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Spatial Data Infrastructure in Africa: A Technical and Institutional Analysis

By

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DECLARATION

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

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DEDICATION

To Nancy, Caren and Darren

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ABSTRACT

In Africa, National Spatial Data Infrastructures (NSDIs) are developing at a slower pace compared to the rest of the world. Information is scarce on the status of Spatial Data Infrastructure (SDI), appropriate development methodologies, and exposition of their social and economic benefits. With this in mind, this thesis set out to assess SDI development in Africa. The aim has been fivefold: to assess the status of SDI; to review technology trends that can support SDI development; to determine the socio-economic benefits of SDI; to develop a methodology for SDI development; and to propose a framework for SDI development in Kenya and similar developing countries. First, the SDI-Readiness model was used to assess the status of SDI in Africa, using primary and secondary data. Of the countries reviewed, the readiness indices were higher for Senegal (0.69), Rwanda (0.65), South Africa (0.64), Ghana (0.61) and Nigeria (0.58), and lower for Tanzania (0.33), Zimbabwe (0.33), Botswana (0.35), Malawi (0.38) and Ethiopia (0.41). At 0.56, Kenya's index fell in between. Overall, the study shows that financial and human resource constraints are the factors most inhibiting SDI development in Africa. Second, a survey of the literature was carried out to determine the reported socio-economic benefits and impacts of SDI development. Data was gathered from countries and regions where similar studies have been carried out, and generalised for application in the African context. The main reported benefits include monetary gains, benefits for citizens, user satisfaction, extension of services, openness and transparency, and improved decision making. Third, a simple geospatial application based on Google Cloud Services was developed in order to demonstrate the technology trends that can support SDI development. Data was obtained from the 2015 Kenya Certificate of Primary Education results, school mapping from 2007, and boundary layers from the Independent and Electoral Boundaries Commission. Subsequently, several operations common to SDIs were carried out. The study shows that cloud and newer technologies can increase uptake of SDIs, through highly scalable services. Fourth, a case study approach helped to develop a methodology for SDI development in Africa, using NSDIs from five countries: South Africa, Canada, Poland, Australia, and the USA. The methodology outlines the steps for successful SDI development: awareness; commitment building; policies; directives and action plans; institutional framework; funding and SDI implementation. Finally, the thesis proposes a framework for SDI development in Kenya and similar developing countries, taking into account the status of the Kenya National Spatial Data Infrastructure. Critical focus was placed on the institutional framework and the role of coordination. The main contribution of the study is to fill the gap in the existing body of knowledge on SDI, generally in Africa and particularly a framework for SDI in Kenya.

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ABBREVIATIONS

AFREF	African Geodetic Reference Frame
AICAD	African Institute for Capacity Development
ARSDI	African Regional Spatial Data Infrastructure
AWS	Amazon Web Services
BNSDI	Botswana National Spatial Data Infrastructure
CEDARE	Centre for Environment & Development for the Arab Region and Europe
CODI	Committee on Development Information
CODIST	Committee on Development Information, Science and Technology
CSW	Catalogue Services for the Web
DBMS	Database Management System
DoS	Director of Surveys
EC2	Amazon Web Services Elastic Compute
FGDC	Federal Geographic Data Committee
FIG	International Federation of Surveyors
FOSS	Free and Open Source Software
GCE	Google Compute Engine
GCS	Google Cloud Services
GDAL	Geospatial Data Abstraction Library
GEOS	Geometry Engine – Open Source
GeoTIFF	Geographic Tagged Image File Format
GI	Geographic Information
GKE	Google Container Engine
GML	Geography Mark-up Language
GSDI	Global Spatial Data Infrastructure
HTML	Hypertext Mark-up Language
HTTP	Hypertext Transfer Protocol
ICT	Information and Communication Technologies
IEBC	Independent Electoral and Boundaries Commission
IEC	International Electro-technical Commission
II	Information Infrastructure
INSPIRE	Infrastructure for Spatial Information in the European Community
ISK	Institution of Surveyors of Kenya
ISO	International Organization for Standardization
JICA	Japan International Cooperation Agency
JPEG	Joint Photographic Experts Group File Interchange Format
JSON	JavaScript Object Notation
JTS	Java Topology Suite
KCGC	King County GIS Centre
KCPE	Kenya Certificate of Primary Education
KML	Keyhole Mark-up Language
KNBS	Kenya National Bureau of Statistics
KNSDI	Kenya National Spatial Data Infrastructure

KPGIS	Kenya Profile for Geographic Information Standards
LIMS	Land Information Management System
LSFSDI	Large Scale Framework Spatial Data Infrastructure
MAFA	Mapping Africa for Africa
MOEST	Ministry of Education, Science and Technology
MoL	Ministry of Lands
NASA	National Aeronautics and Space Administration
NLC	National Land Commission
NMO	National Mapping Organisations
NSC	National Research Committee
NSDI	National Spatial Data Infrastructure
NTS	NetTopologySuite
OGC	Open Geospatial Consortium
OSM	OpenStreetMap
PNG	Portable Network Graphics
RCMRD	Regional Centre for Mapping of Resources for Development
RDF	Resource Description Framework
RECTAS	Regional Centre for Training in Aerospace Surveys
REST	Representational State Transfer
RM-ODP	Reference Model of Open Distributed Processing
SASDI	South African Spatial Data Infrastructure
SDI	Spatial Data Infrastructure
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
SoK	Survey of Kenya
SPARQL	Simple Protocol and RDF Query Language
SQL	Structured Query Language
SVG	Scalable Vector Graphics
ToR	Terms of Reference
UNDESA	United Nations Department of Economic and Social Affairs
UNECA	United Nations Economic Commission for Africa
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
USAID	United States Agency for International Development
WCS	Web Coverage Service
WG	Working Group
WIFI	Wireless Fidelity
WFS	Web Feature Service
WMS	Web Map Service
WMTS	Web Map Tile Service
WPS	Web Processing Service
WWW	World Wide Web
XML	eXtensible Mark-up Language
XSLT	eXtensible Stylesheet Language

1 INTRODUCTION

1.1 Background

There is increasing recognition that spatial data play a critical role in the economic growth and development of countries, in effect promoting the implementation of policy and development initiatives [1]–[3]. Various studies have shown that a large percentage of information used in the planning process has a spatial component [4], [5]. While many countries globally have embraced and continue to improve their National Spatial Data Infrastructures (NSDIs), most countries in Africa are lagging behind.

Spatial (geographic, geospatial, or location) data includes the position, shape, size, orientation and other information about phenomena in a given space [6]. This data is now regarded as a key driver supporting decision-making [7], complementing the conventional trio of social, economic and environmental drivers. Although numerous definitions of spatial data can be found in the literature, all focus on associating locations in some reference system with the properties of those locations [8].

Spatial data includes geodetic, topographic and cadastral information, satellite imagery and orthophotographs, statistics on demographics, transportation, location and delineation of game parks and reserves, among other data types.

At present, there are many challenges confronting mankind most of which can be associated with a location. Social conflict, urbanisation, rural development, climate change, devolution, decentralization and disaster management are among such challenges. The ability to add location to the existing information unlocks the wealth of existing knowledge, and plays a pivotal role in understanding and addressing the challenges [9].

Geospatial data is usually stored in computer systems as raster or vector formats with topology and manipulated by information systems, such as a Geographic Information System (GIS). A GIS comprises of hardware, software, people, and procedures that facilitate the acquisition, storage, management, manipulation, analysis, modelling, display, and representation of spatial data [10]. Most GIS use geometric entities such as points, polygons, lines, surfaces and tessellations to represent data [11].

The evolution of GIS technology has seen progression from project and departmental GIS that dominated the early days, to contemporary enterprise, community and participatory GIS which provide access for the public. As standalone systems, GIS are neither efficient nor effective. If organisations maintain their GIS in silos – commonly known as ‘island of systems’, duplication of effort in data collection and maintenance would be commonplace. Data, information and knowledge in diverse organizations would become trapped in silos due to different syntax, semantics, data structures, platforms, software and human resource capacity. The nature of geospatial data is such that some datasets, which include foundation and framework data, are always required irrespective of the system or application in use [12].

The concept of Spatial Data Infrastructure (SDI) emerged in the nineties, primarily to facilitate sharing and collaboration over spatial data. Boundaries may create communication and collaboration barriers amid organisations, limiting their interaction. In addition, organisations working independently on spatial data collection and maintenance risk duplication, poor distribution of information and knowledge, operational inefficiencies and weak communication and collaboration. SDI is essentially the facilitation of spatial data sharing and exchange between stakeholders to solve societal problems [13].

The need for SDI arises mainly from the demands of the information society, in which the dominant activity is the creation, gathering, storage, processing and distribution of information. If sharing is to succeed, there has to be a high level of collaboration amongst the participants. Mature SDIs are now supporting the spatial enablement of societies [7], [9], and smart cities [14], further increasing the need for spatial data sharing. Compared to GIS, SDI are more complex since they are controlled by a distributed set of stakeholders in diverse agencies [15].

An SDI may provide numerous services, including catalogues of information and services, search by various criteria (such as geographic names), visualization of maps, spatial operations and other geographic information (GI) capabilities and functionalities, and download services.

From the year 2000, SDI development has shifted from data-centred to user-centred model. The latter consists of an active user community which collaborates to use and improve the SDI. To facilitate sharing between many users, SDI has to address and coalesce a wide range of issues such as standards, policies, financial, data, technology and people necessary to ensure the availability of spatial data [13]. SDIs can be scaled to operate at the local, national, regional and even global levels [16].

The development of SDI is an important prerequisite for the efficient management of scarce resources, such as land [1], [3], [17]. The benefits being realised by societies which invest in SDI include economic development, better decision making, new markets, social stability, improved planning, reduction in resource disputes, improved environmental management and the land administration system [13], promotion of technology advances, and steering agencies and organizations to working together.

Despite their numerous benefits, the status of SDI in Africa is still very weak [18]. Existing initiatives tend to focus on the relatively shaky and fragmented SDIs by specific countries, for example [3], [4], [12]. Musinguzi *et al.* and Mulaku *et al.* posited that lack of funds, human capital, spatial datasets, standards, metadata and information sharing policies are some of the challenges hindering SDI development in Africa [3], [12]. At the same time, IT, science and technology, which form the backbone of SDI, continue to advance rapidly [9], [19]. This could offer African countries the opportunity to advance in their SDI development by leveraging the new advances without recourse to older technologies [20].

1.2 Statement of the Problem

That spatial data is significant to economic development is best illustrated by the predicament that the Kenya Revenue Authority (KRA) faced as it tried to widen its tax base in 2013. One of the sectors expected to fill the revenue deficit was the booming real estate sector. The agency acknowledged the contribution of spatial data, but had abandoned plans to procure its own system betting on wider efforts by the government to launch a Land Information Management System (LIMS) [21], [22].

SDIs have enormous potential, such as promoting economic development, facilitating better decision making and supporting a wide range of planning initiatives [13]. When the data and services in an SDI trickle down to citizens, the SDI becomes an Information Infrastructure (II). An II can facilitate platforms that transform societies to virtual communities, giving citizens an opportunity to participate in decision making for socio-economic development.

With the exception of South Africa, and more recently Rwanda, few African countries have made significant progress in SDI development. This is likely because SDI as a concept has not been well understood. It is also possible that due to its complex nature as an II, the methodology being followed by African countries is not appropriate. IIs tend to be more complex to build and operate, and a careful approach is needed in their design [15].

Consequently, there exists a gap since the status of national SDI (NSDI) in Africa remains weak and unknown. There are few visible results several years after their inception, resulting in scanty information on SDI in Africa. The obstacles to Africa’s adoption of SDI, and the prospective consequences of SDI adoption, needs to be probed. Finally, Africa needs to explore the lessons and best practices from mature SDIs - mostly in developed countries [12].

The study seeks to bridge this gap, by highlighting the status of SDI in Africa and the challenges it faces. In the process, the study seeks to answer the following research questions.

a) What is the status of national SDI in Africa?
b) How is SDI important for socio-economic development in Africa?
c) How can technology trends support SDI development in Africa?
d) What SDI implementation methodology is suitable for Africa?
e) What is the framework for SDI development in Kenya?

1.3 Objectives of the Study

In answering these research questions, the study aims to fulfil the following objectives.

a) Establish the current status of national SDIs in Africa
b) Identify the socio-economic benefits and impacts of SDI in Africa
c) Outline technology trends that could support SDI development in Africa
d) Recommend an SDI implementation methodology for Africa
e) Develop a framework for SDI development in Kenya

1.4 Conceptual Framework

The conceptual framework highlighting the study objectives, key variables, methodologies to achieve the objectives, and linkages between the objectives is highlighted in Figure 1.1. Basically, the first three objectives i.e. *status of SDI in Africa*, *socio-economic benefits and impacts of SDI* and *technology trends for SDI* contribute to the developed methodology for SDI in Africa. Based on the latter, a framework for SDI development in Kenya is derived.

1.5 Organisation of the Thesis

This thesis is divided into seven chapters, including this introductory chapter. Except for chapters one, six and seven; each of the other chapters addresses a specific research problem and contains literature review, methodology, results and conclusions.

Chapter One contains the background to the study, problem statement and research objectives. It closes with this outline of the organisation of the thesis.

Using the SDI-Readiness methodology, Chapter Two establishes the status of SDI in Africa. It also presents the status of key SDI components (such as spatial data, standards, and metadata), the perceptions on core spatial datasets, and recent developments of geoportals in Africa.

Chapter Three identifies the socio-economic benefits and impacts of SDI development. This involves an extensive review of literature to determine their costs, and possible socio-economic benefits and impacts.

Chapter Four outlines the technology trends that can support SDI development in Africa. Technology is one of the key drivers of SDI, and one of its most dynamic components. Based on a geospatial application in the cloud environment, the chapter highlights some of the trends that African countries can embrace to support SDI development.

In Chapter Five, a methodology for SDI in Africa is developed. This is one of the most important chapters in this thesis because it attempts to develop a methodology for SDI in Africa, which has been rather elusive. The chapter follows a case study approach based on five countries: Canada, USA, South Africa, Poland and Australia.

Chapter Six provides a framework for SDI development in Kenya and similar developing countries. Finally, Chapter Seven concludes the thesis by outlining recommendations and contribution of the study, including areas for further research.

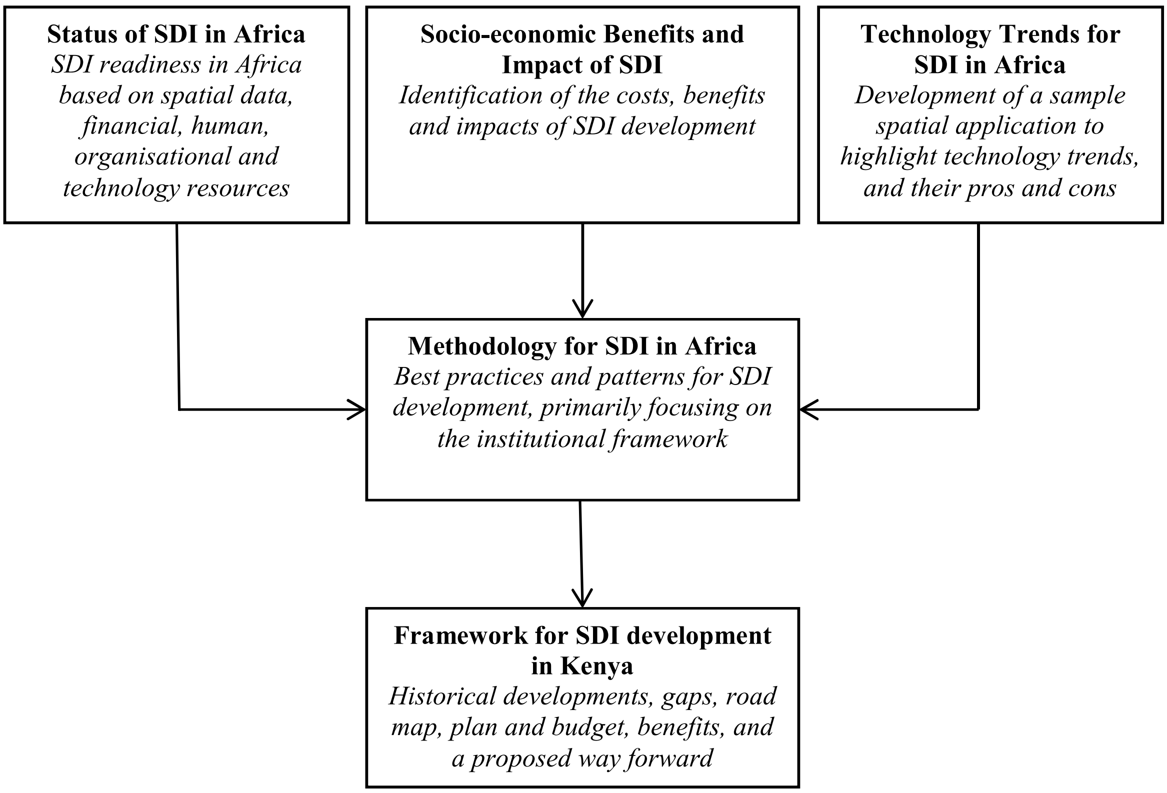

Figure 1.1: Conceptual Framework

2 STATUS OF SPATIAL DATA INFRASTRUCTURE IN AFRICA

Chapter Summary

It is widely recognised that Spatial Data Infrastructure (SDI) play a major role in the social and economic development of a country. Accordingly, several countries have initiated and continue to improve their national SDI (NSDI). Unfortunately for Africa, many countries have little to show for their NSDIs several years after their inception.

This chapter reviews the status of SDI in Africa, based on a survey conducted between April and October 2014. Web searches and data from the United Nations Department of Economic and Social Affairs (UNDESA) E-Government survey of 2014 supplemented the study.

First, an SDI literature review was carried out with a special focus on Africa. Second, primary data was collected through a questionnaire, with respondents drawn from the academia, public, private and research institutions. Third, secondary data was obtained from the UNDESA Survey. Finally, SDI-Readiness indices were computed using the SDI-Readiness methodology.

Of the twelve countries reviewed, comparatively higher indices were established for Senegal (0.69), Rwanda (0.65), South Africa (0.64), Ghana (0.61) and Nigeria (0.58), while lower indices applied for Tanzania (0.33), Zimbabwe (0.33), Botswana (0.35), Malawi (0.38) and Ethiopia (0.41). Overall, West African countries (0.63) outperform their counterparts in East Africa (0.46) and South Africa (0.46). Kenya's index of 0.56 is intermediate. Because no responses were received from Central and Northern Africa, the study fills the gap by reviewing literature on SDI activities in selected countries from these regions.

Countries with higher indices, which is a proxy for the capacity and willingness to develop an SDI, have a better chance of success in SDI development. Although South Africa's index is lower than Senegal's, the former has a more mature NSDI. The difference is that South Africa has consistently set aside resources for SDI development over the past decade, culminating in a reasonably modern geoportal and a strong legal and policy framework.

The study suggests that more emphasis should be placed on improving the human and financial resources devoted to SDI if Africa is to succeed in the realm. Although the presence of geoportal is not necessarily an indicator on the maturity of an SDI, the fact that Rwanda launched its SDI portal in July 2015 validates the results of the study.

2.1 Introduction

2.1.1 Background

The concept of SDI can be traced to the seminal work of John McLaughlin in 1991 [23], who may have coined the term. In 1993, the United States of America's National Research Committee (NSC) recognised the need for sharing and reuse of data [24], primarily to reduce duplication in data collection and management.

SDI emerged in a period characterised by rapid advances in Information and Communication Technologies (ICT). In tandem with societal challenges and needs such as sustainable development and environmental conservation, these advances shaped the early definition and understanding of SDI. Clinton, through Executive Order (EO) number 12906 [25], argued that technology permits improved collection, dissemination, and usage of geospatial data.

Until very recently, most National Mapping Organisations (NMO) specialised in the production of analogue maps, whose consumption was limited to a few application areas drawing its clientele mainly from the local and national governments. With the new technology, the paper maps can be replaced with digital GI. The latter is easier to maintain, manage and distribute through products and services that can serve a wide audience, including ordinary citizens.

Unfortunately, in developing countries such as Kenya [26], Rwanda [4] and Botswana [24], the new digital information is still inhibited by incomplete and out-of-date datasets, inadequate documentation, lack of compatibility among datasets, inconsistencies in data collection, and barriers such as culture, language, finances, technology and human resources [17]. Most countries have found it difficult to obtain the political support needed for successful SDI development [27].

According to the South African Spatial Data Infrastructure Act, an NSDI is defined as "the national technical, institutional and policy framework to facilitate the capture, management, maintenance, integration, distribution and use of spatial information" [28]. On the other hand, the United States of America through Executive Order number 12906 defines an NSDI as "the technology, policies, standards, and human resources necessary to acquire, process, store, distribute, and improve utilisation of geospatial data" [25].

The preceding paragraph highlights two examples of SDI definitions from the multitude available in the literature, which are so vast that Hendriks *et al* [29] classified two elements that can be used when defining SDI: a description of SDI components such as standards or databases, and a listing of SDI objectives such as efficient data access or elimination of data duplication. It is important to note that SDI is multifaceted, complex and dynamic in nature, resulting in different researchers, practitioners and even countries understanding the concept differently.

The definition adopted in this thesis is advanced by the SDI Cookbook, which defines an SDI as "the relevant base collection of technologies, policies and institutional arrangements that facilitate the availability of and access to spatial data" [30]. The Cookbook further expands the definition: "SDI provides a basis for spatial data discovery, evaluation, and application for users and providers within all levels of government, the commercial sector, the non-profit sector, the academia and by citizens in general". This definition is broad enough to be applied in the study context, because it highlights the importance of SDI components including core spatial data, technologies, policies and institutional arrangements.

To be useful to multiple users including citizens, groups and organizations that span the local, national, regional, and even global levels, spatial data should be embedded in a broader infrastructure of physical, virtual, and organizational structures [29]. It requires a high level of coordination, cooperation, and standardisation, to enable integration of data from diverse sources. It also provides a framework for coordinated information development and sharing.

In practice, SDIs are large-scale systems, with scope extending to the local, national, regional, and the global, hosting spatial data, adequate documentation, and a means to search, evaluate, access, and use the data [31]. The SDI must also include the organizational agreements needed to coordinate and administer it at the various levels [26].

2.1.2 Statement of the Problem

If Africa is to achieve rapid and sustainable economic development, information infrastructures (IIs), such as SDIs, are needed to record a variety of data on the environment, socio-economic rights, encumbrances and land uses [13]. In addition, SDIs provide the spatial data needed to facilitate appropriate decision-making.

With the exception of South Africa, few African countries have made significant progress with their NSDIs. The success of South Africa's Spatial Data Infrastructure (SASDI) can be partly attributed to the willingness of the government to provide sustainable funding [32]. Often, it is not technical issues that derail development of spatial information systems, but rather the cultural, political, social and institutional contexts in which the system is implemented [33].

Despite a conducive environment in some countries, such as technical and administrative support, political will, availability of resources, and readiness to develop SDI [3], [4], [24], few tangible results have been achieved several years after SDI inception.

This chapter seeks to examine the status of SDI in selected African countries, with a view to answering the research question: *What is the status of SDI in Africa*?

Makanga and Smit [1] undertook a similar study highlighting status of SDI in Africa in 2009, using a methodology similar to INSPIRE's state of play. This study uses a different methodology, the SDI-Readiness methodology, to present the status in 2014. This latter study not only portrays another dimension to SDI assessment, but also highlights recent progress in SDI development in Africa over the period 2009 – 2014.

2.1.3 Research Objectives

In answering the above research question, the study has reviewed the current status of SDI in Africa, in terms of policies, standards, access networks, data sharing and procedures.

The research objectives were:-

- review the readiness of African countries to implement their SDI,
- measure the perception of African countries on core datasets,
- analyse the development of SDI clearinghouse portals in Africa

2.1.4 Organization of the Chapter

The chapter is structured into four sections, including this introductory section, and appendices. Section 2.2 reviews literature on SDI, focusing more specifically on SDI in Africa and methods for SDI assessment. In section 2.3, the study methodology is presented, including the sampling data collection strategies. Results, discussions and conclusions from the study are presented in section 2.4. Appendix 1 presents the questionnaire used in the study.

2.2 Literature Review

2.2.1 Review of Spatial Data Infrastructure in Africa

The dream of a functioning SDI in Africa has been there for a long time since information requirements for sustainable development require integrating diverse datasets into an SDI [33]. SDI enables the interchanging and integration of spatial data to sustain a more integrated approach to sustainable development. SDI is so important to the contemporarily transforming world: nations which possess a progressive SDI would register improved trade and economic development than those which still rely on traditional forms of information management [34].

Generally, most African countries have inadequate SDI policies, standards and guidelines, with most agencies still independently collecting spatial data that support specific projects [3, p. 792], [24]. This results in duplication in spatial data collection and management, poor data quality, and lack of standards to guide the stakeholders, among other challenges.

The Nairobi statement on spatial information for sustainable development [33] was one of the pioneer initiatives that set the scene for SDI in Africa. The statement made several important recommendations, a few of which may have been embraced by African countries. These were:-

- formation of steering groups that would formulate policy and institutional frameworks;
- solutions starting with realistic objectives that grow through political and market needs;
- establishment of regional co-operation to support cross-border and common interests

At the continental level, the United Nations Economic Commission for Africa (UNECA) is an institution that promotes geospatial initiatives in Africa, through raising awareness, supporting implementation of relevant policies, authoring the Africa SDI Handbook and advocating for the African Regional Spatial Data Infrastructure (RSDI) [35], [36]. The first Committee on Development Information (CODI) meeting in 1999 - CODI I resulted in a resolution to develop geospatial data infrastructures in Africa [35]. Two years later, CODI II reinforced SDI through several recommendations:-

- SDI should be made an integral part of ICT policies, strategies and plans;
- Member states should establish their NSDI with all the necessary components; and
- SDI policies, and institutional, legal and technical frameworks should be developed.

The Committee on Development Information, Science and Technology (CODIST) was formed as a successor to CODI. The main role of CODIST is to assess the factors hindering ICT, geoinformation, science and technology in Africa.

2.2.2 Status of SDI in Selected African Countries

A review of the literature reveals that most African countries have little to show for their NSDI many years after inception [3], [4], [12], [17], [24], [26]. Adapted from Mulaku *et al.* [12] and expanded based on data from additional sources, Table 2.1 highlights the approximate years of SDI inception in various African countries. For each country reviewed, the table also presents an assessment of the SDI status based on literature reviews and web searches.

Table 2.1: SDI inception epochs in selected countries

Approximate Date of SDI Inception	Country	Status of SDI (year 2014)
1996	Algeria	Average
1996	Senegal	Good
1997	South Africa	Very Good
1998	Ghana	Average
2001	Botswana	Average
2001	Kenya	Average
2002	Ethiopia	Average
2002	Mali	Average
2002	Nigeria	Good
2003	Tanzania	Average
2003	Uganda	Average
2006	Libya	Average
2006	Rwanda	Very Good

Uganda: The Government of Uganda has designated the National Planning Authority (NPA), which falls under the Ministry of Finance and Economic Planning, as the lead agency to coordinate the development of the Uganda NSDI (UNSDI) [37]. As at 2016, there was no policy, legal framework or standards to guide the UNSDI.

Table 2.2 presents a listing of topographic map coverage in selected African countries, including Uganda. In many countries, the 1:50,000 mapping series that usually serves as base map in SDIs is either out of date, or incomplete [38].

Musinguzi *et al.* [3] reviewed the status of the UNSDI using a matrix methodology, by comparing information on spatial data ownership, maintenance, use, geographical distribution, institutional mandates and data duplication. The study revealed that most spatial data not only existed in analogue format, but also exhibited variations in critical quality factors such as projection systems.

Table 2.2: Topographic map coverage in selected countries

Country	National Coverage
Uganda	100% coverage at a scale of 1:50,000. Produced between 1964 and 1969
Kenya	85% coverage (1:50,000 in populous areas; 1:100,000 in more remote areas)
Tanzania	95% coverage at 1:50,000 produced in the 1960's and 1970's
Rwanda	100% coverage 42 1:50,000 topographic maps, published between 1986 and 1989
Burundi	100% coverage 42 1:50,000 topographic maps, produced between 1980 and 1983

South Africa: South Africa has consistently devoted the resources required to develop its NSDI, the SASDI. As early as 1997, the National Spatial Information Framework (NSIF) had been established, representing the SDI initiative at the time [39]. A comprehensive legal framework, the Spatial Data Infrastructure Act No 54 [28], has established the SASDI. However, the Committee for Spatial Information (CSI) only began to operate in 2010. More recently, the Pricing of Spatial Information Products and Services [40] and the Base Data Set Custodianship policies [41] were ratified. Despite these progressive strides in South Africa, several challenges have been reported, including the lack of capacity at provincial and municipal levels, under-representation of the private sector, and resistance to change [42]. This serves to underlie that SDIs are large-scale and long-term initiatives that improve with time.

Botswana: Since the early 1990's, Botswana recognised the need for a coordinated approach to spatial data management. It was one of the first African countries to establish a national coordination committee [32], indicating early recognition of the need for SDI. Several systems towards this objective were initiated, notably the Integrated Geographic Information System, State Land Information Management System, and the Tribal Land Management Information System [24]. The need to integrate these systems may have given impetus to the Botswana National Spatial Data Infrastructure (BNSDI). However, the BNSDI has been developing slowly, which can be attributed to its starting off on a much wider scope [24]. This may appear to contravene the recommendations of the Nairobi Statement on Spatial Information for Sustainable Development [33]. In spite of this, Botswana's Digital Information Policy was approved by its cabinet in 2015, with reports indicating that the e-Government initiative has re-invigorated the BNSDI.

Rwanda: The awareness of the importance of GI in Rwanda was emphasised by the NSDI conference held in 2006 [4]. Prior to the conference, the government had recognised that GI is vital for socio-economic planning and development. Rwanda experienced several problems while developing its NSDI, such as institutional, human resources and technical challenges [17]. However, July 2015 saw the launch of the country's SDI geoportal, reflecting the important progress over NSDI. In addition, Rwanda is one of the few countries in Africa with a substantial availability of spatial datasets in digital format. Recent reports indicate that Rwanda has 10.3 million parcel records, and orthophotographs developed between 2008 and 2009, covering 96% of the country at 0.25m resolution [43]. Other milestones include strengthening institutional and organisational frameworks, evidenced by the National Geo-Information Committee (NGIC) I and II meetings held in 2013 and 2014.

Ghana: In an attempt to ascertain the problems facing land administrators in Ghana, Karikari *et al.* [17] established that land-sector agencies in the country needed reorganisation to improve efficiency in service delivery. They suggested the identification and correction of inefficiencies, bottlenecks, duplication, weaknesses, threats, and opportunities in each agency. In 2015, the Ministry of Lands and Natural Resources through the Land Administration Project (LAP) furnished funds for the development of a National Spatial Development Framework (NSDF) for the entire country from 2015 to 2035 [44]. The NSDF is expected to provide support towards development of Ghana's NSDI, which is supported by the same project.

Algeria: The definition and promotion of Algeria's NSDI is led by the National Geographic Information Council (CNIG), which aims to integrate GI policy with the country's information society and digital economy agenda, including the NSDI. In 2015, its government set up a high-level national committee under the leadership of CNIG, to develop the national strategy for the development of the country's NSDI. The NSDI is expected to facilitate the exchange of information and promote widespread use in diverse areas such as defence, security, health, transport of energy and education.

Namibia: In 2015, the government of Namibia approved a policy to guide the establishment of its NSDI. Earlier, section 47 of the Statistics Act No. 9 (2011) had established a committee for spatial data [45]. The committee, comprising of 10 members including the Surveyor General (who acts as the Chairperson) and the Statistician General, came into effect in 2013. The primary responsibility of the committee is to determine data custodians, but it also acts as an authority on NSDI standards [45].

Nigeria: The agency mandated to coordinate SDI development in Nigeria is the National Space Research & Development Agency (NASRDA) [36]. Some researchers, notably Tumba and Ahmad, have questioned the ability of NASRDA to lead the country's NSDI [46]. However, a draft policy has been prepared, which aims to ensure development, implementation and optimal use of geospatial information. Nigeria actively participates in continental activities, such as the

African Geodetic Reference Frame (AFREF).

Kenya: Kenya has made considerable progress with its NSDI, the Kenya National Spatial Data Infrastructure (KNSDI). However, the KNSDI geoportal, the face of an SDI, was not accessible at the time of review. A study by Mulaku *et al*. [12] found out that most geospatial data not only existed in analogue format, but also lacked temporal accuracy. In spite of these drawbacks, several achievements have been made. For instance, some KNSDI standards have been established, along with digitization manuals and guidelines for data sharing [47]. The KNSDI draft policy, which will form the basis for legal and institutional frameworks for KNSDI management, has been developed. However, it is not clear when this policy will be approved. Progress has also been made by relevant agencies: for instance, the Survey of Kenya reported a program of updating topographic map sheets since June 2008 [47].

Ethiopia: In 2009, the Ethiopian Mapping Agency drafted the Ethiopian National Spatial Data Infrastructure (ENSDI) policy, which is expected to provide a framework for the collection, integration, archiving, distribution, use, and sharing of geospatial information. In 2011, the Ethiopian Information Network Security Agency (INSA) established a geoportal to monitor the collection, processing and dissemination of imagery. Since 2014, the ENSDI's mandate has been moved to INSA, which has continued to develop the draft polity, aside from organising a number of workshops. In 2015, INSA was in the process of establishing working groups to facilitate development of the ENSDI components.

Zambia: Previous efforts to establish Zambia's NSDI stalled, due to lack of funding. The Environmental Support Programme was one of the earlier efforts, resulting in development of mapping standards. In 2010, the country held a GIS stakeholders' meeting where a committee was established to spearhead revival of the NSDI. Through e-Government support programmes in 2012, the secretary to the cabinet called a meeting to discuss interlinking all government departments. In 2014, NSDI was established as part of the land audit programme [48], resulting in the aerial photography of 1,800 square km at 0.10m resolution in the main cities, and 36,500 square km at 0.20m resolution for the State Land Areas.

Malawi: In Malawi, the need for coordination of production and management of spatial data arose as early as 1990 [49]. Recent efforts have been geared towards the establishment of the Malawi Geographic Information Council (MAGIC) and a National Spatial Data Centre (NSDC) to coordinate the acquisition and sharing of geoinformation, and to support the development of the NSDI [49]. Some of the challenges that Malawi faces in pursuit of its NSDI include inadequate funding, human resource capacity and legal constraints. A key legal instrument (the Land Bill) has not been ratified, thus affecting development of the NSDI.

Tanzania: The efforts to establish Tanzania's NSDI can be traced back to 2003, when a steering committee was set up to oversee its development. Apart from a SDI draft policy prepared in 2005, little progress has been reported to-date [50]. The main factors contributing to the slow development of the NSDI include the lack of awareness on SDI, lack of an SDI policy, limited funding, lack of institutional leadership, and lack of political commitment.

Senegal: An agreement was signed between Senegal and Canada in 2009, for the establishment of a project to support the development and implementation of Senegal's National Geomatics Plan [51]. To ensure effective implementation of the project (scheduled from 2009 to 2015), Senegal has set up a Consultative Group on Coordination and Geomatics. The project has six components: strengthening of the spatial reference system; development of a geo-directory; development of a web-based geospatial database; implementation of GIS in priority areas to demonstrate their benefits; training; and communication [51].

Overall Review: A review on the status of SDI in Africa was carried out in 2009 by Makanga and Smit, using a multi-view SDI assessment framework similar to INSPIRE's state of play [1]. The study, which was based on four viewpoints, namely organisation, funding, legal frameworks and technical capacity [52], showed that Africa had only three geoportals at the time, in Kenya, Chad, and South Africa. The study further noted a large number of informal SDI projects in Africa, advanced by private enterprises, donors, and international organisations. That Kenya's geoportal has ceased to operate puts to question the sustainability of SDIs in Africa. Table 2.4, sampled from country reports presented at the regional NSDI forum held in Rwanda in July 2015, highlights additional issues affecting SDI development in Africa. Additionally, Table 2.3 presents some of the recent SDI activities in selected countries in Africa.

Another recent review on the status of SDI in Africa was carried out by Guigoz *et al.* following a methodology similar to INSPIRE's state of play in combination with Eelderink's fourteen indicators for assessing NSDIs in developing countries [18]. The study revealed that:

- Africa has the lowest ranking in most SDI variables assessed;
- Africa has very weak SDI status;
- SDI monitoring on the African continent is not yet reliable; and
- Lack of political will to implement SDI is prevalent across Africa.

Table 2.3: Recent SDI activities in selected countries

Country	Recent SDI activities
Botswana	Digital information policy approved by the Cabinet in March 2015
Ethiopia	Received technical assistance from Namibia in 2015 in preparation for census mapping
Ghana	The 20-year National Spatial Development Framework (2015-2035) was approved in 2015
Kenya	Construction of the Kenya Geospatial Data Centre was completed in 2015
Malawi	Three-day workshop held in 2015 to present the atlas and GIS database
Nigeria	A large-scale SDI for the Nasarawa state was completed in 2015
Rwanda	Launched its national SDI geoportal in July 2015
Senegal	An Open Data workshop on access to Geospatial Data was held in September 2015
South Africa	Pricing and dataset custodianship policies were ratified in March 2015
Tanzania	In 2012, Tanzania initiated a project to develop an Integrated Land Information System
Zambia	NSDI Committee appointed by the Secretary to the Cabinet in June 2015
Zimbabwe	In 2015, the Zim-geospatial tool was created to pool geospatial data from multiple sources

Source: GSDI, and Country reports presented at the regional NSDI Forum, Kigali, Rwanda (July 2015)

Possibly realizing that African governments are not doing enough to aid SDI development, Tumba and Ahmad recommended a bottom-up approach [46], which is also recommended by other researchers, such as Makanga and Smit [1], due to the copious informal SDI activities in Africa. Additionally, advances in ICT have given rise to emerging trends, such as Volunteered Geographic Information (VGI), which typically thrive on bottom-up approaches [19].

In practice, however, a balanced top-down in combination with bottom-up approach could be more sustainable for Africa in the long run.

Perhaps the state of SDI in Africa is not gloomy after all, if the work of Chan and Williamson is anything to go by [53]. Using Australia as a case study, they argued that SDI development follows the same pattern as that of any corporate GIS, with the only difference being special partnerships and standardization to make data sharing possible. Agencies developing SDI in Africa may need to review any informal SDI activities, while expanding and incorporating them in the overall NSDI agenda.

