdated ones	This requires technical support team with knowledge of GIS software in use and geodata

The paper argues that since Ministry of Health lacks adequate capacity, it is unlikely to carry out the geodata maintenance operations without collaborating with other organisations, particularly in *edit the model* and *acquire the geodata* processes which require the high level of expertise. Therefore, collaboration is useful in the geodata maintenance. Geodata maintenance as an innovation also needs to be incorporated into operations in HMIS and involves various stakeholders at different levels.

Conclusion

The paper provides the rich understanding of geodata maintenance in the context of health in developing countries by proposing six administrative and technical actions of which the last three actions were derived from geodata collection and geodata update literature (Huisman and de By, 2009; Longley et al., 2015). The first three administrative actions were identified and defined as key actions for the requirements analysis in geodata maintenance.

5.2.2 Acquiring Geodata and Expertise in GIS Implementation for Health Management in Malawi: The Role of Collaboration

Purpose

The paper discusses the role of collaboration in the acquisition of geodata and expertise. Collaboration is considered as one strategy that Ministry of Health had adopted in the implementation and support of DHIS2 in particular and strengthening HMIS in general. This paper recognises geodata as the new type of data to be included in DHIS2 for GIS to function. Another important concern is expertise required in the implementation of DHIS2 GIS. Literature points out that there is shortage of local skilled personnel for GIS implementation in developing countries (Fletcher-Lartey and Caprarelli, 2016; Sipe and Dale, 2003). Collaborative arrangement is suggested as one strategy of mitigating the shortage of such resource (Fletcher-Lartey and Caprarelli, 2016; Ramasubramanian, 1999). Therefore, the objectives of this paper were to identify the external environment as sources of geodata and GIS expertise; and also to investigate the nature and extent of the shortage of geodata and expertise that have driven Ministry of Health in Malawi to opt for collaboration. This paper has adopted the concepts of *dependence* (Pfeffer and Salancik, 1978) and *involvement in collaboration* (Lawrence et al., 2002).

Findings

Findings indicate that Ministry of Health has been dependent on different organisations to access geodata and expertise. As shown in Table 5-2, the paper categorises these organisations as government agencies, non-profit organisations, and academic institutions, which have participated in various GIS initiatives.

Table 5-2: Roles of Collaborating Organisations in GIS Implementation in Malawi's HMIS

Category	Organisation	Participation
Government Agencies	Department of Surveys	- Provided facilitators in GIS training - Deployed GIS professionals in the static map production - Provided geodata e.g. administrative districts
	National Statistical Office	- Provided geodata e.g. administrative districts, villages - Provided facilitators in GIS training
	Department of Lands	- Provided facilitators in GIS training - Deployed GIS professionals in geodata capture
	National Aids Commission	- Provided facilitators in GIS training
Non-profit Organisations	UNICEF	- Financed and coordinated geodata capture
	Japanese International Corporation Agency	- Deploying GIS consultants in the static map production
	ICF International	- Financed geodata capture and conducted GPS training
	Jhpiego	- Deployed GIS professional as implementer
	Baobab Health Trust	- Deployed DHIS2 programmers for support
	HISP Malawi	- Deployed DHIS2 programmers for support
Academic Institutions	University of Malawi	- Deployed GIS researcher as implementer - Deployed DHIS2 programmers for support
	University of Oslo	- Deployed GIS researcher as implementer

Since they have vast experiences in GIS including geodata capture, the government agencies have mainly provided geodata, deployed facilitators in GIS user trainings, and deployed GIS professionals as seconded employees to Ministry of Health in various GIS initiatives. The non-profit organisations have assisted Ministry of Health in financing GIS initiatives and deploying GIS professionals as consultants and IT professionals particularly DHIS2 programmers. Universities have deployed IT professionals including GIS experts as researchers. However, the observation is that these organisations have been collaborating with Ministry of Health to jointly carry out activities in strengthening HMIS in which most GIS implementation activities are embedded. From these categories of collaborating organisations, this paper has identified three collaboration arrangements, which are perceived as *public-public* (Ministry of Health and other government agencies), *public-non-profit* (Ministry of Health and non-profit organisations), and *public-academic* (Ministry of Health and universities).

In all these collaboration arrangements, there are the high level of involvement of collaborating organisations due to deep interactions, joint execution of activities, and bidirectional information flow (Lawrence et al., 2002). There exist deep interactions because apart from the top management of Ministry of Health, collaborations are extended to other personnel at both national and district levels. *Partnerships* and *donations* are two main forms of interactions in which Ministry of Health and collaborating organisations have jointly carried out geodata- and expertise-related activities. Particularly, the non-profit organisations, have donated finances and materials to support geodata capture and user training. The government agencies are sources of geodata through data sharing and GIS expertise. Non-profit organisations and academic institutions are mainly the sources of expertise.

Ministry of Health has depended on other organisations to implement GIS for health management because of the shortage of geodata and expertise as critical resources. The shortage of geodata exists due to failure by Ministry of Health to obtain complete geodata from other organisations, which has forced the ministry to capture geodata in-house. Specifically, geodata for health facilities and their catchment areas have been identified as scarce geodata that cannot easily be obtained through data sharing. From the perspective of geodata acquisition, collaboration plays a great role in both primary and secondary data capture in which collaborating organisations can be partners and/or donors. Due to geodata sharing and in-house geodata capture, Ministry of Health is now custodian of the required geodata of about ten thousand health facilities.

The paper highlights that Ministry of Health accesses GIS professionals from collaborating organisations due to the shortage of skilled personnel. The shortage of GIS professionals exists in Ministry of Health because of financial constraints and employment set-up that lead to the failure of the ministry to recruit its own GIS professionals. Although collaborating organisations are to deploy GIS professionals as seconded employee, consultants and researchers, they are available for a short time, that is, within the time of collaboration. This brings a challenge of having the continued support on the implemented GIS and geodata maintenance. Hence, Ministry of Health has identified substitutes for GIS professionals including HMIS officers, health personnel and DHIS2 programmers to carry out some GIS activities, particularly primary geodata capture and configuring DHIS2 GIS. However, these non-GIS professionals require certain GIS knowledge and skills, which can be acquired through knowledge sharing between GIS professionals and non-GIS professionals.

Conclusion

The paper concurs with previous studies that emphasise collaboration as one strategy for organisations in developing countries to consider when implementing GIS in health due to limited resources (Fletcher-Lartey and Caprarelli, 2016; Kim et al., 2016). Particularly, the paper identifies stakeholders that can be involved in collaborations and how to be involved. Every collaboration involves at least two autonomous stakeholders that are interested in a particular problem domain (Sowa, 2008; Thomson and Perry, 2006).

5.2.3 Exploring Integrative Approach of GIS Implementation: The Case of GIS in Health Management in Malawi

Purpose

As observed in Paper 2, most collaborations are not totally for GIS implementation but for other programs or projects in which GIS implementation activities are embedded. This approach is perceived as the integrative approach of GIS implementation (Ramasubramanian, 1999). Hence, the paper aims at exploring how the integrative approach of GIS implementation has been applied in the health management context and to discuss lessons learnt from Malawi. Out of five stages of the integrative framework, this paper focused on the first three stages – policy or programmatic goals (the first stage), funded programs or projects (the second stage), and implementing activities (the third stage) – since the interest is on the GIS implementation activities. The understanding is that policy or programmatic goals provide the motivation for introducing GIS and they are usually translated into funded programs or projects. GIS implementation activities are part and parcel of those funded programs or projects.

Findings

The paper has found out that there were no policies or other types of documents totally for GIS implementation for health management in Malawi. The GIS implementation has been motivated through policies, strategies and documents of other programs and projects. Findings indicate that GIS implementation activities – spatial data collection, GIS user training and DHIS2 GIS deployment – have been embedded in some projects within the HMIS strengthening program, that is, these GIS implementation activities are to be taken for strengthening HMIS.

The paper has argued that the integration of GIS implementation activities with those of other programs or projects may be determined by the compatibility of activities to be linked, which is perceived as a condition in which two or more activities from different programs or projects are executed together without critical problems or conflicts. This paper has identified shared scope (what to be covered in the project), shared time (when to undertake different tasks), and shared resource (what can be used to meet the scope) as commonalities for achieving the compatibility of activities.

One opportunity of sharing of resources is that non-GIS professionals are able to participate in some GIS tasks such as geodata capture and DHIS2 GIS deployment. However, the main challenge is the lack of control over allocation and use of human resource. For instance, although Ministry of Health has invested in HMIS officers at the district level in GIS knowledge through training, the officers have not been involved in most of GIS implementation activities. This may negatively influence the local expertise building. The paper has noted that in some GIS implementation activities, particularly which are embedded in other projects, HMIS officers are not recognised as the critical resource.

Conclusion

The paper advances the understanding of the integrative approach of GIS implementation in developing countries (Ramasubramanian, 1999); taking this approach as a strategy for involving stakeholders in GIS implementation and also identifying substitutes for GIS professionals. It also reemphasizes the utilization of resources (Ramasubramanian, 1999) such as people and finances through resource sharing, which can result in reducing costs and time.

5.2.4 GIS Initiatives in Health Management in Malawi: Opportunities to Share Knowledge

Purpose

The paper discusses the building of local expertise that is the critical resource in GIS as indicated in Paper 2; and also it has been noted in Paper 3 that non-GIS professionals can be involved in GIS implementation who require adequate knowledge and skills. This paper discusses knowledge sharing as one way of acquiring and accumulating knowledge; involving implementers and users in GIS implementation for health management in Malawi. Analysis and discussions in this paper have been guided by the notion of *knowledge sharing*, particularly opportunities to share knowledge (Ipe, 2003).

Findings

In this paper, findings indicate that GIS knowledge is available at the national level through collaboration (i.e. with GIS professionals from collaborating organisations) and there is a need to share such knowledge with local GIS users particularly at the district levels where DHIS2 GIS is expected to be used. Table 5-3 lists the initiatives that can facilitate sharing of knowledge in GIS applications in Ministry of Health in Malawi (MoH).

At the national level, collaboration has allowed Ministry of Health to build work teams of GIS professionals and non GIS professionals, which has resulted in individual knowledge sharing. In order to reach a larger number of expert users at the district level, the ministry deploys face-to-face user trainings and manuals. Training remains the main method of sharing GIS knowledge with users, which accommodates a large number of participants and enables them to interact. Since user trainings are not conducted frequently and do not cover all required knowledge, user manuals are deployed to supplement training. CMED uses manuals as means of codifying, particularly, task-related knowledge.

Table 5-3: Initiatives Facilitating Sharing of Knowledge

Initiatives	**Remarks**
User training	This is done to transfer knowledge from the national level to district level. In some cases it is within the same level, e.g. during the setup of DHIS2 GIS, there was a training at the national level for GIS implementation team being facilitated by some members within the team
Collaborations	The collaboration is mainly at the national level
Structured work team	It is mainly at the national level; team of experienced (GIS professionals) and non-experienced users (e.g. DHIS2 users)
Learning-by-doing	This is an institutional initiative at the national level and individual initiative at the district level. Some HMIS officers have learned GIS through performing particular tasks requested by other stakeholders in their respective districts.
Codification	There is no much codification of knowledge; particularly the production of documentation. In most user trainings presented in this paper, there were no training manuals that would be referenced at the workplace after training. For spatial data collection, there are some manuals for reference.
Workshops (or meetings)	In MoH, workshops and meetings are always available which HMIS officers attended. MoH can take advantage of these activities to share experiences in GIS among officers.

In the context of geodata maintenance, the knowledge generated through work teams, user training and user manuals is important particularly in carrying out the technical actions of the six proposed actions (see Figure 5-1 and Table 5-1). Some instances are summarized below.

- *Work teams* – In 2002 and 2011, GIS professionals worked together with CMED management in primary and secondary geodata capture and generation of static maps. Through this experience CMED management may be able to *assess the need, acquire the geodata,* and *edit the dataset.*
- *User training* – HMIS officers were trained in GIS in several occasions by facilitators from government agencies on primary geodata capture using GPS, generation of static maps, and spatial data analysis. Knowledge generated may help HMIS officers to *assess the need, acquire the geodata,* and *edit the dataset.*
- *User manuals* – CMED management through GI implementers has been producing user manuals for HMIS officers and other users on how to use GIS; and knowledge generated through those may help to *edit the dataset.* ICF International as the collaborating organization produced the user manual on how to record GPS data, which can be used when *acquiring the geodata.*

Conclusion

The paper contributes to the debate on the importance of building local technical capacity for the sustainability of the implemented GIS because the user organisation cannot depend on consultants or external experts forever (Cavric et al., 2003; Fletcher-Lartey and Caprarelli, 2016; Longley et al., 2015). As observed in Paper 1, Paper 2 and Paper 3, Ministry of Health requires local users to participate in GIS initiatives. Hence, these local users need adequate knowledge and skills to perform as expected.

5.3 Contributions of Papers to Research Questions

This section summarises the paper contributions to the research questions as presented in Table 5-4.

Table 5-4: Summary of Paper Contributions to Research Questions

Research Papers	*What are activities of geodata maintenance in health sector in a developing country setting?*	*How can collaboration assist in the maintenance of geodata in health sector?*	*How can collaboration contribute towards the building of local expertise for geodata maintenance in health sector?*
Paper 1	It proposes six administrative and technical actions for geodata maintenance – *identify the need, communicate the need, analyse the need, edit the model, acquire the geodata* and *edit the dataset*	It identifies which actions may require collaboration – *analyse the need, edit the need* and *acquire the geodata*	It describes needed expertise for the geodata maintenance and which expertise can be accessed through collaboration
Paper 2	N/A	It recognizes geodata as one key exchange resource particularly in public-public collaboration It identifies geodata sharing and capture as means of accessing geodata through collaboration	It recognizes GIS professionals as one key exchange resource in collaborations between Ministry of Health and other organisations.
Paper 3	N/A	N/A	It describes the integrative approach of GIS implementation as one opportunity of identifying substitutes for GIS professionals through human resource sharing leading to local expertise building It describes little control over allocation and use of human resource as a barrier to local expertise building
Paper 4	N/A	N/A	It discusses strategies of sharing knowledge – work teams, user manuals and training – leading to local expertise building

Chapter Summary

This chapter elaborated the concept of *geodata maintenance* in health in developing countries as the combination of six administrative and technical actions – *identify the need, communicate the need, analyse the need, edit the model, acquire the geodata,* and *edit the dataset*. For the user organisation to perform these actions, it mainly requires geodata and GIS expertise as critical resources that are usually acquired from the external environment – government agencies, non-profit organisations and academic institutions – through partnerships and/or donations because the majority of organisations in health sector in developing countries have inadequate capacity. However, since the user organisation cannot depend on external experts forever, it needs to empower its local users to be substitutes for external GIS experts. GIS implementation tasks can be assigned as official duties of local users and in some cases, GIS initiatives are embedded in other projects or programmes. To empower the local users, strategies for local capacity building such as work teams of experienced and non-experienced, user training and user manuals are to be promoted.

The next chapter explicitly discusses these research findings in three broad headings – geodata maintenance as combination of administrative and technical actions, GIS expertise resource dependence in geodata maintenance, and dependence on external environment as collaboration.

Chapter 6: Discussions

This chapter discusses the research findings presented in the previous chapter. As stated in Chapter 1, this research aimed at proposing a framework for geodata maintenance in the context of health in developing countries and investigating the contribution of collaboration towards geodata maintenance and the building of local expertise. The thesis has adopted the concept of *dependence*, that is, the extent to which an organization needs another in relation to a given resource (Klein and Pereira, 2016). In the context of geodata maintenance, discussions focus on the dependence of the user organisation in health sector on the external environment and how it can build its capacity towards the mitigation of resource dependencies. The first section discusses geodata maintenance as combination of administrative and technical actions. The second section discusses the GIS expertise in geodata maintenance. The third section conceptualises dependence on the external environment in geodata maintenance as collaboration.

6.1 Geodata Maintenance as Combination of Administrative and Technical Actions

This section discusses explicitly the proposed framework for geodata maintenance in health sector in developing countries involving six administrative and technical actions to build the rich understanding of the concept of geodata maintenance. To the two actions – geodata collection and geographic database update (Huisman and de By, 2009; Longley et al., 2015), the thesis has identified additional three actions for assessing new user demands and/or real world changes to guarantee changes in geodata. The thesis has further derived two actions from the geographic database update based on the definition by Longley et al. (2015). Discussions on geodata maintenance have been guided by the concepts of resource dependence and geodata completeness.

6.1.1 Geodata Resource Dependence – Criticality, Scarcity and Replaceability

As presented in Section 2.1, geodata is critical resource in any GIS application. The main concern recognised in this research is the shortage or scarcity of geodata, which, from the geodata completeness, has been conceptualised as *omission* in geodata. Omissions in geodata occur when some geodata elements are missing in the geographic database (Yang, 2007). From the three basic spatial features identified in Malawi's DHIS2 GIS as presented in Section 5.2.1, geodata of health facilities and population distribution are scarce as compared to those of health catchment areas that can be modelled with administrative boundaries.

Although all three geodata elements – spatial, thematic and temporal elements – are equally important (Longley et al., 2015; Peuquet, 2002), in the case of DHIS2 GIS, spatial and thematic elements are key geodata elements that require attention in geodata maintenance. However, comparing these two types of geodata elements, the spatial elements are scarcer than thematic elements because in DHIS2 GIS, thematic elements are usually defined and captured when the organisation units are being created or updated. As observed in Malawi, the acquisition of geodata was on the spatial elements of health facilities and catchment areas (particularly health districts and zones) as the organisation units in DHIS2 GIS. This concurs with Braa and Sahay (2012) that the set-up of DHIS2 GIS is basically a matter of populating coordinates of the organisation units. However, with the advances in GIS technology, apart from coordinates of the organisation units, it is possible to include the Google Earth Engine layers and external map layers that also require to be maintained. Thus, in geodata maintenance for DHIS2 GIS, the user organisation is to concentrate on spatial elements of the organisation units and as well as the external map layers.

Although the thesis has applied *omission* from the geodata completeness to determine the scarcity of geodata, it is not the only factor. In some cases, the user organisation can decide not to use the existing geodata due to other factors related to the data quality such as accuracy, lineage and consistency. Huisman and de By (2009) point out that before using geodata, the user organisation needs to check for its quality. Thus, basically, the thesis perceives the scarcity of geodata as the absence of datasets that are fit for the purpose of a GIS application in the user organisation.

Although resource scarcities may force organisations to look for new innovations that use alternative resources (Hessels and Terjesen, 2010), geodata as the resource cannot be replaced or substituted. The only way is to perform geodata maintenance operations to continuously keep geodata as supportive as possible to the GIS users. As Longley et al. (2015) point out, after completing the basic data collection the focus should move on to data maintenance. Since the explicit description on how to perform geodata maintenance is missing in GIS literature, as stated in Chapter 1, six administrative and technical actions – (1) identify the need, (2) communicate the need, (3) assess the need, (4) edit the model, (5) acquire the geodata, and (6) edit the dataset – have been identified (see Section 5.2.1) that are discussed in the next sub-section.

6.1.2 Proposed Six-Actions for Geodata Maintenance

To perform these six actions for geodata maintenance, two key decisions are to be made. First, the user is to identify and communicate the need for change to people responsible for providing the user support for further assessment. Second, after assessing the need, the user organisation should decide whether to proceed with the geodata maintenance. Hence, as illustrated in Figure 6-1, the six actions are categorised into two phases – assessment and geodata update.

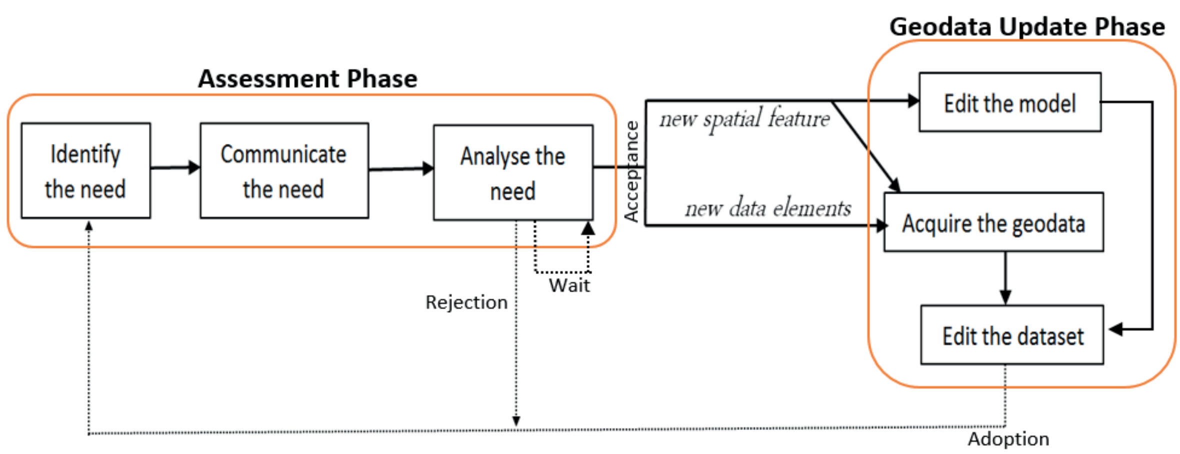

Figure 6-1: Proposed Framework of Geodata Maintenance
(revised from Figure 5-1)

The framework of geodata maintenance has been developed through the empirical analysis of the user support practices and upon the concepts of geodata collection and geographic database update. In every GIS application, the user support provision is required (Longley et al., 2015) and the thesis perceives geodata maintenance as the user support practice to meet requirements imposed by users and as well as due to the real world change. The first three actions – *identify the need*, *communicate the need* and *analyse the need* – are additional to geodata collection and geographic database update for assessing new user demands and/or real world changes and derived from the user support practices in Malawi's HMIS, which thus thesis refers to as the assessment phase. The last three actions are taken as part of the geodata update phase for implementing identified changes. The concept of geographic database update is further extended into two actions – *edit the model* and *edit the dataset*. The observation is that in the context of geodata maintenance, these two actions are to be carried out independently with unique requirements in terms of time, expertise, technology and other resources. In this thesis, the term 'edit' means make changes to an object in the computer (Longley et al., 2015).

Below is the summary of the six actions.

