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Reviewing the Status of National Spatial Data Infrastructure: A case study in Southern Africa countries

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Statement of Authorship

Herewith I declare that I am the sole author of the submitted Master's thesis entitled:

"Reviewing the Status of National Spatial Data Infrastructure: A Case Study in Southern Africa Countries"

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

Vienna, 30. 05. 2021 John, Ogunbiyi

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ABSTRACT

For many years, spatial data infrastructure has provided a reliable platform that facilitates the exchange and integration of geospatial data among citizens, government, and private entities. Regardless of the progress in SDI, the implementation of national spatial data infrastructures has been slow in developing countries, particularly in countries in Southern Africa.

Therefore, it is important to assess the current status of SDI development by tracking implementation and measuring stakeholder accountability. The main objective of this study was to assess the status and current development of the National Spatial Data Infrastructure in selected countries (Botswana, South Africa, Malawi, Zimbabwe, and Tanzania).

The assessment of the status of the NSDI was conducted using two multi-view assessment framework approaches, the organizational assessment method and the modified state-of-play approach. The organizational assessment method includes document analysis, website research, and outreach to relevant NSDI organizations. In addition, the modified state-of-play analysis includes the use of questionnaire survey, document analysis, and website search as tools for data collection. In addition, an implementation of open source tools (Geodjango) was developed to demonstrate the scalability of the NSDI platform.

The results of the multi-view assessment show that sharing and integration of datasets among stakeholders and departments is one of the main barriers to the development of the NSDI in African countries. Some of the components of spatial data infrastructure such as technical infrastructure, legal framework, strategic policy implications, national security, and privacy issues are poorly developed in the selected countries.

The technical approach to facilitating interoperability and sharing of datasets across digital platforms is still at an early stage in Southern African countries, while human and policy issues exist. The desire of government agencies to implement their mandates hinders mechanisms for sharing and effectively distributing spatial data infrastructure in developing countries (UN-GGIM 2020).

Keywords: SDI, NSDI, multi-view assessment framework, SDI status.

ACRONYMS

AARSE	African Association of Remote Sensing within the Environment
ECA	Economic Commission for Africa
EIS-Africa	Environmental Information Systems in Africa
ESRI	Environmental Scientific Research Institute
E.U.	European Union
EUROGI	European Umbrella Organization for Geographic Information
FGDC	Federal Geographic Data Committee
FIG	International Federation of Surveyors
GSDI	Global Spatial Data Infrastructure
ISGM	International Steering Committee for Global Mapping (ISGM)
ISPRS	International Society of Photogrammetry and Remote Sensing
ITC	Information Technology Centre
ISO-TC	International Standards Organization-Technical Committee for Geoinformation
OGC	Open Geospatial Consortium
SADC	Southern African Development Community
SDI	Spatial Data Infrastructure
UN-ECA	United Nations Economic Commission for Africa
UN-GGIM	United Nations Geospatial Information Management
UNEP	United Nations Environment Programme

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Chapter 1 Introduction

1.1 Motivation and Problem statement

The term spatial data infrastructure was first introduced by the United States National Research Council in 1993 to describe policies, institutional arrangements, and technologies for the creation, sharing, and storage of spatial data (Kalantari et al., 2020). The importance of storing geospatial data as entities in different organizations has led to innovative concepts and practices of SDI concepts. Geospatial data need to be represented in a broader context among multiple users, groups, individuals, and organizations at national and regional levels.

In other words, spatial data infrastructure involves the collection, distribution, and storage of geographic information (Cetl et al., 2019). Currently, there is a high demand for geospatial data among organizations and users. This includes spatial enablement (Kerski, 2015) and the development of smart cities (Jovanović et al., 2020).

Over the years, SDI has evolved from a data-driven methodology to a user-centric approach (Alikhanov et al., 2020). The latter is closely linked to the user community vis-à-vis SDI implementation (Kruk et al., 2019). To achieve sustainable SDI development in Africa, it is important to consider collaboration among relevant stakeholders, dataset development, users, policy makers, and organizations (Bowser et al., 2020).

In Africa, especially in Southern African countries, the implementation of spatial data infrastructures faces many problems, such as insufficient funding, lack of accessibility, and slow implementation phase (Mwange et al., 2018; Guigoz et al., 2017; Makanaga and Smit 2010). It is important to assess the current status and organizational processes of spatial data infrastructure in African countries. This study focuses mainly on five selected Southern African countries (Botswana, Tanzania, South Africa, Zimbabwe, and Malawi) based on their past implementation of SDI activities, as shown in Table 1. Currently, there is no officially recognized regional organization leading SDI implementation and coordination in Southern African countries.

Table 1: Spatial Data Infrastructure activities in Southern Africa countries

Country	Some of the Spatial Data Infrastructure SDI activities in selected countries
Botswana	Adoption of a digital data policy by the government in 2015.
South Africa	Adoption of data set and price custody policies in March 2015.
Malawi	GIS and atlas database workshop held in 2015
Tanzania	Reform of the land information system in 2012 by the government of Tanzania.
Zimbabwe	Creation of a geo-framework in Zimbabwe to access spatial data from multiple sources (2015).

Source:National-levelSDIdevelopmentreports(July2015)

This study examines and better understands the current role of SDI in selected Southern African countries. It also supports ongoing development to ensure a spatially enabled society.

1.2 Background Study

The concept of SDIs was initiated in the early 1990s by John McLaughlin (GeoConnections, 2013), mainly to promote the sharing and implementation of spatial data. The implementation of SDIs creates barriers, mainly due to the collection of geospatial data, the distribution of information and knowledge, the risk of data duplication and maintenance, and weak collaboration and communication within organizations (Coetzee et al., 2018).

Many publications have contributed positively to the development of SDI in various aspects (Guigoz et al., 2017; Mwange, Siriba & Mulaku, 2018; Crompvoets et al., 2018; Davis, 2013; Okuku, Bregt and Grus, 2014). These studies provide evidence for addressing societal issues associated with SDI at both the economic and policy levels (Rajabifard and Williamson, 2019). Since the mid-1990s, SDI development has led to extensive geospatial documentation that includes an assessment of the SDI framework (Crompvoets et al., 2018) and the SDI cookbook (Nebert, 2019) Nebert notes that "SDI developments occur at multiple scales, including corporate, local, national, regional, and global."

Southern African countries have come a long way since they formed a regional Community, known as SADC, in August 1992. This institution consists of 16 countries with different national spatial data infrastructure policies. However, the reality of a functioning NSDI between countries has long existed, primarily to make data accessible.

Through SDI, spatial data resources are made available to facilitate decision making about location-based phenomena. There has been considerable effort by international organizations (Global Spatial Data Infrastructure and United Nations Economic Commission for Africa) to promote the development and implementation of NSDI at the regional level. Their efforts seem to be slow due to some SDI-related issues such as funds, insufficient standards, policies and guidelines to promote the development of spatial data infrastructures.

In the selected countries, few SDI activities have taken place at the national level in recent years, due to lack of political support, slow implementation phase, lack of funding, and lack of accessibility to datasets. However, recent NSDI activities in the selected countries include:

- **South Africa**

- Data custody implementation (Feb 2019).

- Spatial Data Infrastructure Act Review Workshop (Sept 2019).

- Review of the Spatial Data Infrastructure Act, 54 of 2003 (Dec 2019).

- Draft map and layout of national land cover classes (July 2020)

- **Botswana**

- Cabinet approval of Digital Information Policy (Mar 2015).

- Implementation of GIS cluster and land information initiatives (Nov 2014).

- Collaboration with ESRI South Africa to improve data integration and sharing (Nov 2014).

- Develop key components of the NSDI (Nov 2014).

- **Malawi**

- A three-day workshop to introduce the GIS and Atlas database (2015).

- Establishment of a national geospatial data center (2008).

- **Tanzania**

- Integration of a land information system (Mar 2012).

- Creation of a geospatial data network (Nov 2015).

- Implementation of mapping software and equipment (Nov 2015).

- **Zimbabwe**

- Production of topographic base maps and thematic maps (Mar 2014).

- Maintenance of the national geodetic control network (Mar 2014).

- Implementation of the Zimbabwe Geospatial Tool (July 2015).

Recent studies such as Maphale (2019), Mwange et al., (2018), and Makanga and Smit (2010) provide further insights into the nature of the spatial data infrastructure within the selected countries. These include;

- **Botswana:** currently there is one SDI coordinating body that faces challenges such as inadequate financial support, insufficiently developed legal framework, policy support, clearinghouse, and stakeholder participation.

- **South Africa:** In 2003, the legal framework was introduced through the Spatial Data Infrastructure Act, 54. Although there has been political support, the NSDI still lacks sufficient funding, infrastructure, and stakeholders.

- **Malawi:** existence of a coordinating body without a legal framework, political support, stakeholder participation, financial support, and clearinghouse.

- **Zimbabwe** reported having no formal coordinating body, with low SDI Readiness Index factor (information, organization, human resources, finance, and technology).

- **Tanzania** does not have an accurate result on the parameters.

Based on the results, these countries are still struggling to implement National Spatial Data Infrastructures (NSDI). Siebritz and Fourie (2015) argued that many African countries are struggling to develop spatial data infrastructure.

In general, Southern African countries are relatively slow in implementing SDI, so this study seeks to identify and understand their development based on their analytical framework (institutional environment, technical infrastructure, and SDI impact). The underdeveloped pace of SDIs is a critical issue that requires further research (Davis, 2013; Crompvoets et al., 2018; Rajabifard et al., 2010; Nebert, 2019).

1.3 Statement of the Problem

Assessment plays an important role in enabling local communities, governments, stakeholders, NGOs, and researchers to make progress in identifying the challenges of NSDI practices (van Loenen, B. 2018). Therefore, SDI assessment is important to monitor and improve the quality of NSDI and provide clear evidence of stakeholder accountability.

Many studies have been conducted on SDI assessment in African countries. However, Maphale (2019) notes that most SDI activities in Africa are informal and therefore it would be challenging to present them in a large context. Moreover, in some selected countries (Malawi, Tanzania, and Zimbabwe), no detailed assessment of SDI activities has been conducted in recent years. In general, the current status of SDI in Southern African countries has not been properly assessed. This problem motivates the research to assess the status and development of NSDI in the selected countries.

1.4 Research Identification

1.4.1 Research Objectives

RO1: To investigate the status of SDI development in the selected countries.

RO2: Identify the key players responsible for the progress and development of SDIs in each country.

RO3: Review barriers/challenges associated with SDI implementation and identify IT trends to promote SDI development in Africa.

1.4.2 Research Questions

The following research questions would be answered in detailed;

RQ1: What are the challenges affecting SDI implementation in the selected countries?

RQ2: Who are the key stakeholders/departments responsible for coordinating SDI activities and how can they work together to achieve a similar goal?

RQ3: How can SDI implementation be effectively managed in the selected countries?

