DEVELOPMENT AND APPLICATION OF A GEO-MEDICAL
INFORMATION DECISION SUPPORT SYSTEM (GeoMedInfo) FOR
MALARIA SURVEILLANCE AND RISK MODELLING IN NYANZA
PROVINCE, KENYA

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in
Public Health Informatics in the School of Health Sciences of Kenyatta University

November 2010
DECLARATION

This thesis is my original work and has not been presented for a degree in any other university

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DEDICATION
This work is dedicated to my beloved wife Nyakoboke; our son Mogere O’Nyaribo; my parents Mr. and Mrs. Mogere, Dr. and Mrs. Oirere and siblings, Mandere, Eric, Denis, Agnes, Jeremy, Rebecca and Ruth whose moral support enabled me to complete my doctoral study.
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TABLE OF CONTENTS

Title                                      Page
Declaration ................................................................. ii
Dedication................................................................. iii
Acknowledgements......................................................... iv
List of Tables............................................................. viii
List of Figures............................................................. ix
List of Abbreviation and Acronyms ......................... xi
Abstract................................................................. xiii

Chapter One: General Introduction

1.1. Background ......................................................... 1
1.2. Statement of the Problem ....................................... 3
1.3. Justification of the Study ........................................ 4
1.4. Research Questions ............................................... 5
1.5. Study Objectives ................................................... 6
1.6. Null Hypotheses .................................................... 6
1.7. Significance of the Study ......................................... 7
1.8. Study Assumptions and Limitation ............................. 7
1.9. The Conceptual Framework of GeoMedInfo Design .......... 8

Chapter Two: Literature Review

2.1. Health Decision Support Systems (HDSS) ..................... 12
2.2. The Health Management Information Systems (HMIS) ........ 13
2.3. Malaria Research and Geographical Information System (GIS) in Africa .... 14
2.4. Current Applications of GIS in Health Research in Africa ....... 16
2.5. Malaria Transmission Mapping and Geo-statistical Modeling .......................... 17
2.6. Current GIS Operability Trends Relevant to Africa ........................................ 18
2.7. The Spatial Data Infrastructure (SDI) .......................................................... 19
2.8. The Kenya National Spatial Data Infrastructure (KNSDI) ............................... 20
2.9. Health Data Modelling ................................................................................. 21
2.10. Examples of the Health Data Models in Developed Countries ...................... 24
2.11. Designing of Spatial GIS Application as Health Decision Support System .... 25
2.12. Designing of GIS Application as Decision Support System ......................... 29

Chapter Three: Materials and Methods
3.0. Introduction ...................................................................................................... 31
3.1. The Study Area ............................................................................................... 31
3.2. Study Design ................................................................................................... 33
3.3. Study Variables ............................................................................................... 34
3.4. Procedures for Development and Customization of the PMIS ....................... 34
3.5. Procedures for Development and Customization of the PMIS ....................... 34
3.6. Data Collection Techniques ........................................................................... 39
3.7. Spatial Data Analyses and Model Validation ................................................. 44

Chapter Four: Results
4.0. Introduction ...................................................................................................... 47
4.1. A Conceptual Health Data Model (HDM) Supportive of the KNSDI ............... 47
4.2. The Patient Management Information System (PMIS) .................................... 57
4.3. Mapping Malaria Transmission in Siaya District .......................................... 65
4.4. A Geospatial Model for Malarial Case Risk Mapping in Kisii Highlands ........ 72
Chapter Five: Discussions

5.1. Development and Application of Health Data Model ........................................ 80
5.2. Implementation of the PMIS at Siaya District Hospital .................................. 80
5.3. Applications of PMIS - Spatial Capabilities to Track Malarial Patients .......... 86
5.4. Relationships between Malaria Prevalence and Environmental Risk Factors .... 89
5.5. Testing of the Hypotheses .............................................................................. 91

Chapter Six: Summary, Conclusion and Recommendations

6.1. Summary of the Study .................................................................................. 93
6.2. Conclusions of the Study ............................................................................ 95
6.3. Implications from the Findings .................................................................... 95
6.4. Operational Recommendations ................................................................... 96
6.5. Suggestions for Further Research ............................................................... 97

References ......................................................................................................... 98

Appendices ......................................................................................................... 110
# List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 3.1</td>
<td>Spatial databases used for spatial analyses</td>
<td>44</td>
</tr>
<tr>
<td>Table 4.1</td>
<td>Case definitions for the study groups</td>
<td>62</td>
</tr>
<tr>
<td>Table 4.2</td>
<td>Geographic data collected from enrolled study participants</td>
<td>67</td>
</tr>
<tr>
<td>Table 4.3</td>
<td>Tabulations of malaria outcome categories compared with proximities of their house to risk factors</td>
<td>69</td>
</tr>
<tr>
<td>Table 4.4</td>
<td>Spatial characteristics of the malarial case households with covariates</td>
<td>70</td>
</tr>
<tr>
<td>Table 4.5</td>
<td>Relationships between malaria cases and each of the risk factors</td>
<td>76</td>
</tr>
<tr>
<td>Table 4.6</td>
<td>Individual regression coefficients for risk factors</td>
<td>77</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1.1 A Schematic Representation of the GIS Concept and Application in Healthcare ................................................................. 8
Figure 1.2 Schematic Representations Showing Linkage of Sub-systems in GeoMedInfo ............................................................... 9
Figure 1.3 A schematic Diagram Representation GeoMedInfo Decision Support System ................................................................. 10
Figure 2.1 PHCDM Class Diagrams .............................................. 26
Figure 2.2 Relationships in PHCDM Classes .................................... 26
Figure 2.3 Relationship Association .............................................. 27
Figure 2.4 Participation Association ............................................. 27
Figure 2.5 Attributes and Data Types ........................................... 28
Figure 3.1 Study Area: Siaya District, Nyanza Province, Kenya .......... 32
Figure 3.2 Study Area: Kisii Highlands Districts, Nyanza Province, Kenya ...... 33
Figure 3.3 Example of the GPS Coordinates Surveyed in Siaya District ...... 40
Figure 3.4 Distribution of Health Facilities in Kisii, Nyamira and Gucha Districts ... 41
Figure 3.5 A Typical Work Flow of Map Digitization for Digital Thematic Maps ... 44
Figure 3.6 A snapshot of the Siaya Geo-database .......................... 46
Figure 4.1 The Conceptual Health Data Model Supportive of Kenya National Spatial Data Infrastructure (KNSDI) ................................ 48
Figure 4.2 Model for “Patient” Class ........................................... 53
Figure 4.3 Model for “Facility” Class .......................................... 55
Figure 4.4 Model for “Location” Class ........................................ 57
Figure 4.5 Model for “Visit” Class ............................................ 57
Figure 4.6 Record Entry User Interface Showing Details of Patient Data Entry .... 59
Figure 4.7 Record Entry User Interface for Patient Household Data Entry ...... 60
Figure 4.8 Record Entry User Interface for Patient Visit Details ............... 61
Figure 4.9 A Snapshots for Record Entry User Interface for Enrolled Patients family History ......................................................... 63
Figure 4.10 A Snapshots for Record Entry User Interface for Enrolled Patients’ Physical Exam ..................................................... 63
Figure 4.11 A Snapshots for Record Entry User Interface for Enrolled Patients’
History Present Illness on Visit.......................................................... 64

Figure 4.12 Malarial Case Household Mapping Overlaid with Covariates for Spatial Analyses................................................................. 68

Figure 4.13 Relative Distances travelled by various Malarial Case Households with regard to Siaya District Hospital (SDH)................................. 71

Figure 4.14 Average Distance between Malarial Case Households and Nearness to Road Network ............................................................ 72

Figure 4.15 Relationships between Malarial Case Households and Nearness to Water Bodies............................................................................ 72

Figure 4.16 The Digital Terrain Model (DTM) Covering the three Districts of Kisii, Nyamira and Gucha ............................................................... 75

Figure 4.17 A Cartographic Presentation of the Malaria Case Surfaces in the Periods (a) 2001 (b) 2003 and (c) 2005 ......................................................... 79

Figure 5.1 A Medical Officer entering Data into PMIS using Touch Screen Technology................................................................................ 83

Figure 5.2 Data Collection Modules of PMIS Utilising Touch Screen Technology..................................................................................... 85
**LIST OF ABBREVIATIONS AND ACRONYMS**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDC</td>
<td>Centre for Disease Control and Prevention</td>
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<td>CDM</td>
<td>Conceptual Data Model</td>
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<td>DBMS</td>
<td>Database Management Systems</td>
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<td>DEM</td>
<td>Digital Elevation Model</td>
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<td>FEWSNET</td>
<td>Famine and Early Warning System Network</td>
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<td>GIS</td>
<td>Geographic Information System</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<td>HIV</td>
<td>Human Immuno-deficiency Virus</td>
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<td>HMIS</td>
<td>Health management information system</td>
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<td>KEMRI</td>
<td>Kenya Medical Research Institute</td>
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<td>KNSDI</td>
<td>Kenya National Spatial Data Infrastructure</td>
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<td>MA</td>
<td>Malaria Anaemia</td>
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<td>MC</td>
<td>Malaria Cases</td>
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<td>MCH</td>
<td>Malarial Case Household</td>
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<td>MoH</td>
<td>Ministry of Health</td>
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<td>MSS</td>
<td>Multi-Spectral Scanner</td>
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<td>NDVI</td>
<td>Normalised Difference Vegetation Index</td>
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<td>NHSSPII</td>
<td>National Health Sector Strategic Plan II</td>
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<td>OMG</td>
<td>Object Management Group</td>
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<td>PHCDM</td>
<td>Public Health Conceptual Data Model</td>
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<td>PMIS</td>
<td>Patient Management Information System</td>
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<tr>
<td>RFE</td>
<td>Rainfall Estimates</td>
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<td>RoK</td>
<td>Republic of Kenya</td>
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<td>SDH</td>
<td>Siaya District Hospital</td>
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<tr>
<td>Abbr.</td>
<td>Full Form</td>
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<tr>
<td>SoK</td>
<td>Surveys of Kenya</td>
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<tr>
<td>SRTM</td>
<td>Shuttle Radar Topographic Mission</td>
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<tr>
<td>TM</td>
<td>Thematic Mapper</td>
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<tr>
<td>UML</td>
<td>Unified Modelling Language</td>
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<tr>
<td>UNESCO</td>
<td>United Nations Educational, Scientific and Cultural Organisation</td>
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<td>WHO</td>
<td>World Health Organization</td>
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<tr>
<td>XML</td>
<td>Extensible Markup Language</td>
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ABSTRACT

In sub-Saharan Africa, malaria is a leading cause of morbidity and mortality. Detailed knowledge of spatial variation of malaria epidemiology and associated risk factors is important for planning and evaluating malaria-control measures. This study therefore investigated an approach in the development and application of a GIS-based healthcare management system with abilities to incorporate climate-based risk predictors of malaria transmission in Nyanza Province. Two sites, Siaya district and Kisii Highlands were selected to implement this study. The PMIS was designed with capabilities to carry out both micro- and macro-levels spatial epidemiologic analyses of malarial transmission. Using Universal Modeling Language (UML) and Microsoft Visio 2003 health data classes, relationships, attributes and data types were modeled which formed the basis for customizing and design of the Patient Management Information System (PMIS). A tailor-made PMIS was then implemented to capture malarial data alongside patient care in Siaya District Hospital, a rural health facility in Nyanza Province, Kenya. A total of 822 malarial case households were tracked and mapped using the Global Positioning System (GPS) and entered into the PMIS. In addition, malaria monthly cases from a total of 127 health facilities in Kisii Highlands were obtained for the period between 1996 and 2005 alongside data on rainfall, Normalised Difference Vegetation Index (NDVI), temperature and Digital Elevation Model (DEM) as possible predictors of malarial risk in the study area. Spatial analyses results revealed that the average distance traveled by study participants to Siaya District Hospital (SDH) was 6km while the longest distance was about 13.15km. There was a significant positive correlation between distances of malaria case households to the health facility, proximity to water bodies and malarial outcomes at 0.05 level of significance (P<0.005). However, no significant differences (p<0.005) were found between malarial case households and controls with regard to proximity to local road network. Regression modelling of malarial transmission in the Kisii Highlands revealed associations between rainfall, NDVI, temperature and DEM and malaria cases in the three administrative districts of Nyamira, Kisii and Gucha. These factors had varied influence on malaria risk transmission with the DEM found to explain most of the malaria case variations in the study area. Geospatial risk models developed for malaria transmission predictions were validated using F-test. The study recommends further testing and validation of both PMIS and the spatial predictive malaria risk model in other parts of the country. The study concludes that it is feasible to develop GeoMedInfo in broader health information sharing nationally, designed as a tool for improved diagnostics, planning and management programming of malarial surveillance system.
CHAPTER ONE
GENERAL INTRODUCTION

1.1. Background

Transmission of malaria is influenced by a set of biological and socio-economic factors, both related to ecological factors distributed non-randomly across space and time. Periodic changes of the spatial patterns of these factors show coincidence with changes of habitat and density of disease transmitting vectors and prevalence of infectious agents. The situation is worsening with large-scale epidemics and increased mortality. Globally, malaria clinical cases reported are in the range of between 350-500 million people causing 1.1 million deaths annually (WHO, 2008). Malaria risk varies across Africa, and even within countries. Studies have shown that malaria vector distribution, transmission rates, and incidence can vary widely over short distances, between neighbouring villages, and even within a single settlement as a result of small-area variations in risk factors (Kreuels et al., 2008).

Epidemic malaria in the Kenya highlands is caused by *Plasmodium falciparum* species and transmitted by *Anopheles gambiae s.s.* and *Anopheles funestus* mosquitoes. Epidemics, in Western Kenya, generally occur in areas at altitudes of between 1500-2200 meters above sea level, where the annual mean temperature varies between 18-22°C (Snow et al., 1998; Noor et al., 2009).

To reduce malaria-related morbidity and mortality, early diagnosis and prompt effective therapy are critical for better patient management. Decision support systems for improved diagnostics, continued and sustained monitoring and evaluation of key health indicators are important components in any malaria management programmes. There have been immense efforts to develop malaria control programmes by estimation of disease burden, monitoring of
disease trends, identification of risk factors, planning, allocation of resources and implementation (Hay et al., 2004).

Geography plays a major role in understanding the dynamics of health, and the causes and spread of diseases (Boulos, 2004). Today’s health planners aim at developing health policy and services that address geographical and social inequalities in health, and therefore benefit from evidence-based approaches that can be used to investigate spatial aspects of health policy and practice, and evaluate geographic equity (or inequity) in health services provision (Higgs and Richards, 2002).

The collection of reliable data is a first step to assessing the status of disease prevalence in communities. Health information systems are therefore central to monitoring intervention programmes and form the basis for effective patient management. They enable evidence-based decision-making, leading to appropriate use of both human and financial resources (Siriba, 2004).

Time is of essence in the fight against the malaria pandemic and data exchange between various hospitals, municipalities and decision-making bodies is a critical component. The logical response to health information needs is a computerized system, which collect and administer health related information within the local context and allow a monitored access to the data from a number of stakeholders (Hay et al., 2000, Hay et al., 2004).

All data have a spatial component and geographic location is a key feature of 80-90% of all environmental data in the US health care system (US Federal Geographic Data Committee, 2003). In the early 1990s, much attention was focused on Geographic Information System (GIS) as a basis for spatial information systems. Soon it became obvious that pure technical
approach had to be replaced by a more holistic approach encompassing organisational, political and technical matters at different local, national, regional, and global levels. The “Concept of Spatial Data Infrastructure (SDI)” became a reality (Boulos, 2004).

In principle, the SDI concept has evolved from earlier data sharing and programme co-ordination efforts to one that encompasses the sources, systems, network linkages, standards and institutional issues involved in delivering spatially related data from many different sources to the widest possible groups of potential users. As noted by Boulos (2004), SDI are based on the idea that data, people, software and hardware interact to create comprehensible, acceptable solutions, for simple and complex problems. Therefore, the need for thoughtful and careful structuring of multi-sectoral information is a basis for development of nationwide Spatial Data Infrastructures. In Kenya, the vision of the Kenya National Spatial Data Infrastructure (KNSDI) for example is to provide a national infrastructure for access and use of geospatial information in decision-making at all levels (KNSDI, 2006). A GIS-based health information system is a significant component of the KNSDI.

1.2. Statement of the Problem

Routine health data collected in Kenya’s Health Management Information Systems (HMIS) is usually presented in isolated tables whose facts are not standardized (Gething et al., 2006). In many instances, there is duplication of effort and difficulties in linking spatial and non-spatial datasets. The quality of health data is often highly variable with little standardization in definitions and methodologies, making information sharing difficult and therefore weakening the decision-making process at all levels of the healthcare system (Othieno, 2005).