- *Identify the need* – The thesis derived this action from the user support provision in which users identify new needs initiated by direct change on spatial feature, change on health data, or external systems. This concurs with the statement of Huisman and de By (2009) that data maintenance is for meeting requirements imposed by users and/or due to the real world change.
- *Communicate the need* – The thesis derived this action from the user support provision in which users report their new needs to the support staff within the organisation for the assistance.
- *Analyse the need* – The thesis derived this action from the user support provision in which users expect the support staff to respond their new demands by implementing appropriate changes or reporting to them with reasons that their new demands would not be met.
- *Edit the model* – The thesis perceives this action as part of the geographic database update involving changes to the geographic database schema (Longley et al., 2015) and further extends by including the software customisation since GIS software may be adapted to align with changes in data models.
- *Acquire the geodata* – The thesis perceives this action as the geodata collection involving data sharing and capture (Longley et al., 2015). In addition, data preparation is required (Huisman and de By, 2009) including preprocessing.
- *Edit the dataset* – The thesis perceives this action as part of the geographic database update involving changes to spatial and thematic elements; that is, the definition of this action is the same as in Longley et al. (2015).

The rest of this sub-section elaborates these six actions.

Identify the need – Administrative Action

Huisman and de By (2009) state that (spatial) data maintenance is for meeting requirements imposed by users and as well as due to the real world change. In the case of requirements imposed by users, the identification of change in geodata is twofold. First, the change can be directly on a spatial feature in terms of changing its location and/or attributes, or a new feature is created, or existing one is no longer required, which result in maintaining geodata of such spatial feature. Some spatial features change their elements more frequently than others. For instance, in Malawi's health sector, geodata of health facilities change more frequently than those of health catchment areas. Even within the set of health facilities, those with temporary structures such as village and outreach clinics are more likely to change locations or attributes or new clinics are established than those with the permanent structures like health centres and hospitals. Second, demand can be on health data required by health programs or services that may lead to changes in geodata particularly, when the concerned health data has the spatial dimension that can well be processed and presented by adopting a GIS technology. As an example, here is the request from one health program coordinator:

> "… we have under five children in our nutrition program as outpatients whom we visit in their respective homes for different services… we appreciate if we can manage to track them and visualise their locations for the logistical purpose …"

This demand can be met by implementing a tracking application (for example, a DHIS2 Tracker) with recorded GPS data and then GIS can be used to visualize spatial information. In DHIS2 GIS, it is possible to display the geographical location of events registered in the DHIS2 tracker provided that events have associated GPS coordinates (DHIS2 Documentation Team, 2018).

In the case of the real world change, a demand for change in geodata is initiated by external systems over which the user organisation has no control. In Malawi's health sector, as in other developing countries (Saugene and Sahay, 2011), the public administrative system is one of such external systems. Due to the scarcity of geodata of health catchment areas, administrative district boundaries are used and thus, any changes in administrative boundaries affect health catchment areas. However, as observed in this research, the maintenance of such geodata is the responsibility of other government agencies; not Ministry of Health. As Huisman and de By (2009) point out, although users can collect their own geodata, collection and maintenance of base data remain responsibility of the various government agencies that are responsible for collecting topographic data for the entire country. Administrative boundaries are part of the base data.

Communicate the need – Administrative Action

Findings indicate that the need for change is communicated to HMIS officers at the district level and the CMED management at the national level as the HMIS expert users for further action. This communication follows the structure of governance (i.e. information flows) in Malawi's HMIS and different ways of interactions between the expert users and novices exist. This implies that reporting of user demands to the support staff in geodata maintenance may not require its own specific communication system. That is, the action of *communicate the need* in geodata maintenance should follow the existing governance structure of the user organisation. Specifically, if GIS is embedded in a particular information system, for example DHIS2 GIS in Malawi, the communication in geodata maintenance should follow the existing communication protocols of the system.

Analyse the need – Administrative and Technical Action

In this thesis, *analyse the need* is perceived as the requirements analysis in the geodata maintenance involving the data modelling and the determination of the availability of expertise and other resources for the process to be successful. Data modelling is essential in an operational GIS; developing a set of constructs for representing objects and processes (Longley et al., 2015). However, the examination of expertise and information technology environment is also vital. In GIS, as in any other information system, the requirements analysis provides the detailed information necessary for the implementation of user needs, including the examination of information technology environment (Meaden, 2013; Somers, 2008). Thus, as indicated in Section 5.2.1, for geodata maintenance, four basic factors to be considered in *analyse the need* have been identified: - (1) when to implement the change, (2) level or type of the change, (3) an expected effect on GIS technology and related systems, and (4) responsible personnel and required expertise. The first factor is the outcome of the action of *analyse the need* that is acceptance, wait, or rejection (see Figure 6-1) as discussed below. The second and third factors are further discussed in the last three actions in the geodata update phase. The fourth factor is discussed in Section 6.2.

When to implement the change in geodata can be decided based on two factors: the criticality of geodata in a GIS application and the scarcity of other resources including expertise, hardware and software. Thus, the outcome of *analyse the need* – acceptance, wait or rejection – are discussed from the perspectives of these two factors.

- **Acceptance** – This is when geodata are critical to meet a new demand and other required resources are available and accessible for implementing the demand. The acceptance results in the adoption of operational GIS by completing the last three technical actions. Findings indicate that the operational DHIS2 GIS is possible when at least geodata of health facilities and catchment areas are available. Therefore, the update of such geodata is a priority.
- **Wait** – This occurs when geodata are critical but there are inadequate resources for implementing the demand. In the case of population distribution, Ministry of Health was to wait for the upgrade of DHIS2 to support map of layers from Google Earth Engine including the population layer. However, the user organisation needs to decide how long to wait before implementing a particular change; otherwise the outcome can be equally considered as rejection if the waiting time is longer than expected.
- **Rejection** – The user organisation can reject the process of geodata maintenance based on that the affected geodata is not critical to the current or proposed operations. For example, the demand of tracking outpatients in the nutrition program (as quoted above) was not implemented because it was not critical to operations of the nutrition program. However, when the environment favourably changes, it is possible to reconsider the rejected demand and all three stages in the assessment phase are to be carried out.

In the case of demand from users, the outcome of *analyse the need* is one of the three (acceptance, wait or rejection) while in the case of the real world change, the outcome is either acceptance or wait. It is rare to reject the change in geodata due to the real world change. The understanding is that if the real world change affects a GIS application, new geodata of affected spatial features are usually critical. The challenge can be that the user organisation has inadequate resources to support the change or the concerned external organisations delay to update geodata; resulting in the *wait* state.

As stated earlier, if the acceptance is the outcome of *analyse the need*, the last three technical actions are carried out. Below are discussions on the three actions.

Edit the model – Technical Action

Data models suggested in *analyse the need* are to be implemented through the action of *edit the model* that is one type of the change in geodata maintenance. From the perspective of geodata completeness, this action aims at achieving the model completeness so that geographic database is able to answer questions of 'where', 'what', and 'when'. New spatial features require being properly integrated with the existing ones in GIS for the effective spatial analysis and visualisation, which is usually achieved by editing the geographic database schema. Geographic databases are one important class of models to be edited for meeting user requirements (Huisman and de By, 2009). Usually, however, edited models bring changes in data manipulation, analysis and visualisation resulting in adapting GIS software to align with those changes. Longley et al. (2015) emphasise that spatial data models have a strong influence on the analyses that can be undertaken. The spatial analysis is the functional requirement of GIS software. As observed in this research, customisation of DHIS2 GIS is required, including the DHIS2 upgrades, to meet user needs. Thus, apart from editing database schema, the thesis has recognised the software customisation as another task in *edit the model*. The customisation may also include other software related to GIS, particularly if GIS is embedded in another information system as in the case DHIS2. As stated earlier in this sub-section, one factor to be considered in *analyse the need* is the identification of expected effect on GIS technology and related systems.

Acquire the geodata – Technical Action

One functional component of a GIS application is the data collection and preparation (Huisman and de By, 2009; Longley et al., 2015), which the thesis perceives as the technical action of *acquire the geodata.* The aim of this action is to mitigate the scarcity of geodata. In this research two ways of acquiring geodata have been experienced – data sharing and data capture, which are explicitly discussed in GIS literature (Gelagay, 2017; Huisman and de By, 2009; Longley et al., 2015). Data preparation involves preprocessing; converting geodata into forms suitable for entry into a GIS application.

Edit the dataset – Technical Action

This action aims at achieving the data completeness by editing spatial and/or thematic elements. Because location and attribute data are usually variable independent of one another (Ulubay and Altan, 2002), in DHIS2 GIS, this is possible to capture attribute data as part of the organisation units and then coordinates of those organisation units can be populated separately into the database. As illustrated in Figure 6-1, before *edit the dataset* is performed, the user organisation should make sure that required spatial features and geodata have been modelled and acquired respectively.

This section has elaborated the proposed six administrative and technical actions to build the rich understanding of the concept of geodata maintenance as defined by Huisman and de By (2009) as the combined activities for keeping geodata up-to-date and as supportive as possible to GIS users. Table 6-1 summarises the basic tasks in each action of geodata maintenance.

Table 6-1: Basic Tasks in Each Action of Geodata Maintenance

Action	Basic tasks
Identify the need	• Identifying the need for change in geodata and/or health data
Communicate the need	• Reporting the new demand to the support staff through standard procedures
Analyse the need	• Developing constructs for representing objects and processes (i.e. data modelling) • Examining the expertise, information technology environment and other resources
Edit the model	• Editing the geographic database schema • Customising GIS software and related systems
Acquire the geodata	• Collecting geodata; data sharing, and primary and secondary data capture • Preparing geodata including preprocessing
Edit the dataset	• Editing spatial and thematic elements

It has been observed that in geodata maintenance, expertise is one key resource. Findings in Section 5.2.1 indicate that in Malawi, there are different people in HMIS who may be involved in one or more actions in geodata maintenance and require different knowledge and skills. Hence, the next section discusses the importance of GIS expertise in geodata maintenance and responses to the scarcity of such resource.

6.2 GIS Expertise Resource Dependence in Geodata Maintenance

This section discusses the importance of GIS expertise in geodata maintenance from the resource dependence perspective. Specifically, the section discusses which actions of geodata maintenance may require dependence on the external environment apart from the geodata collection and how to mitigate such dependence. The knowledge source map (Eppler, 2001, 2008) has been used to visualise the sources of GIS expertise with the aim of identifying which actions are likely to require the external support.

6.2.1 GIS Expertise Resource Criticality and Scarcity

Literature has emphasised the criticality of expertise in GIS (Campbell and Shin, 2011; Cavric et al., 2003; Longley et al., 2015). The shortage of GIS experts or professionals can negatively affect the ability of the user organisation to utilise GIS. From three key groups of people to be typically involved in day-to-day GIS operations (Longley et al., 2015), the thesis has identified GIS users and external consultants as required people in geodata maintenance. Ministry of Health in Malawi cannot manage to employ dedicated and properly trained GIS staff to support GIS operations including geodata maintenance due to the scarcity of finances and employment setup, which results in the scarcity of GIS experts or professionals. Hence, the ministry depends on other organisations to access such resource otherwise it would be difficult to implement and manage GIS. The scarcity of GIS professionals is frequently cited in GIS literature in developing countries and depending on the external experts is considered as the option (Fletcher-Lartey and Caprarelli, 2016; Longley et al., 2015).

GIS professionals, however, can be replaced. The thesis has recognised that Ministry of Health is promoting substitutes for GIS professionals as one way of reducing dependence on the external environment. As Hessels and Terjesen (2010) point out, resource scarcities may force organisations to look for new innovations that use alternative resources. In the context of geodata maintenance, substitutes for GIS professionals may play the role in the continued administration of spatial change and the sustained availability of geodata. Therefore, the next subsection discusses on the GIS expertise resource replaceability in geodata maintenance in health sector.

6.2.2 GIS Expertise Resource Replaceability

The shortage of GIS professionals can be mitigated through the engagement of non-GIS professionals to carry out some GIS implementation tasks. The thesis has recognised two categories of non-GIS professionals as non-IT professionals and IT professionals. Figure 6-2 illustrates the sources of expertise as non-IT professionals (health personnel, CMED management and HMIS officers), local IT professionals (local IT staff), external IT professionals (DHIS2 programmers) and external GIS professionals. Among the six-actions of geodata maintenance, it has been observed that GIS professionals are likely required in *analyse the need, edit the model,* and *acquire the geodata.* With reference to Table 6-1, these actions include highly technology-based tasks in which GIS technology specific knowledge is expected. In the actions that highly involve geodata-based tasks, GIS professionals can easily be substituted with non-GIS professionals as in *analyse the need, acquire the geodata* and *edit the dataset*. In the cases of *identify the need* and *communicate the need*, as observed in Section 5.2.1, any user can be involved and GIS/IT professionals are not required. Therefore, the rest of this subsection discusses the GIS expertise replaceability in the actions of *analyse the need, edit the model, acquire the geodata* and *edit the dataset.*

Analyse the need – With the tasks of data modelling and examining expertise and technology environment among other resources (Table 6-1), the action of *analyse the need* requires people with adequate knowledge of both the context (i.e. application domain) and technology to be implemented. That is, the technology, application and implementation specific knowledge (Puri, 2007) are required to determine the complexity of change and required resources for its implementation. CMED management and HMIS officers (identified as the substitutes for GIS/IT professionals) are non-IT professionals with no adequate GIS technology specific knowledge. Hence, they are unlikely to identify an exhaustive set of GIS operations for implementing all new user demands as expected in this action. However, since they have vast experiences in health management (i.e. the application specific knowledge), they have the vital role in analysing relevant spatial and non-spatial data for addressing new user demands with the support of the GIS/IT professionals when relevant technology specific knowledge is needed. In addition, CMED management understands bureaucratic rules, guidelines and financial norms prescribed by the government of Malawi and the donor agencies particularly non-profit organisations, which may also be required in *analyse the need* to identify potential sources of the required resources. The thesis perceives this type of knowledge as the implementation specific knowledge (Puri, 2007).

Figure 6-2: Sources of Expertise in Geodata Maintenance in Malawi's Ministry of Health (adopted from Eppler, 2001)

Edit the model – Since editing the database schema and software customisation are key tasks, this action requires both database management and application development skills, which are technology specific. As Puri (2007) points out, GIS is both database system and a set of operations working with geodata. Longley et al. (2015) state that in a GIS application, application developers are needed to enhance existing applications and develop new ones to meet new user demands. Hence, properly trained GIS/IT professionals are essential in this action. As illustrated in Figure 6-2, this action cannot be performed by non-IT professionals such as CMED management and HMIS officers. As with other GIS software, DHIS2 GIS is always customised to accommodate new demands of its user community as in the case of population distribution in which DHIS2 GIS was to be upgraded to the latest version.

Acquire the geodata – Like in *analyse the need,* in the action of *acquire the geodata,* GIS professionals are critical when the technology specific knowledge is needed to complete the task. This action involves data collection and preparation (Table 6-1), which can be performed by non-GIS professionals (Figure 6-2) particularly primary data capture due to the advances in GIS technology. Findings indicate that the primary data capture can be performed by non-GIS professionals including health personnel at district and facility levels due to the advances in GPS technology. This observation concurs with findings from other previous studies citing that with availability of cheaper and more friendly data capture equipment, organisations in developing countries are able to collect their own geodata (Fletcher-Lartey and Caprarelli, 2016; Huisman and de By, 2009; Mennecke and West Jr., 2001). GIS professionals are likely required in the secondary data capture in which advanced skills of GIS are critical such as in the *digitizing* processes.

Edit the dataset – Unlike the *edit the model,* in the *edit the dataset*, the involvement of GIS professionals is not necessary important. Expert users in organisations, for instance HMIS officers and CMED management in Malawi, just need basic GIS knowledge and skills to edit spatial and thematic elements in the geographic databases. With advances in GIS software, the human effort in importing geodata is increasingly being reduced. Contemporary GIS are equipped with an extensive array of tools for editing spatial data and attributes (Longley et al., 2015). In the case of DHIS2 GIS, user friendly tools exist like GML file importing and manual data entry that can be used to edit the geographic database. Even anyone who is familiar with DHIS2 can apply these tools. With an example of the DHIS2 tracker, once GPS data is captured, events can be presented on map; that is, GPS data is automatically captured into DHIS2 GIS.

In summary, external experts are required in geodata maintenance particularly in the actions of *analyse the need, edit the model,* and *acquire the geodata*, which need advanced knowledge of GIS technology that is not easily available in health sector. However, the availability of external experts is not continuous, which may contribute to the failure of having the continued support to the implemented technologies and data maintenance. As in the case of Ministry of Health in Malawi, since IT professionals from other organisations are deployed to the ministry within specific periods, they have limited times to participate in implementation and provision of necessary support. In supporting the suggestion of building local capacity for GIS implementation in developing countries (Cavric et al., 2003; Fletcher-Lartey and Caprarelli, 2016; Kim et al., 2016; Ramasubramanian, 1999), the following subsection discusses the identification of substitutes for GIS professionals and how to build the in-house expertise.

6.2.3 Identifying Substitutes for GIS Professionals and Building In-house Expertise

Since heavily depending on the external environment to access required GIS expertise brings financial and knowledge-related challenges to the user organisation (Cavric et al., 2003; Longley et al., 2015), this section discusses various opportunities for building the in-house expertise to mitigate such dependence. These discussions elaborate the claim of Ramasubramanian (1999) of making sure that knowledge created during the GIS implementation is left behind with local users for continuing using and supporting the system. The focus is on the role of the integrative approach of GIS implementation (Ramasubramanian, 1999) and opportunities of knowledge sharing (Ipe, 2003;

Willem and Buelens, 2007) in the building of local expertise. According to Ramasubramanian (1999), in the integrative approach, GIS implementation activities are embedded in those of other projects or programs. Since substitutes are local users, first, this subsection discusses who these local users are with the understanding that not all local users can be substitutes for GIS professionals.

Local GIS Users

Longley et al. (2015) suggest professional users and as well as clerical and technical users as two groups of GIS users who are typically involved in GIS operations. In the context of HMIS in Malawi, professional users include health managers, health personnel, CMED management, researchers, planners and policy makers who may utilise the output from the GIS for their professional work while technical users include HMIS officers, local IT staff and CMED management as the expert users providing necessary user support. As illustrated in Figure 6-2, CMED management, HMIS officers, health personnel and local IT staff have been recognised as the potential substitutes for GIS professionals. Apart from health personnel at health facilities, however, findings in Section 5.2.1 indicate that the user base of geodata maintenance could not ignore people at the community level at which majority of health facilities reside. The HMIS deals with data of various events happening in local communities and as indicated in Chapter 1, the 90% of health facilities are at the community level in the custodian of community health workers who are neither health professionals nor technical users. The community specific knowledge (Puri, 2007), particularly that of community health workers, can play the vital role in geodata maintenance particularly in *identify the need* and *communicate the need*. As observed in India, the building of geographic databases in GIS implementation for land management involved members of local communities (Puri, 2007). Hence, apart from the professional and technical users (Longley et al., 2015), the thesis argues that local communities should also be considered as part of the users in geodata maintenance.

Identifying Substitutes for GIS Professionals through Integrative Approach

On the one hand, some GIS implementation tasks are duly assigned to the existing workforce as part of their respective official duties and appropriate resources including knowledge are provided. In Malawi, one role of HMIS officers is to maintain geodata for health facilities in their respective health districts and hence, they were trained in GIS and provided with GPS for geodata capture. On the other hand, the thesis has recognised the integrative approach of GIS implementation (Ramasubramanian, 1999) as one strategy of identifying substitutes for GIS professionals. Findings in Section 5.2.3 indicate that it is possible to embed GIS implementation activities in other programs or projects in which non-GIS professionals can be involved and the substitution is possible through the sharing of human resource.

In the context of geodata maintenance, the thesis has identified two actions – *acquire the geodata* and *edit the model* – in which the integrative approach can easily be adopted. In *acquire the geodata*, particularly in the primary data capture, the physical visits to spatial features such as health facilities are required. It can be relatively cheap in terms of sharing of human resources, finances and time if the geodata acquisition is associated with other activities that are to be carried out during the physical visits to those spatial features. Findings indicate that the identification of the health personnel to be involved in *acquire the geodata* has been through the integrative approach. In *edit the model*, it is possible to share the human resource if GIS is embedded in another information system that is being implemented as with the case of the DHIS2 GIS deployment in which DHIS2 programmers can be highly involved. However, the integrative approach of GIS implementation may result in the little control over allocation and use of human resource, which can be one barrier to local expertise building as observed on HMIS officers in the DHIS2 GIS implementation (Section 5.2.3).

Building Local Expertise – Knowledge Sharing

Literature has recognised the training of existing workforce as one response to the scarcity of GIS professionals (Cavric et al., 2003; Fletcher-Lartey and Caprarelli, 2016; Kim et al., 2016). The thesis reemphasises this claim and further identifies other opportunities of sharing knowledge namely work teams and user manuals that may lead to the building of local GIS expertise. The majority of identified substitutes for GIS professionals (see Figure 6-2) are non-IT professionals who require adequate technology specific knowledge to be capable of carrying out GIS related activities. To impart the required knowledge in the local users (i.e. the substitutes for GIS professionals), the user organisation needs to provide opportunities for knowledge sharing between external GIS/IT professionals and local users.

User training – Although user training is dominant method of sharing knowledge in GIS implementation in Ministry of Health in Malawi, it has come with challenges. On the one hand, the deployment of DHIS2 GIS has resulted in increasing the user base including the custodians of health facilities at facility and community levels who are not direct users of DHIS2 but have influence on the geodata maintenance. Organising formal GIS trainings to these users can be expensive exercise in terms of finances and time. One way to address this concern is through the integrative approach of GIS implementation, that is, to embed particular GIS-based knowledge in other trainings that are frequently conducted at the district, facility and community levels in which custodians of health facilities are involved. On the other hand, GIS user trainings are not conducted frequently to cope with updates in DHIS2 GIS and do not cover all required areas of GIS knowledge due to mainly time and financial constraints. Since users need continuous accumulation of knowledge, it is important to consider other mechanisms to supplement training that the thesis has recognised as structured work teams and user manuals.

Work teams of external GIS experts and local users – Apart from training, findings in Section 5.2.4 indicate that establishing work teams of both experienced and non-experienced GIS users in various GIS implementation activities has led to the sharing of knowledge through learning-by-doing particularly at the national level. Forming strategic alliances with organisations having the desired knowledge can be valuable to the user organisation for learning new knowledge (Ramasubramanian, 1999; Sirmon et al., 2007). Although CMED management has been recognised as one substitute for GIS professionals, it has not participated in any GIS training. It has acquired necessary GIS expertise through interactions with the external GIS experts as one CMED manager emphasised:

> "GIS professionals being deployed as Technical Assistants have imparted GIS knowledge in us. Imagine, since 2002, I have been working with them in various GIS projects and

> now I call myself the GIS expert user although I am the statistician by profession. I have been providing GIS services to different people within and outside the ministry."