Table 2.4: Challenges and Achievements of SDI in selected countries

	Botswana	**Rwanda**	**South Africa**
Lead agency	Department of Surveys and Mapping	Rwanda Natural Resources Authority	Department of Rural Development and Land Reform
Institutional Arrangements	National Geographic Committee (NGCC) is the overseeing committee NGCC established 6 working groups • Education and Training, Standards, Institutional Framework, Architecture and Infrastructure, Metadata and Fundamental Datasets	Key institutions: • Rwanda Natural Resources Authority and Office of Registrar of Land Titles • Department of Lands and Mapping • Ministry of ICT and RDB • Sector Ministries – sectoral data • Educational institutions	Stakeholders mainly from the public sector and the academia Four Working Groups: policies, standards, marketing & education SDI Act establishes the Committee for Spatial Information (CSI) • The CSI Appoints data custodians The National Spatial Information Framework (NSIF):- • Provide administrative support to the CSI, Assist CSI monitor adherence to the act & policies, Provide support to custodians and state organs and Serves as the secretariat to the CSI
Challenges	• Weak institutional arrangements • Incompatible datasets • Lack of metadata and standards • Capacity building at all levels • Data duplication • Technology acquisition and maintenance • Poor NSDI coordination	• Lack of SDI policy, legal and institutional frameworks • Lack of data standards • Data custodians not yet identified • Most data produced by consultants • Data security concerns • Data in different projection systems • Poor data sharing culture	• Appointment process taking longer, poor attendance of meetings, ICT Infrastructure issues • Bureaucratic processes take too long • Budget limitations • Securing broad-based buy in • Resistance to approved policies • Lack of capacity at lower government levels, e.g. provincial • Low involvement of the private sector
Achievements	• Interim committee appointed • Draft data sharing policy prepared • Continuously Operating Reference Stations to support SDI • Important datasets have been developed	• NGIC I&II successfully executed • Buy-in from key government officials • Capacity building - awareness and training • Metadata creation from various institutions • NSDI draft concept paper in place • Launch of the Rwanda Geo-portal • Clear vision and road map	• SDI Act and various policies (pricing, custodianship) are in place • Clear institutional framework • Custodians have been identified, and their roles defined • Procurement of standards from the South African Bureau of Standards to implement policies • Various portals - SASDI, CSI, EMC, and the Data Capture Project Register (DCPR) are available • Clear vision and road map

Source: Country reports presented at the regional NSDI Forum, Kigali, Rwanda (July 2015)

2.2.3 Assessment of SDIs

There are several SDI assessment methodologies with differing degrees of maturity and purpose. Notable examples include the SDI-Readiness [54], Clearinghouse Suitability [55], [56], State of Play [57], Organizational (Institutional) [58], Performance-Based [59] and Cadastral [60]. The salient features of these methodologies are summarised in Table 2.5.

The SDI-Readiness methodology has been selected for use in this study for several reasons. First, the methodology, according to the current literature, has not been used extensively in SDI assessment studies in Africa. Second, the study by Makanga and Smit [1] used a methodology similar to INSPIRE's state of play; so by using the SDI Readiness methodology, this study presents a different perspective to SDI assessment in Africa. Third, the methodology fits not only within the study objectives, but also in the study context since most countries in Africa did not have mature SDIs at the time of writing this thesis in 2016.

2.2.4 Summary of Literature Review

From the literature reviewed, the issues affecting SDI in Africa can be summarized as follows:

- low mapping coverage, resulting in lack of data, and outdated data;
- lack of standards, resulting in low inter-operability between datasets;
- lack of cooperation between agencies resulting in redundant production of data;
- lack of metadata giving rise to poor use of data;
- lack of qualified human resources;
- lack of financial resources;
- poor prioritization and lack of political will; and
- lack of policy and legislation.

Together with the fact that there is no strong regional body in charge of coordinating and setting standards for SDI in Africa, the above factors have derailed SDI development in Africa.

Table 2.5: Common multi-view methods for assessing SDIs

Method	Maturity	Purpose / Description	Purpose	Measurement
SDI-Readiness	High	Uses five factors (information, people, financial resources, and organization and access networks) to assess the readiness of a country to develop and use SDI.	Knowledge and developmental evaluation.	Survey
Clearinghouse Suitability	High	Measures the global development and impact of SDI geoportals.	Knowledge and developmental evaluation.	Surveys, web crawlers, and key informants
State of Play	High	Measures the status and development of SDIs using information on the status of six factors (fundamental and framework data, metadata, legal framework and funding, access and other services, standards and thematic environment).	Developmental Accountability	Utilises country reports, surveys, web crawlers and key informants.
Organizational (Institutional)	Medium	Measures SDI development from the institutional point of view using seven factors: vision, leadership, communication, self-organizing ability, awareness, financial sustainability and status of delivery mechanism.	Developmental evaluation	Case study
Performance-Based	Low	Uses the Performance-Based Management (PBM) to measure the reliability, efficiency and effectiveness of SDIs, to answers questions about SDI efficiency and results.	Purpose Evaluation	Not available
Cadastral	Low	Measures five evaluation criteria to evaluate the performance of SDIs: (the management level, the policy level, the operational level, influencing factors and assessing performance) of Land Administration Systems (LAS), since LAS can be compared to SDI.	Knowledge and Accountability evaluation	Survey

Source: Grus *et al.* [52]

2.3 Methodology

2.3.1 The SDI-Readiness Index

This study uses the SDI-Readiness methodology developed by Delgado Fernández *et al.* [54], whose output is the SDI-Readiness index. Widely considered as a multi-criteria decision making tool, it determines the capacity and willingness of a country to develop and use SDI. It can be used to compare the development of SDI over a period of time, in a particular administrative unit, such as a country, or as a snapshot of the status of SDI in the unit.

The dependent variable is the status of SDI, while the explanatory variables are the five factors supporting SDI development: organization, information, technology, human and financial resources. These are expounded in the following paragraphs.

Organization: This factor employs three variables: SDI vision, institutional leadership and legal framework [54]. SDI vision is the recognition of key decision makers (such as the president) on the importance of SDI development. Institutional leadership is the coordination by one or more institutions for SDI development, while the legal framework takes into account the existence of any kind of legal instrument (such as a policy, directive, decree, agreement or law) that can partly or fully support the development of SDI.

Informational: This factor has two variables: fundamental datasets and metadata availability. Fundamental datasets is a general term that refers to foundation and framework spatial datasets (for example geodetic control, aerial photographs and satellite imagery, digital elevation models, height datum, and bathymetry) [61]. Metadata availability refers to the availability of data or information describing the spatial datasets and other resources used in the SDI.

Human Resources: Considers three variables: the human capital index; culture/education on the importance of SDI; and individual leadership. The human capital index is an aggregate variable taken from the UNDESA survey of 2014 [62] and comprises of adult literacy, gross enrolment ratio, expected and mean years of schooling. Culture/education refers to the capacity building for SDI, and the awareness of its impact on society. Finally, an SDI requires at least one leader or champion to oversee its development, which constitutes the individual leadership.

Financial Resources: These can be obtained from three main sources: the government; cost recovery; and private sector funding. Funding is needed to finance various SDI activities such as preparation of data resources and metadata, purchase of computer hardware and software, development of the institutional framework and the legal environment, training and capacity building.

Technology: constitutes four variables: web connectivity; communication infrastructure; use of open source software, and the availability of commercial or in-house spatial software. The Web connectivity index is also obtained from the UNDESA survey of 2014 [62], and constitutes a score derived from a quantitative analysis of the national web presence of the UN member states. Similarly, the communication infrastructure is obtained from the UNDESA survey.

2.3.2 The SDI-Readiness Model

The SDI-Readiness index is formalized by the disaggregated model based on Delgado Fernández *et al*. [63], and applies compensatory logic to solve the conjunction and disjunction. The basic concept of the model is outlined in the following paragraphs.

In Boolean logic a predicate p is a mapping from the universe set X to {0, 1}. For example, the sentence 'x was born in year y' declares a model in which the predicate p from the set of pairs (x, y) to {0, 1}, assigns 1 if x was effectively born in year y and 0 if it cannot be assured that x was born in year y. The propositional connectives ∧, ∨, y and ¬ denote operations [64]:-

- p ∧ q is true when and only when both p and q are true. It is called conjunction, and symbolizes the inclusive use of "and" in natural language
- p ∨ q is false when and only when both p and q are false. It is called disjunction, and symbolizes the use of "or" in natural language
- ¬p is true when p is false, and conversely. It is called the negation of p.

Applying Fuzzy Logic to SDI-Readiness Model

A fuzzy-based model was chosen because of the qualitative nature of some factors. An outline of the variables is given in Table 2.6. Accordingly the following propositions are formulated.

A country has a suitable organizational level to develop SDI provided that it has an appropriate level of vision on SDI, institutional leadership *and* legal framework [54], [63].

$$O = (O_v \wedge O_l \wedge O_a) \tag{1}$$

A country has a suitable level of information to undertake SDI development provided that there is an appropriate availability of digital geospatial information *and* metadata; *or* a strong level of metadata [54], [63]. Given the current situation in Africa (i.e. low mapping coverage and outdated datasets), we make a slight modification to the model by ignoring the latter.

$$I = (I_c \wedge I_m) \tag{2}$$

A country has a suitable level of human resources to develop SDI provided that there is an appropriate level of: human capital, SDI culture *and* individual leadership [54], [63].

$$H = (P_c \wedge P_s \wedge P_l) \tag{3}$$

A country has a suitable level of financial resources to undertake SDI provided that there is an appropriated level of government funding *or* private sector funding *or* an appropriated level of return on investment from the geospatial industry [54], [63].

$$F = \left(F_g \vee F_p \vee F_r\right) \tag{4}$$

A country has a suitable level of technology to develop SDI provided that there is an appropriate level of technological infrastructure, web connectivity *and* an availability of software *or* own geoinformatics development *or* an open source culture [54], [63].

$$A = \left(A_t \wedge A_w \wedge (A_s \vee A_d \vee A_o)\right) \tag{5}$$

Combining the above gives rise to the disaggregated model represented by:

$$SDI - Readiness = (O_v \wedge O_l \wedge O_a) \wedge (I_c \wedge I_m) \wedge (P_c \wedge P_s \wedge P_l) \wedge (F_g \vee F_p \vee F_r) \wedge \left(A_t \wedge A_w \wedge (A_s \vee A_d \vee A_o)\right)^{0.5} \tag{6}$$

Finally, applying compensatory logic yields the expression labelled (7) [63], [64]:

$$SDI - Readiness = (O_v * O_l * O_a)^{\frac{1}{3}} * (I_c * I_m)^{1/2} * (P_c * P_s * P_l)^{\frac{1}{3}} * \left(1 - \left(\left(1 - F_g * 1 - F_p * 1 - F_r\right)^{1/3}\right)\right)^{1/3} * \left(\left(A_t * A_w * \left(\left(1 - (1 - A_s * 1 - A_d * 1 - A_o)^{1/3}\right)\right)^{1/3}\right)\right)^{1/2} \tag{7}$$

Table 2.6: SDI-Readiness Index variables

Factor	Definition of Factor	Variable	Definition of Variable	Source
Organisation Index	Consists of: SDI vision, institutional leadership and legal framework	SDI Vision, O_v	Awareness of politicians on the importance and development of a National SDI	Survey
		Institutional Leadership, O_l	SDI coordination by one or more institutions	Survey
		Legal Framework, O_a	Existence of any kind of national legal instrument (law, policy, directive, or agreement) to support SDI	Survey
Information Index	Availability of fundamental spatial data	Spatial Data Availability, I_c	The availability of spatial data e.g. foundation data, framework data etc.	Survey
	Metadata availability	Metadata availability, I_m	Metadata availability	Survey
Human Resources Index	Incorporates the: Human capital index, culture/education on SDI and individual leadership	Human Capital Index, P_c	UNDP education index	UNDESA
		Culture/Education, P_s	The capacity building and awareness of the impact of SDI evidenced through workshops or seminars	Survey
		Individual Leadership, P_i	One or more champions who lead SDI development,	Survey
Financial Resources Index	Sources of funding for SDI	Government Funding, F_g	There is funding from the Government	Survey
		Private Sector Funding, F_p	There is funding from the private sector	Survey
		Geospatial industry funding, F_r	A high level of return on investment from the geospatial industry	Survey
Technology Index	Communication infrastructure, web connectivity, spatial software and use of open source resources related to SDI	Technology Infrastructure, A_t	An appropriate level of technology infrastructure	UNDESA
		Web connectivity index, A_w	There is an appropriate level of web connectivity	UNDESA
		Spatial Software, A_s	Availability of spatial software	Survey
		Geo-informatics development, A_d	Availability of own Geo-informatics development	Survey
		Open Source Resources, A_o	Evidence of open source culture	Survey

Source: Grus *et al.* [52]

2.3.3 Definition and Measurement of Variables

An inspection of the questionnaire shows that most, if not all, factors are qualitative. Similar to the arguments advanced by Espín Andrade *et al*. [64], category scales (or classifications) are assigned to real values. In a seven tier classification system, presented in Table 2.7, the assigned values range from 0.1 to 1.0 at intervals of 0.15 [63], [64].

Table 2.7: Seven-tier classification scheme

Tier	Classification	Assigned Value
7	Extremely High	1
6	Very High	0.85
5	High	0.7
4	Medium	0.55
3	Low	0.4
2	Very Low	0.25
1	Extremely Low	0.1

2.3.4 Administering the Questionnaire

The study is based on both primary and secondary data. Secondary data was obtained from the UNDESA survey conducted in the year 2014, yielding the variables web connectivity index, communication infrastructure index and human capital index. Primary data collection took place between April and October 2014 using a questionnaire to collect data for the remaining variables.

In addition, the author attended the SDI forum in Kigali, Rwanda in July 2015 at which he was able to gather useful information from key people in SDI development from several African countries. The forum was organized by the Regional Centre for Mapping of Resources for Development (RCMRD) and Rwanda Natural Resources Authority (RNRA), and supported by NASA and USAID through the SERVIR project. Representatives from member countries presented reports on the status of NSDI, such as availability of core datasets, policies and legal instruments, institutional frameworks, among others.

Using Adobe Professional, the questionnaire was developed to allow electronic administration between April and October 2014. To increase the quality of the results, the sample was drawn from key individuals and institutions involved in SDI in Africa.

The questionnaire was structured into four major components: identification, respondent details, factors influencing SDI readiness (organisational, informational, human resources, access network and technology, and financial resources), and details of the NSDI (geoportal web address, name or organisation coordinating NSDI and its website address). In addition, the questionnaire invited respondents to share their perception on the availability of core datasets in their countries.

More than 250 questionnaires were sent to the recipients. However, only 16 responses were received from 12 countries. The low response rate can be attributed to several factors. First, although many countries in Africa have initiated some form of NSDI, progress in Central Africa has been generally slow, and in North Africa geo-information is closely linked to security and therefore not much is publicised [65]. Thus respondents may fail to share their experiences. Second, the questionnaire was self-administered, which generally attracts lower response rates.

The returned responses are considered representative. First, 25 countries are included in the sample, representing 46 percentage points (see Figure 2.1). Sampling was done in such a way that each region (for example West Africa) is represented by five countries, with each country having an equal chance of being selected. From the sample, 12 countries responded, indicating a response rate of 48 percentage points. Where no responses were received, the gap was filled by reviewing literature on SDI development and activities in the countries. Second, the study relies both on primary and secondary data. Primary data was obtained through a questionnaire, and secondary data from UNDESA survey of 2014. Hence, it used data collected rigorously by UN agencies. Lastly, most countries in Africa are similar (in terms of technological, human capital and data availability), hence the sample can be taken to be representative.

2.4 Results and Discussion

2.4.1 Summary Statistics

Table 2.8 presents the distribution of questionnaire responses by variable. The three variables obtained from UNDESA survey (web connectivity index, communication infrastructure index, and human capital index) are excluded from this table. To interpret values in this table, “a value x” at the intersection of the variable “Metadata Availability” and “Tier 4” implies that x respondents selected “Medium level of metadata availability describing spatial datasets” according to what is presented in Table 2.7.

Figure 2.1 highlights the countries from which responses were received. The responses are predominantly from the Eastern, Southern and Western African countries. No responses were received from Northern and Central Africa. In some way, the variation in responses can be used to gauge the level of “interest” in SDI development in the regions.

Table 2.8: Distribution of responses by variables

Variable	**Tier**							
	7	**6**	**5**	**4**	**3**	**2**	**1**	**Total**
Vision	1	2	0	5	2	5	1	16
Institutional	0	1	4	4	4	1	2	16
Legal	2	3	0	2	6	1	2	16
Fundamental Datasets	0	2	1	4	3	5	1	16
Metadata Availability	1	3	2	8	0	1	1	16
Culture / Education	2	0	6	5	2	1	0	16
SDI Champion	1	1	5	5	3	1	0	16
Commercial Software	1	2	2	4	3	3	1	16
Open Source Software	0	2	4	6	1	3	0	16
Government Funding	1	2	1	4	5	3	0	16
Cost Recovery Funding	3	2	5	4	1	1	0	16
Private Funding	3	5	2	5	1	0	0	16

2.4.2 Computation of the SDI-Readiness Index

Figure 2.2 is a graphic depiction of the computed SDI-Readiness indices. Senegal has the highest score (0.69), followed by Rwanda (0.65), South Africa (0.64), Ghana (0.61) and Nigeria (0.58). From the tail end, we have Tanzania (0.33), followed by Zimbabwe (0.33), Botswana (0.35) and Malawi (0.38).

Figure 2.1: Countries from which responses were received

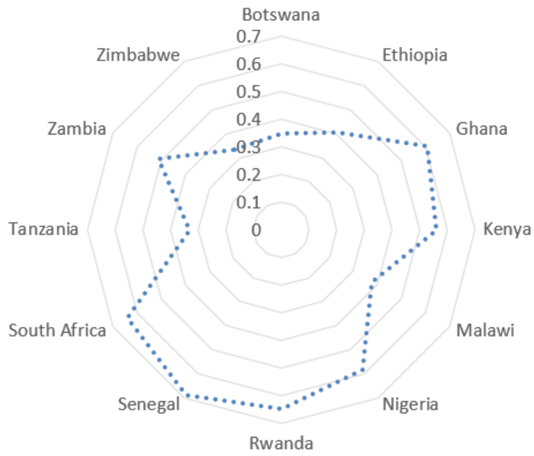

Figure 2.2: Computed SDI-Readiness indices

Finally, the overall contribution to the index by each factor is represented in Table 2.9. Clearly, more effort needs to be done to improve the human and financial resources needed to develop and advance SDIs in Africa.

Table 2.9: Contribution to the SDI Index by each factor

Country	Organisation	Informational	Human Resource	Technology	Financial	Index
Botswana	0.1357	0.2345	0.5244	0.6530	0.4665	0.3477
Ethiopia	0.5466	0.4000	0.3820	0.4340	0.3038	0.4058
Ghana	0.6459	0.6837	0.5537	0.5904	0.5673	0.6063
Kenya	0.5676	0.5500	0.5178	0.6148	0.5500	0.5592
Malawi	0.5960	0.6837	0.2668	0.3382	0.2030	0.3755
Nigeria	0.7468	0.6205	0.3742	0.5390	0.7274	0.5841
Rwanda	0.8411	0.6837	0.5263	0.5225	0.7274	0.6489
Senegal	1.0000	0.7714	0.5802	0.5729	0.6069	0.6893
South Africa	0.7114	0.7348	0.6039	0.6649	0.5130	0.6404
Tanzania	0.2802	0.2500	0.4158	0.4468	0.3038	0.3307
Zambia	0.5500	0.5500	0.4627	0.4517	0.5673	0.5140
Zimbabwe	0.2924	0.3708	0.4433	0.5664	0.1531	0.3342
Overall	**0.5761**	**0.5444**	**0.4709**	**0.5329**	**0.4741**	**0.5030**

As seen in Table 2.9, Senegal has an apparent perfect score of 1.0 under organisation factor. This means that, according to the respondents, the country has a very high level of organisation (i.e. vision on SDI, institutional leadership and legal framework) necessary to develop SDI.

2.4.3 Core Spatial Datasets

Respondents were asked to state the core spatial datasets supporting NSDI that are perceived as important in their countries. Core or fundamental datasets are the datasets commonly used by many applications and can promote wider use of the SDI. For this study, UNECA's Mapping Africa for Africa (MAFA) [61] datasets are used. In this classification, primary data consists of datasets in Levels 0, 1 and 2, while the rest constitute secondary data. The definition of these levels is presented in Table 2.10.

Table 2.10: Definition of MAFA core dataset levels

Level	Classification	Definition
Level 0	Primary Data	Data essential for all subsequent datasets and first in the production process
Level 1	Primary Data	Geo-spatial data, which rely on Level 0 data for their creation
Level 2	Primary Data	Geo-spatial data related to manmade features
Level 3	Secondary Data	Generic thematic data based on primary data and derived by analysis
Level 4	Secondary Data	Specific thematic data derived by analysis

The aim of examining perception on core spatial datasets, which is presented in Table 2.11, was to gauge the informers' awareness of the existence of the datasets. From this table, it can be inferred that many core spatial datasets are still not yet readily available in Africa; and in addition, there is possible lack of awareness of the existence of such datasets.

Table 2.11: Perception on core spatial datasets in Africa

Dataset	Perception	Level	Dataset	Perception	Level
Geodetic Control Points	94%	Level 0	Airports and Ports	72%	Level 2
Height Datum	61%	Level 0	Populated Places	67%	Level 2
Geoid Model	50%	Level 0	Land Parcels / Cadastre	61%	Level 2
Natural Water Bodies	83%	Level 1	Land Use Planning Zones	61%	Level 2
Aerial Photography	67%	Level 1	Road Centrelines	56%	Level 2
Satellite Imagery	61%	Level 1	Railways	56%	Level 2
Digital Elevation Model	61%	Level 1	Land Tenure	50%	Level 2
Spot Heights	56%	Level 1	Power	44%	Level 2
Bathymetry	39%	Level 1	Telecommunications	39%	Level 2
Coastline	39%	Level 1	Postal or Zip Code Zones	33%	Level 2
Government Units	100%	Level 2	Bridges and Tunnels	28%	Level 2
Roads	83%	Level 2	Street Address	22%	Level 2
Feature Names	78%	Level 2	Soils	67%	Level 3
Enumerated Areas	72%	Level 2	Geology	67%	Level 3
Place Names	72%	Level 2	Land Cover	61%	Level 3

2.4.4 National Clearinghouse Portals

Part of the questionnaire invited respondents to state the internet address to the countries' NSDI, which is usually the clearinghouse portal. The existence of a clearinghouse portal is a good pointer to the development of SDI in a country. Of the countries surveyed, only South Africa's SDI portal was operational to some good level of sophistication. The Nigerian portal existed albeit with only basic functions. More recently, in 2015, Rwanda's SDI portal was launched.

2.5 Summary and Conclusions

In this chapter, we have examined the status of SDI in several African countries in the year 2014. We collected primary data using a self-administered questionnaire (supplemented with secondary data) and analysed the data using the SDI-Readiness methodology.

In general, an index higher than 0.8 implies that the country is completely SDI capable with possible progress towards a spatially enabled society [66]. If the index falls between 0.6 and 0.8, the country is almost ready for SDI; whereas an index between 0.4 and 0.6 implies that more work needs to be done to successfully develop SDI. Indices below 0.4 indicate that a lot more work still needs to be done.

Several issues come to the fore. The first is that some countries, notably Senegal, Rwanda, South Africa and Ghana, have reasonably high levels of readiness to develop their NSDI. If such countries can set aside resources on sustained basis, then they stand a good chance of success in their SDI development. A good example in this respect is South Africa, which has consistently promoted an enabling environment that facilitates SDI development (for example, through establishment of a legal framework, policies and sustainable funding). Although the existence of a geoportal may not necessarily indicate the maturity of an SDI, the fact that Rwanda launched its SDI geoportal in July 2015 validates our results.

Secondly, the study shows that human resources (at 0.4709) and financial resources (at 0.4741) are the two factors most deterring SDI development in Africa. More effort to improve these factors is needed (especially in countries with lower SDI-Readiness indices). This conclusion may be justified because inadequate human and financial resources may inhibit development of technologies, organisational and information resources (core datasets and metadata) needed for SDI development.

Finally, the study shows that not all African countries are fully aware of, and are adopting UNECA's recommended core spatial datasets for Africa [61]. Eventually, Africa will progress towards a supra-national SDI and it is important that a common definition of core spatial datasets is accepted. This will eventually promote semantic consistency and cross border applications.

The study faced several challenges. The first is the low response rate, which resulted in an apparent concentration of Anglophone over Francophone countries in the sample. Secondly, there is a general lack of data on SDI monitoring in Africa, even by key institutions such as UNECA [18]. This forced the researcher to collect primary data, which is expensive. Finally, this research was not funded making it difficult to net wider responses or aggressively administer the questionnaire throughout the continent. For instance, the researcher could not translate the questionnaire into other languages, such as French. Therefore, responses may not necessarily be representative of the entire African continent.

3 THE SOCIAL AND ECONOMIC BENEFITS OF SDI

Chapter Summary

Over the past few years, a number of countries (notably Canada, Australia, the USA, South Africa and Germany) have developed and continue to improve their National Spatial Data Infrastructures (NSDIs). In return, these countries expect numerous SDI benefits, such as economic development, development of new information markets, cost reduction, and better data and decision making quality.

An exposition of the socio-economic benefits and impacts of SDI is useful in many ways. First, SDI leaders and practitioners can use the findings to obtain support for SDI. Second, these studies can help inform better understanding of the long-term impact of an SDI to the society. In turn, this can be used to ascertain whether the SDI is meeting its objectives, thus helping to redefine and improve it. Third, social and economic studies can contribute to the scarce knowledge base on the benefits and impact of SDI development.

The main problem with SDIs particularly in Africa is that very few studies have been carried out to establish their social and economic benefits. With this in mind, this chapter sought to review the benefits that African countries stand to realize if they develop SDI, while answering the research question: *How is SDI important for socio-economic development in Africa?*

To answer the research question, a detailed survey of the literature was carried out. The countries and regions considered in the survey include Kosovo, Catalonia, Lombardia, and an array of other regions and countries where studies targeting socio-economic benefits of SDI, return on investment (ROI), and cost-benefit studies have been carried out.

The study shows that SDI development can lead to many benefits, such as: monetary gains, better prepared personnel, improvements in organisations participating in or using the SDI, benefits for citizens, user satisfaction, extension of services, openness and transparency and improved decision making processes. In addition, the delayed or complete rejection of SDI development could have a negative impact on the social-economic development of a country.

3.1 Introduction

3.1.1 Background

A Spatial Data Infrastructure (SDI) is a long-term and evolving concept that typically consists of multiple components and can be developed at various levels ranging from the local to the global [67]. The implication is that a significant outlay of financial resources is required to build and operate an SDI, which is why it is important to identify and communicate its benefits and impacts. This is important for the buy-in from policy and decision makers.

At the core of an SDI is an authoritative, reliable and accurate set of geospatial information (foundation data). Developing foundation data is no mean task, requiring effort from many stakeholders who should collaborate and adhere to agreed policies and standards. However, many SDI researchers agree that sharing is difficult [68], and the agencies tasked with developing SDIs will encounter many problems, such as institutional barriers, inadequate funding, and lack of political will [69]. These problems are often more prominent in developing countries due to the scarcity of resources.

Spatial data, and indeed SDI, have very big potential. It is generally accepted that the majority of the data and information needed for decision making in the public and other sectors have a spatial component [5], further serving to underlie the importance of SDIs. A lot more benefits can accrue if the data and services are provided in a shared manner facilitated by an SDI.

One of the challenges that SDI champions may face is proving that SDI is useful to the society. A common approach to SDI development, especially in developing countries, is to tag the initiatives to these challenges [32], hoping to draw the attention of policy and decision makers.

SDIs can provide a basis for the discovery, evaluation and use of spatial data by various users drawn from the government, the private sector, non-profit organisations, the academia and even the citizens [30]. Therefore, it is important to assess the costs, benefits and impacts of SDI development, taking into account that the establishment and maintenance costs are mostly upfront while benefits accrue much later [70].

Most SDI assessments are usually required at the ex-ante stage when there is need to endorse the investment [70]. Given that SDIs are long term initiatives, continuous evaluation (which includes establishment of socio-economic benefits and impacts) ought to be an integral part of the SDI development process [23], within the strategic and operational plans. SDI assessments should not only justify development expenditure, but should also determine whether the SDI is achieving its objectives [59]. Integrating continuous evaluation in SDI development is today an important practice embraced by most of the mature SDIs.

In most African countries, the value of geoinformation has not been fully unlocked due to several challenges [3]. Some of these are: overlaps and duplication of effort, inadequate access to spatial data, information and knowledge, and the multiplicity of standards and data formats. In most cases, the centralized coordinated system for geospatial data management which is contingent to successful SDI development is absent [71].

One of the common practices in SDI assessment is a focus on additional elements that create the SDI. These include metadata creation, development of services (discovery, transformation, view and download), policies on data access and use, and the coordination measures that tie together the disparate data stores and suppliers [70]. Data creation and maintenance under the purview of National Mapping Organisations (NMO) would be ongoing with or without the SDI. Thus, costs related to data creation and maintenance are usually ignored.

The typical costs incurred during SDI development may include technology (hardware, system design and software), management and maintenance (development of standards, data, policies and metadata); process changes in organisational models, consultation and coordination, and training and capacity building, [70].

The potential benefits of SDI may include efficiency gains (such as economic and time savings in online services, reduced costs and improvement in human capacity), efficacy impacts (such as improved service delivery, tax collection and management, and access to better decisions), and democracy benefits (such as new products and services, better sharing of knowledge, improved access to information, business opportunities, and value-added services) [70], [72].

One of the best pointers to the potential benefits of SDIs is given by Lance and Bassol´e [27], who argued that infrastructure investments such as SDIs, can lead to socio-economic outcomes, which further affect infrastructure investments and development.

3.1.2 Statement of the Problem

The slow uptake of SDI especially in Africa, can partly be attributed to the lack of awareness of its socio-economic benefits and impacts. The availability of such information may make it easier to sell the concept of SDI to stakeholders, especially decision and policy makers.

The more successful SDIs, such as Europe's INSPIRE and Canada's CGDI, have gone to great lengths in establishing regular socio-economic impact studies [23], [72]. For example, CGDI undergoes regular reviews partly to fulfil the requirement that performance data should be incorporated in progress reports [59]. The reviews also justify extra funding, and establish the effectiveness of the CGDI.

Besides, SDIs draw expertise from many disciplines, such as geomatics, economics, computer science and sociology [67]; meaning that socio-economic studies have to take diverse views into account. Generally, this is one of the reasons why the concept of SDI remains fuzzy, and estimating the costs and especially benefits may not be straightforward [68], [73].

Another concern is that the current knowledge base on SDI is strongly focused on technical and institutional issues, at the expense of the socio-economic issues [67]. One possible reason for this practice is that social-economic studies are more difficult to carry out, given the difficulties in estimating and quantifying some of the benefits.

Building an SDI requires setting up technical and institutional platforms to improve access to geospatial data, developing and aligning policies to promote data sharing, developing standards to enforce interoperability between data and systems, reducing duplication in data collection, and improving the geospatial information for better decision-making. This is no mean task for which decision and policy makers are often keen to assess its viability.

If Africa is to succeed in SDI development, social-economic and impact studies should be incorporated for informed decision making. With this in mind, this chapter seeks to answer the research question: *How is SDI important for socio-economic development in Africa?*

3.1.3 Research Objectives

In answering the above research question, the study fulfils the objective of reviewing the socio-economic benefits that African countries stand to benefit if they develop SDI.

Other objectives are:-

- An outline of the typical costs and benefits of SDI development
- A presentation of several social-economic case studies available today
- A theoretical framework that underpins social-economic impact SDI studies

3.1.4 Organization of the Chapter

The rest of this chapter is organized as follows.

Section 3.2 reviews literature on socio-economic SDI studies. Since the methodology followed is a survey of the literature, this section also includes the methodology, results and discussion of the results.

3.2 Literature Review

3.2.1 The Social and Economic benefits of SDI

The overarching aim of SDI development is to realize short and long-term benefits to societies investing in them. Some of the benefits cited in the literature are quite lofty, including development of new information markets, socio-economic development [25], social cohesion, sustainable development, environmental management, reduced disputes, food security, poverty reduction, improved land administration [13], creation of job opportunities [72], productive use of resources, regional integration, and international cooperation.

Other benefits are more mundane, such as improvement in tactical and strategic decision making in diverse areas such as agriculture, business applications such as insurance and retail analysis, defence, disaster management, education, emergency services, energy, forestry, land information management, health, military and transportation [31], [74].

Investment in SDI is commonly justified in terms of their ability to ameliorate access to spatial data and services, reduce costs through less duplication, and provide standards, policies, tools and other mechanisms to promote data sharing at various levels ranging from the local to the global [74]. Access to reliable and up-to-date spatial information can reduce risks in planning process for ministries and agencies, local and county governments, and other stakeholders.

Despite the numerous benefits cited above, determining the value of SDI is still a challenge due to several factors, such as [29], [68], [74]:

- it is difficult to quantify some benefits (e.g. reduced risk in the planning process);
- SDI is defined and understood differently amongst countries and disciplines; and
- generally, estimating benefits is more difficult than estimating the costs

In Africa, there is massive underutilization of Geographic Information (GI), often caused by lack of awareness, outdated or lack of core spatial data, lack of documentation of the available datasets, weak access and exchange mechanisms, lack of interoperability amongst datasets, and insufficient technical and human resources to exploit data and knowledge [75].

Some researchers posit that Cost Benefit Analysis (CBA) and Return On Investment (ROI) studies, which are part of socio-economic studies, should focus on specific application areas contributing to the SDI (for example cadastres), or smaller jurisdictions within the hierarchy (such as a county), rather than the entire SDI [68]. This approach renders the study more manageable, given the challenges of conducting socio-economic studies. Many studies that are available today have followed this approach.

Based on experiences of address data sharing, South Africa has identified several potential benefits of its national SDI [68]. These benefits, which have not been quantified in monetary terms, are:-

- reduced costs of data handling;
- improved data quality;
- return on investment;
- improved decision making and planning; and
- financial benefits.

Kenya's National Spatial Data Infrastructure (KNSDI) draft policy [76] has identified some potential benefits of SDI development:-

- information market development, by treating information as an economic good;
- sustainable development, for effective and efficient use of scarce resources; and
- transparent and participatory governance, by using geoinformation to involve citizens.

3.2.2 Typical Costs of Setting up an SDI

Two funding requirements can be identified for SDI, including funding for SDI coordination, and for SDI implementation [23]. The former is needed to cover the costs of the coordinating secretariat, such as basic infrastructure maintenance, development of geoportals, organisation of workshops and seminars, and inter-agency coordination.

The actual costs of SDI implementation are usually much higher than for coordination funding. Such costs may include establishing partnerships with custodians, data maintenance, training and capacity building, identifying and preparing resources (human, financial, data and hardware), strategic planning, monitoring and evaluation, governance, metadata creation and maintenance, development of applications and geo-services, operation and management costs, and implementation of standards [45].

For example, the coordination funding required by the Federal Geographic Data Committee (FGDC) of the USA between 2000 and 2005 was $4 million per annum; while the actual cost of NSDI implementation reached highs of $5 billion per annum [73].

Implementation of Namibia's NSDI Strategic Plan which runs from 2015 - 2020 is projected to cost N$45 million which is about US$3.5 million [45]. In the early days, Kenya's NSDI initiative (KNSDI) largely relied on foreign funding from Japan and when the funding ended, the KNSDI development stagnated. According to the draft KNSDI policy, the implementation plan is expected to cost Kenya Shillings 7 billion (about $70 million) over a 5 year period [76].

It is worth pointing out that national governments typically provide the bulk of initial funding for the more successful SDIs [73], because an SDI is an important national initiative with potential to improve service delivery. Additional funding may flow from other sources, such as the private sector, donor funding, and cost recovery.

Typically, different countries have different SDI funding requirements. The funding needs might depend on several factors, such as the size of the country, number of actors involved in geospatial activities in the country, complexity of the political and cultural environment, availability of datasets in the required digital format, availability of metadata, conducive policy and legal environment, and other local factors. If the SDI-readiness index is lower, then more resources are likely necessary to support the SDI.

The typical costs associated with establishing an SDI can be summarised as follows [23], [73]:-

SDI Organization

SDI development is normally assigned to a lead agency, and typical costs associated with this responsibility are:

- hiring staff or upgrading skills of existing ones,
- setting up facilities (office space, furniture, computers and access network links),
- stakeholder engagement (travel, living and meeting expenses),
- engagement of specialised experts
- development of publications and regulations

Foundation and Framework Data

Foundation and framework data provide a basis for the integration of other datasets within the SDI. In some cases, particularly in developing countries, the data may exist in analogue format [3], or in diverse projection systems; in which case additional resources are required to improve the quality of the data, or to add and improve metadata. The actual production and maintenance of spatial data is normally assigned to data custodians.

Other data related costs may include data maintenance, which includes regular updates to the existing data. Some countries have used policies to establish the frequency after which existing data should be updated.

Metadata

Metadata is data or information about data, services, and other resources. Metadata may assist in the documentation and structured search of data and services. The costs associated with metadata development may include training and capacity building, hiring of consultants and software developers, and hardware and software purchase. Increasingly, cloud-based systems are used to deliver content and services in contemporary SDIs.

Standards

Standards provide uniform and interoperable patterns for creating, reproducing, updating and maintaining spatial data and services [77]. Organizations developing SDI may need resources to identify and set national requirements for interoperability. They may also need resources to plan, coordinate and support the development of selected standards.

Whilst most countries have adopted common standards (notably ISO and OGC), effort is still needed to have them embraced (through training and capacity building) within the SDI and the institutional framework.

Technology

Generally, the cost of technology is usually higher compared to other SDI components [72]. Technology components are some of the most visible components in an SDI, most notably in the form of a geoportal. Typical technology costs may include the following.

- development and deployment of geoportals at various levels;
- purchase of geospatial software;
- development of internal applications;
- development of applications by the private sector; and
- hardware and cloud systems

Supporting and Monitoring SDI Adoption and Implementation

Developing an SDI requires significant effort because many different actors are involved, with diverse levels of technical skills, resources and priorities [70]. In this respect, resources are needed for training, outreach and communication. In addition, there is need to develop online training aids, e-learning systems, webcasts, seminars and workshops.

People Related Costs

This component includes the salaries and expenses incurred by people charged with managing the SDI, citizens who access information, training new and existing staff, conference and benchmarking costs, software development costs [73], and other related costs.

3.2.3 Return on Investment (ROI) Studies

Return on Investment (ROI) studies are usually applied to projects and investments in the private sector. The benefits and costs, which are strictly financial, are usually expressed as cash flows over time. Internal Rate of Return (IRR) and Net Present Value (NPV) are the techniques commonly used in ROI studies [23]. Some of the prominent ROI studies documented in the literature are now presented.

Booz Allen Hamilton Study

Generally, projects that adopt geospatial interoperability standards can yield higher ROI. Booz Allen Hamilton [71], [78] compared two projects one of which used geospatial interoperability standards, yielding a risk-adjusted ROI of 119%. This implies that for every unit cost on investment, 1.19 units were saved on operations and maintenance.

Other benefits cited by the Booz Allen Hamilton study [71], [78] are:

- Projects that implement interoperability standards can realize savings of up to 26 %
- Standards-based projects have lower maintenance and operational costs
- Standards-based projects benefit future projects through knowledge recycling
- Projects that depend on open standards can return up to 55% more value
- Use of standards can reduce transaction costs for sharing spatial data
- Standards clarify investment decisions by making implementation understandable

King County

A 2012 study conducted in the 5975 km^2 King County in the Washington state of the USA, with a population of 2 million in 2013, highlighted the immense benefits of geospatial technologies. The study was funded by the King County GIS Centre (KCGC) [79].

The 'with-vs-without' research methodology, was used to gauge how GIS technology has changed agency output and efficiency, and the subsequent benefits therein. Data collection and analysis involved three steps: 1) qualitative interviews with employees and managers in county agencies, to gauge the role of GIS in the agencies; 2) use of the results to develop a conceptual model of how GIS is used by the agencies; and 3) an online survey, administered via email to 175 employees and managers in the county agencies that used GIS technology [79].