Double reporting of hospital visits, decentralized and uncoordinated data collection between sites and responsible ministries as well as difficulties in linking spatial and non-spatial data sets
are reported as the major impediments to accurate and complete information (Sipe and Dale, 2003). The fragmentation of HIS and services leads to overlaps, gaps and a lack of standard definitions for data, reports and technological solutions (Monterio 2003, Chilundo and Aanestad 2003). Fragmented HIS do not only increase the burden to health workers at the peripheral level of the health sector but also increases the running costs and utilization of limited resources and limit the ability to obtain on overall picture of the health status of the community (Kimaro and Nhampossa 2005). Another consequence of the fragmentation of HIS is that data collection is redundant, implying that several data elements are collected several times for different systems. This leads to inconsistency and increases the workload on health data collectors. The observed inadequacies raise many questions on the structure of the HMIS and its compliance with the already established Kenya Spatial Data Infrastructure (KNSDI) and other internationally established standards.

1.3. Justification of the Study

The attempt to use Information Technologies (IT) including Geographic Information Systems (GIS) in supporting healthcare management has been widely accepted by many healthcare organizations (Hightower, et al., 1998). Geographic Information Systems (GIS) are computerized systems that combine spatial and descriptive data for mapping and analysis. Their main strength is their ability to integrate different types of data on to a common spatial platform. This study looked at an approach to design and develop a GIS application embedded in a Patient Management Information System (PMIS) for the malaria surveillance and risk modelling in Nyanza Province.

Although the World Health Organization (WHO) model for Electronic Information Systems (EIS) is widely acceptable (Braa et al., 2003), its application to developing countries could be problematic (Nhampossa and Sahay, 2005) because of different country situations. Limitation
on analytical capabilities of most EIS restricts their utility constraining fully integration with the local health information systems. Best practices on implementation of EIS in developed countries may also mask local and regional specific differences and may not be relevant for local health planning. This study aimed to design and develop an information system that collects data in the context of clinical patient care whereby the objective of patient management would co-exist with that of collecting data for biomedical research.

The purpose of the study was therefore to develop a computer GIS application system involving designing, prototyping, customizing and applications for spatial analyses of malaria transmission. Design involved building up of data model and structure and development involved prototyping of the system application in Siaya District Hospital (SDH). Development was more concentrated towards the creation of spatial database components and linking it with the non-spatial PMIS database.

1.4. Research Questions

1. What information or data elements should be included in the conceptual health data model and its representation?

2. How feasible is it to implement a Patient Management Information System (PMIS), based on a geographic health data model in a rural health facility?

3. What is the relationship between malarial case outcomes and distances travelled by patients to the health facility, their households’ proximities to water bodies and road network?

4. What associations exit between malaria prevalence and selected environmental risk factors?

5. What is the predictive power of a malaria transmission model using selected environmental risk factors?
1.5. **Study Objectives**

1.5.1. **Broad objective**

To investigate an approach for development of a geo-medical information decision support system (**GeoMedInfo**) and its application for malaria surveillance and risk mapping in Nyanza Province, Kenya.

1.5.2. **Specific objectives**

1. To develop a conceptual health data model supportive of the Kenya National Spatial Data Infrastructure (KNSDI),
2. To implement a Patient Management Information System (PMIS) based on a geographic health data model so as to investigate aetiologies of malaria,
3. To assess relationships between malarial case outcomes and distances travelled by patients to the health facility, their households’ proximities to main water bodies and road network,
4. To determine associations between selected environmental risk factors and malaria prevalence,
5. To compute a geospatial predictive model for malaria transmission using selected environmental risk factors.

1.6. **Null Hypotheses**

\[ H_0 \] Malaria case outcomes are not influenced by distances\(^1\) travelled by patients to the health facility, their households’ proximities to water bodies and road network,

\[ H_0 \] Selected environmental risk factors do not have equal predictive power for malaria prevalence.

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\(^1\) The metric used is the euclidian distance as a cost impedance factor
1.7. **Significance of the Study**

Building, changing or improving a new computer system or information infrastructure must be integrated with the existing system or work environment. The Patient Management Information System was implemented in a poor-resource environment with malarial case household data collection being in the rural setting in Nyanza Province. The system was customised and designed to collect data with enhanced spatial analytical capabilities. In view of the paucity of geo-spatial dimensions of malaria transmission studies, results from this study will contribute to the development of evidence-based, GIS-driven national spatial health information infrastructure and surveillance services in Kenya.

1.8. **Study Assumptions and Limitation**

The study assumed that each patient suffering from malaria was taken to a registered health facility and that he or she came from within the study area. The study further assumed that such cases were recorded accordingly by the national HMIS. Equally important was the assumption that the outcome of the malarial management was appropriately captured. The retrospective malaria cases data for spatial modelling relied on hospital data. Consequently, they have limitations that are inherent to this type of data. This study assumed that these limitations were likely to be random and hence would not introduce a bias. It is also worth noting that the data used in this study refer to hospital records maintained by HMIS department of health facilities thus representing lag time. One of the draw backs of the PMIS GIS application is that it uses ESRI Map object 2 as mapping software for its operation which is not a free software. This creates dependency on the ESRI license which may limit its use. Further work thus needs to be done to build an independent desktop GIS application platform which uses open source mapping software.
1.9. **The Conceptual Framework of GeoMedInfo Design**

High-level development of health data model in support of the Kenya National Spatial Data Infrastructure (KNSDI) is critical in the spatial investigations of disease transmission patterns countrywide. Modelling of geo-environmental risk factors to malarial infections at national, regional and local areas is therefore important. This can be done more conveniently by the applications of geographic information system (GIS).

The basics in the development of *GeoMedInfo* decision support system for healthcare are the GIS concept used earlier by Mogere *et al.* (2003) and shown in Fig. 1.1.

![Figure 1.1: A schematic representation of the GIS concept and application in healthcare (Mogere *et al.*, 2003)](image)

Mapping of socio-economic and demographics data including the type of roofing, type of walls
and size of parcels of land entail the development of a Household Information System (HIS) embedded in a Health-GIS environment and which would then be technically linked to PMIS core database to establish *GeoMedInfo* (Fig. 1.2)

![Geo-Medical Information Decision Support System](image)

*Figure 1.2: Schematic representations showing the linkage of PMIS and Health – GIS in the proposed *GeoMedInfo* (Mogere *et al.*, 2005).*

Development of *GeoMedInfo* exploits information already contained in the patient enrolment records in hospitals whose disease outcomes are known. At the hospital, the Patient Management Information System (PMIS) is used to store, retrieve and transact patients records and information for improved healthcare. As a decision support system, *GeoMedInfo* is achieved through computer programming using ArcObjects (Mogere *et al.*, 2005) to create links with the operational Patient Management Information System (PMIS).

The decision support system incorporates GIS capabilities that include map digitization, development of control points and geo-referencing under a standardized spatial environment. Spatial data standardization and transmission is dealt with through the KNSDI process. A complete schematic representation that visualizes *GeoMedInfo* decision support system is shown in Figure 1.3.
Figure 1.3: A schematic diagram representation *GeoMedInfo* decision support system (Mogere *et al.*, 2005)
Data entry, validation and reporting sub-systems were developed as components of the larger GeoMedInfo system. The aim is to use a computerized data entry and validation systems, which would provide an automated means of producing standard reports, summaries and maps for health personnel. This is because of the strong spatial analysis functionalities of the proposed GeoMedInfo for spatial health data in Kenya.
CHAPTER TWO
LITERATURE REVIEW

2.1 Health Decision Support Systems (HDSS)

The search for better methods of patient management includes the use of computerized decision support system by physicians, nurses, or patients to reduce time and costs. Computerized medical information systems can be used to prompt better patient care (Fitzmaurice et al., 2000; Walton et al., 1997; Vadher et al., 1997; Purves, 1998), improve coordination of care between primary and secondary care (Morris et al., 1997), monitor the health of populations (Laporte et al., 1994; Hobbs et al., 1995; Whitelaw et al., 1996) and undertake primary care based research.

Issues of confidentiality and legality of the electronic patient record has been studied by a number of scholars (Anderson, 1995; Anderson, 1996). Such electronic personal health records can enhance patient registration and appointment systems and repeat prescribing. The use of such software provides an algorithm, reduces disparities among providers in decision-making, and increases adherence with care standards (WHO, 2000). The potential also exists for enhancing pattern recognition in individual patients, which could assist in the detection of interfering drugs or foods. This is particularly important in the management of malaria.

Health information support systems have been confirmed to enhance adherence, improved outcomes and reduced costs, especially if complications are considered in cost analyses (WHO, 1999; Greenwood et al., 1991; Kariuki et al., 2003). The proposed development of GeoMedInfo decision support system would attempt to reduce costs and increase effectiveness of managing malarial patients in the long term. The system would also contribute towards tracking of patient compliance in the paediatrics ward of Siaya District Hospital (SDH). All these are expected to improve malarial case management in general at the facility. This study is of interest to all health care providers involved in managing malaria and geo-spatial health practitioners who may use
such system. It presents the use of customized GIS as a powerful tool for malaria micro-epidemiology in a rural set-up, such as Western Kenya.

2.2. The Health Management Information Systems (HMIS)

World Health Organization (2004) defines HMIS as a specially designed information system to assist in management and planning of health programmes. Faraja (2003) also define a Health Management Information System (HMIS), as “a set of tools and procedures that a health programme uses to collect, process, transmit, and use data for monitoring, evaluation and management of health services at all levels”. Thus, HMIS is a process through which health-related data are gathered, shared, analyzed, and used for decision making (WHO, 2000). Its objective is to produce information for taking action in the health sector (RHINO, 2003).

Health data in Kenya is handled by Health Management Information System division under the Ministry of Public Health. In practice, the division collects and disseminates data on morbidity, mortality, immunization, child health, disease prevalence, laboratory findings, service utilization, disease surveillance, health facilities, personnel, health expenditure and population (RoK, 2003). Previous studies undertaken show that the Ministry of Health has a very fragmented information system with data presented in non-standardized isolated tables, variable quality information, duplication of effort and difficulties in linking spatial and non-spatial data sets (Gething et al., 2006; Othieno, 2005; and Odhiambo, 2000).

According to WHO (2000), methods for data collection should address the different users of health-related information. It is however, observed that HMIS employs only a couple of these methods i.e. routine and surveillance data collection, with information collected revolving around a patient and a health facility (RoK, 2008). Based on the Health Policy Framework Paper (1994 - 2010), HMIS needs assessment report (2003) and the current National Health Sector Strategic Plan II (NHSSPII) 2005 – 2010 (Reversing the current trends), have outlined those areas that
require immediate attention. Among the priorities is to provide clear policy guidelines on HIS. Currently, data collection is conducted through a network of 5,170 peripheral health facilities and 234 hospitals that are distributed throughout the country in 78 different health districts (ROK, 2008).

The report on the Assessment of the Health Information System of Kenya (2008) observes that Health Management Information Systems are faced with lack of a written health information policy to ensure compliance and enforcement in reporting. The report reveals that reporting from NGO and private health facilities is far lower than their share of health service provision. WHO argues that restructuring routine and surveillance methods and integrating them with sample registration systems offers an opportunity to create reliable, sustainable and cost-effective information systems (WHO, 2000).

## 2.3. Malaria Research and Geographical Information System (GIS) in Africa

In the last decade, in Africa, the incidence of malaria has been escalating at an alarming rate, accounting for 90% of malaria cases in the world (WHO, 1996). Malaria is the second leading disease in terms of disease burden (World Bank, 1993) after HIV (WHO, 2000). It is estimated that malaria causes disease in 400 million individuals in Africa and is responsible for 20–50% of all hospital admissions. Mortality associated with malaria has not improved in the past 30 years (Anderson, 1996) and severe malaria anaemia is on the increase (Marsh and Snow, 1999). One study has estimated that during 1995, 0.75 to 1.3 million deaths resulted from malaria in Africa and that approximately 80% of these occurred in children < 5 years of age (Noor et al., 2009).

The development of drug-resistant strains of the malaria parasite *Plasmodium falciparum*, has been one of the greatest obstacles to controlling the disease (Trape and Rogier, 1996). Drugs such as chloroquine, which were once highly effective, are already useless for treating malaria in many parts of the world (Krishna, 1997). Frequent armed conflicts, migration of non-immune
populations, changing climatic patterns, adverse socio-economic patterns, high birth rates and changes in the behaviour of the vectors are also responsible for the upsurge (Nchinda, 1998). The upsurge has also been attributed in part to the declining nutritional status of individuals in both urban and rural areas (Stock, 1995). Malaria and underdevelopment are closely intertwined. The disease causes widespread premature death and suffering, imposes financial hardship on poor households, and holds back economic growth and improvements in living standards. Malaria flourishes in situations of social and environmental crisis, weak health systems and disadvantaged communities (WHO, 2000). Early diagnosis and prompt effective therapy can reduce significantly the effects of malaria-related morbidity and mortality. Development of all possible diagnostics information support systems would therefore form an important component in any malaria management programme.

A number of authors (Briggs and Elliott, 1995; Moore and Carpenter, 1999 and Vine, 1998) have reviewed the applications of Geographical Information Systems (GIS) in health research. Its role particularly in malaria epidemic management in Sub-Saharan Africa cannot be overemphasized. GIS has however, been found to be under-utilised, and in the Africa setting, it has been less clear whether GIS technology is both applicable and sustainable. GIS is a tool of great inherent potential for malaria surveillance as the disease is largely determined by environmental factors (including the socio-cultural and physical environment), which vary greatly in space. The spatial modelling capacity offered by GIS is directly applicable to understanding the spatial variation of disease, and its relationship to environmental factors and the health care system (Gosoniu, 2008). Public health practice needs timely information on the cause of disease and other health events to implement appropriate actions. GIS is such an innovative technology for generating this type of information. Unfortunately, the importance of the spatial distribution of disease has been too often overlooked (Scholte and de Lepper, 1991).

Due to information technology infrastructure and cost constraints, there is lack of reliable statistics
and disease reporting in Africa. Where data do exist, they tend to be clinically (as opposed to diagnostically) based. Disease estimates in Africa can therefore range between 'educated guesses and wild speculation' (Snow et al., 1999). GIS can help significantly in this area by filling the gaps through empirical disease modelling techniques.

Health systems in Africa face increasingly diverse and complex health problems, rapidly growing populations, and severe resource constraints. Improving the performance of health systems has been identified as a major global health priority (WHO, 2000). Health systems' performance makes a profound difference to the quality, as well as the length of the lives of the billions of people they serve. If health systems are poorly constituted and managed, life-enhancing interventions cannot be delivered effectively to those in need. Malaria would be such an example of a disease that thrives in the absence of well-constituted, effective health systems (Briggs et al., 1995). This is particularly important for Africa where health systems often perform poorly and are unreliable. Measuring performance of Africa's health system would therefore require at least good information infrastructural support to be able to tap into the benefits of evidence medicine concept (Briggs et al., 1995).

2.4. Current Applications of GIS in Health Research in Africa

Geographical Information Systems (GIS) has been widely applied to the understanding and management of malaria in Africa. For example GIS has been used to generate models of malaria occurrence (Craig, 1999; and MARA, 1998), seasonality (Tanser et al., 2002 and Hay et al., 1998) and transmission intensity (Kleinschmidt et al., 2000; Thomson, et al., 1996, 1999; Snow et al., 1998; Thomas and Lindsay 2000; Rogers et al., 2002) using climatic and remotely sensed data. The outputs of such models have been combined with population data (Snow, 1999a and Snow 1999b) to estimate population exposure, mortality and morbidity (Snow, 1999a and Snow 1999b) and to analyse the effects of climate change on malaria (Lindsay and Martens, 1998; Hay et al., 1998; Hay, 2002). GIS has been used to map malaria vectors (Smith et al., 1995; Ribeiro, 1996),
vector habitats (Minakawa et al., 2002) and infection (Omumbo et al., 1998). It has also been used in the management and control of malaria (Booman et al., 2000), to measure the effects of access to malaria treatment (Schellenberg et al., 1998) and to evaluate the effects of intervention strategies (Thomson et al., 1999).

There has been application of GIS in the management of other health conditions in Africa. GIS has been used to map tuberculosis cases (Beyers et al., 1996), HIV (Tanser et al., 2000) and health systems (Zwarenstein et al., 1991). In a rural area of KwaZulu-Natal, GIS has been used to analyse the distribution of treatment points and the effect of community-based (as opposed to facility-based) treatment on increased access to nearest treatment supervision point (Tanser et al., 1999; Wilkinson and Tanser, 1999). Most research has focussed on temporal analysis ignoring the spatial dimensions of the disease epidemic. Yet, spatial analysis may be an important tool to monitor the epidemic, predict future treatment demands and to target areas for public health interventions. In addition, mapping of malaria high-risk areas could prove invaluable to malaria management in Africa. This technology could also assist in the optimal spatial organisation of health care delivery including home-based care. The difficulty of obtaining disease data however, is a major obstacle to the use of GIS in health research in Africa.