Despite the investment of GIS knowledge in HMIS officers at the district level, Ministry of Health still needs to build GIS expertise at the national level where DHIS2 GIS is hosted and managed. The migration to DHIS2 in 2012 resulted in detaching roles and responsibilities from HMIS officers of managing DHIS and assigned to the CMED management at the national level. This observation supports the statement that involving local users in GIS implementation and providing effective mechanisms for the transfer of skills and knowledge to those local users usually result in the continuity of GIS use (Cavric et al., 2003), that is, some users become local experts in the continuous process of improving the use of the system, even after the external experts have left (Kimaro, 2006).

GIS user manuals – In Malawi's Ministry of Health, user manuals are taken as another means of sharing knowledge with local users. This reemphasises the point that instruction manuals are other means of delivering training (Meaden, 2013). GIS, as with other information systems, comes with instruction manuals that are usually too technical for local users or their content does not cover all necessary knowledge areas of GIS. For instruction manuals to be effective, their content should be localised and self-explanatory, which may enable the self-learning. However, the development, production and distribution of localised GIS instruction manuals may require financial resources and expertise in various subject matters such as geodata, hardware and software. This can influence the user organisation to depend on other organisations to access such resources due to its inadequate capacity. For instance, in the implementation of DHIS2 GIS, localised instruction manuals for HMIS officers were developed by the DHIS2 GIS implementers with the support of DHIS2 programmers. Even the instruction manual for GPS data collection during the service provision assessment survey was developed by ICF International. In the context of geodata maintenance, two key GIS instruction manuals are required – geodata- and software-related manuals, which usually contain technology specific knowledge, that is, knowledge about GIS capabilities for managing spatially referenced data. As Puri (2007) points out, technology specific knowledge is codifiable and hence transferable. Manuals are taken as the means of codifying particularly task-related knowledge – 'know-what' (Ipe, 2003). Geodata-related manuals are to provide the expertise for the action of *acquire the geodata* while software-related manuals are for *edit the model* and *edit the dataset*.

In this section, the thesis has shown that due to the financial constraints and the employment setup, Ministry of Health is not able to recruit its own GIS/IT professionals. Although the opportunities for knowledge sharing exist, it is difficult to impart knowledge and skills in the substitutes for GIS/IT professionals to the level of GIS/IT experts because most substitutes are from statistics and economics background. As a result, in the context of geodata maintenance, the ministry will still need to depend on other organisations (i.e. external environment) to access required GIS/IT expertise particularly in the actions that require advanced technology specific knowledge such as *analyse the need, edit the model* and *acquire the geodata*. The next section conceptualises this dependence on the external environment as collaboration. In GIS implementation in developing countries, scholars have suggested collaboration between organisations as one way of addressing the issue of limited GIS expertise (Fletcher-Lartey and Caprarelli, 2016; Kim et al., 2016; Ramasubramanian, 1999).

6.3 Dependence on External Environment as Collaboration

As stated in the previous section, DHIS2 programmers and GIS professionals are deployed to Ministry of Health from other organisations. Therefore, this section discusses how Ministry of Health accesses those IT professionals from the external environment through collaboration with the understanding that, as Bénaben et al. (2006) point out, collaboration has been applied in different disciplines and contexts with numerous concepts, classifications, definitions and forms among other constructs. Findings in Section 5.4.2 indicate that GIS is one IT function in HMIS in Malawi and Ministry of Health accesses the scarce geodata and expertise from the external environment through various collaborative arrangements. Discussions in this section are guided by characteristics of collaboration suggested by Bedwell et al. (2012) and involvement in collaboration (Lawrence et al., 2002).

6.3.1 Problem Domain and Participating Organisations

As indicated in Section 5.2.2, Ministry of Health depends on three key groups of organisations – government agencies, non-profit organisations and academic institutions (i.e. universities) – to access limited resources including GIS/IT professionals. Due to the integrative approach of GIS implementation (Ramasubramanian, 1999) the dependence on the external environment has been mainly established for strengthening the national HMIS and not necessarily for GIS implementation. Thus, the thesis has considered HMIS strengthening as the main problem domain in which different organizations with shared interests have participated in different projects including GIS implementation. However, in the thesis, the interest is on GIS implementation as the specific problem domain in which problems usually relate to expertise, geodata, hardware and software that, according to Longley et al. (2015), are fundamental elements of GIS. In the context of geodata maintenance, Ministry of Health has engaged with other organisations to access expertise for addressing geodata- and expertise-related problems mainly in the actions of *analyse the need, edit the model* and *acquire the geodata*. The thesis has recognized concerns relating to technology from the perspective of geodata maintenance as discussed in Section 6.1 with the understanding that choice of technology depends on data needs.

Due to mutual interdependence and vast experiences in GIS including geodata capture, the government agencies voluntarily engage with Ministry of Health in GIS initiatives and they are usually involved in both geodata- and expertise-related problems. Likewise, Ministry of Health works together with non-profit organisations with the common understanding of building a collective capacity to handle both geodata- and expertise-related problems. However, these non-profit organisations are not experts in GIS as compared to the government agencies mentioned above but they have capacity to recruit and deploy necessary GIS/IT professionals to Ministry of Health.

In the context of information systems, the dependence of public organisations on academic institutions exist particularly in the design and implementation of such systems and this is also emerging in health. In developing countries, GIS literature has recognised dependencies on academic institutions as one way of building local expertise through training (Cavric et al., 2003; Fletcher-Lartey and Caprarelli, 2016). However, in developing countries, academic institutions can also play a crucial role in development and implementation of technological innovations through research. As presented in Section 5.2.2, Ministry of Health depends on University of Oslo (which is also the core developer of DHIS2) and University of Malawi in DHIS2 projects with the fundamental goal of conducting research. The ministry is taken as the research site through which different technological innovations are piloted and implemented. On the one hand, this is beneficial to Ministry of Health in terms of accessing GIS/IT expertise at low cost since logistical expenses of postgraduate students are usually covered by University of Oslo. This observation concurs with the claim of Nasirin, Birks and Jones (2003) that the establishment of a good relationship with key vendors of the software is to have a good system support, which enables a substantial cost reduction in the system implementation process. In addition, knowledge is shared with the users through interactions. On the other hand, this dependence enables University of Oslo to obtain user experiences for the enhancement of DHIS2 GIS. Campbell and Shin (2011) state that the development of GIS software is guided by the needs and demands of its application users. In this context, there exists bidirectional information flow (Lawrence et al., 2002) in which the ministry and academic institutions learn from each other.

6.3.2 Structure of Coalition – Donations and Partnerships

Findings in Section 5.2.2 indicate that participating organisations are involved in different GIS implementation activities in two main ways – *donation* and *partnership* – which are some dimensions of the structure of coalition formed between the user organisation and its external environment (Lawrence et al., 2002). Finance is identified as one key donation to support both geodata- and expertise-related activities. This finding concurs with other scholars that GIS implementation is an expensive venture (Fletcher-Lartey and Caprarelli, 2016; Longley et al., 2015; Msiska, 2009; Sipe and Dale, 2003). As earlier stated in Section 6.2, finance is the scarce resource in government agencies and hence, Ministry of Health depends on other organisations particularly non-profit organisations to access most of financial resources for GIS implementation. In the case of geodata, funds are provided for the geodata capture while for the workforce, the financial support is in terms of funding user training and hiring external GIS/IT professionals.

Government agencies have provided geodata to Ministry of Health, which the thesis takes as another donation; that is, material support in aid of activities (Lawrence et al., 2002). This donation is the form of geodata sharing, which is just the part of *acquire the geodata* in the geodata maintenance. The rest of the actions require people to perform various tasks. From the discussions in Section 6.2, although there are opportunities of substituting GIS professionals, the GIS expertise resource replaceability is not possible in all actions of geodata maintenance. As illustrated in Figure 6-2, in some actions, GIS professionals are required who are usually deployed to the ministry as consultants, seconded employees or researchers from other government agencies, non-profit organisations and academic institutions.

However, the user organisation and participating organisations have to share responsibilities. In Ministry of Health, external GIS/IT professionals work jointly with local users in which there is always the agreed division of labour and it is often formalised through, for example, the memorandum of understanding and project-based contracts. GIS/IT professionals are deployed to Ministry of Health as the technical assistants and assigned to certain projects with specific objectives to achieve. The thesis perceives this type of arrangement as *partnership*. McDougall (2006) states that partnerships usually operate through formal agreements with specific goals. According to Lawrence et al. (2002), in the partnership, the user organisation and participating organisations jointly perform tasks. The establishment of work teams of external GIS experts and local users as discussed in Section 6.2.3 is achieved through the partnership.

6.3.3 External Environment for Geodata Maintenance and Collaboration Arrangements

The thesis perceives government agencies, non-profit organisations and academic institutions as the external environment, which Ministry of Health depends on to access geodata and expertise for the GIS implementation. In the context of geodata maintenance, the dependence on the external environment involves the organisations through donations and/or partnerships as discussed above. With reference to Figure 6-2, Figure 6-3 illustrates the role of the external environment in geodata maintenance in Malawi's Ministry of Health. With their vast expertise in the geodata management, government agencies can mainly provide the support to Ministry of Health in the actions of *analyse the need* and *acquire the geodata* through partnerships and donations. In the case of academic institutions, the support is through partnerships in *analyse the need* and *edit the model*. Particularly, the support provision is in the data modelling and software customisation. Non-profit organisations can support the ministry in all three actions of *analyse the need, edit the model* and *acquire the geodata* through partnerships and donations. Due to their financial capacity, non-profit organisations are able to hire GIS/IT professionals to work with Ministry of Health and provide finances.

As characteristics of collaboration (Bedwell et al., 2012), from the discussions in this chapter, there exist *shared goals* of solving geodata- and expertise-related problems in GIS implementation in Ministry of Health, involvement of multiple *social entities* (i.e. government agencies, non-profit organisations and academic institutions), participation of the organisations in *joint activities*, and *reciprocity*. Hence, the thesis perceives the dependence of Ministry of Health on other organisations as *collaboration* with three different collaboration arrangements – *public-public* (Ministry of Health and other government agencies), *public-non-profit* (Ministry of Health and non-profit organisations) and *public-academic* (Ministry of Health and academic institutions). In their study of collaboration in e-government services, Dawes and Eglene (2008) suggest three types of collaboration arrangements in the government setting – public-public, public-private and public-non-profit. However, the public-private collaboration has not been experienced in this study with the reason being that in Malawi, GIS has been used for decades and at the large scale in government agencies as compared to private organizations. But this does not mean that the public-private collaboration is not important in GIS implementation for health management in developing countries. In other contexts, particularly where private institutions greatly participate in GIS initiatives, the public-private collaboration may exist. For instance, in Malaysia, Othman et al. (2017) discuss the possibility of collaboration between public and private entities in the spatial data infrastructure.

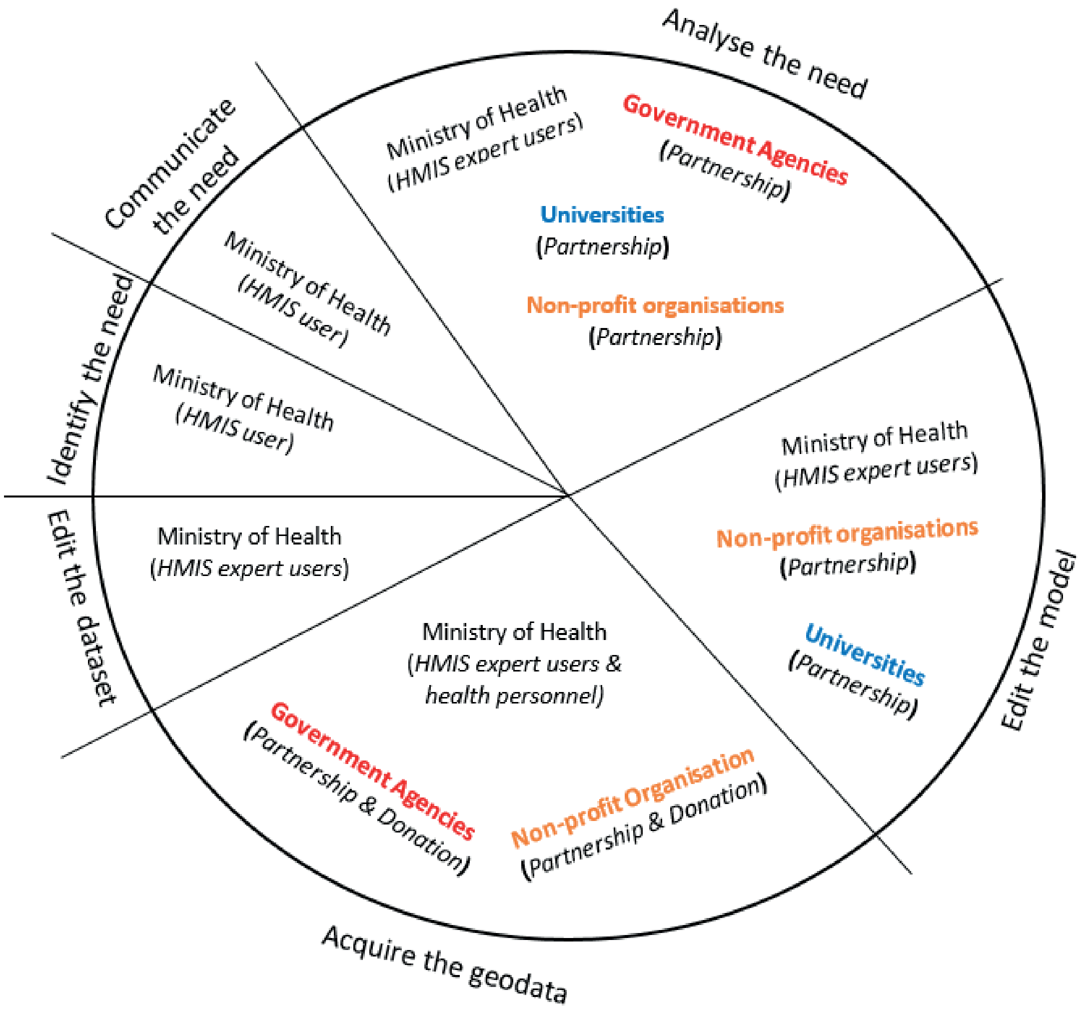

Figure 6-3: External Environment for Geodata Maintenance in HMIS in Malawi

6.3.4 Geodata Maintenance and Collaboration in Developing Countries

From the discussions above, the thesis has demonstrated that geodata maintenance requires collaboration in some actions due to the scarcity of in-house expertise using the case of DHIS2 GIS in Malawi. Thus, in this sub-section, the thesis summarises how findings in Malawi can be applicable in a different context. Since geodata maintenance is one functional component in GIS, the findings of geodata maintenance and collaboration from Malawi can as well be applicable in other developing countries and even in different organisations. Figure 6-4 illustrates the external environment for geodata maintenance in an organisation.

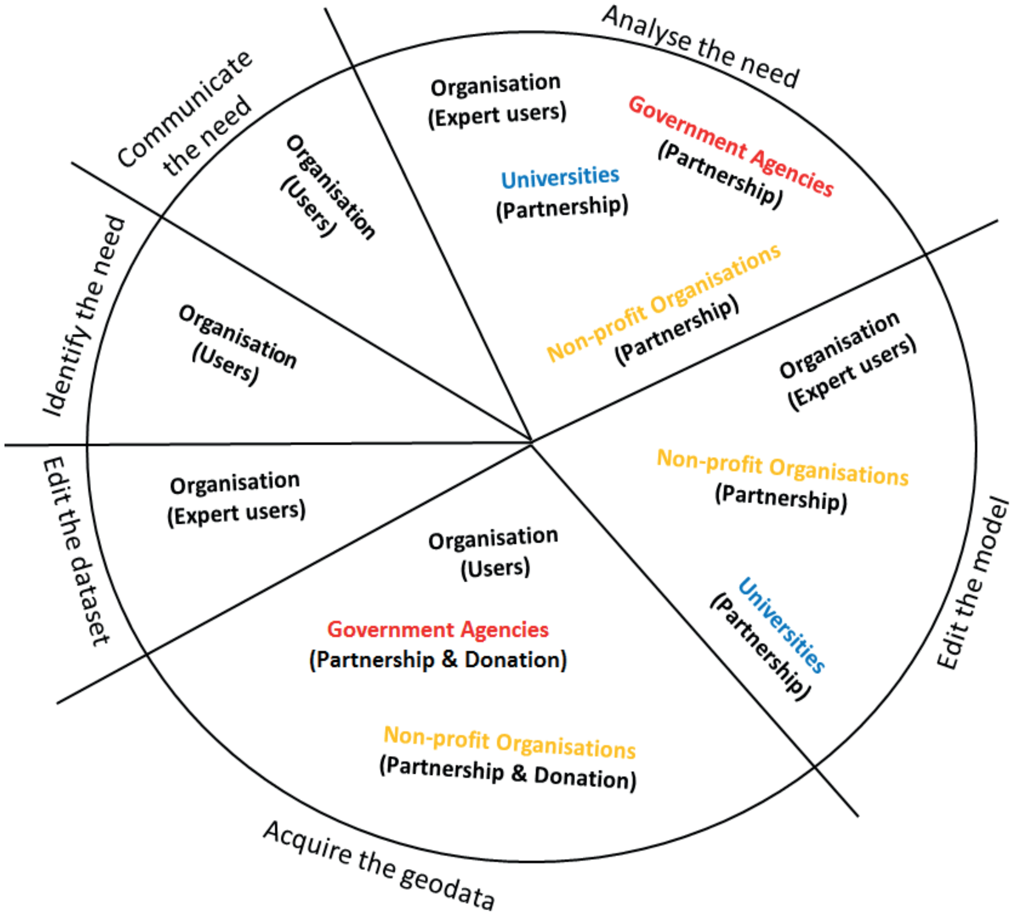

Figure 6-4: External Environment for Geodata Maintenance in an Organisation

Organisation – This is any organisation that is responsible for geodata maintenance of its GIS applications.

Expert users – In information systems in developing countries, technical staffs exist that provide support to users of those systems. The chance is that if the technical staffs are given adequate GIS/IT expertise, they can be the substitutes for GIS/IT professionals. This may lead to the mitigation of dependence on the external GIS/IT experts.

Government agencies – In most developing countries, government agencies are given the mandate of managing national spatial data and/or carry out GIS projects, which work closely with other organisations in different sectors such as agriculture, water, environment and health among others. Hence, these government agencies usually employ GIS experts to whom other organisations can have the access to through collaboration.

Non-profit organisations – In developing countries, non-profit organisations (NPOs), including both local and international non-government organisations (NGOs) and the donor community, work together with government agencies in different information technology projects including GIS in which NPOs deploy necessary experts to enhance staffing and provide financial support.

Universities – In developing countries, most universities have departments including Geography, Land Surveys, Geology and even Information Systems that provide training and research in GIS; building necessary GIS expertise for their respective countries and beyond. Universities usually work together with public and private organisations in various GIS projects.

Chapter Summary

This chapter explicitly discussed the proposed framework for geodata maintenance in health sector in developing countries and the contribution of collaboration towards geodata maintenance and the building of local expertise. Geodata is critical and scarce resource in developing countries that cannot be replaced with other resources. For the long-lived GIS applications, the user organisation needs to perform geodata maintenance when a new demand arises. However, not every demand may result in geodata maintenance. Therefore, the decision should be made whether it is vital to bring changes in geodata or not. To achieve this, the framework suggests doing the requirements analysis through the first three actions – *identify the need, communicating the need* and *analysing the need* – to decide whether to wait, accept or reject the change. If the decision is the acceptance, geodata update is to be carried out – *edit the model, acquire the geodata* and *edit the dataset*.

In geodata maintenance, different people with different expertise are required. GIS experts are critical and as well as scarce resource. However, they can be replaced particularly in the actions of *analyse the need, acquire the geodata,* and *edit the dataset*. Substitutes for GIS experts can be through duly assigning GIS tasks as part of local users' respective official duties and/or the integrative approach of GIS implementation in which some local users can participate in GIS initiatives. Since the majority of identified substitutes for GIS professionals are non-IT professionals, the user organisation needs to provide opportunities for knowledge sharing between external GIS/IT professionals and local users.

In addition to user training, the thesis recognised other opportunities of sharing knowledge – work teams and user manuals – that may lead to the building of local GIS expertise. Despite having the opportunity of substituting external GIS experts with local users, the external experts are still required in geodata maintenance particularly in the actions of *analyse the need, edit the model,* and *acquire the geodata*, which need advanced knowledge of GIS technology that is not easily available in health sector. To access such experts, the user organisation is to be in partnerships with other organisations having such required experts or capacity to recruit them; that is, geodata maintenance requires collaboration in some actions due to the scarcity of in-house expertise.

The next chapter summarises the key research contributions and as well as conclusion of the thesis including the implications for practice.

Chapter 7: Contributions and Conclusion

This chapter summarises the key contributions of this study in the first section. Summary of answers to the research questions is in the second section. Implications for practice are highlighted in the third section including suggested areas for the further study.

7.1 Research Contributions

This section summarises the key conceptual and practical contributions of this research.

7.1.1 Conceptual Contribution

The thesis advances the work of Huisman and de By (2009) and Longley et al. (2015) on the description of geodata maintenance by explicitly identifying and defining its actions and elaborating geographic database update. In other words, the thesis builds the rich understanding of the concept of geodata maintenance that has partially been described in the work of Huisman and de By (2009) and Longley et al. (2015). From the definition of geodata maintenance as the combined activities for keeping the dataset up-to-date (Huisman and de By, 2009), only two actions – geodata collection and geographic database update – have explicitly been discussed in GIS literature. Hence, the thesis has extended the set of actions to six of which the first three actions – *identify the need*, *communicate the need* and *analyse the need* – are for assessing new user demands and/or real world changes to guarantee changes in geodata. The thesis argues that apart from the geodata acquisition and geographic database update, geodata maintenance requires the requirements analysis because it is important for the user organisation to decide how proposed changes in geodata should be efficiently and effectively implemented and sustained.

Longley et al. (2015) take geographic database update as any change to spatial elements, thematic elements, object relationships, or database schema. In the context of geodata maintenance, the thesis recognises two actions from this definition – *edit the dataset* (changes to spatial and thematic elements) and *edit the model* (changes to object relationships and database schema). In practice, these actions have unique requirements in terms of time and expertise among other resources. In addition, in many cases, geographic database update mainly involves changes to spatial and thematic elements as compared to changes made to database schema or object relationships. In modern GIS technology, upgrades on GIS takes care of updates on database schema as the case of DHIS2 GIS, which results in minimising required effort of the user organisation in updating the database schema. Instead, the focus has moved to the customisation of GIS software to accommodate required changes in geodata, which the thesis considers as the part of *edit the model*.