Even with the most reasonable estimate, in which cash flows are discounted at 3%, the county's GIS program is estimated to have earned an NPV of $776,361,408 between 1992 and 2010 [79]. The discount rate assumes that the county's opportunity cost of capital is 3%, that is, on average county projects and investments yield a 3% return on investment [79].

3.2.4 SDI Impact Studies

Some cost-benefit studies have shown that the benefit-cost ratio resulting from SDI can be as high as 4:1, and in some cases even higher [45]. This implies that every unit cost leads to a four-fold benefit.

This statistic is corroborated by the findings from Kenya's Huduma centres. Although not geospatial in orientation, the centres provide a range of public services, such as national identification cards, police abstracts and stamp duty assessment. According to ministry data, the Government spent 3 billion Shillings to build the centres and has realised over 12 billion shillings over a three year period (2013 – 2016). Establishing the centres has realised many other benefits, such as crowding out anti-social behaviour (for example, corruption). SDIs can be likened to these centres since they would provide similar public geospatial services.

Whilst the actual benefits of SDI are difficult to determine, several countries have attempted to estimate the benefits of SDI development. A few relevant examples are now outlined.

Kosovo

Covering an area of 10,908 km^2 with an estimated population of 1,859,203 in 2014, Kosovo is a landlocked country in the Balkan Peninsula. It is projected that its NSDI will incur an initial cost of €1,300,000, and thereafter an annual recurring cost of €450,000 [72]. A review of the initial cost reveals that 58% of the amount will go to Information Technology (IT), and 12% to data components. Similarly, IT costs accounts for a large percentage (18%) of the recurring costs, while the percentage consumed by the other components (research, governance, data sharing, metadata creation, standards, outreach, and capacity building) is relatively lower.

A notable point is that Kosovo's geospatial data (including metadata) was available in an appropriate digital format prior to SDI development. This might explain the low budget of SDI development. In case the data exists in analogue format, or in different projection systems, then additional resources will be required to convert the data prior to its use in an SDI. In addition, Kosovo is a small Country, and therefore may need fewer resources to develop its SDI.

Kosovo has not yet quantified the actual benefits of its NSDI in monetary terms, but has indicated anticipated potential benefits [72]. These are:-

- reducing data production costs;
- eliminating duplication in data acquisition;
- efficiency in data access;
- higher quality of data for sound decision-making;
- a more efficient and transparent government;
- better service delivery;
- market expansion through the formation of beneficial partnerships; and
- improving policy decisions based on easily accessible geospatial data

Catalonia

Catalonia is one of the 21 sovereign communities of Spain, covering an area of 32,108 km^2. It comprises of 946 municipalities, 41 counties and 4 provinces. The probable population in the year 2014 was about 7.5 million.

The Catalonia Spatial Data Infrastructure (IDEC), started off in the year 2002 [80]. In 2007, a study was conducted by the Centre of Land Policy and Valuations of the Universitat Politècnica de Catalunya, on the socio-economic impact of the IDEC. The study, which was commissioned by the Joint Research Centre (JRC) of the European Commission, was based on a sample of 23 local authorities and 15 end-user organisations [70]. Twenty of the authorities were participating in the IDEC, while 12 of the organisations were geospatial private companies.

The total direct costs (i.e. metadata development, development of a geoportal, data preparation, applications development, hardware, software, and management) of setting-up, maintaining and developing the IDEC over a five year period (2002-06) was €1.5 million. Indirect costs, such as office space and communication expenses, were excluded. Overall, 57% of the total cost was absorbed in the technical and data-related components, and 43% on awareness and management activities [80]. Over 76% of the total cost was absorbed by human resources during the launch period, an item accounting for over 90% of costs during IDEC operation.

The assessment of the IDEC assumed that relevant datasets existed in digital format, and the projected costs did not include data creation and maintenance. Where datasets exist in analogue format, which is quite common in developing countries, then additional time and financial resources are needed to prepare the data into relevant digital format.

The study showed that the main benefits of the IDEC are internal efficiency in the public administration establishments (time saved in internal queries by staff, time saved in attending to queries by the public and time saved in internal processes), and effectiveness benefits by external actors, including the citizenry (time saved by the public and by companies that need information for their day-to-day business) [70].

Generalising the detailed findings from sample of the local authorities to the population of 100 authorities using the IDEC, the estimated internal efficiency savings exceeded €2.6 million per annum. Similar savings in effectiveness benefits were also realised.

In a nutshell, the total investment to set up the IDEC and develop it over a four year period (2002-2005) is recovered in less than a year. Table 3.1 outlines the benefits of the IDEC.

Table 3.1: Benefits of the IEDC

Indicator	**Result**
Capital savings	60% of respondents indicated perceived savings in consumables, such as paper and ink in map production given that the IEDC had published the maps online.
Increased motivation by employees	40% indicated an increased motivation as a result of the IEDC, 30% had a “medium” level of motivation, and 30% were not particularly interested.
Introduction of new processes	45% indicated that the IDEC had made it possible to do things in new ways, particularly in the departments having direct contact with citizens. 55% indicated no significant change or new process introduced.
Increased data sharing and improved decision-making	25% indicated a very significant contribution, 40% some contribution, and 35% indicated no contribution.
Indicators of new interactive services and accesses	60% had incorporated new geo-services in their web sites through the IDEC
User satisfaction – External users	Respondents could not provide any measure of satisfaction from external users
User satisfaction – Internal users	50% reported a high degree of satisfaction, 15% a medium level of satisfaction, and 35% were neither satisfied nor interested

Source: Craglia and Campagna [70]

Lombardia

Lombardia is one of the twenty administrative regions in the northwest of Italy, covering an area of 23,844 km^2, with an estimated population of 10 million in 2014. Similar to Catalonia, Lombardia was used as a pilot study during the development of INSPIRE.

This study took place during a two-year period (2008-2009) as part of a concerted arrangement between the JRC and the regional government Lombardia. While the Catalonia study focused had on benefits of efficiency and effectiveness, the Lombardia study focused on benefits of democracy [70].

The methodology used was similar to Catalonia's, except that it involved interrogating private-sector companies involved in Environment Impact Assessment (EIA) studies. These companies were facing a range of challenges in finding geospatial information relevant to the EIA studies. The actors taking part in the Lombardia study were the regional government, local authorities, the academia, technology providers, utility companies, professionals (architects, planners and engineers who were involved in spatial planning preparation), and developers.

The total annual cost of poor data access was estimated in the range 100-200 million Euros. Meanwhile, the total annual cost to develop and operate the SDI for the first three years (2004-2006), was 1.36 million Euros, 48% being absorbed by technology components while the remainder went to SDI management and maintenance.

The findings of the study showed that the SDI had resulted in net benefits of approximately €3 million per year in this application domain alone [70]. Moreover, developers and regulators who use the same data and knowledge ended up collaborating with each other, resulting in more effective management of the development process.

Table 3.2: Benefits of the Lombardia study

Indicator	Result
Average saving to find and access the data needed for the EIAs/SEAs	11% in terms of cost
Average saving to find and access the data needed for the EIAs/SEAs	17% on time
Use of the same base of data and knowledge between developers and regulators	more effective management of the regional development process

Source: Craglia and Campagna [70]

Other Studies

Other studies have also reported qualitative benefits of SDI. For example, the following regions Piedmont, Navarra, Wallonia, Flanders, North-Rhine Westphalia, Bavaria, Northern Ireland, Brittany and Vysočina (all in Europe) have variously reported the following SDI benefits [70]:-

- positive cultural change (through cooperation and sharing of resources);
- more coordinated data collection initiatives;
- reduced duplication and waste;
- agreement on core fundamental and framework datasets;
- more evidence-based applications e.g. land-use planning and agriculture;
- time and cost savings; and
- improved understanding amongst agencies on the problems affecting the society

3.3 Methodology and Results

3.3.1 Introduction

The main drawback with socio-economic and impact studies is that they can only be executed after a significant part of the SDI has been setup. Practically, this requires studying the actual users of the SDI, and using them to establish the socio-economic benefits and impacts of SDI [70].

Among the other challenges faced by SDI socio-economic and impact studies is that the existing knowledge base on these studies is rather scarce. Additionally, the benefits of an SDI tend to be realised much later on, which might discourage policy and decision makers. Third, it is difficult to estimate and measure some of the benefits resulting from SDI, such as citizen goodwill and decision making quality.

Similar studies can be carried out in African countries with relatively mature SDIs, such as South Africa and Rwanda. Kenya's national SDI initiative (the KNSDI) had stagnated at the time of review in 2016, and could not therefore be the focus of a substantive SDI socio-economic and impact study.

Given these challenges, the methodology employed in this chapter critically reviews literature on socio-economic and impact studies of SDI development, and generalises them to Africa. To derive the benefits and impacts, two steps were followed: a) identification of the SDI benefits and impacts, and b) generalisation of the benefits and impacts for application in the African context, bearing in mind the political context, cultural context, and other local factors.

3.3.2 Critical evaluation of the Studies

The Catalonia and Lombardia Studies

The Catalonia and Lombardia studies (see section 3.2.4) were funded by the JRC prior to implementation of INSPIRE in Europe. The proponents of INSPIRE wanted credible evidence on the benefits and impacts of SDI development, prior to embarking on the initiative. Given this background, these studies are highly credible.

The techniques and methodology followed to identify, gather and analyse the data was also adequate, further contributing to the credibility of the studies. The theoretical background that underpins estimation of SDI benefits and impacts is also well covered. Given this scenario, it is highly unlikely that the authors were prejudicial.

The studies form a good theoretical foundation which can be replicated in the context of developing countries. However, the drawback is that most developing countries do not yet have mature SDIs. In Africa, focus can be directed to countries with higher SDI maturity, such as South Africa and Rwanda.

King County

The King County study (see section 3.2.3) was funded by KCGC, and the analysis accounted for most of the costs, but only part of the benefits. It can be argued that the study mainly focused on efficiency gains rather than effectiveness and democracy benefits. Notwithstanding that the study was well funded, it highlights the fact that estimating SDI benefits can be difficult.

The benefits that may not have been incorporated include the ease of access to geospatial data using new technologies (such as mobile mapping), new types of geospatial data output, and increased modelling, analytical and research capabilities made possible by the GIS technology.

A major shortcoming of the study is the inability to disentangle efficiency gains resulting from the use of GIS technology. Another drawback is that the efficiency benefits of GIS technology appear rather high, possibly because most other effectiveness and democracy benefits were not well estimated.

3.3.3 Sources of Data

This socio-economic and impacts study of SDI relies on secondary data derived from existing social-economic and impact studies on SDI development in several countries and regions around the world.

A substantive SDI socio-economic and impact study requires an existing SDI. The population of the study is all countries or regions in the world with mature SDIs or sophisticated GIS. The sample is drawn from the population comprising of countries and regions where socio-economic benefits and impact studies have been carried out.

Based on the foregoing, the study has reviewed the following countries and regions: King County in the USA; Kosovo in the Balkans; Catalonia in Spain; and Lombardia in Italy.

The Catalonia study primarily focused on the internal efficiency and effectiveness benefits of SDI while the Lombardia and Kosovo studies focused on the wider socio-economic benefits and impacts of SDI.

3.3.4 Summary and Conclusions

The applicability of the generalised SDI socio-economic benefits and impacts is supported by the notion that social-economic benefits and impact of SDI development are additive. This means that the benefits and impacts are likely to be realised in other regions, having been realised elsewhere. For example, the benefits and impacts realised in Kosovo are more likely to be realised in Kenya, although there might be slight differences due to geographical status of the SDI, orientation, country size, level of technological, culture, political orientation, and other factors. Table 3.3 lists some of the benefits that countries investing in SDI can realise.

Several problems were encountered in the study. First, most countries in Africa (as at 2016) did not have mature SDIs. Second, Kenya's KNSDI would have formed the basis of a case study; but the initiative had stagnated. There are several prerequisites for a proper socio-economic and impact study on SDI including the existence of a mature SDI, and responses from users of the SDI.

Table 3.3: Potential socio-economic benefits of SDI

Impact		**Indicator**	**Measure**	**Results**
Efficiency	Monetary Gains	Savings in time	hours/month	500
		Savings in consumables	%	> 50%
		Savings from data and service re-use	%	> 70%
		Savings from adoption of standards	%	> 30%
	Better prepared personnel	More motivated employees	%	> 35%
	Improvements in the organisation	Time saved in the redesigned processes	%	> 50%
		New processes (e.g. cadastre maintenance)	number	New processes introduced by the SDI
		Interoperable services (e.g. public service)	number	Highly interoperable services
		Improved data sharing	number	Improved data sharing
		Better planning of actions and decisions	number	Better decisions and actions
		Online geoservices	number	Better access to services
Effectiveness	Benefits for residents	Time saved by residents	%	> 30%
		Time saved by companies	%	> 30%
	User satisfaction	Repeat users of services	%	> 90%
		Volume of data queries and downloads	number	High
		User satisfaction	%	> 90%
	Extension of services	Use of new services by businesses	%	> 90%
		Use of new services by residents	%	> 90%
		Uses enabled exclusively by SDI	number	High
Democracy	Openness and transparency	Interactive services and web access	number	High
		Available metadata records	number	High
	Participation	Complaints, queries, errors transmitted electronically	number/month	Low
		Suggestions transmitted electronically	number/month	High

4 TECHNOLOGY TRENDS FOR SDI IN AFRICA

Chapter Summary

Over the past few years, several technology initiatives have emerged, notably cloud computing, big data analytics, Volunteered Geographic Information (VGI), Free and Open Source Software (FOSS), Internet of Things (IoT), and linked data. These technologies have great potential for supporting Spatial Data Infrastructures (SDIs).

Coupled with mature industry standards, such as the Web Feature Service (WFS) and the Web Map Service (WMS) from the Open Geospatial Consortium (OGC), there could be no better time that developing countries can use these initiatives to support their national SDIs (NSDIs).

This study reviews the contribution of new technologies to SDI development, while answering the research question: *How can technology trends support SDI development in Africa?*

A geospatial application based on Google Container Engine (GKE), an Infrastructure as a Service (IaaS) cloud, has been developed. Data was sourced from the 2015 Kenya Certificate of Primary Education (KCPE), the school mapping data of year 2007 from the Ministry of Education, Science and Technology (MOEST); and administrative layers from the Independent and Electoral Boundaries Commission (IEBC).

By using FOSS software in the cloud environment, several operations and analyses typically common in SDIs were carried out. These included database development, metadata creation, use of geo-services, queries based on views and layers from the underlying database, creation of styles using Styled Layer Descriptors (SLD), front- and back-end system development and configuration of the servers. Additionally, a cost estimate for developing SDIs in a GCS cloud environment has been presented.

Although the new technologies may not necessarily lead to wider SDI adoption, the study has shown that these trends can increase the chances of SDI development and adoption. The trends can facilitate utilisation of cost-effective FOSS software and permit highly scalable geo-services, which in turn may lead to better SDIs. This is particularly true in developing countries where financial and human resources are limited.

4.1 Introduction

4.1.1 Background

It is often argued that technical components are easier to deal with than the non-technical ones when developing SDIs [67]. Technology components, which are part of technical components, include access networks, geoportals and technical standards.

In spite of being easier to deal with, a significant amount of financial resources are often expended in technology components. More significantly, technical components are the most visible in SDI, facilitating effective communication with decision makers who are often keen to ascertain their benefits using cost-benefit analysis (CBA) and other analysis techniques.

There are several reasons why consideration of technology components is important in SDIs. First, distributed network access through various applications and geoportals, is what makes spatial data more readily available to end users. Secondly, ICT is one of the major drivers shaping and influencing SDIs. In addition, the identification of trends that impact SDI can help in development of policies to regulate and deal with any emergent issues [23]. Finally, some studies have shown that the low level of web connectivity and IT infrastructure in Africa could be contributing to the slow development of SDI on the continent [81].

The new wave of applications allowing ordinary citizens to participate in and contribute spatial content [82] is an important trend, facilitated by technology components. Notable applications following this framework include OpenStreetMap (OSM), Wikimapia and Google Maps [19]. Some of these applications can be considered as VGI, since a wide range of users contribute and improve spatial content. Such applications fit within the framework of web 2.0, providing bi-directional collaboration in which users not only interact with content, but also contribute some of it [19].

Web 2.0 describes a shift from static content where users are passive consumers to a broader platform of communication and collaboration, which in turn strengthens the role of citizens as SDI stakeholders [15]. The bottom-up approach to SDI development fits within this approach, since it recognises the contribution of citizens at lower levels in the hierarchy.

Cloud computing is another emerging trend influencing SDIs. Simply put, a cloud is a utility based computing model that provides a service allowing resources to be rapidly and efficiently scaled on demand [83]. Cloud enables ubiquitous, convenient, elastic, scalable, on-demand access to pooled resources, such as computation, networks, storage, applications and services. Within the cloud ecosystem, there is an emerging shift from virtualised to container services.

Geoprocessing services, which have tended to be slower within contemporary SDIs, can be implemented much more efficiently in a cloud. Additionally, clouds can enable geospatial professionals to focus on their core domain, leaving routine IT tasks to the cloud provider [15].

The preceding paragraphs illustrate a few of the technology trends with potential to influence SDIs. This chapter seeks to establish whether such technologies and trends have the potential to promote wider adoption of SDIs in Africa.

4.1.2 Statement of the Problem

Whilst some developing countries are still struggling to develop their NSDIs, technologies that support SDIs are advancing at a breath-taking pace. For instance, since the United States NSDI was initiated in the mid-nineties, data sharing technologies have advanced significantly rendering the initial SDIs obsolete [84]. Some researchers have questioned the dominant top down model, which tends to render SDIs less capable of evolving with new trends [15], [46].

Contemporary SDIs face many challenges, serving as a stark reminder that SDI is complex and careful approach is needed in its design. Some of these challenges include: diverse user requirements which are often demanding and unknown; the need for SDI to support new and challenging functionality; user tasks which are unfamiliar to application developers; the lack of SDI interconnection and scalability; and reliance on ageing technologies [15], [82]. Whilst the emerging technologies have the potential to reduce these challenges, an understanding of their nature may help in better SDI development.

An SDI is useful if it has a significant and growing number of users, which Díaz *et al* [15] refer to as the installed base. This may help the SDI to gain widespread usage and acceptance, be able to adapt easily to new technologies, and sustain itself in the long-run [15]. This can only be possible if the SDI is based on adaptable technologies and frameworks.

As at 2016, many African countries did not have mature and functioning SDIs: critically, they still lacked strong inter-agency coordination requisite for SDI development. Furthermore, Africa was still characterised by slow SDI development [18], which can be corroborated by the low number of national SDI geoportals on the continent.

This situation gives rise to several problems. First, there are very few national SDI geoportals in Africa, which others can use as a reference during SDI development. The widespread availability of geoportals can be useful in several ways, such as informing implementers of the key technologies and approaches to be considered. Second, the current technology landscape is characterised by rapid changes and choices, making it difficult to select the optimal choice. Third, although many successful national and regional geoportals are operational, such as SASDI and INSPIRE, the selection of an optimal technology choice may not be obvious.

The chapter attempts to bridge the gap by reviewing the contribution of new technology trends to SDI development in Africa, with a view to answering the research question: *how can technology trends promote development of SDI in Africa*?

4.1.3 Research Objectives

The objective of the chapter is to review technology trends (for example big data, linked data, cloud computing, Representational State Transfer (REST), VGI, web 2.0) and how they can promote wider adoption of NSDIs in Africa. Where possible, the potential and challenges of these technologies are reviewed.

4.1.4 Organization of the Chapter

After this introductory section, section 4.2 of the chapter reviews literature related to IT trends for SDI, focusing more specifically on trends that African countries can use to promote wider adoption of their NSDIs. Section 4.3 discusses the methodology adopted in the study. Finally, the results, discussions and conclusions from the study are presented in section 4.4.

4.2 Literature Review

4.2.1 Introduction

This section reviews literature related to IT trends that have potential to contribute and positively influence SDI development.

4.2.2 The IT Building Blocks of an SDI

Service Oriented Architecture (SOA)

SOA is a design pattern focusing on generic services that can be reused across heterogeneous and distributed applications. SOA, which is based on the notion that components can be built as services, facilitates the registration, discovery and binding of services or processes to create new applications [85].

There are two notable implementations of SOA: Simple Object Access Protocol (SOAP) and REST. The latter is a set of architectural principles that transmit data over Hypertext Transfer Protocol (HTTP) using request parameters, treating data as a resource which in turn is represented uniquely by a Uniform Resource Identifier (URI) [86]. SOAP, On the other hand, is a specification used for exchanging structured information in eXtensible Mark-up Language (XML) format using the HTTP POST request.

REST based implementations tend to be less complex than SOAP, implying that SDIs can derive more advantages by adopting REST approaches.

OGC Web Services

Web services are self-describing and self-contained applications that can be invoked over the internet through HTTP using messages encoded in XML format [84]. Spearheaded by the OGC, these web services can be classified into [87]:

- *data visualization*, such as WMS;
- *data services,* such as WFS and Web Coverage Service (WCS);
- *processing services,* such as Web Processing Service (WPS);
- *data presentation*, such as Styled Layer Descriptor (SLD);
- *querying and transport*, such as Geography Mark-up Language (GML);
- *publication and discovery,* such as Catalogue Service for the Web (CSW); and
- *data storage*, such as Web Map Context (WMC)

A few of these services are now discussed.

Web Map Service (WMS)

WMS is an OGC standard for data visualization enabling visual overlay of diverse geographic content over the internet. The end product is a two-dimensional, geo-referenced raster in a formats such as Portable Network Graphics (PNG), Joint Photographic Experts Group File Interchange format (JPEG), and Geographic Tagged Image File Format (GeoTiff) [86]. WMS may help in the discovery and visualisation of spatial data held in SDI catalogue services [23], because it retrieves a map that is already rendered from the data [87]. The key strength of WMS is that rendering takes place on the server and the output is ready for display by clients in an appropriate format.

Web Feature Service (WFS)

WFS is a service designed for standardized request and response of vector data. The service does not specify how the data should be rendered, thus facilitating the sharing and manipulation of geospatial data. In other words, WFS facilitates the raw access to geospatial information [23]. WFS is suitable for selecting, adding, updating, deleting and filtering geospatial data. Unlike WMS, which produces a map ready for display, WFS provides access to raw vector data [86].

Web Coverage Service (WCS)

WCS does the same for raster data as WFS does for vectors: it returns the raw raster data. WCS can be used for request and response of a coverage or a set of features. Examples of data that can be returned include aerial photographs, satellite imagery, and space-varying phenomena such as elevation data [86]. WCS not only provides access to raster data in collection with detailed characteristics of the data, but also a rich syntax for requests and operations against the raster data, such as interpretation and extrapolation [23].

Web Processing Service (WPS)

WPS is a paradigm shift from *data* providing services (such as WCS and WFS), to *service* providing services [87]. WPS can be used to publish and execute geo-processes over the web [88]. It enables the dynamic binding, sharing, publishing, discovery and use of geo-processes over the web [89]. WPS can also facilitate service chaining in an SDI for orchestrating complex processes through a sequence of sub-processes. Examples of WPS implementations are the Java-based 52°North (www.52north.org/wps) and Python-based PyWPS (www.pywps.org/)

[88]. Both are implementations of the WPS standard, enabling standard deployment of geo-processes over the web.

Other Services

Whilst services such as search, visualization and access are essential to SDI [23], other services that are often needed are application, catalogue or registry, portrayal, and processing services.

4.2.3 Geoportals

The word portal originates from the Latin word *porta*, which means doorway, gate or entrance. Thus, web portals are web sites that act as a gateway to an assortment of information resources, such as datasets, services and catalogues [84].

Similarly, geoportals (or geospatial portals) are gateways to geospatial content. Sometimes referred to as clearinghouse portals [25], geoportals are websites where geospatial resources (such as spatial data and services) can be published and later discovered [84], making it easier to find, access and use them. Geoportals are an essential and highly noticeable component of an SDI, serving as an entry point to the SDI.

A geoportal, illustrated in Figure 4.1, is typically used as a single window into the SDI [23]. A range of distributed applications and services address the needs of users, ranging from generic end-user requirements to more sophisticated needs of suppliers who may contribute content and services. A range applications based on core SDI components, which are developed by software developers and suppliers, ultimately contribute to the SDI development process.

From a technology point of view, the ideal SDI has a distributed architecture, exposing a variety of data and services contributed by diverse organisations. This architecture enables detached systems to collaborate and communicate with each other [46]. Standardised web services provide the foundation for interaction amongst applications, allowing users and even other applications to contribute, search, access, exchange, and use geospatial data.

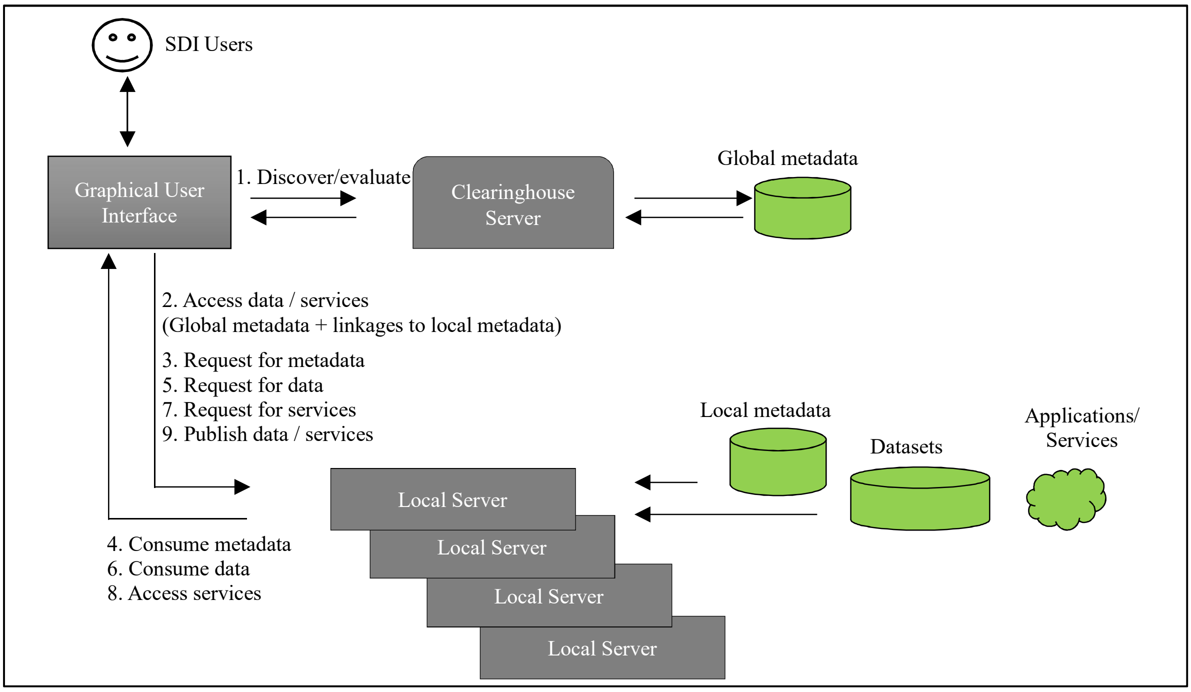

Figure 4.1: Schematic illustration of a geoportal
Source: Bishr and Radwan [90]

4.2.4 The Software Architecture of an SDI

A software architecture can be described as the structure of a system, usually formed by software elements or components, and their properties, interrelationships and relationship with their environment [91]. The software architecture of most contemporary SDIs is based on the Reference Model of Open Distributed Processing (RM-ODP) standard [92]. RM-ODP is jointly developed by ISO and the International Electro-technical Commission (IEC). It is an international standard providing a conceptual framework for architecting open, distributed and complex systems in an incremental manner.

RM-ODP defines five viewpoints on the system and its environment [92]:

- *enterprise*: dwells on the scope, purpose and policies of the system;
- *information*: dwells on the semantics of the information and processing performed;
- *computational*: functional breakdown of the system into interacting objects;
- *engineering*: mechanisms supporting distributed interaction between components; and
- *technology*: focuses on technology choices in the system

The software architecture of an SDI is an important consideration to the extent that it facilitates its design and understanding. Normally, the architecture is documented by a set of views, viewtypes and styles [91]. Whereas views are representations of elements or components and their relationships, viewtypes are allowed element and relationship types. A style is a special viewtype that may define general semantics. For example, it may specify that only certain elements and relationships from a viewtype are allowed.

RM-ODP defines views or representation of elements in a distributed system, and provides a concrete architectural basis upon which SDIs can be developed [23].

4.2.5 IT Trends influencing SDIs

As at 2016, there are several technology trends, which have potential to offer new approaches to support development of SDIs, notably Internet of Things (IoT), Linked Data, the Semantic Web and Cloud Computing. These trends complement the OGC's standards with new ways that can enhance SDI development. This section expounds on some of these trends.

Internet of Things

Internet of Things (IoT) usually involves sensors embedded in appliances and electronic devices, which can be connected to each other through bluetooth, mobile or wireless fidelity (WIFI) networks [93]. Real-time and high-spatial-resolution data can be provided by various geo-sensors, ranging from weather stations, to marine sensors, unmanned aerial vehicles, and satellites. To integrate such geo-sensors into SDIs, the Sensor Web Enablement (SWE) standard has been developed by the OGC [15].

IoT facilitates improved means for collecting and accessing near real-time information, and therefore can significantly contribute to SDIs through timely provision of spatial data.

Linked Data

Linked Data refers to a set of practices for publishing and connecting structured data on the semantic web. It involves a representation of data using a framework known as the Resource Description Framework (RDF) [94]. Linked Data facilitates the linking of data to other data, thus contextualising and adding value to the existing data. Whilst the World Wide Web (WWW) is a web of interlinked documents using Hypertext Mark-up Language (HTML), the semantic web is a network of interlinked machine readable data using RDF [95].

Linked Data is supported by four principles:-

- the use of URIs to name resources or objects on the semantic web;
- the use of HTTP URI's to look up the names;
- lookup of data using RDF and Simple Protocol and RDF Query Language (SPARQL); and
- the use of links to URI's allowing discovery of more things

GML is the publication of spatial data according to predefined data specifications, and is a common data sharing format in SOA-based SDIs. Linked Data differs from GML in that the former facilitates an open publication environment in which additional information and data from other sources can be easily linked. It is possible to transform existing GML data into RDF using eXtensible Stylesheet Language (XSLT), which may facilitate publication of geospatial data in contemporary SDIs as Linked Data [95].

According to Díaz *et al* [15], Linked Data offers several benefits to SDIs, including: simplified integration of heterogeneous data through shared vocabularies, which increases the availability of information resources; improved means for encoding, describing and interlinking data, thereby improving access to data through links and crawling mechanisms; and a uniform model for data and metadata, which improves the descriptions and quality of data resources.

Big Data

The term Big Data became accepted around the year 2010, although the concept may have existed before that date under different terminology. Generally, it refers to the high-volume, high-velocity, high-variety, high-veracity, and high-value information that require new ways of processing [96]. Big Data may contribute to SDIs by providing [6]:

- storage and processing of geospatial content through cloud computing;
- a new source of innovation leading to new geospatial solutions; and
- new bodies of knowledge and scientific communities, and new specialized conferences

Big Data often comes from the cloud, and conversely SDIs may contribute to it as follows:

- creation of new analytical possibilities and the discovery of new facts;
- location reference serve as an integrator/aggregator with other information sources; and
- geo-visualization, which may provide more analysis and insights to decision-makers

Open Data

Open Data can be classified in several ways, such as geospatial, government, scientific, and historical open data. It is the initiative and idea of universal free accessibility and availability of data. Generally, it makes data more accessible for use to other purposes than it was intended. Data is considered 'open' if anyone can freely use, reuse, and even redistribute the content [97].

Although SDI and Open Data overlap and complement each other, the main difference between them is that agreements on commonly used standards and are widely missing in the latter. In addition, Open Data tends to focus on content rather than infrastructure and interoperability, the key tenets of an SDI.

Cloud Computing

Cloud Computing describes an approach in which applications, services and datasets are no longer located on local computers, but distributed over remote facilities [15]. It is an evolution from technologies such as virtualisation, grid and utility computing [83]. A grid is a network of spatially distributed computation or data resources, accessible via open and standardized interfaces [89]. On the other hand, virtualisation is an abstraction process that creates a virtual, rather than real, instance of a resource (such as an operating system). Cloud Computing is a facilitator of other emerging trends, such as Big Data [6].

Clouds can be deployed as private (operated solely for one organization), public (hosted offsite in a shared manner and made available to the general public), and hybrid (a combination of private and public clouds, bound together by open or proprietary technologies). Cloud provides a means to host and serve a large volume of data and computing resources without significant capital investment [94]. This is particularly attractive to SDIs in developing countries with limited financial and human resources.

Cloud Computing can provide a flexible and transparent access to resources such as software, hardware, data, computation and storage [23]. Clouds can be deployed at three service levels as illustrated in Figure 4.2. In decreasing order of control and increasing order of security, these levels are [83]:

- *Infrastructure as a Service (IaaS)* offers complete access to basic computational facilities, such as hardware, technology and virtual machines (VM). Users have full control over the facilities, including storage, operating systems, and applications. Examples of IaaS include the Amazon Elastic Compute Cloud (EC2) and Amazon Simple Storage Service (S3).

- *Platform as a Service (PaaS*) offers runtime environments - such as databases, operating systems, web service and application frameworks, security mechanisms, and middleware - as a service in which users can develop and install custom applications developed using programming languages and tools supported by the platform. Examples are Google App Engine (GAE), Microsoft Azure Engine, and GroundOS (GOS).
- *Software as a Service (SaaS)* offers ready to use applications delivered as a service. This differs markedly from the traditional on premise software. Users run the applications in the cloud, without managing the hardware infrastructure or platform. Esri's ArcGIS Online and Salesforce.com CRM are examples of SaaS clouds.

Other than IaaS, PaaS and SaaS clouds, Data as a Service (DaaS) is a service typically essential for geospatial applications due to large volumes of data involved. DaaS is usually implemented within a SaaS, PaaS or IaaS solution, to provide data within applications supporting the discovery, access, manipulation, and use of the data. Google Maps is an example of a DaaS.

Cloud Computing presents two major benefits to SDIs: simplified deployment and maintenance of SDI services (hence increased number of content offerings); and reduced costs of providing content and applications (hence increased quality of service) [15]. Other benefits include: demand for framework data, which is best provided through cloud services; the increasing need for high volume datasets, and the high computational requirements of SDIs [23]. Despite their numerous benefits, there are several limitations of Cloud Computing, such as reduced security, availability, privacy, integrity, confidentiality, legal, liability and regulation [23], [83].

Volunteered Geographic Information (VGI)

VGI can be defined as the use of content generated by users in the geospatial domain [23]. VGI typically involves an active user community, playing a more influential or organised role in data collection and correction, for example. In addition, VGI can act as a valuable mechanism to promote public participation, thus engaging and empowering citizens [94].

User generated content can also help local communities generate and access spatial data especially where powerful entities such as the Government, large corporations and powerful individuals commoditize data [97], reducing its accessibility. This is a fundamental problem to SDI development in Africa. Thus, VGI can be used to alter the relative power that traditional producers of data hold, while facilitating avenues for local communities to influence change.

SDIs can benefit from VGI in several ways. Content produced by citizens is cost effective since local knowledge, skills and expertise is utilised. Furthermore, VGI offers the ability to access real-time data thus enhancing the timeliness of the content. An active user community is one of the requirements for SDI, and VGI encourages participation. VGI has been successfully used during disasters, such as the Haiti's earthquake in 2010 [98]. Like other emerging technologies, VGI can result in risks such as poor data quality, legal issues, and security.

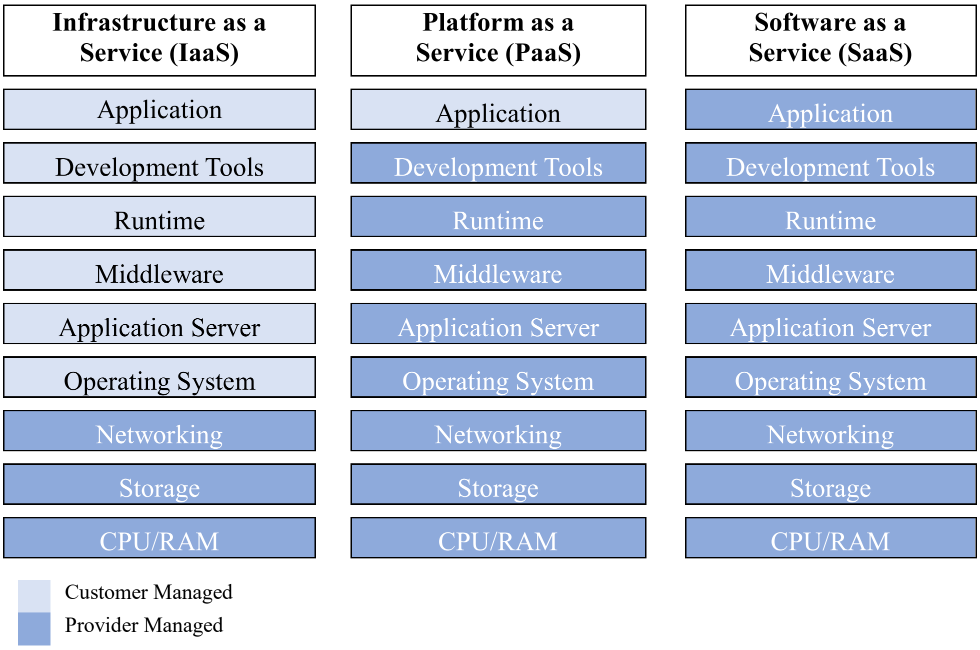

Figure 4.2: Features of cloud services

Free and Open Source Software (FOSS)

The motivation behind free software is freedom, akin to freedom of speech, and not free-of-cost advantages. Free software grants the freedom of use, modification and redistribution while proprietary software takes the freedom away [86]. The term *Open Source* means the availability of the software's source code, with a license authorising anyone to use, modify, and even redistribute the software.

In countries where development of SDIs is in the early stages, availability of FOSS offers a genuine alternative to proprietary software [94]. The drawback with FOSS is that the ongoing maintenance and training skills have to be developed internally, necessitating the need for higher qualified Geospatial and IT personnel.

FOSS used for geospatial applications may be categorised as: Desktop GIS, Spatial Database Management Systems (DBMS), Web Map Servers, Server GIS, Web GIS clients, Mobile GIS, Libraries, GIS Extensions, Plug-ins and Application Programming Interfaces (APIs), Remote Sensing Software, and Exploratory Spatial Data Analysis (ESDA) software [86].

The open source geospatial community has a well-established arrangement through the Open Source Geospatial Foundation (OSGeo) and a vibrant user community championing its use and development [94]. To date, FOSS are experiencing an increasing level of collaboration among projects [86]; resulting in projects such as the Java Topology Suite (JTS), Geometry Engine - Open Source (GEOS), and NetTopologySuite (NTS), as well as interoperability libraries such as Geospatial Data Abstraction Library (GDAL). With the introduction of OGC standards, these projects are competing for compatibility with each other.