1.5 Structure of the Thesis

This thesis consists of seven different chapters with detailed information about each topic.

Chapter 1: includes the introduction, study background, problem statement, research objectives, research questions, and organization of the thesis.

Chapter 2: includes the literature review. Some of the relevant topics covered are: Status of SDI development in selected countries, the role of SDI in sustainable development, the nature of SDI, the components of SDI, and the stages of SDI development.

Chapter 3: covers evaluation approaches and SDI partnerships; SDI evaluation approaches, taxonomy for SDI evaluation, SDI partnerships, and conclusion.

Chapter 4: covers introduction, OGC web services, new developments of OGC API, software consideration and overview of SDI platform architecture.

Chapter 5: covers the research methodology; introduction, approach adopted, problems encountered and conclusion.

Chapter 6: results and discussion on the status of NSDI.

Chapter 7: Conclusions and recommendations.

Chapter 2 Literature Review on Spatial Data Infrastructures

2.1 Introduction

Spatial data infrastructures (SDIs) are indispensable multi-data systems used to promote good governance, technical infrastructure, and decision-making within local, national, regional, and global communities (Crompvoets et al., 2018). However, the goal of SDI is to facilitate the exchange, distribution, and sharing of geospatial data between micro and macro institutions (Rajabifard and Williamson, 2019). Ajmar (2011) describes spatial data infrastructure (SDI) as a framework that includes geospatial data, metadata, tools, and networked users to ensure effective use of SDI. According to Idrizi (2018), SDI components include the institutional framework, standards, organizational guides, delivery mechanisms, and human and financial resources. These components are used to acquire, process, distribute, store, and share georeferenced spatial data to promote spatial data services.

In Africa, the implementation of NSDIs has been adopted by many institutions such as AARSE, ECA, ESRI, EIS-Africa, ITC, ECA, and UNEP. More awareness has been created through seminars, presentations and workshops at regional and national levels in recent years. Currently, the spatial data infrastructure in Africa is underutilized. Several factors affect a country's or region's ability to use geospatial data. These include uncertainties in data discovery, lack of awareness among decision makers, poor interoperability between datasets, access and sharing mechanisms, and insufficient technical and human resources (Guigoz et al., 2017). Therefore, countries in the Southern African region need to revise their data management strategies and adopt a new strategy to promote geographic information and interaction between users and producers.

In summary, SDI is concerned with the coordination and sharing of geospatial data among stakeholders/users within the geospatial data community. It also provides a suitable environment for relevant stakeholders, users, and spatial data producers. This ensures effective collaboration within organizations to achieve common goals at different policy/administrative levels.

2.2 The Concept of Spatial Data Infrastructure

In general, the development of SDIs has focused primarily on stakeholder concepts and needs by enabling organizations to achieve similar goals. The primary purpose of SDIs is to promote the sharing and exchange of geospatial data among stakeholders within the geospatial community (Crompvoets et al., 2018). Organizations responsible for SDIs integrate standards, policies, data access, and technologies to facilitate the sharing of geospatial data (Grus et al., 2011). Proponents of SDIs cite goals and benefits such as technical frameworks (improved application development), institutional frameworks (promotes legal frameworks and governance within the spatial data infrastructure), economic benefits (prevents data redundancy), and social benefits (promotes management and decision making).

In addition, SDI has the potential to spatially enable governments to achieve three core values (Crompvoets et al., 2008):

- **Effective and transparent coordination:** users can access spatial information to facilitate decision making.
- **Promoting environmental sustainability:** this enables consistent monitoring of spatial indicators across the country or region.
- **Ensure financial stability** by developing products and services based on a wealth of spatial data.

The most important goal of SDI includes (Leon, 2018) maintaining interoperability of spatial data within and outside the organization.

2.3 Status of SDI Development in Selected Southern Africa Countries

A review of literature such as Mwange et al. (2018), Mwungu (2017), Guigoz et al. (2017), Okuku et al. (2014), Maphale and Smit (2021) shows that many African countries have been slow in adopting SDI concepts. Over the years, there have been changes in the adoption and implementation of SDI within the selected countries. These include:

-South Africa: in recent years, South Africa has consistently improved SDI activities (SASDI). In 1997, the National Spatial Information Framework (NSIF) was created, representing the SDI initiative (Siebritz and Fourie, 2015). The legal framework of the Spatial Data Infrastructure.

Act No. 54 (2003) was implemented through the SASDI, which includes the pricing of spatial data products. The Base Dataset Custodianship Act was passed in 2015. Notwithstanding the progressive trends in SDI development, many challenges have been reported. These include low capacity at municipal and provincial levels, funding, and lack of private sector representation (Mdubeki, 2015). This underscores the fact that SDIs require a long-term and large-scale initiative with further improvements over time.

-Botswana: In 1990, Botswana recognized the importance of creating a sustainable spatial data management system. It was one of the first countries in southern Africa to establish a national coordinating committee (Mwungu, 2017). It also recognized the need for proper coordination. Many organizations, such as the Tribal Land Management Information System and the Integrated Geographic Information System, were initiated to achieve this goal (Maphale and Phalaagae, 2014). The need to access and share spatial information led to the creation of the Botswana National Spatial Data Infrastructure. Maphale and Phalaagae (2014) recognized the starting point in a broader context, similar to the Nairobi Statement on Spatial Information for Sustainable Development (Fraisl, 2020). In addition, digital data policy and e-government standards were introduced by Botswana's SDI committee in March 2015.

-Tanzania: The concept of NSDI was first introduced in 2003 by the regional spatial data infrastructure development committee. In 2015, the SDI policy was introduced, with little progress in implementation (Mwaikambo and Hagai 2015). Some of the factors responsible for slow SDI development include lack of funding, inadequate awareness, lack of institutional framework, underdeveloped SDI policy, and political commitment.

-Malawi: The need to coordinate geospatial data production and management began in the early 1990s. There are ongoing efforts to promote organizational approaches through the engagement of the National Spatial Data Centre and the Malawi Geographic Information Council. These national organizations manage geospatial data collection, integration/sharing, and support the development of the NSDI. Malawi's challenges in implementing SDI include legal constraints, lack of funding, and human resources.

-Zimbabwe: The country's spatial data infrastructure was established during the SADC Regional Remote Sensing Unit (RRSU) General Assembly in April 2003. In June 2004, the Global Spatial Data Infrastructure (GSDI) organization unveiled the Zimbabwe Spatial Data Infrastructure (ZSDI). At the national level, the Survey Institute of Zimbabwe (SIZ) promotes geomatics and surveying. In addition, Zimbabwe is mainly an agro-based economy, and SDI would be a critical infrastructure to improve the country's economy (Shoko and Njike, 2011). Therefore, it is important to pursue innovative approaches to SDI implementation and coordination in Zimbabwe.

Makanga and Smit (2010) conducted a research to assess the development of spatial data infrastructure in African countries by using SDI assessment methodology with multiple views. In 2010, a study was conducted by Makanga and Smit to examine the status of SDI in Africa using a multi-view SDI assessment framework similar to the status of INSPIRE. The study focuses on four components: Technology, Organization, Financing, and Legal Framework (Grus et al., 2011). Within Southern African countries, the results show that only South Africa has a geoportal. The study also found many informal SDI activities in the region, mainly driven by the United Nations and private organizations.

A more recent study on SDI in Southern African countries was conducted by Maphale (2019). The results show some limitations related to the implementation and development of spatial data infrastructures within the countries of Africa. Other research findings include;

- At the regional level, SDI monitoring is not sustainable (Mdubeki, S., 2015).
- Apart from South Africa, most countries in the region rank low based on SDI key variables (Mwungu, 2017).
- There is a lack of political interest in SDI implementation (Maphale, 2019).

2.3.1 Factors influencing SDI development in Africa

(a) Political level

Political components include geographic, social, and historical aspects of the country in question. This aspect includes government control over policies related to geospatial data collection, dissemination, and legal protection, such as restrictions related to intellectual property rights, pricing, and privacy issues. Good SDI practices include government taking actions that take into account the geographic, historical, and social context of the country.

(b) Management Level

Access Networks: Assessment of the access networks component includes challenges related to data formats, accessibility of data, delivery mechanisms for data, and the cost of data available to users. Indicators may also include data delivery mechanisms, procedures, access pricing, and access to inter-institutional links or value-added arrangements within the private sector.

Standards: The Standards component assessment process covers how the government administration manages organizational arrangements for geospatial data coordination. The component consists of an assessment of government agencies involved in providing geospatial data for large- and small-scale mapping, land titling, and socioeconomic statistics. In addition, the assessment considers standardization constraints such as core datasets, interoperability, and data modeling practices at the national level. Management level indicators could include the size of government agencies involved with geospatial data, their activities, and how they communicate with each other. For comparisons with other developing and developed countries, indicators could include core data sets, standardization decisions for access networks, and data modeling techniques used to define spatial data sets.

(c) Operational Level

Data: The data component can be assessed by evaluating data models and spatial data sets within different organizations, data collection methods, data maintenance, creation of a national core data set, data accuracy, and quality. Best practices could include clear and transparent data definition (accuracy, content, and quality) to promote easy accessibility for different organizations and users.

Access network: in most cases, responsibility at the operational level depends significantly on government operating units, which includes data provisioning and the access network. However, the access network component can be assessed by measuring the availability, reliability, and capacity of the data network. Indicators may include data volume and response time, with good practices depending on the network and managing large volumes of data within a short response time.

(d) Influencing factors

People: The People component is evaluated in three SDI contexts: Data Providers, Data Integrators, and Value Creators. Therefore, the evaluation needs to assess the situation within these three components in terms of training opportunities, human resources, market conditions, and capacity building for geospatial data. Good SDI practices allow end users easy access to data products; integrators can also operate under favorable market conditions if data providers can deliver data effectively and efficiently.

(e) Performance evaluation

This link has not been addressed in much SDI research, but it is also relevant to the overall assessment of national infrastructures. In most cases, evaluation could include review of strategies, goals, system performance and reliability, and user satisfaction. In addition, indicators could consist of adoption of SDI principles, geospatial data use and dissemination, and user satisfaction surveys. Good SDI practice can be assumed when all SDI concepts are adopted, there is extensive use and dissemination of spatial data sets, and users demonstrate satisfaction with SDI services.

The possible indicators proposed in Table 2 are only a general framework for evaluating SDI; nevertheless, they help in evaluating SDI and valuable indicators in developing countries.