2.5. Malaria Transmission Mapping and Geo-statistical Modeling

Maps of malaria distribution are valuable in increasing the effectiveness of decision-making. Maps are also useful to assess the effect of intervention programs by estimating the malaria distribution prior and post interventions. Recently, there is a renewed interest in mapping malaria (Snow et al., 2005; Hay et al., 2006) as well as different efforts in assembling existing malaria data (Guerra et al., 2007); MARA project newly funded by Bill and Melinda Gates foundation in 2007; Mekong malaria (Socheat et al., 2003).
The pioneers in using Bayesian statistics in spatial epidemiology of malaria were Diggle et al. (2002) who fitted a geo-statistical model on malaria survey data from The Gambia without having produced a malaria risk map. Gemperli et al. (2005) and Gemperli et al. (2006) produced maps of malaria transmission in Mali and West Africa, respectively, making use of the Garki transmission model and Bayesian kriging. Gemperli (2003) was also the first to consider the non-stationarity feature of malaria and map malaria risk in Mali. Sogoba et al. (2007) fitted Bayesian geo-statistical models to identify the environmental determinants of the relative frequencies of An. gambiae s.s. and An. arabiensis mosquitoes species and to produce smooth maps of their spatial distribution in Mali.

Statistical models are useful for quantifying the relation between malaria risk and environmental factors and upon this relation predicting malaria risk at locations without observed malaria data. Malariological data are correlated in space since locations in close proximity have similar risk. Standard statistical methods assume independence of the observations and are not appropriate for analyzing spatially correlated data because they underestimate the standard error and thus the significance of the risk factors would be overestimated (Ver Hoef et al., 2001). Although the integrated GIS and remote sensing are valuable tools, they are not able to quantify the malaria-climate relation and to produce model-based predictions. Some GIS softwares have limited statistical capabilities, but these are inadequate for analyzing prevalence survey data.

2.6. Current GIS Operability Trends Relevant to Africa

GIS is largely technologically (as opposed to research) driven. As a technological tool it is rapidly evolving in its utility in operational research. As software becomes increasingly powerful and new datasets become available, GIS is increasingly being used to understand and forecast the dynamics of (particularly environmental) disease (Briggs and Elliott, 1995; Vine, 1998).

There are however, a number of obstacles for the advancement of GIS in health in Africa. Access
to spatial data continues to be difficult and expensive (Briggs and Elliott, 1995). There is however, some hope in the development of GIS as a tool in health management through global project like the Global Spatial Data Infrastructure (Holland et al., 1999) (embedded within which is the SDI – Africa project) and the EIS – Africa (EIS-Africa, 2002) projects which aim to support ready access to geographic information to support decision making at all scales for multiple purposes. Geographic datasets are being developed for some countries in Africa through these initiatives, but a systematic programme is required to make geographic data readily available for the continent as a whole. The most cost-effective answer to the data deficit and poor vital registration and health statistics problem in Africa is the establishment of sentinel geo-referenced demographic and health surveillance systems. This would enable the elucidation of small-scale disease patterns (micro-epidemiology) that could be modelled using coarser resolution data and the coverage extended. The INDEPTH network is a network of these sentinel surveillance sites, 23 of which are in Africa (INDEPTH, 2002). The sites follow up a designated population intensively over time collecting highly accurate demographic, vital event (e.g. births, deaths, migrations) and health data on a routine basis.

2.7. The Spatial Data Infrastructure (SDI)

Spatial Data Infrastructure (SDI), alternatively referred to as Geospatial Data Infrastructure (GDI), is a combination of technology, institutional arrangements, policies and people that enable the discovery, evaluation, access and application of geospatial data by all users from all sectors of the economy, plus the general citizenry (Mulaku, 2002a).

The term *National Spatial Data Infrastructure* was first coined by Professor John McLaughlin of the University of New Brunswick, Canada, in his conference paper of 1991 (McLaughlin, 1991). The challenge that users of geospatial information were not aware of the existence of data and that they had no idea whether a certain dataset could meet their application requirements, led to a
situation where organizations duplicated other organizations’ data collection efforts (McLaughlin, 1991).

Some geospatial data themes for an area were collected again and again at great expense, with possibilities of gaps. This was the basis for the development of the SDI concept. SDI initiatives are intended to remedy this situation (WHO, 2004). The SDI concept has evolved from earlier data sharing and programme coordination efforts to one that encompasses the sources, systems and network linkages, standards and institutional issues. SDI is a growing data resource to which data producers can contribute, it is therefore envisioned that SDI will continue to evolve and improve (WHO, 2004). SDI can also help users with various applications, for example, tracking ownership of public land, management of watershed data by a jurisdiction beyond its boundaries and a regional transportation planning project. The SDI capabilities enable documentation of all types of geospatial data such as local scientific or engineering projects, and environmental monitoring (Tanser and Le Suer, 2002).

When SDI is considered at the national level, it is called a National Spatial Data Infrastructure (NSDI), a strategic national resource. If the concept is extended across international boundaries to a region or continent, it results in a Regional Spatial Data Infrastructure (RSDI) (Tuladhar, 2004).

Further extension involving the entire globe, it results in a Global Spatial Data Infrastructure (GSDI) (Mulaku, 2002a). However, GSDI can only be realized by completing NSDI’s or RSDI’s around the globe (Clarke, 2001).

2.8. The Kenya National Spatial Data Infrastructure (KNNSDI)

Kenya envisages establishing a national repository of its spatial data holdings and providing the mechanism that would enable its access, sharing and dissemination through a technological process known as a National Spatial Data infrastructure (NSDI). The Vision of KNSDI, according
Among the objectives of KNSDI is the development of acceptable standards for data, data production and data distribution; and to develop a solution for easy discovery and access of geospatial datasets (KNSDI Secretariat, 2006). The KNSDI committee standard working group has prepared, as part of practical standards, the Kenya Profile for Geographic Information Standards (KPGIS).

2.9. Health Data Modelling

According to Goodchild (2007) data modelling refers to defining a set of expectations about data, identifying the data structure and representing the structure for a particular application. The representation has a particular purpose or focus. The Entity Relationship Diagram (ERD) is the most popular type of data model (Data Management Centre, 2008). The data model should be both flexible and extensible in order to meet the evolving business world. A data model makes it easier to understand the meaning of the data, and thus data is modelled to understand: each user’s perspective of the data; the nature of the data itself, independent of its physical representations; and the use of data across user views (Conolly and Begg, 2005).

2.9.1. Levels of data modelling

Data models exist at multiple levels. Each type of data model has characteristics that make it more useful than other types for a particular purpose. There are models that are very useful for high-level planning and project definition. These models tend to minimize technical details and focus instead of delineating and defining subject areas and classes of information of interest to executives, high-level decision-makers, and subject matter experts. These models are not useful for evaluating
or implementing a database design. For a data model to be useful to a database design activity, it needs to include technical details such as database key structures, data types, and the physical properties of tables and columns (CDC, 2000). There are three data model levels according to Connoly and Begg (2005); conceptual data model, logical data model and physical data model. This research focused on the conceptual health data modelling for the PMIS design and customization.

2.9.3. Data modelling methodologies

Methodologies for modelling data include Hierarchical models, Network models, Relational models, Entity-Relationship models, Entity Attribute Value models, and Object-oriented models. The object-oriented (OO) methodology was used to model health data. Object oriented data modelling is based on the premises that the world is divided into objects that have properties, behaviour and relationships with other objects. Object oriented modelling resembles our experience with the world. In this case objects are modelled after real world entities and are given behaviour that mimics or models some relevant aspect of their behaviour in the real world (Tomlinson, 2003). The OO data models thus allows for rich and complex descriptions of the real world and the ability to set up data structure that users find easy to understand.

The structural component of an object is described by means of attributes or by its characteristic features whereas the behavioural component of an object is represented as a set of methods (operations) that the object performs in appropriate situations (Taylor, 1993). Each object oriented has a unique identifier that is independent of the values of its attributes (Tuladhar, 2004). Objects communicate with one another through messages. The defined behaviours can then be used to send messages to other objects, to communicate the state of an object by reporting current values, to store new values, or to perform calculations. Object oriented data models have several concepts, which include:
Classes: A class is a description of a set of related objects with a uniform set of attributes and methods (Tuladhar, 2004). The objects that belong to a particular class are called instances of that class. Classes can be nested to any degree, and inheritance will accumulate down through all the levels (Tomlinson, 2003).

Encapsulation: Describes that each object packages together a description of its state (properties) and behaviour (methods or operations that can be performed on an object). The concept of encapsulation means that an object contains both the data structure and the set of operations that can be used to manipulate it (Connolly and Begg, 2005).

Relationships: This is an interaction between two objects. Relationships describe how objects are associated with each other and define rules for creating, modifying and removing objects (Tomlison, 2003). Two types of relationships are used in the object-oriented data models and these include associations and multiplicity. An association is a structural relationship that specifies how objects of one class are connected to objects of another class. Aggregation and composition are specialized types of the association relationship. Multiplicity or cardinality on the other hand is used to indicate the degree of object participation i.e. the number of objects that can be associated with another object. There are three (3) basic cardinalities: one to one (1:1), one to many (1:M) and many to many (M:M) (Tomlison, 2003).

Inheritance: Inheritance refers to the ability of one class (sub class) to inherit the identical functionality of another class (super class), and then add new functionality of its own (Bell, 2003). Inheritance thus defines generalization and specialization relationships between classes by developing abstractions or subtypes of classes.

2.9.3. Notation of data models

The Unified Modelling Language (UML) has emerged as the successor for expressing and annotating models (Connolly and Begg, 2005) and was adopted by KNSDI (ROK, 2007). UML is a standard notation for representing the structure of data in the object-oriented community (David
and Hay, 1999) with a diagrammatic representation. The UML can be used for many purposes such as: visualizing and documenting workflows and processes and designing and developing databases and information systems (ESRI, 1999). Since the UML uses the same language in all phases of the system development and operation, it allows the users, clients and developers to communicate effectively.

UML defines nine types of diagrams: class (package), object, use case, sequence, collaboration, state chart, activity, component, and deployment (Booch et al., 1999). According to Connolly and Begg (2005) these diagrams describe the static and the dynamic relationships between components.

2.10. **Examples of the Health Data Models in Developed Countries**

The work of other countries to define and implement their own national health information infrastructures has produced useful models. Australia established a National Health Information Agreement (NHIA) in 1993, including the Commonwealth, State and Territory health authorities, the Australian Bureau of Statistics, and the Australian Institute of Health and Welfare. The NHIA seeks to improve the quality of health data and information and foster cooperation in the development of a national health information infrastructure. It ensures that the collection, compilation, and interpretation of national information are carried out appropriately and efficiently [http://www.aihw.gov.au/].

In 1998, the United Kingdom National Health Service (NHS) released "Information for Health 1998 - 2005: An Information Strategy for the Modern NHS." The strategy commits the NHS to: lifelong electronic health records for every person in the country; round-the-clock on-line access to patient record and information about best clinical practices for all NHS clinicians, hospitals and community services sharing information across the NHS information highway; fast and convenient public access to information and care through on-line information services and
telemedicine; and the effective use of NHS resources by providing health planners and managers with the information they need. Committing £1 billion to this initiative, the government established a new NHS Information Authority that is responsible for developing national products and standards for local use and the availability of high quality information (http://www.nhsia.nhs.uk/).

In USA, many breakthrough efforts have helped lay the foundation for a national health information infrastructure (NHII). The promise of advanced computing and telecommunications technology stimulated work on an electronic patient record to facilitate the capture and analysis of health care information. In the year 2000, the USA through its Center’s for Disease Control and Prevention (CDC) produced a Public Health Conceptual Data Model (PHCDM) (www.cdc.gov/nchs/data). The PHCDM is mainly used by application systems and database developers in developing computerized information systems for use in public health (CDC, 2000). It provides a framework for identification, and organization of public health concepts and data standards. The PHCDM is presented in details in the section that follow.

2.11. The Public Health Conceptual Data Model (PHCDM)

The PHCDM was developed by the Centres for Disease Control and Prevention (CDC) under the U.S. Department of Health and Human Services (see Appendix 2 to see graphical representation of the model). The primary objective of the PHCDM is to facilitate use of data standards in public health data collection, management, transmission, analysis, and dissemination.

The PHCDM uses the Unified Modelling Language (UML) conventions in data notation (Bell, 2003). The following components of UML are used (Mohd et al., 2002): Classes and Relationships; and Attributes and Data types.

**Classes:** There are four core classes in the PHCDM. These core classes are Health-related Activity, Location, Material, and Party. Classes are depicted in the data model diagram by
a rectangular box with a line dividing the box into two sections. The name of the class appears in the top section of the box. Figure 2.1 below shows the representation core classes of the PHCDM, with each class name appearing on top of the rectangle.

![Figure 2.1: PHCDM Class Diagrams](image)

**Relationships:** Relationships are depicted in the model diagram by lines connecting the related classes. The PHCDM uses three methods of relating classes: Supertype/Subtype Relationship, Relationship Association and Participation Association. The supertype/subtype relationship is depicted on the data model diagram by a line drawn between the subtype and the supertype. The line has an arrowhead on one end pointing to the supertype (Larman, 2005). Figure 2.2 below depicts the supertype/subtype relationships in the PHCDM core classes.

![Figure 2.2: Relationships in PHCDM Classes](image)
A subtype inherits all the attributes of the super type class. A relationship association reflects the relationship between instance of a class or its subtypes and another class or its subtype. These relationships are represented in the PHCDM by four “relationship” classes, each associated with one of the four core classes. The relationship associations are depicted in the model diagrams by a rectangular box representing the relationship class and a pair of association lines connecting the relationship class to the core class that is linked by the relationship [http://www.aihw.gov.au/]. Figure 2.3 illustrates the Activity Relationship.

Figure 2.3: Relationship Association

The symbols “1” and “0..*” that appear on the association lines depict the multiplicity of the association between the relationship class and the core class.

The participation association is a special relationship used in the PHCDM to depict the relationships that exist between the core classes. Each core class has a many-to-many relationship to all of the other core classes. Figure 2.4 depicts the participation association:

Attributes and Data Types: Attributes are the specific items of data that can be collected for a class in the PHCDM. Each attribute has a name, a description, and a data type assignment. An attribute name suggests the meaning of the attribute, while the description defines it, provides examples, and includes relevant discussion. The data type assigned to
an attribute extends the definition of the attribute. A data type is a specification of the allowed format for the values of an attribute (Larman, 2005).

Attributes and their data type assignments are shown in the data model diagram by listing them in the lower section of the rectangle representing the class. In Figure 2.5 below the attributes of the party, party relationship and individual classes are depicted in the second compartment of the triangles. The following diagram is an example of three classes and their attributes.

![Figure 2.5: Attributes and data types](image)

Attributes of a supertype are inherited by its subtypes. In Figure 2.5, the attribute Party Identifier in the supertype Party class is also an attribute of the subtype class Individual (as well as all the other subtypes of Party).

The data type assigned to an attribute is represented in the data model diagram by the inclusion of the data type name following the attribute name, separated by a colon (Larman, 2005).
2.12. Designing of Spatial GIS Application as Health Decision Support System

Geographical and attribute data are the core elements of geographic information system (Sauerborn and Karam 2000). Source of geographical data are usually, digitized maps from paper maps. As the paper maps are often outdated omitting new village or road, especially in developing countries, Global Positioning System (GPS) is used to correct or complete paper maps. Satellite map can also be used as a source of geographical data.

In this study, source of geographical data were digitalized maps in Nyanza Province. GPS was used to locate the position of the health facilities, malaria case households and road network. The primary source for GIS applications within a health information system are routine HIS data, like health infrastructure (that is hospital or health facility and any information related to them such as health and performance indicators (Sauerborn and Karam, 2000).

Access to health care is an important issue in most of the countries. Access describes people’s ability to use health services when and where they are needed (Aday and Anderson 1981). GIS helps to put emphasis on the geographical dimensions of access. Healthcare decisions are strongly influenced by the type and quality of services available in the local area and the distance, time and cost of traveling to reach those services. GIS has been used to create better measures of geographical access and to analyze geographical inequalities in access as well as those patterned along social and economic lines (McLafferty, 2003).

GIS applications development and implementation is normally based on IS methodologies (Geogiadou et al., 2005) aiming at developing a closed system by a closed project organization for a closed customer organization within a closed time frame. GIS are often products of the developed world context and introducing or building such system in developing countries involves large complexities dealing with social, cultural, technological, political and contextual issues. These issues could be better understood by conceptualizing GIS as HIIS, as they provide a more
sophisticated health and social system perspective to study large heterogeneous and complex systems and emphasizes that the social and technical are not separated and are instead constituted and constitutive of each other (Geogiadou et al., 2005).

The cultivation approach used in this study emphasizes that HIIS design should be in small steps and incremental, and by focusing on improvisation or changing of small parts of networks (particular user group) while keeping consideration of the dynamics of the whole network in this case the proposed GeoMedInfo. GIS implementation in developing countries has been concentrated mainly on top-down and data centric approaches which needs to be changed to a cultivation approach as the changeover required for the adaptation of new GIS technologies involves a deep organization change including both technological and non technological components.

Large scale GIS applications like the proposed GeoMedInfo cannot be analyzed and implemented using ordinary systems development principles because they do not consider all the complexity arising from the multiple levels, its dynamic nature and the involvement of multiple user groups and needs. This thesis therefore demonstrates how GIS can be made a part of existing installed base by cultivating the existing PMIS for new technology and also designing and modifying the GIS components, thus enabling it to be integrated with the installed base.
CHAPTER THREE
MATERIALS AND METHODS

3.0. Introduction
This chapter describes the materials and methods that were used to collect and analyze data for this study. These included description of the study area, research design, study variables and procedures for development, customisation and application of a computerised Patient Management Information System (PMIS). Description of data collection techniques and approach to assembling climatic covariates used in spatial modelling are provided. This chapter also highlights the management of data from the study and analyses including the predictive spatial model establishment and validation.