4.3 Methodology

4.3.1 Introduction

This section outlines the methodology, which involves development of a geospatial application that maps the performance of a key national examination in Kenya, the Kenya Certificate of Primary Education (KCPE). This examination was conducted in 2015, and involved 938,738 candidates in 25,121 schools.

The aim of the application is to demonstrate the technology trends suitable for SDI development in Africa, which practitioners can use as a reference. Ideally, the application should have been developed within the context of an existing SDI geoportal, which unfortunately did not exist in the study context in 2016.

The application uses MOEST datasets which were chosen due to their higher availability. The datasets include the geographical locations of schools taken from the national school mapping project of 2007. Administrative boundaries, such as constituencies and counties from the IEBC, are also used.

4.3.2 Description of the Methodology

The application utilises contemporary technologies (such as cloud) to demonstrate some of the technology trends that can be used to support SDI development in Africa.

One of the most important considerations is choice of a cloud platform. There are several types of clouds, such as GCS, AWS and Microsoft Azure Engine. GCS is preferred for several reasons. First, it is a flexible and powerful cloud, facilitating Google Compute Engine (GCE), GKE and GAE services. Secondly, it is still a relatively new entrant with promising potential for the highly demanding geospatial industry.

Google Container Engine (GKE)

GKE, which is an IaaS cloud, was launched in August 2015. It provides standard IaaS cloud features (see Figure 4.2), and takes its offering to a higher level through Docker containers and Kubernetes.

Docker uses Linux container technology to package applications into portable, hardware- and platform-isolated containers. For instance, an SDI could use a container providing a specific geoprocessing service; or a container facilitating complete access to a set of OGC services (WMS, WFS, WCS and WPS). Docker provides the lifecycle management of containers.

On the other hand, Kubernetes is Google's open-source cluster manager for orchestration and management of container clusters. In an SDI, Kubernetes could be used to start more instances of a popular container as the number of user's increases. When the needs of an application grow, Kubernetes could be used to dynamically size a cluster with more CPU or memory [99].

Among the attractive GKE features include: automated container management for running Docker containers; easy setup of clusters; declarative management of container resources (for example, CPU and memory) in a simple human readable JavaScript Object Notation (JSON) or YAML file; and a flexible, free and open source environment.

As at 2016, Google was charging a time-based fee for management of GKE cluster depending on the number of nodes in the cluster. Whereas a cluster with less than 6 nodes was free of charge, the one with 6 or more nodes cost $0.15 per hour. To minimise on the cost, this application used three nodes.

Configuration of the GKE Platform

The GCS can be accessed at https://console.cloud.google.com/. Authentication is granted using a standard Google Account.

The GKE platform defines the following terms:

- a *container* comprises of isolated VM installed on the operating system's kernel;
- a *container cluster* consists of a specified number and type of GCE instances;
- a *pod* is a group of containers scheduled on the same host;
- pods serve as units of deployment, scheduling and replication; and
- a *replication controller* ensures that a number of pod *replicas* are running at any time

Software Considerations

Like any standard geospatial application, choices were made on the spatial DBMS, web server, server-side geo-services, and client-side interaction.

GeoServer, a Java-based and open-source software, was chosen to serve geo-services. The software can be used to publish geospatial data on the network using OGC standards, such as WMS, WFS, WCS, Web Map Tile Service (WMTS), CSW and WPS. GeoServer functions as the reference implementation of the OGC.

Another open-source software chosen is PostGIS, a spatial database extender for PostgreSQL

DBMS. PostGIS enables spatial SQL queries using spatial operators, such as *Point in Polygon,* which can facilitate the determination of a county (polygon) to which a school (point) belongs.

The application uses a web server known as Nginx (pronounced *engine-x*). Running on Linux technology, Nginx is an open source web server that can serve requests such as HTTP, HTTPS, SMTP, HTTP cache and load balancing.

OpenLayers, an open source JavaScript library for displaying geospatial data in web browsers, was also used. It provides an API for building web-based geospatial applications. Together with HTML, OpenLayers was used to provide an interface to the application and for client-side user interaction. This helped in the display of maps and support for user interaction.

The selected technology stack (Linux, Nginx, GeoServer, PostGIS, OpenLayers, Docker and Kubernetes) is completely FOSS. This not only highlights the potential for FOSS in modern geospatial information management, but also reduces software licensing costs. Support and online communities on FOSS are readily available, making it easy to access help and support during set up and configuration.

Installation Steps

The first step involved activating the Google Cloud Shell, which runs a virtual machine instance of Debian Linux operating system. The shell provides command-line access to computing resources hosted on GKE, using two main utilities known as *gcloud* and *kubectl*.

The next step involved using gcloud to set up the GCE compute zone, as shown in Code 4.1. GCE resources reside in regions or zones, a geographical location where a resource runs, which is known as a compute zone.

```
$ gcloud config set compute/zone us-central1-b
```

Code 4.1: Creating the GCE Compute Zone

There are many Docker images that can be reused, and two images identified for this study are: github.com/kartoza/docker-geoserver and hub.docker.com/r/mdillon/postgis/. These are used to create the GeoServer and PostGIS containers, respectively. Retrieving the images can be accomplished by the commands shown in Code 4.2.

```
$ docker pull mdillon/postgis
$ docker pull kartoza/geoserver
```

Code 4.2: Pulling Docker Images

The next step involved creating a GKE cluster with three nodes on which GeoServer, PostGIS and the Nginx containers will run. Code 4.3 shows the creation of a cluster named gscont.

```
$ gcloud container clusters create gscont --num-nodes 3
$ gcloud config set container/cluster gscont
$ gcloud container clusters get-credentials gscont
```

Code 4.3: Creating the Cluster

The application makes use of persistent disks, allowing the three containers to preserve their state across shutdown and start-up. Two disks are created as shown in Code 4.4.

```
$ gcloud compute disks create --size 200GB postgis-disk
$ gcloud compute disks create --size 200GB geoserver-disk
```

Code 4.4: Creating the Disks

The final step involved creating and starting the pods, and the services used to access them. Pod and service specifications were defined in YAML files. For example, Code 4.5 shows how the PostGIS pod and its corresponding service were created. The complete list of YAML files is given in Appendix 2.

```
$ kubectl create -f mpostgres.yaml
$ kubectl create -f postgres-service.yaml
```

Code 4.5: Creating the Pods

The webserver container has been customised, since it serves custom content (JavaScript, html and images) which are specific to the application. Thus, a docker image based on Nginx was created, as shown in Code 4.6. To create a running web server instance, see Code 4.7.

```
FROM nginx
EXPOSE 80
COPY webdir /usr/share/nginx/html
```

Code 4.6: Nginx Dockerfile

```
$ docker build -t gcr.io/myphdprj/phd-nginx:v1 .
$ gcloud docker push gcr.io/myphdprj/phd-nginx:v1
$ kubectl run phd-nginx --image=gcr.io/myphdprj/phd-nginx:v1 --port=80
$ kubectl expose rc (OR pod) phd-nginx --target-port=80 --
type="LoadBalancer”
```

Code 4.7: Creating the Nginx web server

By inspecting kubectl output (see Code 4.8 and the output in Code 4.9), GeoServer is running on 8.35.197.101; and can be accessed at: http://8.35.197.101:8080/geoserver/web. Opening this link loads the GeoServer login screen. Additionally, the web server based on Nginx is running on 146.148.76.240, and can be accessed by: http:// 146.148.76.240 /index.html.

```
$ kubectl get services gsfrontend psfrontend phd-nginx
```

Code 4.8: Inspecting the Services

```
$ kubectl get services
```

```
NAME          CLUSTER-IP       EXTERNAL-IP     PORT(S)     AGE
gsfrontend    10.103.247.146   8.35.197.101    8080/TCP    5h
kubernetes    10.103.240.1     <none>          443/TCP     1d
psfrontend    10.103.251.124   <none>          5432/TCP    5h
```

Code 4.9: Detailed Service Endpoints

The complete code listing is available on github: github.com/cmwange/gisongcs and has also been included in Appendix 2.

4.3.3 Data Sources

The KCPE results of 2015 (the results dataset) was obtained from MOEST. The schools dataset, which contains spatial coordinates of schools, was obtained from the Kenya Open Data Portal[1]. The latter is an extract of data collected by MOEST in its school mapping project of 2007 [100]. Administrative boundary layers such as wards, constituencies, and counties were obtained from the IEBC.

Table 4.1 presents the population and sample for each dataset. To be included, a record in the schools dataset must be easily identifiable by name in the results dataset. The two datasets reveal a lot of duplicates, naming anomalies, and other inconsistencies, which explains the relatively low sample representation of 55% and 59%. However, this was considered representative since the sample accounts for more than 30% of the population.

Table 4.1: Datasets in the Study

Dataset	Population	Sample	%	Source
Primary Schools	25,121	13,890	55	MOEST School Mapping, 2007
KCPE Results 2015	938,738	551,150	59	MOEST, 2015
Wards	1,450	1,444	99	IEBC
Constituencies	290	290	100	IEBC
Counties	47	47	100	IEBC

4.3.4 Data Loading

By loading the data into PostGIS database, GeoServer can be used to serve WFS, WMS, and WCS content. Additionally, the application can be extended to provide more sophisticated geoprocessing services using WPS as is typical in SDIs.

Data loading was done in two steps: generation of SQL scripts, using shp2pgsql; followed by population of data into the database. Code 4.10 shows an example. The Spatial Reference Identifier (SRID) 4326 refers to the new World Geodetic System (WGS 84), given that the

[1] www.opendata.go.ke/Education/Kenya-Primary-Schools/p452-xb7c

datasets are in this reference system. The data is stored in a database named “gis”.

```
$ shp2pgsql -s 4326 counties.shp counties > counties.sql
$ psql -f counties.sql gis
```

Code 4.10: Data load Scripts

4.3.5 Justification of the Methodology

As at 2016, the KNSDI was neither mature nor operational. There wasn’t a national geoportal accessible to the public. Ideally, this application should have been developed within the KNSDI geoportal, by integrating with existing fundamental datasets. It is for this reason that a rather stand-alone application was developed to outline trends for SDI in Africa.

4.4 Results and Discussion

An analysis and discussion of the results are presented in this section.

4.4.1 Data Portrayal and Download

The application serves a number of spatial services (notably WMS and WFS) depicting spatial characteristics of the dataset. Some of the maps are shown in Figures 4.3, 4.4 and 4.5.

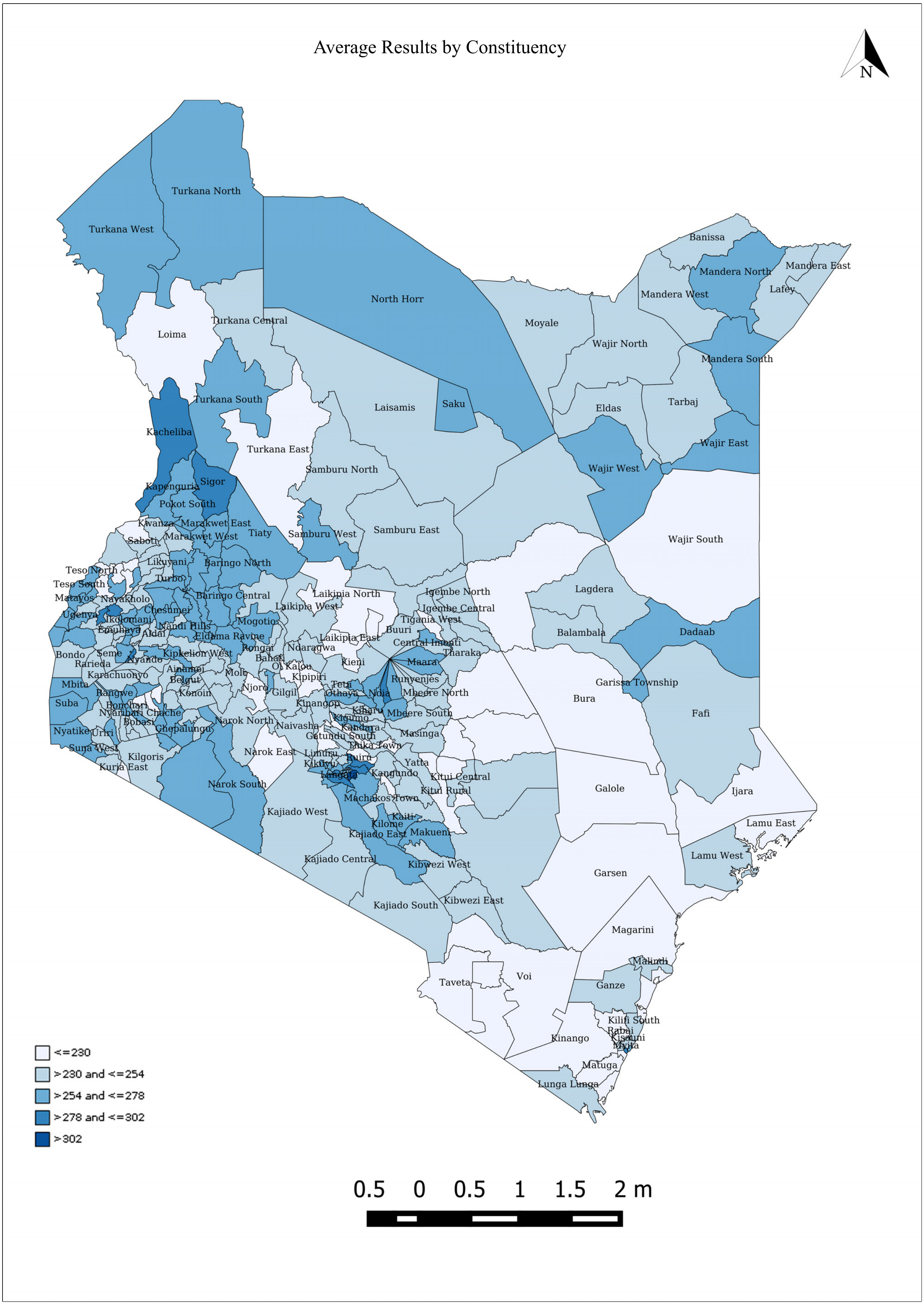

Figure 4.3: Average KCPE 2015 Results by Constituency

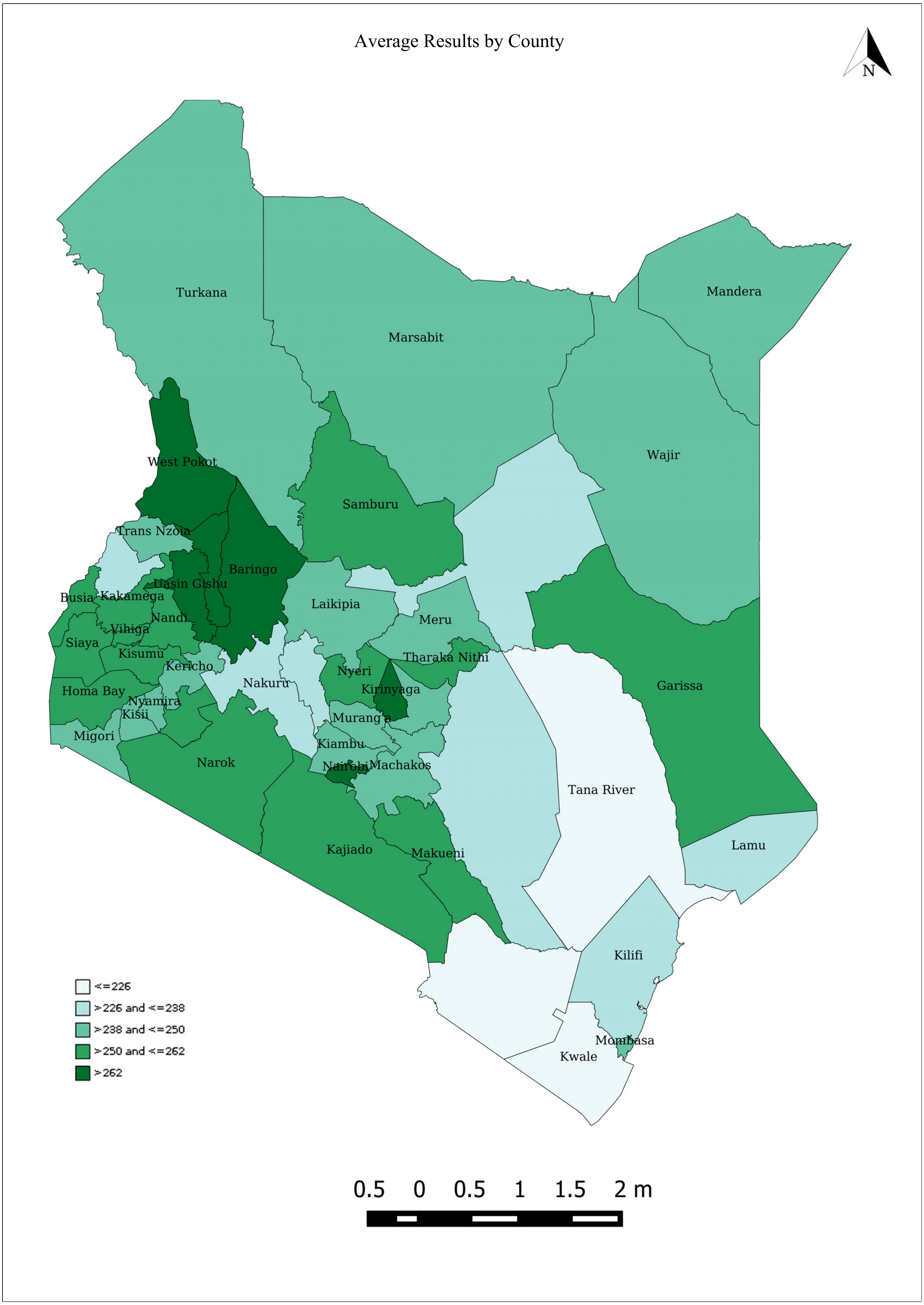

Figure 4.4: Average KCPE 2015 Results by County

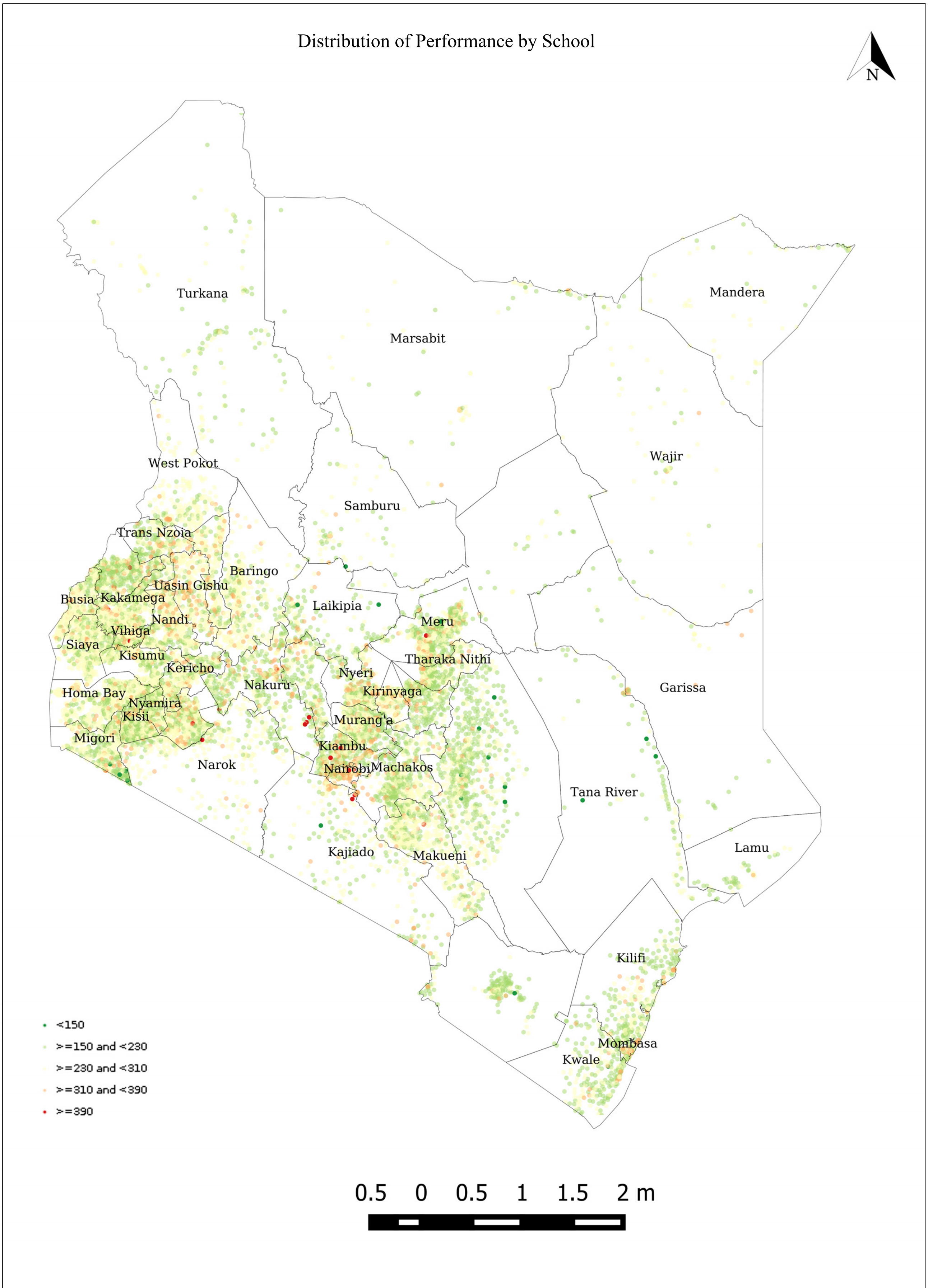

Figure 4.5: Distribution of Average Performance by School

4.4.2 Spatial Queries

The database can be used to build and visualize complex spatial queries. For instance, one might be interested to know which counties produced the top 100 candidates, or the bottom 100. Two queries in Code 4.11 have been used to produce the output in Figures 4.6 and 4.7.

```
CREATE VIEW county_all_zero AS
SELECT counties.county_cod, counties.county_nam, counties.geom, 0 as count
FROM  counties;



CREATE VIEW county_bottom_100_final AS
SELECT county_bottom_100.county_cod, county_bottom_100.county_nam,
county_bottom_100.geom, county_bottom_100.count
FROM county_bottom_100

UNION

SELECT county_all_zero.county_cod, county_all_zero.county_nam,
county_all_zero.geom, county_all_zero.count
FROM county_all_zero where county_all_zero.county_cod NOT IN (
       SELECT county_bottom_100.county_cod FROM county_bottom_100);



CREATE VIEW county_top_100_final AS
SELECT county_top_100.county_cod, county_top_100.county_nam, county_top_100.geom,
county_top_100.count
FROM county_top_100

UNION

SELECT county_all_zero.county_cod, county_all_zero.county_nam,
county_all_zero.geom, county_all_zero.count
FROM county_all_zero where county_all_zero.county_cod NOT IN (
       SELECT county_top_100.county_cod FROM county_top_100);
```

Code 4.11: Sample Spatial Queries

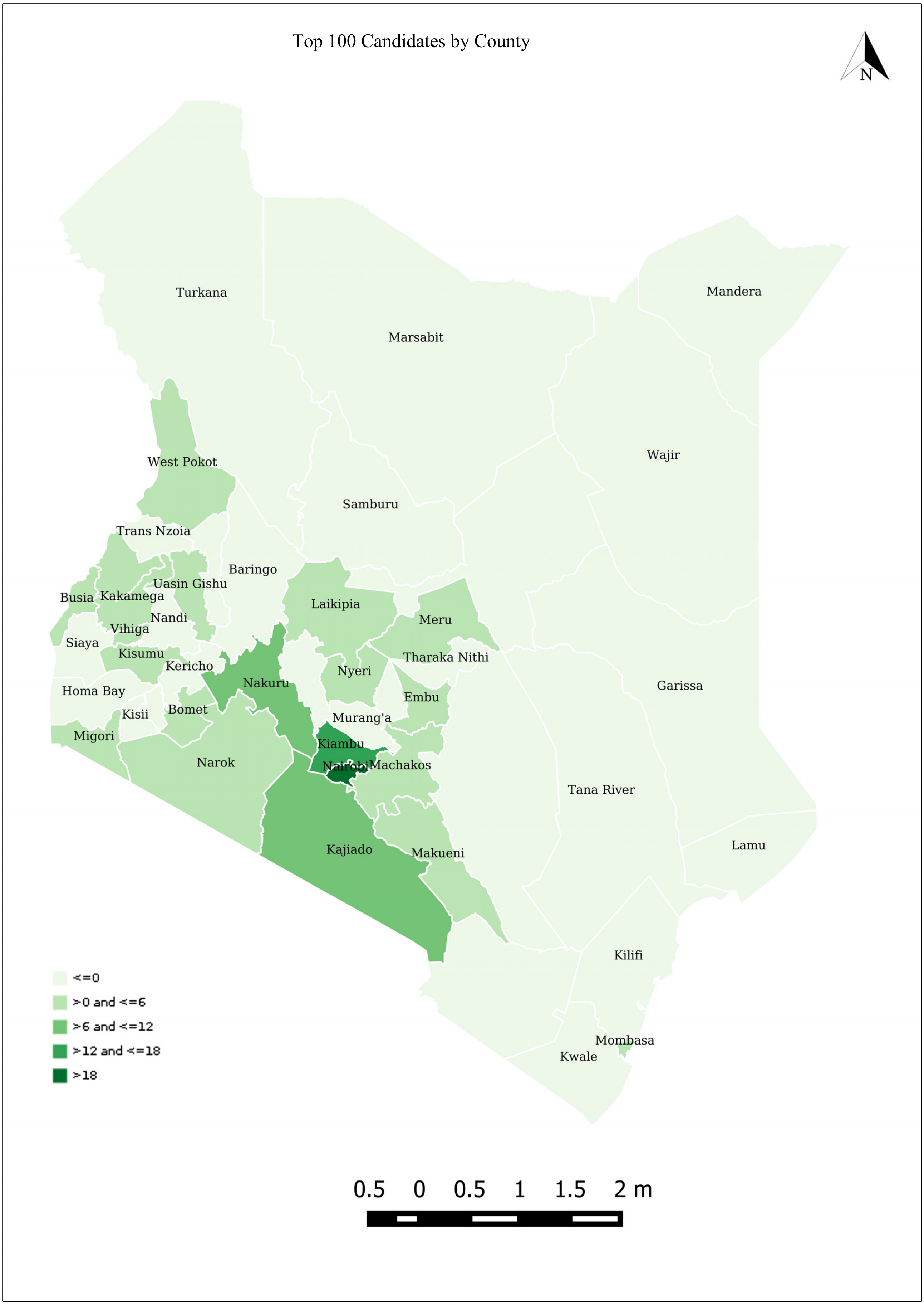

Figure 4.6: Top 100 Pupils by County

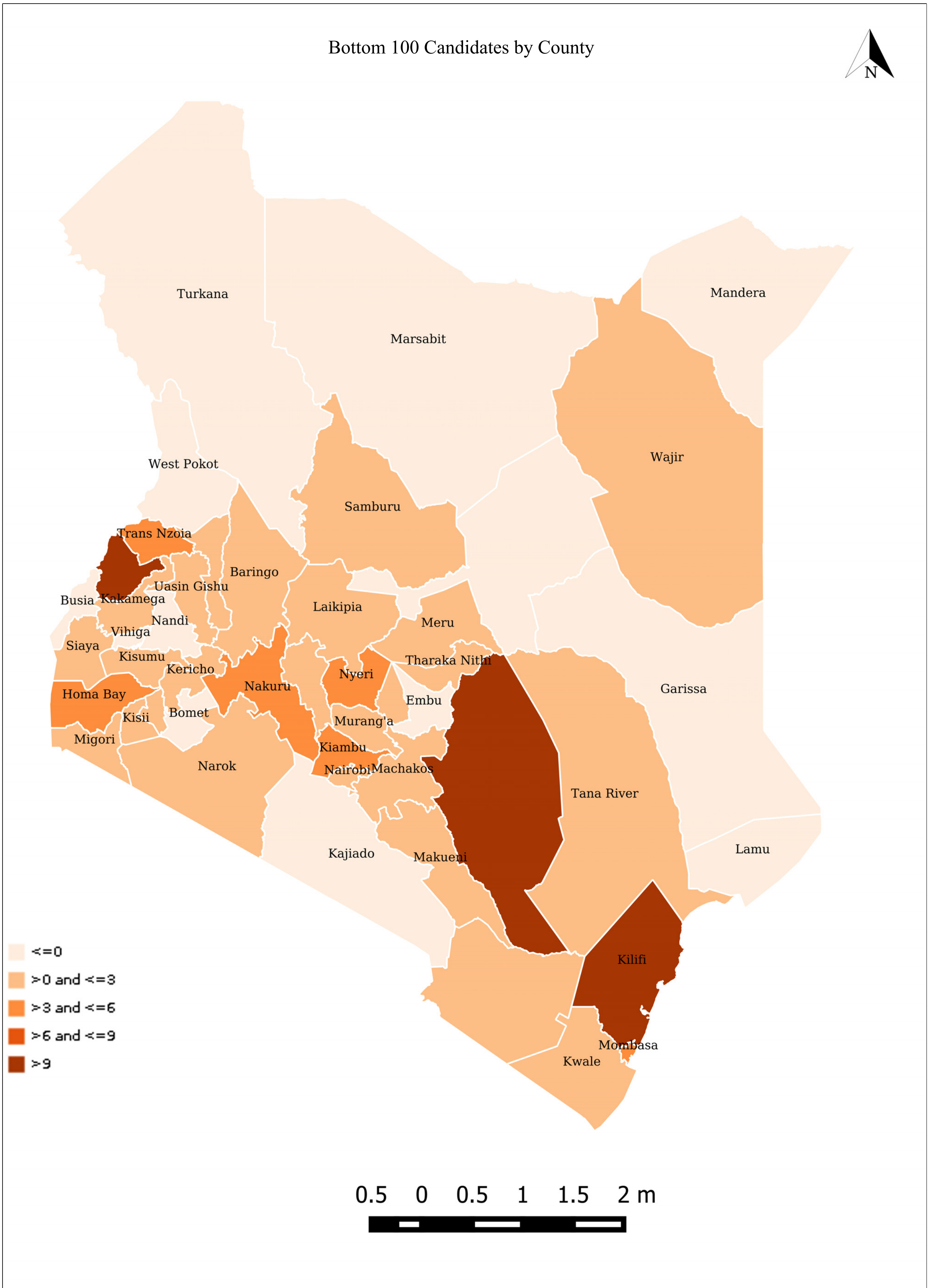

Figure 4.7: Bottom 100 Pupils by County

4.4.4 Potential for SDI

The study adds to the existing body of knowledge on technology choices for SDI development, by outlining the potential of the GCS cloud. In addition, the study presents a synopsis of the benefits and challenges of new trends such as cloud, FOSS and Big Data in SDI development.

Through Kubernetes, GCS provides superb scalability features, allowing computing resources to be scaled on-demand. Scalability is desirable in SDIs, which scale to the national and higher levels. This can be used to serve a large number of users, through efficient geoservices.

The application has been configured on a minimal virtual machine type (1 VCPU and 2 GB RAM). More powerful machine types are available, including high-CPU (32 VCPU and 28 GB RAM) and high-memory (32 VCPU and 208 GB RAM). Time and financial resources did not allow for testing higher machine types, which attract higher charges.

4.4.5 Cost Estimate of the GCS

An area of obvious interest is to estimate what it would cost for part of Kenya's national SDI (the KNSDI) geoportal hosting core spatial data to be deployed in a GCS cloud environment.

Given the weak status of the KNSDI [101], several assumptions are made, in order to eliminate the extraneous variables so that the focus is directed on the cost of cloud deployment. First, it is assumed that the KNSDI policies and standards have been finalised, and are used widely by most stakeholders. Second, it is also assumed that data custodians have been identified using policies and legal instruments. Third, data and metadata are widely available in a suitable digital format, and the KNSDI takes advantage of new trends for SDI development.

Table 4.2 shows a listing of potential custodians for the core spatial datasets. Although the focus is on custodians of core spatial datasets, there would be additional KNSDI stakeholders offering a host of application datasets, such as the National Environmental Management Authority (NEMA), and the Kenya Wildlife Services (KWS). For simplicity in the estimation, these stakeholders are excluded from the analysis.

Table 4.2: KNSDI Core Datasets and Custodians

KNSDI Dataset	MAFA Dataset	Definition	Potential Custodian
Geodetic control	Geodetic control points	List of coordinates with information on history	Survey of Kenya , Ministry of Lands
Geodetic control	Height datum	List of primary height points (vertical datum)	Survey of Kenya , Ministry of Lands
Geodetic control	Geoid model	Geoid-ellipsoid separations (heights)	Survey of Kenya , Ministry of Lands
Digital imagery	Photography and Imagery	Aerial photography and Satellite imagery	Survey of Kenya , Ministry of Lands
Elevation	Spot heights	Heights of peaks	Survey of Kenya , Ministry of Lands
Elevation	Bathymetry	Vertical distance from the surface to the lowest tide	Survey of Kenya , Ministry of Lands
Elevation	Coastline	Limit of land features usually at mean high water level	Survey of Kenya , Ministry of Lands
Hydrology	Natural water bodies	Watercourses, drainage network, and inland water bodies	Ministry of Water and Irrigation
Administrative boundaries	Governmental units	Administrative and Jurisdictional limits/boundaries	Survey of Kenya, Ministry of Lands
Administrative boundaries	Populated places	Urban areas, towns, localities, and rural settlements	Kenya National Bureau of Statistics
Administrative boundaries	Enumeration areas	Areas for collecting demographic information	Kenya National Bureau of Statistics
Geographic names	Place and feature names	Names of places, cultural and geographic features	ICT Authority
Parcel boundaries	Land parcels/cadastre	Land parcel/cadastre boundaries	Lands, Land Adjudication and Settlement
Parcel boundaries	Land tenure	Details of all tenures, e.g., ownership, vesting	Lands, Land Adjudication and Settlement
Geographic names	Land-use planning zones	Boundaries of permitted/restricted land use	Lands, Land Adjudication and Settlement
Transportation	Roads	Network of physical roads and carriageways	Kenya National Highways Authority
Transportation	Railways	Network of railway lines	Kenya Railways Corporation
Transportation	Airports	Location of airports and navigation aids	Kenya Airports Authority
Transportation	Ports	Location of sea ports, and navigation aids	Kenya Ports Authority
Utilities	Power	Trunk / national grid power lines / major installations	Kenya Power and Lighting Company Ltd.
Utilities	Telecommunications	Communication networks and major assets	ICT Authority
	Land cover	Observed bio-physical cover over on the earth's surface	The Kenya Soil Survey
	Soils	Boundaries and classifications of soil resources	The Kenya Soil Survey
	Geology	Boundaries and classification of geological units	Directorate of Resource Surveys and Remote Sensing
Vegetation	Forest Conservation		Directorate of Forest Conservation

Table 4.3 highlights the cost of deploying an SDI in a cloud environment. In order to highlight the cost of cloud deployment, the figure excludes the cost of additional SDI activities, such as data and metadata development, preparation of standards, policies, and the institutional framework.

If each custodian hosts its datasets in a GCS cloud using medium sized virtual machines (16 VCPU, 60 GB RAM, and 1TB storage each), then the estimated annual cost for each custodian of hosting on GCS is $27,000.

This cost was obtained from Google's cloud price list as at 2016. Similar to the application demonstrated in the study, the set up assumes that each custodian utilises three virtual machines, including a database server, an application server (e.g. GeoServer), and a web server based on Nginx to serve content using OGC services and Open Layers.

If each custodian gets its staff trained on setup and administration, then the annual training cost per custodian is $14,500, which includes consulting fees.

Table 4.3: GCS Cost Estimate

			Cost (US $)				
Item	**Qty.**	**Unit**	**Unit Cost**	**Year 1**	**Year 2**	**Year 3**	**Total**
GCS Cloud Virtual Machines	3	Month	750	27,000	27,000	27,000	81,000
Training and Capacity Building	3	Session	1,500	4,500	4,500	4,500	13,500
Consulting Fees				10,000	10,000	10,000	30,000
Geoportal Development				15,000	5,000	5,000	25,000
Sub Total				56,500	46,500	46,500	149,500
Miscellaneous		10%		5,650	4,650	4,650	14,950
Sub Total (per custodian)				62,150	51,150	51,150	164,450
Grand Total	**14**	**Custodians**		**870,100**	**716,100**	**716,100**	**2,302,300**

4.4.6 Areas for Further Study

Several challenges were encountered in the study. First, significant time was spent matching records in the results and schools datasets. This problem can be minimised by use of Linked Data, where concerned agencies cooperatively work together to improve data management. Additionally, although Google provides a free trial period, continued use of GCS has a cost implication. The application has been shut down but can be restarted in case there is need.

The following are recommendations for further improvement.

- The application can be extended to utilise mobile data collection tools (such as Esri's Survey 123), empowering schools with the ability to update their schools' data.
- The application can be extended to use Linked Data. Each school would be allocated a unique URI identifying it on the web, and storing its data in RDF format.
- A survey on the worldwide adoption of cloud and other technologies in SDI can be carried out. The study can verify if the technology trends lead to wider adoption of SDIs

4.5 Summary and Conclusions

Supported by an application based on contemporary technologies, the study highlights some of the technology trends and choices that can support SDI in Africa. Building upon the sample, developing countries can adopt some of the principles presented. The study not only highlights the technology choices available today, but also a reference sample application.

Time and financial resources did not allow for testing the scalability of the application. However, the study has shown that Cloud Computing has the potential to facilitate scalable web services in the cloud, thus increasing uptake of SDIs. Cloud services can provide higher quality services, improved performance, reliability of GI services, and improved accessibility to geospatial data and services. Several risks and benefits of cloud computing and other trends, which practitioners should be aware of, have been discussed.

FOSS software, including PostGIS, GeoServer, Linux, Kubernetes, Docker, and OpenLayers, have been used extensively. The application has shown that FOSS software can support SDI in Africa, where resources are generally scarce. However, these technologies come with a steep learning curve, which can be managed through training and capacity building.

Part of the data used in the study was obtained from the Kenya Open Data Portal. Availability of readily accessible data is not only a catalyst for successful SDI development, but also a means of creating more employment opportunities, entrepreneurship through data and service provision, and an agile ecosystem of developers built around SDIs.

Other than trends for SDI, the application may be of interest to practitioners in the education sector who may want to carry out spatial analysis of the existing data in a cloud environment. The same principles can be applied to other areas, including agriculture and climate change.

5 SDI IMPLEMENTATION METHODOLOGY FOR AFRICA

Chapter Summary

Spatial Data Infrastructures (SDIs) have enormous potential, ranging from supporting the protection and betterment of a country's social, cultural, economic, environmental and natural resources, to the promotion of local, regional and global competitiveness, innovation, productivity, job creation, and the information economy. In spite of these benefits, national SDIs in Africa are developing at a slower pace compared to the rest of the world.

There are several possible reasons for the slow development of SDIs in Africa. For a start, the concept may not be well understood, or it is complex and the approach being followed may be inconsistent in the African context. It is also possible that institutional frameworks are hindering development of sustainable SDIs. Being a long-term initiative, an SDI requires more coordination and collaboration amongst the stakeholders.

Using a case study approach, the chapter reviews five successful NSDIs across the world and proposes an implementation methodology suitable for Africa. The critical issues that African countries ought to consider in SDI development are reviewed.