Table 2: Potential Indicators for Evaluating SDIs

Components	Potential Indicators
Policy level (Policy)	- data collection process and use of geospatial data - existence of a government policy for SDIs - management of intellectual property rights, privacy issues and pricing
Management level (Access Network)	- procedure and delivery mechanism - value-adding agreements

	- accessibility - access pricing
Management level (Standards)	- interoperability - definition of core datasets - data modelling - Organizational arrangements for geospatial data coordination - institutional arrangements of entities providing spatial data services - standardization agreements for data dissemination and access network
Operational level (Data)	- data maintenance - data format - definition of core datasets - data collection method - data accuracy and quality
Operational level (Access Network)	- data quantity - type of network - response time
Influencing factors (people)	- training opportunities - organizations size and people involved - market situation for data integrators, data providers and end-users
Performance Evaluation	- user satisfaction - revenue and reliability - degree to which goals and strategies are met - dissemination and use of space and information

2.4 The Role of SDI for Sustainable Development

Good governance and data sets are two key components needed to promote decision-making and sustainable development (DESA, 2020). However, good governance promotes effective institutional, legal, socioeconomic, and policy frameworks. In addition, constraints related to geospatial data sharing and coordination among decision makers, national governments, and agencies have proven elusive (Scott, G., and Rajabifard, A., 2017). Many developing countries face a lack of interoperability within data sources and low data quality. In most cases, this results in governments providing duplicate or inconsistent data quality to facilitate decision-making (UN-GGIM 2015a).

While the concept of spatial data is increasingly embraced in developing countries, many countries face limited data accessibility and inadequate data visualization tools. To promote sustainable SDI development, it is important to adopt innovative geospatial data approaches. This requires scaling up existing initiatives and innovative applications. The lack of up-to-date basemaps and essential geographic datasets (land cover, elevation, transport, land ownership, geographic names, drainage, and geodetic control) remains a challenge for African countries (GSDR, 2015).

SDI is an essential component that provides the best information for good governance in the community. Therefore, it is the government's responsibility to ensure effective SDI development (Sjoukema et al., 2017). In terms of sustainability, developing countries face issues such as the legal and institutional framework to promote SDI developments.

2.5 Nature of SDI

Many authors and government institutions give different definitions about the nature of spatial data infrastructure. However, the word "spatial" means the interactions of phenomena in space, such as shape, distance, area, size, shape, angle, and dimensional representation (one-, two-, three-, and four-dimensional). In other words, it refers to the representation of data (spatial data). According to Chen et al. (2009, p.13), data is defined "as an automated representation of attributes that represent the real and simulated world." This includes the collection, processing, and presentation of data in a graphical, statistical, and textual format. At an advanced level, data provide insights into knowledge and information. Bowker et al. (2010, p.98) define data "as a broad domain of pervasive, enabling resources through networking."

Based on the above definitions, it is clear that the term "spatial" is associated with space,

e.g., region, country, city, etc. Within the geospatial domain, it can be used interchangeably (Davies,
2013). The data definition indicates that factual information refers to a specific phenomenon in space, e.g., a regional extent or a national boundary, etc. Many authors defined SDI at different levels such as local, national, regional, and global forms, depending on the objective and information needs, as shown in Table 2 by Rajabifard (2008).

Table 3: Selected Definitions for Spatial Data Infrastructure (Warnest, M. (2005)

Reference (Source)	Definition of Spatial Data Infrastructure
McLaughlin and Nichols (1992)	The components of SDI include information sources such as metadata, databases, data networks, geospatial data, institutional frameworks, technology (which consists of the collection, representation, and management of datasets), policies, institutional arrangements, and standards.
Former President's United States Executive Order (Clinton, 1994)	The components of the NSDI include standards, policies, technology, and human resources needed to facilitate the storage, distribution, management, and promotion of the use of geospatial data.
European Union (European Commission, 1995)	The EU Geographic Information Infrastructure (EGII) provides for the effective development of European regulatory frameworks to achieve its goals. In addition, EU member states promote spatial data infrastructure regulation, policy, incentives, and structures.
Thompson (1995)	NSDI use information technology to manage, collect, and disseminate geospatial data at the national level.
Australia New Zealand Land Information Council (ANZLIC,	According to ANZLIC, the national spatial data infrastructure consists of four main components: datasets, institutional framework, clearinghouse networks, and technical standards.

1996)	
Federal Geographic Data Committee (FGDC, 1997)	The national SDI includes standards, guidelines, and methods for maintaining technological and organizational interaction to manage and execute geospatial data.
Global Spatial Data Infrastructure (GSDI) Conference (1997)	The GSDI encompasses data, guidelines, standards, technologies, human and financial resources needed at the regional and international levels to achieve the necessary goals.
Dutch Council for Real Estate Information (RAVI) (Masser, 1998b)	The national spatial data infrastructure includes the collection of spatial data sets, technological components (hardware, software, and electronic information), standards, policies, and knowledge that provide geographic information needed to accomplish a task.
Hoffman (1999)	A spatial infrastructure (data, knowledge discovery, and information) involves the integration of spatial components within society.

The definitions in Table 2.1 span more than two decades. They were shaped by different regions and countries based on their contexts and general perceptions of time and place. However, the above definitions do not ignore emerging meanings among scholars and practitioners. These include;

-Crompvoets et al., (2018) define "spatial data infrastructure as a component that facilitates the coordination of data sharing and exchange among stakeholders within the spatial data community."

-Béjar et al, (2012) define SDI as a composition of spatial nodes connected to the spatial data infrastructure.

-Rajabifard and Williamson (2019) define SDI as "a multi-tiered arrangement of interconnected SDI components based on partnerships at the local, state, national, regional, and global levels."

-Grus et al., (2011) define NSDI as a systematic framework that provides access to the exchange and use of geospatial data at the state level.

-Cooper et al., (2014) define SDI as "an advancing concept to promote, coordinate, and monitor the exchange of geospatial data, services, and metadata."

From the definitions, it is clear that SDI has different meanings among practitioners and researchers. The goals and components associated with SDI definitions are legitimately identified in this research study. However, the influence of political activities ranges from local, national, regional, and global SDI levels. A political influence associated with these definitions is summarized by Craglia et al. (2012) as follows:

> "Regardless of the different approaches, definitions, and interpretations of SDI development, geospatial data has a major impact on the manifestation of government policies and initiatives (e-government)."

SDI indicates an emerging phenomenon and offers opportunities for empowering diverse communities (Rajabifard, 2008; Scott and Rajabifard, 2017; Crompvoets et al., 2018).

2.5.1 Hierarchical Nature of NSDIs

The hierarchical nature of NSDIs defines relationships between political and administrative levels (Rajabifard and Williamson, 2019). Following the release of the Executive Order on the Coordination of Spatial Data Acquisition and Access, many countries around the world have implemented NSDIs. However, the goal of SDI is to maintain data consistency and reduce duplication of information between agencies (FGDC, 2020). The concept of SDI hierarchy was developed by (Rajabifard et al., 2010) to address the complex vertical and horizontal relationships between the administrative and policy levels of SDI, as shown in Figure 2.1.

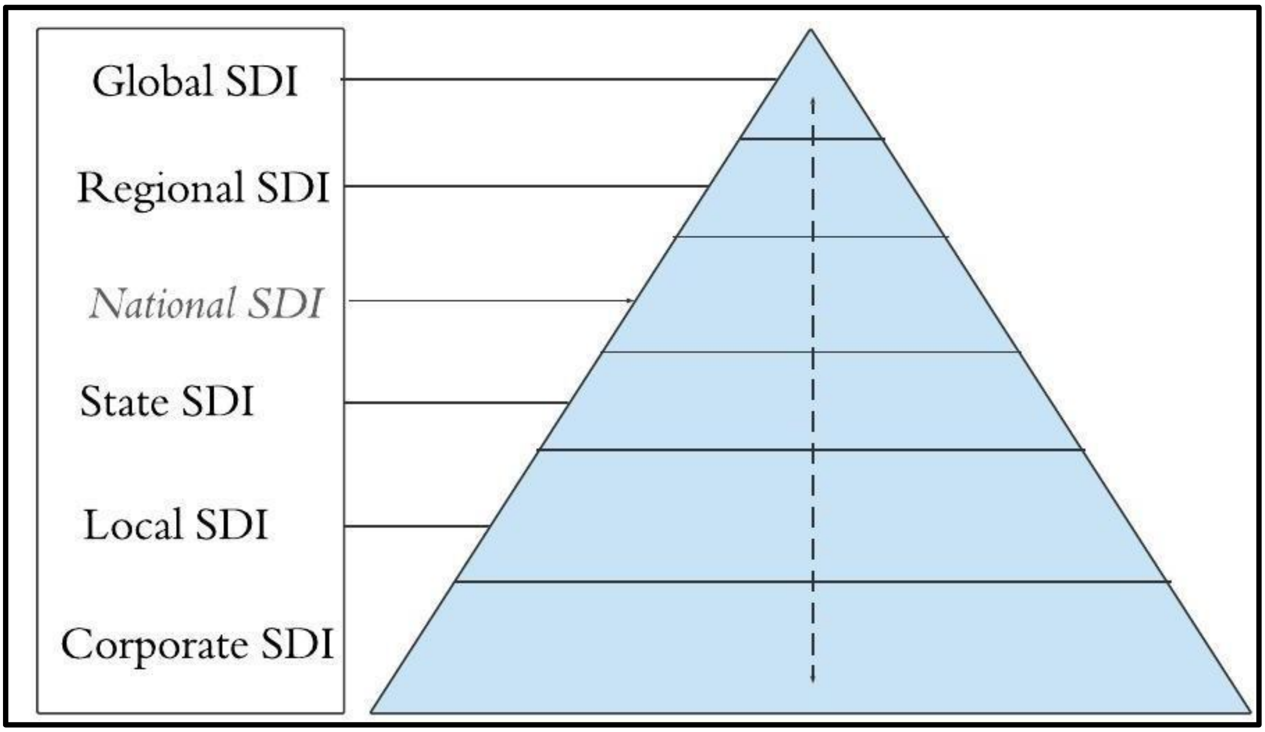

Figure 1: SDI hierarchy (Adapted from Rajabifard et al., 2010)

The vertical and horizontal relationships of the hierarchy are essential for partnerships between administrative and policy levels to promote data sharing across the SDI system. The hierarchical structure depicted in Figure 2.1 shows that the national level provides a link between lower and higher levels of SDI (Rajabifard et al., 2010). In addition, the national SDI provides a central link between the lower and higher levels to ensure appropriate standards, data exchange, and guidelines.

Masser (2019) describes NSDI initiatives:

> "At the national level, SDI concepts are implemented and formulated by the governments of different countries to manage their national geographic information resources".

In addition, there are methods in the hierarchy such as collaboration between partitioners, partnerships, and SDI contributions from individual organizations.

2.5.2 Top-down and bottom-up model

The top-down model relies on regulations and laws or another directive (executive visionary). The model requires spatial information producers to make their datasets discoverable and accessible as part of SDI (Cooper et al., 2013). Some notable examples include SASDI (South Africa Spatial Data Infrastructure) and the United States National Spatial Data Infrastructure.