The thesis takes *geodata maintenance* as the combination of administrative and technical actions to keep the dataset up-to-date and as supportive as possible to users of a particular GIS application in which the data set is (to be) used; involving actions for assessing demands that bring changes in geodata and those for acquiring and updating geodata.

7.1.2 Practical Contribution

Practically, the thesis provides the framework for geodata maintenance in health in developing countries; highlighting key decisions including when and whom to collaborate with in order to leverage limited resources in the user organization. Since for the long-lived GIS applications, geodata maintenance is complex and expensive (Longley et al., 2015) and many organisations in health sector in developing countries have the shortage of local GIS expertise (Fletcher-Lartey and Caprarelli, 2016; Kim et al., 2016; Msiska, 2009; Sipe and Dale, 2003), the user organisation should make decisions on when and how to collaborate with other organisations in order to access GIS expertise at low cost, and at the same time, to provide opportunities for imparting knowledge to local users for continued GIS support after collaboration has expired. Based on insights from Malawi, the thesis has suggested that the user organisation should decide on:

- actions of geodata maintenance that may require collaboration; including *analyse the need, edit the model* and *acquire the geodata;*
- collaborating partners and their roles; for example, government agencies, non-profit organisations and academic institutions that can be involved through partnerships and donations
- local users to be substitutes for GIS experts in some actions like *analyse the need, edit the model, acquire the geodata* and *edit the dataset;* the thesis recognises expert users as key local users;
- mechanisms of building capacity to local users such as user training, work teams and instruction manuals particularly expert users

7.2 Answering the Research Questions

This research aimed at proposing a framework for geodata maintenance in the context of health in developing countries and investigating the contribution of collaboration towards geodata maintenance and the building of local expertise. To achieve these aims, three research questions were drawn and hence, this section answers the questions.

The first research question related to the understanding of the concept of geodata maintenance; building a framework for geodata maintenance by identifying and defining its activities.

RQ1. What are activities of geodata maintenance in health sector in a developing country setting?

The thesis has identified and defined six administrative and technical actions for geodata maintenance in health sector in developing countries as follows.

1. *Identify the need (administrative action)* – The thesis derived this action from the user support provision in which users identify new needs initiated by direct change on spatial feature, change on health data, or external systems. The thesis elaborated the determination of changes in geodata as (1) demand can be directly on spatial features and (2) demand can be on health data required by health programs or services that may lead to changes on geodata.
2. *Communicate the need (administrative action)* – The thesis derived this action from the user support provision in which users report their new needs to the support staff within the

organisation for the assistance. The thesis takes this action as a communication between the system users and technical support staff and it may follow the existing governance structure of the user organisation in which GIS application is used.

3. *Analyse the need (both administrative and technical action)* – The thesis derived this action from the user support provision in which users expect the support staff to respond to their new demands; whether to implement the change or not. The thesis perceives this action as the requirements analysis for the geodata maintenance involving the spatial data modelling and its final outcome of *accept, wait* or *reject* is based on the criticality of the affected geodata and availability of other resources such as expertise and technology.
4. *Edit the model (technical action)* – This action is considered as the action of changing both data models in the geographic database (i.e. the geographic database update) and application models including the software customisation since GIS software may be adapted to align with changes in data models.
5. *Acquire the geodata (technical action)* – This is geodata capture and sharing that enable the availability of geodata; that is, mitigating the scarcity of geodata.
6. *Edit the dataset (technical action)* – This action involves changes to geometry and attributes as part of geographic database update. The thesis has recognised this action as the way of achieving the data completeness.

The thesis also describes how these actions can sequentially be carried out. However, in practice, the fourth and fifth actions – *edit the model* and *acquire the geodata* – are not necessary to be carried out in that order. In some cases, *edit the model* may not be required; for example, when changes are only on elements of already modelled spatial features. In other cases, *acquire the geodata* can be done before *edit the model*.

The second question related to the role of collaboration in geodata maintenance; identifying which activities may require collaboration.

RQ2. How can collaboration assist in the maintenance of geodata in health sector?

From the proposed six actions of geodata maintenance, the thesis has demonstrated that collaboration can mainly be required in the technical actions such as *analyse the need, edit the model* and *acquire the geodata* that need the expertise in GIS software being used or to be used and the acquisition of geodata due to the shortage of such skilled personnel in the user organisation. As observed in this research, through *partnerships,* the user organisation can access IT/GIS professionals from the collaborating organisations who jointly carry out these technical actions with the expert users in the user organisation. Collaboration can also assist in the geodata maintenance through *donations* of geodata and finances in the technical action of *acquire the geodata*. Since the acquisition of geodata is expensive particularly in the primary and secondary data capture, the user organisation may rely heavily on the external environment for the financial and material support. Another observation is that collaboration can catalyse the sharing of geodata, that is, organisations that are in collaborate can easily share geodata as compared to those not in collaboration.

The third question related to the local expertise; exploring the role of collaboration in the local expertise building.

RQ3. How can collaboration contribute towards the building of local expertise for geodata maintenance in health sector?

In the health sector in developing countries, the main concern is the shortage of local expertise for GIS implementation. As observed in this research, financial constraints and the employment set-up contribute to failure of recruiting the required IT/GIS professionals. Hence, the user organisation is forced to depend on external environment to access the expertise. However, such dependence cannot always be easy to manage if alternatives are not strategically put in place. As in the case of Malawi, IT/GIS professionals are usually deployed within specific periods in line with lifespans of collaborative activities. This creates the GIS expertise gap that can be reduced through the building capacity of local users. Any GIS application needs the continuous support in its lifetime. Therefore, the thesis has identified three key opportunities of knowledge sharing – work teams, user training and instruction manuals – that lead to the building of the local GIS expertise and in which collaboration can play a great role. Through *partnerships*, it is possible for the user organisation to establish work teams of the external GIS experts and non-GIS experts (local users). The external GIS experts are able to share their knowledge and skills with the local users (particularly expert users as identified in this study) through their interactions when working together. To some local users, the required GIS expertise can be obtained through user trainings and instruction manuals. In most cases, as observed in this research, user trainings are usually facilitated by the external IT/GIS experts from and user instruction manuals are provided. Even the development of user instruction manuals requires the subject experts. User trainings and development of instruction manuals may also require adequate financial support that can be provided by the external environment through *donations*.

7.3 Implications for Practice

In the context of GIS implementation, the proposed geodata maintenance framework is viewed as the part of the maintenance of an installed GIS in which the user organisation is expected to maintain the system and data in order to cope with environmental and organisational changes. Once the GIS is installed, the user organisation requires the continuing support including the geodata maintenance since geodata is important component of any GIS that consumes the largest portion of organisational GIS resources. Thus, the installed GIS needs the geodata maintenance to continue functioning into indefinite future. Even when GIS is embedded in another information system like DHIS2 in which the management structure and IT environment are already in place, the setting up of GIS concentrates more on geodata than technology and expertise. Decisions on the enhancement of hardware, software and expertise can be based on the geodata needs. As observed in this research, since GIS is embedded in DHIS2, the implementation of DHIS2 has addressed most of issues concerning GIS and the focus has been on geodata. Thus, the implementation of DHIS2 GIS can mainly involve processes related to the geodata maintenance.

In geodata maintenance in health sector in developing countries, collaboration is required due to the shortage of resources. One concern in collaboration is the problem domain. From the definition of a problem domain as the area of expertise or application that needs to be examined to solve a problem, the thesis perceives the problem domain for collaboration in geodata maintenance in developing countries from two perspectives. First, it is to identify a main problem domain that is usually related to a context of GIS implementation since it is unique to a particular organisation or context. In developing countries, GIS implementation is usually embedded in the other policies, programs or projects. This implies that the concerned policy, program and project can be taken as the area of application to be examined to address issues concerning geodata maintenance. From the collaboration perspective, it is possible to establish collaboration arrangements to address problems of the concerned policy, program or project in which the GIS implementation is embedded. In this research, the national HMIS was examined to elaborate how to address challenges in geodata maintenance and GIS expertise building through collaboration, because most collaboration arrangements were established for strengthening the national HMIS.

Second, GIS is the unique discipline having fundamental elements including geodata and expertise that have unique challenges to be addressed during the GIS implementation. Majority of geodata and expertise challenges are not usually specific to a certain context or organisation in which GIS is to be implemented. The observation is that this situation enables the user organisation to collaborate with other organisations that have no interests in the main problem domain (i.e. the context in which GIS is being implemented) but they have interests in the specific problem domains of geodata and expertise. Ministry of Health collaborates with other government agencies having interests in geodata and GIS expertise problem domains and not necessarily in strengthening HMIS, while collaborations with non-profit organisations and academic institutions are for strengthening the national HMIS. From this understanding of the problem domain in GIS implementation, the user organisation can collaborate with organisations from different sectors, which may result in different collaboration arrangements such as public-public, public-non-profit and public-academic collaborations.

In geodata maintenance, it is assumed that the user organisation is the custodian of geodata that is responsible for data management processes. However, the thesis has not discussed what level of capacity the user organisation such as Malawi's Ministry of Health is expected to have as the custodian of geodata. Thus the thesis suggests a further study on how to institutionalise the geodata maintenance in HMIS data management practices.

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Appendices

Appendix 1 – List of Papers

Paper 1: Chikumba, P. A. and Chisakasa, G. (2018) Towards Geodata Maintenance: A Case of DHIS2 GIS Implementation in Malawi. *Journal of Health Informatics in Development Countries,* Vol. 12, No. 2

Paper 2: Chikumba, P. A. Acquiring Geodata and Expertise in GIS Implementation for Health Management in Malawi: The Role of Collaboration. *Under review in Journal of Information Systems and Technology Management*

Paper 3: Chikumba, P. A. (2017) Exploring Integrative Approach of GIS Implementation: The Case of GIS in Health Management in Malawi. Paul Cunningham and Miriam Cunningham (Eds): IST-Africa 2017 Conference Proceedings, IIMC International Information Management Corporation

Paper 4: Chikumba, P. A. and Naphini, P. (2018) GIS Initiatives in Health Management in Malawi: Opportunities to Share Knowledge. T.F. Bissyande and O. Sie (Eds.): *AFRICOMM 2016*, *LNICST 208*, pp. 263–272, https://doi.org/10.1007/978-3-319-66742-3_25

Paper 1

Chikumba, P. A. and Chisakasa, G. (2018) Towards Geodata Maintenance: A Case of DHIS2 GIS Implementation in Malawi. *Journal of Health Informatics in Development Countries,* Vol. 12, No. 2

Journal of Health Informatics in Developing Countries

http://www.jhidc.org/
Vol. 12 No. 2, 2018

Submitted: May 17th, 2017 Accepted: September 22nd, 2018

Towards Geodata Maintenance: A Case of DHIS2 GIS Implementation in Malawi

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Abstract:

Background: As noted in literature of geodata maintenance, the emphasis is on the geographic database update. However, geodata maintenance is beyond the geographic database update. Thus, this paper proposes administrative and technical actions for geodata maintenance in health in which GIS is becoming popular.

Methods: This case study was conducted in health management in Malawi. An interpretive qualitative research method was adopted. Data was collected through participant observation, as the principal method, which was supplemented by semi-structured interviews and artifact examination. Participant observation was done in one and half years during the deployment of DHIS2 GIS. Thematic analysis was employed as the data analysis approach.

Findings: This study has identified six necessary actions for geodata maintenance: (1) identify the need, (2) communicate the need, (3) assess the need, (4) edit the model, (5) acquire the geodata, and (6) edit the dataset. The first two actions are administrative and the last three actions are technical while the third one is both administrative and technical.

Conclusion: The geographic database update involves two actions: edit the model and edit the geodata. Other four actions are required for acquiring geodata to make a complete set of geodata maintenance operations. However, to have a sustainable geodata maintenance, there is a need to incorporate geodata maintenance into operations of health management information system in general and GIS implementation process in particular. The involvement of stakeholders at all levels is also essential.

Keywords: Geodata; Geodata Completeness; Geodata Maintenance; Geographic Database Update.

1. Introduction

In literature of Geographic Information System (GIS), it has been emphasized that data is fundamental. Without adequate and reliable data, GIS is not useful [1]. The adequacy and reliability of data can be achieved through data maintenance. The data element of GIS includes both spatial data (also referred to as geodata) and non-spatial data. In this paper, the interest is on geodata, which models user defined geographic entities or spatial features. Geodata is geographically referenced in some consistent manner using, for example, latitudes and longitudes, national coordinate grids, or postal codes [2].

In health sector, as observed in the studies of Chikumba [3], Msiska [4] and Saugene and Sahay [5], geodata suffers from lack of maintenance. Geodata needs to be continuously maintained to a certain

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level of usefulness so that its quality is not diminished. In addition to accessibility and development of geodata as fundamental to GIS, maintenance of geodata is also of paramount importance. Data maintenance is a process of continual improvements and regular checks for keeping the high quality data.

In literature of geodata maintenance, the focus has been on update of geographic databases [1, 6]. Geodata maintenance is beyond the geographic database update. Data maintenance incorporates key components of data management process and involves organized administrative and technical actions. This paper intends to contribute to geodata maintenance in health sector in developing countries, in which GIS is becoming popular. The case used in this study is DHIS2 GIS implementation in Malawi. The aim of this study was threefold, firstly to summarize the current state of knowledge with respect to geodata maintenance, secondly to use interpretive and qualitative methods to investigate readiness for geodata maintenance in health management in Malawi and lastly to propose administrative and technical actions for geodata maintenance in health management.

2. Geodata Maintenance and Completeness

2.1 Geodata Maintenance

Geodata has properties that need to be well defined and continuously maintained: *what* (thematic elements, i.e. attributes), *where* (spatial elements, i.e. space or location), *when* (temporal elements, i.e. time and events) [7] and *relationship* between spatial features [8]. Although space is the dominant member of these components, time is critical to understanding phenomena as events that appear and disappear in space over time; and without theme there is only geometry [9]. The attributes represent elements that are not geometrical and are used, for example, in queries, analyses and visualization of spatial data. The degree of importance of relationships between spatial features depends on an application being used in GIS. Ulubay and Altan [8] argue that an effective geodata management requires that location and attribute data be variable independent of one another i.e. attributes can change character but retain the same location and vice-versa.

Geodata is held in a geographic database, which is constantly updated as new information arrives in order to continuously support user requirements. Longley, Goodchild, Maguire and Rhind [1] define a *geographic database update* as any change of geometry, attributes, or database schema. Required tasks include edits of geometry, attributes, indexes, topology, and even importing and exporting data. There are other required actions to be performed apart from the database update. According to British Standards Institution [10], *maintenance* is the combination of technical and administrative actions aimed at retaining an item in a state in which it can perform a required function. From the data perspective, "maintenance of (spatial) data can be defined as the combined activities to keep the data set up-to-date and as supportive as possible to the user community" [6]. Huisman and de By [6] explain that data maintenance involves acquisition and capturing of new data into the system, possibly replacing outdated data; and the need for such actions stems from requirements that the users impose or due to changes in the real world. Hence, in this paper, *geodata maintenance* is taken as a set of organized technical and administrative actions that are carried out in order to keep geodata valuable in a particular GIS application.

Geodata, as a resource, has a value that is to be maximized. In this paper, the value of geodata is in form of a solution to a GIS problem or satisfaction of a GIS need. Thus, the value of geodata needs to be maintained in order to continuously meet GIS needs and solve GIS problems. The maintenance of geodata in an organisation leads to improved and new usage of the data thereby leveraging its value. However, maintenance of data requires a well-specified management regime [11], which means that during geodata maintenance right decisions should be made at certain points of time.

2.2 Geodata Completeness

Geodata requires being complete and well matched with existing data so that they can be properly integrated. If a new dataset is placed correctly into the context of other available data, it is utilized as expected [8]. It is necessary to make different datasets compatible so that they are reasonably displayed on the same map for sensible analysis [12]. In a successful integration of different datasets, the completeness is one of the concerns to be addressed. *Geodata completeness* refers to the exhaustiveness of set of spatial features and their attributes in the geographic database in relation to an abstract universe or model world [9, 13]. The abstract universe is a representation of the reality with a desired level of simplification or generalization [9]. For instance, in most GIS applications, health facilities, such as hospitals, are usually represented as points in geographic databases.

The completeness of geodata is generally assessed at two levels: model and data completeness [9, 13]. When the model and/or digital data are not complete, geodata maintenance is probably required. *Model completeness* is the commission or omission relationship between the spatial features in the model world and those in the reality whereas *data completeness* refers to the commission or omission relationship between datasets and their attributes defined in the model world and those available in the digital data [13]. Basically, according to Yang [13], *omission* means that some required spatial features and/or their attributes are not included in the geographic database while *commission* means that extra spatial features and/or their attributes, which are not necessarily required, are included in the geographic database.

Since different people use GIS for different purposes and the phenomena they study have different characteristics, right decisions should be made about what features should be modeled and how they should be represented in GIS [1]. This model completeness is application dependent in the sense that the model world is created for a particular application [13] and therefore, it is an aspect of the fitness-for-use [14]. This implies that this type of completeness is achieved if the context of GIS is properly analysed by defining problems to be solved. As Ramasubramanian [15] points out, the clarity in problem definition is critical in GIS implementation. Once a spatial feature has been modeled, it is expected that required elements (i.e. spatial, temporal, and thematic) are collected and captured into the geographic database. At this stage, the data completeness is assessed. Data completeness is application independent and hence geodata can be shared and re-used in various contexts.

3. Research Context

This study was conducted in the public health sector in Malawi from June 2015 to December 2016. Malawi is a landlocked country in southeast Africa and borders with Tanzania to the northeast, Zambia to the northwest, and Mozambique to the east, south and west. The health system has five levels of management (nation, zone, district, facility, and community). There are twenty-nine health districts, which are grouped into five health zones. In every health district, there is a district health office (DHO), which is responsible for providing all necessary support to health facilities in its health district; including planning, coordination, management, monitoring and evaluation. The health district is further divided into health facility catchment areas within which there are communities and villages.

Since 2002, there have been various initiatives in order to strengthen Malawi national HMIS and different technologies have been implemented including DHIS2 in 2012. DHIS2 (www.dhis2.org) is a tool for collecting, validating, analysing, and presenting aggregate and patient-based statistical data, tailored (but not limited) to integrated health information management activities. From 2015, the MoH has been implementing DHIS2 GIS in order to enhance data analysis, integration and presentation. During the time of our study, CMED was carrying out a major reform on DHIS2; that is, the reconfiguration of DHIS2 in which the deployment of GIS was one of its milestones.

This study involved participants from the national and district levels. At the national level, participants were from Central Monitoring and Evaluation Division (CMED) and DHIS2 team. To strengthen its national health management information system (HMIS), the MoH established CMED that is involved in coordination, data management, advocate and facilitation of the information use in various activities such as policy formulation, planning and program implementation at all levels. Since CMED does not have adequate technical capacity for implementing and supporting DHIS2 and other technologies, in 2009, the MoH established a technical team, referred to as DHIS2 team, which is composed of information technology (IT) experts from some of its collaborating partners. CMED coordinates the activities of DHIS2 team. At the district level, participants were from Blantyre health district, which is one of the largest districts with the population of slightly over 1 million and has both city (having a central/referral hospital) and rural settings. In addition, it was close to where the authors live. Thus, it was relatively cheap to visit in terms of logistics.

4. Research Methods

In this single case study, interpretive qualitative research methods were adopted to understand social and natural settings and practices on the building and maintenance of geodata. People have different ways of looking at the reality [16] and it is important to study them in their natural settings aiming at producing factual descriptions [17]. Participant observation was the principal data collection method, which was supplemented with semi-structured interviews and artifact examination.

4.1 Participant Observation

Participant observation allowed us to observe and participate at the same time. In this research, we participated as GIS implementers in the DHIS2 GIS deployment exercise. We were part of DHIS2 team. As the implementers, we participated in various activities starting from acquisition of spatial data up to demonstration of the live DHIS2 GIS. First, geodata were acquired from various sources such as CMED, UNICEF Malawi, Jhpiego and National Statistical Office (NSO). Second, the geodata completeness were assessed in which missing geodata were identified. Third, the missing geodata were internally developed. Fourth, geodata were preprocessed to make it suitable for uploading into DHIS2 GIS. Fifth, setting up and testing of DHIS2 GIS were done concurrently. The last activity was to demonstrate the live DHIS2 GIS to some users for their feedback; three CMED managers at the national level and two HMIS officers and two health program coordinators in Blantyre health district. All demonstrations were done at the participants' workplaces.

4.2 Semi-structured Interviews

As the participant observers, interviews enabled us to step back and examine the interpretations of our fellow participants in some details [18]. Semi-structured interviews were conducted at different times and in some cases, we had to interview one participant more than once, which provided us opportunity to confirm, verify and even build on information from previous interviews [19]. At the national level, eight interviews were conducted with two CMED managers and three members of DHIS2 team. These interviewees interact with DHIS2 almost on daily basis. At the district level, five interviews were conducted with two HMIS officers and three health program coordinators in Blantyre health district. HMIS officers are the data managers and provide support to users of health information systems in their respective health districts. They work closely with health program coordinators. All interviews were conducted at the individual participant's workplace. During interviewing, we used the note-taking technique to record responses in which rough but extensive notes were made. Immediately after the individual interview, we wrote up our notes in full and sent to the respective participant through email for verification and feedback.

4.3 Artifact Examination

The examination of artifacts provided us with the avenue of gathering data apart from the participant observation and interviews. Norum [20] refers to artifacts as "things that societies and cultures make for their own use" including written texts (e.g. documents, diaries, memos, meeting minutes, letters), archival records, and those in the form of film, television, and music. Various documents were analysed which involved minutes, emails, reports, policies, strategies, manuals, and forms. The main objectives were to understand (a) policies, procedures and strategies that govern the implementation of various technologies and data management; (b) various roles in the implementation of technologies; and (c) various ways of presenting data and information. Apart from documents, geodata of administrative boundaries and health facilities were analysed for completeness and relationships.

4.4 Data Analysis

This case study employed thematic analysis approach, which is a qualitative analytic method for identifying, analysing and reporting patterns (themes) within data. The notions of model and data completeness guided the data analysis. The concept of completeness was applied to understand required spatial features and datasets for GIS application in the health management, and what kinds of maintenance practices are expected on geodata.