One of the key findings from the study is the importance that should be attached to coordination for successful SDI development. To emphasise the role of coordination, the study has proposed a pan-African regional SDI (RSDI) similar to Europe's INSPIRE. This RSDI is denoted by the term African Infrastructure for Spatial Information (AISI).

The methodology developed has proposed several steps for successful SDI development. These are: awareness creation, consensus building, sustainable institutional framework, development of policies, sourcing SDI initial funding, making inventory of systems, datasets and human capacity, professional capacity building, development of standards, development of data and metadata catalogues, setting up of geoportal(s), building geo-literate citizens, and monitoring and evaluation.

Other SDI success factors include the establishment of the SDI objective(s), using policies to establish an institutional framework (lead agency, SDI committee(s) and custodians), selection of models for SDI development, use of directives and action plans, seeking political support at all levels, and availing adequate SDI funding.

5.1 INTRODUCTION

5.1.1 Background

A Spatial Data Infrastructure (SDI) is a distributed system designed to facilitate co-operation amongst data producers, users, and other stakeholders [102], including the citizenry. Broadly, an SDI refers to the infrastructure, that is, the physical and organizational structures, needed to facilitate the effective and efficient access and use of spatial data [29]. SDIs ought to promote the production of better data, and not just more data [71].

SDIs are facilitating evolution of Geographic Information Systems (GIS) from stand-alone to distributed systems based on autonomous and interoperable services [23]. Rajabifard *et al.* [13] posited that SDIs are the partnerships between stakeholders in many jurisdictions, enabling governments, businesses, the academia, and even the citizens to share and use spatial data and services to meet their needs.

SDI is still a relatively new concept that was introduced in the 1990's, but has since gained widespread use and adoption. That a large percentage of data for planning has a spatial component [5], coupled with the need to open up data and increase competitiveness, further increases the need for SDIs.

To date, notable SDIs include national SDIs (such as the South Africa's SASDI), supranational or regional SDIs (such as Europe's INSPIRE), and the Global Spatial Data Infrastructure (GSDI). SDI involves a multifaceted digital environment hosting a range of distributed datasets which adhere to agreed standards, policies, institutional arrangements and technologies [103].

SDI is primarily concerned with the facilitation of exchange and sharing of spatial data between various stakeholders [13]. It is an evolving concept providing an integrated view of spatial data management. The need for sharing is clear since organisations eventually depend on others to fill gaps in their spatial data requirements [4].

A typical SDI is made up of a number of components and elements [13], [102]:

- catalogues and geoportals, for discovery and access of data and services;
- metadata, to capture the structure and properties of data, services and other resources;
- foundation and framework data, commonly used datasets based on agreed standards;
- application or thematic datasets for specific application needs;
- standards promoting interoperability, sharing and reuse;

- institutional cooperation, for efficient and effective spatial data management;
- policies that promote data sharing, open data, privacy, pricing and custodianship;
- appropriate human resources; and
- distributed networks and technologies providing a means of access to the data

From the foregoing, it is evident that an SDI involves a wide range of activities from technical ones, such as data management, technologies and standards; to institutional activities such as policies, organizational aspects, financing and human resources [31]. The typical components in an SDI are shown in Figure 5.3.

SDIs can be considered as an information infrastructure (II), which is generally more complex to build and operate. This led Budhathoki and Nedović-Budić [67] to express concern that the current SDI knowledge base is neither well grounded in theory nor sufficient for sustainable SDIs. It is partly for this reason that some SDIs are developing slowly. Even mature SDIs are not spared: for instance, performance issues and inability to serve a wide range of user needs have been reported [92].

Given the high failure rates of SDIs particularly in developing countries, there is need to review sustainable SDI models. Such a model is required to outline the nexus of the SDI development process, and its set up across many organizational levels, which accommodates all participants in the SDI [67]. This can be done while taking into account the social, economic, cultural and political factors in the context of the SDI.

To set the scene for the arguments advanced in this chapter, we reiterate that development of SDI's particularly in Africa faces several challenges, notably [1], [3], [67]:

- spatial data is often duplicated;
- low budgetary priority for SDI development;
- data for one application may not be easily available to other applications;
- sharing is still impeded by substantial non-interoperability;
- institutions are not accustomed to working together;
- many governments are unwilling to share and open up their spatial data;
- poor documentation renders most datasets incomplete or incompatible;
- lack of metadata inhibits the ability to find and use data;
- absence of key datasets (for example cadastres);

- existing datasets are often outdated;
- most spatial datasets exist in analogue format;
- legal restrictions to existing datasets (through copyrights and licenses);
- cost restrictions to existing data;
- barriers to information access (such as bureaucratic red tape); and
- lack of human capacity to exploit the spatial data

5.1.2 Statement of the Problem

That only a few countries in Africa – notably South Africa, and more recently Rwanda, have reached more advanced stages in SDI development is worrying. Despite the potential of SDIs, developing and maintaining them remains elusive [104].

There could be several reasons for the slow development of SDIs in Africa. First, the concept of SDI may not be well understood. Second, SDI is complex and the approach being followed may be not be compatible in the African context. Finally, the set-up of organizational and institutional frameworks in Africa may be impeding SDI development.

An SDI can be regarded as an II consisting of diverse users and organizations. As postulated by Budhathoki and Nedović-Budić [67] and Díaz *et al.* [15], an II is generally more complex, builds on its installed base such as the number of SDI users or services provided, is an open system, and supports any number of users with diverse needs. An II does not only gradually expand, but also transforms, as more users and services are added to it [67].

The traditional system development methodology of technology-centred design may work well for smaller systems, but is inadequate and risky for IIs and SDIs, which tend to be larger in scale. Thus, a careful approach is needed in the design and development of an SDI.

This chapter sought to bridge this gap, by proposing a model suitable for SDI development in Africa. It follows the case-study approach, based on a critical examination of best practices from mature SDIs in selected countries, with a view to answering the research question: *What SDI implementation methodology is suitable for Africa?*

5.1.3 Research Objectives

The main objective of this chapter is to recommend a methodology for SDI development in Africa. This includes a review of some considerations that African countries could heed as they develop their SDIs. The supposition that there is a methodology problem is based on the fact that SDIs are developing slowly in Africa. Furthermore, SDIs tend to be complex for several reasons [29]:

- multiple and heterogeneous SDI objectives;
- multiple SDI users with divergent needs and technological capabilities;
- many SDI components, often listed as unordered components in definitions;
- rapid development of technology components;
- structure of SDIs, spanning many hierarchies, often ignoring network relationships; and
- many disciplines with an interest in SDI, such as geomatics, ICT and economics

The main aim of this chapter is to develop a methodology which African countries can follow during SDI development. This involves an extensive examination of selected SDIs available today, and drawing inferences that can be applied in the African context.

5.1.4 Organization of the Chapter

Section 5.2 analyses literature related to SDI, focusing more specifically on models of SDI development. In section 5.3, the methodology adopted in the study is presented. Results, discussions and conclusions from the study are presented in section 5.4.

5.2 LITERATURE REVIEW

5.2.1 Introduction

The successful development of an SDI requires an in-depth understanding of the concept, contributing components [13], and their roles within the SDI. This section dwells on the typical structure, models and components of an SDI.

5.2.2 Understanding SDI

There are three themes that underpin all SDIs [67]:

- policy and organization (institutions, management, financial, politics and culture);
- sharing and interoperability (custodianship, standards and policies); and
- discovery, access and use of the spatial data (technology and technical components)

A typical SDI consists of a network of organizations (see an example in Figure 5.1), each of them exposing spatial data via geospatial services (such as discovery, access, and visualization) to serve a broad range of needs. Services are provided by a wide spectrum of suppliers, guided by policies and interoperable standards.

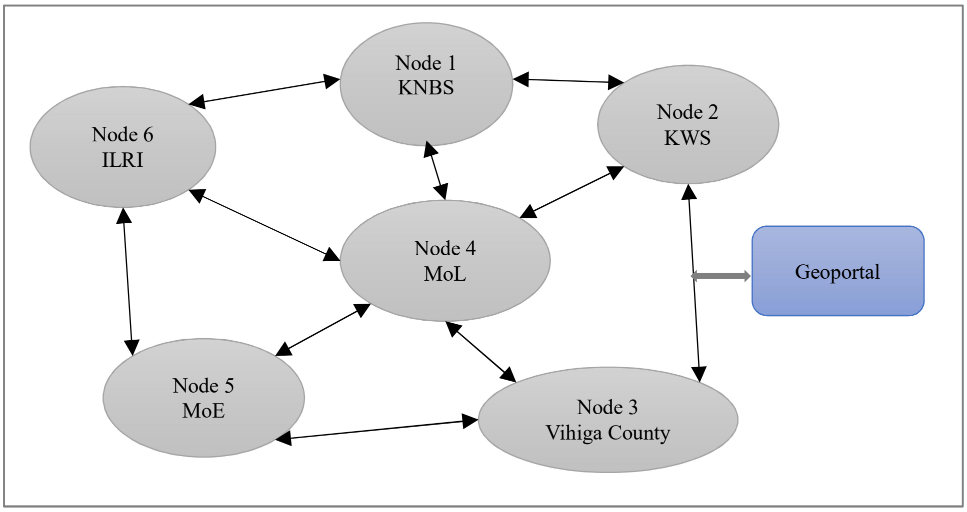

Figure 5.1: Structure of an SDI
(Based on selected organisations in Kenya)

The typical components of an SDI are outlined in the succeeding paragraphs.

Data

Data are the facts and figures that reside in the SDI participatory databases, and are the most valuable asset in the SDI. They can be categorised as foundation, framework or application data.

Foundation data: the basic, must have datasets needed by most of the SDI participants, such as geodetic control, orthophotographs, topographic mapping, administrative boundaries, and gazetteers. They are used as a basis for value addition, or to correctly register a theme.

Framework data: data that are commonly needed for applications to provide thematic information, such as transportation, hydrography, cadastre, land use, geology and soils.

Application data: data that provide information about specific applications, such as national parks, tourist attractions, wetlands, location of schools, and plant distribution.

As reflected in Figure 5.2, foundation data have the highest data sharing opportunities, and consequently have the widest usage compared to other datasets. Thus, foundation data have the highest SDI value. The production and maintenance of foundation and framework data is normally the mandate of an appointed public agency, usually referred to as a ‘custodian’. As custodians are funded by taxpayers, such datasets should be widely available at little or no cost.

A survey conducted during the 2007 regional consultation by the UN agencies held in Nairobi, established that 80% of the data held and maintained by each agency was the same as those held by other agencies. Only 5% represented data uniquely contributed by individual agencies [71]. This indicates that the level of duplication is very high.

Metadata

Commonly defined as data or information about data and services, metadata may help to describe the content, condition, source, ownership, quality, age, and fitness for purpose [84]. The primary purpose of metadata in an SDI is to enable data and services to be well understood, shared widely and used effectively by all types of users.

Based on metadata, the SDI community could organize (inventory) datasets or services, index them to permit structured searches (catalogue), and provide users with adequate information (document) about them [34].

Metadata that may describe data include dataset title, coverage (spatial and thematic), form, format, source scale, access protocols, cost, last update, accuracy, lineage etc. An SDI must organise metadata systematically, thereby allowing users to immediately know what data is available to allow efficient search [34].

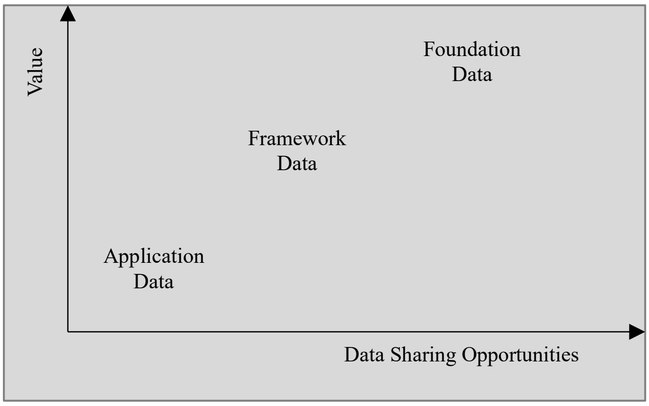

Figure 5.2: Datasets in an SDI

In general, metadata serves four functions:

- location of datasets or services;
- evaluation (or assessment) of datasets or services;
- access to datasets or services; and
- use of the datasets or services

The scope and description of metadata may vary and should be guided by an agreed standard. Most countries use the *ISO 19115: Geographic information – Metadata* standard.

Metadata can be developed at three levels: *core metadata,* such as title and source scale (which enables discovery and high level evaluation of fitness of use and accessibility); *exploration metadata,* such as accuracy and currency (which enables the user to ascertain fitness for use and accessibility); and *exploitation metadata,* such as delivery mode and dataset access (which enables access, delivery and application of the data).

Institutional Cooperation

This constitutes the mechanisms needed to enable key stakeholders to collaborate and actively engage in the SDI. It is essential for creating and maintaining the synergies required around the SDI. It can take the form of legislation, regulations, policies, written agreements, or informal negotiation [23].

Institutional arrangements facilitate access to distributed spatial data in the custody of diverse stakeholders. Such arrangements may help improve maintenance of the data and metadata, reduce duplication in data collection and management, foster standards and core datasets development, and facilitate compliance with national and international standards.

Often related to corporate interests and ambitions [75], institutional issues are generally more difficult to address than the technical ones. When considering institutional issues, the key choices to be considered are [23]:

- the model to be used for SDI development;
- the institution or individual to lead development of the SDI;
- the key actors in the SDI initiative;
- how the key actors are engaged and related to each other; and
- data custodians, who are authoritative sources of core spatial datasets

Figure 5.3 highlights institutional cooperation in relation to other SDI components. The core SDI components (people, technology, metadata and data) are subject to standards. Standards together with core components support services facilitating discovery, access and use of the SDI. Institutional cooperation is the glue that holds the SDI together.

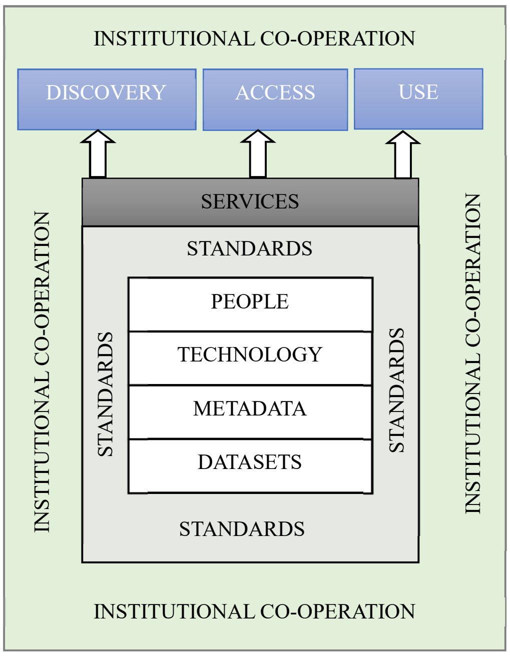

Figure 5.3: Detailed components of an SDI

Standards

Standards can be defined as the 'documented agreements containing technical specifications or other precise criteria to be used consistently as rules, guidelines or definitions of features to ensure that materials, products and services are fit for their intended purpose' [77].

Standards may allow organizations to efficiently share and use spatial data and technologies, enrich data and service quality, facilitate data sharing and interoperability, and bring a level of systematization and automation in the SDI [34].

Standards are used to primarily promote interoperability. This is the ability of independent, diverse and dispersed entities (e.g. data, services and applications) to communicate and interact or be used together despite their differences [105]. Interoperability includes syntactic, semantic and schematic interoperability.

Syntactic interoperability is the ability to deal with formatting and data exchange, and is easily achieved by ad hoc standards. Schematic interoperability is described by classifications and hierarchical structures; while semantic interoperability harmonizes meanings of terms [15]. The latter can be improved using metadata standards, data schemas and ontologies.

The OGC standards have systemized metadata and a host of application services, while ISO/TC 211 has defined standards for imagery, geo-services, and quality and information management.

Several types of standards can be distinguished for SDI:

- *data standards* for consistent quality and efficient data interchange between systems;
- *Information Technology (IT) standards* for hardware, software and communication;
- *educational standards* define the qualifications for geo-information professionals;
- *organisational standards* for standardization processes; and
- *SDI performance standards* that help evaluate the performance of an SDI

Technology

The enabling technologies for SDI comprise computer networks, clearinghouses and geoportals, the internet, and web services. Today, new trends such as Cloud Computing, VGI, Linked Data, and Big Data are increasingly supporting SDI development [106]. Although technology components that support SDIs are currently very mature, significant financial and human resources are often required to support and develop them.

People

People in SDI are those that run the system, and the end users who not only access and use the SDI, but also develop value added products that become part of the data resource. They include geospatial and ICT personnel, business administrators, suppliers of spatial data and services, and geo-literate citizens.

SDI Policies

By definition, policies are the official guidelines on how the SDI is to be setup, managed and sustained for the widest benefit of stakeholders involved. They are the operational- or strategic-level mechanisms needed to expedite the development and use of an SDI [23].

Strategic policies address high-level issues such as SDI directives which can be used to put in force compliance with given standards or processes. Conversely, operational policies address lower-level concerns such as lifecycle management of spatial data (e.g., setting up of guidelines and manuals on data collection, management, and dissemination) [23].

SDI Policies are mainly needed for the following:

- data development, e.g. policies on the need for standards and metadata;
- data access e.g. policies on the right to public information;
- policies on data commercialization;
- intellectual property, how creativity can be protected by copyright, patents and licenses;
- policies on data custodianship; and
- policies on SDI data security, funding, technology and capacity building

5.2.3 The Ideal SDI

According to Corbin [105], more successful SDIs are characterised by steady political backing at the highest possible level through their development.

In the early days, SDI development took a broad-based approach that encouraged collaboration amongst data producers primarily to pool and share data resources. Thus, the ideal SDI has all the distributed datasets in the SDI fully integrated [13], giving rise to a data-centric SDI.

Data-centric SDIs mainly focused on five SDI components, including: datasets, metadata, technical standards, institutional frameworks, and access networks. This approach, also known as the product-based model, places less emphasis on the people in an SDI.

The interaction between people and various SDI components acts like a double edged sword. It is people who drive development of SDI, while at the same time interaction between people and various SDI components contributes most to its complexity [13]. The process-based model emerged around the year 2000 to address limitations of the product-based model.

An SDI can be described as an ideal SDI if it has the following characteristics [31], [105]:

- the SDI is developed, used, and maintained by custodians responsible for core datasets;
- there is a common spatial data foundation readily accessible at little or no cost;
- data in the SDI follow common standards, developed and agreed by all stakeholders;
- application data are compatible with foundation data;
- an enabling legal environment facilitates development of the SDI;
- the SDI may span from local to national and even regional and global levels;
- data produced in one jurisdiction is compatible with data produced in others;
- the SDI produces information useful for decision making and public consumption;
- responsibility for producing and maintaining spatial data is widely shared;
- the cost of managing data is justified in terms of public or private benefits and gains;
- duplication and overlap is avoided where possible; and
- the SDI is ready to answer current needs (e.g. in emergencies and disasters)

An SDI architecture is made up of five key elements, including data, metadata, applications, services, and people. Data and metadata are the core of an SDI [107]. Services and applications enable access to the data, producing information for consumption and decision-making by various users, such as the citizens, service integrators, data providers, metadata, and services.

The success of an SDI requires sustained commitment to the development and adoption of standards [34]. The ideal SDI should be based on open and interoperable standards and specifications for operational transactions and information exchange, and should focus on identifying and promoting existing open standards, and developing new ones as needed through the help of standards organizations.

Other key issues for consideration when developing SDIs include the hierarchies of servers and registration authorities, the interconnection of systems forming part of the SDI, and the need for security and authentication mechanisms [23].

The successful development of SDIs is contingent upon the following factors [75]:

- clearly defined core (or base) spatial datasets;
- adherence of the datasets to known and accepted standards;
- accessible documentation (metadata) about existing datasets;
- adequate human and technical resources to collect, maintain, distribute and use the data;
- policies and practices that promote the exchange and reuse of spatial datasets; and
- institutions that collaborate to improve and advance the SDI

5.2.4 SDI Development Models

Ever since the concept of SDI began, several patterns of SDI development have emerged. This sub-section reviews some of these patterns.

Top-down vs Bottom-up Model

Commonly known as the *mandatory model,* the top-down model is normally backed up by legislation, regulation or some other type of directive (executive visionary). The model may require spatial information producers to make their datasets discoverable and accessible in the SDI [23]. Notable examples of this popular model include the USA’s National Spatial Data Infrastructure (NSDI) and the South African Spatial Data Infrastructure (SASDI).

Tumba and Ahmad argued that the top-down approach is increasingly becoming unpopular due to high failure rates manifesting contemporary SDIs [46]. Furthermore, an effective SDI should involve users at the lowest possible levels in its jurisdiction; and the top-down approach may not effectively promote lower-level participation.

The alternative to the top-down model is the *voluntary or bottom-up* model, comprising of SDIs that originate from existing initiatives at lower levels in the jurisdiction on a voluntary basis (early adopters). Although less prevalent, the model has been successfully used to develop the Canadian Geospatial Data Infrastructure (CGDI) [23]. Collaborative efforts are essential in this model since no single organisation can develop an SDI.

Most African countries have little to show for their NSDIs many years after inception, implying that the dominant top-down approach may have limitations in the African context. Makanga and Smit noted a high number of informal SDI activities in Africa, and proposed a bottom-up approach to SDI development [1].

There are other reasons why the bottom-up approach is becoming popular. Improved web sensor GIS and new technologies, which thrive under the bottom-up approaches, are recognised as genuine contributors to SDI. In addition, the bottom-up model encourages participation at the lower level(s) at which participants understand their spatial data needs much better.

<u>Product- vs Process-Based Models</u>

According to Rajabifaad *et al.* [13], the product-based model pursues the objective of linking existing and potential datasets in the jurisdiction. An illustration of this model is presented in Figure 5.4. The product model was prevalent in the earlier SDIs, which are commonly referred to as 'first generation' SDIs. These SDIs focused on data development and management, and technology was their main source of complexity [104].

The process-based model, depicted in Figure 5.5, facilitates a framework which promotes the management of information assets [13]. SDIs that follow this model are commonly referred to as 'second generation' SDIs. These SDIs, which are responsive to different stakeholders, are characterised by a wide range of users, and processes that promote partnerships and agreements [70]. The objective of an SDI is to provide better communication channels for the SDI participants for improved sharing of spatial datasets, knowledge infrastructure and capacity building.

Leadership responsibility in second generation SDIs is often based on new and independent organisational models, whilst in first generation SDIs, it is often based on National Mapping Organisations (NMOs).

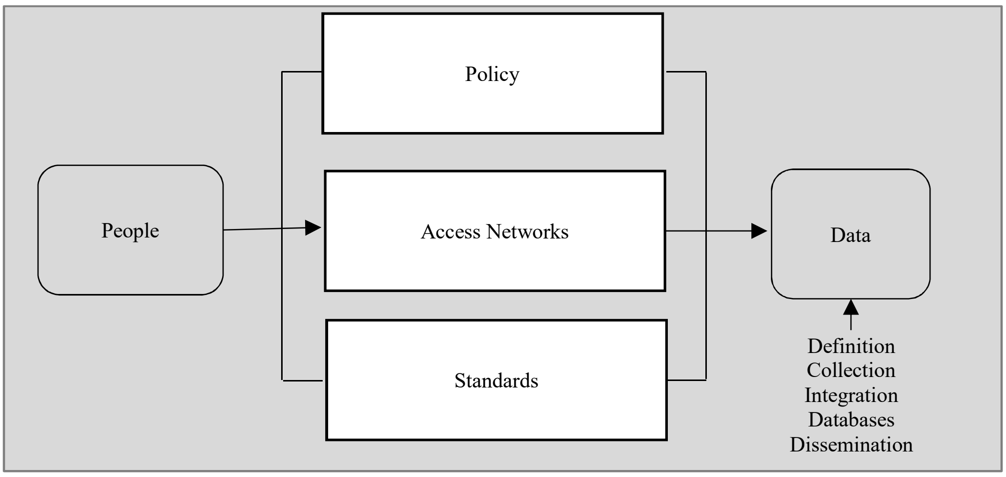

Figure 5.4: SDI Product Model
Source: Rajabifard *et al.* [13]

The process model succeeded the product model mainly to address limitations of the latter. First, SDIs had become popular resulting in an increase in the number of users [104]; often with diverse needs. Facilitating interaction between data, people, and various agents became a focal point. Second, this model sought to address several emerging issues [29]: the dynamic nature of SDI due to rapid technology changes, the hierarchy of SDI ranging from global, regional, national and down to the local and corporate levels, involving many relationships, and the many disciplines with an interest in SDI.

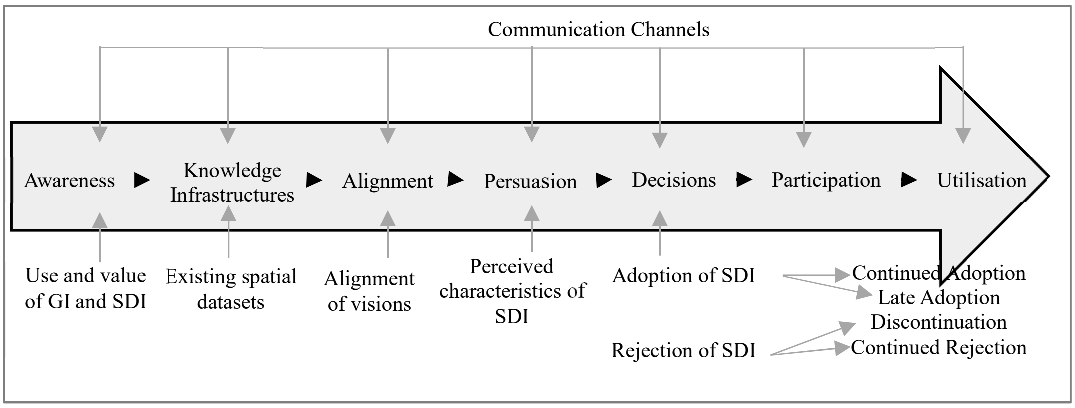

Figure 5.5: SDI Process Model
Source: Rajabifard *et al.* [13]

By setting up a geoportal, a catalogue system and spatial datasets, the coordinating agency is able to increase the knowledge infrastructure for that community which enables them to better identify appropriate datasets and communication links with custodial agencies [13].

Hierarchies of SDI

In order to apply the models for SDI development discussed so far, that is, top-down vs bottom-up models, and the product- vs process-based models, it is important to highlight that the social environment in which the SDI is developed influences rate of adoption. SDI is an evolving concept that sustains different perspectives depending on the context, user's interests, and roles within the SDI [29].

According to Rajabifard *et al.* [13], the nature of an SDI, as perceived by the members of a social system, determines its rate of adoption. This may explain why some countries have mature and improving SDIs while in others, such as Botswana [24], Kenya [12] and Uganda [3], several attempts have been made but the initiatives remain patchy. An SDI developed following a particular methodology may be successful in one community, but fail in others.

The social system is a set of interrelated units (such as communities, states and counties) that are engaged in joint problem solving to accomplish common goals. The characteristics of the social systems can influence the approach taken to develop an innovation [13]. In other words, an understanding of the social system can help in the selection of an appropriate strategy for SDI development.

The different characteristics of social systems adopting an SDI can be attributed to a number of factors, including culture [67]. However, the objective towards SDI development is to take advantage of common interests toward achieving certain goals [13]. Similarly, SDIs can be likened to the hierarchies commonly found in organisations. As shown in Figure 5.6, these are operational, management and strategic levels.

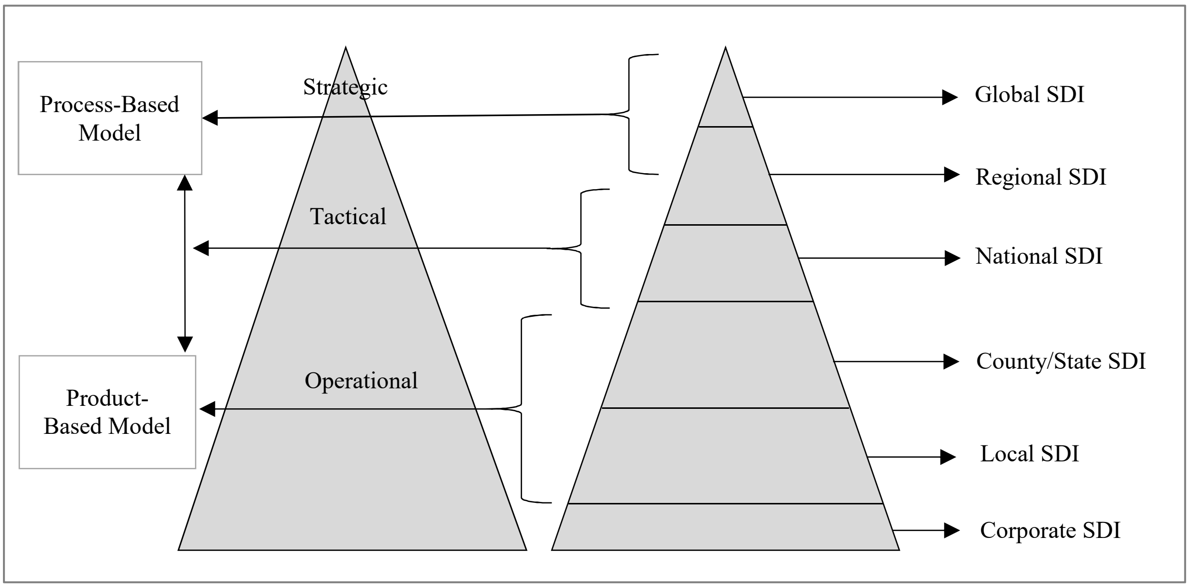

Figure 5.6: Hierarchies of an SDI
Source: Rajabifard et al. [13]

As seen in Figure 5.6, an SDI initiative belonging to the higher levels of the SDI hierarchy – for example a supranational SDI or an RSDI, may gain more by adopting the process-based model. A notable example is INSPIRE, a regional SDI that facilitates development of NSDIs in respective member states.

The roles of various levels of SDIs depicted in Figure 5.6 have been summarised as follows. The global SDI (GSDI) facilitates development of global standards, treaties and agreements. RSDIs conform to the GSDI, by defining and facilitating regional standards for NSDIs, and promoting regional partnerships. NSDIs conform to the RSDIs, by facilitating development of national standards, policies and legislation [108].

A product-based model may be more appropriate for an SDI if the aim is to link databases of the respective political/administrative levels in the community. On the other hand, if the main aim is to define a framework to facilitate the management of spatial information assets, then a process-based model would be more appropriate.

The same argument can be advanced considering the political system in use. If the community is a federated system of sub-units, then more advantage can be gained from adopting a process-based model, due to the voluntary nature of participation in these systems. Non-federated systems can select between the models to optimize advantage [13].

Lance *et al.* [69] expressed concern that most government structures are incompatible with structures needed for successful SDIs. A fundamental dilemma exists when implementing SDI, because SDIs are cross-agency initiatives while governments are fundamentally structured around boundaries (departments, programs, hierarchies and authority).

Although the concept of SDI is well understood by practitioners, its development process is not as straight forward [27]. An accepted, sequential methodology does not exist. To this end, many generic guides have been developed, which are reviewed in later sections of this chapter.

5.2.5 Regional Forum on NSDI

In July 2015, the Regional Forum on National Spatial Data Infrastructure in Kigali, Rwanda, brought together member States of the Regional Centre for Mapping of Resources for Development (RCMRD) i.e. Botswana, Burundi, Ethiopia, Ghana, Kenya, Lesotho, Malawi, Mauritius, Namibia, Rwanda, South Africa, South Sudan, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe.

The forum was organized by the RCMRD, the host institution Rwanda Natural Resources Authority (RNRA), the National Aeronautics and Space Administration (NASA), and the United States Agency for International Development (USAID), through the SERVIR project.

The main objectives of the forum were to equip high level officials in member States with the information necessary to implement NSDI, establish a community for practitioners and policymakers to share ideas, best practices, and lessons learned, and to improve the overall implementation and evaluation of NSDI efforts. Panellists discussed most aspects of SDI, including data, metadata, standards, policies, technology and infrastructure. Delegates were asked to become NSDI champions in their countries, and promote SDI awareness.

5.3 METHODOLOGY

5.3.1 Introduction

This section reviews the methodology used in the study, while highlighting the data requirements, data collection mechanisms, and sampling methodology.

5.3.2 Case Study Methodology

This study has been designed as a case study, where features common to successful SDIs are empirically identified and then used to derive a general methodology for SDI development in Africa.

A case study can be used to develop new theories and hypotheses that are tested rigorously in later studies [11]. Additionally, the case studies offer an effective mechanism to convey the underlying factors that lead to success in SDI development [23]. This method appears appropriate to this study, since the aim is to develop a methodology for SDI in Africa.

The study specifically looks for the following information in the selected case studies:

- background, environment and justification for the SDI
- details of the SDI implementation, including institutional and methodology highlights
- good practices and lessons learned

To determine the SDI methodology for Africa, the following steps are followed:

- literature review is carried out on selected SDIs to identify common features
- the patterns in the features are identified
- the patterns are amalgamated to derive the SDI methodology for Africa

5.3.3 Data Sources

The study relies on secondary data, derived from literature in selected countries with mature SDIs. Critical focus is placed on the methodology and institutional frameworks prevailing in the selected countries.

The population of the study comprises all countries with mature SDI, i.e. a country with an SDI that has a substantial installed base and the geoportal being available and providing a wide range of data and services. The sample is drawn from the population such that at least one country from each major continent is represented. These are the Americas, Africa and the Middle East, Asia and Oceania, and Europe (see Table 5.1).

Table 5.1: Selected sample and population

Continent	Population	Sample
Americas	USA, Canada, Brazil, Argentina, Chile, Mexico, Uruguay, Venezuela	USA, Canada
Africa and Middle East	South Africa, Abu Dhabi, Saudi Arabia,	South Africa
Asia and Oceania	Australia, New Zealand, India,	Australia
Europe	The Netherlands, United Kingdom, Germany, Poland, Spain, France, Norway, Portugal,	Poland

In summary, the study reviews the Canadian Geospatial Data Infrastructure (CGDI), the South African Spatial Data Infrastructure (SASDI), the Polish NSDI (Krajowa Infrastruktura Informacji Przestrzennej (KIIP)), the USA National Spatial Data Infrastructure (NSDI) and the Australian Spatial Data Infrastructure (ASDI).

5.3.4 Summary of the Case Studies

The detailed case studies used in this chapter are presented in Appendix 3. A summary of key features and lessons learnt from the case studies are outlined in the succeeding paragraphs and in Table 5.2.

Canada's CGDI

GeoConnections, the CGDI's lead agency, has embraced a broad-based approach by partnering with government agencies, the private sector and the academia. Emphasis has been placed on getting as many stakeholders on board as possible. As a result, the CGDI manifests as a sector- and industry-wide SDI initiative.

The CGDI supports shared decision making necessary for resolving many horizontal and inter-jurisdictional challenges. The existence of a vibrant private geo-information sector has greatly influenced the CGDI.

Based on the bottom-up approach (which is suitable where SDI is well understood), the CGDI does not rely on national laws and regulations, but on strong national policies and standards. All stakeholders have a chance to contribute to the SDI development process.

South Africa's SASDI

South Africa has followed the top-down SDI development model. Laws and policies have been used to establish the SASDI. An outline of the duties and responsibilities of key stakeholders, such as data custodians, is clearly defined using policies. Generally, the top-down approach is suitable where the SDI is less well understood, and SASDI shows that clear guidelines at all levels may promote the better understanding of an SDI.

Poland's KIIP

KIIP presents an interesting case study, in the sense that the SDI was initiated to promote entrepreneurship and job creation, which are perennial problems in Africa. KIIP shows that SDIs are more likely to succeed if there is a shared driving agenda.

Furthermore, KIIP demonstrates the considerable role of governments in promoting SDIs. Poland is a European country and INSPIRE requires member states to pass legislation and rules for SDI implementation. INSPIRE also requires member states to support education and training of staff and citizens in SDI skills and awareness promotion.

USA's NSDI

The NSDI shows that political support at the highest level (e.g. the president) can have a major impact on SDI development. But first of all, the president must be made aware of the benefits of an SDI. The NSDI has been developed in a complex environment with many stakeholders of diverse interests. Key strategies have been devised through policies and rolling strategic plans to manage the complex SDI environment. In addition, the NSDI shows that consistent research and funding can be very instrumental to the success of SDI.

Australia's ASDI

ASDI aims to maximise economic, social and environmental benefits. It also focuses on industrial development, the information society, and tackling contemporary challenges, such as globalization, environmental degradation and natural resource depletion. One of the striking features of the ASDI is the prominence of communications and consultation strategies; which involve regular briefing to senior executives.

Table 5.2: Summary of the case studies

	SASDI	**KIIP**	**ASDI**	**CGDI**	**NSDI**
Objective of the SDI	Facilitation of sharing and avoidance of duplication in spatial data	Entrepreneurship and job creation	Maximising the economic, social and environmental benefits; facilitating industry development; globalization; and environmental concerns.	Competitiveness, innovation, productivity, incubator effects in information value-adding industries, and job creation	Reduce duplication of effort, improve quality, reduce costs, make geographic data more accessible, increase the benefits of using available data, and to establishment of key partnerships
Directives and Action Plans	The SDI Act of 2003	The Act of 2009 and the INSPIRE directive of 2007	No directive	No directive	Executive Order number 12906 of 1994
Collaborative partnerships	Facilitated by the Committee for Spatial Information (CSI) and the National Spatial Information Framework (NSIF)	Governmental relations and procedures	ANZLIC, in association with partners from the government, private, public and academic sectors	All-inclusive partnerships through GeoConnections	Initially focused on federal agencies but focus has recently shifted to a more broad-based approach
Institutional Framework	*Lead Agency:* Department of Rural Development and Land Reform (DRDLR) Implementation committee: a) CSI. The CSI consists of a principal committee, and six sub-committees (Data; Systems; Standards; Policy and Legislation; Education and Training; & Marketing and Communication. The CSI appoints data custodians. b) National Spatial Information Framework (NSIF) co-ordinates the development of the SASDI.	*Lead Agency*: Minister of Administration and Digitisation / General Surveyor of Poland Implementation Committee: National Committee	Lead Agency: ANZLIC *Implementation committee:* one representative each from the eight Australian state and territory governments, the Australian Commonwealth Government, and the New Zealand Government. The representatives are heads of spatial information coordinating bodies.	*Lead Agency:* GeoConnections *Implementation Committee:* Management Board consisting of officials from the federal agencies, and representatives from academia and industry.	*Lead Agency:* FGDC, established by the President's Office of Management and Budget. *Implementation committee*: Comprises of chairpersons of the thematic subcommittees and 'cross-cut' working groups, and representatives from federal agencies and other stakeholder groups.

Source: Appendix 3

5.3.5 Justification of the Methodology

This study has been designed as a case study. It recommends the methodology that African countries can follow in SDI development. We recognise differences in the political, cultural, economic, social, and language in each country. We also know that a method for SDI development may work well in one context but fail in another. However, the limited timelines and funding available for this project did not allow development of specific methodologies for each region, or each country.