3.1. The Study Area
The study was conducted in two selected sites to represent both the lowland and highland regions of Nyanza Province, Kenya, including Siaya and Kisii Highlands. Malaria is the primary cause of childhood morbidity and mortality in Nyanza Province. Mosquito vectors in this area are *Anopheles gambiae* s.s., *Anopheles arabiensis* and *Anopheles funestus* (Hay *et al.*, 2002). Falciparum malaria transmission in Siaya is described as holoendemic with residents receiving 100-300 infective mosquito bites per annum (Bloland *et al.*, 1999). The three districts of Kisii, Nyamira and Gucha are densely populated and agriculturally productive. The districts have been described as a stable malaria endemic region (Hay *et al.*, 2006) amongst the recently defined 15 districts in the Kenya Highlands that are prone to epidemics, meriting special attention for surveillance to increased epidemic preparedness (ROK, 2001).
3.1.1. Siaya district

The district lies at an altitude of between 1140 and 1430m above sea level. The annual rainfall is between 800 and 2000 mm with an average annual temperatures ranging from 15 to 30ºC (RoK, 2000). The population is approximately 500,000 people, with 81,304 children being of less than 5 years of age while infant and under-five years mortality rates are 176/1000 (17.6%) and 257/1000 (25.7%), respectively (McElroy et al., 2001). Inhabitants of the study area are predominantly Luo (> 96%), making population culturally homogeneous (Bloland et al., 1999). The main hospital in Siaya District is the Siaya District Hospital which has 260 beds with a 60-bed paediatrics unit (ROK, 2001). The most intense malaria transmission occurs during the seasonal rainfalls in April to August and November to January (Beier et al., 1994). Fig. 3.1. shows the Siaya District showing the location of Siaya District Hospital.

Figure 3.1: Study Area: Siaya District, Nyanza Province, Kenya
3.1.2. Kisii highlands: Kisii, Nyamira and Gucha districts

The Kisii highlands lies between 34° 37’ 13”E to 35° 06’ 15” E and 0° 24’ 19” S to 0° 58’ 42” S. Altitude ranges from around 1170m to 2214m above mean sea level, with a dense network of river valleys that generally flow westwards. The region has an average annual rainfall of about 2200mm with the long rain season between the months of March and May and the short rains between September and November. According to the 1999 human population and household census, the population density in the study area averages about 675 people per square Kilometre (ROK, 2001). Fig. 3.2. show the location of the three administrative districts of Kisii highlands including Kisii, Nyamira and Gucha.

Figure 3.2: Study Area: Kisii Highlands Districts Nyanza Province, Kenya

3.2. The Study Design

This study applied interventional, hospital based prospective study design to implement the Patient Management Information System (PMIS). The geospatial predictive risk modelling for malaria
transmission was composed of a cross-sectional, retrospective study design covering ten years between 1995 and 2005.

3.3. Study Variables

3.2.1. Independent variables

The independent variables used in the study included: rainfall, temperature, digital elevation model (DEM), Normalised Difference Vegetation Index (NDVI) and distances (proximities) of malaria case households to water bodies, road networks and Siaya District Hospital (SDH).

3.3.2. Dependent variable

The dependent variable was malaria cases from selected health facilities in Nyanza Province, Kenya.

3.4. Inclusion Criteria for Malaria Cases (MC)

Confirmed positive malaria cases amongst paediatrics patients reporting to the health facilities within the geographical location were included in the study. In addition, only malaria case households that consented were mapped.

3.5. Procedures for Development and Customization of the PMIS

3.5.1. Approach in PMIS system acquisition, development and customization

The Baobab Health Partnership (BNP) at Kamuzu Central Hospital in Lilongwe, Malawi (Lewis, et al., 2005) developed the original computer system design in 2000. It was therefore necessary to customize the software, model the data to suit the local conditions, and introduce both spatial and non-spatial analytical functionalities into the system. This research was therefore conceptualised to develop a PMIS that enhanced complex biomedical research data capture while achieving the goal of clinical management of malarial patients in a rural health facility. This study therefore
reused approximately 60% of the existing software code from the original computer system to design, develop and customize the PMIS before its implementation in study area.

Even though the original computer system was user defined, scalable and had a flexible software application, customization for local use was necessary. For example;

i) Before “populating” database with data elements, it was required first to create different interfaces to enter the “lookup tables”

ii) GIS application interface (to link with non-spatial) analytical capabilities were created. For example, the “query feature” was changed to accept spatial component.

Participatory action research was used more in the development and customization of non-spatial component of the PMIS while comparatively less on the spatial component of the system. The participatory action research was chosen to understand the complexity of introducing a computerised system in a rural health facility thereby introducing change in the health information system.

Action research is often structured as a 5 phase, cyclical process, whereby this approach first requires the establishment of a client-system infrastructure or research environment in this case the severe malarial anaemia research project which was being implemented by Ongecha et al. (2006). The PMIS implementation process was therefore structured in the following 5 phases;

i) Recognising the information needs, associated problem behind it and prioritising the needs for malaria research and patient care (diagnosis),

ii) Design and developing the system prototype (action planning),

iii) Customizing and implementing the prototype in the system (evaluating), and
iv) Reflecting on the results, documenting the knowledge gained and repeating the cycle (specify learning).

Due to the constraints of time, organisation structure of HMIS and its process, implementation of the system prototype could not be completed during this research period. However, all these processes were used explicitly in design and building the PMIS non-spatial component prior to its implementation in the Siaya District Hospital (Lewis et al., 2005; Mogere et al., 2005).

3.5.2. Design and customization of the PMIS non-spatial component

The PMIS was designed for use in a rural hospital, built on a framework developed by Baobab Health Partnership (BHP) in Lilongwe, Malawi. The PMIS employed three technologies to foster robustness in a resource-poor setting:

i) Fault-tolerant hardware utilising redundancy to protect data during power failure, hard disk crash, or power supply malfunction;

ii) Compact touch-screen workstations allowing clinical staff to manage data with minimal training while consuming only 20% of the power of desktop computers;

iii) Barcode printers and scanners that facilitated rapid access to patient information.

The PMIS form based data entry screens were initially developed in Microsoft Excel, which looked like the paper reporting forms (see appendix 4). The drawback however, was that it did not have any functionality to check on the data. Later, the data entry screens were developed using Microsoft Visual Basic 6.0. The PMIS interface would validate data collected in real-time thus promoting data accuracy and completeness, and track patient movement through the facility.
3.5.3. Development of data model and the design of PMIS spatial component

The spatial GIS application component was developed and customized with capabilities of being used in a regional scale for predicting malarial risk. Object oriented modelling concepts and techniques were adopted according to Tuladhar (2004). Universal Modelling Language (UML) was used to annotate the syntactic, semantic and positional elements of the health data model. UML was considered because of its wide adoption by Object Management Group (OMG) as a successor of model notation (David, 1999). The Kenya National Spatial Data Infrastructure (ROK, 2007) has also adopted it. Model formulation was then done iteratively and involved identification of entities and relationships types, determination of attribute domains; determination of candidate keys, primary keys and alternate key attributes; checking for model redundancy; and then validation of the model. At each level the model was reviewed for completeness and then developed using Microsoft Visio 2003.

After the data model validation and development was done, it was used to structure the spatial data component of PMIS system. It was therefore necessary to develop a software link “bridge” that enabled provision of data from GIS application in the same way as accessing data from non-spatial component of the PMIS. The “bridge” was created using Microsoft Visual Basic 6.0 and MS Access as an internal database used in mapping health facilities and data elements. Using a unique ID for identifying the district and health units, malaria case data routinely collected through HMIS were entered in the PMIS, and could be exported to a Zip drive, and stored in Excel spreadsheet.

3.5.4. Developing the PMIS-GIS integration and functionalities

In all the files, which were accessed from PMIS, it contained unique ID of surveyed districts and health facilities represented in PMIS application programme together with code names. The PMIS-GIS application was generalised and allowed for selection of non-spatial PMIS databases and spatial component (Maps) to link with. After designing the “bridge” (using Visual Basic) and the form based data entry screens, then analysis and routine reports functionalities were
incorporated. Using the Point Attribute Table (PAT) files of malaria case household, GPS positions of individual homesteads and health facilities were generated using Arc/Info.

Finally, the PMIS was developed to have the following functionalities:

i) Patient information retrieval
   Since the attribute information was attached to the PMIS, a touch screen on respective patient or geographic unit retrieved the information attached

ii) Search capabilities
   Patient information were promptly searched from the malaria-based PMIS on a case-by-case basis to determine the need for any intervention on individual cases

iii) Overlaying attributes
   Different data layers such as distances of malaria case household to nearest water bodies, road networks and health facilities were integrated in the PMIS-GIS application. It was also possible to incorporate other malaria risk predictors including temperature, rainfall, DEM and NDVI to enable spatial investigations for malaria transmission in a region-wide scale.

3.5.5. The PMIS applications: micro- and macro-level spatial epidemiology of malaria

The analytical application capabilities of the PMIS were divided into micro- and macro-level spatial epidemiologic analyses of malaria in Nyanza Province. The micro-level spatial epidemiology of malaria focused on a single health facility serving one district, the Siaya District Hospital, while at macro-level application involved selected multiple health facilities spread across a large geographical area of the three administrative districts of Kisii, Nyamira and Gucha Districts.
The PMIS-GIS applications in Siaya District provided the malaria infections situation at household level with a principal focus on associations of malarial case households and travel costs impedance to population movements as regards proximities to a) Siaya District Hospital (SDH), b) water bodies and c) road networks.

The macro-epidemiology analysis utilized routinely collected data, obtained retrospectively from the health management information system to describe the relationships between malaria cases and climatic risk factors including their strengths of association with the reported malaria cases using Bayesian geo-statistical modelling techniques (Gosoniu, 2008). The climatic risk factors considered included, NDVI, temperature, rainfall and DEM.

3.6. Data Collection Techniques

3.6.1. Malaria case households (MCH)

The malaria case households (MCH) data was obtained from the paediatrics patients enrolled in the severe malaria anaemia study project following the research protocol described by Ongecha et al. (2006). Children of both sexes aged 0 to 3 years visiting the hospital, suffering from malaria were eligible for enrolment in the study. After the parent/guardian of the child consented to participate in the study, a questionnaire (See appendix 4) was administered to collect relevant demographic and clinical information. Once enrolled and using the patient data already captured by the hospital system (PMIS), mapping of homesteads of study participants were done using GIS applications. Global Positioning System (GPS) coordinate points of study individual homesteads were collected using a handheld/navigational GPS receiver in Siaya District. Figure 3.3 gives some of the GPS points showing the distribution of the malaria case households.
3.6.2. Malaria cases and GPS data of study health facilities

A ten-year retrospective review of paediatric health records were matched with health facilities in the study districts of Kisii, Nyamira and Gucha and incorporated into the PMIS-GIS application for analyses. These data were retrieved from the hospital records using the HMIS databases and/or archives following procedures reported in the Paediatric Appropriateness Evaluation Protocol (PAEP) as modified by Esmain et al. (2000). Malaria monthly cases from a total of 127 health facilities in the three districts were obtained. The data consisted of monthly records of slide-confirmed malaria case diagnoses from the health facilities for a period of 10 years between 1995 and 2005. The data, therefore, represented Malaria Cases (MC) seen each month at health facilities identified by a unique facility code and as reported by national health system through HMIS. The Malaria Cases (MC) data was used as the dependent variable in the spatial modelling. Figure 3.4 shows distribution of health facilities in Kisii, Nyamira and Gucha Districts.
Figure 3.4: Distribution of health facilities in Kisii, Nyamira & Gucha Districts
3.6.3. Assembling the spatial data for malaria transmission modelling

3.6.3.1. Malaria prevalence and population data: Providing precise malaria prevalence rates requires precise catchment area population. Unfortunately, area population information is not routinely collected in the hospitals; it is assumed therefore that most inpatients came from the immediate surrounding. The prevalence of a disease is the total numbers of cases of a disease in a given population at a specific time expressed as a percentage. To provide demographic information the study used population estimates from Kenyan National censuses of 1989 and 1999 (ROK, 2001) with projections to the study period.

3.6.3.2. NDVI and temperature data: The study utilized Multiple Landsat image bands representing different wavelengths from the ultraviolet through the visible and infrared portions of the electromagnetic spectrum. The Landsat system of remote sensing satellites, currently operated by the EROS Data Center (http://edc.usgs.gov) of the United States Geological Survey, carries two multi-spectral sensors. The first is the Multi-Spectral Scanner (MSS) which acquires imagery in four spectral bands: blue, green, red and near infrared. The second is the Thematic Mapper (TM), which collects seven bands: blue, green, red, near-infrared, 2 mid-infrared and one thermal infrared. The MSS has a spatial resolution of 80 meters, while that of the TM is 30 meters.

In the study area, Landsat Thematic Mapper (TM) imagery for the period of 1995, 2001, 2003, 2005 and 2006 were obtained. From this imagery the Normalised Difference Vegetation Index (NDVI) and temperature were extracted. The NDVI provides a measure of the amount and vigor of vegetation, which will be the breeding sites of mosquitoes. The NDVI transformation is computed as the ratio of the measured intensities in the red (R) and near infrared (NIR) spectral bands using the following formula: \( \text{NDVI} = (\text{NIR} - \text{red}) / (\text{NIR} + \text{red}) \). The resulting index value is sensitive to the presence of vegetation on the Earth's land surface and can be used to address issues of vegetation type, amount, and condition. A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves. Temperature on the other hand, which was
extracted from the Landsat imagery (band 6H and 6L), regulates the development rate of both the mosquito larvae and the malaria parasite (*Plasmodium* species) within the mosquito host.

**3.6.3.3. Rainfall and DEM datasets:** The Rainfall Estimates (RFE) data was obtained from Famine and Early Warning System Network (FEWSNET) website of the Africa Data Dissemination while the DEM was extracted from the Shuttle Radar Topographic Mission (SRTM) data (Jarvis *et al.*, 2008).

**3.6.3.4. Roads and administrative boundaries datasets:** Roads and administrative boundaries data were respectively digitized from thirteen topographic map sheets: at a scale of 1:50,000 obtained from the Surveys of Kenya covering the study area. The topographical maps were scanned and geo-referenced. The complete work flow chart of map digitization process is presented in Fig. 3.5.

The criteria for inclusion of data in spatial modelling included availability of the dataset and data completeness. Therefore, the periods where data was available for each of the risk factor under study included data for the months of February, 2001; May, 2003 and April, 2005. Table 3.1 shows summary of status of these datasets used in spatial modelling.
Figure 3.5: A typical work flow of map digitization for digital thematic maps

Table 3.1 Spatial databases used for spatial analyses

<table>
<thead>
<tr>
<th>Factors</th>
<th>Source Dataset</th>
<th>Year available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaria case Hospitals (MC)</td>
<td>HMIS</td>
<td>2001-2003 &amp; 2005</td>
</tr>
<tr>
<td>Digital Elevation Model (DEM)</td>
<td>SRTM</td>
<td>1995-2005</td>
</tr>
<tr>
<td>Rainfall</td>
<td>FEWSNET</td>
<td>1999-2005</td>
</tr>
</tbody>
</table>
3.7. Spatial Data Analyses and Model Validation

GPS coordinates for surveyed health facilities and malarial case households were obtained using a handheld, navigational GPS receiver. After collection of GPA data from each health facility, it was entered into an excel database and matched to an independent health facilities and malaria cases database later, all the data were then entered into a customized Microsoft Access (Microsoft 2007) database to include information on survey location, survey timing (month and year) and malaria case category.

The datasets used in this study were then composed into a geo-database in ArcGIS software (Boulos, 2005); that is, a generic name for a geographic database, which is a core geographic information model used to organize GIS data into thematic layers and spatial representations. The geo-database is also a GIS and DBMS standards-based physical data store usually designed as an open simple-geometry storage model in ArcGIS 9.0® system software (Earth Systems Research Institute Redlands, CA, USA) softwar (Gore, 1999). The particular data layers that were constituted into a geo-database for spatial analysis (Fig. 3.6) were; health facilities, malaria case households, Normalised Difference Vegetation Index (NDVI), temperature, rainfall, roads, administrative boundaries and Digital Elevation Model (DEM). Others included; travel distances of malaria case households to SDH, water bodies and road networks.

Proximities of malarial case household to water bodies, road network, and health facilities were then obtained using the NEAR command in Arc/Info while malaria transmission prediction modelling utilised logistic regression.