5. Research Findings

From the perspective of geodata completeness, three aspects have been applied in this study: the reality, the model world, and the digital data. The research findings have been presented in respect of these aspects. The aspect of reality has helped in the definition of an application domain of DHIS2 GIS in Malawi through identifying necessary spatial features and their relationships. The aspect of model world has assisted in understanding thematic and spatial elements of the spatial features for DHIS2 GIS database. The aspect of digital data has defined the geodata for DHIS2 GIS implementation. In this section, we have assessed geodata being used in DHIS2 GIS in order to understand its completeness and this has led to the identification and definition of administrative and technical actions on geodata maintenance.

5.1 Institutional Arrangement – The Reality

To determine spatial features for DHIS2 GIS in Malawi, we briefly describe its context from the institutional arrangement perspective. In this paper, *institutional arrangement* is taken as a formal governance structure that is established to manage human interactions and its rules and regulations which often form the basis for guiding activities of the organisation [21]. In the context of health management, this arrangement involves networks of entities and organisations in planning, provision, management and monitoring of health programs and services. As shown in Table 1, the focus is on management levels, healthcare services, health facilities, and CMED personnel.

Table 1: Management levels, healthcare services, health facilities and CMED personnel

Management Levels	Healthcare Services	Health Facilities	CMED Personnel
Nation	Tertiary	Central Hospitals	Health Economists, Statisticians, DHIS2 Team, M&E Officers
Zone			
District	Secondary	District Hospitals	HMIS Officers
Facility	Primary	Rural Hospitals down to Health Posts	Facility In-charge
Community		Village & Outreach Clinics	Community Health Workers

When we talk of GIS application in health, health facilities are very critical because "central to a fully operational Health Information Systems (HIS) is a basic inventory of all functioning health facilities and the services they provide" [22]. We take a health facility as any place where people can go and get required health services which are provided by a health care agency. In Malawi, all health facilities from central hospitals down to health posts have permanent structures. Village and outreach clinics have temporary structures such as houses of community health workers or small summer huts constructed by communities. In some cases, outreach clinics can be serviced at a community facility (e.g. school). The health facilities are grouped into three: primary, secondary and tertiary (see Table 1). Primary healthcare is the first contact for healthcare services which are usually provided by community/rural hospitals down to village and outreach clinics. Secondary healthcare services are provided by district hospitals. Tertiary healthcare services are provided by central hospitals.

Health facilities provide various health services to the population in their respective catchment areas. The World Health Organisation defines the catchment area as a geographic area served by a health program or institution and it is delineated on the basic of such factors as population distribution, natural geographic boundaries and transportation accessibility [23]. In Malawi's health system, the critical catchment areas are health districts. Health facilities, except the central hospitals, are grouped by the health districts and they report to their respective District Health Offices (DHOs). The central hospitals provide specialized services to the nation at large and they report directly to the national level.

Population distribution is one of the requirements in the GIS implementation for health management in Malawi, which refers to as the arrangement or spread of people living in a given catchment area usually according to variables such as age, gender, and economic status. For example, the MoH and other stakeholders need population distribution data for estimating who may have access to the health facilities within the recommended distance of 8 kilometres. Data on population distribution in the catchment areas can help in planning, health service delivery, monitoring and evaluation, among others.

In DHIS2, the hierarchical structure has been implemented with respect to the management levels; having organisation units which represent the catchment areas and health facilities. Data analysis at the district level is usually by health facilities while at the national level it is by health districts and in some cases by health zones. DHOs need to know various events occurring in their respective health facilities. Central hospitals have their own structures of wards, departments, and hospital. One participant pointed out that a central hospital is not really a single facility but “a group of hospitals which are represented by specialized departments.” In DHIS2, central hospitals form their own ‘virtual’ zone and have departments and wards. Figure 1 illustrates the hierarchical difference between a health district (e.g. Blantyre) and a central hospital (e.g. Queen Elizabeth).

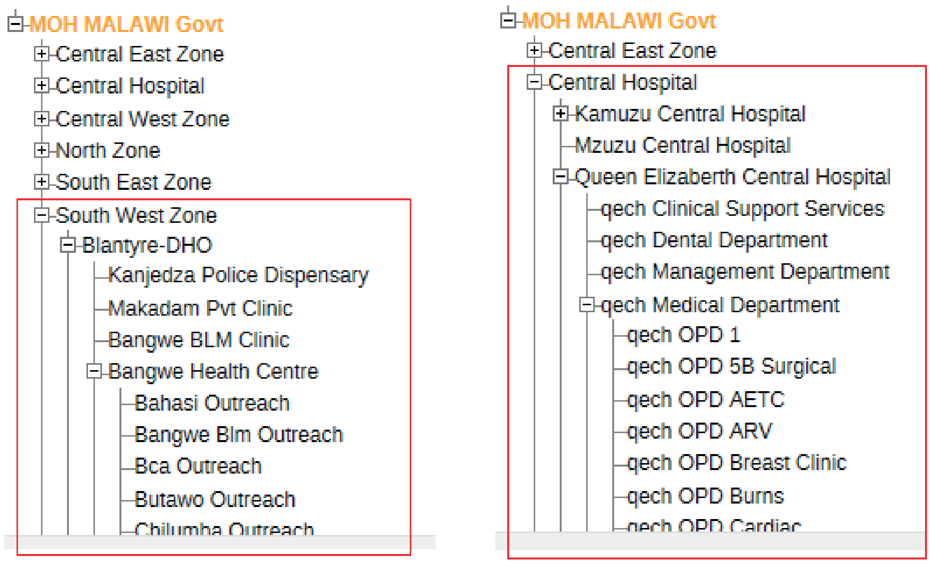

Figure 1: Part of Blantyre DHO and Queen Elizabeth Central Hospital

One of the responsibilities of CMED is to implement and manage technologies, including DHIS2 GIS, with support of its collaborating partners such as universities, non-governmental organisations (NGOs), development partners, and other government agencies. This is due to inadequate technical capacity in CMED. CMED has no ICT personnel; IT Unit of the MoH is mainly responsible for hardware and software maintenance, and the payroll system. As a long-term strategy, CMED has been investing on HMIS officers at the district level in terms of GIS capacity building. One participant said: “As custodians of GIS in their respective health districts, we bought GPS for all HMIS officers and then trained them.”

5.2 Model Completeness – The Model World

Since geodata models geographic entities for a particular GIS application, it is important to identify which spatial features are to be modelled. This information may help to determine relevant sources of data and build required spatial datasets. A good model contains relevant spatial features and their attributes [9, 14] so that the acquired geodata answers questions of ‘what’, ‘where’ and ‘when’ [7]. If relevant spatial features are not identified properly, this can affect the acquisition of data and even its maintenance. In this study, we have identified three basic spatial features namely health facilities, catchment areas and population distribution, which are needed by health programs and services in

DHIS2. We have assessed the model completeness of DHIS2 GIS from the perspectives of these three spatial features.

In DHIS2 GIS, health facilities are represented as points. However, the main concern is the central hospital as a reporting health facility. In practice, departments and wards usually report data. In the current status of DHIS2 GIS, spatial analysis is possible at the hospital level but not at department and ward levels. As illustrated in Figure 1, the departments and wards are included in DHIS2 but they are not effective in GIS module because they do not have spatial elements. One participant said: “Usually at this central hospital, health managers and other stakeholders demand the analysis by department or ward.” By considering departments and wards as part of DHIS2 GIS, we have noted that issues concerning map scale and level of details in the visualization should carefully be considered. For instance, if departments and wards are represented as points, the central hospital itself may be represented as a polygon. However, in DHIS2 GIS, polygons are usually used to represent health catchment areas.

Geodata of health districts, as catchment areas, is not commonly available. Instead, administrative boundaries are used. This has raised some concerns. First, in some cases, administrative boundaries mismatch with the structure of health systems. For instance, in some situations, health facilities are outside the administrative district (see Figure 2(A)). However, it is possible to have health facilities outside the administrative district “because of how the district health catchment area has been defined”- one participant commented. Second, as illustrated in Figure 2(B), there exist two health districts (i.e. Mzimba South and Mzimba North) in one administrative district (i.e. Mzimba) which has resulted in not being included in the spatial analysis.

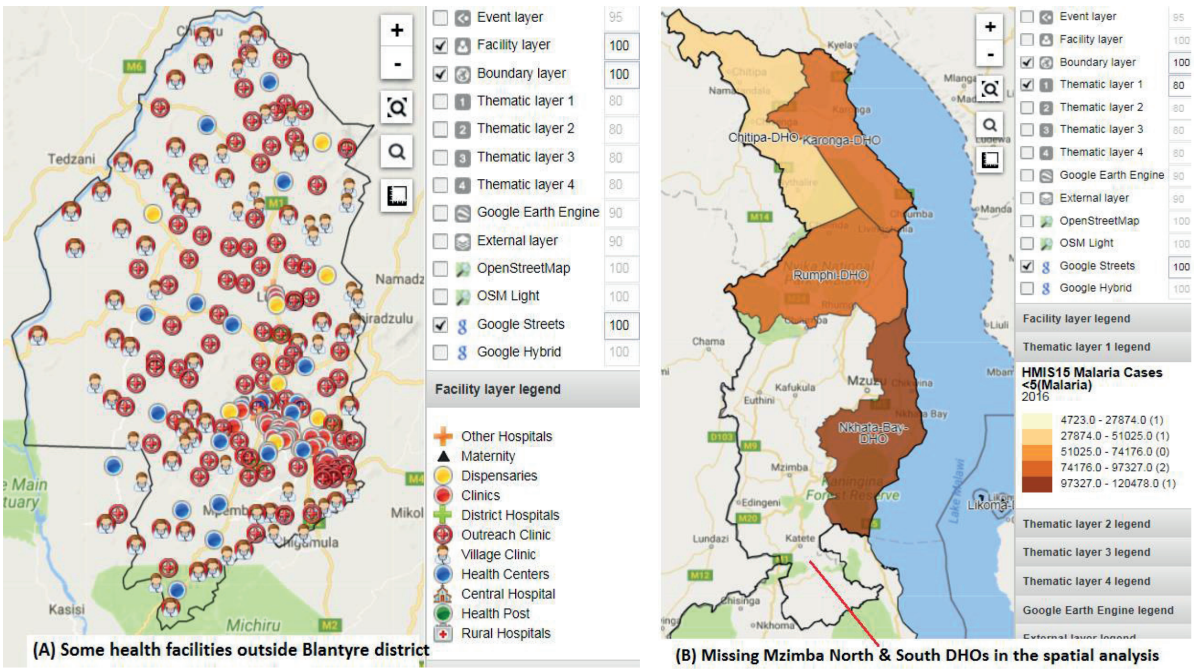

Figure 2: (A) Health Facilities in Blantyre and (B) Spatial Analysis of North Zone

In version 2.21 of DHIS2, the one being used by the time of this study, population distribution has not been modeled. The version 2.24 or later of DHIS2 supports map of layers from Google Earth Engine including the population layer. Hence, to include the population distribution is just a matter of migrating to the latest version of DHIS2. The Google Earth Engine layer allows people to display satellite imagery and geospatial datasets with planetary-scale analysis capabilities. However, participants in this study mentioned age groups (e.g. under 5 children) as one specific characteristic of the population. This requirement is difficult to be met in the population layer from the Google Earth Engine. Overhead imagery has its own limitations; for example, it "may reveal a building and may even indicate that it is a factory but usually cannot detect the products made" [24].

5.3 Data Completeness – The Digital Data

In Malawi, the existing spatial datasets in DHIS2 GIS include health facilities, health zones, and health districts. These datasets have spatial elements – that are represented by longitudes and latitudes – and thematic elements for describing the spatial features. Geodata of health facilities were sourced from CMED and UNICEF and that of districts were sourced from National Statistical Office (NSO) and Jhpiego. Geodata of health zones were generated internally. One important observation is that regardless of its source, every dataset requires to be verified and preprocessed. In the preprocess exercise, spatial data is converted into a form suitable for entry into GIS application [25]. In DHIS2 GIS, data sets are converted into GML (Geography Markup Language) format before being imported into the geographic database. GML is the XML grammar that serves as a modeling language for geographic systems and as an open interchange format for geographic transactions on the Internet.

The verification on geodata was performed in consultation with HMIS officers and CMED management to check for the digital data completeness. This exercise involved three main activities. First, we checked if organisation units in DHIS2 had corresponding spatial data elements and added health facilities that were not available in DHIS2. Second, we renamed organisation units which had the similar names, particularly village and outreach clinics. Third, we checked if health facilities in DHIS2 were assigned to the right facility type; otherwise affected health facilities would not correctly be analysed and visualized in GIS application.

Geodata of health facilities from CMED has few attributes (see Figure 3) as compared to that from UNICEF (see Figure 4). Attributes of geodata from CMED include facility name, type, ownership (controlling agency), and administrative location (e.g. district and region). Geodata from UNICEF has additional attributes of contact of facility in-charge (name, email, and phone), cluster, and status of facility (functional or non-functional).

	A	B	C	D	E	F	G	H	I	J
1	YEAR	FACILITY NAME	DISTRICT	REGION	FACILITY TYPE	OWNERSHIP	SOURCE	LATITUDE	LONGITUDE	DATUM
2	2013	Amitofo Care Centre	Blantyre	South	Clinic	NGO	GPS	-15,74768	35,107470	WGS84
3	2013	Aquid Lifeline Project	Blantyre	South	Clinic	NGO	GPS	-15,622170	35,056040	WGS84
4	2013	Auction Holdings Clinic	Blantyre	South	Clinic	Company	GPS	-15,811950	35,064170	WGS84
5	2013	Ayali Private Clinic	Blantyre	South	Clinic	Private for profit	GPS	-15,659290	35,021140	WGS84
6	2013	Bangwe Health Centre	Blantyre	South	Health Centre	Government/public	GPS	-15,82382	35,08046	WGS84
7	2013	Beit trust Cure International Hospital	Blantyre	South	Other Hospital	Mission/ Faith-based (other than CHAM)	GPS	-15,80354	35,01753	WGS84
8	2013	Belton Kapyepye Memorial Clinic, Kapyepy	Blantyre	South	Clinic	Private for profit	GPS	-15,80869	34,99434	WGS84
9	2013	Bernald Kachale Private Clinic	Blantyre	South	Clinic	Private for profit	GPS	-15,78018	35,07352	WGS84
10	2013	Blantyre Adventist Hospital	Blantyre	South	Other Hospital	Christian Health Association of Malawi (CHAM)	GPS	-15,7824	35,0031	WGS84
11	2013	Blantyre City Assembly Clinic	Blantyre	South	Clinic	Government/public	GPS	-15,80333	35,03895	WGS84
12	2013	Blantyre Dream Project Clinic	Blantyre	South	Health Centre	NGO	GPS	-15,79182	35,01273	WGS84

Figure 3: Part of geodata from MoH collected in 2013

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Health_Facility	Village	GVH	TA	District	Eastings	Northings	Type_of_Facility	Controlling_Agency	Name	Phone	Email	Cluster	Status	Year
2	BAHASI	Wisiki	Mwamadi	Machinjiri	Blantyre	35,100392	-15,833177	Outreach	CBO	Brenda Katunga	881061577	N/A	Bangwe	Functional	2015
3	BALAZA	Balaza	Chibweya	Chigaru	Blantyre	34,905817	-15,419463	Outreach	MoH	Masauko Jumbe	993901196	N/A	Mdeka	Functional	2015
4	BALUTI	Baluti	Chiimire	Somba	Blantyre	34,991079	-15,826820	Outreach	MoH	Alick Phiri	882658056	N/A	Zingwangwa	Functional	2015
5	BANGWE	Namatapwa	Mwamadi	Machinjiri	Blantyre	35,080477	-15,823832	Health Centre	MoH	Christopher Mkunga	888371775	cmkunga@yahoo.com	Bangwe	Functional	2015
6	BANGWE BLM	Mwamadi	Mwamadi	Machinjiri	Blantyre	35,080416	-15,830897	Outreach	MoH	Lizzie Mwambazi	881558969	N/A	Bangwe	Functional	2015
7	BCA	Chipagala	Mtenje	Machinjiri	Blantyre	35,076611	-15,842377	Outreach	MoH	Lydia Maulidi	882919019	N/A	Bangwe	Functional	2015
8	BLANTYRE ADVENTIS	Blantyre City	Blantyre City	N/A	Blantyre	35,003089	-15,782349	Hospital	CHAM	Kirby Kasinja	1820488	bah.hosp@yahoo.com	Blantyre Adve	Functional	2015
9	BONDO	Mlomba	Likomba	Machinjiri	Blantyre	35,080881	-15,667137	Village Clinic	MoH	Simon Dzimbiri	884280169	N/A	South Lunzu	Functional	2015
10	BOTA	Bota	Lunguzi	Lundu	Blantyre	35,04368	-15,435089	Village Clinic	MoH	Rabson Jeremiah	888498872	N/A	Lundu	Functional	2015
11	BUTAWO	Butawo	Mwamadi	Machinjiri	Blantyre	35,109931	-15,808739	Outreach	MoH	Evon Ng'omba	884262347	N/A	Bangwe	Functional	2015
12	CHABVALA	Chabvala	Chabvala	Kasisi	Blantyre	34,834342	-15,833894	Health Centre	MoH	Calisto Ngwira	998918838	N/A	Chabvala	Functional	2015
13	CHAGWIRAUTA	Chagwirauta	Imbwa	Kunthembwe	Blantyre	34,858251	-15,807708	Village Clinic	MoH	Chiyanjano Chilombo	881033389	N/A	Chabvala	Functional	2015
14	CHAKWIYA	Chakwiya	Chakwiya	Makata	Blantyre	35,102671	-15,551672	Village Clinic	MoH	Mercy Muhaniwa	996029252	N/A	Makata	Functional	2015
15	CHALIMBA	Makochera	Chilipa	Makata	Blantyre	35,10367	-15,662377	Village Clinic	MoH	Grey Kazembe	999218699	N/A	Makata	Functional	2015

Figure 4: Part of geodata from UNICEF collected in 2015

During the service provision assessment survey in 2013, out of 1060 only 977 health facilities were visited [26], which means that 83 health facilities were not available in the dataset including Zomba mental hospital (the referral hospital). During the deployment of DHIS2 GIS, out of 8632 village and outreach clinics, 209 clinics were not added in DHIS2 due to unavailability of their respective clusters. In this context, the cluster is a health facility which a village or outreach clinic should report to. We reported this to HMIS officers in affected health districts, CMED and UNICEF for necessary actions. One important response was that some clusters had not yet been added in DHIS2 as health facilities or their names had changed. The DHIS2 GIS implementation team and HMIS officers took necessary actions collaboratively.

As mentioned earlier, administrative boundaries are used to model health districts and zones. Two main activities were done to make sure that the geodata is complete for DHIS2 GIS. First, geodata of health zones had to be created by dissolving administrative districts. In GIS, *dissolve* is a process of creating a new feature by merging adjacent polygons or lines that have a common value in a specified attribute. We applied the 'dissolve' tool in ArcGIS 10.2 to generate the new dataset of zones. As shown in Figure 5, it is possible to have the spatial analysis by health zones. Second, in the case of Mzimba, there was a need to split it into two health districts. This idea was presented to some participants in this study and the CMED management, and all agreed to it. However, both technically and legally, it is not easy to demarcate administrative area. The administrative area is legally documented and if it is to be changed, the legal protocols need to be followed. For the sake of this study and to be used in DHIS2 GIS, Mzimba was split into Mzimba South and Mzimba North by dissolving health facility catchment areas that were created in 2003. Figure 6 illustrates the demarcation of Mzimba into the two health districts.

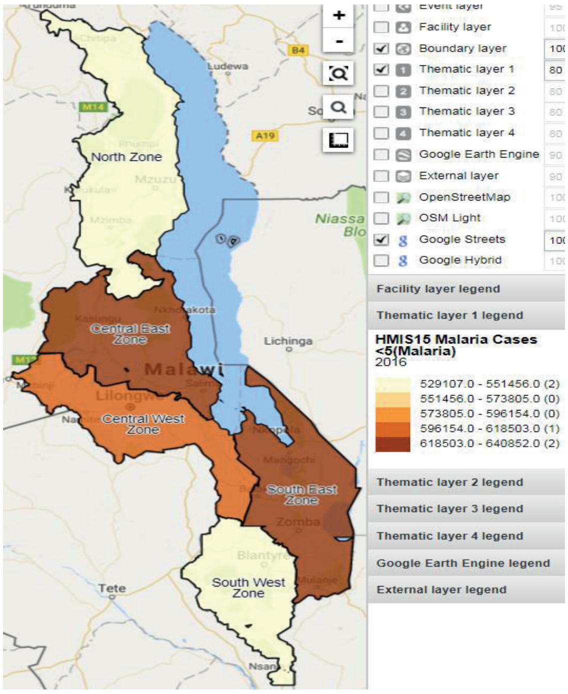

Figure 5: Spatial Analysis by Health Zone

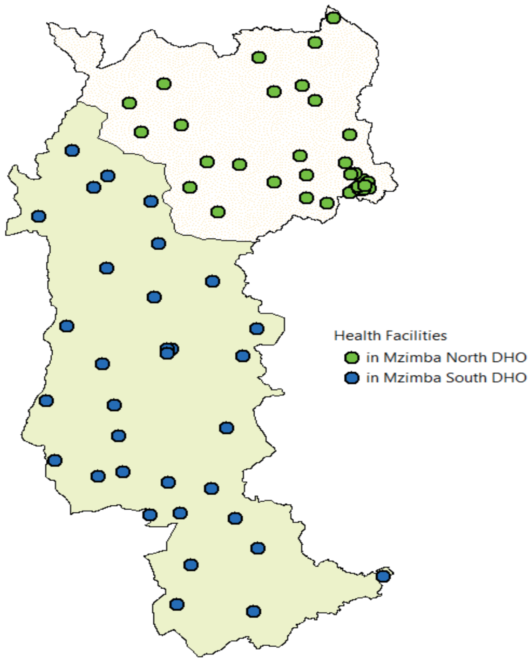

Figure 6: Mzimba North & South

6. Analysis and Discussions: Towards Geodata Maintenance

In the definition of geographic database update [1], the concept of change is emphasized. Any change to geometry, attributes or database schema is determined by a certain problem to be solved or a need to be met. Since a geographic database is always updated when new data exists [1], our observation is that before the database is updated, certain actions should be performed to generate such data. This case study has revealed such actions. Thus, this section discusses those proposed actions and the context in which they may be performed.