5.4 RESULTS AND DISCUSSION

5.4.1 General Observations

There exists a guide for SDI development in Africa, the *SDI Africa: an Implementation Guide* [75]. In addition, several other guides and manuals have been developed for use in other jurisdictions, notably the *SDI Cookbook* [30], *SDI Manual for the Americas* [23] and the New Zealand's *Spatial Data Infrastructure Cookbook* [109]. These are valuable documents offering insights into the best practices, lessons learnt, case studies, guidelines, and other important information for SDI development.

However, caution should be taken when using these guides as they tend to be very generic. Thus, a structured approach provided by guides is still needed but practitioners should be open to flexibility. Lance and Bassol´e argued that infrastructure development, including SDIs, cannot be planned and controlled [27]. In reality, however, most aspects of SDI should be planned since it can help to secure government support and funding.

It has already been pointed out that following the same recipe for building SDIs in different jurisdictions usually leads to different and often unexpected results [104]. In addition to the methodology proposed, a few issues that cut across the board in the case studies reviewed are pointed out, and have not been addressed in the *SDI Africa: an Implementation Guide*.

5.4.2 African Infrastructure for Spatial Information (AISI)

The case studies have shown that collaboration and coordination at the local, national and regional levels, as well as between public and private organisations, is essential to the success of SDI. Although the Permanent Committee for SDI in Africa had been in existence since 1999 [32], its contribution to the African RSDI has not been felt. UNECA has contributed to SDI in Africa, but lacks the mandate to prescribe standards and policies for SDI in Africa [1], [18].

In addition, there exists sub-regional partners in each of the Regional Economic Communities (REC) of Africa, such as RCMRD, RECTAS and CEDARE [61]. Although their contribution towards SDI development in their respective mandates is substantial, that each operates in its own jurisdiction poses the risk of uneven patterns in SDI development.

Similar to Europe's INSPIRE, an agency modelled around the process-based approach is needed to support a pan-African SDI. This agency would be tasked with enforcing standards, prescribing policies, carrying out research, and addressing perennial problems inhibiting SDI development in Africa, such as lack of datasets, funding, and understanding of SDI.

The case studies have shown that existence of an overarching agency tends to direct focus and momentum towards SDI development. Although other names may have been proposed, we coin the name *Africa Infrastructure for Spatial Information (AISI)* to refer to the agency.

SDIs often exhibit centralizing tendencies that may run counter to federated and devolutionary concepts [67]. Additionally, SDIs are long term initiatives that require coordination across various stakeholders, often contradicting the budgetary and administrative structures in Africa [32]. AISI would be expected to arbitrate on these and other challenges.

5.4.3 SDI Africa: An Implementation Guide

The existing SDI implementation guide for Africa is very valuable but is outdated. It was seemingly last updated more than 7 years ago, during which time many changes have taken place since. The update, which should be carried out regularly, can be coordinated by the proposed AISI with support from universities and research institutions.

Notable changes that should be added or improved in the guide are:-

Measuring and Monitoring Impacts and Benefits

Since SDI is a complex and long term initiative, there is need to incorporate monitoring and evaluation at every stage in its development. Furthermore, to effectively sell the SDI concept, especially to policy and decision makers, practitioners ought to demonstrate tangible benefits and impacts of an SDI.

According to GeoConnections [23], current SDI assessment techniques – commonly referred to as measuring and monitoring, can be classified into two categories, i.e. Readiness and Performance. While the former is a fact-gathering exercise to determine the status of an SDI, the latter seeks to determine if the SDI is meeting its objectives. In general, continuous monitoring and evaluation should be part of the SDI development process [67], and therefore African countries should entrench evaluation and monitoring into their SDIs.

SDI Technologies

The utility and value of any system increases if its performance is adequate and security is guaranteed. Recent reports in Kenya revealed that most Government websites including KNSDI's had weaknesses and could have been hacked [110], and such concerns have to be addressed.

The typical technology components that underpin SDIs include open standards, registries of services, metadata, security, and authentication mechanisms [23], most of which have been developed by ISO and OGC. Africa should develop SDIs based on these technologies while applying best practices from mature SDIs. In addition, Africa should cultivate an environment that supports development of standards, policies, technologies and institutions supporting SDI.

The role of users

SDIs are expected to scale up to the national level, and possibly beyond, providing spatial services to a variety of users with different needs and skillsets. Timely involvement of prospective users in the development of SDIs will contribute to enhanced usability, acceptance and success. The diverse backgrounds and often limited skills of non-specialists require approaches different from the ones taken for specialist users [67].

In addition, SDIs draw on knowledge from many disciplines, including geomatics, geography, sociology, informatics, legal, organizational studies, public administration, economics, computer science, information technology, cognitive science, political science, organizational studies, and environmental studies [67]. This is one of the major reasons why the perspectives of users from diverse disciplines has to be taken into account during SDI development.

5.4.4 SDI Methodology for Africa

Finally the SDI methodology for Africa is proposed, derived after reviewing the earlier presented case studies, SDI implementation manuals and relevant literature. The steps outlined are based on the SDI process model, supported by patterns derived from the case studies.

Awareness

Awareness involves the recognition of the need for the SDI, including awareness of the technological opportunities to meet the need. The case studies have shown that awareness must be present at the highest levels in the decision making hierarchy, if the SDI is to be successful.

Furthermore, the objective(s) of the SDI should be clearly enunciated. Different countries formulate different objectives: for example, Poland's objective is to promote entrepreneurship and job creation using the SDI. In Canada and the USA, SDIs have been developed to promote regional and global competitiveness, innovation, productivity, incubator effects in information value-adding industries, and job creation. African countries have an even better opportunity by virtue of the many problems (e.g. poverty) that can be addressed with support of SDI.

Status Survey

Canada and Australia are federal systems with a history of high computerisation of land records at sub-national levels (for example, at the provincial level in the case of Canada). Hence the need for SDI in such countries may have been well understood in advance. It seems plausible that their SDIs evolved as solutions to complexities experienced in these systems.

In other cases, there is need to understand current circumstances with regard to spatial data and other SDI components. Thus, a survey can be carried out to verify the status of spatial data availability, software and network services, user expertise, and institutional arrangements. The survey can highlight constraints and opportunities for SDI development. In 2001, Canada commissioned a private firm KPMG (Klynveld Peat Marwick Goerdeler) to carry out a similar survey before the country embarked on the CGDI.

Commitment Building

The survey in the previous step can help identify agencies within governments that already use spatial data, albeit in disordered ways. Once key partners have been identified, the next step is commitment building establishing custodians, their mandate, and resources for development of the SDI. Some countries like South Africa favour the top-down model, while others like Canada have chosen a more consensus-based bottom-up approach.

The case studies have shown that most countries with mature SDIs use the private sector extensively to improve data availability, development of information systems and geoportals. By extension, African countries should develop strategies aimed at engaging the private sector. In addition, the academia should be extensively used to carry out research for developing sustainable SDIs.

Policies, Directives and Action Plans

The overall strategic policy is a document to be considered and approved by a government official(s) higher up in the hierarchy. In a country such as Kenya, such a policy would most probably require parliamentary debate and approval. This policy should define the overall vision and mission of the SDI.

If the country favours the top-down approach to SDI development, then strategic policies and legal instruments should be developed directing the establishment of the NSDI, and setting up relevant institutional frameworks. Similar to the USA's Executive Order number 12906 [25], or South Africa's' SDI Act [28], such directives can identify and define data custodians, their roles and responsibilities, implementation committee(s), among other prerequisites.

On the other hand, if the country prefers the bottom-up approach, then there is need to develop strong collaborative partnerships at all levels. This is similar to Canada's GeoConnections program, which seeks to bring together the Government, private sector and the academia.

In addition to the overall SDI policy, there is need for focused policies that identify and address operational issues concerning individual agencies, data themes and technologies. Such policies include pricing, data access, licensing, sharing, and Intellectual Property Rights. These policies should be developed by African countries to support SDI development.

Institutional Framework

The strategic policy may have identified the lead agency to facilitate the implementation of the SDI. As seen in the case studies, lead agencies tend to be driven by inter-agency committee(s) drawn from stakeholders in the geoinformation sector. Given that no single organization can develop an SDI, committees usually play a broader role towards SDI development.

Typically, the lead agency is strongly associated with National Mapping Organisations (NMO). In other cases (e.g. Namibia), the lead agency is associated with the National Statistics Agency [45]. In either case, the case studies have shown a pattern of inter-agency committee(s) (e.g. the CSI in South Africa) spearheading SDI development.

The inter-agency committee should facilitate a conducive environment for SDI development, by encouraging an inclusive approach. It should also facilitate collaboration with the academia and other research institutions concerned with carrying out research. In addition, policies could be used to define the roles and responsibilities of participants, such as data custodians.

SDI Strategic plan and Funding

Successful SDIs are typically based on sustainable funding models, given that SDIs are long-term initiatives. Primarily, strategic plan(s) identifying the main activities in SDI could be developed, from which a budgetary estimate is obtained. All countries reviewed in the case studies have followed this approach – typically through rolling 5-year plans and budget.

The NSDI of the USA, ASDI of Australia and the CGDI of Canada are funded primarily by the respective central governments. It is therefore imperative that sustainable funding through government is required if SDI development is to be successful in Africa.

Where possible, donor funding can be used as a supplement, but this should not be the primary source of funding. Given their long-term nature, SDIs could rely on their government for initial funding; but in time, more sustainable self-financing and cost recovery models could be used.

SDI Implementation

Once the policy frameworks and strategic plans are in place, development of the SDI should commence. In a nutshell, this entails implementing the policies and strategic plans.

Specifically, implementation involves identifying and preparing resources (human, financial, software etc.) to be employed, determining near term deadlines and milestones, identifying which staff needs extra skills, professional capacity building, building geo-literate citizens, data development, development of standards, building of metadata catalogues, setting up geoportal(s), setting up monitoring, and day-to-day governance arrangements.

Monitoring and evaluation should be an integral part of SDI development process, typically through annual reviews. This assessment could ascertain if the SDI is meeting its objectives, as well as the progress of the various SDI components.

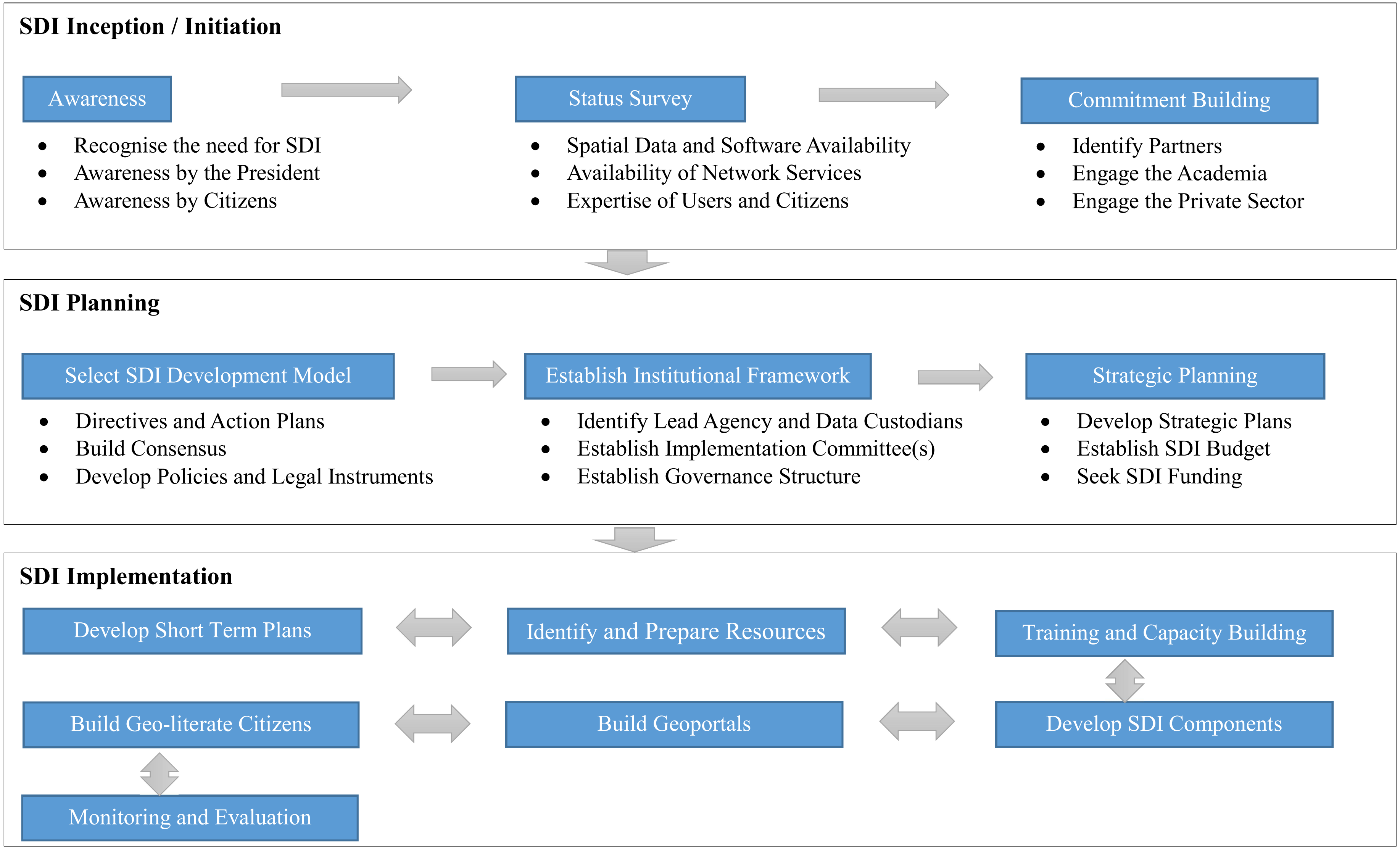

Figure 5.7: SDI Development Methodology

5.4.5 Summary and Conclusions

In this chapter, we have examined the SDI methodology for Africa. A case study approach has been followed, where SDIs from selected countries are reviewed. Recognising that no single methodology fits the needs of all countries, the chapter outlines key steps that African countries can consider during SDI development.

Several issues come to the fore. The first is that there are complex organisational and institutional issues that need to be addressed during SDI development. Luckily for Africa, there exists a wealth of knowledge including mature SDIs across the world that can be used as a reference. Secondly, a methodology tailored to SDI development in Africa is needed. This chapter has made the first attempt towards developing the methodology.

6 KNSDI: CURRENT STATUS AND THE WAY FORWARD

6.1 Introduction

This chapter dwells on the fifth and final research question: *what is the framework for SDI development in Kenya*? The methodology involves amalgamating the research findings from the first four research questions and applying them in the Kenyan context.

The Kenya National Spatial Data Infrastructure (KNSDI) is a national stakeholder's initiative that strives to provide better access for all Kenyans to spatial data. The main purpose of the initiative is to eliminate wastage of resources and duplication in data production. Users should be able to acquire consistent datasets that meet diverse requirements, even though the data is collected and maintained by different agencies [111].

KNSDI's mission is to promote the production, sharing and use of geospatial information for sustainable development. Its vision is to be the leading national infrastructure for access and use of geospatial information in decision making for sustainable development.

The need for KNSDI becomes apparent when Government agencies and other organizations need to respond quickly to natural disasters, industrial accidents, environmental crises, and other contemporary challenges [112].

For the past 15 years, KNSDI has witnessed significant progress. Firstly, relevant standards and digitization manuals have been developed, albeit in the absence of a policy. Secondly, the KNSDI policy has been drafted [113]. The policy, which is awaiting approval by relevant stakeholders, is expected to lead to the legal framework facilitating custodianship, confidentiality, security, liability, copyright, privacy, data access, data ownership, capacity building, funding, and research [114]. Thirdly, the stakeholders agreed on the fundamental datasets: elevation; hydrology; vegetation; utilities; transportation; geographic names; parcel boundaries; administrative boundaries; geodetic control; and digital imagery [113]. In many respects the datasets are similar to UNECA's recommended datasets for Africa [61], except that the latter is more elaborate.

As at 2016, the Survey of Kenya (SoK) under the Ministry of Lands (MoL), served as the KNSDI's lead agency. KNSDI is serviced by a secretariat comprising of a team from the SoK, headed by the Director of Surveys (DoS). The initiative draws its stakeholders from the academia, the public and private sectors, civil society organisations, and international organizations. The secretariat reports to the KNSDI National Steering Committee, which in turn reports to the National Executive Committee [111].

KNSDI is a priority issue at a policy level, indicating a recognition for its importance [115]. Furthermore, the KNSDI policy has proposed a budget and work plan [76]. In spite of this, development and progress of the KNSDI remains slow.

Another concern is that the KNSDI website (www.knsdi.go.ke) was not even accessible as at 2016, denying vital information to the public and researchers. The standards, manuals and other documents developed from earlier efforts should be disseminated through the website for access by the stakeholders.

The pilot clearinghouse portal was launched in 2008 with assistance from the Japan International Cooperation Agency (JICA). The portal was developed using ESRI's GIS portal toolkit, ArcGIS 9.2, ArcSDE 9.2, ArcIMS 9.2, SQL Server 2000, Apache and Tomcat [113]. However, newer versions of these technologies have emerged, rendering the portal obsolete.

In spite of these concerns, KNSDI remains a priority issue on Kenya's national development agenda, given the fact that most of the information required for sound decision making is based on geospatial data [5].

Like many developing countries, Kenya faces challenges to its SDI aspirations, such as inadequate funding, outdated and scarce datasets, and the lack of a formalized strategy or policy. In some cases, access to information is still a challenge, signifying technical and institutional barriers [97]. Data is often seen as a commodity or source of power by those who control it [97], indicating that key Kenyan stakeholders have not yet realised that data is more valuable if shared widely.

According to Mwange *et al*. [101], Kenya's 2014 SDI-readiness index was only 0.56, implying that significant work is still required to revive and improve the KNSDI. These results generally concur with a study conducted by Guigoz *et al.,* which reported very weak SDI status in most African countries including Kenya [18]. Okuku *et al*. concluded that KNSDI development is at best ad-hoc and fragmented [81]. The major causes of the slow KNSDI include lack of political will [32], lack of funding [81], [101], and the lack of an enabling policy framework.

The benefits of a functioning SDI have been elaborated in Chapter Three. Similarly, a prototype SDI application based on newer technologies was developed in Chapter Four. The two chapters should offer vital lessons to SDI practitioners in Kenya as they strive to develop the KNSDI.

As seen in Chapter Five, SDI is a long term initiative requiring sustainable government funding and a well-developed institutional framework. A typical SDI may involve many stakeholders, including data custodians, suppliers of various services, committees and working groups (WGs), the secretariat, the government, private and NGOs, and the general citizenry. Thus, KNSDI champions should continue to strengthen SDI committees and WGs, prepare and execute work plans, facilitate workshops and seminars, develop policies (strategic and operational), draft laws in support of the KNSDI, implement standards [32], develop fundamental data and metadata, and other tasks. Focus should now be on less talk and more action.

6.2 History and Current Status

6.2.1 Introduction

The approach adopted to setting up the KSDI is presented in this section. The content is based on examination of secondary data – such as conference presentations, newsletters, workshops, seminars and minutes of meetings, and discussions with relevant stakeholders.

6.2.2 Chronology of Major KNSDI Events

The establishment of the KNSDI can be traced to the year 2001, through efforts of various stakeholders including the SoK, the then Nairobi City Council (NCC), MoL and the Institution of Surveyors of Kenya (ISK). Other external stakeholders were the Federal Geographic Data Committee (FGDC), GSDI and JICA. The chronology of events leading to the KNSDI has been summarised in the following paragraphs.

The international conference on spatial information for sustainable development, organised by the ISK, FIG and the UN Habitat, was held in Nairobi in October 2001. The conference came up with the 'Nairobi Statement on Spatial Information for Sustainable Development', outlining a raft of recommendations. One of the significant affirmations was that 'developing countries should form National Steering Groups which in turn would formulate appropriate policy and institutional frameworks' [33].

In November 2001, the 5th Africa biannual GIS conference was held in Nairobi, attracting over 450 participants. The theme of the conference was to promote geospatial information for sustainable development in Africa. It was generally agreed that Africa should be at the forefront in promoting GIS, Global Mapping and the GSDI initiatives.

The first KNSDI workshop was held in November 2001. The aim of the workshop was to bring stakeholders together and emphasise the role of geoinformation. Other objectives included creation of awareness amongst data producers, and consensus building [26]. The need for dedicated coordination of information resources was also recognised. The workshop resulted in several recommendations [112]:

- KNSDI should be spearheaded by a government organization;
- SoK should assume the responsibility of the KNSDI secretariat;
- SoK should call the first NSDI meeting at which a steering committee would be formed;
- an inventory of available datasets and projects in progress should be documented;

- the necessary legal framework should be established;
- SoK should provide up to date large scale and small scale basic datasets;
- SoK should setup and control standards of spatial data and metadata; and
- SoK should device a cost recovery mechanism for information being distributed

In April 2002, the second KNSDI workshop was held, primarily to take concrete steps towards the establishment of the KNSDI. A 3-tier organisational structure was proposed (see Figure 6.1), consisting of the executive and steering committees, and four working groups (WGs) [26].

The proposed mandates of the executive and steering committees were rather narrow and weak. For instance, the executive committee was mandated to oversee the operations of the steering committee and WGs, while the steering committee regulated the WGs. WGs, comprising of specialist experts amongst the stakeholders, made recommendations to the steering committee on their assigned Terms of References (ToRs):

- *Standards*: framework data, coding, reference systems, exchange formats, and metadata
- *Legal*: copyright, liability, privacy, data policy (access, restriction and pricing)
- *Education*: training, curriculum, research, sensitization and liaison
- *Dissemination*: clearinghouse, metadata and the KNSDI website

It is at this juncture that the Government of Kenya requested the Government of Japan (through JICA) for assistance in a number of programmes, of a technical and financial nature. The study for the establishment of Spatial Data Framework for the City of Nairobi [26] was one of the programmes.

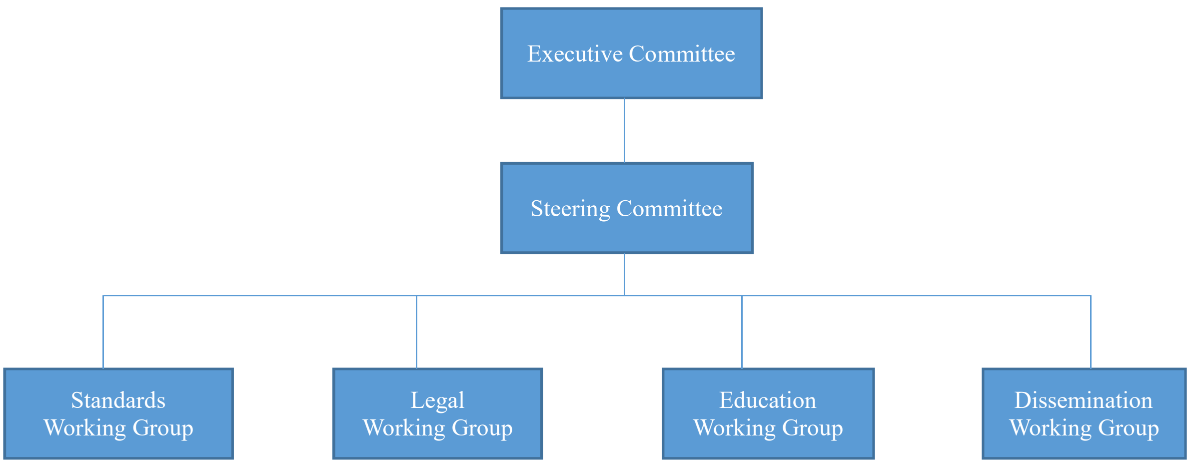

Figure 6.1: Initial KNSDI Organizational Structure

The third KNSDI workshop was held in September 2002, and focused on building consensus and cooperation amongst organisations. Key participants included the SoK, NCC and JICA. Deliberations resulted in the Large Scale Framework Spatial Data Infrastructure (LSFSDI) project, which had recognised the need for accurate and timely foundation data. Commencing in February 2003, LSFSDI was a 2-year project whose objectives were [26]:

- preparation of digital spatial data for Nairobi at scales of 1:2,500 and 1:5,000;
- creation of a GIS model for the city of Nairobi as a case study; and
- pursue technology transfer and capacity building

In March 2003, the SoK received financial assistance from JICA with which to establish an inventory of existing spatial datasets and their specifications. The study involved interviewing relevant personnel from selected organizations [26].

In April 2005, the Office of the President issued a circular to all ministries and public institutions directing the development of fundamental spatial data to enhance e-government and support for the Land Use Policy, which had identified the need for a Land Information Management System (LIMS) [81]. At the same time, the Government requested for technical assistance from the Government of Japan to strengthen SoK's capability in the application of GIS technologies [113].

The fourth KNSDI workshop was held in November 2005, attracting over 70 participants [81]. The workshop reviewed achievements of workshops I, II and III, the ToRs and membership for the WGs. The KNSDI secretariat was also established.

The fifth KNSDI workshop was held In March 2006. Several progress reports were presented by the WGs. It was also reported that the first version of the KNSDI draft policy had been developed [116].

The primary purpose of the policy is to strengthen spatial data sharing. It is also expected to promote a common understanding and mechanism for the production, access and utilisation of geo-information from multi-sectoral agencies under the forestry, health, agriculture, education, energy, environment, fisheries, security, tourism and transport sectors [76], [116]. Although county governments had not been established at the time, they are now expected to play a pivotal role towards the KNSDI. This suggests a need to review and overhaul the draft policy to incorporate the new players.

After careful evaluation and bilateral discussions, Japan offered technical assistance through JICA for the implementation of KNSDI in three phases [113], as listed in Table 6.1. Phase I of the project commenced in October 2006, and became known as the 'Project for Strengthening Survey of Kenya for GIS promotion in the Republic of Kenya' [115].

Table 6.1: Implementation of the KNSDI

Phase	Description
I	Build capacity of the lead agency, SoK
II	Promote the use and application of GIS technology in Kenya
III	Construction of the KNSDI

In November 2006, the first standards seminar was held at AICAD under the theme 'Strengthening capacity and Promoting Geo-information sharing in Kenya' [117]. The seminar attracted 55 participants from 18 organizations who were sensitized on the need for KNSDI standards [113], in effect promoting the KNSDI project and facilitating more collaboration.

In July 2007, the second standards seminar was held at AICAD, attracting 79 participants who also reviewed development of metadata. The aim of the seminar was to disclose the Kenya Profile for Geographic Information Standards (KPGIS). KPGIS was adapted from the Kenya Standards (KSISO) 19100, which in turn was adapted from the ISO Standards 19100 [115]). The six standards are [81], [113]:

- KSISO 19101 GI – Reference model;
- KSISO 19109 GI – Rules for application schema;
- KSISO 19111 GI – Spatial referencing by coordinates;
- KSISO 19113 GI – Quality principles;
- KSISO 19114 GI – Quality evaluation procedures; and
- KSISO 19115 GI – Metadata.

In addition to the six standards, three map digitizing manuals were also developed [117]:

- thematic map database;
- national digital topographic map database (scale of 1:50,000); and
- topo-cadastral map database (scale of 1:10,000).

In February 2008, the third standards seminar was held at Ramada hotel, Nairobi. The theme of the seminar was 'Application of Standards for Spatial Data Building and Sharing'. During this seminar, the verification trials of the standards were presented. Other activities included launching of the KNSDI pilot clearinghouse portal [117], whose existence was confirmed two years later by Makanga and Smit [1].

Through JICA, Japan dispatched a technical team to Kenya in May 2008 to carry out an evaluation of the achievements of Phase I of the project (see Table 6.1) [115]. An evaluation report was prepared and presented to the Kenyan and Japanese Governments.

The recommendations of the report highlighted the status of data sharing, and the government fears about it. For instance, it cited instances where offering digital data on the internet would make it difficult for SoK to charge for its use [118]. Furthermore, SoK would find it difficult to justify the cost of any data updates if the utility of the KNSDI was to be low. Consequently, the data to be offered free of charge included basic feature framework (water bodies, political boundaries, and traffic), while the rest would be offered through offline conventional media, such as CDs, subject to confirmation of use [118].

In August 2008, MoL brought the draft KNSDI policy to stakeholders for deliberation. Meanwhile, phase I of the project as listed in Table 6.1, came to an end in October 2008.

In October 2008, the fourth seminar was held at AICAD to review the KNSDI draft policy [116]. It was during this seminar that a committee of experts was formed, consisting of the private sector, representatives from academia, Government, civil society, and members from the KNSDI secretariat [116]. The committee held three consultative meetings.

The committee reviewed a wide range of issues, including fundamental and thematic datasets, standards and metadata. It was noted that the existing laws did not address emerging legal issues, and an enhanced legal framework would be needed to address data ownership, pricing, custodianship, confidentiality, copyright, privacy, liability, funding, access, and security. The committee also proposed policy recommendations, and an implementation plan.

In May 2009, the committee of experts produced the final version of the KNSDI draft policy [116]. Generally, the policy establishes a strategy for the collection, integration, distribution, and sharing of geospatial information [111].

In August 2009, the KNSDI policy workshop was held at the Kenya School of Monetary Studies (KSMS). The final draft policy was presented to stakeholders [111], who adopted it with some amendments such as definitions and semantics of terms, standards, metadata, legal framework, copyright, pricing, data access and data security. The committee of experts was mandated to present the KNSDI policy to the MoL through the DoS.

The seventh KNSDI workshop was held in September 2009, at which JICA announced the end of funding. The events that unfolded from this point concur with the findings of Lance [32], who argued that the project approach to SDI development raises sustainability concerns. SDIs that are based on this approach tend to wane when the project comes to an end.

In July 2010, the committee of experts held a meeting and approved amendments to the policy. The secretariat was asked to finalise and submit the policy higher up in the hierarchy through the MoL. In addition, the KNSDI institutional framework (see Figure 6.2) was proposed [76].

In July 2011, the Kenya Open Data Initiative (KODI) was launched, exposing a variety of data to the public, such as development, demographic, statistical, and expenditure. It was intended to improve service delivery, facilitate job creation, enable citizen feedback and better-informed decision making, and improved transparency and accountability [97]. Most of the data is not essentially geospatial, although some have coordinates that can be spatially represented. Like other open data systems, the main concern is that the data is not well documented by metadata. However, KODI and KNSDI are expected to complement, but not replace, each other [106].

In 2013, a presidential directive was issued moving the KNSDI from the MoL to the ICT Authority. A review of the Kenya National ICT Masterplan (2014 – 2017) reveals that KNSDI is indeed one of the flagship projects to be implemented by 2018 [119]. However, the MoL and SoK are conspicuously missing from the list of key institutions. In 2015, another directive from the Office of the Deputy President moved the KNSDI back to the MoL.

The preceding paragraph highlights a possible lack of understanding on the definition, purpose, and main actors in SDI development. Typical tasks carried out during SDI development may overwhelm a single organisation. Besides, SDI is an important national and multi-sectoral task requiring input from multiple stakeholders.

A significant development in 2016 was the anchoring of KNSDI into the Survey Act CAP 299. The proposals have taken into account a possible institutional framework, but have fallen short of considering the role of custodians. Given that an SDI is a multi-sectoral initiative, embedding it in the act may limit the contribution of other professionals. A better approach is to develop a separate law that specifically deals with the KNSDI, through an act of parliament.

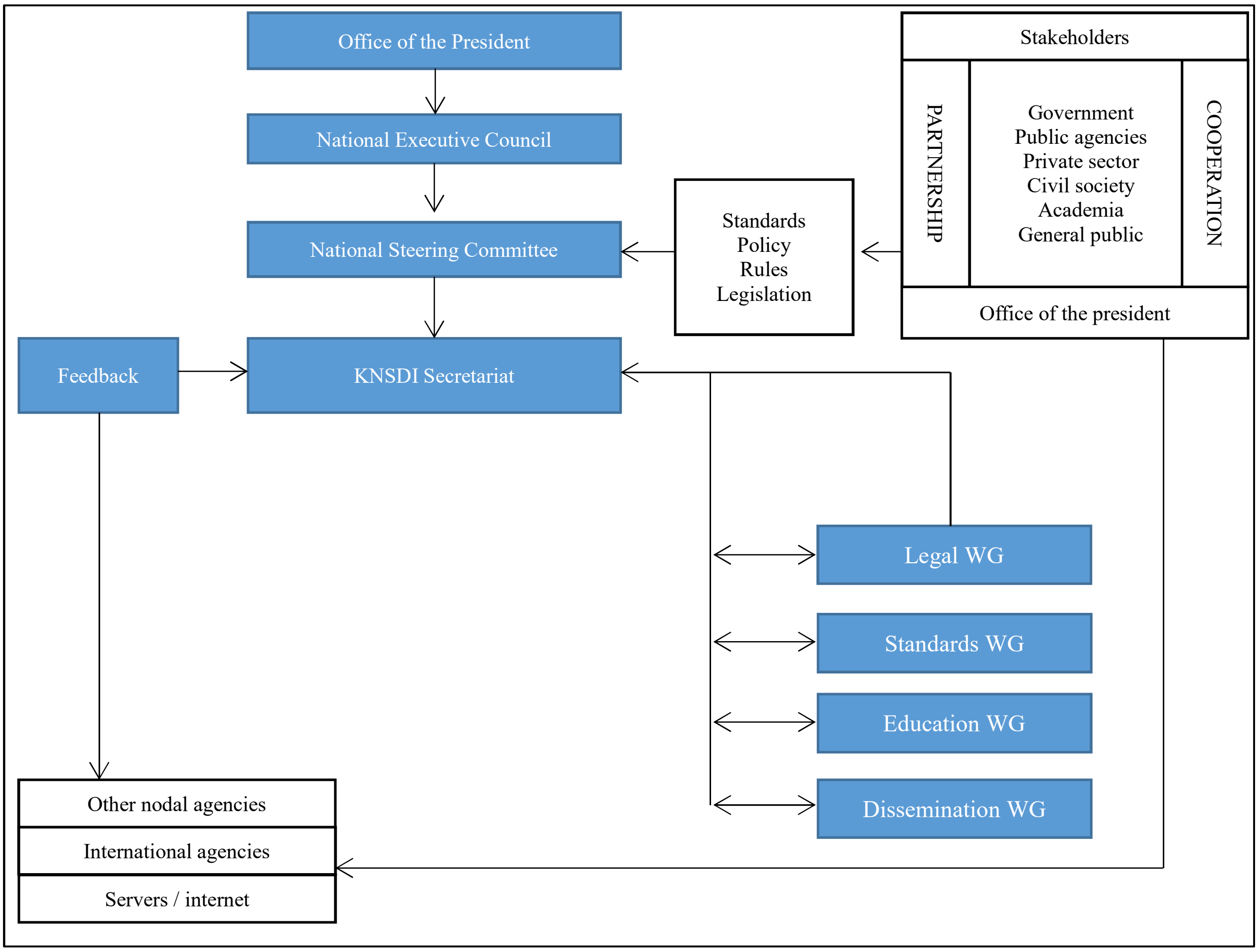

Figure 6.2: KNSDI institutional framework according to the draft policy
Source: KNSDI Draft Policy [76]

6.2.3 KNSDI in the context of Devolution

In August 2010, Kenya ushered in a new constitutional dispensation, one of whose pillars is the concept of devolution of governance to 47 county governments. Devolution is one among several forms of decentralization, which is a characteristic of most contemporary government systems. Decentralization is based on the principle of subsidiarity, which assigns previously centralised functions to sub-national units [120]. Federation is another concept closely related to devolution, but in which an initially centralised country cede some autonomy to regional governments for an anticipated greater collective good.

Decentralised systems can be much more sensitive to local needs, because feedback on changes needed by players is immediately perceived by those with a responsibility to make changes.

Since county governments operate at lower levels, they require large-scale datasets for routine decision making. Large-scale datasets are voluminous, dynamic and generally have more data maintenance overheads. In contrast, national spatial datasets are small-scale, and may have less need for maintenance [121]. Granted, both forms of government should be controlled by the same standards, policies and legislation.

The operational obligation for KNSDI could be moved to survey departments in the counties, with the national government retaining more strategic roles. Strategic roles may include the development of policies, standards, legislation, and liaison with other regional and global SDI initiatives. The counties should embrace these standards and policies, while supporting better information management at their level. The information generated at county-level is not only beneficial to them but also to the country as a whole.

Similar to the arguments advanced by Rajabifard *et al.* [13], county governments and other lower level units can successfully align their geospatial initiatives with the KNSDI by adopting the product-based model, focusing on data production and maintenance. On the other hand, the National government is better placed embracing the process-based model, which focuses on the development of policies, standards, and the legal framework needed for the KNSDI.

6.2.4 Achievements of the KNSDI

KNSDI is listed as a priority project in Kenya's Vision 2030, and in the strategic plan of the MoL [115], underscoring recognition of its importance.

One of the major achievements of the KNSDI is the development of fundamental datasets [114]. The datasets include: establishment of large-scale spatial data framework (digital maps) for Nairobi city, Port of Lamu, city of Mombasa, municipality of Malindi, resort cities under the LAPSSET[2] Project; digitization of 1.5 million parcels for titling; scanning and computerization of 66,000 survey records; vectorization of 1:1M and 1:250,000 topographic maps covering the entire country; vectorization and updating of topographic maps at 1:50,000; and preparation of base map series at 1:25,000.

Other major achievements include [47], [116]:

- formulation of KPGIS standards for data production;

[2] Lamu Port, South Sudan, Ethiopia Transport Corridor. See www.lapsset.go.ke

- technical competence in map digitization and specifications;
- development of guidelines (copyright, pricing and security) to facilitate data sharing;
- training and capacity building in GIS;
- organizational setup (the lead agency, the secretariat and WGs have been established);
- draft KNSDI policy which is awaiting approval by the authorities; and
- prototype clearinghouse portal has been developed

Although significant achievements have been realised, the status of the KNSDI was average in 2014 [101]. The geoportal was not accessible, and significant operational barriers still exist, such as costs and access restrictions to data [97].

6.3 The KNSDI Way Forward

This section outlines a possible KNSDI way forward.

6.3.1 Institutional and organisational Arrangements

Since the KNDSI's inception, responsibility for its leadership has largely been vested in the SoK which falls under the MoL. The selection of SoK as a lead agency was because the agency occupies a critical position at the national level, through which it generates key fundamental datasets, and its parent ministry is a key stakeholder in the lands sector.

However, the slow development of KNSDI raises concerns regarding the current institutional and governance framework, and the capacity and willingness of the stakeholders. Whilst SoK has made significant progress, a fully functional KNSDI has not been realised.

Some of the concerns are:

- more than 15 years since inception, yet the KNSDI is still not operational;
- the KNSDI draft policy was initiated 10 years ago, yet the policy is not yet ratified;
- lack of capacity within SoK after JICA's support ended in 2009;
- in 2013, KNSDI was moved to ICT Authority, and again back to SoK in 2015; and
- lack of political will.

There is nothing more that can be done other than continuing to strengthen the capacity of the lead agency, SoK. It should also be highlighted that SoK is operating within the prevailing institutional and governance frameworks, and as such needs support.

Furthermore, custodianship (which eliminates data duplication and facilitates better data management) and partnerships (which promote sharing and extend local capabilities in terms of technology, skills, knowledge, data, roles and responsibilities) [14], should be encouraged and promoted through relevant KNSDI policies.