To validate developed models, the predictive ability of spatial models was assessed using of F-test according to Gosoniu et al. (2006). T-test was then applied to confirm significance of each regression at various confidence intervals (0, 20 and 30). Appendix 8 gives a summary of F-test comparing observed and calculated figures.
Figure 3.6: A snap shot of the Siaya geo-database
CHAPTER FOUR

RESULTS

4.0. Introduction

This chapter presents the results of the development of health data model for the PMIS, description of the PMIS implemented at SDH and spatial analyses of the malaria transmission in the Nyanza province, Kenya. The findings of the study are organized according to the specific study objectives.

4.1. A Conceptual Health Data Model (HDM) Supportive of the KNSDI

4.1.1. Model notation: The health data model presentation used in the design and customization of PMIS is presented in Figure 4.1 while the static model is provided in appendix 1. It is based on object-oriented technology whereby each object class was modelled together with its attributes. A class is represented by a rectangle with three compartments. The top most compartments bear the class name and the middle bears the class attributes. The third compartment is left blank based on the KNSDI notation framework.

Health data was divided into two core classes: the “Patient” and “HealthFacility”. The two core classes share a common class “Location” by virtue of their location. A patient, the main entity in “Patient” class resides in a given location and a health facility, the main entity in “HealthFacility” class, is located at a given location. A relationship class called “Visit” was used to model the relationship between patient and health facility.

4.1.2. Modelling the “patient” class

A patient is a person reported to be sick or with signs of a particular ailment visiting a given hospital. A patient was modelled as a “Patient” class. “Patient” class is associated with health facility via relationship class called “Visit” class.
Figure 4.1: The Conceptual Health Data Model supportive of the Kenya National Spatial Data Infrastructure (KNSDI)
The patient class is a super type of health related activity subclass and it has the following attributes:

*PatientId*: This is a unique identifier, modelled as string data type, for each individual patient record. The *patientId* identifies the patient uniquely to enable spatial-temporal use and analysis of data related to a given individual. This is especially useful when making comparisons across records obtained from different health facilities to the two sites in Nyanza province. This research proposes the use of Birth Certificate Number as the unique identifier. In an ideal situation, each individual bears a birth certificate and each birth certificate is for a single individual. This is basically a one to one relationship as an individual holds only one birth certificate. Using the Birth certificate approach can facilitate unique identification of patients.

*FirstName, SurName and OtherName*: These represented the name identifiers of given patient. The *FirstName* and *OtherName* were the names assigned to a patient, usually at birth. The *SurName* is the family name of the patient or the second name of the parent. All the three attributes were modelled as string data type.

*BirthDate* and *DeathDate*: The attributes were modelled as date data types and they represented the date of birth and death respectively. They are particularly important when clustering patients by age to define vulnerable age groups.

*Gender*: This attribute was modelled as character data type and gives the patient’s sex as either male or female.

*Occupation*: This attribute was modelled as character data type and it represents the occupation in which the patient person is employed in. For patients below employment age it can be blank.

*NextOfKin*: This attribute was modelled as character data type and it gives the patient’s next of kin who may be contacted in case of emergency.
Religion: This attribute was modelled as character data type and it gives the patient’s religious affiliation. This attribute is important in data mining especially in determining how religious practices affect the health of a person.

Nationality: This attribute was modelled as character data type and it gives the patient’s nationality. This attribute was not however, expected to vary as the study assumed that only population from catchment area visited the health facility.

The “Patient” class is a super type of “HealthRelatedActivity” class. A health-related activity is an action performed for the purpose of documenting, investigating, or improving the health condition of a patient. Examples of health related activities include the following: interventions such as surgical operations or vaccination and administration of a medication; referral to another provider; and diagnostic observations about a patient’s condition. The attributes of “HealthRelatedActivity” class included the following:

HealthRelatedActivityCode: It was modelled as string data type and is an instance identifier for a health-related activity. It uniquely identified a particular instance of a health-related activity class.

HealthRelatedActivityDate: It was modelled as date time that reflects when the health related activity instance occurred and recorded.

ActivityDescriptiveText: It was modelled as a piece of free text or multimedia data that described the activity in all necessary detail. This attribute was proposed to be a descriptive supplement to an activity type code, not a replacement. There was no restriction on length or content imposed on the description attribute. However, the content of the description is not considered part of the functional information communicated between systems. Descriptions were meant to be shown specifically to interested individuals.
The “HealthRelatedActivity” class was modelled as Super type of “Intervention”, “Observation” and “Referral” subclasses; and they inherit the attributes of “Patient” class.

An intervention is the administration of a substance or technique to provide care for or to prevent a condition. This includes vaccinations and preventive therapy as well as medication given to the patient directly for therapeutic purposes. "Intervention” class is a subtype of “HealthRelatedActivity” class and its attributes include the following:

* **InterventionID**: This was modelled as a string data type to uniquely identify a given intervention.

* **InterventionDescription**: This was modelled as free text describing the physical form in which intervention is delivered; examples include tablet, capsule, suppository, and solution or the route through which the intervention is administered to the object of the intervention. For medication it includes oral, intravenous, subcutaneous, subdermal, and intramuscular.

The “Intervention” class had two subtypes: “Procedure” and “Medication” subclasses.

“Procedure” subclass was modelled with two attributes: ProcedureName and ProcedureId, which were respectively modelled as a character name describing the procedure and string identifier for uniquely identifying a given procedure.

“Medication” subclass was modelled with two attributes; MedicationName and MedicationId which were respectively modelled as a character name describing the medication type and string identifier for uniquely representing a given medication type.

An observation, according to (CDC, 2000), is an "act of recognizing and noting a fact often involving measurement with instruments” and at the same time observation is also "a record or
description so obtained” that is obtained through recognizing and noting. Thus an observation is “both the action and measurement procedure” and the resulting information that was obtained.

The model understands the result to be entirely dependent on the observation action, and thus modelled the result as a component (attribute) of the Observation action rather than as an independent entity. Observations are actions performed in order to determine an answer or result value. Observation result values are specific information about the observed object. The type and constraints of result values depend on the kind of action performed. “Observation” class was therefore modelled as a Subtype of “HealthRelatedActivity” Class with the following attributes:

- **ObservationId**: This was modelled as a string data type to uniquely identify a given type of observation.
- **ObservationDiagnosis**: This was modelled as character to give the conclusion drawn from analysis of the signs and symptoms exhibited or described by an individual. The conclusion can be in terms of the disease the patient is suffering from.
- **TestName**: This was modelled as character data type to describe a procedure followed to objectively measure or evaluate the presence or status of a condition.
- **TestResult**: This was modelled as Boolean data type as true or false to give the result value of an observation activity
- **ObservationDescription**: This was modelled as free text describing the observable symptoms

A referral is an introduction of an individual or individuals from one health care organization to another for the purpose of diagnosis or treatment. “Referral” class was thus modelled as a Subtype of “HealthRelatedActivity” class and its attributes included:

- **ReferralDescription**: Free form text describing the referral.
- **ReferralReasonText**: Free form text providing reason for the referral as well as the action that is expected or requested upon receipt of the referral.
4.1.3. Modelling of the “Health Facility” class

A health facility is a site where health care is provided. It was modelled as “HealthFacility” class associated to “Patient” class and its attributes included:

* **FacilityId:** This was modelled as a string unique identifier for each facility. A unique ID to which all collected data are associated should identify each facility. This is especially so when trying to combine information coming from different surveys or health facilities. This is not an easy issue to manage, as health facilities are dynamic and
evolve through time (for example the ID of one facility might be assigned to another facility after the facility has closed). This research proposes the development and maintenance of health facility registries as part of an HMIS. In this case, a “lookup table” should be included that provides a link between the facility code and the facility name as was implemented by the PMIS.

*FacilityName:* This was modelled as a character data type indicating the name of the health facility. Each healthy facility name was related to the health “*FacilityId*” which uniquely identified it.

*FacilityType:* This was modelled as character data type and gives the level or type of a health facility.

*FacilityTypeCode:* This was modelled as string data type to uniquely identify a type of health facility identified under facility type attribute.

*FacilityBedCapacity:* This was modelled as number data type to show the maximum bed capacity of a given hospital.

*NumberOfDoctors:* This was modelled as number data type to show the number of doctors in a given hospital

*NumberOfNurse:* This was modelled as number data type to show the number of nurses in a given hospital

*FacilityDate:* This was modelled as date data type to indicate the date in which the information for the health facility was recorded. This is especially so in instances of facility upgrading or expansion in which case the facility type or bed capacity may change respectively.

For the purpose of mapping and to make it possible to find the location on a map or physically navigate to the location, this study included the following attributes in the “HealthFacilityClass”:

*Latitude:* Indicates the latitude of the location as measured in degrees north or south of the equator.

*Longitude:* Indicates the longitude of the location as measured in degrees west or east of the prime meridian.
It should be noted that latitudes and longitudes can be expressed in multiple ways: degrees, minutes, seconds, decimal minutes, or decimal degrees. Decimal degrees are the most common. According to SoK (ROK, 2007), decimal degrees are the preferred choice for recording facility locations for the following reasons:

a) Easy of storage as decimal values compared to degrees, minutes, and seconds;
b) Easy to import the results into a GIS or other mapping application, since many commonly used GIS programs require latitude/longitude values to be in decimal degrees; and
c) It clearly delineates the various hemispheres – locations north of the equator will have a positive latitude value, while locations south of the equator will be negative.

This study incorporated latitude/longitude attributes to the “HealthFacility Class” during the implementation of PMIS spatial component.

Datum: Datum refers to the model of the earth used by the GPS and how that model relates to the “true” shape of the earth. Like coordinate systems, there are a variety of different data available for use.

LocationDate: This was modelled as date data type to show the time in which the longitude or latitude of a health facility was recorded. This is important especially in the event that a health facility has been relocated from its initial position. Figure 4.3 presents the model for “Facility” class

![Figure 4.3: Model for “Facility” class](image)

4.1.4. Modelling of the “Location” class

Knowing the administrative unit where a facility is located or where a patient resides is useful for aggregating the surveyed data according to the administrative level of the country. With
coordinates of health facilities captured, it is possible to locate the facilities in their respective administrative unit through a GIS overlay and application. However for patients, it may not be possible to track their coordinates, and thus relating them to the lowest administrative units is important. Mapping of individual patient households was only possible under research environment like the ‘severe malaria research project in Siaya’ whereby it was possible to map GPS data of patient.

The location class is based on a hierarchy of Kenya’s administrative units and it has the following attributes:

- **VillageName:** This was modelled as a character data type and gives the name of the village or estate in which the patient person resides or the health facility is located.
- **StreetName:** This was modelled as a character data type and gives the name of the street name in which the patient person resides.
- **SublocationName:** This was modelled as a character data type and gives the name of the sub-location in which the patient’s/health facility’s village belongs to.
- **SublocationCode:** This attribute was modelled as string data type and gives the sublocation’s code. It should be noted however, that Ministry of Health (MoH) is not the authority in maintenance of administrative units’ data.
- **LocationName:** This was modelled as a character data type and gave name of the location in which the sub-location belongs to.
- **LocationCode:** This was modelled as string data type and gave the location’s code.
- **DivisionName:** This was modelled as a character data type and gave the name of the division in which the location belongs to.
- **DivisionCode:** This was modelled as string data type and gave the Division’s code.
- **DistrictName:** This was modelled as a character data type and gave the name of the district in which the division belongs to.
- **DistrictCode:** This was modelled as string data type and gave the district’s code.
- **ProvinceName:** This was modelled as a character data type and gave the name of the province in which the district belongs to. Figure 4.4 shows a model of location class.
4.1.5 Modelling of the “Visit” class

A patient visits a number of health facilities across space and time. It was therefore important to model this spatial temporal relationship for the sake of completeness of the health data. The relationship between “patient” and “HealthFacility” classes was modelled as a many to many relationship with “Visit” class”. The following were the attributes for the “Visit” class.

\[ \text{VisitDate: This was modelled as date data type to show the time instance in which this relationship occurred.} \]
\[ \text{FacilityId: This was facility’s unique identifier for identifying a facility participating in this relationship.} \]
\[ \text{PatientId: This was a patient’s unique identifier for identifying a patient participating in this relationship.} \]

Figure 4.5 shows a model of “Visit” class.

4.2. The Patient Management Information System (PMIS)

4.2.1. System (PMIS) implementation: The process of building PMIS occurred over a period of 12 months, followed by 6 months of testing and debugging during stable operations. A pilot system was installed within six months after starting the development of the PMIS. The PMIS
became stable within one year of the start of development. Training for all the six clinical staff using the system was completed in two days. Staff incorporated the PMIS into their work flow immediately following the training and provided feedback for usability improvement during the first six months of stable operation.

To begin the implementation process, points of divergence were identified between the PMIS, which has a primary goal of improving patient care, in contrast with a model that incorporated the additional objective of collecting data for biomedical research. After primary differences were identified a scope of work was formulated. Additional data elements to be collected in the research were compiled and incorporated into a new data model. Once the new data model was established, the existing user interfaces were modified to match the patient flow and data collection points as well as to allow users to enter additional data elements required for malaria research. The development process cycled through several iterations of modifying the scope of work, adjusting the data model, changing the user interfaces, followed by testing, debugging and observations of system usage.

The PMIS implemented at Siaya District Hospital was maintained on-site for 24 months, used for the capture of epidemiological and research data and complete clinical histories for the paediatric Malarial Anaemia patients. Data collected by the PMIS provided the daily feedback on system usage, retrieval of patient records and clinical diagnoses.

The PMIS enabled collection of data in real-time as patients move through the clinic, from registration through examination and admission until discharge. Clinicians entered data into the system at each point of contact. In addition to entering data into the PMIS, clinicians continued to record the data on paper forms developed before the system was implemented.
The PMIS data collection processes were designed and customized after the paper-based data collection processes. The paper collection process had remained intact to provide a back-up copy of the data, as well as a reference for data quality maintenance during the initial design iterations of the PMIS. The PMIS printed out exam note and treatment sheet records on paper to stay with the patients admitted to the ward. Figure 4.6 shows details of patient data entry user interface.

![Patient Data Entry Interface](image)

**Figure 4.6: Record entry user interface showing details of patient data entry**

### 4.2.2. System (PMIS) patient management:

The PMIS was used to track patients as they move through the clinic. Upon arriving at the clinic, patients move through the following stages: (1) Registration/Check-in, (2) Physical History, (3) Patient Measures, (4) Examination Waiting Area, and (5) Examination Room. Following the exam, the clinical officer decides to admit the patient to the clinic or to send the patient home to be treated as an outpatient. After checking in at registration, patients complete a History of Present Illness interview with the registration clerk. The clerk adds the patient to an examination waiting list. A nurse takes patients from the waiting list and completes physical measurements before a clinical officer removes the patient from the
waiting list to complete the examination. Figure 4.7 shows the record entry interface for the patient household data.

The PMIS enhanced complex data capture and clinical management support for both clinical care and malarial anaemia research simultaneously. This was accomplished by capturing a wealth of epidemiological and clinical research data for the study while supplying relevant parts of the data to clinicians to maintain electronic medical records and to manage patient movement throughout the clinic. The system supported investigation of Malarial Anaemia (MA), the primary clinical manifestation of severe childhood malaria in holoendemic *P. falciparum* transmission areas such as Siaya District, in Nyanza Province. Reduced haemoglobin (Hb) levels in children with SMA (Hb < 6.0 g/dL) are exacerbated by a number of factors including co-infection (HIV, bacteremia, and hookworm), nutritional deficiencies, hemoglobinopathies, and socio-demographic factors. The PMIS was designed so as to collect data on these important co-factors as well. Figure 4.8 shows record entry interface for patient visit details while Table 4.1 gives standard case definitions of the study groups for various malarial outcome categories.
Figure 4.8: Record entry user interface for patient visit details
Table 4.1: Case definitions for the study groups (Ongecha et al., 2006)

<table>
<thead>
<tr>
<th>Categories</th>
<th>Definition upon recruitment into the study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy Controls (HC)</td>
<td>Children with a malaria-negative smear for <em>P. falciparum</em> parasitemia, Hb ≥ 11.0 g/dL, free of fever or diarrhea for the last 14 days, and no prior hospitalizations</td>
</tr>
<tr>
<td>Hospitalized Controls (HosC)</td>
<td>Children with a malaria-negative smear for <em>P. falciparum</em> parasitemia and Hb &lt; 11.0 g/dL presenting with mild infections like cough</td>
</tr>
<tr>
<td>Uncomplicated Malaria (UM)</td>
<td>Children with a malaria-positive smear for <em>P. falciparum</em> parasitemia (of any density), absence of anemia (i.e., Hb &gt; 11.0 g/dL), and free from the symptoms of severe malaria, such as hypoglycemia</td>
</tr>
<tr>
<td>Mild Malarial Anemia (M/MA)</td>
<td>Children with a malaria-positive smear for <em>P. falciparum</em> parasitemia (of any density), Hb of 8.0 - 10.9 g/dL, and free from the symptoms of severe malaria, such as hypoglycemia</td>
</tr>
<tr>
<td>Moderate Malarial Anemia (MdMA)</td>
<td>Children with a malaria-positive smear for <em>P. falciparum</em> parasitemia (of any density), Hb of 6.1 - 7.9 g/dL, and free from the symptoms of severe malaria such as hypoglycemia</td>
</tr>
<tr>
<td>Severe Malarial Anemia (SMA)</td>
<td>Children with a malaria-positive smear for asexual <em>P. falciparum</em> parasitemia (of any density) and Hb ≤ 6.0 g/dL. Children with cerebral malaria, a rare event in high transmission settings, were excluded from the study</td>
</tr>
</tbody>
</table>
The following figures; 4.9, 4.10 and 4.11 show samples of snapshots for record entry interface for enrolled patients’ (a) family History; (b) Physical Exam and (c) History of Present Illness on visit, respectively.