6.1 Proposed Actions for Geodata Maintenance

From the findings presented above, we have identified actions that are necessary in maintaining geodata to a certain level of usefulness. The process of maintaining geodata is initiated by a need that is imposed by a data user or due to a real world change. This need is to be communicated to an agency that assesses the need for its feasibility. Then, the agency provides feedback to the reporting agency whether it is possible to implement the change or not. If it is possible, the geographic database update is expected to take place and the reporting agency and other stakeholders are communicated accordingly. In this context, we have proposed six actions as (1) identify the need, (2) communicate the need, (3) assess the need, (4) edit the model, (5) acquire the geodata, and (6) edit the dataset.

6.1.1 Identify the Need

In information systems, users always have new requirements in order to be in line with changes in the context or beyond. These new demands influence some changes in the system including data. In GIS, geodata is among the key resources in meeting user needs. We have observed that a change in geodata can be influenced by demands from within or outside the health management system. In over 20 years ago, the political system in Malawi demanded the split of some administrative districts. It took the government of Malawi a long time to update geodata of affected districts. For instance, administrative boundaries, used in studies of Chikumba [3] and Saugene and Sahay [5], were not updated to reflect the change. The Ministry of Health (MoH) has no direct control over such external demands. Hence, in this paper, our interest is on demands imposed by GIS users within the health management system.

We have observed that demands from the national level affect two or more health districts, programs or services. For example, the decision on building geodata for Mzimba North and South health districts was from the national level. Even including the population distribution in DHIS2 GIS was the decision made at the national level. Demands at district and lower levels are particularly those affecting health facilities. HMIS officers are responsible for making sure that details of health facilities in their respective health districts are always up-to-date in DHIS2. At the community level, village and outreach clinics are under the management of community health workers (CHWs) who are probably to identify any changes affecting geodata of those health facilities.

Demands can also come from a service or program. For instance, in planning and monitoring service, DHIS2 users need to use GIS in assessing the accessibility of health facilities, which may lead to determination of locations of new health facilities. The nutrition program expects GIS to enhance the monitoring and tracking services by providing spatial visualization of locations of its clients and associated logistics resources.

6.1.2 Communicate the Need

All health-related issues concerning the nation are managed at the national level and those concerning individual districts are managed at the district level. The data management in HMIS follows this type of governance. CMED officers manage data at the national level while HMIS officers are data managers at the district level. We have observed that issues concerning geodata of health facilities are reported to HMIS officers and those concerning the geographic database model, like the issues of Mzimba and population distribution, are reported to CMED at the national level. Even issues being raised by health program coordinators, such as patient tracking in the nutrition program, are reported to CMED at the national level because it involves many health districts. These demonstrate that demands should be communicated to the right authority or office for further assessment.

6.1.3 Assess the Need

We recommend that a change on geodata should carefully be analysed in order to determine its complexity and required resources for its implementation. The nature of change can differ depending on what part of geodata is likely to be affected. For instance, changes on the database schema require the technical know-how on database management and GIS, including programming in some cases, which may result in consuming more technical resources than those changes on attributes. Some concerns in the assessment of the need are:

- Level of the change – it can be on the database model, spatial or thematic elements.
- When to implement the change – a change can take time (e.g. boundary data); or it needs urgent attention (e.g. a new health facility); or it can wait; or even not to be implemented.
- Responsible personnel and required competence – a change can be done at the district level or national level by the internal personnel or the external expertise.
- An expected effect on GIS technology and related systems – sometimes, a change needs the upgrade of technology through, for example, migrating to the latest version, developing an additional application, or reconfiguring some components.

6.1.4 Edit the Model

According to Longley, Goodchild, Maguire and Rhind [1], *editing* is the process of making changes to a geographic database, which involves adding new objects or replacing existing ones. Generally, the type of change can be either a new spatial feature or new data entry. If a new spatial feature is demanded, the model may be modified. In this process, the new spatial feature is to be integrated with existing ones in the geographic database so that it can easily be analysed, presented and visualized [8, 12]. The focus is on defining relationships between spatial features, which is the application-dependent.

6.1.5 Acquire the Geodata

Geodata can be acquired through various ways such as being sharing, internally developing or capturing in the field. "Geodata may be collected by both government organisations as well as private agencies … be shared and re-used by different users and applications" [2]. This is achievable if there are no critical omissions or commissions and the dataset is in the suitable format for maximum efficacy [27]. The organisation is forced to capture geodata in the field or develop internally if there is no other source to get such geodata. In collaboration with other organisations, the MoH captured the geodata of health facilities.

6.1.6 Edit the Dataset

The new data entry involves changes on spatial and/or thematic elements; add new contents or replacing outdated ones. Mzimba South and North health districts were added as new objects in the health district dataset, in which spatial and thematic elements were entered into the geographic database. The health zones, as catchment areas, were already modeled in DHIS2 and what remained was to acquire and update their spatial elements.

6.2 Proposed Model for Geodata Maintenance

From the discussions above, in Figure 7, we illustrate how the proposed actions for the geodata maintenance are related. As shown in Table 2, they are categorized as technical and administrative actions. In this paper, we take both administrative and technical actions as any actions or decisions made by stakeholders of a particular GIS application that affect the maintenance of geodata. Technical actions require the practical knowledge of GIS while administrative actions may not really need such knowledge.

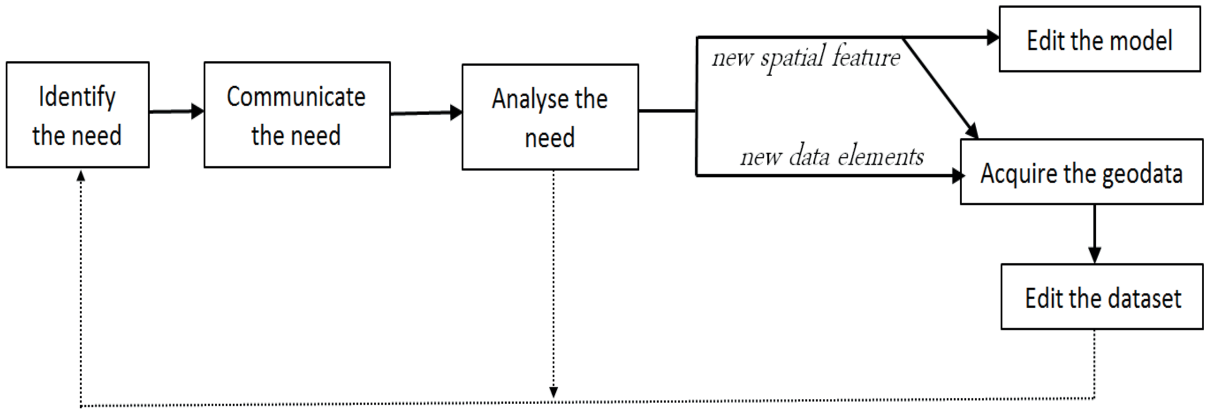

Figure 7: Proposed Actions for Geodata Maintenance

Table 2: Categories of Proposed Actions

Action	Category	Description
Identify the Need	Administrative	A stakeholder in the GIS application domain identifies a need for change in the system.
Communicate the Need	Administrative	The need is communicated to a responsible agency for further actions. The reported need is to be documented for sharing and referencing.
Assess the Need	Administrative/ Technical	This involves both administrative and technical decisions. If the reported need is complex and external support is required, collaborating partners can be consulted for assistance in terms, for example, finances, expertise or materials. Basic knowledge of GIS and geodata is required.
Edit the Model	Technical	This is the responsibility of technical people, who have the practical knowledge of GIS including database management. In most cases, these are developers or implementers of GIS.
Acquire the Geodata	Technical	This requires geodata sharing and practical knowledge of geodata collection using at least GPS. It also requires basic knowledge of coordinate systems e.g. longitudes and latitudes.
Edit the Dataset	Technical	This is the responsibility of technical support teams (e.g. DHIS2 team at the national level and HMIS officers at the district level), who have practical knowledge of GIS and geodata.

In the context of government, geodata can generally be in three categories namely physical data (physical features on the Earth); political data (artificial designations that define an area as part of political entity); and socioeconomic data (e.g. population, economics, and social patterns) [24]. We treat health facilities as physical data; health districts and zones as political data; and population distribution as socioeconomic data. In terms of acquisition and management of these types of data, each category has unique characteristics. We have observed that health facilities require frequent changes, particularly village and outreach clinics. Due to their temporary structures, village and outreach clinics are likely to change locations over a short time or even become non-functional, and new clinics are established. Even thematic elements, such as contact details of a facility in-charge (see Figure 4), are expected to change frequently due to the mobility of health personnel.

Although the users of DHIS2 GIS are at the national and district levels, community health workers (CHWs) at the community level may play a great role in the maintenance of geodata, particularly that of village and outreach clinics. Since geodata is a new phenomenon to CHWs, it is important to have a conducive environment for promoting their involvement in geodata maintenance. They can be involved in *identify the need* and *communicate the need* processes. As observed in some studies – for example Moyo, Nkhonjera and Kaasbøll [28] – both technical and social systems should be considered in the implementation of technical phenomena at the facility and community level; including management commitment and individual attitudes towards a phenomenon.

Geodata maintenance requires resources such as people, hardware, software, procedures, reliable communication systems and finances among others. Collaboration has enabled the MoH to acquire necessary geodata for DHIS2 GIS. We argue that collaboration is also useful in the geodata maintenance, mainly in *edit the model* and *acquire the geodata* processes. Since it lacks the IT capacity, CMED is unlikely to carry out its geodata maintenance activities without being assisted by other organisations. In the health sector, collaboration is a key to success in the delivery of health program or service, and implementation and maintenance of technologies due to the complexity of health problems. Collaboration can accomplish complex and far-reaching tasks more effectively than individual institution doing alone. CMED can utilize existing collaborations to complement its resources in geodata maintenance as it has done in other GIS initiatives.

7. Conclusion

In literature of data maintenance in GIS, much has been discussed on the update of geographic databases, which involves changes on spatial and thematic elements, and database schema (model). From the discussions above, we relate *edit to the model* to changes on the database schema and *edit the dataset* to those on geometry and attributes (i.e. spatial and thematic elements). This study has demonstrated that, additional four actions are required to have a complete set of geodata maintenance operations involving both administrative and technical actions. The four actions are *identify the need, communicate the need, assess the need* and *acquire the geodata*. As Longley, Goodchild, Maguire and Rhind [1] and Huisman and de By [6] point out, geographic database is always updated when new data arrives or is acquired. These four additional actions are necessary to make new data available for the geographic database update. However, these proposed actions are based on our observations during the implementation of DHIS2 GIS in Malawi. Further studies are required.

From the definition of GIS implementation as an on-going process of decision-making through which users become aware of, adopt, and use GIS [15], we take geodata maintenance as part of this process. All involved agencies need to be aware of and adopt good practices on geodata maintenance in order to build a culture towards the sustainability of DHIS2 GIS. Geodata maintenance as an innovation needs to be incorporated into operations of HMIS. In order to promote the involvement of various stakeholders at different levels, there is a need, for example, to have reliable management support and ongoing communication among those stakeholders.

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Paper 2

Chikumba, P. A. Acquiring Geodata and Expertise in GIS Implementation for Health Management in Malawi: The Role of Collaboration. *Under review in Journal of Information Systems and Technology Management*

Paper 3

Chikumba, P. A. (2017) Exploring Integrative Approach of GIS Implementation: The Case of GIS in Health Management in Malawi. Paul Cunningham and Miriam Cunningham (Eds): IST-Africa 2017 Conference Proceedings, IIMC International Information Management Corporation

IST-Africa 2017 Conference Proceedings
Paul Cunningham and Miriam Cunningham (Eds)
IIMC International Information Management Corporation, 2017
ISBN: 978-1-905824-57-1

Exploring Integrative Approach of GIS Implementation: The Case of GIS in Health Management in Malawi

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Abstract: Various researchers have proposed different approaches for implementing GIS in developing countries. One of them is an integrative framework from which the GIS implementation is typically linked with the implementation of other policies or programs. There is little discussion on benefits and risks of this approach particularly in health. Therefore, this case study aims at exploring this approach, particularly challenges being associated with it because there are observations of such practices in Malawi. It has been observed that it is possible to link GIS implementation activities with those of other programs or projects. This link helps to share resources: e.g. human, tools and time but more attention should be on priorities of implementation activities and utilization of such resources. However, it is not all activities that can be linked due to some factors. Some decisions need to be made ensuring that the linking is possible.

Keywords: Integrative framework, GIS implementation, DHIS2 GIS, GIS elements.

1. Introduction

Health Information System (HIS) requires the relevant technologies and tools for organizing and presenting information for easy access and interpretation. One of these technologies can be a geographic information system (GIS) which is a computer-based system for mapping and analysing things that exist and events that happen on Earth through integration of common database operations with the unique visualisation and spatial analysis benefits offered by maps. Both public and private sectors are developing innovative ways to make use of such data integration and visualization power of GIS. GIS has been applied in planning and management of health care services [1] because of, for example, its ability to manage large volumes of data quickly and readily produce spatially-oriented output [2]. The combination of GIS and health applications with decision-making processes can assist in operational and management controls, and strategic planning [3].

In developing countries, GIS is applied in many health areas including health programs and management. However, GIS is not used to address pressing needs in ways that are sustainable and decision process oriented. This can be due to numerous challenges existing when implementing GIS. The literature has argued that many challenges are related to organisational issues. Adoption of IT depends on the quality and extent of management involved in the process; for instance, a GIS implementation requires selection of the proper 'strategy' [4], which is a contingent plan of action designed to achieve a particular goal.

Researchers have proposed different approaches or frameworks for successfully implementing GIS in developing countries. One of them is an integrative framework from Ramasubramanian [5] in which the GIS implementation is typically linked with the implementation of other policies or programs; i.e. the GIS implementation is embedded in development of policies, programs, or projects. There have been observations of such practice in the DHIS2 GIS implementation in Malawi in which most activities have been integrated with those of other programs. In Malawi, Ministry of Health (MoH) has been using DHIS2 since 2012 aiming at introducing the national integrated health management information system (HMIS). DHIS2 (www.dhis2.org) is a tool for collection, validation, analysis and presentation of aggregated statistical data. Apart from tables and charts in DHIS2, MoH has decided to use GIS as one way of improving analysis, integration, reporting and presentation.

Since its proposition, there is little discussion on benefits and risks of this integrative framework, particularly in health. In this paper, the interest is on challenges being associated with the integrative approach. This case study tries to answer the following question: How can the integrative approach affect the implementation of GIS? There are several activities which are executed during the implementation of GIS and they are in line with the major elements of GIS: people, data, technology and procedures [6, 7]. Hence, this paper explores the integrative approach of GIS implementation from the perceptive of these major elements using the case of DHIS2 GIS in Malawi. The findings have been presented from three characteristics drawn from the integrative framework [5].

The rest of the paper is as follows. The second section defines the integrative framework and three characteristics being applied in this study. The research methods have been presented in the third section. The fourth section describes some GIS implementation activities that have been carried out in Malawi. Challenges of the integrative approach have been discussed in the fifth section and the paper ends with the conclusion.

2. Integrative Approach of GIS Implementation

In this case study, the GIS implementation is taken as the activities for putting the innovation into practice and incorporating it into existing and developing operations [8], in which there is an on-going process of decision-making through which users become aware of, adopt, and use GIS [5]. The GIS implementation process involves various stages such as planning, requirements analysis, design, acquisition and development, and operation and maintenance, in which different decisions and activities should be made and carried out respectively. According to Ramasubramanian [5] the integrative approach allows researchers to identify issues and decisions that may have preceded discussions on GIS implementation as well as those that are likely to impact the implementation process.

The focus in this paper is on decisions made and activities carried out in the stage of acquisition and development of GIS-related resources in relation to people, data, technology, and procedures. From the strategic management perspective, an organisation needs to acquire resources from external sources to improve its resource portfolio and sometimes it accumulates its own resources [9, 10]. For instance, in the case of the DHIS2 GIS implementation in Malawi, the GIS knowledge has been accumulated through training while spatial data has acquired through data sharing and primary data capture in response to changing GIS user needs.

As stated earlier, people, data, technology and procedures are the key elements of GIS [6, 7] which relate to each other. Hence, the GIS implementation activities have been presented from the perspective of these key elements: user training, spatial data collection, GIS deployment, and policies and strategies. People are the most important part of GIS who overcome shortcomings of the other three elements. They should have adequate skills and knowledge in order to manage other elements. With reference to the case used in this research, people involve mainly end-users of GIS and technical support team including implementers. In the public sector, to get the required skills and knowledge, user training is usually the method used.

GIS integrates data from multiple sources and data accuracy determines the types of questions and problems to be addressed by a GIS application. Both spatial and non-spatial data are important in GIS. Spatial data is a type of data which is geographically referenced in some consistent manner using, for example, latitudes and longitudes, national coordinate grids, or postal codes [11]. Non-spatial data represents a type of data which is not geometrical and are used, for example, in queries, analyses and visualization of spatial data. In this paper, the focus is on the spatial data because non-spatial data is only handled by other systems such as DHIS2. The spatial data is available and accurate through proper data collection (data capture, transfer, and sharing) and preprocessing.

Technology (hardware and software) determines type of problems to be solved and also matches needs and skills of its users. It is used in GIS activities such as data acquisition, preprocessing, data management, manipulation and analysis, and output generation. Technology should carefully be deployed and used to the expectations of users. This can be achieved if a GIS application operates according to well-designed plans and business rules (including models and operating practices) of a concerned organisation which should clearly be defined in policies and strategies. The activities should be performed in a well-defined and consistent manner to produce correct and reproducible results from GIS.

Literature has revealed that studies of GIS implementation are either on 'factors' (that enable or impede implementation) or 'process' (which are key steps or decisions that are made during implementation). As a result, some approaches of GIS implementation are factor-oriented while others are process-oriented [5]. Hence, Ramasubramanian [5] proposes an integrative framework of GIS implementation in developing countries from which three characteristics have been drawn and used to analyse and discuss the findings in this study.

The first characteristic is that the integrative framework accommodates both 'factor' and 'process' approaches. GIS implementation is a process in which management should make informed decisions at certain points in time. During assessment of GIS implementation in developing countries, apart from identifying factors that affect the process in a particular organisational setting, it is also important to analyse the key steps that are made in order to identify how the implementation occurs in reality [5] and for example, this helps to understand why certain decisions have been made in that time [12].

The second characteristic is the motivation for introducing GIS. The integrative framework begins with policy or programmatic goals that provide the motivation for introducing GIS. Therefore, in any assessment of GIS implementation, the contents of programs or policies being pursued and their direct and indirect effects on implementation processes and subsequent outcomes must be taken into account [5].

The third characteristic is that GIS implementation activities are linked with those of other programs or projects. In this case, GIS implementation is part of implementation activities being carried out in a particular program or project. For example, health personnel can collect coordinates of health facilities while they have gone to those facilities for supervisory visits.

3. Methodology

This case study was conducted at the national level in Malawi health sector between June and November 2016. Malawi is a country in southeast Africa, which borders with Tanzania to the northeast, Zambia to the northwest, and Mozambique to the east, south and west. The health system has five levels of management: nation, zone, district, facility, and community. Participants in this case study were from Central Monitoring and Evaluation Division (CMED) and DHIS2 team. The DHIS2 team is responsible for providing technical support to DHIS2 users at both national and district levels in MoH. This team includes members from HISP Malawi, MoH-IT unit, JHPIEGO/SSDI, Baobab Health, University of

Malawi and University of Oslo, and coordinated by CMED. MoH established CMED as one way of strengthening its HMIS, whose overall objective is to continuously collect, analyse and use data to monitor and evaluate progress towards achieving goals and objectives of the health sector. CMED is implementing DHIS2 GIS. The GIS application in MoH started as early as 2002 when a booklet of maps of health facilities was produced and distributed in compact discs (CDs). Since then, there have been several GIS initiatives and in this study the focus is on policies and strategies of Health Information System (HIS), GIS user training, spatial data collection, and deployment of DHIS2 GIS.

Qualitative and interpretive research methods were applied in this case study. The data was collected through participant observations, interviews, and analysis of documents. The participant observations were done during the deployment of DHIS2 GIS because the author was among facilitators of the process. The deployment involved preprocessing of spatial data and setting up of DHIS2 GIS. Face-to-face interviews with five participants (members of DHIS2 team, and CMED officials) were conducted focusing on the effort and plans on the GIS implementation. Focus was on how they had carried out GIS implementation activities, the support they have been getting from other institutions and available internal capacity. The author analyzed four documents which have included GIS directly or indirectly: Health Information System - National Policy and Strategy, Malawi National Health Information System Policy, Malawi Health Sector Strategic Plan, and Incorporating Geographic Information into Demographic and Health Surveys. The analysis and discussion of empirical material were guided by the key elements of GIS [6, 7] and three characteristics drawn from the integrative framework.

4. GIS Implementation Activities

In Malawi, MoH has been carrying out various GIS implementation activities (see Table 1 and Table 2). In this paper, the activities have been presented in four main categories: policies and strategies, spatial data collection, GIS user training, and DHIS2 GIS deployment, which are in relation with the key elements of GIS.

Table 1: GIS Implementation Activities in Malawi MoH

2003	2009	2010	2013	2015	2016
HIS Policy – MoH	GIS User Training – MoH	GIS User Training – MoH	GIS User Training – MoH Health Sector Strategic Plan – MoH Program document – ICF International Mapping health facilities – ICF International & MoH	Revised HIS Policy – MoH Mapping village & outreach clinics (Phase 1) – UNICEF	Mapping village & outreach clinics (Phase 1) – UNICEF Deploying DHIS2 GIS – MoH

Table 2: GIS implementation activities embedded in other activities

Activity	Comment on Integration
Spatial data collection in 2013	Integrated with SPA survey and the SPA program document indicates spatial data collection as one of its activities.
Spatial data collection in 2015/2016	Not integrated with any other program
GIS user training in 2009	Integrated with user training program of DHIS2
GIS user training in 2010	Not integrated with any other user training program
GIS user training in 2013	Not integrated with any other user training program
Deployment of DHIS2 GIS in 2016	Integrated with the ‘reconfiguration’ program of DHIS2 and GIS deployment was one of its activities

4.1 Policies, Strategies and Program Documents

GIS is one of the issues that MoH is considering in its socio-economic policies. In 2003, MoH formulated HIS policy and strategy [13] which intended to provide a framework for management and use of information in planning, management and monitoring of health services and performance. In this document, MoH recommended the application of GIS as a powerful visual tool for planning and monitoring of health services; emphasizing on geographical variations in types and magnitude of problems, equity in distribution of health services, and service utilization. The policy defined explicitly the purpose of GIS, spatial data collection and update, access of GIS, purchase of hardware, and data analysis.