The case studies in Chapter Five revealed a pattern from a single organisation spearheading SDI to broad-based governance structures based on committees, for example the CSI in South Africa, and the FGDC in the USA. Some SDI researchers notably Lance, advocated for the committee approach to SDI development [32]. The committee should forge a stronger political influence, and seek necessary support including SDI funding.

Generally, the governance structure should facilitate development of the SDI components (core spatial data, metadata, standards and policies), as well as design and implement the SDI. It should also manage funds committed to the SDI, develop a performance management framework and strategic plan, and establish a monitoring and evaluation program.

A similar structure to oversee the KNSDI is recommended in Figure 6.3. Its embryonic structure is already in place as the current KNSDI organisational/governance structure, but needs to be strengthened as suggested in the following paragraphs.

- Executive Committee: The composition of this committee should be 10 – 15 members of mostly Principal Secretaries and executive-level directors, as listed in Table 6.5. Its chairperson should be appointed by the Minister, and the DoS should be its secretary. Meeting at least eight times a year, its proposed functions are given in Table 6.2.

Table 6.2: Proposed functions of the executive committee

▪ Executive oversight and administrative leadership;
▪ Align KNSDI activities with state policies and programs;
▪ Monitor inputs, procedures, outputs, and outcomes;
▪ Review and recommend legislation and procedures;
▪ Coordinate and plan utilisation of national funds for KNSDI development;
▪ Make decisions on the targets, strategies, and activities of the KNSDI institutional framework;
▪ Establish policies that promote development of KNSDI components (e.g. core datasets);
▪ Promote and manage capacity building;
▪ Set short-term and annual plans, long-term plans, targets and budgets; and
▪ Set and align policies and standards

- Steering Committee: The composition of this committee should be 15 – 20 members of mostly technical heads or directors, as listed in Table 6.5. It should draw a maximum of 4 members from the executive committee, 2 technical members from the MoL, technical heads from key ministries and agencies, heads of WGs, a representative from the academia (with a bias to geospatial sciences), the civil society, and the private sector. Chaired by the DoS, this committee should work closely with all stakeholders, meeting at least eight times a year. Its proposed functions are given in Table 6.3.

Table 6.3: Proposed functions of the steering committee

▪ Provide technical leadership and oversight;
▪ Implement policies determined by the executive committee;
▪ Coordinate and monitor activities of WGs;
▪ Review, assess, research, and propose items of technical nature to the executive committee;
▪ Review status of KNSDI (performance, development of components) on a regular basis;
▪ Establish data custodians, and working groups;
▪ Align multi-agency budget and resource requests; and
▪ Perform other tasks delegated by the executive committee

- WGs are responsible for concept and implementation of the KNSDI. Membership should be drawn from geospatial data producers and consumers. This includes the county governments, KNBS, NLC, ICT Authority, ministries (ICT, Health, Devolution and Planning, Environment, ICT, Education, Agriculture, Forestry, Transport, Security, Tourism, Environment), relevant NGOs, the private sector, research, and the academia. WGs could meet more regularly, at least once a month.
- The current WGs lack a crucial ToR (or a new WG) to articulate the architecture, technology and design of the KNSDI. A new WG 'Technology and Architecture' has been proposed.
- Working on a fulltime basis, the secretariat should report to the executive committee but support all committees, working groups, and all other stakeholders (see Figure 6.3). Some countries, for example Namibia, have located the secretariat in an organisation that is not a primary custodian of spatial data [45]. Table 6.4 lists the proposed functions of the secretariat.

Table 6.4: Proposed functions of the KNSDI secretariat

▪ Facilitate, coordinate and implement decisions of the committees and WGs;
▪ Coordinate, monitor progress, guide the committees and WGs in the same direction;
▪ Provide technical, logistical and secretarial support;
▪ Provide coordination support to the KNSDI development process;
▪ Secure communication support, public relations, quality control;
▪ Setup and maintain the KNSDI geoportal and website, and the metadata catalogue;
▪ Establish a helpdesk to assist users with general queries and problems;
▪ Document current spatial data and planned data collection initiatives; and
▪ Ensure compliance with legal and policy framework by the geospatial community.

Table 6.5: Composition of the KNSDI Committees

Number	Description	Executive Committee	Steering Committee
		Representative(s) at a time	
1	Representative of the Minister (e.g. the Principal Secretary)	1	
2	Representatives from the Ministry of Lands		2
1	Director of Surveys *	1	1
1	Kenya National Bureau of Statistics (KNBS) *	1	1
1	ICT Authority *	1	1
1	Institution of Surveyors of Kenya (ISK) *	1	1
1	Teaching / Research in Geospatial Sciences		1
47	Representatives from each of the County Governments	5	4
18	Technical heads from key Ministries and Agencies		2
18	Executive heads from key Ministries and Agencies	2	
14	Representative from each Data Custodian **	3	2
1	Civil Society		1
1	Representatives from the Private Sector		1
5	Heads of Working Groups		3
	Total	**15**	**20**

* Member of both committees

** See Table 4.2

Unless otherwise specified, members serve a 3-year term renewable once. Quorum: 50%

6.3.2 KNSDI Funding

The importance of adequate KSDI funding has already been emphasized. It is a concern that after JICA's financial and technical support ended in 2009, KNSDI activities largely halted. Additional funding options, including direct funding from the Government, cost recovery, donor funding and public-private partnerships should be explored. Apparently, South Africa's SASDI is on track because of direct funding from the Government [32], while Rwanda's SDI is gaining momentum due to high political support [1].

The study has already pointed out that there are broadly two funding requirements for SDIs: for SDI coordination, and implementation. SDI implementation involves stakeholders carrying out activities in their mandates that are geared towards SDI development.

A review of the 2016/2017 programme-based budget from the Kenya's National Treasury [122] indicates that there is no direct budgetary allocation to the KNSDI. Apparently, the allocation has been absorbed in other activities and programmes, notably the Land Reform, Land Policy and Planning and Land Survey. It is important that funding for the KNSDI should appear as a separate programme in the national budget, to help the lead agency focus on implementation.

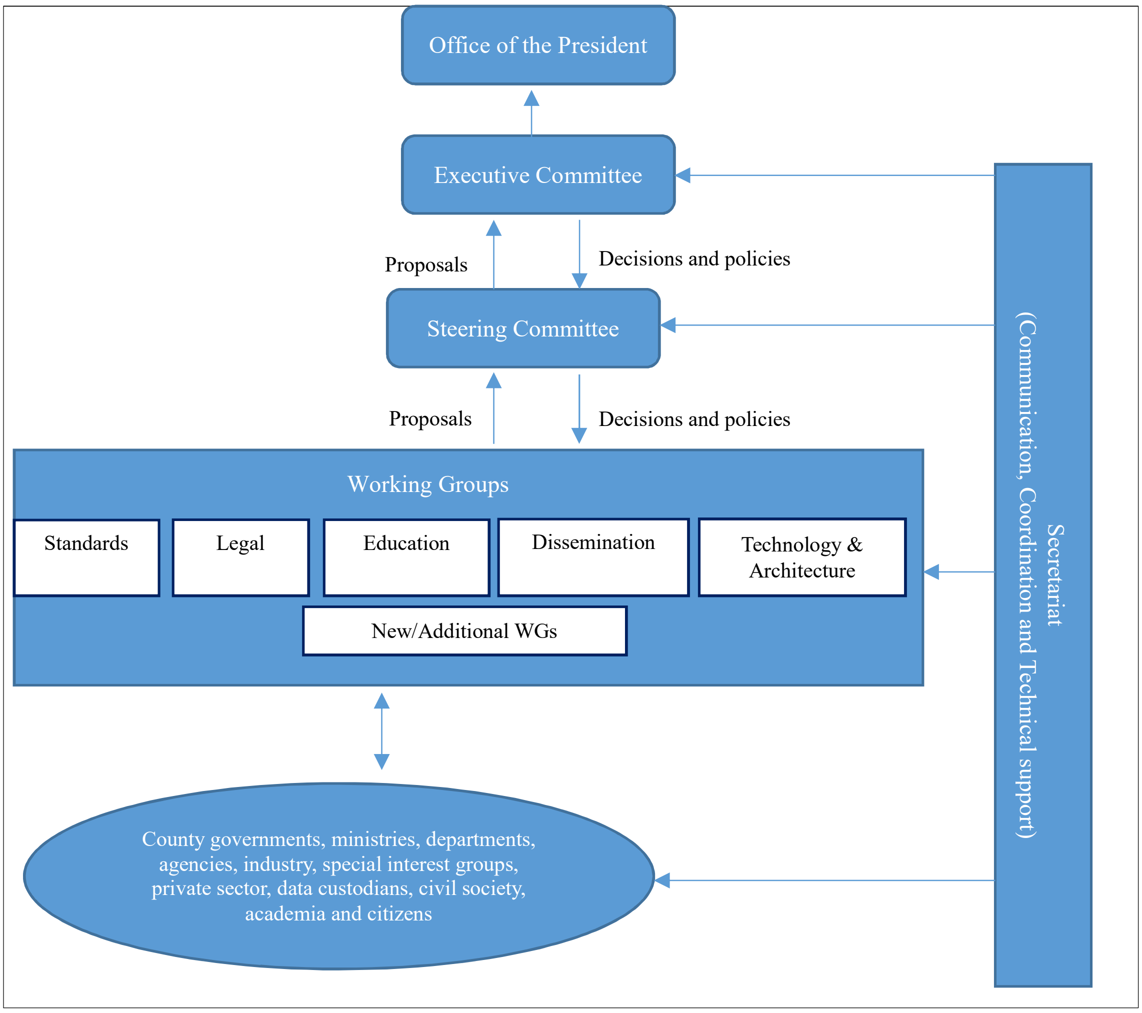

Figure 6.3: Proposed KNSDI institutional framework

Informal sources at the SoK revealed that Ksh. 300,000,000 (approx. US$ 3,000,000) has been set aside for the KNSDI in the 2016/2017 financial year. This sum may be adequate to finance the secretariat; but inadequate for the overall SDI development, according to Appendix 4.

Another observation is that there are several programmes in other ministries that have proposed geospatial initiatives, indicating possible overlap and duplication. Utility of the KNSDI by many stakeholders would reduce overlaps. Naturally, departments and programmes compete for the national budget, implying that the SDI leaders have to sell the KNSDI more effectively.

6.3.3 The KNSDI Design Blueprint

Given the complexity that is manifest in SDI development, the KNSDI should be based on a design blueprint. The proposed institutional framework, particularly the Technology and Architecture WG, should spearhead development of this blueprint. However, all parties need to understand that the KNSDI is neither an ordinary information system, nor part of the Kenya Open Data initiative. An SDI has a wider scope; it requires fundamental datasets, metadata, policies and standards, and collaborative effort amongst institutions and agencies.

For a start, the initial design can be based on the RM-ODP framework. Subsequently, this will evolve into a concrete national framework, facilitating an ecosystem of consumers, system architects, data and service suppliers, application developers, and consultants. In a nutshell, the SDI should facilitate an evolving ecosystem that caters for the needs of all stakeholders.

While developing standards, the KNSDI has tended to focus on data standards at the expense of information technology, SDI performance, organisational, and education standards. The process of architecting a national blueprint will also require development of information technology standards that provide guidelines on the KNSDI design.

SDIs need to create an active community of users, suppliers of data, programs, and services. An application development framework should be facilitated allowing developers to extend the SDI through innovative frameworks and applications. Technology trends such as Big Data, Cloud Computing, and VGI should be embraced, because they can increase wider adoption of the KNSDI [106].

6.3.4 Proposed KNSDI Road Map

Appendix 4 outlines the proposed road map towards the KNSDI, including the estimated time lines and budget. The budget is approximately 7 billion Kenya Shillings over a five-year period, which is the typical strategic planning cycle in Kenya. The budget takes into account the proposed institutional framework, including county governments and data custodians.

Since it may not be practical to start off on a full-scale as implied by this road map, a phased pilot approach may be adopted where a few stakeholders – such as county governments, are used as proof of concept.

For instance, a scaled-down prototype of the KNSDI, consisting of 3 county governments, 3 core spatial data custodians, and 3 nodal agencies is given in Table 6.6, which is extracted from Appendix 4. The cost of most of the other components (such as central geoportal, development of KNSDI policies and standards) remain largely the same. Thus, a phased KNSDI prototype would incur about 378 million Kenya Shillings in the first year, and 1.5 billion Kenya Shillings over a five-year period.

Table 6.6: KNSDI Phased Road Map

	Year					
Item	**1**	**2**	**3**	**4**	**5**	**Total**
Status Survey	20.60	-	-	-	-	20.60
Legal and Policy Framework	30.90	-	12.88	-	12.88	56.65
Establish KNSDI Secretariat	50.47	30.80	31.77	32.79	33.87	179.70
Establish KNSDI Structure	23.90	25.09	26.35	27.66	29.05	132.04
KNSDI Strategic Plan	15.45	-	-	-	-	15.45
Data and Metadata Development	49.44	50.55	51.72	52.95	54.23	258.89
Develop and Implement Standards	28.84	28.84	28.84	28.84	28.84	144.20
Develop Technology Architecture	23.69	13.39	13.39	13.39	23.69	87.55
Central Geoportal	28.43	28.43	28.43	28.43	28.43	142.14
County Geoportals	22.87	22.87	22.87	22.87	22.87	114.33
Develop KNSDI Website	4.64	4.64	4.64	4.64	4.64	23.18
Setup Nodal Agencies	25.54	25.54	25.54	25.54	25.54	127.72
Monitoring and Evaluation (M&E)	16.48	16.48	16.48	16.48	16.48	82.40
Develop Geoliterate Citizens	10.30	10.30	10.30	10.30	10.30	51.50
Research and Outreach	17.20	17.20	17.20	17.20	17.20	86.01
GRAND TOTAL	**378.01**	**274.12**	**290.40**	**281.09**	**308.00**	**1,531.62**

In Millions Kenya Shillings

The anticipated annual benefits of a fully developed KNSDI are given in Appendix 5. The benefits were derived based on the framework developed in Chapter Three. A fully functional KNSDI may give rise to benefits amounting to over 7.2 billion Kenya Shillings per annum.

However, the benefits may not be realised immediately in the short-term during which costs dominate. In reality, most of the benefits (including intangible ones not indicated) may accrue in subsequent years once the KNSDI has matured and is fully operational.

6.3.5 KNSDI Recommendations

This section outlines general recommendations in respect of the KNSDI.

a) The draft KNSDI policy should be finalised, paving way for legal and institutional frameworks necessary for the management of spatial data, appointment of most of the data custodians, and development of the SDI components.
b) For the KNSDI to be successful, it is critical that it be tied to a national agenda priority, such as employment creation, supporting food security, or reducing corruption. More mature SDIs have embraced this approach. Poland for example, strives to create employment opportunities through its national SDI.
c) All stakeholders should utilise SDI documents and artefacts developed from past initiatives (standards, guidelines, policies, and manuals) in their day-to-day work. The KNSDI secretariat should actively disseminate these documents on the KNSDI website.
d) In order to increase awareness and secure buy-in at all levels, the KNSDI secretariat should disseminate as much information as possible on its vision, mission, and objectives to all stakeholders. The secretariat should increase the frequency of public relations and outreach activities.
e) An SDI is a long-term initiative. Nothing in it should be static, including standards, policies, guidelines, manuals, metadata, foundation and framework data, human resources, the geoportal and the website. The secretariat should strive to improve the documents and artefacts that have been developed from past initiatives. As work practices, technologies and the political environment changes, so does the SDI.
f) The geoportal is one of the most visible components in an SDI. As at 2016, the KNSDI geoportal was not accessible, making it difficult to assess its development and progress. However basic it is, the geoportal should be activated and improved continuously.
g) To strengthen institutional partnerships and collaboration, a custodianship policy should specify the role of agencies and institutions involved in spatial data production. In addition, other policies including intellectual property, data development and access, data commercialisation, security, and funding should be developed.
h) The KNSDI website should include links to the metadata catalogue, the geoportal, and other geoportals provided by nodal agencies. It should also keep a register of existing datasets and type, which should be referenced before any data collection initiative.

i) Based on the case studies reviewed in Chapter Five, Table 6.7 outlines the proposed success criteria for the KNSDI.

Table 6.7: KNSDI success criteria

▪ Establish operational governance committees at various levels to oversee the KNSDI; ▪ Set the KNSDI objective(s), vision and mission; linking them to national agenda such as vision 2030; ▪ Solve contemporary problems (e.g. corruption, development, job creation) using the KNSDI; ▪ Develop short- and long-term KNSDI strategic and operational plans; ▪ Align geospatial projects funded by donors to the KNSDI strategic and operational plans; ▪ Communicate the KNSDI benefits widely; ▪ Seek political support at the highest level (including the president); ▪ Secure sustained funding; ▪ Promote SDI research; ▪ Recognise the contribution (and ownership) of all stakeholders, including the private sector; ▪ Continuous training and development of human resources; ▪ Continuous performance monitoring and evaluation; ▪ Design the KNSDI within a Performance-Based Management system; ▪ Select an SDI development approach suitable to the context; ▪ If bottom-up, develop partnerships with all agencies; ▪ If top-down, use legal instruments to direct establishment of the KNSDI, and key SDI components; ▪ Encourage data intensive frameworks (product models) at the country and other lower levels; ▪ Use policies to prevent possible conflict areas, such as data duplication, security and privacy; ▪ Fast track approval of the KNSDI draft policy; and ▪ Step towards a geoliterate population

7 CONCLUSIONS, RECOMMENDATIONS AND CONTRIBUTION

7.1 Conclusions

The study sought to review SDI development in Africa, which is slower in pace compared to the experiences elsewhere in the world. The objectives of the study were to:-

- establish the current status of national SDIs in Africa
- identify the socio-economic benefits and impacts of SDI in Africa
- outline technology trends that could support SDI development in Africa
- recommend an SDI implementation methodology for Africa
- develop a framework for SDI development in Kenya

These objectives have been achieved, and it is concluded that:

- More emphasis should be placed on improving the availability of financial and human resources for SDI development. These factors ranked the lowest after reviewing the status of SDI in Africa. In addition, no African country has an SDI readiness index higher than 0.7, confirming the low levels of SDI development in Africa.
- Successful SDI development can lead to many benefits, which far outweigh its costs. Some of these benefits include economic and sustainable development, monetary gains, time savings, new information markets, support for land administration, better quality of data and information, and better planning and decision making. Others include better data management, customer satisfaction, operational and strategic benefits, benefits for citizens, extension of services, openness, transparency, and increased participation in decision making. The study has provided a framework for such future studies in Africa.
- Emerging technologies such as cloud computing, FOSS, and VGI can increase uptake of SDIs, through highly scalable geoservices, cost effective software, and data. An application was developed to highlight the key concepts and potential of new trends.
- An SDI methodology for Africa has been developed, outlining the steps for the SDI development process. Based on a case study approach, the study found that strong coordination and institutional framework are pivotal to successful SDI. As such, the study has proposed the African Infrastructure for Spatial Information (AISI) as the pan-African RSDI framework for Africa.

- A framework for re-launching the KNSDI, which had stagnated as at 2016, has been developed. Gaps and areas for further improvement have been proposed, in addition to a plan and budget estimates for re-launching the KNSDI.

7.2 Recommendations

From the study, it is recommended that:

- African countries should strive to improve their SDIs by providing sustained funding and developing human resources. However, the other components of SDI, such as data, metadata, policies, standards, and legal frameworks, should also be improved. By improving these factors, the SDI readiness indices would be improved and subsequently the success of SDI development.
- The availability of socio-economic benefits and impact studies of SDI are valuable, because they facilitate a better understanding of the SDI which in turn leads to its successful development. A successful SDI gives rise to many benefits such as economic development and employment creation. Slow or delayed SDI development comes at a cost due to missed opportunities. Thus, African countries should develop SDIs and monitor their success to realise their many benefits.
- New technology trends (such as cloud computing, FOSS and VGI) should be embraced by African countries because they can significantly contribute to the success of SDIs. Such trends may give African countries a chance to develop SDI following newer approaches which are more adaptable to technology changes
- A methodology for SDI development in Africa, which was based on best practices from mature SDIs, has been developed. This should be adopted by African countries to support the SDI development. The proposed methodology is generic, and can be customised depending on political and cultural context, current level of SDI development, and other local factors. It can form an important reference point for African countries as they develop their SDIs.
- Kenya should restart the KNSDI, by allocating more financial resources, developing human resources, supporting the SDI development framework (legal and technical), developing SDI components (data, metadata, policies, and standards), seeking political support, and developing the institutional framework. Kenya's SDI-Readiness was still average in 2014 [101], and more effort is still required to improve it. Although several

KNSDI documents and artefacts have been developed (standards, manuals and a draft policy), they are neither widely available nor used by the stakeholders. The study has proposed an institutional framework, which should be adopted. A plan and budget has been developed which should be used as a basis for re-launching the KNSDI

7.3 Contribution

The study mainly contributes to the academic dimension, by filling the gap in the existing body of knowledge on SDI particularly in Africa. No single study in the literature assessed, has examined SDI in Africa with the detail presented in this thesis.

Specifically, the academic contribution of the study is:-

- increased body of knowledge on SDI in Africa
- SDI status, Social and Economic Benefits, Technology Trends
- methodology for SDI development in Africa
- framework for SDI in Kenya

In addition, the study may be useful to the general public, professional bodies (e.g. the ISK in Kenya), governments at various levels, policy makers and other stakeholders involved in SDI through the following:-

- addition to the very limited body of knowledge on SDI in Africa, thereby contributing to a better understanding of the issues involved
- promotion of a spirit of collaboration and participation to issues, thus educating and empowering the general public to improve their SDI
- an aid to policy making organs of African governments, helping them gain insight into various issues affecting agencies involved in SDI development
- an information tool to consultants who may need to provide accurate information on SDI development in Africa
- an aid to companies implementing SDI, which may also be providing SDI advisory services
- a roadmap and framework for SDI implementation in Kenya and similar developing countries

7.4 Areas for Further Research

The main limitation to this study was the inadequacy of long-term funding for the required continental coverage. As a result, several gaps have been identified which can be improved in future studies.

First, the response rate to the questionnaire in Chapter Two was rather low. Although data from other sources such as the UNDECA Survey of 2014 and the SDI Forum in Kigali, Rwanda were used to supplement the study, another study may be required to reach out to more countries. In addition, the questionnaire was self-administered, which generally attracts a lower response rate. While face-face interviews would have been ideal, the approach requires enormous time and financial resources to cover the whole continent. This predicament can be alleviated if key agencies responsible for geoinformation in Africa, such as UNECA and the proposed AISI, can contribute to research by continuously collecting data on SDIs.

Second, the study could be improved by assessing the benefits and impact on a specific application area or jurisdiction, such as the LIMS project under implementation by the National Land Commission in Kenya, or a county government in Kenya that has embraced SDI or a county-wide geoinformation system. In this case, the ex-ante and ex-post estimate of the costs and benefits could be established and used to evaluate the potential socio-economic benefits. This is necessary since it is difficult to assess the entire SDI context.

Finally, the study could be improved by examining the cost effectiveness of the new technology trends vis-à-vis the contemporary approaches. For instance, an estimate of costs and expenses comparing the two could be assembled. In addition, the study could review the uptake of new technologies by African countries, the cost effectiveness of the new technologies, and whether the new technologies give rise to wider adoption of SDIs.

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APPENDICES

Appendix 1: Questionnaire

	Introduction							
	Hello, My name is Mr. Collins Mwange Mwungu from the University of Nairobi, Kenya. I am carrying out research for my PhD titled "Spatial Data Infrastructure in Africa: A Technical and Institutional Analysis", and I'd like to ask your views on a number of issues. Part of this study involves checking the present status Spatial Data Infrastructure (SDI) in Africa. During this study, I will interview some people involved in SDI in Africa. All data and information collected will be treated with confidentiality and used for the research purpose only. Your support in this study will be highly appreciated.							
1	Questionnaire Identification							
	This section is for official use only. Do not fill this section.							
	Questionnaire Number:							
	Date Submitted (dd/mm/yyyy):		Date of Interview (dd/mm/yyyy):			Date Returned (dd/mm/yyyy):		
	Result:			1. Completed				
				2. Refused				
				3. No Response				
				4. Other (Please specify)				
2	Respondent							
	Title:		Mr.		Mrs.		Ms.	Hon.
			Dr.		Prof.		Other (Specify)	
	Your Name:							
	Designation:							
	Name of Organisation:							
	Physical Address:							
	Post Code:				Country:			
	Telephone:				Fax:			
	Email:				Website:			
3	Which of the following best describes your organisation? (Tick all that apply.)							
		1. Government Ministry/Department			2. Local Authority			
		3. Non-Governmental Organization (NGO)			4. Semi-Governmental/Parastatal			
		5. Academic/Research Institution			6. Private Company			
		7. Other (Specify):						
4	Factors that Influence SDI-Readiness							
4.1	Organizational Factors							
	This view includes organizational factors that influence the readiness of the SDI-initiative. These are: Vision, Institutional and Legal Framework.							

4.1.1	**Vision**	
	A practical and organizational issue to take is the development of a vision, detailing the desired future and a clear sense of how SDI components could serve that future and help to realize it. This also involves setting clear priorities and defining a strategy or policy to accomplish this vision. What is the level of vision by the Government regarding the importance and development of a National Spatial Data Infrastructure?	
	Check (X) one box only.	
	☐	Maximum level of government participation in defining a strategy of the national SDI
	☐	Important ministries are strongly involved in setting strategies for the national SDI
	☐	A formulated Vision forms a crucial starting point for launching the national SDI
	☐	A formulated vision does exist, but has low impact on the development of the national SDI
	☐	A vision is being formulated
	☐	A few sectors show interest in having a vision
	☐	No vision exists, as well as no intention exists to formulate a vision
4.1.2	**Institutional Leadership**	
	This factor refers to the leadership within the institutional framework. An SDI requires one or more institutions that coordinate its activities. What is the level of leadership within the institutional framework of one or more institutions that coordinate the activities relating the national SDI?	
	Check (X) one box only.	
	☐	Maximum leadership of one or more institutions that coordinate the activities relating to the national SDI
	☐	Very High leadership of one or more institutions that coordinate the activities relating to the national SDI
	☐	High leadership of one or more institutions that launch the crucial activities relating to the national SDI
	☐	Medium leadership of one or more institutions that coordinate partly the activities relating to the national SDI
	☐	Low leadership of one or more institutions that start to set up the institutional framework
	☐	Very Low leadership of one or more institutions that show interest to set up the institutional framework
	☐	No leadership of one or more institutions
4.1.3	**Legal Environment**	
	This factor refers to the creation of a legal environment that leads to a national SDI being legally embedded. The legal framework of a SDI consists of legal instruments such as laws, policies, directives and commitments. What is the level of the legal environment support to the national SDI-initiative?	
	Check (X) one box only.	
	☐	Existence of a legal framework that supports the national SDI at a maximum level
	☐	Legal instruments are applied that strongly motivate all the activities relating the national SDI
	☐	An established legal framework that supports the national SDI is under construction
	☐	Existence of a framework, but it is incapable of supporting the national SDI
	☐	Creating isolated legal instruments that might support the national SDI

		No existing legal instruments at the national level. However, the instruments exist at organizational / sector-level
		No existence of any legal framework (including instruments) that might support the national SDI-initiative
4.2	Information Factors	
	This view refers to the availability of core/fundamental spatial datasets and metadata. It includes SDI-content factors that influence the readiness of the SDI-initiative. The factors are: digital spatial availability and metadata availability.	
4.2.1	Fundamental Datasets for Africa	
	For the purpose of this section, the core / fundamental datasets are the datasets identified by the Mapping Africa for Africa (MAFA) study for use in Africa. These are listed below. Which core/fundamental datasets that support the national SDI are available in your country?	
	Check (X) as applicable.	

	Dataset	Definition
	Geodetic control points	List of coordinates with information on history of establishment and design
	Height datum	List of primary height points (vertical datum surface)
	Geoid model	Geoid-ellipsoid separations (heights at individual points)
	Aerial photography	Aerial photography
	Satellite imagery	Satellite imagery
	Digital elevation model	Vertical distance from the earth's surface to a base defined by the agreed datum
	Spot heights	Heights of peaks
	Bathymetry	Vertical distance of earth's surface from base defined by lowest astronomical tide
	Coastline	The limit of land features usually at mean high water level.
	Natural Water Bodies	Watercourses, drainage network, and all inland water bodies (streams, rivers.)
	Governmental Units	Administrative and Jurisdictional limits/boundaries (international, national …)
	Populated Places	Population centres including urban areas, towns, localities, and rural settlements
	Enumeration Areas	Boundaries of areas delineated for collecting demographic census information
	Place Names	Official and local names of places
	Feature Names	Official and local names of cultural and geographic features (including roads)
	Land Parcels/Cadastre	A consistent framework of land parcel/cadastre boundaries for land tenure
	Land Tenure	Current, proposed and historical details of all tenures, e.g., ownership, vesting
	Street Address	Unique Street Address of parcels/properties
	Postal or Zip code zones	Boundaries of post code areas
	Land-use planning zones	Boundaries of permitted/restricted land use e.g. conservation, heritage, restricted
	Roads	Network of physical roads and carriageways
	Road centrelines	Centreline of roads and carriageways
	Railways	Network of railway lines

		Airports and ports	Location of airports, sea ports, and navigation aids
		Bridges and tunnels	Bridges and tunnels
		Power	Locations of trunk / national grid power lines / major installations, and sources
		Telecommunications	Locations of trunk communication networks and major assets
		Land cover	Observed bio-physical cover over on the earth's surface
		Soils	Boundaries and classifications of soil resources
		Geology	Boundaries and classification of geological units
4.2.2	Availability of Fundamental Datasets		
	This factor refers to the availability of core/fundamental spatial datasets (see 5.2.1 above) in digital format crucial for the national SDI. What is the availability of the core/fundamental spatial datasets in digital format?		
	Check (X) one box only.		
		Complete/total availability of core spatial datasets in digital format	
		Availability of core spatial datasets in digital format at an appropriate scale that cover the whole country	
		Availability of core spatial datasets in digital format at an appropriate scale covering the main regions of the country	
		Partial availability of core spatial datasets in digital format at levels that are insufficient for being a decisive factor	
		Availability of some core spatial datasets in digital format for some regions in the country	
		Availability of very few core spatial datasets in digital format	
		No availability of any core spatial datasets in digital format	
4.2.3	Metadata Availability		
	This factor refers to the content of Core Spatial Datasets. Matadata is "data about data" or descriptions of any database contents. In SDI, it usually includes dataset title, coverage (spatial and thematic), form - analogue or digital, format, source, scale, access protocols, cost, last update, accuracy, lineage etc. What is the level of metadata to support the national SDI in your country?		
	Check (X) one box only.		
		Complete/total availability of metadata describing spatial datasets	
		Very high availability of metadata describing spatial datasets	
		High level of metadata availability describing spatial datasets	
		Medium level of metadata availability describing spatial datasets	
		Low level of metadata availability describing spatial datasets	
		Very low level of metadata availability describing spatial datasets	
		No availability of any metadata describing spatial datasets	
4.3	Human Resource Factors		
	This view includes human factors that influence the readiness of the SDI-initiative. These are: human capital, SDI education/culture, individual leadership.		
4.3.1	Culture/Education on SDI		
	This factor refers to the capacity building and the awareness of the impact of spatial data on the well-functioning of society, including businesses, public entities and academic institutions and may ease the efforts to participate in the SDI and to acquire funding for SDI development. Investment of significant resources to build capacity and to raise community awareness of spatial data and technologies such as courses, workshops and seminars are important in order to realize the full potential of SDIs. What is the level of Culture/Education that supports the national SDI?		
	Check (X) one box only.		

		Maximum level of SDI-culture and education (capacity building) among the stakeholders
		Very high level of SDI-culture and education (capacity building) among the stakeholders
		High level of SDI-culture and education (capacity building) among the stakeholders
		Medium level of SDI-culture and education (capacity building) among the stakeholders
		Low level of SDI-culture and education (capacity building) among the stakeholders
		Very low level of SDI-culture and education (capacity building) among the stakeholders
		No existence of any SDI-culture and education (capacity building among the stakeholders
4.3.2	SDI Champion (Individual Leadership)	
	A very critical issue of SDI development is leadership. SDIs need a champion, or an entity which promotes, and coordinates the development of a SDI. This leader has to initiate an agenda building process and start to bring the community together. A leader can be appointed by a formal mandate, often political support. A leader can also emerge from existing coordination activities, or from the achievements and enthusiasm of respected individuals. What is the presence of such leadership in the SDI-initiative in your country?	
	Check (X) one box only.	
		Existence of absolute individual leadership
		Very High individual leadership
		High individual leadership
		Medium individual leadership
		Low individual leadership
		Very Low individual leadership
		No existence of any individual leadership
4.4	Access Networks and Technology	
	This view includes technological factors i.e. (Communication infrastructure, web connectivity, and availability of commercial or in-house spatially-related software, Use of Open source services) that influence the readiness of the SDI-initiative The access networks and technologies are critical from a technical perspective to facilitate the use of data and services by people. They seek to facilitate access to relevant data sources and spatial information services by anyone, anywhere.	
4.4.1	Availability of commercial or in-house spatially-related software	
	This factor refers to the level of commercial or in-house software availability that forms a key aspect of a SDI. What is the level of availability of commercial or in-house spatially related software that supports the national SDI?	
	Check (X) one box only.	
		Maximum availability of commercial or in-house spatially-related software that fits the demands of the national SDI
		Very high level of availability of commercial or in-house spatially-related software
		High level of availability of commercial or in-house spatially-related software
		Medium level of availability of commercial or in-house spatially-related software
		Low level of availability of commercial or in-house spatially-related software
		Very Low level of availability of commercial or in-house spatially-related software
		No availability of commercial or in-house spatially-related software
4.4.2	Use of Open Source Services	
	This factor refers to the level of the use of Open source (free of cost) services. What is the level of availability of Open Source spatially related software and services that supports the national SDI?	

	Check (X) one box only.	
	☐	Only Open source services are used for all services needed within a SDI
	☐	Very high level of the use of Open source services
	☐	High level of the use of Open source services
	☐	Medium level of the use of Open source services
	☐	Low level of the use of Open source services
	☐	Very Low level of the use of Open source services
	☐	No use of Open source services
4.5	Financial Resources	
	This view includes the funding factors that influence the readiness of the SDI-initiative. It refers to SDI funding by: governmental, cost recovery, private sector and enterprise funding. The view focuses on the sources of funding in order to develop a SDI. Funding is needed in order to finance SDI-management and coordination tasks, institutional framework, legal environment, hardware, (commercial) software, capacity building, metadata preparation, and data collection. Funding is a complex issue with many stakeholders and different funding arrangements.	
4.5.1	Governmental Funding	
	What is the government's role (level) as source to finance the national SDI initiative?	
	Check (X) one box only.	
	☐	The national SDI is only funded by the government and no other funds are needed.
	☐	Very High level of funding by the government to finance the national SDI-initiative
	☐	High level of funding by the government to finance the national SDI-initiative
	☐	Medium level of funding by the government to finance the national SDI-initiative
	☐	Low level of funding by the government to finance the national SDI-initiative
	☐	Very Low level of funding by the government to finance the national SDI-initiative
	☐	No funding by the government to finance the national SDI-initiative
4.5.2	Funding by means of Cost Recovery	
	What is the level of funding the national SDI through the application of policies regarding cost recovery?	
	Check (X) one box only.	
	☐	SDI is only funded by means policies regarding cost recovery and no other funds are needed.
	☐	Very High level of funding by means of the application of policies regarding cost recovery
	☐	High level funding by means of the application of policies regarding cost recovery
	☐	Medium level funding by means of the application of policies regarding cost recovery
	☐	Low level funding by means of the application of policies regarding cost recovery
	☐	Very Low level funding by means of the application of policies regarding cost recovery
	☐	No funding by means of the application of policies regarding cost recovery
4.5.3	Private and Enterprise Sector Funding	
	What is the level of contribution by the private sector and enterprises to finance the national SDI?	
	Check (X) one box only.	
	☐	The national SDI is only funded by the private sector and/or enterprises
	☐	Very High level of funding by the private sector and/or enterprises to finance the national SDI
	☐	High level of funding by the private sector and/or enterprises to finance the national SDI
	☐	Medium level of funding by the private sector and/or enterprises to finance the national SDI
	☐	Low level of funding by the private sector and/or enterprises to finance the national SDI

		Very Low level of funding by the private sector and/or enterprises to finance the national SDI	
		No funding by the private sector and/or enterprises to finance the national SDI	
5	National Spatial Data Infrastructure		
5.1	Name of Organization(s) co-coordinating the National SDI activities		
5.2	Website of the organization in 5.1 above		
5.3	Name of contact person in the organization in 5.1 above		
5.4	Telephone contact of 5.3 above		
5.5	Email address of 5.3 above		
5.6	Web address entry point of the National SDI portal or clearinghouse		
Thank you very much for your time in completing this survey.			

Appendix 2: Code scripts

geoserver.yaml: This script creates the GeoServer pod

```
apiVersion: v1
kind: Pod
metadata:
  name: geoserver
  labels:
    name: geoserver
spec:
  containers:
    - image: kartoza/geoserver
      name: geoserver
      ports:
        - containerPort: 8080
          name: geoserver
      volumeMounts:
          # Name must match the volume name below.
        - name: geoserver-persistent-storage
          # Mount path within the container.
          mountPath: /opt/geoserver/data_dir
  volumes:
    - name: geoserver-persistent-storage
      gcePersistentDisk:
        # This GKE persistent disk must already exist.
        pdName: geoserver-disk
        fsType: ext4
```

geoserver-service.yaml: This script creates the Geoserver service

```
apiVersion: v1
kind: Service
metadata:
  labels:
    name: gsfrontend
  name: gsfrontend
spec:
  type: LoadBalancer
  ports:
    # The port that this service should serve on.
    - port: 8080
      targetPort: 8080
      protocol: TCP
  # Label keys and values that must match in order to receive traffic for
this service.
  selector:
    name: geoserver
```

postgres.yaml: This script creates the PostGIS pod

```
apiVersion: v1
kind: Pod
metadata:
  name: postgis
  labels:
    name: postgis
spec:
  containers:
```

```
    - resources:
        limits:
          cpu: 0.5
      image: mdillon/postgis
      name: postgis
      env:
        - name: POSTGRES_USER
          value: postgres
        - name: POSTGRES_PASSWORD
          value: xxxxxxxxx
        - name: DB_PASS
          value: xxxxxxxxx
        - name: POSTGRES_DB
          value: gis
        - name: PGDATA
          value: /opt/postgis/data_dir
      ports:
        - containerPort: 5432
          name: postgis
      volumeMounts:
          # This name must match the volumes.name below.
        - name: postgis-persistent-storage
          mountPath: /opt/postgis
  volumes:
    - name: postgis-persistent-storage
      gcePersistentDisk:
        # This disk must already exist.
        pdName: postgis-disk
        fsType: ext4
```

postgres-service.yaml: This script creates the PostGIS service

```
apiVersion: v1
kind: Service
metadata:
  labels:
    name: psfrontend
  name: psfrontend
spec:
  ports:
    # The port that this service should serve on.
    - port: 5432
  # Label keys and values that must match in order to receive traffic for
this service.
  selector:
    name: postgis
```

auto.sh: A Linux script to automate creation of containers, pods and services

```
!/bin/sh
gcloud config set compute/zone us-central1-b
gcloud container clusters create gscont --num-nodes 3
gcloud compute disks create --size 200GB postgis-disk
gcloud compute disks create --size 200GB geoserver-disk
kubectl create -f mpostgres.yaml
kubectl create -f postgres-service.yaml
kubectl create -f geoserver.yaml
kubectl create -f geoserver-service.yaml
kubectl get services gsfrontend psfrontend
```

cleanup.sh: A Linux script to automate clean-up of containers, pods and services

```
!/bin/sh
gcloud config set compute/zone us-central1-b
kubectl delete service gsfrontend
kubectl delete service psfrontend
kubectl delete pod geoserver
kubectl delete pod postgis
gcloud container clusters delete gscont
gcloud compute disks delete postgis-disk geoserver-disk
```

Accessing GeoServer in the cloud

First use the GKE to inspect the services to determine the IP Address:

```
$ kubectl get services gsfrontend psfrontend
NAME         CLUSTER-IP       EXTERNAL-IP    PORT(S)    AGE
gsfrontend   10.103.247.146   8.35.197.101   8080/TCP   5h
kubernetes   10.103.240.1     <none>         443/TCP    1d
psfrontend   10.103.251.124   <none>         5432/TCP   5h
```

gsfrontend is running on 8.35.197.101, so to access Geoserver we use the standard GeoServer URL: http://8.35.197.101:8080/geoserver/web.