Figure 4.9: A snapshot of record entry user interface for enrolled patients’ Family History

Figure 4.10: A snapshot of record entry user interface for enrolled patients’ Physical Exam
4.2.3. **System (PMIS) specifications – hardware:** Five touch-screen workstation computers were successfully connected to a server through an Ethernet network of 100BaseT CAT-5 wiring and a network switch. The workstation computer is based on a 266 MHz Intel Pentium platform with 32 MB of RAM. A Micro Touch Systems Clear Tek 3000 capacitive touch screen sensor is added over the 10.4 inch 800 x 600 pixel dual scan display, and a San Disk 256 MB IDE Flash Drive is used in place of a conventional hard disk to reduce current consumption and increase the robustness of the system. The server is a Dell Power Edge 2400 series computer with dual redundant power supplies and 5 x 9 GB SCSI hard disks arranged in a level 5 RAID configuration. A Zebra TLP2488 thermal transfer barcode label printer is connected to the workstation computer via a parallel interface. The workstation computer communicates with the server through a D-Link external network adapter connected via a USB interface. The server, workstations, and printers are each powered via an Uninterruptible Power Supply (UPS).
4.2.4. System (PMIS) specifications – software: The PMIS utilized a combination of commercial and custom-built applications. The server ran on the Windows 2000 Professional operating system. The data was stored in a relational database using Microsoft SQL Server 7 database software. Workstation computers run a custom-written application developed in Microsoft Visual Basic running on a stripped-down version of the Microsoft Windows 98 operating system. To assure data security and confidentiality, the study established redundant steps during the implementation of the PMIS:

1. All accesses to the PMIS were password protected
2. Access to data for various users was limited to only those aspects of the PMIS for which they were responsible.
3. Twice a day, the PMIS automatically backed up its entire database to a Zip disk.
4. At the end of the day when the PMIS computer was shut down, the entire database was again backed up unto a Zip disk. The backup Zip disk was taken home every night by the system administrator/manager.
5. Once a week, the PMIS’ system administrator ensured a copy of entire database on a Zip disk was placed on the main computer at SDH.

4.3. Mapping Malaria Transmission in Siaya District
The spatial analysis feature in the PMIS spatial GIS application was able to perform geographical analyses of the malaria transmission in Siaya District. There were 822 malaria case households mapped in Siaya District whereby complete laboratory investigations for detection of malarial anaemia were available for each of the 802 households. The malarial case households used for final spatial analyses were therefore only for those, whose complete disease (malaria) outcomes (i.e. malarial categories) were already established and recorded at SDH through the PMIS.
4.3.1. Mapping of housing structures

Mapping of housing structures was based on type of wall (i.e. brick or mud), window type (i.e. none, screened or unscreened) and roofing material (i.e. iron-sheets or grass-thatched) used in construction of the houses. Findings from the study indicated that majority of the houses (71.4%, 585 of 822) had mud-walls and 25.5% (209 of 822) were constructed from bricks. There were only a few (0.2%, two of 822) houses which were tin-walled. Approximately, half of the houses (49.5%, 405 of 822) had grass-thatched roofs, while 46.8% (383 of 822) contained corrugated iron sheets and 0.9% (7 of 822) had roofs constructed from other materials (i.e. asbestos, tiles, or tin). Additionally, the type of windows in the houses were mapped and categorized as screened (46.0%, 377 of 822), no windows (40.3%, 330 of 822) or un-screened (10.5%, 86 of 822). This study established no significant differences on housing structures among malarial case households at 0.05 level of significance (p<0.005).

4.3.2. Relationships between malarial case households’ distances and covariates

Spatial data for each malarial case household was collected over a period of 18 months from January 2005 to June 2006 by tracking malaria patients using the information provided by patients during the enrolment period. The purpose of mapping was to collect spatial data for each corresponding malaria patient already enrolled in the severe malaria study. Earlier, in the SDH paediatrics ward records, every study participants enrolled in the study were allocated a Unique Identification Number (UIN), which was computer generated and bar coded for confidentiality by the PMIS. Table 4.2 gives the data collected for ease of tracking patients during study enrolment period.
Table: 4.2: Geographic data collected from enrolled study participants

<table>
<thead>
<tr>
<th>P.O. Box</th>
<th>Sub location</th>
<th>Nearest school</th>
</tr>
</thead>
<tbody>
<tr>
<td>District</td>
<td>Village/estate</td>
<td>Nearest market</td>
</tr>
<tr>
<td>Location</td>
<td>Homestead</td>
<td>Nearest Church</td>
</tr>
<tr>
<td>Chief</td>
<td>Assistant chief</td>
<td>Village elder</td>
</tr>
</tbody>
</table>

Given the information above, by the use of a vehicle, it was therefore possible to drive to the malarial case household and subsequently take GPS coordinates of homesteads. Now, using the GPS coordinates to link each malarial case at SDH with corresponding case household location in the study area was done. Distances between individual malarial case households and environmental covariates (water bodies/drainage, road network and SDH) were then obtained using the NEAR command in Arc/Info. Figure 4.12 shows the results of spatial analyses for various covariates under the study. Table 4.3. shows the malarial outcome categories compared with proximities to selected risk factors.
Figure 4.12: Malarial case household mapping overlaid with covariates for spatial analyses; (a) Shows relationships between malaria case household and water bodies. Spatial analyses were performed on the datasets showing proximity of malaria patients’ homesteads to roads, SDH and the streams in (b), (c) and (d) respectively (clockwise).
Table 4.3. Tabulations (frequencies) of malaria case outcome categories compared with proximities of their house to selected environmental risk factors at various distances (between <0.5km and 1.25km).

<table>
<thead>
<tr>
<th>Malaria outcome categories</th>
<th>Mean distance in meters to SDH</th>
<th>Proximity to road network</th>
<th>Proximity to water bodies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>250</td>
<td>750</td>
<td>1250</td>
</tr>
<tr>
<td>Severe malaria anemia</td>
<td>136</td>
<td>106</td>
<td>80</td>
</tr>
<tr>
<td>Moderate malaria</td>
<td>100</td>
<td>56</td>
<td>54</td>
</tr>
<tr>
<td>Mild malarial anemia</td>
<td>78</td>
<td>55</td>
<td>51</td>
</tr>
<tr>
<td>Uncomplicated malaria</td>
<td>15</td>
<td>22</td>
<td>17</td>
</tr>
<tr>
<td>Health controls</td>
<td>25</td>
<td>44</td>
<td>38</td>
</tr>
</tbody>
</table>

*Appendix 3 shows arithmetic mean distances travelled by study participants to SDH and malaria case outcomes*
Correlation spatial statistics were applied to establish relationships between malarial case households and the covariates (proximity to access road\textsuperscript{2}, nearness to water bodies\textsuperscript{3} (drainage) and distances travelled by patients/clients to Siaya District Hospital). Table 4.4 gives the proportions (frequencies) of different malaria case household categories and the average distances travelled to the environmental covariates.

Table 4.4: Spatial characteristics of the malarial case households with covariates

<table>
<thead>
<tr>
<th>Covariates</th>
<th>250 (&lt;500m)</th>
<th>750 (501-1000m)</th>
<th>over 1250 (&gt;1001m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to SDH</td>
<td>n=293 (36.5)</td>
<td>n=148 (18.5)</td>
<td>n=361 (45.0)</td>
</tr>
<tr>
<td>Control</td>
<td>n=36 (50.7)</td>
<td>n= 14 (19.7)</td>
<td>n=21 (29.6)</td>
</tr>
<tr>
<td>Proximity to drainage</td>
<td>n=401 (50.0)</td>
<td>n=364 (45.4)</td>
<td>n=37 (4.6)</td>
</tr>
<tr>
<td>Control</td>
<td>n=24 (33.8)</td>
<td>n= 45 (63.4)</td>
<td>n=2 (2.8)</td>
</tr>
<tr>
<td>Proximity to roads</td>
<td>n=14 (1.7)</td>
<td>n=27 (3.4)</td>
<td>n=63 (88.7)</td>
</tr>
<tr>
<td>Control</td>
<td>n=24 (5.98)</td>
<td>n= 45 (12.36)</td>
<td>n=2 (5.41)</td>
</tr>
</tbody>
</table>

Note: For purposes of spatial analyses purposes, a distance interval of 500m (0.5km) was used. Taking mid points, for example, malarial case households within 500m of a distance to SDH, the mid-point record is 250m.

4.3.2.1. Proximity to Siaya district hospital (SDH)

Findings from this study show that 55 percent of the malaria patients reporting to SDH pediatric ward and who were enrolled under this study came from a radius of 1km of the health facility. The longest distance by malaria patients to SDH was about 13.15km (13,150m) at a bearing of about 118°. On the other hand, the shortest distance travelled by malaria patients to

\textsuperscript{2} Road network means - all classified roads including classes A, B, C, D, E and special purpose roads (classes F to W) normally with a width of more than 9m as a right of way.

\textsuperscript{3} Water bodies means - main water bodies including rivers, streams, lakes and swamps identifiable on Kenya’s topographic maps. Water pools within the home steadsteads were not included.
SDH was found to be 0.64km (640m) at a bearing of about 78°. The arithmetic mean distance travelled by patients to the Siaya District Hospital (SDH) was found to be 6km (6,000m). Figure 4.13 shows relative distances to SDH between various malaria case outcomes.

Figure 4.13: Relations between various malaria outcomes and case households’ proximity to SDH

4.3.2.2. Travel cost impedance to nearest provider: proximity to road network

Overall, nearness to a road network for malarial case households was found to be an average of 1.55km (1550m). The longest distance for malaria case household to a road network was found to be 5.75km (5750m) while the shortest was only 10m. Figure 4.13 shows the relationship between malaria case outcomes and household proximity to the nearest road network.
4.3.2.3. Proximity to main water bodies (drainage)

There was a drastic drop of malarial case households with longer distances from water body (Fig. 4.15). The average distance of malaria case household to water bodies was about 0.5km (500m). Malarial case household location was however, statistically a significant predictor (p<0.001) of malarial outcome category when distance to water body was less than 1km. The implications of this finding is that proximity to a water body as a risk factor for malaria transmission is only plausible if proximity is within a radius of 0.5km.
Figure 4.15: Relationships between case households and nearness to water bodies

4.4. A Geospatial Model for Malarial Case Risk Mapping in Kisii Highlands

For each of the environmental risk factors, a model surface was created. The malaria cases obtained from the HMIS were the basis for the Malaria Cases (MC) surface, whose preparation was based on the assumptions that: the cases reported and recorded at the District and sub-District hospitals were not included in the surface modelling. This was to avoid any double entry due to referral cases from the health centres and dispensaries in the district. In addition, the study assumed that the patients would go to the nearest health facility.

A total of 45 individual regressions were performed initially for the February 2001, May 2003 and April 2005, and then one and two months before combined for each of the factors proposed under the study (see appendix 7). This was to account for a possible time lag between changes of risk factors to the onset of malaria. Malaria cases surfaces were created using spline interpolation. Figure 4.16 shows the malaria case surfaces for February, 2001, May 2003 and April 2005. Appendix 5 and 6 provides selected health facilities surveyed and malaria case data collected between 1995 and 2005.

Regression made it possible to examine the relationship between two quantitative variables in terms of the correlation between the variables (i.e., their degree of association) and a best-fit trend line that expresses mathematically the character of the relationship. The $r$ in Table 4.5 represents the correlation coefficient between DEM, NDVI, rainfall, temperature (independent variables) and the malaria cases (dependent variable), while $r^2$ represents the extent of variability in the malaria cases explained by DEM, NDVI, rainfall and temperature (low, high). For example, in Feb. 2001, about 9% (i.e., $r^2$ squared) of the variance in the malaria cases would
be caused or explained by the DEM. Afterwards, it was necessary to perform a combined regression between the malaria cases and all the risk factors combined for each of the epoch.

4.4.1 Relationships between malaria cases and environmental risk factors

The relation between malaria incidences and environmental risk factors was investigated to find out existing relationships between malaria prevalence and a number of geographic variables, including: the Normalised Difference Vegetation Index (NDVI), temperature, rainfall, and Digital Elevation Model (DEM). Regression equation was established for the three epochs to investigate relationships between each of these factors and the malaria cases in the study area. Table 4.6 shows relationships between malaria cases and the individual environmental risk factors. It should however, be noted that the data available for NDVI and temperature did not cover the entire area of study. This necessitated adjustment of the study area for purposes of spatial analyses. Fig. 4.16 shows the digital terrain model (DTM) for the Kisii Highlands.
Fig. 4.16 The DTM covering the three districts of Kisii, Nyamira and Gucha.
Table 4.5: Relationships between malaria cases and each of the risk factors

Regression equation: $M_c = a + b \times \text{Factor}$; $r$ is the coefficient of correlation

<table>
<thead>
<tr>
<th>Factor</th>
<th>DEM(m)</th>
<th>NDVI</th>
<th>Rainfall(mm)</th>
<th>Temperature(C - high)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$a$</td>
<td>$b$</td>
<td>$r$</td>
<td>$a$</td>
</tr>
<tr>
<td>Feb. 2001</td>
<td>713.7774</td>
<td>-0.23339</td>
<td>-0.30113</td>
<td>311.473</td>
</tr>
<tr>
<td>May 2003</td>
<td>315.2479</td>
<td>0.008727</td>
<td>0.00864</td>
<td>411.862</td>
</tr>
<tr>
<td>April 2005</td>
<td>-86.2555</td>
<td>0.257859</td>
<td>0.17648</td>
<td>356.736</td>
</tr>
</tbody>
</table>

Note (n): Feb 2001 (HF=67; MC=27,045); May 2003 (HF=55; MC=19,185); April 2005 (HF=30; MC=9,594) whereby n is the number/population, HF is the Health Facility and MC is the Malaria Cases
Table 4.6: Individual regression coefficients for risk factors

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>2001</th>
<th>2003</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>t_test (198942)</td>
<td>Coefficient</td>
</tr>
<tr>
<td>Intercept</td>
<td>889.616879</td>
<td>37.551052</td>
<td>-3412.62643</td>
</tr>
<tr>
<td>dem_all</td>
<td>-0.026343</td>
<td>-20.164967</td>
<td>-0.028447</td>
</tr>
<tr>
<td>Ndvi</td>
<td>-648.572616</td>
<td>-56.426884</td>
<td>-357.863472</td>
</tr>
<tr>
<td>Rfe</td>
<td>0.261281</td>
<td>4.695664</td>
<td>-0.790281</td>
</tr>
<tr>
<td>Temp_high</td>
<td>3.412381</td>
<td>1.455509</td>
<td>-0.790281</td>
</tr>
<tr>
<td>Temp-Low</td>
<td>-19.857847</td>
<td>-5.087145</td>
<td>5.327927</td>
</tr>
</tbody>
</table>
4.4.2. The multiple regression models for three epochs: 2001, 2003 and 2005

The multiple regression equation for the three epochs using coefficients obtained from spatial analyses would then be:

**In Feb 2001**

\[ M_c = 899.616879 - 0.026343 \times \text{dem} - 648.572616 \times \text{ndvi} + 0.261281 \times \text{rfe} + 3.412381 \times \text{temp(h)} - 19.857847 \times \text{temp(l)} \]

Individual Regression Coefficients

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>t_test (198942)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>899.616879</td>
<td>37.551052</td>
</tr>
<tr>
<td>dem_all</td>
<td>-0.026343</td>
<td>-20.164967</td>
</tr>
<tr>
<td>ndvi_2001</td>
<td>-648.572616</td>
<td>-56.426884</td>
</tr>
<tr>
<td>rfe2001</td>
<td>0.261281</td>
<td>4.695664</td>
</tr>
<tr>
<td>temp_2001h</td>
<td>3.412381</td>
<td>1.455509</td>
</tr>
<tr>
<td>temp_2001l</td>
<td>-19.857847</td>
<td>5.087145</td>
</tr>
</tbody>
</table>

Similarly, the multiple regression equations for 2003 and 2005 could be established using the individual regression coefficients as shown below; and the corresponding malaria cases surfaces are given in Figure 4.16.