In 2015, a revised HIS policy was released [14] which has not directly mentioned GIS. This is because "… the policy is open for any relevant technologies …", one participant commented. For instance, there are various projects of implementing electronic HIS such as mHealth and GIS, among others [15]. However, in this policy, there are some statements which can influence the use of GIS as a relevant technology. As examples, the policy emphasizes the utilization, coverage and equity of services delivered, and aggregate data repository (which is currently DHIS2).

Apart from the policies, there are strategic plan and program document which also specify the role of GIS directly or indirectly. Malawi Health Sector Strategic Plan [16] addresses issues of equity including gender and geographical location. This spatial dimension can well be supported by GIS. The service provision assessment (SPA) survey of ICF International has a program document [17] explaining how spatial data collection should be integrated with the demographic and health surveys. Hence, mapping of health facilities in 2013 by ICF International and MoH was done during the SPA survey.

4.2 Spatial Data Collection

In this paper, the focus was on two major projects of collecting coordinates of health facilities across the country, which were executed differently by institutions within the health sector. In 2013, while carrying out the national SPA survey, MoH and ICF International collected coordinates of public health facilities (from central hospitals down to health posts) and some private facilities. This spatial data collection was one of activities in the SPA survey and health officers, e.g. medical assistants and nurses from health centres, were trained on how to collect coordinates of health facilities using Global Positioning System (GPS). The SPA survey took at large-scale a detailed look at the status (especially availability and quality of services) of health facilities in Malawi and it was conducted within eight (8) months [18].

Then in 2015 and 2016, UNICEF Malawi collected coordinates of public health facilities including village and outreach clinics. This second spatial data collection project was not integrated with any other project or program. This mapping of health facilities was to generate evidence for future planning exercises; for example, using the spatial data to conduct gap analysis aiming at revealing the population living in deprivation. This spatial data collection took almost two years. The team composed of UNICEF (as funder, facilitator, and quality controller); and MoH (providing health technical capacity). The technical GIS support was provided by officers from the department of Lands.

4.3 GIS User Training

The GIS user trainings involved mainly district HMIS officers from all health districts and central hospitals, and M&E officers from zonal health offices. Since that time DHIS2 GIS had not been yet deployed, ArcGIS or ArcView were used instead. Unfortunately till the time of this study there were no any GIS applications in health districts for HMIS officers to use. In 2009, the user training included DHIS2 (for 3 days) and GIS (for 2 days). Most trainees complained on lack of hands-on practical sessions because the 2 days were not enough for GIS beginners. Since that training was for building capacity in GIS particularly in spatial data collection, capturing, preprocessing, and analysis, they needed enough time to learn various concepts both theoretically and practically. It has been observed that afterwards, user trainings in 2010 and 2013 were conducted only on GIS and for 5 days each. However, there are suggestions of conducting GIS and DHIS2 together in future trainings since "the GIS will soon be part of DHIS2" one participant commented.

4.4 DHIS2 GIS Deployment

GIS in DHIS2 (i.e. DHIS2 GIS) is one of the tools used to disseminate and present data as maps. This GIS module is bundled in DHIS2 which allows integration of non-spatial data collected in DHIS2 with spatial data stored in the same database [19]. Hence, setting up of DHIS GIS is basically a matter of populating coordinates of the organisation units (e.g. health facilities and catchment areas) into the database. Immediately the population of coordinates is done, maps will be available in the GIS module.

In MoH, setting up of DHIS2 GIS has been one of the activities of 'reconfiguring' DHIS2, which started in February 2016 and GIS was set up in September 2016. In this project, activities were to build a new server for backup purposes; clean up the database; redefine indicators; and refine entry forms and remove those no longer needed. The GIS was set up by the same DHIS2 team which was reconfiguring DHIS2 with the facilitation of the author. Two training sessions (of one day each) were organized to equip the DHIS2 team with basic knowledge of DHIS2 GIS set up and use, since it was the first time for the team to carry out such exercise and members had inadequate GIS knowledge. Before setting up DHIS2 GIS, there was cleaning up and pre-processing of spatial data.

5. Discussions

The GIS implementation, as a process, involves a set of activities that should be carried out. Decisions are made on what resources to use and how and when to execute activities based on various factors or conditions. As mentioned earlier, in the integrative approach, the GIS implementation is embedded in the implementation activities of other programs or projects. Taking example of DHIS2 GIS implementation, it is part of the implementation of DHIS2. Since its introduction in 2012, there have been extensions to DHIS2 to include other technologies such as GIS in order to enhance data analysis, integration and presentation [15]. But the observation was that no all GIS implementation activities were related to DHIS2 implementation as shown in Table 2. Some activities were linked to those of other programs or projects. The good part is that all these programs or projects are within the umbrella program of strengthening HMIS in Malawi, which started as early as 1999. Therefore, in this paper, the GIS implementation activities are taken as some of activities for strengthening the HMIS. From the characteristics drawn from Section 2, the discussions focus on the motivation for introducing GIS, and benefits and challenges of linking implementation activities.

5.1 Motivation for introducing GIS

Every organisation needs a plan for implementing GIS with business rules, models, and operating practices [6, 7] which can be defined in policies, strategic plans, or program documents. The policies, strategic plan and program document, presented in this paper, have in one way or other included statements that could motivate for introducing GIS. In HIS policy and strategy of 2003, there is a statement stating GIS purpose and use. It has been observed that since the introduction of this policy, there had been various GIS initiatives such as the purchase of hardware and training of HMIS officers. "In 2005 we bought GPS and distributed to HMIS officers in all DHOs", one participant said. It may be argued that these decisions were influenced by the HIS policy and strategy which supports the argument by Ramasubramanian [5] that the content of policy or program/project document provides motivation for introducing GIS. Taking also example of the spatial collection exercise in 2013, it was clearly outlined in the project document what and how spatial data should be collected and by who during SPA surveys.

The policies, strategic plan and project document used in this study have not outlined all key elements of GIS. For instance, the HIS policy and strategy of 2003 focused only on issues of spatial data, people and hardware while as the project document is only spatial data collection. Even in both the HIS policy of 2015 and strategic plan for health sector of 2011-2016, there is no single statement about GIS; although there are statements that demonstrate the presence of spatial dimension of data which can easily be supported by GIS. Literature has discussed the importance of GIS in health; e.g. analysis of healthcare needs, access, and utilization [20]. However, there is no guarantee that these statements can always motivate the introduction of GIS. Taking the example of spatial data collection in 2015/2016, it was motivated by user needs in the sense that existing tools or technologies could not support the assessment of population living in deprivation. Hence, the management at UNICEF decided to apply GIS.

Majority of participants have commented that decisions on recent GIS activities have not really been influenced by the policies; for example, the choice and deployment of DHIS2 GIS. In 3 years ago, CMED recommended the use DHIS2 GIS in health management. As mentioned earlier, GIS module is bundled in DHIS2 which easily integrates spatial and non-spatial data [19]. Other reasons, what the participants mentioned, there is no need to design and develop a new GIS application and since DHIS2, as the formal central data repository, is already established and stable, same resources such as people and technology can easily be upgraded and used in the GIS implementation.

5.2 Benefits and Challenges

One major benefit of the integrative approach might be the utilization of resources such as human capital and time. However, the focus or priority on activities and resources can be a challenge. When GIS implementation activity is carried out together with that of another program, there is sharing of resources, as also pointed out by Ramasubramanian [5], which can result in reducing costs and time. Taking the example of spatial data collection in 2013, same health staff was used in both service provision assessment and collection of coordinates and it was possible to collect spatial data of 977 health facilities within eight months. This can be taken as an achievement because data collection in GIS is the most time-consuming and expensive, yet important, task [21]. Even the deployment of DHIS2 GIS was not taken much time because GIS is inbuilt, and installation of DHIS2 takes care of GIS. The setup of DHS2 GIS took only one week.

However, it is important to make right decision in order to avoid ignoring important issues as far as GIS implementation is concerned. For instance, deployment of human resource and priority of activities need attention when adapting the integrative approach. For successful execution of activities, resources need to be evaluated, manipulated, and deployed appropriately within the environmental context of the organisation [9]. GIS requires well-trained and skilled people to handle its implementation activities.

In the case of spatial data collection, skills and knowledge are some factors that determine the quality of data. Although data quality is beyond the scope of this study, it is expected that the quality of spatial data collected in 2013 could be affected because people involved were health personnel with little knowledge of GIS; they were just trained in GPS use during the SPA exercise. However, some studies have shown that due to declining prices and improving user-friendliness of GIS technology, many institutions in health in developing countries are able to collect and analyse spatial data using their own local resources. For example, in Nigeria and other developing countries, declining prices and improving accuracy of GPS have made even the health personnel, who have little skills and knowledge of GIS, being able to collect spatial data by themselves [22-25].

Involving health practitioners in collection of coordinates did not mean that there were no GIS knowledgeable people within MoH. May be, it was just a choice of 'who should do what'. For instance, in spatial data collection in 2013, HMIS officers were not involved although the exercise was done in their respective health districts and by that time they had already been trained in GIS. This was because "…in this exercise, the core work was not spatial data collection but the assessment of health facility status … we felt that HMIS officers had no great role to play …medical officers and nurses managed to collect coordinates after being trained …", one participant emphasized. This demonstrates that if a decision is not carefully made on deployment of human resource, skills and knowledge of some people will be underutilized. However, this decision was made with respect to availability of financial resources and time.

Even in spatial data collection in 2015-2016 and set up of DHIS2 GIS, HMIS officers, whom MoH has invested in terms of training, were not involved. Since HMIS officers are expected to provide all necessary GIS support to users at district level, they need a conducive environment to practice what they have learnt so that they can continuously improve their knowledge and skills through learning-by-doing [26]. Success in operational management of GIS requires customer support, effective operations, data management, among others [21]. Therefore, HMIS officers need the development of skills and knowledge for easy management of GIS.

Human resource can be underutilized because of priority given to implementation activities. One participant emphasized that in spatial data collection in 2013, the main work was to assess health facility provision and not necessarily collecting coordinates. The priority of activities can also bring delay in the execution of GIS implementation activities. For example, in the deployment of DHIS2 GIS, GIS setup activities were not given the first priority as compared to DHIS2 reconfiguration activities which resulted in delay of setting up GIS; it took almost six months from the commencement of DHIS2 reconfiguration project since they wanted to complete high priority level activities first.

6. Conclusion

The main aim of this case study was to explore the integrative approach in GIS implementation: understanding how this approach can affect the implementation of GIS. It has been observed that the integrative approach can help to share resources such as human capital and time but attention should be on priority of activities and utilisation of resources.

There are factors that can determine whether to link or not a GIS implementation activity with other program activities. One factor can be 'compatibility' of activities to be linked. In this context, the 'compatibility' is taken as a condition in which two or more activities from different programs or projects are being executed together without problems or conflict. This can be achieved if there are commonalities among the activities; for example, time frame, shared resource and reference point. GIS implementation activity is expected to be carried out within the time of other program/project activity. The spatial data collection in 2013 was within the time frame of SPA survey. The setup of DHIS2 GIS was within the time frame of the DHIS2 reconfiguration project. People involved in GIS implementation activity may also be involved in other activities. This enhances sharing of human resource but attention should be on the utilization of GIS skills and knowledge which can result in reliable operational GIS. SPA survey and spatial data collection targeted the same health facilities as reference point.

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Paper 4

Chikumba, P. A. and Naphini, P. (2018) GIS Initiatives in Health Management in Malawi: Opportunities to Share Knowledge. T.F. Bissyande and O. Sie (Eds.): *AFRICOMM 2016*, *LNICST 208*, pp. 263–272, https://doi.org/10.1007/978-3-319-66742-3_25

GIS Initiatives in Health Management in Malawi: Opportunities to Share Knowledge

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Abstract. Knowledge is recognized as the most important resource in organisations including public organisations and its management is considered critical to organizational success. The literature suggests the development of indigenous knowledge as one of characteristics of the successful GIS implementation in developing countries. The topic of knowledge has been discussed extensively in the information system and organisation literature but much is written about *why* managing knowledge is important to organisations and little on *how* knowledge is identified, captured, shared, and used within organisations. As a contribution to '*how*', this paper discusses opportunities of sharing knowledge in the GIS implementation in health management through some initiatives in Malawi. We can confidently say that there are a number of GIS implementation activities in the health sector in Malawi which are important for knowledge sharing but they are not utilised as expected.

Keywords: Health management · GIS initiatives · Knowledge · Knowledge sharing

1 Introduction

Today, strengthening and sustaining the use of computerised health information systems (HIS) is believed to be mainly based on intangible assets such as knowledge and skills. Employee's knowledge and skills in using computer systems have become a critical factor for successful use of information technology (IT) in organisations [1]. In the case of Geographic Information System (GIS) in developing countries, there are several challenges and some of them are related to the lack of knowledge and skills. In GIS, people are the most important part who can overcome shortcomings of the other elements [2]. GIS users need certain knowledge and skills in order to use GIS properly [3]. Longley et al. [4] argue that GIS technology is of limited value without people who manage and develop plans for applying it to real world problems.

In developing countries, including Malawi, GIS is applied in various health areas such as health programs, health management, primary health care, and health research. Since 2002, there have been GIS initiatives in Malawi towards the implementation of GIS in health management with the aim of improving data integration, analysis, and visualization. The combination of GIS and health applications with decision-making

T.F. Bissyande and O. Sie (Eds.): AFRICOMM 2016, LNICST 208, pp. 263–272, 2018.
https://doi.org/10.1007/978-3-319-66742-3_25

processes can assist in the operational control, management control and strategic planning [5].

Knowledge is recognized as the most important resource, and its management is considered critical to organizational success [6]. Literature suggests the development of indigenous knowledge as one of the successful GIS implementation characteristics in developing countries [7]. Knowledge can be understood as information processed by individuals relevant for the performance of individuals, teams, and organisations [8]. Kim and Lee [9] have taken knowledge as a fluid mix of framed experiences, contextual information, values, and expert insight that provide a framework for evaluating and incorporating new experiences and information.

With reference to the case, this paper focuses particularly on the sharing of IT knowledge between GIS implementers and technical support teams. Proper transfer of knowledge and skills from the system implementers to target system users, particularly in developing countries, is crucial in realizing the intended benefits. López et al. [10] define IT knowledge as the extent to which the firm possesses a body of technical knowledge about elements such as computer systems (in this case, GIS). According to Taylor in 1971, cited in [10], the technical knowledge is the set of principles and techniques that are useful to bring about change toward desired ends.

The topic of knowledge has been discussed extensively in the information system and organisation literature [11], but much is written about why managing knowledge is important to organisations and little on how knowledge is identified, captured, shared, and used within organisations [6]. As a contribution to 'how' (processes of), this paper discusses opportunities of sharing knowledge in the GIS implementation in health management in Malawi through some GIS initiatives. The paper tries to answer the following two questions: Which opportunities to share knowledge exist in GIS initiatives in health management in Malawi? How can opportunities to share knowledge be utilised for knowledge sharing? These research questions have been answered through the analysis of empirical material being guided by the notion of knowledge sharing, particularly opportunities to share from Ipe [6]. The rest of the paper includes the concept of knowledge sharing, study methodology, GIS initiatives, opportunities to share knowledge and conclusion.

2 Knowledge Sharing

It has been observed that there are significant changes on how public organisations are being managed; moving from a traditional, bureaucratic approach to a more managerial one [8], in which knowledge is recognized as one of critical resources. In this context, the public organisations are treated as knowledge-based organisations, which have to contend with competition for resources [8] and there is the need for processes that facilitate the creation, sharing, and leveraging of knowledge [6]. In this paper, some processes in the GIS implementation in health management and how they can facilitate the sharing of knowledge as a critical asset have been discussed. This study takes resources as assets and capabilities that are available and useful in solving GIS-related problems or meeting GIS user needs. Generally, assets and capabilities are respectively what an organisation has and does [12]. A capability is repeatable patterns of actions in the use of assets to create, produce or offer a good or service to a particular market or user [13]. Knowledge, as an asset, needs to be acquired and accumulated [14]; this can be through sharing because knowledge multiplies when it is shared effectively [15]. When we talk of knowledge, learning can be one of the strategies for accumulating such an asset in which interactions occur between individuals, teams, or organisations and hence knowledge is shared.

Within organisations, knowledge is at multiple levels: individual, group and organisation. In this paper, the individual knowledge sharing is emphasised with the understanding that without individuals the knowledge cannot be created, and unless individual knowledge is shared, the knowledge is likely to have limited impact on organisational effectiveness [6]. Knowledge sharing refers to the provision of knowledge to help and collaborate with others to solve problems, develop new ideas, or implement policies or procedures [8]. According to Ipe [6] there are three types of individual knowledge: 'know-how' (experience-based), know-what (task-related), and dispositional knowledge (including talents, aptitude, and abilities). It is expected that knowledge held by an individual is converted into a form that can be understood, absorbed, and used by other individuals [6].

Ipe [6] suggests four major factors that influence knowledge sharing between individuals in organisations: (a) the nature of knowledge, (b) the motivation to share, (c) the opportunities to share, and (d) the culture of work environment. By its nature, knowledge exists in tacit and explicit forms whose difference is related to the ease and effectiveness of sharing [16]. Tacit knowledge is situated in the deep recesses of the human mind and non-codifiable [15] and its tacitness is natural impendiment to the successful individual knowledge sharing in organisations because it cannot be communicated or used without the knower [6]. On the other hand, explicit knowledge is recognised and expressed by formal techniques; it can be easily codified, stored and transferred across time and space independent of knower [6, 16]. Explicit knowledge can be generated through logical deduction and acquired by formal study while tacit knowledge can only be acquired through practical experience in the relevant context, which Lam [17] refers as learning-by-doing.

In order to share tacit and explicit knowledge opportunities, either formal or informal, should exist in the organisation. Acording to Ipe [6] formal opportunities are formal interactions (including training programs, structured work teams, and technology-based systems) that are designed to acquire and disseminate knowledge while as informal opprtunities include personal relationships and social networks that facilitate learning and knowledge sharing. However these opportunities alone, without personal motivation, cannot bring much influence on the knowledge sharing. Ipe [6] argues that individuals are not likely to share knowledge without strong personal motivation. Knowledge sharing is challenging because, for example, it is typically voluntary and individual's tacit knowledge is difficult to transfer [8]. Therefore, it is important to understand what motivate individuals to share knowledge; for example the perceived power attached to the knowledge, reciprocity that results from sharing, relationship with recipient, and rewards for sharing [6, 16, 18].

Generally, knowledge is actually created, shared, and used by people in organisations [6] and hence the knowledge sharing should involve dissemination of individual work-related experiences, and collaborations among individuals, subsystems and organisations [9]. Ahmad et al. [15] emphasise that the ability to share knowledge among collaborators represents possibly the greatest strategic advantage an organisation can achieve; for instance, for the public organisation the knowledge sharing represents the means for continous performance improvements.

3 Study Methodology

This case study was conducted at the national level in Malawi health sector between June 2015 and September 2016. Malawi is a landlocked country in southeast Africa and it has borders with Tanzania to the northeast, Zambia to the northwest, and Mozambique to the east, south and west. In its health system, there are five levels of management (nation, zone, district, facility, and community). The GIS application in Ministry of Health (MoH) in Malawi started as early as 2002 when a booklet of maps of the health facilities was produced and distributed in compact discs (CDs). Since then there have been several GIS initiatives and in this study the focus is on the user training, spatial data collection and mapping, and composition of technical team at the national level.

The qualitative interpretive research methods were applied in this case study. The data was collected through observations, interviews, and analysis of documents. One stakeholder meeting was organised to share experiences on the GIS related activities by various institutions in the health sector and how to work together on the GIS implementation. The first author attended that meeting as a passive observer. Participant observations were also done through out our study period in MoH. Face-to-face interviews with five participants (IT officers and M&E officers) were conducted focusing on the effort and plans on GIS implementation and activities that had been already carried out. Another issue was on the support they have been getting from other institutions and internal capacity they have on the GIS implementation. Various documents were analysed including Health Information System (HIS) policy, electronic Health Information System (eHIS) strategy, and training reports and manuals. The analysis of empirical material was guided by the notion of knowledge sharing, particularly opportunities to share from Ipe [6].

4 GIS Initiatives: From 2002 to 2016

Table 1 below summaries some GIS initiatives in MoH from 2002 to 2016. Most of these activities were carried out by MoH in collaborations with its development partners and other government agencies. The GIS initiatives are presented in three categories: user training, spatial data collection and mapping, and composition of technical teams at both district and national levels.

In Malawi the health sector governance structure has the national and district levels. To strengthen the health management information system (HMIS), MoH established Central Monitoring and Evaluation Division (CMED) in its Planning Department which involves coordination, data management, advocacy and facilitation of information use in various activities at all levels in the health sector. CMED is also

Table 1. Some GIS initiatives in health sector in Malawi

Category	Initiatives	Participation/Collaboration
User training	2008 – inter-institutional training	MoH and its partners, other government agencies; one facilitator from WHO
	2009 – intra-institutional training	Zone M&E officers, and HMIS officers from districts and central hospitals; one facilitator from Surveys Department
	2010 – intra-institutional training	Zone M&E officers, and HMIS officers from districts and central hospitals; two facilitators from Surveys Department and NAC
	2013 – intra-institutional training	HMIS officers from districts and central hospitals; two facilitators from NAC and Lands Department
Spatial data collection and mapping	2002 – mapping public and CHAM health facilities	Pioneered by a consultant from JICA with support from Surveys Department and MoH Planning Department
	2008 – mapping ART clinics (HIV/AIDS program)	NSO, MoH, NAC, CDC, University of Pennsylvania, Roads Authority, Surveys Department, WHO
	2011 – updating 2002 mapped public and CHAM health facilities	Pioneered by a consultant from JICA with support from Surveys Department and Planning Department of MoH
	2013 – coordinates for public and private health facilities	ICF International and MoH
	Since 2015 – coordinates for village and outreach clinics	UNICEF Malawi, MoH and Lands Department
Technical team	At district level	HMIS officers and IT officers
	At national level	HISP Malawi, MoH-IT unit, JHPIEGO/SSDI, Baobab Health, University of Oslo

Note: CDC – Centre for Disease Control, HMIS – Health Management Information System, M&E – Monitoring & Evaluation, NAC – National Aids Commission, WHO – World Health Organisation, CHAM – Christian Health Association of Malawi, JICA – Japanese International Corporation Agency, MoH – Ministry of Health, NSO – National Statistical Office.

responsible for implementation and management of technologies, including GIS, in HMIS. At the national level CMED has inadequate technical capacity and therefore it gets much technical support on the implementation of various technologies from its partners. In the case of GIS implementation, it has been observed that the technical expertise has been from outside the health sector in both user training and spatial data collection and mapping.