Tumba and Ahmad argued that the top-down approach has become uncommon in Africa due to the high error rate against contemporary SDIs (Tumba and Ahmad, 2014). In most cases, an SDI should empower users at the lowest levels in its jurisdiction; and the top-down approach does not effectively promote lower-level participation. The alternative to the top-down model is a bottom-up or voluntary model that involves SDIs that have voluntarily emerged from existing initiatives at lower levels in the jurisdiction (early adopters). This model has been successfully used to develop the Canadian Geospatial Data Infrastructure (CGDI) (GeoConnections, 2013). Collaborative efforts are essential in this model, as no single organization can develop an SDI.

In developing countries, despite years of SDI implementation, there are few NSDI activities. This implies that the general top-down approach has its limitations in the African context. Makanga and Smit identified many informal SDI activities in Africa and proposed a bottom-up approach to SDI development (Maphale and Smit, 2021).

2.5.3 Product- and process-based approaches to SDI

Product-based and process-based SDI development methodologies are two predominant views documented by Rajabifard & Williamson (2019). The product-based approach focuses on the technical solutions within SDI initiatives. While the process-based practice is concerned with the development of systems, procedures, and processes in the management of spatial information.

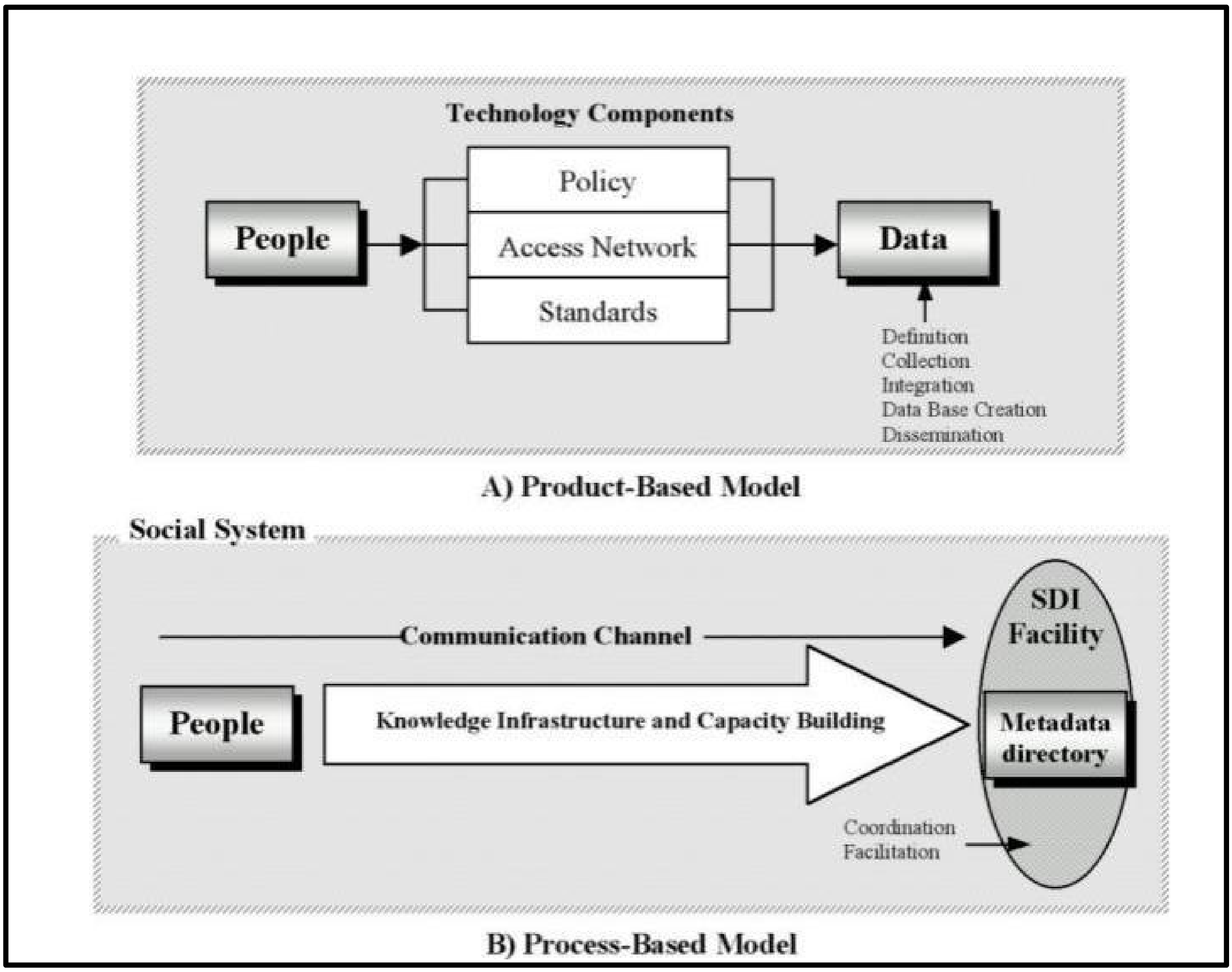

Figure 2: Product and Process-Based Models for SDI development (Rajabifard & Williamson, 2019)

Rajabifard & Williamson (2019) identified two theories in contemporary SDI development based on the goals, strategies, and status of the SDI initiative at different levels. The product-based model, depicted in Figure 2a, denotes a centralized system in terms of spatial databases at each administrative/policy level in a community. The process-based model, shown in Fig. 2b, represents the second approach in the development of SDI. Rajabifard's second model defines the SDI framework in promoting asset management. Thus, it provides communication channels for communities to share and use datasets rather than linking available datasets. This is a positive contribution that shows the holistic concept of spatial data infrastructure by incorporating both technological and social strategy.

2.6 SDI Components

SDI components include technical standards, institutional frameworks, clearinghouse networks, and basic frameworks that provide access to documentation of existing spatial data (metadata) and spatial data sets (measures) (ANZLIC, 2019). On the other hand, the institutional framework defines the administrative and policy arrangements for data creation, maintenance, and access through relevant datasets and standards. The clearinghouse network provides access to technical standards and the policies of the institutional framework. At the same time, the basic data sets are developed through organizational frameworks and technical guidelines.

In addition to the required components, human components such as data providers, geospatial data users, and value-added parts interact to support SDI development (Williamson et al., 2014).

Table 4: An Overview of the Spatial Data Infrastructure

DATA	Spatial data sets provide information related to spatial location and suppor essential functions within a country. They provide a consistent spatial referenc and context across multiple information technology domains. Thus, ar organization can consider the need for geospatial data in terms of the strategi approach to support its goals. In this context, geospatial data support the activities of many users, private and public institutions. Spatial data elements include administrative boundaries, geodetic control, geographic names and places, cadastre, elevation, transportation, hydrology, street addresses, and orthoimagery. The information is highly dependent on short- and long-term organizational needs.
INSTITUTIONAL FRAMEWORK	This includes the coordination, management, legislative, and policy components of an SDI. The institutional framework depends on successful partnerships and communication among relevant organizations and jurisdictions.

PEOPLE	This includes data stewards, users, providers, and administrators. In most cases, users are small, medium, or large business owners/individuals and public/private organizations. There are many users of the spatial data infrastructure, these include; -Census -Census projects and natural resource management. - Socio-economic issues and health monitoring programs. -Cadastral project and land management -Transportation infrastructure The different SDI applications, apart from the traditional mapping and land management structure, imply that both administrators and users of geospatial data have different professional and educational backgrounds.
STANDARDS	Precise standards and guidelines are needed to promote the sharing, integration, and distribution of geospatial data. However, standard components such as metadata, data models, and interoperability should be precise for access and pricing of geospatial data among relevant stakeholders.
TECHNOLOGY	It is about distribution and access to spatial networks and other geographic datasets among users. This concept also includes data acquisition, storage, integration, enrichment, and maintenance of geospatial data.

The attributes and components of SDI are closely interrelated and often overlap. These are not the only factors that influence SDI, but they are integrated components that have been identified and segmented to facilitate further discussion and provide means to isolate institutionally driven issues that impact spatial data infrastructure partnerships. The summary of SDI components is presented in Table 4.

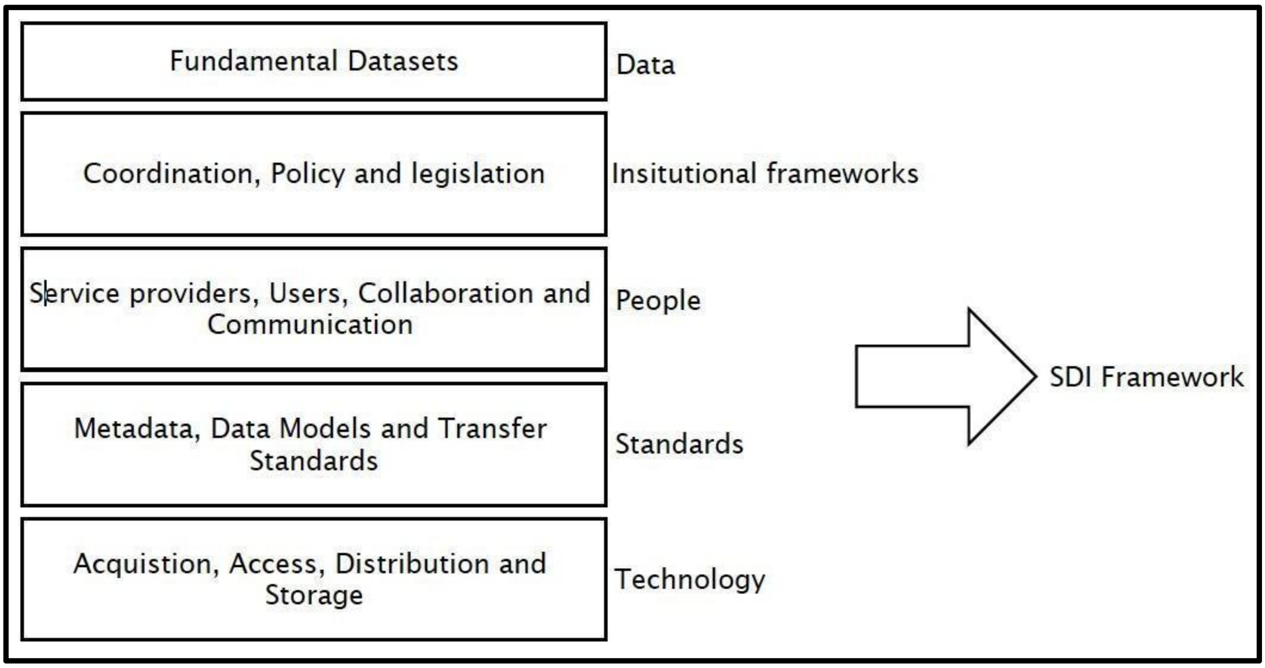

Figure 3: Components of an SDI Framework

The technological aspects of the spatial data infrastructure are governed by the mutual interaction between people and data using the access network, standards, and policies. Rajabifard's diagram (see Fig. 4) describes the dynamic interactions between geospatial data and people within an SDI.