Useful commands

Listing what is currently running

```
$ kubectl get po
```

Executing interactive commands in a container

```
$ kubectl exec -ti postgis -- /bin/sh
```

Executing one-time commands in a container

```
$ kubectl exec postgis -- cat /etc/hostname
```

Viewing logs on a container

```
$ kubectl logs -f postgis
```

Creating a database on a PostGIS Pod

```
$ kubectl exec -ti postgis -- /bin/sh
# psql postgrespsql: FATAL: role "root" does not exist
# psql -U postgres
postgres=# create user root with password 'xxxxxxx';
CREATE ROLE
postgres=#\q
# psql -U root postgres
```

Viewing list of existing databases

```
postgres=>\l
```

Connecting to the 'gis' database

```
$ kubectl exec -ti postgis -- /bin/sh
# psql -U root postgres
postgres=> \connect gis
```

Listing tables in the 'gis' database

```
gis=> \dt
```

Transferring SQL files from local machine to remote pod:

```
Create the sql:
shp2pgsql -s 4326 Final_Counties.shp counties > counties.sql
Shapefile type: Polygon
Postgis type: MULTIPOLYGON [2]

Transfer the sql to remote pod:
kubectl exec -i postgis -- /bin/bash -c "cat > /XX.sql" < XX.sql
kubectl exec -i postgis -- /bin/bash -c "cat > /opt/postgis/XX.sql" < XX.sql

Run the SQL remotely:
First Delete table, if necessary:
# drop table XXX
# psql -U postgres -f counties.sql gis
# psql -f counties.sql gis
Or directly:
gis=#  \i counties.sql

Inspecting the Services
$ kubectl get services gsfrontend
NAME         CLUSTER-IP       EXTERNAL-IP    PORT(S)    AGE
gsfrontend   10.103.247.146   8.35.197.101   8080/TCP   5h
kubernetes   10.103.240.1     <none>         443/TCP    1d
psfrontend   10.103.251.124   <none>         5432/TCP   5h

Changing the machine Type
See: https://cloud.google.com/compute/docs/instances/changing-machine-type-
of-stopped-instance

gcloud config set compute/zone us-central1-b

gcloud compute instances stop gke-gscont-772083c3-node-8e2i
gcloud compute instances set-machine-type gke-gscont-772083c3-node-8e2i --
machine-type custom-1-2048
gcloud compute instances start gke-gscont-772083c3-node-8e2i

gcloud compute instances stop gke-gscont-772083c3-node-unof
gcloud compute instances set-machine-type gke-gscont-772083c3-node-unof --
machine-type custom-1-2048
gcloud compute instances start gke-gscont-772083c3-node-unof

gcloud compute instances stop gke-gscont-772083c3-node-x48z
gcloud compute instances set-machine-type gke-gscont-772083c3-node-x48z --
machine-type custom-1-2048
gcloud compute instances start gke-gscont-772083c3-node-x48z
```

Appendix 3: SDI Case Studies

The Canadian Geospatial Data Infrastructure (CGDI)

Context

Administratively Canada is a federal system of government. Land administration is carried out at the provinces. This results in a high degree of centralisation in handling of spatial data in each province [105]. As a result, Canada has a history of massive digital spatial databases at the provinces.

Furthermore, the private sector has been very instrumental in supporting the CGDI courtesy of the Geomatics Industry Association of Canada (GIAC) [105]. The CGDI started in the nineties when various levels of government, industry bodies and other stakeholders realised the benefit of a common, shared platform. They combined their efforts towards developing the CGDI.

Initially, the primary objective of the CGDI was to improve the accessibility of all spatial datasets to all stakeholders, making them widely available. Another objective was to make the CGDI ubiquitous and self-sustaining, effectively supporting the sustainable protection and betterment of the country's social, health, economic, natural and cultural resources. To meet this objective, the Government set up and funded GeoConnections, an initiative that brings together the private sector, all levels of government, the academia and even the citizens to work together in establishing the CGDI [105]. GeoConnections is managed by the Earth Sciences Sector (ESS) of Natural Resources Canada (NRC).

GeoConnections is supported by five key policy objectives [23]:

- *Access Data*: making spatial data more widely available on the internet such that all stakeholders including the citizens can access the data,
- *Framework Data*: establishing key datasets that makes it easier to integrate diverse data for effective decision making and development of value added products,
- *Geospatial Standards*: increasing interoperability of Canadian geospatial datasets with international standards, enabling Canadian businesses to trade with other nations,
- *Partnerships*: increasing collaboration and partnership within the government, the academia and the private sector to capitalise on their combined expertise,
- *Supportive policies*: development of policies at all levels to increase participation of the private sector, and to develop electronic commerce

The CGDI has four major components [92]:

- *framework data*, amalgamated from territorial, provincial and federal agencies;
- *common data policies*, formulated and adhered to by territorial, provincial and federal agencies, to eliminate obstacles to sharing of information hence reduced duplication;
- *standards* facilitating data sharing to improve interoperability. Standards are developed jointly by territorial, provincial and federal agencies, and international negotiations; and
- *enabling technologies* based on open specifications and standards, integrating data from multiple, diverse and distributed sources

The first phase of CGDI was in operation from 1999 to 2005, receiving federal funding of $60 million. The objective was to develop policies, standards, technologies and partnerships needed to build the CGDI. The program was renewed for an additional 5 years (2006 – 2010) with an additional budget of $60 million to maintain and improve the CGDI. The third phase was executed over the period 2010 - 2015 received a further funding of $19 million. This phase mainly focused on the following:

- public security;
- public health;
- aboriginal issues; and
- environment and sustainable development

The funding looks somewhat lower, but it should be remembered that Canada already had a tradition of large computerised databases at the provincial levels where the bulk of data generation, human resource costs, and hardware and software costs were incurred.

Institutional Framework

GeoConnections is the CGDI's lead agency. GeoConnections is a national partnership led by NRC facilitating access to and use of spatial data in Canada. GeoConnections was established in the year 1999 and has since administered development of the CGDI [92].

GeoConnections is guided by a Management Board. The board consists of senior government officials drawn from federal agencies who are represented on the Inter Agency Committee for Geomatics, territorial and provincial representatives from the Canadian Council on Geomatics, and representatives from academia and industry. The Assistant Deputy Minister of the ESS chairs GeoConnections [105].

Canada is one of the pioneer countries fostering a broad-based joint initiative to develop its NSDI, the CGDI. CGDI is driven by partnerships among territorial, provincial and federal agencies; the industry and the private sector; and the academia. GeoConnections fosters collaboration amongst these agencies to satisfy the country's geospatial demands by making it widely available.

The GeoConnections governance structure is shown in Figure 7.1.

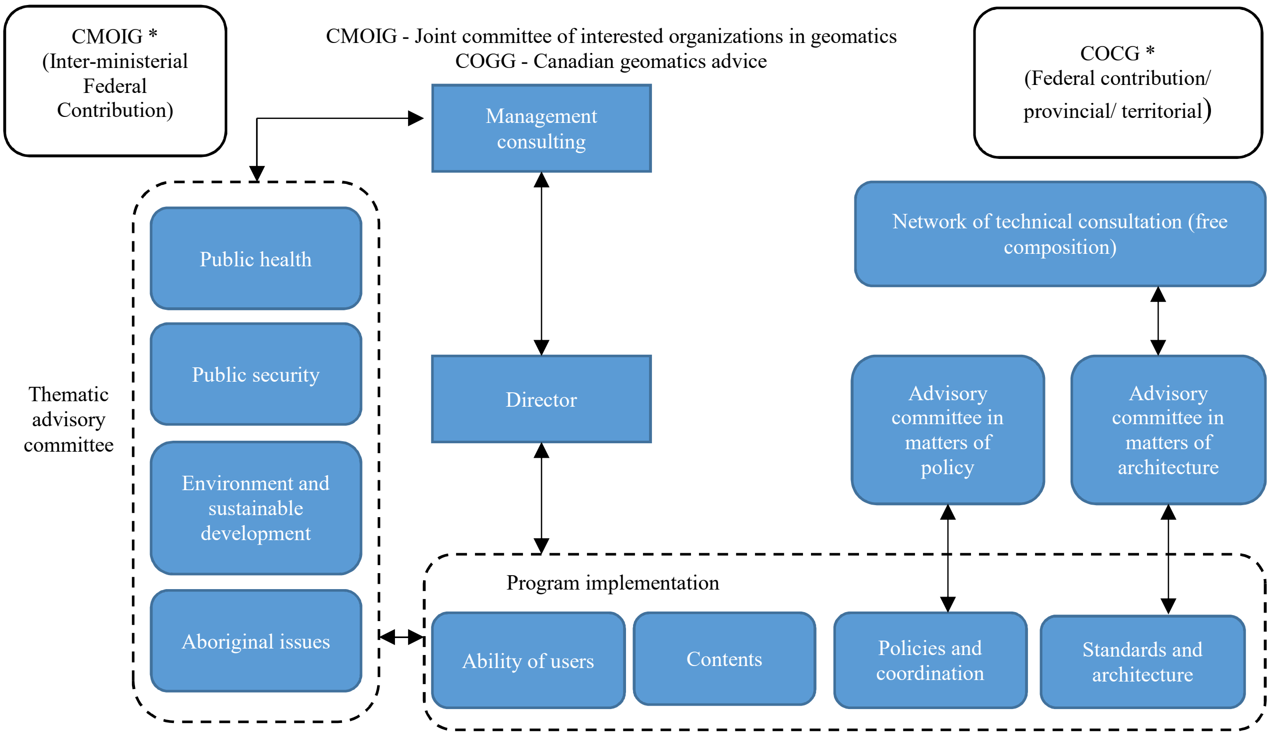

Figure 7.1: Geo-connections governance model
Source: GeoConnections

The South African Spatial Data Infrastructure (SASDI)

Context

SASDI is a mature NSDI within the study context. The SDI is supported by several policies, and a well-developed legal framework and an institutional framework.

Institutional Framework

The Department of Rural Development and Land Reform (DRDLR) executes five programmes [42]:

- Administration
- Geospatial and Cadastral Services
- Rural Development
- Restitution
- Land reform

The *National Geomatics Information Management Service* is a branch within the Geospatial and Cadastral Services programme. It facilitates provision of geospatial data and information, deeds registration, cadastral surveys, spatial planning, and technical services supporting land development and the SASDI. The branch is headed by the Chief Surveyor General of South Africa [42].

The National Spatial Information Framework (NSIF) is an initiative coordinating development of SASDI at the national level. Its mandate is to establish and maintain the SASDI, and provide administrative support to the Committee for Spatial Information (CSI). Among its major responsibilities are assisting the CSI to monitor adherence to the SDI Act and policies, providing support to custodians and other state organs, evaluating the success of policies implemented and serving as a secretariat to the CSI.

The CSI consists of several members appointed by the responsible Minister [28]:

- one representative appointed by the Minister
- two representatives of the national department for Lands
- one representative of Statistics South Africa
- one representative of the national department of Provincial and Local Government
- one representative of each national departments of state identified by the Minister

- one representative from each provincial government
- two representatives from local municipalities, each from a rural and urban municipality
- one representative from the Council of Government Information Technology Officers
- a representative of professional association of persons in GI Science
- one person involved in research or teaching of GI Science
- representatives of the interests of public entities
- one representative from each data custodian as identified by the Minister

Legal Framework

The South African SDI Act (No. 54, 2003) [28] was assented to in January 2004. The Act established the CSI, the SASDI, and the Electronic Metadata Catalogue (EMC). It facilitates development of policies and standards (borrowed from ISO, OGC and SABS). The latter promotes the sharing of geospatial data and information. It also facilitates development of metadata to eliminate duplication in data collection. Finally, it facilitates the appointment and specification of duties and responsibilities for data custodians.

Sections 1 to 11, 13 and 19 to 22 of the Act came into operation in May 2006; while the remaining sections were approved by the President in May 2015 [41], [40].

The CSI has developed two major policies:

- Base Data Set Custodianship Policy
- Policy on Pricing of Spatial Information Products and Services

These policies were approved by the Minister in March 2015. The SDI Act and the two policies define a comprehensive legal and institutional framework, through the following principles:

- *Authority*: custodians have authority over data sources. They are responsible for data capture, validation, maintenance and management;
- *Cooperation and Coordination*: custodians are directed to work together to facilitate data sharing thus avoiding unnecessary duplication;
- *Access*: custodians must disclose or make base datasets available to the public on request, unless exempted under the Promotion of Access to Information Act (PAI);
- *Shared base data set custodianship*: it is possible to have more than one custodian for the same dataset;

- *Quality*: the custodian must ensure that the dataset is accurate and satisfies user needs for the purpose for which it was obtained;
- *Base dataset governance*: it is possible to establish the role of base data coordinator to encourage base data governance;
- *Adherence to standards*: custodians must adhere to standards prescribed by the Minister, and any other standards to promote interoperability;
- *Rights*: custodians are entitled to charge a fair amount for provision of spatial information. Users have a responsibility to report data deficiencies.

The criteria for selecting custodians is: mandated responsibility (through legislation, policies or directives); resources and infrastructure available to perform the function (capacity); and request by the CSI to be a base data set custodian [41].

The Pricing Policy recognises two categories of spatial information products and services:

- Products usually available from the organisation: these are listed in the organisations manual of records in line with section 14 of the PAI Act, revised annually;
- Products and services customised by the organisation for clients on specific request: these are value-added products and services

SASDI mainly focuses on five areas:-

- Inventory of who has what data, of what type and quality;
- Data capture project register, by custodians who maintain data and metadata;
- Metadata providing adequate information for assessment of data;
- Standards facilitating data and metadata capture and encoding; and
- A catalogue facilitating structured search and comparison of resources

COst of Fulfilling User Request (COFUR): The pricing structure of spatial information is based on recouping the cost of materials used for postage, packaging and dispatch, printing and copying. Public agencies may provide spatial information products and services at a price less than the COFUR price. The workstation and staff member effort is excluded in cost recovery. The Minister may, upon receiving a request and on the CSI recommendation, exempt the public sector agency from COFUR pricing. The pricing structure is designed to encourage small enterprises and non-conventional users to get involved in the spatial information industry.

The Polish National Spatial Data Infrastructure

Context

The Polish national SDI, Krajowej Infrastruktury Informacji Przestrzennych (KIIP), is an example of an NSDI under the INSPIRE directive. INSPIRE itself is not an NSDI but a regional SDI (RSDI), contributing to the development of SDIs in the European Union (EU) member states. INSPIRE has been transferred onto the national legislation of member states, directing them to provide certain data, information, metadata and web services in their SDIs [15]. The directive ensures that SDIs of member nations are interoperable at all levels. It also ensures that the data can be used across borders.

INSPIRE was established by Directive 2007/2/EC of the European Parliament and Council. INSPIRE is based on the components of the national and sub-national SDI created by member states of the EU. The directive focuses on five key areas:-

- metadata;
- systematisation and interoperability of spatial data and services for certain themes;
- network technologies and services;
- measures for sharing spatial data and services; and
- coordination and monitoring measures

Commencing in the year 2005, the first phase of KIIP mainly focused on improving competitiveness of enterprises by providing them with online access to spatial data (such as cadastral data) and services. This phase came to an end in the year 2008, and envisaged the following benefits:-

- use of spatial data to promote entrepreneurship, innovativeness and competitiveness;
- provision of information to improve decision making, especially investment decisions;
- support for eGovernment, by modernizing public administration through ICT;
- awareness and importance of spatial data (such as cadastral) among entrepreneurs;
- time and cost savings for entrepreneurs through the use of geoinformation services;
- contribution to development of an information society

The second phase commenced in 2009. This phase illustrates the impact that a directive (in this case, INSPIRE) can have on development of an NSDI. The phase envisaged the following objectives:-

- development of metadata enabling access to basic services of spatial data;
- a security policy implementing confidentiality, integrity and availability (CIA);
- utilization of registers, databases and maps to develop the NSDI; and
- promoting interoperability of spatial datasets and services

At present (in the year 2016), KIIP is fully operational within the framework of INSPIRE. It facilitates consistent access to spatial data and services at the national and regional levels. KIIP interconnects institutions from the private sector, the government, the academia, stakeholders and even the citizens. The SDI enables electronic integration of datasets provided by diverse stakeholders via the geoportal.

GEOPORTAL 2 (the geoportal developed during the second phase of KIIP) is co-financed by the EU, within the framework of the Programme Innovative Economy (2007-2013). It is under priority axis 7 - information society – establishment of electronic administration. KIIP has various nodes operating at three levels: district, central and provincial.

The datasets of the register of lands and building, referred to as 'EGiB', are hosted in the districts, while the warehouses of the topographical data are hosted in the provinces.

The United States National Spatial Data Infrastructure (NSDI)

Context

Politically and administratively, the United States of America (USA) is a federal republic. The USA includes 50 states, 1 district, and more than 3000 counties and 7000 cities [105]. The decentralized nature of US governance means that many agencies are involved in the geospatial industry [20]. Since the government system has a federal structure, some responsibilities for geographic information are handled at the local government and state levels [105].

According to the Executive Order (EO) of the year 1994 [25], the objective of the NSDI is to create a reliable infrastructure providing consistent, accurate, and timely data to all users.

The goals of the NSDI are:

- decrease duplication of effort in data collection amongst agencies;
- enhance data quality;
- minimise the acquisition costs of spatial data;
- make spatial data more accessible to the public;
- increase the value of existing data; and
- initiate major partnerships to increase availability of spatial data

In the year 1990, the Office of Management and Budget (OMB) made revisions to Circular A-16 which had been published in the year 1953. This revision created the FGDC.

FGDC aims to promote coordinated generation, use, dissemination and sharing of spatial data across federal agencies. Another key objective is development of a national digital spatial base serving the federal, state, and local governments, and the private sector. This initiative would be linked by spatial data developed according to agreed standards. In turn, this data would enable sharing and efficient transfer of information between all stakeholders [102].

In 1994, President Clinton signed EO number 12906 [25]. The order chartered the FGDC to coordinate and lead development of the NSDI. Among other targets, the EO set a deadline of January 2000 for the initial implementation of a national digital geospatial data Framework, which was to be prepared in consultation with tribal, state and local governments [25].

The EO recognised that geographic data and information is critical to environmental protection, economic development and stewardship of natural resources. The EO mandated the FGDC to develop measures aimed at maximising the collective effort of the private sector, tribal, state and local governments, and other stakeholders in sharing costs of acquiring geospatial data consonant with the order [25]. The FGDC was to carry out this task within the law.

The concept of the NSDI has evolved since the 1990s but continues to retain the original vision. Today (in the year 2016), it is generally understood that the NSDI must be [102]:

- a sustainable infrastructure serving the present and future needs;
- a foundation supporting the use of geospatial data for improved decision making;
- a resource enabling people and organizations to work together towards everyday goals;
- a collection of timely and accurate geospatial data for local, national, and global use;
- an infrastructure for geospatial applications and services; and
- a flexible base that changes in tandem with user and business needs, and technology

Institutional Framework

The FGDC is the NSDI's lead agency [102]. The organisational structure (as at 2016), roles and responsibilities are depicted in Figure 7.2.

- the executive committee is a subsidiary of the steering committee. It advises the president and vice president on key priorities for geospatial initiatives;
- the steering committee provides leadership to coordinate NSDI development;
- the FGDC coordination group facilitates coordination between federal agencies, and supervises the activities of sub-committees and groups;
- Subcommittees, Working Groups and Geospatial Line of Business Work Groups
    - a sub-thematic committee for each data theme of national interest
    - one or more federal agencies responsible for each thematic sub-committees
    - working groups have a vertical reach, extending to other SDI components (for example, standards and metadata)
- The National Geospatial Advisory Committee includes representatives of 28 NGOs and the governmental. It recommends and advises on geospatial policy and issues.

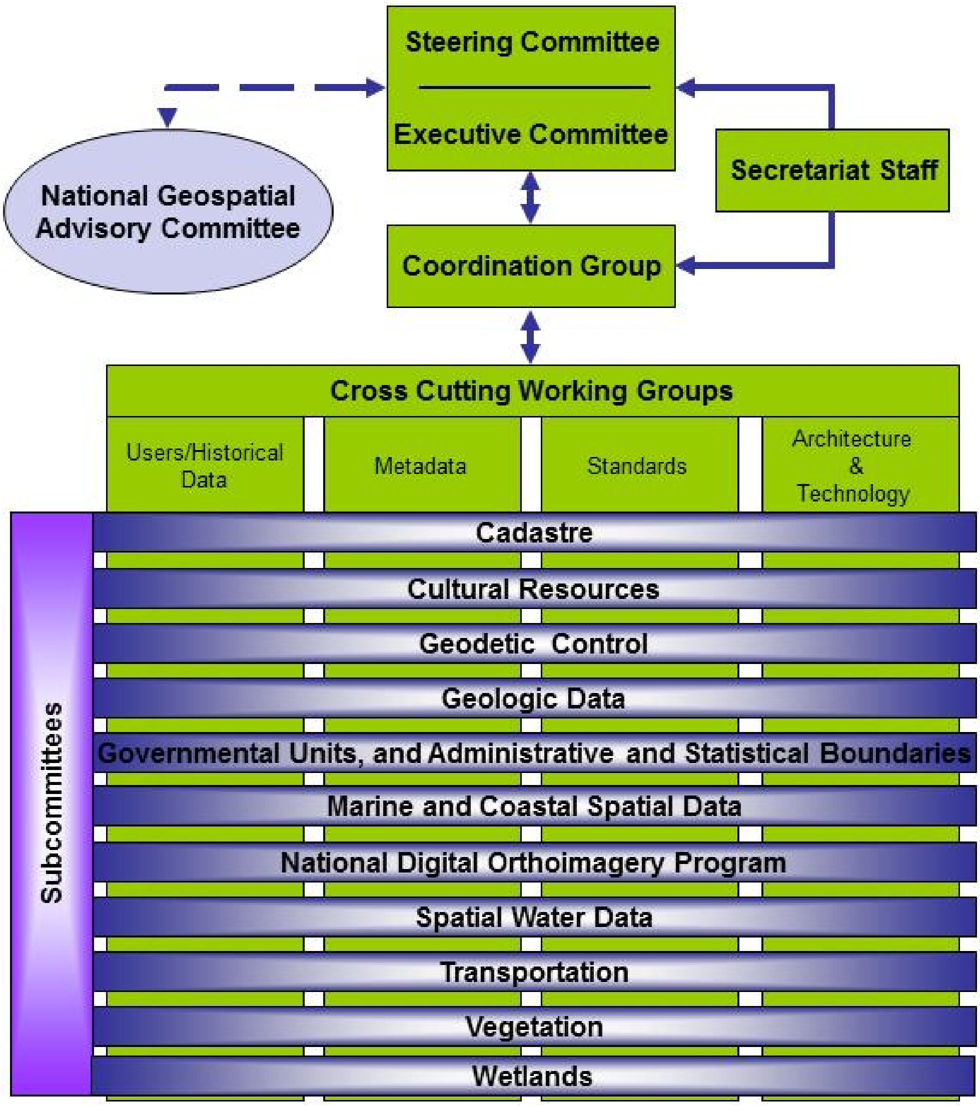

Figure 7.2: FGDC structure, roles and responsibilities
Source: FGDC

The Australian Spatial Data Infrastructure (ASDI)

The administrative structure of Australia is a federal system with two territories and six states making up the Commonwealth of Australia [105].

In the year 2004, the Australia New Zealand Land Information Council (ANZLIC) had envisaged the creation of a dispersed network of consistent databases linked by common standards. Each database was to be managed by custodian(s) with incentive and expertise to maintain the database to agreed standards.

At the time, ASDI consisted of four core components [105]:

- an institutional framework facilitating measures and policies for building, maintaining and accessing the ASDI;
- a set of technical standards defining key features of the datasets;
- an assemblage of core datasets generated within the institutional framework, which are fully compliant with the technical standards; and
- a clearinghouse portal accessible in consonance with policy determined within the institutional framework

Institutional Framework

ANZLIC is the ASDI's lead agency. ANZLIC facilitates a framework and policies for geospatial data management of New Zealand and Australia. Although ANZLIC was established in 1986, it only became operational in the year 1996 [105].

Custodianship plays an important role in the ASDI. A custodian has the responsibility to ensure that core datasets are collected and maintained according to agreed standards. The dataset, whose format and condition should comply with ASDI policies and standards, is made available to the user community via the clearinghouse portal. The structure of ANZLIC is depicted in Figure 7.3.

Council members are responsible for coordinating implementation of policies on geospatial information management and operational issues within their respective jurisdictions. For each data theme, a custodian is appointed in accordance with predetermined criteria. Most often, a government agency is appointed a custodian. The criteria used to select a custodian is:-

- the agency has legal responsibility to capture and maintain the geographic information
- the need for the agency to use geographic information for its current operations

- the competency of the agency in production and updating of the information
- economic justification (the agency is best placed to collect the information)
- the level of integrity required for spatial information

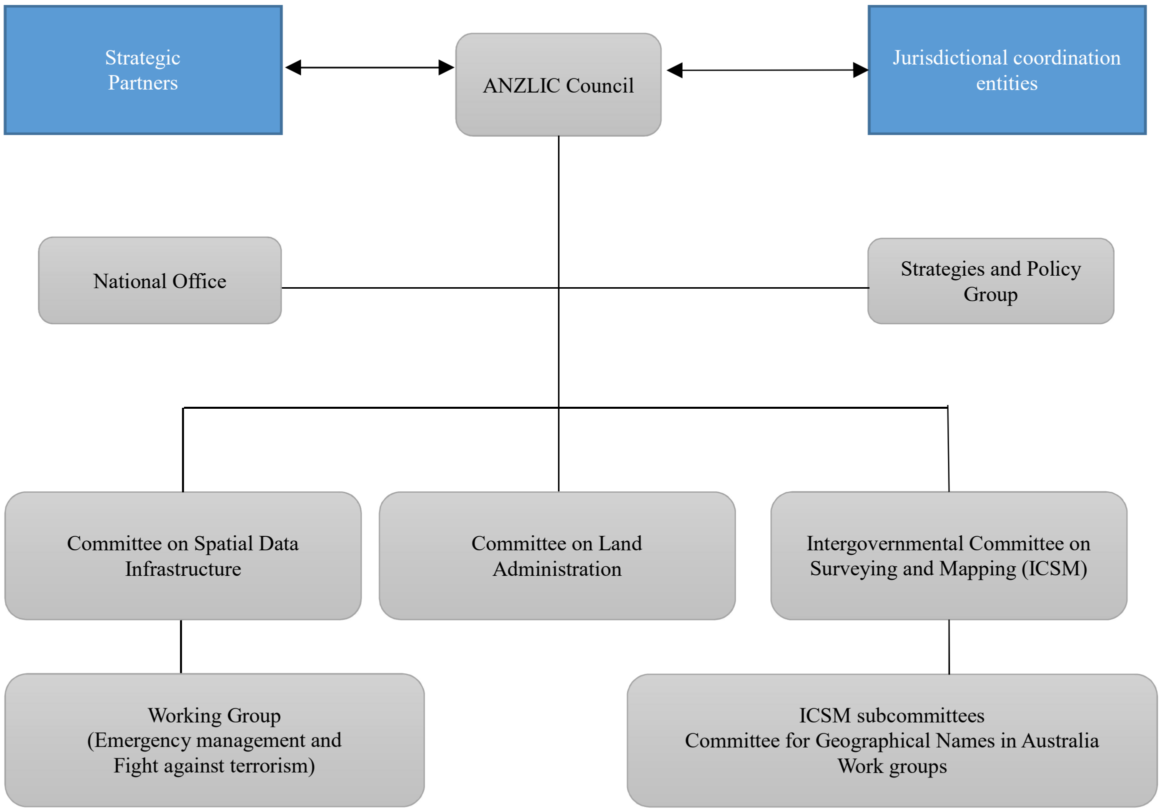

Figure 7.3: Structure of ANZLIC
Source: ANZLIC

Custodians have the right to set a fair price for acquisition of data under their responsibility. They also have the right to establish formal agreements on revenue sharing, fees, and feedback on quality of data, rights of copyright and intellectual property.

The annual budget of the Council is about AU $ 900,000 (about US $ 660,000 at November 2016 rates), of which about half is consumed by projects supporting implementation of ASDI.

ASDI comprises of a geospatial data repository (web portal), standards and metadata. The data repository is used to search for geospatial data by the use of metadata. To purchase a set of data, the user is redirected to the depositary of the website where data is stored. Currently (in the year 2016), ASDI had over 24 nodes and 30 000 entries. Access to the portal and metadata is free.

Appendix 4: Proposed KNSDI Road Map

(In millions Kenya Shillings)

		Year						
Item	**Details**	**1**	**2**	**3**	**4**	**5**	**Sub Total**	**Total**
Status Survey								**46.4**
Establish availability of data and skills	e.g. Data quality and adherence to standards	46.4					46.4	
Legal and Policy Framework								**56.7**
Finalise KNSDI policy	Two workshops & work meetings	5.2					5.2	
Develop legal framework	Workshops, outreach, meetings	10.3		5.2		5.2	20.6	
Develop operational policies	Two workshops & work meetings, 5 policies	15.5		7.7		8.7	30.9	
Establish KNSDI Secretariat								**307.9**
Establish secretariat	10 staff, full time based at the SoK	37.1	38.9	40.9	42.9	45.1	204.9	
Office space	Existing facilities shall be used							
Hardware and equipment	Motor vehicles and computers	51.5	5.2	5.2	5.2	5.2	72.1	
Telephone and internet services		2.5	2.5	2.5	2.5	2.5	12.4	
Administrative expenses	Water, electricity, telephone, printing	3.7	3.7	3.7	3.7	3.7	18.5	
Establish KNSDI Structure								**132.0**
Identify lead agency	Using a legal or policy instrument						-	
Establish committees	Using a legal or policy instrument							
Executive committee	10 meeting 8 times/year	3.3	3.5	3.6	3.8	4.0	18.2	
Steering committee	20 meeting 8 times a year	8.2	8.7	9.1	9.5	10.0	45.5	
Five working groups	10 per group meeting 12 times/year	12.4	13.0	13.6	14.3	15.3	68.3	
Office Space	Meetings at the secretariat offices							
Organisational and Governance Structure								**9.3**

		Year						
Item	**Details**	**1**	**2**	**3**	**4**	**5**	**Sub Total**	**Total**
Membership of committees	Using a legal or policy instrument	3.1					3.1	
Membership of working groups	Using a legal or policy instrument	3.1					3.1	
Functions, roles and responsibilities	Using a legal or policy instrument	3.1					3.1	
KNSDI Strategic Plan								**31.0**
Develop KNSDI strategic plan	6 months to develop plan	25.8					25.8	
Dissemination and workshops	Dissemination /workshops	5.2					5.2	
Develop Data and Metadata								**1,035.6**
Appoint 12 data custodians	Using a legal or policy instrument						-	
Training and capacity building	Once a year for 5 days	3.7	3.7	3.7	3.7	3.7	18.5	
Salaries of staff (2 per custodian)	Staff involved in SDI development	89.0	93.4	98.1	103.0	108.2	491.7	
Software licensing	DBMS, OS and GIS software	30.9	30.9	30.9	30.9	30.9	154.5	
Metadata development		12.4	12.4	12.4	12.4	12.4	61.8	
Develop and improve data quality		61.8	61.8	61.8	61.8	61.8	309.0	
Develop and Implement Standards								**213.7**
Identify suitable standards		2.1	2.1	2.1	2.1	2.1	10.3	
Data production standards	Most already developed						-	
Data presentation standards	Most already developed						-	
Data transfer and exchange standards	Most already developed						-	
Metadata standards	Most already developed						-	
Training standards	Most already developed						-	
IT standards	Most already developed						-	
Update and improve standards	Continuous activity	2.1	2.1	2.1	2.1	2.1	10.3	

		Year						
Item	**Details**	**1**	**2**	**3**	**4**	**5**	**Sub Total**	**Total**
Training and capacity building	3 times a year each 5 days	23.2	23.2	23.2	23.2	23.2	115.9	
Consultancy services	Engage consulting firm, once a year	15.5	15.5	15.5	15.5	15.5	77.3	
Technology Architecture								**141.6**
Hire consultant	Engage consulting firm, once a year	10.3	10.3	10.3	10.3	10.3	51.5	
Document architecture	Using RM-ODP	25.8				25.8	51.5	
Training and capacity building	Once a year for 5 days	7.7	7.7	7.7	7.7	7.7	38.6	
Central Geoportal								**332.7**
Build applications		20.6	20.6	20.6	20.6	20.6	103.0	
Software licensing	DBMS, OS and GIS software	2.6	2.6	2.6	2.6	2.6	12.9	
Build metadata catalogue		7.7	7.7	7.7	7.7	7.7	38.6	
Computer hardware	Cloud provider, or hardware purchase	2.8	2.8	2.8	2.8	2.8	13.9	
Consultancy	Engage a consulting firm once a year	25.8	25.8	25.8	25.8	25.8	128.8	
Training and capacity building	3 times a year for 5 days	0.9	0.9	0.9	0.9	0.9	4.6	
Establish main geoportal	Internet and network services	6.2	6.2	6.2	6.2	6.2	30.9	
County Geoportals								**2,686.8**
Build applications		48.4	48.4	48.4	48.4	48.4	242.1	
Software licensing	DBMS, OS and GIS software	121.0	121.0	121.0	121.0	121.0	605.0	
Build metadata catalogue		48.4	48.4	48.4	48.4	48.4	242.1	
Computer hardware	Cloud provider, or hardware purchase	130.7	130.7	130.7	130.7	130.7	653.5	
Consultancy	Engage a consulting firm once a year	121.0	121.0	121.0	121.0	121.0	605.0	
Training and capacity building	3 times a year for 5 days	43.6	43.6	43.6	43.6	43.6	217.8	
Establish county geoportals	Internet and network services	24.2	24.2	24.2	24.2	24.2	121.0	
Develop KNSDI Website								**36.1**
Computer hardware	Cloud provider, or hardware purchase	5.2	5.2	5.2	5.2	5.2	26.0	

		Year						
Item	**Details**	**1**	**2**	**3**	**4**	**5**	**Sub Total**	**Total**
Consultancy	Engage consulting firm, once a year	2.1	2.1	2.1	2.1	2.1	10.3	
Setup Nodal Agencies	12 nodes for the core data providers							**920.8**
Build applications		30.9	30.9	30.9	30.9	30.9	154.5	
Software Licensing	DBMS, OS and GIS software	61.8	61.8	61.8	61.8	61.8	309.0	
Computer Hardware	Cloud or hardware purchase	37.1	37.1	37.1	37.1	37.1	185.4	
Consultancy		24.7	24.7	24.7	24.7	24.7	123.6	
Nodal geoportals	Internet services	29.7	29.7	29.7	29.7	29.7	148.3	
Monitoring and Evaluation								**360.5**
Track KNSDI usage	Capture statistics						-	
Assess KNSDI state of play	Annual assessment	41.2	41.2	41.2	41.2	41.2	206.0	
Training, outreach & communication		10.3	10.3	10.3	10.3	10.3	51.5	
Develop online training aids		20.6	20.6	20.6	20.6	20.6	103.0	
M&E reports								
Geoliterate Citizens								**278.1**
Develop e-learning aids		3.1	3.1	3.1	3.1	3.1	15.5	
Production of webcasts		3.1	3.1	3.1	3.1	3.1	15.5	
Production of fliers	Online training aids and fliers	1.0	1.0	1.0	1.0	1.0	5.2	
Workshops & seminars	1 per year in 47 counties	48.4	48.4	48.4	48.4	48.4	242.1	
Research and Outreach								**418.2**
Carry out research on SDI	Studies in Kenya	51.5	51.5	51.5	51.5	51.5	257.5	
Fund studies on SDI	10 per year	15.5	15.5	15.5	15.5	15.5	77.3	
Newsletter production	Quarterly	1.2	1.2	1.2	1.2	1.2	6.2	
Partnerships and funding		5.2	5.2	5.2	5.2	5.2	25.8	
Benchmarking		10.3	10.3	10.3	10.3	10.3	51.5	
GRAND TOTAL		**1,527**	**1,345**	**1,366**	**1,361**	**1,408**	**7,007**	**7,007**

Appendix 5: Annual Benefits of the KNSDI

(In millions Kenya Shillings)

Benefit	**Description**	**Implication**	**Contribution of SDI**	**Net Benefit(s)**
Improved Taxation	20,000 landlords each with potential to pay an average tax of Ksh. 150,000 per year	3,000	30%	900
Improved revenue collection	County governments will be able to collect more revenue owing to higher availability of spatial data provided by the SDI	1,410	50%	705
Reduced Corruption and mismanagement of public funds	Corruption and mismanagement of public resources in Kenya could be as high as Ksh. 270b per annum. An SDI would provide a platform for authorities to take more decisive actions, especially in the Lands sector	270,000	0.5%	1,350
Savings by Citizens	An average number of 150,000 citizens accessing geospatial services per month, and each incurring Ksh. 1500 before the SDI	2,700	60%	1,620
Savings by Companies	100 agencies contributing to the SDI, each incurring Ksh. 200,000 per month on consumables, hardware and software, and inefficiencies in duplicate data collection	240	60%	144
Better Decisions	Better decisions as a result of the SDI, contributing to sustainable and socio-economic development, better environment management and land administration. This assumes the cost of bad decisions is Ksh 3b per annum.	3,000	25%	750

Benefit	Description	Implication	Contribution of SDI	Net Benefit(s)
Savings due to service automation	100 agencies contributing to the SDI, each able to redeploy an average of 2 staff members to other services due to service automation	240	50%	120
Savings on operations and maintenance	Projects based on geospatial interoperability standards yield a risk-adjusted ROI of 119%. Assume Kenya's investment in the geospatial sector is Ksh. 1.5b annually, and operations and maintenance costs are 15%	225	119%	268
New Information Markets	Kenya's Gross Domestic Product (GDP) was Ksh. 7 trillion in the year 2016, and ICT sector contributed 10%. Assume that, to start with, the KNSDI contributes a paltry 0.02% to the GDP through new information markets	7,000,000	0.02%	1,400
Grand Total				**7,257**