**In May 2003:**

\[ M_c = 3412.6264 + 0.0285 \times \text{dem} + 357.8635 \times \text{ndvi} + 0.7903 \times \text{rfe} + 155.4075 \times \text{temp(h)} - 5.3280 \times \text{temp(l)} \]

Individual Regression Coefficients

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>t_test (198942)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-3412.626438</td>
<td>-71.675537</td>
</tr>
<tr>
<td>dem_all</td>
<td>-0.028447</td>
<td>-19.676407</td>
</tr>
<tr>
<td>ndvi_2003</td>
<td>-357.863472</td>
<td>-25.357360</td>
</tr>
<tr>
<td>rfe2003</td>
<td>-0.790281</td>
<td>-28.383894</td>
</tr>
<tr>
<td>temp_2003h</td>
<td>155.407526</td>
<td>27.800636</td>
</tr>
<tr>
<td>temp_2003l</td>
<td>5.327927</td>
<td>1.087231</td>
</tr>
</tbody>
</table>
In April 2005

\[ M_c = 18288.3523 + 0.2493 \cdot \text{dem} + 916.1962 \cdot \text{ndvi} + 42.2567 \cdot \text{rfe} - 481.9566 \cdot \text{temp}(h) - 342.8491 \cdot \text{temp}(l) \]

<table>
<thead>
<tr>
<th>Individual Regression Coefficients</th>
<th>Coefficient</th>
<th>t_test (198942)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-13255.352312</td>
<td>-59.766644</td>
</tr>
<tr>
<td>dem_all</td>
<td>-0.249369</td>
<td>-21.469021</td>
</tr>
<tr>
<td>ndvi_2005</td>
<td>-916.196179</td>
<td>-7.776946</td>
</tr>
<tr>
<td>rfe2005</td>
<td>-42.256665</td>
<td>-47.421341</td>
</tr>
<tr>
<td>temp_2005h</td>
<td>481.956584</td>
<td>23.451754</td>
</tr>
<tr>
<td>temp_2005l</td>
<td>342.849052</td>
<td>10.053325</td>
</tr>
</tbody>
</table>

Figure 4.17 shows a cartographic representation of malaria case surfaces in periods 2001 (a), 2003 (b) and 2005 (c).

![Figure 4.17: A cartographic representation of the malaria case surfaces in the periods 2001 (a), 2003 (b) & 2005 (c)](image)

The malaria case surfaces and geospatial regressions for the three epochs for the study are are presented in Appendix 7.
5.1. Development and Application of Health Data Model

This study established a health data model that can be seen as “guiding templates” for developing or re-engineering existing systems to improve healthcare. The data model developed was useful to structure development of the spatial component of the PMIS that was implemented in SDH. Kenya’s health data revolves around a patient (individual) and a health facility. Routine and surveillance data is primarily collected, stored and retrieved at these levels (ROK, 2008). Disease surveillance data generally covers data from the community or facility through to the national or, indeed, the global levels (WHO, 2000). Sources of such data include health facility records, laboratory reports, case reports, and surveys, all of which are used to identify disease outbreaks, monitor trends in events of public health significance, identify the characteristics of those infected (such as age, sex, and location), and produce mapping of disease incidence. Routine health information systems or service statistics, on the other hand, comprise a very broad range of health data including health system inputs, processes, and outcomes, as well as facility-based mortality and morbidity rates.

Whereas the reach of such data covers all levels of the health care system, its availability in an easy to retrieve and standardized format is at stake (ROK, 2008). It therefore makes sense to develop a model that addresses and conforms to health data collected. The health data model has an advantage of establishing electronic health records or health databases which are interoperable.

5.2. Implementation of the PMIS at Siaya District Hospital

While developments of patient management information systems have been attributed in improved patient care, their applications in resource – poor settings remain to be demonstrated. The PMIS was designed as a tool for improved diagnostics, planning and management programming of malarial patients in the paediatrics ward at Siaya District Hospital. The PMIS system was designed to be interactive which means that project medical officers were responsible to maintain and update their part of the database. Implementation of such a system provided a model on how clinical practice guidelines can be integrated into the care process by computer to assist clinicians in managing a specific disease through helping them comply with
set care standards. The PMIS was designed to collect data in the context of clinical patient care whereby the objective of patient management would co-exist with that of collecting data for biomedical research.

5.2.1. Background to the patient management information system (PMIS)

An alternative approach to paper-based data collection and double data-entry is to use a computer-based data collection system that, while more costly than double data-entry, controls incompleteness and forces consistency of data (Lewis et al., 2005). A touch-screen based Patient Management Information System (PMIS) was implemented at SDH and performed real-time data-collection for biomedical research and facilitated patient management, providing electronic medical records to augment paper-based medical records used by clinical staff. The system was installed in a malaria research clinic in the Siaya District of Nyanza Province, Kenya, to support a multidisciplinary basic research while at the same time improve on healthcare service delivery.

5.2.2. The PMIS system acquisition:

The PMIS hardware design, including touch-screen workstations, bar code scanners, bar code label printers and central server were adopted as implemented in a PMIS designed for Kamuzu Central Hospital in Lilongwe, Malawi (Gerry, Personal Communication, 2005). This earlier implementation of the PMIS demonstrated the robustness of the hardware in a 700 bed facility, serving referral patients from the central region of Malawi in a resource-constrained environment. The software applications employed by the PMIS in Malawi were also adopted, including the relational database, and touch-screen and server operating systems. Several modules from a custom-developed software application designed for use on the touch-screen workstations formed the foundation and framework for a new application built for use in research at the paediatric clinic at the Siaya District Hospital. The usability and design features of the custom application developed for Malawi also proved to be robust and were incorporated into the new PMIS software for malaria research at Siaya District Hospital. The new spatial component was however, incorporated into the non-spatial PMIS component to strengthen the GIS analytical capabilities.

5.2.3. The PMIS general features:

The PMIS software was configured to start-up in full screen mode when the computer is powered-on and also capable of shutting down the computer. As such, the end user only interacts with the custom-written software application for touch-screen
use and is not required to use a mouse or a keyboard at any time. Additionally, the end user does not come into contact with the workstation operating system during normal system use, which prevents the workstation from being used for non-work related purposes such as playing games, chatting, or surfing the Internet. In this way the workstation was configured as a PMIS “appliance” rather than a desktop computer that is capable of running many types of software.

The PMIS application provided electronic patient records in order to improve patient care while creating a direct benefit to the clinician as a result of entering patient data. In addition to functioning as an information system for clinical care, the PMIS supported clinical management by collecting time stamped data. The PMIS recorded time stamps for each clinical event so that it could also provide data on patient movement through the clinic and system-user activity. Touch-screen workstations were located at every point of data collection in order to support patient management rather than inconveniencing clinicians by requiring them to move to another location to enter data or retrieve information (Fig. 5.1). The system configurations allowed data to be entered retrospectively in case of an extended power outage or other cause of system down-time.

5.2.4. System hardware: Reliability and robustness of the PMIS hardware were dependent upon four fundamental design features. These are fault-tolerant computing, resource conservation, touch-screen workstations, and use of barcodes. The combination of these technologies allows the system to remain durable and usable in a resource-constrained setting.

Fault-tolerant systems employ redundant hardware to maintain reliability and protect data in the event of hardware failure due to wear and tear, disaster, or theft. The system incorporates fault-tolerance in its central server by employing multiple hard disks that prevent loss of data and allow the system to keep running in the event of a hard disk failure. Furthermore, dual redundant power supplies on the server allow it to maintain power in the event of the failure of one power supply. Each computer in the system is supported additionally by an Uninterruptible Power Supply (UPS) that serves as a back-up power source. This allows the computers to withstand a brief power outage and to shutdown properly in the event of an extended power outage.
Conservation of resources through minimal power consumption is a valuable attribute for a system in a resource-constrained country like Kenya (Rotich et al., 2003). The touch screen workstations are compact and require only 20% of the power consumed by a desktop computer. Conserving power also permits the computers to run longer on back-up power.

The use of touch-screen workstations allowed clinical staff who were unfamiliar with a mouse and keyboard to manipulate the touch-screen interface comfortably with relatively little training. The workstation features a capacitive touch-sensor that the user can directly touch with his or her fingertip as opposed to using a stylus. It could be perceived that the use of a touch screen would increase the transmission of communicable diseases unless the screen was to be disinfected before each patient examination. However, this would also hold true for other objects used to record information which are not normally disinfected, such as a pen for writing examination notes (Lewis et al., 2005).

A fourth technology employed by the PMIS was a barcode scanning system that expedites information retrieval and minimizes data entry errors. At the time of patient registration, a barcode label printer prints a label that is affixed to the patient’s health passport. Barcodes are
also printed on the patient’s admission forms and examination notes. Once a clinician or clerk has logged into the system, he or she can quickly call up the patient’s electronic medical record by scanning a barcode on the patient’s documentation. The registration barcode would either be electronically scanned (by a bar code reading device) or keyed into the System to ensure confidentiality and secure health data prescription. For each enrolled patients under study, there was the Universal Unique Identifier (UUID) printable in human readable form. The “Registration UUID” was the primary attribute of the “Patient Prescription Release Request” message that retrieves a prescription from the PMIS to enable dispensing of drugs.

5.2.5. System software: The three major components of the PMIS software were custom-written application that collected data, a relational database in which the collected research data was stored, and the operating systems used by the central server and touch screen workstations. Of these major components of the system software, three design features were essential to the functionality of the system. These are the user interface, data validation, and the data model.

The custom application used to enter data and retrieve information was designed completely for use on touch screen workstations. The PMIS user interfaces feature buttons, onscreen-keyboards and keypads, scrolling list boxes, and other controls that are sized and spaced to accommodate the area of a fingertip rather than the much smaller pointer of a mouse. Responses to questions are selected from standardized lists as much as possible, minimizing the amount of free-text input. A notable design feature was the wizard-style interface. Wizard interfaces guide the user through each process in a linear, step-by-step manner. Only one data element can be collected at a time. This simplifies and organizes the process of data collection for the clinical staff, and allows staff to move rapidly through data collection processes once they become familiar with each process (Fig. 5.2).

The user interface was designed to support data validation for each data element entered to the greatest degree possible. Data was validated for both completeness and consistency. The application prevents any process from being completed until all required data elements have been entered. This ensured that the user will not forget to enter vital data elements and also prevents any misunderstanding on the part of the users about which data is required and which is
optional. Furthermore, the PMIS was designed to validate data for consistency where possible, checking data for out-of-range values and logic.

Figure 5.2: Data collection modules of PMIS utilising touch screen technology

For example, a user cannot enter a future birth date for a patient, and cannot enter return visit for a patient before they have completed an initial visit. The validation functionality in the PMIS protected data as it is being entered into the system, so that the user can correct his or her own data entry errors at the time of entry. Furthermore, the user enters data as a domain expert, sidestepping the problem of using a data-entry clerk who may not fully understand the data, may be unable to read a user's handwriting, or may impose incorrect assumptions upon the collected data during the data entry process.

The PMIS data model was designed carefully to protect the quality of the data collected, allow for analysis and reporting, and support expansion of the system to include additional data elements of spatial data at a later time. Data relationships were identified and data elements were
grouped into multiple tables according to relationships evidenced by the data needs of the study. Data relationships were enforced by the database to preserve data quality and alert developers when the PMIS application was attempting to store incomplete or invalid data into the relational database.

5.2.6. Overcoming challenges of developing the system

Developing information systems to be used in resource-constrained environments is clearly an ambitious exercise. This study pursued this goal in spite of challenges of such computerized systems in similar settings (Rotich et al., 2003) because of the believe that the potential to improve data quality exists while improving the level of patient care if all potential threats are addressed. During implementation, the researcher addressed these threats by applying the principles of medical informatics – to augment the clinician’s ability using information technology – in the following ways:

1. Creation of an information system, as opposed to a data collection system, in which data is collected and information is provided in return to the clinical setting.
2. Addressing the issue of lack of computer literacy among clinical staff by providing an optimal form of human computer interaction, the touch screen.
3. Tailored the PMIS-software used in the clinic to match the existing information flow and support the clinician’s activities without imposing constraints on the process of patient management.
4. Design and customization of the PMIS was phased out, first with implementation of non-spatial component then spatial applications was incorporated to support the spatial analytical capabilities.

5.3. Applications of PMIS - spatial Capabilities to Track Malaria Patients

To strengthen paediatrics patients’ demographic information, and to track and monitor disease dynamics, a Geographical Information System (GIS) application component was developed. By interfacing malaria-GIS with Patient Management Information System (PMIS), it was possible to perform spatial analyses. While Malarial Anaemia (MA) study (Ongecha et al., 2006) focused on investigations of the molecular basis for disease outcomes in infants and young children with malaria and paediatric HIV-1 in the study area, this study aimed at characterizing environmental risk factors that would offer spatial dimensions of malarial outcomes. Associations between
malaria case outcomes with proximities of the households to sources of water bodies (drainage), road network and the Siaya District Hospital (SDH) were established.

Types of houses constructed would be a measure of the level of wealth of population. For example, a recent study in western Kenya observed that brick walled houses is 9 times more expensive than mud-walled houses and iron-sheet roofs were 2.5 times more expensive than grass-thatched roofs (Meltzer et al., 2003) and are good indicators of levels of socio-economics of society. However, other previous studies illustrates that socio-demographic indicators may not be strong indicators of childhood anaemia and Malaria Anaemia (Schellenberg et al., 1999). Therefore, it was important to establish spatial relationships between risk factors and malaria case outcomes.

5.3.1. Distance travelled by patients to the nearest health facility
Distance to healthcare provider has been recognized as a significant barrier to healthcare access (Guagliardo, 2004). However, no study has been done in Kenya to test the effect of spatial accessibility on actual healthcare service delivery outcomes. A test on statistical differences between distances travelled by patients to SDH and their malaria case outcomes was significant at 0.05 level of confidence (P<0.005). The implications of this finding confirm that distance to nearest health facility plays a role in determining malaria case outcomes for reported cases at the district hospital. This study established that more case households with severe malaria anaemia outcomes were positively associated with longer distances than the other case households (i.e. moderate, mild and uncomplicated malarial case households) compared with the ‘controls’.

It is likely that parents delay to seek treatments for the children unless it is recurrent during which chronic form of malaria would have resulted. It is also possible that the child would have undergone home self-case management before travelling to the nearest health facility in this case, SDH. This would be partly due to cost associated with travel and poverty levels in the district, which work counterproductive to district health service utilization. Elsewhere, travel distances have been found to affect utilization of mental health and alcoholic treatment services (Fortney et al., 1995, Fortney et al., 1999, Fortney et al., 2000). This study supports results by Guagliardo (2004) that by measuring spatial accessibility of health service locations, it is possible to identify areas of provider shortage and reveal social disparities especially in rural areas (Morrill et al.
This study has revealed that severer cases of malaria anaemia are associated with patients who travelled longer distance to SDH.

### 5.3.2. Travel cost impedance to nearest provider: proximity to road network

Travel cost impedance to nearest provider is an intuitive and commonly used measure of spatial accessibility to healthcare. It is typically measured from the patients’ residence or from a population centre, such as the geometric centroid of a county of residence, depending on the resolution of available data (Guargliardo, 2004). Travel impedance, sometimes referred to as travel cost, is often measured in straight line, travel distance along a road and/or rail system, or estimated travel time via a transportation network.

Distances from malaria case households and malaria outcomes was found to be not statistically significant (p<0.001) compared with controls. It is therefore noteworthy that perhaps the most important travel cost impedance would be that of distance travelled to SDH rather than access to nearest main road network in the area. It would be interesting to examine travel cost impedance to other healthcare providers other that SDH in relation to the overall spatial accessibility to healthcare by the local population. This study revealed that distance travelled by patients to SDH determines the severity of malaria case outcomes.

### 5.3.3. Proximity to main water bodies for malarial case households

There was a significant negative correlation with malarial outcomes between distances of case household and a water bodies. It is well known that malaria vectors may travel some distance to find a blood meal (Carter et al., 2000) although studies of malaria risk around known breeding sites, including swamps, have demonstrated increased transmission within several hundred meters of these sites (Staedke et al., 2003).

Although, no larval mosquito sampling was conducted to confirm these predictions, recent mathematical models have demonstrated that proximity to water bodies may increase malaria risk regardless of whether those bodies are suitable for adult mosquito emergence (Le Menach et al., 2005), suggesting the importance of identifying potential water collection sites irrespective of larval sampling. The varied topography of the study area and its likely effects on malarial transmission underscore the need to consider not only household- and individual-level factors, but broader geographic and environmental context determinants of risk (Brooker et al., 2004).
was therefore necessary to consider other environmental risk factors including NDVI, DEM, rainfall and temperature to establish their relationships with malaria transmission in the study area.

5.4. Relationships between Malaria Prevalence and Environmental Risk Factors

Modelling of risk factors for transmission of malaria in localized scale is expected to be a major breakthrough for early diagnosis and effective therapy. This study set to investigate relationships between malaria prevalence and a number of geographic variables, including: the Normalised Difference Vegetation Index (NDVI), temperature, rainfall, and Digital Elevation Model (DEM). Various datasets were composed into a geo-database organizing the GIS data into thematic layers using appropriate spatial representation. For each of the risk factors, malaria cases model surfaces were created using spline interpolation. For each factor, a regression model equation was developed, for the three epochs (2001, 2003 and 2005) whereby all the spatial data for each factor of analysis were available. Afterwards, the models were validated using $F$-test. Study results showed a positive causal-effect relationship between malaria cases and selected environmental risk factors. Their individual contribution to the intensity of malaria transmission in the study area was not uniform. The DEM was found to have a stronger contribution to the malaria cases in the study area than either NDVI, temperature and rainfall.