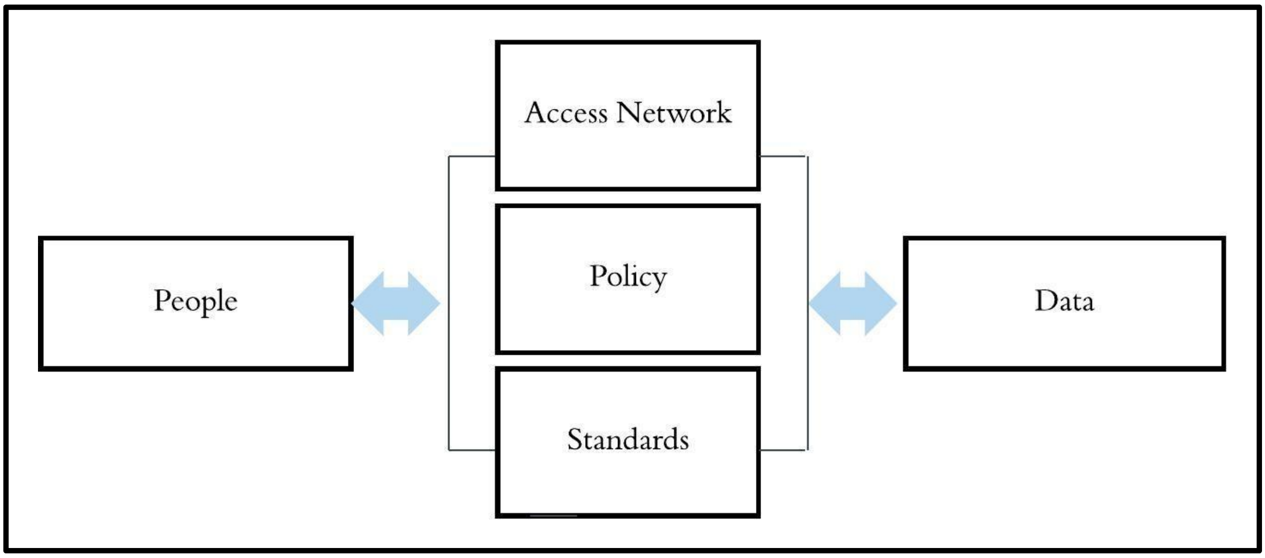

Figure 4: The relationships between components of SDI (Rajabifard & Williamson, 2019)

The dynamic nature of the SDI component is attributed to technological advancements and changing user needs. Other important factors related to policies, interoperability, and networks also influence the system (Rajabifard & Williamson, 2019).

2.6.1 Data

Geospatial data is a key component in decision making and identifying trends for various purposes or applications such as core data, baseline data, reference data, or fundamental data (Bone et al., 2016). Since the early 1990s, geospatial data has been considered ubiquitous (Coleman et. al., 2016). However, the ubiquity of geospatial data played an important role in the development of the spatial data infrastructure. Geospatial data are collected through GPS surveys, land surveys, photogrammetry, and remote sensing data. They are then processed to create cartographic map representations such as topographic maps, conservation maps, cadastral maps, weather maps, tourist maps, geological maps, and engineering maps, etc.

Organizations often use these map representations to achieve various goals and gain insight into the physical world. Thematic maps are another form of map representation available through base datasets (Abramic, 2017). At the regional level, spatial information is produced in many organizations, including federal, state, provincial, and in most cases, municipal. These datasets are maintained with varying accuracies, ranging from 250 m down to about 1 m. The datasets are created in collaboration with data providers and producers to ensure national coverage and a wide range of end-user applications (GeoConnections, 2013).

There are many different forms of geospatial data, classified by (Laura et al., 2017) as follows:

- **Raster data:** Geographic space grouped in regular patterns, such as rectangular and average geographic values recorded at each node of the pattern.
- **Vector data:** Generally, geographic features are represented in a geometric format such as points, lines, and polygons.
- **Raster:** It represents elevation data captured by rectangular or square patterns.

- **Triangulated Irregular Networks (TINs):** this represents elevation data captured using an irregular pattern at different heights.
- **Imagery:** geographic data acquired with various multi-band sensors and stored in pixel format.

Examples of imagery data include SPOT, Landsat, and AHRR imagery.

- **Digital photography:** includes geographic data captured with photographic images and stored in pixel formats. Examples of digital photography include digital orthophotos.

2.6.2 Institutional Framework

Early proponents of SDI emphasized the need for SDI development (Williamson et al., 2014). The increasing use of datasets has increased the collection, provision, and storage of spatial information. However, the role of the private and public sectors has changed government practices from service providers to coordinate, facilitate, shape policy, and frame SDI activities. For example, governments are increasingly outsourcing non-core activities to the private sector and community (ANZLIC, 2019).

The term "mapping" refers to the collection and distribution of spatial data that allows land departments and mapping companies to be managed by the government. This allowed mapping companies and land departments to be centralized or managed by government monopolies. This existing pattern persisted for centuries and affected the management of geospatial data (GSDI, 2013). In line with e-government mandates around the world, cross-organizational coordinating bodies have emerged in the public sector. These bodies manage the business and reusable services of exchanging digital data for citizens, commercial customers, and other government users (Nerbert, 2019).

The primary role of the trusts within the SDI institutional framework is to establish policies for the authorization and pricing of geospatial data. Licensing (pricing) provides legal and commercial means to protect the interests of users and providers. Another consideration is the need for community services, promotion of industrial development, and pricing. Geospatial licensing manages the risk associated with the use of geospatial data (ANZLIC, 2019).

Technological advances provide opportunities and limitations in the collection, management, use, and distribution of geospatial data. In the context of SDI, technical infrastructure addresses the physical attributes and nature of spatial data infrastructure such as distribution networks, access, clearinghouses, and other methods by which users can access datasets. Advances in information technology have led to effective updates to the geospatial data infrastructure through remote connection servers. However, geospatial data infrastructure is not limited to geographic information, but also to Internet bandwidth accessibility.

2.6.3 People

At the national, regional, and global levels, SDI involves various stakeholders from government districts and the private sector. To build an SDI, stakeholders need to identify the competency model of stakeholders and SDI activities (Nebert, 2019). This approach involves implementing a "community-based" spatial data infrastructure through collaboration and identification of opportunities in the community.

Data custody is an important part of data management because it provides clear information about the authoritative sources, products, and data security measures associated with users. However, data custody refers to the elimination of data duplication, management information attributed to the spatial data infrastructure. The creation and management of spatial data products enables users to access the spatial data infrastructure (Indrajit, 2020).

In addition, data managers manage datasets in the form of collaboration between regional, national, and local providers or users within the community. Technological advances have led to a paradigm shift: SDI is no longer developed by providers, but users are the active drivers in building SDI (Williamson et al., 2014).

2.6.4 Technology

Technology creates a strong link between metadata, clearinghouses, and standards. A geospatial data clearinghouse can be viewed as an electronic utility for viewing, searching, ordering, promoting, and disseminating geospatial data from various sources on the Internet (Crompvoets & Bregt, 2018). The FGDC defines clearinghouse as a "decentralized system of servers accessible via the Internet and consisting of field-level information such as digital geospatial data" (FGDC, 2020). Thus, a clearinghouse consists of servers that provide search, discovery, and access to geospatial data through a descriptive data structure called metadata. Most often, the metadata is collected in a standard format to make it easier for users to find geospatial data within multiple organizations (Crompvoets & Bregt 2018).

The FGDC clearinghouse is an example of a national catalog service. However, clearinghouse services such as the FGDC are a good example of technological advancement while using the retrieval and search protocol (ANSI Z39.50-1995 (ISO 10163-1995)) to query and display information on web clients. The connected network approach goes beyond the original metadata registration tasks. However, it allows users to view and query geographic information, such as naming, downloading, and printing geospatial data in both vector and raster formats.

The draft allows access to geographic information using existing international software and interchange protocols developed by the Open GIS Consortium (OGC) (as shown in Fig. 5), the ISO TC 211 working group, and the World Wide Web Consortium (W3C).

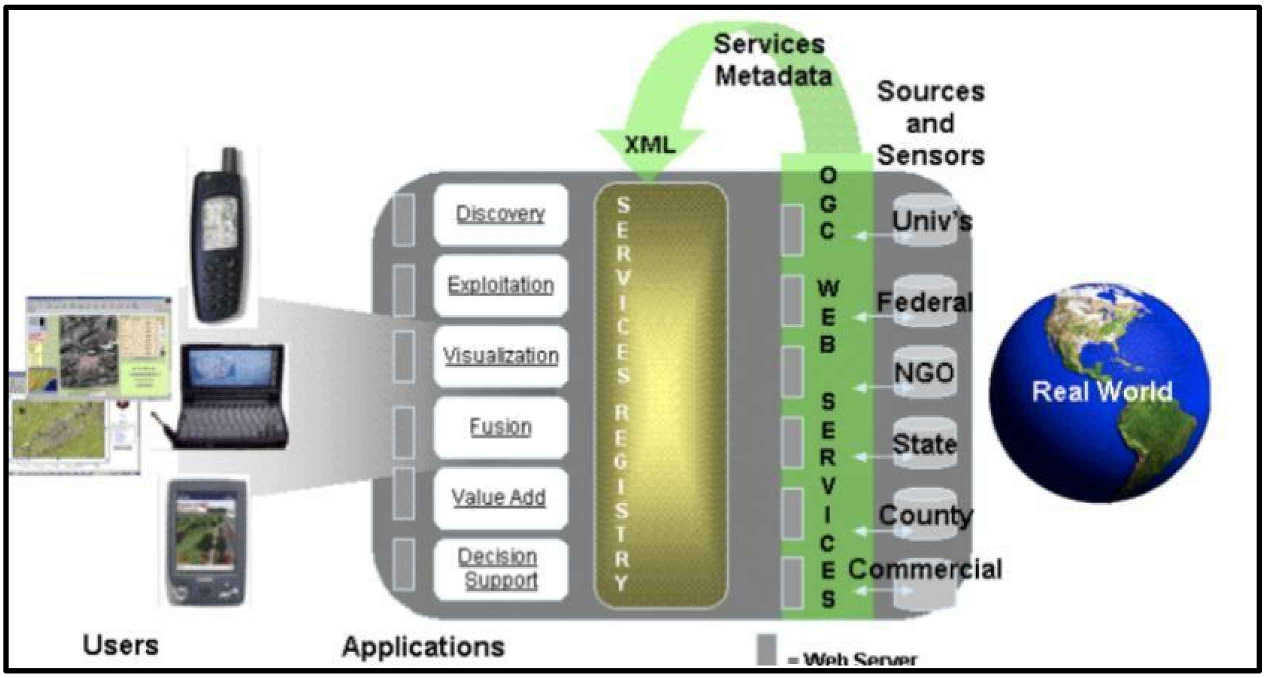

Figure 5: OGC Web Services 'Vision', Connecting Users with Source Data, Applications and Services (ANZLIC, 2019)

In a broader context, web services such as OGC Web Services (OWS) provide the standards-based evolutionary framework to promote seamless integration of online geoprocessing and location-based services (Omidipoor et al., 2021). OWS enables distributed geoprocessing systems to communicate over the Web through similar HTTP and XML technologies. OGC Web Services provides a vendor-neutral, interoperable framework for Web-based discovery, visualization, analysis, and use of geoprocessing functions and sensor-based data.