CMED has put much effort at the district level in terms of developing GIS-related knowledge to HMIS officers through training. With reference to Table 1, the first GIS training for local capacity was conducted in 2009 and participants were all HMIS officers from District Health Offices (DHOs) and central hospitals, and M&E officers from zones. The training was just for introducing GIS and was facilitated by a GIS expert from Surveys Department. A year later, second training was provided to the same officers covering the spatial data collection using GPS and facilitated by two GIS experts from Surveys Department and NAC. The same HMIS officers were also trained in 2013 by two GIS experts from Lands Department and NAC. In the past three years, CMED recruited and deployed IT officers in all DHOs and central hospitals to work with HMIS officers but they have not been given any GIS training.

Table 2 summarizes some initiatives that can facilitate knowledge sharing in GIS application the Ministry of Health (MoH).

Table 2. Some initiatives that can facilitate sharing of knowledge

Initiatives	Authors' remarks
User training	This is done to transfer knowledge from the national level to district level. In some cases it is within the same level, e.g. during the setup of DHIS2 GIS, there was a training at the national level for GIS implementation team being facilitated by some members within the team
Collaborations	The collaboration is mainly at the national level
Structured work team	It is mainly at the national level.
Learning-by-doing	This is an institutional initiative at the national level and individual initiative at the district level. Some HMIS and IT officers have learned GIS through particular tasks requested by stakeholders in their respective districts.
Codification	There is no much codification of knowledge; particularly the production of documentation. For example, in almost all user trainings presented in Table 1, there were no training manuals that would be referenced at the workplace after training. For spatial data collection there are some manuals for reference.
Workshops (or meetings)	In MoH, workshops and meetings are always available which HMIS and IT officers attended. MoH can take advantage of these activities to share experiences in GIS among officers.

5 Opportunities to Share Knowledge

In Malawi, as observed in other developing countries [19–21], there is no adequate GIS expertise and it is difficult to recruit people with all necessary GIS knowledge and skills. Alternatively, CMED has been developing such resources internally and the emphasis has been on the technical team at district level. It has been observed that CMED pays much attention on GIS user training and structured work teams which are some of formal opportunities to share knowledge [6]. In this regard, this paper discusses how these opportunities are utilised for sharing knowledge in the GIS implementation in health management in Malawi with emphasis on collaboration and learning-by-doing.

The literature of GIS implementation in developing countries emphasises the importance of collaboration [7, 20, 22]. Ramasubramanian [7] has observed that strategic alliances could promote the sharing of resources; for example, in GIS programmes of Vista University and University of Pretoria, these universities collaborated with local and international organisations and the programmes were successful. In Mozambique, despite having a number of institutions being involved in GIS activities, they face some challenges due to lack of ‘strong’ institutional collaboration [22]. This has also been observed in this case study; CMED collaborates with other institutions which are experienced in GIS and its use. In user training and spatial data collection, Departments of Lands and Surveys, and NAC have played great roles with their vast experiences in GIS. In terms of the knowledge acquisition and accumulation these collaborations has allowed CMED to build work teams of both experienced and non-experienced GIS users, leading to knowledge sharing. As Sirmon et al. [23] point out, if an organisation may not have the required knowledge, it might form strategic alliances with those having the desired knowledge which can be valuable to the organisation for learning new knowledge.

Training is one of the formal opportunities that help sharing knowledge. In all GIS user training, there were experienced facilitators from other government agencies, sharing knowledge with non-experienced HMIS officers. This demonstrates the collaboration aiming for HMIS officers to acquire the required knowledge. Due to the decentralization in public sector in Malawi, HMIS officers have been providing all necessary technical support at district level; such as data verification, compilation, analysis, reporting and provision of feedback to health facilities [24]. It is a good decision to invest in HMIS officers in terms of GIS knowledge because it is recommended that when building local capacity the local team should be equipped with understanding of both the application domain and the technology being implemented; this contributes towards the sustainability of the system [25]. HMIS officers have vast experience in the health information management because majority has worked with district health managers since the establishment of HMIS in 2002. Providing them with GIS knowledge and skills can equip them with both understanding of the health management (as application domain) and GIS (as technical domain) which might contribute towards the sustainability of GIS in health management.

However, it has been observed that HMIS officers are not given a conducive environment to practice what they have learnt so that they can improve their knowledge through learning-by-doing [17]. It was expected that they would be part of the spatial data collection exercises in 2013 and 2015-2016 because by then HMIS officers had been trained in GIS, but it has not been the case. In 2013 the exercise of spatial data collection was done by medical assistants and nurses during the service provision assessment at health facilities. Only two HMIS officers were involved in compiling data in this exercise at the national level. Although the spatial data collection being facilitated by UNICEF from 2015 is for mapping village and outreach clinics in their respective districts, HMIS officers are not included; instead the GIS technical support has been provided by officers from Department of Lands. In 2016, CMED has been in the process of setting up GIS on DHIS 2 for the health management and this exercise is also in the hands of GIS experts from development partners; HMIS officers are not part of the implementation team at the national level (see Table 1 – technical team at national level).

It is necessary for CMED to provide a suitable work environment for HMIS and IT officers at the district level to continuously share the individual knowledge, which in this case study has been observed as lacking. It could be better for HMIS and IT officers to be part of work teams of the spatial data collection and GIS configuration exercises so they would share knowledge and put that knowledge into practice. Another observation is that HMIS officers were trained in many occasions since 2009 but there had been no GIS applications for them to put the knowledge into practice. Now CMED is implementing GIS in the health management and it is expected that HMIS and IT officers will be providing all necessary technical support but they are also not participating in the exercise. The inclusion of these officers could create an opportunity of sharing knowledge through learning-by-doing and at the same time building social networks and relationships that may result in the continuity of individual knowledge sharing. There is a high possibility that after the GIS implementation exercise these implementers will be there and then HMIS and IT officers are to take over the responsibility of the system management and maintenance. One participant said: "*We bought GPS for HMIS officers and we trained them because they would be custodians of GIS in their respective health districts"*

Most of activities in GIS implementation have been carried out at the national level and in some cases it is difficult for HMIS and IT officers to be part of the work teams due to the culture of work environment and the nature of work [6]. There are 68 officers (34 HMIS officers and 34 IT officers) in 29 DHOs and 5 central hospitals and it is not easy to include all of them in, for example, spatial data collection or setting up of GIS. These activities require very few skilled people. In 2013 coordinates of health facilities were collected as part of the service provision assessment which involved mainly health practitioners such as medical assistants and nurses. Therefore, MoH decided not to include HMIS officers. One participant commented: "*In this exercise we felt HMIS officers would not have much work to do … instead we trained medical assistants and nurses on collection of coordinates using GPS while they were assessing health facilities…*"

6 Conclusion

From the discussion above, we have noticed that GIS knowledge and skills are available at the national level through collaborations and there is a need to transfer such knowledge and skills to the technical team at the district level. The collaborations provide a platform for acquiring required GIS knowledge from the outside of MoH but the challenge is how to maintain it. It seems that HMIS and IT officers, who are 'prospective' custodians of GIS in the health management, are ignored in many GIS implementation activities which could help them to accumulate the relevant knowledge. Although it is fine now that the development partners are providing all necessary technical support in the GIS implementation, it reaches a point in time when majority of these GIS experts will not be available.

It has been observed that CMED takes mainly user training as a strategy for sharing the knowledge with the HMIS and IT officers and this knowledge needs to be continuously accumulated. In this context the learning-by-doing strategy [17] is essential because, for example, it provides an environment for accumulating individual tactic knowledge which contributes the large portion of individual knowledge. Apart from the user training, CMED needs to continue promoting structured work teams by including HMIS and IT officers in some GIS implementation activities in so doing the officers can have a chance to build personal relationships and social networks that may provide the environment for continuous sharing of knowledge. Some task-related (know-what) and experienced-based (know-how) knowledge [6] can be codified, for example, as documentation so it might easily be shared at any time and any place. In conclusion, we can confidently say that there are a number of GIS initiatives in the health sector in Malawi which are important for the knowledge sharing but they are not utilised as expected.

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Appendix 2 – Documents for Ethical Clearance

Appendix 2.1 – Introductory Letter from University of Oslo

UiO **University of Oslo**
Department of Informatics

Malawi Ministry of Health

Date: 10th June, 2015

Patrick Chikumba – Development of geographical functionality in DHIS

Malawian citizen Patrick Chikumba is a lecturer in information technology at the University of Malawi. He did his MSc at University of Oslo in 2009 with a thesis on geographical information system technology for showing distribution of medicines on maps.

Chikumba started PhD studies at University of Oslo in January, 2015 with a dissertation on geographical information systems. His focus is health managers' utilization of health information presented in maps. In order to carry out an empirical study, he would need to develop maps and mapping software in cooperation with health managers and have them evaluate the solutions.

We therefore request that Chikumba being allowed to participate in the ongoing work on improving the Malawian health information system. His project will in particular feed into development of dashboards, something which is suggested by Global Fund, Gates Foundation, UNICEF and other donors.

Vennlig hilsen

Jens Kaasbøll

Jens Kaasbøll
Professor

Appendix 2.2 – Approval from National Health Sciences Research Committee

Telephone: + 265 789 400
Facsimile: + 265 789 431
e-mail mohdoccentre@gmail.com
All Communications should be addressed to:
The Secretary for Health

In reply please quote No. MED/4/36c

MINISTRY OF HEALTH
P.O. BOX 30377
LILONGWE 3
MALAWI

18th December 2015

Patrick Albert Chikumba
Polytechnic

Dear Sir/Madam,

Protocol #15/5/1439: Exploring roles of GIS in health management from information use perspective: An action-case from Malawi

Thank you for the above titled proposal that you submitted to the National Health Sciences Research Committee (NHSRC) for review. Please be advised that the NHSRC has **reviewed** and **<u>approved</u>** your application to conduct the above titled study.

- **APPROVAL NUMBER** : **NHSRC # 15/5/1439**
  The above details should be used on all correspondence, consent forms and documents as appropriate.
- **APPROVAL DATE** : **18/12/2015**
- **EXPIRATION DATE** :This approval expires on **18/12/2016**
  After this date, this project may only continue upon renewal. For purposes of renewal, a progress report on a standard form obtainable from the NHSRC secretariat should be submitted one month before the expiration date for continuing review.
- **SERIOUS ADVERSE EVENT REPORTING** :All serious problems having to do with subject safety must be reported to the National Health Sciences Research Committee within 10 working days using standard forms obtainable from the NHSRC Secretariat.
- **MODIFICATIONS**: Prior NHSRC approval using standard forms obtainable from the NHSRC Secretariat is required before implementing any changes in the Protocol (including changes in the consent documents). You may not use any other consent documents besides those approved by the NHSRC.
- **TERMINATION OF STUDY**: On termination of a study, a report has to be submitted to the NHSRC using standard forms obtainable from the NHSRC Secretariat.
- **QUESTIONS**: Please contact the NHSRC on Telephone No. (01) 789314, 0888344443 or by e-mail on mohdoccentre@gmail.com
- **Other:**
  Please be reminded to send in copies of your final research results for our records as well as for the Health Research Database.

SECRETARY FOR HEALTH
2015 -12- 18
P.O. BOX 30377, CAPITAL CITY, LILONGWE 3

Kind regards from the NHSRC Secretariat.

....

<u>FOR CHAIRMAN, NATIONAL HEALTH SCIENCES RESEARCH COMMITTEE</u>

PROMOTING THE ETHICAL CONDUCT OF RESEARCH
Executive Committee: *Dr.B. Chilima (Chairman), Prof. E. Molynuex (Vice Chairperson)*
Registered with the USA Office for Human Research Protections (OHRP) as an International IRB
(IRB Number IRB00003905 FWA00005976)

Appendix 2.3– Introductory Letter from CMED

REF. No. HMIS/ 14 **31st October, 2016**

FROM : THE SECRETARY FOR HEALTH, P.O BOX 30377,
LILONGWE 3;

TO : THE PROGRAMME MANAGER, MALARIA;
: THE PROGRAMME MANAGER, NUTRITION;
: THE PROGRAMME MANAGER, FAMILY PLANNING;
: THE DISTRICT HEALTH OFFICER, MCHINJI;
: THE DISTRICT HEALTH OFFICER, BLANTYRE.

IMPLEMENTATION OF DHIS2

The Department of Computing and Information Technology at The Polytechnic, University of Malawi is facilitating the implementation of DHIS2 GIS, with support from UNICEF. The first step of setting up the DHIS2 GIS was done in September, 2016.

In order to get feedback from end-users of the system to make improvements, the lead partners Mr Patrick A. Chikumba, and Ms Gloria Chisakasa from the University of Malawi would like to visit your department/district to have discussions with the HMIS and IT Officers. The visits will be conducted from November 2016 to January 2017. We therefore request the support of the HMIS or IT officers, when the partners visit your office.

Please contact Mr Chikumba on 0885 123 533 or patrick_chikumba@yahoo.com for any further clarification that may be required.

Isaac Dambula
For:**SECRETARY FOR HEALTH**

Appendix 2.4 – Informed Consent for Face-to-face Interviews

All correspondence to be addressed to the Principal

University of Malawi – The Polytechnic, Private Bag 303, Chichiri, Blantyre 3, Malawi

Tel: (+265) 1 870 411 Fax: (+265) 1 870 578 E-Mail: principal@poly.ac.mw

PRINCIPAL Prof Grant Kululanga, PhD. Eng., MSc. Eng.,BSc. Eng., MASCE

[Informed Consent Form for National Health Program Manager, District Health Program Coordinator, District Assistant Statistician & IT Officer, CMED Official, DHIS2 Technical Officer]

This informed consent form is for the Assistant Statisticians & IT Officers, CMED Officials, DHIS2 Technical Officers, and health program managers & coordinators at both national and district levels in Malawi who are invited to participate in the academic research: Geographic Implementation for Health Management.

This research is being conducted by Mr. Patrick Albert Chikumba of The Malawi Polytechnic, Department of Computing and Information Technology, Private Bag 303, Chichiri, Blantyre 3 (*Email*: pchikumba@poly.ac.mw, *Tel*: +265 888 522 731) as the part of his PhD study at University of Oslo, Department of Informatics in Norway.

The research has been approved by National Health Sciences Research Committee (NHRSC), Ministry of Health, P. O. Box 30377, Lilongwe 3, Malawi and can be contacted on *Tel:* +265 1 726 422 / 418, or *Email*: mohdoccentre@gmail.com .

Introduction

I am Patrick Albert Chikumba, working for University of Malawi – The Polytechnic. I am doing research on the implementation of Geographic Information System (GIS) for health management, particularly in the health programs in Malawi. I am going to give information and invite you to be part of this research. You do not have to decide today whether or not you will participate in the research. Before you decide you can talk to anyone you feel comfortable with about the research. You can take time to reflect on whether you want to participate or not. This consent form may contain words that you do not understand. Please ask me and I will take time to explain to you.

Purpose

GIS remains a significantly powerful but it is under-utilized analytical tool particularly in developing countries including Malawi. It is believed that for health managers to appreciate the powerfulness for an information system, it is important they understand its roles in the local context. The research is being conducted in Malawi, in health sector particularly at the national and district levels, within the context of the Health Information Systems Programme (HISP) in collaboration with University of Oslo, Department of Informatics. The scope of this research is about the implementation of GIS for health management.

Type of Research Intervention

This research will involve your participation in face-to-face interviews, observations and GIS evaluation that will take place at your premises.

Participant Selection

You are being invited to take part of this research because I feel that your experience can contribute much to my understanding and knowledge of health management practices and how GIS can support those practices.

Voluntary Participation

Your participation in this research is entirely voluntary. It is your choice whether to participate or not. You may change your mind later and stop participating even if you agreed earlier.

Procedures

In this research, data will be collected in three ways: interviews, observations and GIS evaluation and it is expected that you will participate in all three ways.

A. Face-to-face Interviews

During the interview, I will sit down with you in a comfortable place at your premises. If you do not wish to answer any of the questions during the interview, you may say so and I will move to the next question. No one else, but I, will be present unless you would like someone else to be there. The information recorded is confidential, and no one else except me (Patrick Albert Chikumba) and my supervisors (Professor Johan Kaasbøll and Associate Prof. Petter Nielsen) will access the information documented during your interview. The tape-recording will only be used with your consent. If it is used no-one will identified by name on the tape.

B. Observations

Participant observation will be applied at the national and district levels. I will be part of DHIS2 technical team and particularly working on DHIS GIS and providing some technical support to you as the prospect DHIS2 GIS user. I will also attend some of your management meetings and forums which you participate in and do some presentations. This will allow my interactions with you and become part of your community.

C. GIS Evaluation

After deploying the GIS, you will be asked to evaluate it and then provide a feedback in terms of your feelings, suggestions and any other on how best it can be improved. You will be provided with an adequate training before using the system.

Duration

The research takes place in 17 months in total (August 2015 to December 2016). Your participation will be mainly during interviews and evaluations (one 45 minute interview at the beginning of research and another one after GIS evaluation).

Risks

This research will not involve any sensitive and personal issues. However, you may feel uncomfortable talking about some of the topics. You do not have to answer any question or take part in the interviews/observations/GIS evaluation, if you feel it is too personal or it makes you uncomfortable.

Benefits

There will be no direct benefit to you. However, during this research you will be provided training on using GIS and GIS will be implemented for you to use it for your day-to-day work.

Privacy and Confidentiality

I will not be sharing information about you to anyone else apart from my academic supervisors. The information that I collect from this research project will be kept private. Your personal data will not be recorded. All data and audio recordings (if any) will be stored on one machine and protected by passwords. Only my supervisors and I (the researcher) will have the access to the data. In the final reports and publications, the data will be made anonymous.

Study Approval

This proposal has been reviewed and approved by National Health Sciences Research Committee (NHSRC), which is committee whose task it is to make sure that research participants are protected from harm. If you wish to find about more about NHSRC contact The Chairperson of NHSRC, Ministry of Health, P. O. Box 30377, Lilongwe 3, +265 1 726 422/418, mohdoccentre@gmail.com.

Certificate of Consent

I have been invited to participate in research about the implementation of GIS for health management.

I have read the foregoing information. I have had the opportunity to ask questions about it and any questions I have been asked have answered to my satisfaction. I consent voluntarily to be a participant in this study.

Print Name of Participant: ____

Signature of Participant: ____

Date: ____

Statement by the researcher

I have actually read out the information sheet to the potential participant, and to the best of my ability made sure that the participant understands his/her role in this research.

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

A copy of this Informed Consent Form has been provided to the participant.

Print Name of Researcher: ____

Signature of Researcher: ____

Date: ____

Study Site: ____

The end

Appendix 3 – Face-to-face Interview Guides

Appendix 3.1 – Interview questions to CMED managers

1. How long has CMED used GIS in health management and why is it necessary to use GIS?
2. Which GIS initiatives have CMED had so far?
3. How has CMED obtained or acquired spatial data and expertise for such GIS initiatives?
4. How does CMED update geodata for its GIS applications?
5. What critical challenges has CMED faced when managing those GIS initiatives and what strategies to minimize those challenges?
6. Which support and how has CMED obtained from other organisations in various GIS initiatives?
7. Why has CMED chosen DHIS2 GIS as compared to those GIS software it has used before?
8. What plans does CMED have on the implementation of DHIS2 GIS and what type of support does CMED need from other organizations?

Appendix 3.2 – Interview questions to DHIS2 programmers

1. Which organization do you come from?
2. How long are you at CMED?
3. How long have you used DHIS2?
4. How have you obtained required skills and knowledge of DHIS2?
5. Who need your technical support here at CMED and how do you interact which them?
6. Have you used GIS before? If yes, for what purpose? How did you learn GIS?
9. What challenges do you encounter on your day-to-day work?

Appendix 3.3 – Interview questions to officers from collaborating partners

1. Which GIS initiatives in Ministry of Health has your organisation participated?
2. What type of support has your organisation provided to Ministry of Health or CMED in those GIS initiatives? How has the support been provided?
3. Does your organisation have GIS expertise? How has it got GIS expertise?
4. What challenges has your organisation encountered during its participation?

Appendix 3.4 – Interview questions to HMIS officers

1. How does HMIS data flow from health facilities up to the national level?
2. What type of technical support do you provide to DHIS2 users?
3. What type of assistance do you get from CMED at the national level?
4. Apart from DHIS2, which other information systems or technologies do you provide support?
5. When you are writing HMIS reports, do you include any maps? If yes, how do you get the maps?
6. Have you participated in any GIS initiatives? If yes, when, where and how did you participate? What knowledge and skills did you obtain?
7. Now CMED is implementing DHIS2 GIS that is expected to be used in all health district offices (DHOs). What are your expectations?
8. What challenges do you encounter on your day-to-day work?

Appendix 3.5 – Interview questions to district health program coordinators

1. How does your health program data flow from health facilities up to the national level?
2. What technologies and information systems do you use to process your data?
3. Where and how do you get technical assistance when using those information systems or technologies?
4. How do you normally present your data and information in your reports?
5. Do you maps in your reports? If yes, how do you get them?
6. What challenges do you face when accessing the data that you need to use in your report or any other daily work?

Appendix 4 – Online Interview Guide

DHIS2 GIS Implementation in Malawi – Online Interview Guide for HMIS Officers

CMED has set up DHIS2 GIS for use in the new DHIS2 system to be released soon. The project of implementing DHIS2 GIS in Malawi is being facilitated by Patrick Albert Chikumba (PhD student from University of Oslo) and Gloria Chisakasa (Master study from University of Malawi). GIS is Geographic Information System. Ministry of Health is promoting the use of maps through DHIS2 GIS. Usage of maps in DHIS2 will supplement the other reporting tools such as tables and graphs which are being used at the moment.

We have developed this online interview guide to gather basic information on your role in DHIS2, experience in GIS and expectations in DHIS2 GIS. The guide has six (6) questions.

For any further information when and where necessary, please contact Patrick Albert Chikumba on pchikumba@poly.ac.mw and Gloria Chisakasa on gchisakasa@poly.ac.mw

Questions

1. How long have you been in this position of HMIS officer?
2. Describe at most five main activities you do in DHIS2?
3. Have you ever used GIS before? If yes, for how long and what purpose?
4. Have you ever attended any GIS training? If yes, where and when? What skills and knowledge did you obtain from those trainings?
5. Now CMED has implemented DHIS2 GIS that is expected to be used in all DHOs in Malawi. What are your expectations on this DHIS2 GIS?
6. Do you have any other information that you want to share with us concerning GIS?

The end of questions