5.4.1. Development of geospatial predictive model for malaria transmission

The time of resolution and availability of dependent data (malaria cases) and the independent data (DEM, NDVI, rainfall and temperature) influenced the particular period for multiple regression analysis. While individual regressions with each risk factors and MC were established, caution has to be exercised because spatial resolution of the datasets was quite varying across the three years. The inconsistency of the results with each individual factor across the three epochs may indicate that the factors considered are not the only factors that influence the malaria prevalence in this region. Other than environmental, anthropogenic factors would also be responsible for malaria prevalence especially malaria control programmes all of which need to be considered (Craig et al., 2007).

Other studies have however; found the month of survey to be a significant predictor of prevalence. This may also explain the inconsistency noticed in the spatial model across surveyed
months that is Feb, 2001; May, 2003 and April; 2005. To measure stability of the model and therefore intra-annual variation with malaria prevalence, the research would have required data from the same localities in different months for the studied three epochs. This was not possible under this study as no consistency data for all risk factors was available.

In order to have a better picture and establish weighting of individual environmental risk factors on malaria prevalence, a multiple regression was established. This study showed that DEM had a stronger influence on the malaria cases observed in the region compared to the other selected covariates. The variance in malaria cases can thus be explained better with DEM (non-temporal factor) in the study area than the spatial-temporal factors (NDVI, temperature and rainfall). Correlation effect among the environmental variables would however, blur individual risk factors’ and effects consistency as malaria case predictors. Related studies have found associations between malaria prevalence and selected environmental risk factors as predictors of malaria cases (Craig et al., 2007). Rainfall and annual mean temperature data utilized by Omumbo et al. (2005) to model spatial malaria transmission established that the two risk factors as likely plausible predictors for malaria prevalence. The two factors have also been used to explain the inter-seasonal variation of malaria incidence (Crag et al., 2004). Elsewhere, precipitation and temperature have also been found to be associated with the malaria parasite (Noor, 2008).

As noted earlier, this study investigated relationships between spatial distributions of reported malaria cases and selected environmental risk variables with the aim of developing a geo-statistical model for surveillance and risk mapping in Kisii Highlands. The importance of establishing spatial dimensions of malaria prevalence in a localized scale cannot be overemphasized. This study therefore has highlighted how analyzing routine malaria data would be used to develop spatial indicators for surveillance, forecasting and early warning systems. Using spatial regression statistical model, the study revealed a positive causal-effect relationship between malaria cases and the selected environmental risk factors. The multi-regression model was thus applied to estimate the level of contributory effects of each of the environmental factor to Malaria Cases (MC) in the study area.
5.4.2. Validation and applications of the geospatial predictive model for malaria

For the multiple regressions, the coefficient of regression indicates the relationship between the independent variables and the dependent variable (malaria cases). The square of $r$ shows the variability of the predicted malaria cases. The F value indicates the overall significance of the regression equation (i.e., whether or not the independent variables, taken jointly, contribute significantly to the prediction of the dependent variable). The adequacy of the overall regression was therefore tested and verified using the $F$-test. The T-test was used to confirm the significance of each regression at various confidence intervals (0.1, 0.05, 0.025, 0.01 and 0.005). See appendix 8 providing a summary of $F$-test values; comparing both the calculated and observed from t-tables. Differences between the calculated value and the one obtained from the t-tables can be explained by the differences between the resolutions of the layers. For each regression equation and based on the degrees of freedom and the residuals, values were obtained from statistical tables (t-test) at 0.1, 0.05, 0.025, 0.01 and 0.005. Overall, the regression (see Appendix 8) was found to be significant at various confidence intervals (0.1, 0.05 and 0.01).

5.5. Testing the Hypotheses

Hypothesis One:

*Malaria case outcomes are not influenced by distances travelled by patients to the health facility, their households’ proximities to water bodies and road network*

Table 4.3, provides associations between malarial case households outcomes with proximities to nearest sources of water bodies (drainage), road network and the Siaya District Hospital (SDH). There was a significant correlation between distances of case households to SDH and malarial outcomes at 0.05 level of significance (P<0.005) presented by Fig 4.13. This is Consequently, as the hypothesis distances travelled by patients to nearest health facility were found to influence malaria case outcomes in Siaya District, Nyanza Province. Those who travelled longer distances to reach SDH were found to have severer malaria anaemia compared with those who travelled shorter distances.
Hypothesis Two:
Selected environmental risk factors do not have equal predictive power for malaria prevalence
As indicated in tables 4.4 and 4.5, malarial cases and their correlation coefficients were statistically significant in the multi-regression equations. Consequently, these variables were found to have varied power for prediction of malarial cases in the Kisii Highlands. The multiple regression equation showed that the DEM has a stronger predictive power of malaria cases than other environment risk factors in the study area.
CHAPTER SIX
SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1. Summary of the Study
The proposal to develop and implement GeoMedInfo was out of the desire to incorporate geo-environmental risk predictors into the clinical practice for better disease control management. The development of environmental risk factors for disease development in this case malaria precedes building of a geo-medical information system. It is noteworthy that Kenya’s spatial data infrastructure process requires building different sub-systems aligned and supportive to the spatial data infrastructure initiative (www.knsdi.go.or.ke). In the health sector, development and applications of GeoMedInfo decision support system would support the KNSDI process.

6.1.1. Building a GIS-driven spatial health information system in Kenya
Establishment of health data model is geared towards establishing a readily and easily accessible repository of healthcare foundation database to which other data can be attached in line with the requirements of KNSDI. Consistent data capture and systematic information transformation processes can thus result in more effective evidence being available to support health management systems. In addition, value-added information can be supplied back to the clinician at the point of care, not only improving the clinician’s ability to deliver quality health care but also providing an incentive to the clinician to capture the highest quality data as a by-product of providing first quality care. This was demonstrated by the implementation of a PMIS in Siaya District Hospital whereby PMIS was designed and implemented as an information system rather than a data collection tool.

6.1.2. Implementation of patient management information system
Implementation of PMIS at Siaya District Hospital facilitated the capture and analyses of both spatial and non spatial health data. The system-demonstrated robustness while improving completeness and consistency of data and providing clinicians with access to malarial patient information. Inspite of the many documented challenges of electronic information systems in healthcare both in resource-constrained environments and in non-resource constrained environments, implementation of this system demonstrated the potential of building patient
information systems to both collect reliable spatial data and improve early warning system that is important in disease control management. The success of the system would therefore be attributable to the novel approach, using highly reliable hardware and software tailored to specific needs of the user, in addition to the integration of data collection into the patient management process.

6.1.3. Applications of geographic information system to study malaria epidemiology

Further, this study demonstrates how geospatial tools and information can be used to examine risk factors and their relative contribution to the disease burden, in this case malaria in the region. By combining reported malaria cases and the four (4) environmental risk factors in an innovative way using a multi-regression model, location-based intervention services can be analyzed for gaps and planned better. Data quality in terms of accuracy, completeness and consistency is still wanting in Kenya’s health system. Despite these shortcomings in Kenya’s Health Management Information System (HMIS), geospatial models are useful to focus surveillance and for monitoring changing epidemiology of malaria.

Linkages of predictive models with other models of interventions and health systems would be a powerful tool for health planning. Since geo-statistical methods can be useful to predict and model missing datasets, it would in turn aid the mapping of disease prevalence over some geographic area. Therefore, by examining past trends as well as the present situation it is possible to establish obvious patterns and clusters in space and time for better malaria control planning.

Caution should however, be exercised in any applications of this predictive model and sensitivity to context as more studies are needed to further improve on the model utilising higher quality of spatial data. By combining malaria prevalence data and environmental risk factors innovatively using geospatial modelling techniques, local based intervention services (for example malaria control programmes) can be improved.
6.2. Conclusions of the Study

The following conclusions were made from this study:

a) It is feasible to develop and implement a health management information system based on health data model. The established health data model provided a guiding template on which PMIS database was designed and customised in a systematic manner.

b) Implementation of PMIS at SDH for more than 2 years demonstrates that it is possible to design a health management system for a rural resource-constraint setting to collect data in the context of clinical patient care whereby the objective of patient management would co-exist with that of collecting data for basic research.

c) Spatial analyses capabilities of the PMIS GIS application was also demonstrated. Spatial analyses showed that patients travelled an average of 6KM to access health services in the Siaya District Hospital (SDH). More than half (55%) of study participants travelled more distance to access SDH health services compared to WHO recommended spatial accessibility of within 2KM. Longer distances travelled by patients to reach SDH were associated with severer malarial case outcomes than shorter distances. Given that SDH is a referral health facility within Siaya District, the study has therefore shown a clear evidence of social inequity in spatial distribution of healthcare service provision in the study area.

d) Almost half (45%) of study participants travelled >1km to access SDH health services while WHO’s recommended spatial accessibility is <1km

e) Strong positive associations exists between malarial transmission and selected environmental risk factors including DEM, NDVI, temperature and rainfall. However, in the final multiple variable model, DEM was found to be a highly plausible predictor of malarial risk compared with other risk factors.

6.3. Implications from the Findings

(1) Planning of Disease Control Programme

Results from spatial analyses for both Siaya and Kisii Highland Districts emphasize the ability of a GIS-driven malaria information system to provide quick and reliable information for planning disease control programmes. For example, the imposition of a buffer zone around a particular geographic landmark, e.g., water bodies, and the estimation of the impact of excluding house of “mud-walled” construction type from it by simulation, would be used to estimate the potential
impact of such an intervention. Such analyses would also enable the health administrators in allocating or re-allocating health care resources more equitably.

(2) Reporting of Routine Health Data

The malaria case data utilised routinely collected from public health facilities to develop the predictive malarial risk model. Malaria case data is routinely collected from government health care institutions where the case have been confirmed by blood filming. These data is available monthly from regional malaria control officers situated in districts. Although this gives an idea of the caseload and the monthly changes in these areas, this would further be improved if data from the private sector are also be included. This will give a more accurate figure for demarcated administrative areas for purposes of carrying out spatial analyses on correlating risk factors with malaria prevalence.

6.4. Operational Recommendations

The health data model is not an end in itself, it is a means through which logical data models and physical data models could be developed. The health data model could serve as a blue print for a health database development nation-wide. As regards to health data model and implementation of PMIS, the following recommendations were made;

a. The nation-wide databases should consider the use of Birth Certificate Number as the unique identifier for patients

b. There is need to develop and maintain health facility registries as part of the HMIS. A standardization of the health facility Identification (ID) could include facility and facility name and the GPS coordinate as implemented by the PMIS.

Furthermore, the predictive malarial risk model developed needs further evaluations and validation with more and higher quality spatial data. To improve the geo-statistic model for malaria risk mapping and surveillance, the following are suggested;

a. The Ministry of Health should ensure that high quality routine health data is collected in terms of completeness, validity and consistency.

b. Researchers involved in health-geographic studies should obtain more spatial data with high spatial resolution consistent with malarial cases data to further validate relationships with environmental risk factors.
c. There is need to further evaluate stability of the established geospatial predictive model for malaria risk mapping in the study area. More observations should be taken on the effect of month and/or time of year during spatial data analyses to the observed malaria transmission.

6.5. Suggestions for Further Research

Taking into account the delimitations of the study, the following areas for further research are recommended:

a. Expand research to more sites countrywide to study spatial accessibility of populations to both healthcare interventions and national health system.

b. Due to funding constraints, PMIS was implemented only in Siaya District. It is therefore recommended that PMIS application systems be expanded to other sites in both rural and urban to compare findings.

c. Further validation of the geospatial predictive models developed with better spatial data quality is necessary. The predictive malaria risk geo-spatial model considered only four (4) environment risk factors in Kisii Highland and only for three epochs (2001, 2003 and 2005) where there was complete data for both malaria cases and selected environmental risk factors. It is therefore important to run the model using more climatic-based risk factors with better spatial quality.
REFERENCES


Malaria Atlas Project [http://www.map.ox.ac.uk](http://www.map.ox.ac.uk)


APPENDICES

Appendix 1: Static Data Model Presentation

' Static Model

Public Class Medication
    Public MedicationCode As String
    Public MedicationName As Char
End Class ' END CLASS DEFINITION Medication

' Static Model

Public Class Observation
    Public ObservationId As String
    Public ObservationDiagnosis As Char
    Public ObservationDescription As Char
    Public TestName As Char
    Private TestResult As Char
End Class ' END CLASS DEFINITION Observation

' Static Model

Public Class Patient
    Public PatientId As System.Collections.ArrayList
    Public FirstName As Char
    Public SecondName As Char
    Public OtherName As Char
    Public BirthDate As Date
    Public DeathDate As Date
    Public Gender As Char
    Public Occupation As Char
    Public NextOfKin As Char
Public Religion As Char
Public Nationality As Char
End Class ' END CLASS DEFINITION Patient

' Static Model

Public Class Procedure
Private ProcedureId As String
Private ProcedureName As Char
End Class ' END CLASS DEFINITION Procedure

' Static Model

Public Class Referral
Private ReferralId As String
Private ReferralDescription As Char
Private DescriptionReason As Char
End Class ' END CLASS DEFINITION Referral

' Static Model

Public Class Visit
Private VisitDate As Date
Private PatientId As String
Private FacilityId As String
End Class ' END CLASS DEFINITION Visit

' Static Model

Public Class HealthFacility
Public FacilityId As String
Private FacilityName As Char
Private FacilityType As Char
Private FacilityTypeCode As String
Private FacilityBedCapacity As Integer
Private FacilityDate As Date
Private Latitude As Char
Private Longitude As Char
Private Datum As Char
Private LocationDate As Date

End Class ' END CLASS DEFINITION HealthFacility

' Static Model

Public Class HealthRelatedActivity
    Private HealthActivityCode As String
    Private ActivityName As Char
    Private ActivityDate As Date

End Class ' END CLASS DEFINITION HealthRelatedActivity

' Static Model

Public Class Intervention
    Public InterventionId As String
    Public InterventionName As Char

End Class ' END CLASS DEFINITION Intervention

' Static Model

Public Class Location
    Public VillageName As Char
    Public StreetName As Char
    Public SubLocationName As Char
    Public SubLocationCode As String
Public LocationName As Char
Public LocationCode As String
Public DivisionName As Char
Public DivisionCode As String
Public DistrictName As Char
Public DistrictCode As String
Public ProvinceName As Char

End Class ' END CLASS DEFINITION Location
Appendix 2: A Representation of the Public Health Data Model – PCDHM
Appendix 3: Average distances in meters of malaria case households from Siaya District Hospital (SDH).

<table>
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<th>Average distance (Metres): from SDH</th>
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<th>SMA (1)</th>
<th>ModMa (2)</th>
<th>MidMa (3)</th>
<th>UnCoMa (4)</th>
<th>Controls (5)</th>
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Appendix 4: Questionaire used During Enrollement for the Severe Malaria Study.
# ENROLLMENT FORM

Severe Malarial Anaemia Study

## PHYSICAL EXAMINATION

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<td>Dry tongue/mucous membrane</td>
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<td>Skin pinch goes back slowly (&gt; or = 2 seconds)</td>
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Blantyre Coma: Calculate score using Blantyre Coma tool

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Total

Scores

Comments for abnormalities:

DIAGNOSIS (check all that apply)

- Severe anaemia with malaria
- Uncomplicated malaria
- Severe malaria with respiratory distress

DIAGNOSIS (check all that apply)

- Other (specify)

DRUGS PRESCRIBED (check all that apply)

- Paradox
- Multivitamins
- Pyrimethamine/Sulfha
- Iron
- Quinine
- Paludrine/Paludrine

Other (specify)

Day 14 follow-up date: [Day] [Month] [Year]

Next follow-up date: [Day] [Month] [Year]

Examiner's signature: [Day] [Month] [Year]

Supervisor's signature: [Day] [Month] [Year]
## Appendix 5: Selected Health Facilities from Kisii Highlands

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Appendix 7: Some of the Regression Analyses and Malaria Case Surfaces created using Malaria Cases and NDVI for 3 Epochs

**February 2001:** \[ M_c = 311.473328 - 29.11678\text{NDVI} \quad r = -0.018021 \]

Malaria Case Surface: Malaria Cases Surface and NDVI
**May 2003:** $M_{c} = 411.861956 - 178.703207 \cdot NDVI \quad r = -0.067987$

**Regression Parameters:**
- $X$ axis: ndvi03
- $Y$ axis: mc
- Coef. of Det. $= 0.864$
- Std. Dev. of X $= 0.091581$
- Std. Dev. of Y $= 214.722399$
- S.E. of Estimate $= 214.255329$
- S.E. of Beta $= 6.167987$
- Test for Beta $= -45.085365$
- Test for Beta $^2$ $= -42.028077$
- Sample Size $n$ $= 985788$
- Apparent df $= 999726$

_Malaria Case Surface: Malaria Cases Surface and NDVI_
April 2005: \( Mc = 356.736888 + 13.214958 \text{NDVI} \) \( r = 0.005014 \)

Malaria Case Surface: Malaria Cases Surface and NDVI
### Appendix 8: A summary of F-test (comparing calculated versus tables)

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Appendix 9: Published Papers from this Research