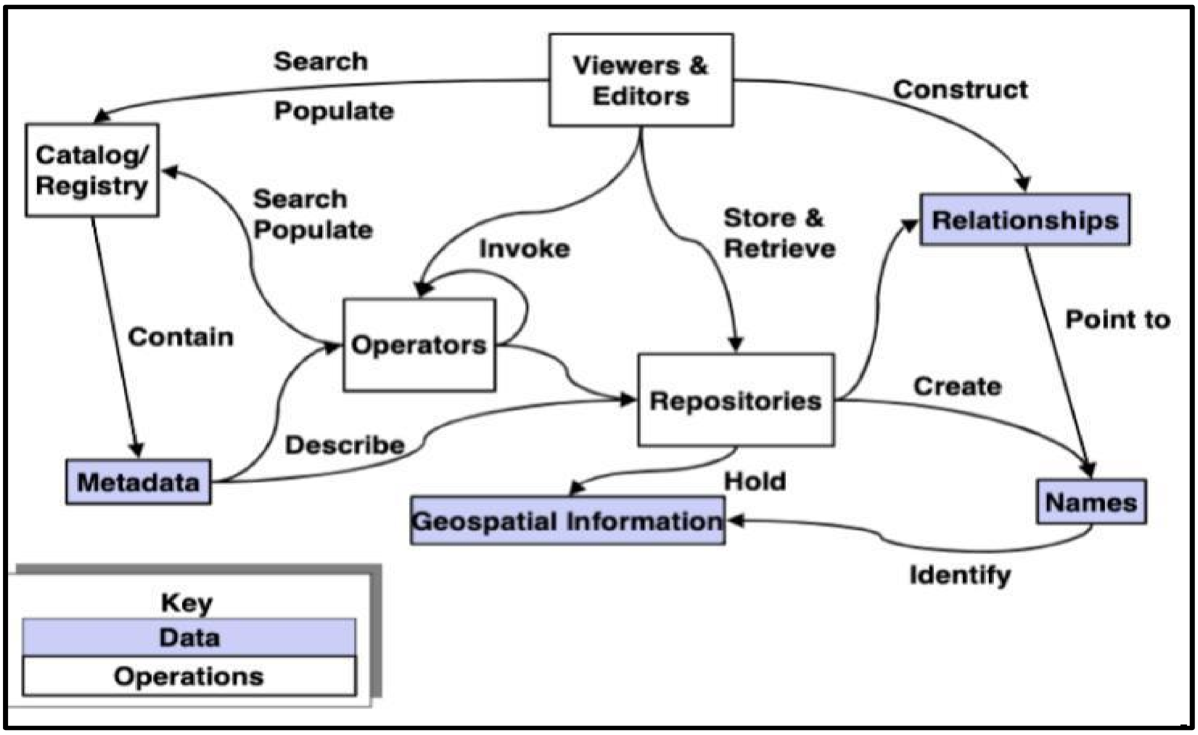

Figure 6: Properties and classes of the OWS generic architecture

These web services are addressable via a URL and a connected network. The OWS framework also allows multiple services to be connected in series and the internal business logic to be kept independent. Figure 6 provides an overview of the architectural scheme for OWS. This schema shows the generic nature of services participating in different sites and geoprocessing activities. It also shows the benefits associated with the applications.

2.6.5 Standards

Geospatial data standards are a key component in the development of SDI. The conventionality of geospatial data allows it to be located, exchanged, and used anywhere. Therefore, technical measures are essential for the exchange of geospatial data products and information. Technical standards facilitate the improvement and assessment of data quality. The guidelines for

Spatial Data Standards include data models, reference systems, data quality, metadata, and data transfer (Harvey et al., 2012). The main goal of incorporating geospatial data standards is to promote the distribution and delivery of geospatial data between users, systems, as well as applications. Some of the institutions responsible for data standardization are ISO (International Organization for Standardization), W3C (World Wide Web Consortium), national coordinating bodies, and the Open Geo-spatial Consortium (OGC).

These organizations develop, set standards, and design schemas to enable effective communication between geospatial data sources and access to a wide range of users.

2.7 European Policy for a Common Data Space

The European strategy for data aims to create a monopoly market for data to improve Europe's global competitiveness and data sovereignty. In addition, a common European data space would ensure that more data become accessible for use in society and that organizations and individuals generating the data remain in control (Calzada et al., 2020).

In the context of the spatial data infrastructure, data-driven applications will benefit citizens and businesses in many ways. These include;

- Creating a clean and safe transportation system
- Reducing the cost of public and geospatial services
- Promoting sustainability and energy efficiency
- Improving the health care system
- Generating new products and services.

To further secure the EU's leadership role in the global economy, the EU intends to introduce the European Strategy for Data;

- A legislative action on data management, reuse and access. For example, sharing data between businesses and government agencies to achieve public policy goals.
- Enabling access to fair, secure and competitive cloud services by facilitating a procurement marketplace for data processing services and creating an applicable legal framework for cloud services.
- Investing €2 billion in a high-impact European project to develop data processing infrastructures, architectures, data exchange and governance mechanisms for effective data exchange and convergence of energy-efficient cloud infrastructures and services.
- Make data accessible to a wide audience by providing high-quality, publicly available datasets across the EU and enabling free reuse.

Currently, the European Commission has published a report on Business-to-Government (B2G) Data Sharing. The report includes a high-level expert group making policy, financial, and legal recommendations to promote sustainable practice and scalable public interest in the EU.

2.7.1 From Data Infrastructures to Data Spaces

In addition to the SDI components addressed, two aspects should be added to prevent vendor-centric development with low user adoption. First, the SDI stakeholders involved must actively participate in the co-design and co-creation of the SDI implementation (infrastructure component). Second, it is important to consider the notion of "spatial" data to extend the capabilities of device networking and the Internet to generate data sets (Swan et al., 2012). As a result, SDIs can benefit from approaches and technologies in emerging data spaces, defined by the European Commission as "a seamless digital platform with the scalable capability to develop new products and services based on data availability" (EC, 2018).

However, if a spatial data space is to be created with sustainability in mind, it could require a decade of planning. Today, all that is required is technological development, which did not exist when INSPIRE was conceived in 2007. Given the rapid pace at which technology is developing, African countries can emulate this new development. As a starting point, Figure 7 shows a framework of the data space that considers SDI components. This spatial data infrastructure architecture captures emerging technological trends to illustrate the interconnection between stakeholders with an increasingly rich ecosystem of technologies and approaches.

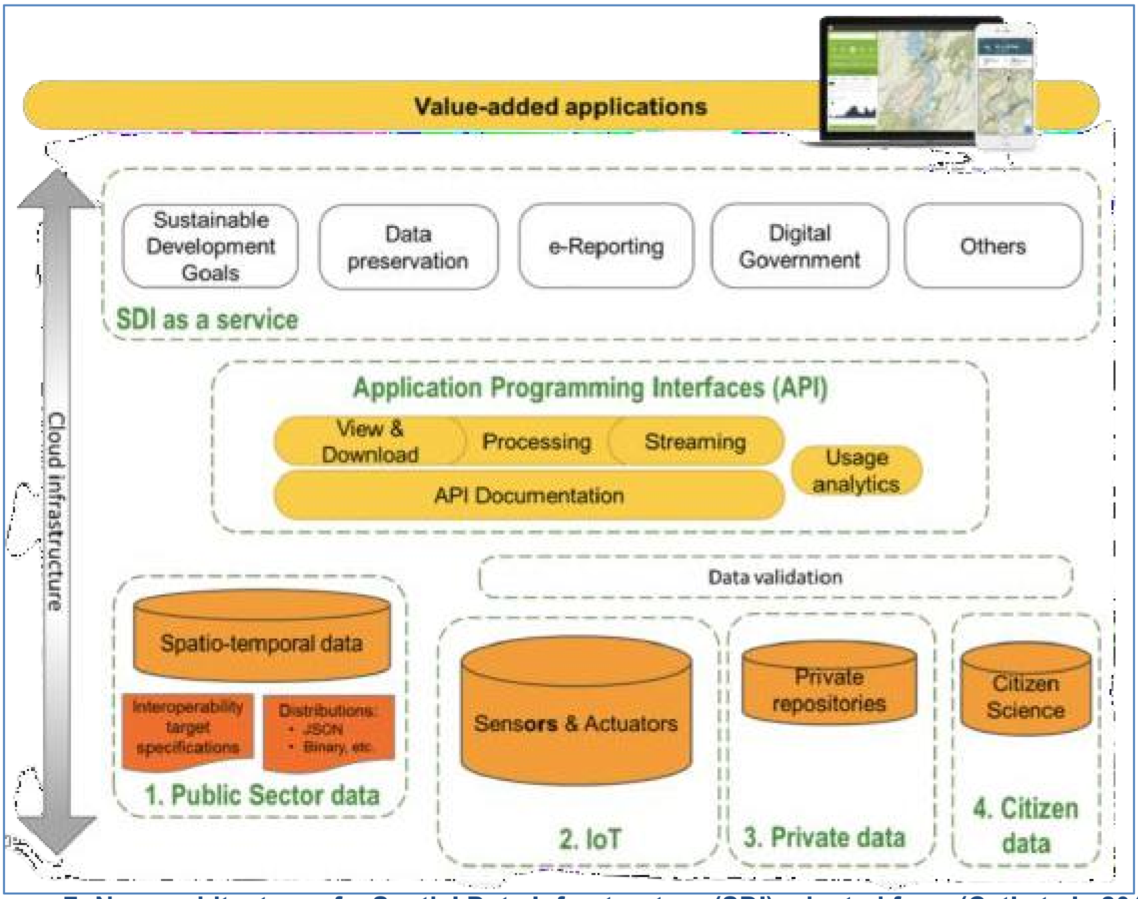

Figure 7: New architecture of a Spatial Data Infrastructure (SDI) adapted from (Cetl et al., 2019)

2.7.2 Data spaces

In our digital world, data is an essential building block that generates more and more information about our daily lives. Large amounts of data are produced in public organizations, including spatial data, meteorological information, geospatial data or traffic flows. According to European Policy Dataspace (March 2021), the amount of data is expected to increase by 5% between 2018 and 2025. It is important to think about what methods can be used to process the huge amounts of data faster to meet the needs of users.

However, data is driving innovation for small and large businesses. For example, remote sensing data collected by sensors can help farmers manage land and crops with high precision. Collecting information about the environment would help combat natural disasters such as forest fires and floods, which are particularly common in developing countries.

To achieve this progress, data must be effectively stored and shared based on EU data protection rules, such as respect for intellectual property, protection of personal data, and trade secrets (INSPIRE, 2020). As a result, EU countries are creating a new data model with clear rules for the European single market for data, open yet sovereign, that can also be emulated by African governments.

2.8 The Stages of SDI Development

There are four stages in SDI development: the stand-alone stage, standardization at the technical level, the intermediate stage, and the network stage (Loenen, 2018). The stages are accessible from theories of organizational, management, and administrative process (Donker et al., 2017).

Stage 1: Stand-alone

This is the first stage of SDI development; many organizations build their infrastructure at this stage (Loenen, 2018). The lack of appropriate agendas influences this stage; therefore, engagement in managing the organizational structure for data sharing at the internal and external levels is not possible (Loenen and Grothe, 2014).

Stage 2: Standardization of the technical level

In this stage, external developments have influenced organizational change, such as increased pressure for organizations to operate effectively under new technologies (Loenen, 2018). In addition, organizations rely on information provided by other institutions to improve internal development. Regardless, there are many limitations and difficulties in prioritizing SDI (Loenen and Grothe, 2014). Leaders are involved in developing the spatial data infrastructure, data sharing policies, leadership discussion, and ways to implement SDI activities.

Stage 3: Intermediate stage

The intermediate stage involves implementing the SDI vision (Loenen, 2018). Many organizations tend to introduce new changes that require clear communication, such as best practices (Loenen and Grothe, 2014). At this stage, organizations focus on the core values and relationships of spatial information (Loenen, 2018).
However, a national cadastral database can be linked to other databases to provide additional registrations and access to topographic data within the federal survey agency.

This process ensures that the cadastral database content consists of up-to-date and efficient datasets that are widely accepted at the national and international levels. The intermediate stage ensures that the organization has an updated database with strong links between stakeholders and the organizational structure.

Stage 4: Network Stage

The network stage focuses on innovative motives for SDI development. (Loenen and Grothe, 2014). The main goal is to support SDI network organizations to enable clear vision and communication (Loenen, 2018). Organizations are interdependent due to their shared SDI responsibilities. In this stage, consistent frameworks and large-scale data sets are generalized to smaller scales.

As explained in these four stages of SDI evolution, it is clear that each stage has to do with the goals of SDI and the degree of collaboration among actors. The latter has to do with the scale in the hierarchical management of SDI.

2.9 Conclusion

SDI is an essential component that supports decision-making and meets social, environmental, and economic needs within the community. Aside from the need for SDI, there is much debate about the characteristics and nature of SDI development. Regardless, the concept of spatial data infrastructure is complex. It involves the interaction of stakeholders within and between different sectors such as academia, government, private organizations, and industry.

This chapter examined the concept and terms associated with spatial data infrastructure. Then, contemporary SDI concepts and international trends were examined, followed by an assessment of SDI components. In addition, this chapter provides information on spatial data infrastructure theory and concepts to examine the nature of national governance as well as organizational collaboration.

Chapter 3 Evaluation Approaches and Partnerships for Spatial Data Infrastructure

3.1 Introduction

The Oxford Dictionary defines evaluation as "a collective term used to monitor the achievement of a predetermined objective (training, systematic, and inductive action) after successful implementation." For humans, evaluation is a natural process. Many people tend to think carefully before taking strategic action.

Over the years, research evaluation has increased within the information system. In the commercial environment, specialized academic journals provide platforms for practitioners and academics to provide information on theories, data relevance, and methodology. Public sector organizations face similar issues. Institutional settings, technical infrastructure, and impact issues require comprehensive evaluation within government organizations such as SDI, available in electronic format. Evaluation has received considerable attention within the geospatial information community (Piattoeva and Saari 2020). Homburg (2020), refers to evaluations based on international standards as a "competitive means" to measure performance.

Spatial data infrastructure has become a significant avenue for geographic information development, including government initiatives and policies such as e-governance, innovation, interoperability, legal frameworks, and enhanced infrastructure, etc. SDI evaluation approaches have matured with a steady increase in research techniques, from questionnaires to case studies and theoretical frameworks (Craglia and Jackson, 2012; Crompvoets et al., 2018; Delgado et al., 2008; Masser 2019). Thus, there are concerns about the difficulty of identifying and measuring benefits as we move from a data-centric SDI approach to a service-centric approach (Grus et al., 2011).

3.2 Evaluation Approaches for Spatial DataInfrastructures

Evaluation studies have received much attention within the geospatial information community (Nedovic-Budic, 2017). With the redesign of inter-organizational GIS, the complexity of evaluating key indicators and the SDI evaluation process has increased significantly. SDI assessment involves identifying and incorporating spatial data components (Loenen, 2018; Masser, 2019).

Conceptual studies include examining the relationship between assessment criteria and different SDI hierarchy levels (Steudler, 2003). Additionally, readiness issues related to economic, organizational, and communication factors have been examined (Delgado et al., 2008). Currently, there are concerns about the degree of difficulty in measuring and identifying benefits, such as improving the complexity of SDI from a data-centric to a service-centric point.

As SDI concepts are fully understood as geographic information technology for institutional environments and technical infrastructures, another change is the shift to a governance-centric SDI assessment.

3.2.1 Taxonomy for SDI Evaluation

SDI evaluation efforts have different themes (national, regional, global, conceptual, and organizational) and different study objectives (performance measurement, understanding, consensus building, and lessons learned), as well as different methods (e.g., website surveys, automatic event identification, computer simulation, questionnaires, prototyping, theory, and case studies). The focus of the evaluation depends mainly on data, services, and SDI implementation issues, as shown in Table 5.

Table 5: Summary of SDI evaluation approaches

Author	Scope	Objectives	Methods	Main Focus
Crompvoets et al., (2018)	Regional	Performance measurement of clearinghouses	Internet browsing, case studies and measurement of characteristics	Data management

Loenen and Grothe (2014)	National	Assessment of organization al context	Case studies and organizational empowerment	Management
Delgado et al., (2005)	Global	Multi-view framewor k assessme nt	Questionnaires	Data management and some governance issues
Lubida et al., (2020)	National	Agent-based modelling approach	Case study	Data availability and standards
Maphale (2020)	Regional	Constraints oriented approaches	Case study and Questionnair es	SDI implementation in Africa
Mwange (2017)	Regional	Technical and Institutional Analysis	Case studies and organizational assessment	National SDI in Africa

This summary provides an overview of different assessment methods as well as objectives based on different authors.

-SDI governance assessment: a good example of SDI governance assessment was conducted in Europe by Crompvoets et al. (2018). In this case, the scope of "going global" was mainly limited to a focus on governance as a representative of national SDI initiatives. A similar approach was considered by Vandenbroucke et al. (2011) and Delgado et al. (2008) at the regional level (European Union) and global level, respectively. Although the problems identified in these studies were more complex, they included legal, organizational, and financial components. Delgado et al. (2008) sought to capture progress within SDI readiness through the use of questionnaires and existing frameworks, while Vandenbroucke et al. (2011) examined the impact of the INSPIRE Directive and compliance of EU member states through peer feedback, publications, websites, and report review. Van Loenen (2018) also assumed an accurate outcome in the context of national SDI success based on four organizational indicators.

-SDI learning evaluation: recent studies by Maphale (2019) and Masser (2019) can be considered SDI learning evaluations, although the evaluation is a "comparative case study" rather than a computational simulation of a complex reality. The study includes both SDI models (e.g., countries with the same development approaches) and lessons learned from their experiences. For the Africa case study, Maphale (2019) focused on SACU countries (South Africa, Botswana, Namibia, Lesotho, and Swaziland). Lessons learned include the benefits of sustained political support, a strong coordinating body, and the benefits of phased implementation to describe the opportunities. According to the European study identified by Mulder et al. (2020), European models include assessing organizational and state-level initiatives in SDI development.

-SDI sense-making assessment: the first global SDI study, conducted by Onsrud (1998), is a good example of an SDI sense-making assessment. The study focused on evaluating uncertainties and SDI approaches on a global scale. This method involves official and unofficial information from individuals at the national level sharing different opinions and building consensus on the nature, scale, and scope of SDI. Experimental approaches such as modeling and prototyping are part of sense making assessments. For example, Sjoukema et al. (2021) investigated spatial data infrastructure interactions using an agent-based modeling approach. The model included four agents (such as data providers, platform providers, users, and actors) that send messages and respond directly to each other. By simplifying these interactions and developing a generic model, it is possible to improve the SDI framework using an agent-based model.

-Evaluate SDI exploratively: the interpretive study by Vilches-Blázquez and Ballari (2020) showed the diversity of spatial data infrastructures as a good example of exploratory evaluation. The theoretical tool for evaluating SDI initiatives is divided into four blocks (standardization, adoption, monitoring, and boundaries). To assess effectiveness, the authors argued that performance monitoring and quality improvement of data is an essential component of SDI evaluation. Additionally, they focused on the goals and outcomes in each context. Furthermore, they recognize the importance of evaluating the potential of SDI to generate and deliver spatial data products and services to users. To develop a framework for socio-political and cultural interactions within SDI

implementation, the authors assumed that stakeholders will be conflicted. Thus, conflict will help balance interests and generate further SDI concepts, services, and applications. In summary, SDI assessment is a broad component to promote SDI services.

3.3 Partnerships in SDIs

SDI partnerships involve collaboration of processes and products between relevant institutions through innovative approaches. According to Mulder et al. (2020), "partnership is a mechanism used by government agencies, experts and local authorities, public and private sectors to achieve a specific goal. "

It involves various forms of organizations at the local, national, and global levels. To foster successful partnerships in developing countries, institutions must act and think strategically with respect to specific goals and available resources. Rajabifard et al. (2010) asserted that SDIs aim to create an environment in which actors (both producers and users) collaborate in a cost-effective manner to better achieve organizational goals.

Partnerships should not only measure SDI development processes, but they must also be effective enough to provide benefits related to the intended goal. In other words, partnerships should be aligned with national SDI development. Many studies, such as Crompvoets et al. (2018), concluded that the concepts of spatial data infrastructure are complex and require future studies.

In recent years, African scholars have conducted research on SDI discourses at the national level. These activities have led to successful SDI partnerships (Mdubeki, 2015; Makanga and Smit 2010; Maphale and Phalaagae, 2014; Mwang, Mulaku, and Siriba 2018).

3.3.1 Components of the partnership framework

It is important for organizations in developing countries to identify partnership needs. Key components that can influence partnerships include culture, capacity building, economic issues, political issues, security issues, and stakeholders. Effective partnerships require significant time and collaborative efforts to create the right framework. Therefore, it is essential to evaluate partnership concepts based on the underlying organizational, technical, and data policy frameworks.

- Culture

According to Van Lonen (2018), "SDI development is a gradual process." This statement is part of organizational cultures in developing countries. Organizational stakeholders in developing countries should know that NSDIs are better achieved through the sharing of resources and ideas rather than the concept of individuals. Legislative frameworks need to be visionary and based on step-by-step processes. Regardless, the lack of stakeholder awareness for effective participation in NSDI activities is proving difficult in many developing countries.

- Capacity building.

In the SDI context, capacity building refers to the effective execution of tasks by establishing the principles of an SDI initiative. However, stakeholders develop creative capabilities with the goal of solving problems related to geospatial data sharing, integration, dissemination, management, and collection. Capacity building not only includes SDI development and institutional settings, but should also include development and institutional settings.

For successful SDI development and an active partnership framework, comprehensive training is an important indicator and parameter required. Willamson et al. (2014) argue that the training process requires a new way of sharing and exchanging data sets. This also provides solutions for the benefit of different partners.

According to Rajabifard (2010), there are several capacity building factors that are required for successful SDI initiatives. These factors include financial capacity, technological capacity, and human resources. Capacity building factors identified by Rajabifard and Willamson (2019) include: The level of stakeholder awareness of SDI values; the state of communications and infrastructure; the economic and financial stability of each member country (this includes the ability to finance the cost of participation); the need for long-term investment plans; the availability of resources (a lack of funding could be an incentive to build partnerships, so it is important to have stable income); regional market pressures (the state of regional markets and proximity to other markets).

Capacity building focuses mainly on administrative development through formal training, seminars, and workshops to educate incompetent personnel within an SDI project. However, Rajabifard and Williamson (2019) argue that capacity measures can be enhanced by maintaining and development of institutional infrastructures through sustainable means. In addition, decision makers and companies should be aware of potential infrastructure investments.

- Security Aspects.

SDI activities involve multiple stakeholders within a distributed network. The use of spatial data enables stakeholders to achieve their goals, such as geoprocessing, spatial analysis, decision-making facilitation, and route analysis optimization. In addition, it is important to consider that the data and services produced by the initiatives are accessible through trusted and registered sources. Maintaining security within the SDI environment also concerns both users and producers. While adequate security measures can further improve the quality of an SDI initiative, they also attract more organizations and late SDI adopters. Other possible means to increase the data quality of initiatives include: a) conducting regular updates to geospatial data and services, b) maintaining technical infrastructures such as innovations, enhanced infrastructures, and innovations, c) limiting access to the initiative by unregistered users, d) cybersecurity monitoring and security measures, e) fostering partnerships for value-added information.

- Stakeholders

Successful SDI implementations among developed nations have defined SDI stakeholder roles within initiatives. Among the selected countries, there are coordinated authorities and lead organizations at each jurisdiction level. Such an arrangement can foster partnership and build trust among stakeholders. It also increases stakeholder awareness by providing the proper channels for disseminating information to other stakeholders and avoiding data duplication.

In most cases, institutions have the right to implement their goals to meet their needs. A sustainable infrastructure component can be achieved through interoperability of technical standards. In addition, member states need to study the impact of each organization's investment in spatial data infrastructure (Borzacchiello & Cragila, 2013).

For example, conducting early impact assessment activities, similar to INSPIRE in 2003-04, where programmed activities were launched to review the benefits and cost assumptions of the initiative (Ogryzek et al., 2020)

3.4 Stewardship within the Spatial DataInfrastructure

Stewardship encompasses all activities that promote the accessibility and usability of metadata and data (Addison et al., 2015). Over the past two decades, the U.S. legislature and federal government have established policies, mandates, guidelines, and regulations to promote digital scientific data.

These policies include:

- U.S. Federal Information Security Management Act (U.S. Public Law 107-347 2002);
- Guidelines for Promoting Scientific Integrity (OSTP 2010);
- U.S. Information Quality Act (U.S. Public Law 106-554 2001, Section 515), also known as the
- Data Quality Act;
- Open Data and Sharing Guidelines.

In response to the challenges and impacts of the changing digital environment, the National Academy of Sciences (NAS), along with the National Academy for Engineering in the United States, has encouraged good stewardship of research data to promote transparency and data sharing (NAS, 2009). However, the Group of Earth Observation (GEO) has called for "free and open sharing of metadata, data, and products" by defining data sharing principles toward efficient and open access to data (GEO Data Sharing Working Group, 2014). Other scientific institutions and scientific publishers, such as those involved in the Coalition on Publishing Data in the Earth and Space Sciences (COPDESS), have introduced a position paper calling for data used in publications to be "free, usable, open, and available" (COPDESS, 2015). In addition, the World Data Service (WDS), in collaboration with the International Council of Science (ICSU), requires compliance with the WDS commitment to "open data sharing, data preservation, data and service quality" as a specific condition of membership. (https://www.icsu-wds.org/organization; see also WDS Scientific Committee 2015).

Relevant stakeholders from industry, academia, scientific publishers, and funding agencies have formally endorsed the FAIR (also known as Findable, Accessible, Interoperable, and Reusable) data principles for stewardship and scientific data management (Wilkinson et al., 2016). These government mandates and regulations, as well as principles established by scientific organizations, funding agencies, societies, and scholarly publishers, have established stewardship requirements for government-funded digital scientific data.

From an SDI perspective, stewardship depends significantly on building a geospatial data infrastructure to manage the complexity of geospatial data through partnerships, technologies, and policies. Many government institutions have begun developing SDI to connect people with data at the national level, suggesting that SDI is a "socio-technical" platform (Georgiadou 2005). This suggests that SDI should be user-driven and focused on ever-changing technologies. According to Brous (2014), the essential goal of SDI development should be to connect people to data. It should also include necessary elements of governance such as standards, policies, preservation, systems, and delivery mechanisms (Willamson 2004 and Georgiadou 2005).

3.5 Conclusion

In recent decades, developing countries have struggled to establish SDI initiatives and foster partnerships due to some of the issues identified in this chapter. This session considered evaluation approaches and partnership frameworks for successful SDI implementation in Africa, particularly in Southern African countries. Separately, building geospatial data through an operational partnership process is about the following: Reduction of data duplication, sharing and exchange of data among stakeholders, common geospatial reference framework, and reduction of transaction costs for geospatial information.

In the context of SDI, evaluation and partnerships have enabled geospatial data communities and custodians to become involved. Partnership approaches help leverage existing data infrastructures and reduce development costs. Therefore, it is important for Southern African countries to enter into partnerships to foster geospatial data and custodian communities.

Chapter 4 Open-Source Based Geo-platform to Support Spatial Data Infrastructure

4.1 Introduction

According to the ICA (International Cartographic Association), cartography is defined as "the art, science, and technology of making and distributing maps" (ICA, 1973 p.1). In other words, cartography deals with the act of producing maps (Piovan, 2020).

In addition to map production, cartography is an academic discipline that includes professionals at various levels (national, regional, and international), conferences, journals, educational programs, and so on. Generally, maps are application-oriented and represent changes in data type and symbolization. Digital maps consist of web accessibility with user-centered data (e.g., navigation bar). They also include less important data (e.g., base map) to represent locations.

In recent years, there have been advances in spatial data representation that include open source and free software compatibility (FOSS), Volunteered Geographic Information (VGI), Linked Data, cloud computing, and Big Data analytics. This chapter explores the contribution of new cartographic representation technologies to the development of SDI.

Free access to open source software and Open Geospatial Consortium (OGC) tools such as WMS and WFS provides a great opportunity for developing countries to support the development of their national SDIs. Other services provided by FOSS software include database development, server configuration, metadata, and Styled Layer Descriptors (SLD), which is cost-effective for the development of cloud-based SDI applications.

For this research, a geospatial application was developed using the Geodjango framework. The final output displays point locations of international organizations within Southern African countries and geo-routing services. This trend promotes the use of low-cost FOSS software and geospatial services, which in turn may lead to better adoption of SDI development in developing countries where financial and human resources are limited.

4.2 OGC Web Services

Web services are compatible applications accessible over the Internet using HTTP and encoded messages such as the XML format. Web services are divided into:

- Data visualization, for example WMS (Web Map Services).
- Data processing services (Web Processing Service).
- Data retrieval and publication (CSW: Web Catalogue Service).
- Data presentation (SLD: Styled Layer Descriptor).
- Data services such as WFS (Web Feature Service) and WCS (Web Coverage Service).

4.2.1 Web Map Service (WMS)

Web Map Service is an OGC specification for data visualization. It provides a visual overlay of various geographic data on the Internet. The output is in the form of two-dimensional georeferenced raster images that are available in various formats such as PNG (Portable Network Graphics), JPEG (Joint Photographic Experts Group File Interchange), and GeoTiff (Geographic Tagged Image File Format). However, the WMS can be used for data visualization and spatial information retrieval within SDI catalog services because it is capable of retrieving rendered maps from existing data.

4.2.2 Web Feature Service (WFS)

The Web Feature Service is a data-centric service used to standardize queries and send responses to vector data. In most cases, the service does not specify the rendering process, but facilitates the sharing and manipulation of geospatial data. Thus, WFS provides access to basic geospatial data. WFS is mainly used to add, select, delete, update, and filter geospatial data. Unlike WMS, which provides a map, WFS provides access to raw vector data.

4.2.3 Web Processing Service (WPS)

Web Processing Service consists of service-oriented applications used in publishing geospatial data on the Internet. This facilitates dynamic data exchange, binding, discovery, publication, and use of geospatial processes on the Web. However, WPS provides complex processing services by using a sequence of sub-processes. Some examples of WPS implementations are the Java-based 52oNorth (https://52north.org/software/software-projects/wps/) and the Python-based PyWPS (https://pywps.org/). These two implementation tools promote the WPS standard and the provision of geoprocessing services on the Internet.

4.3 New Development of the OGC-API

The OGC API includes standards that provide access to resources through the use of the HTTP protocol. In most cases, the OGC API defines a set of functions that apply to all other OGC APIs. Various OGC standards extend API common with specific features called resource type. The resource type can be accessed through OGC API via a Universal Resource Identifier (URL). URLs are composed of three groups:

- Access paths: unique paths to resources.

- Dataset Distribution API: it provides the endpoint corresponding to a dataset distribution, where the landing page resource is defined by OGI-API common, known as Base URL or {datasetAPI}.

- Query: parameters to change the representation of a resource or resources, such as the encoding format.

4.3.1 Coverage Implementation Schema

The OGC API Coverage Standard provides the framework for accessing coverages, as defined in the Coverage Implementation Schema (CIS), via web APIs. An overview of the CIS data model is shown in Figure 8.

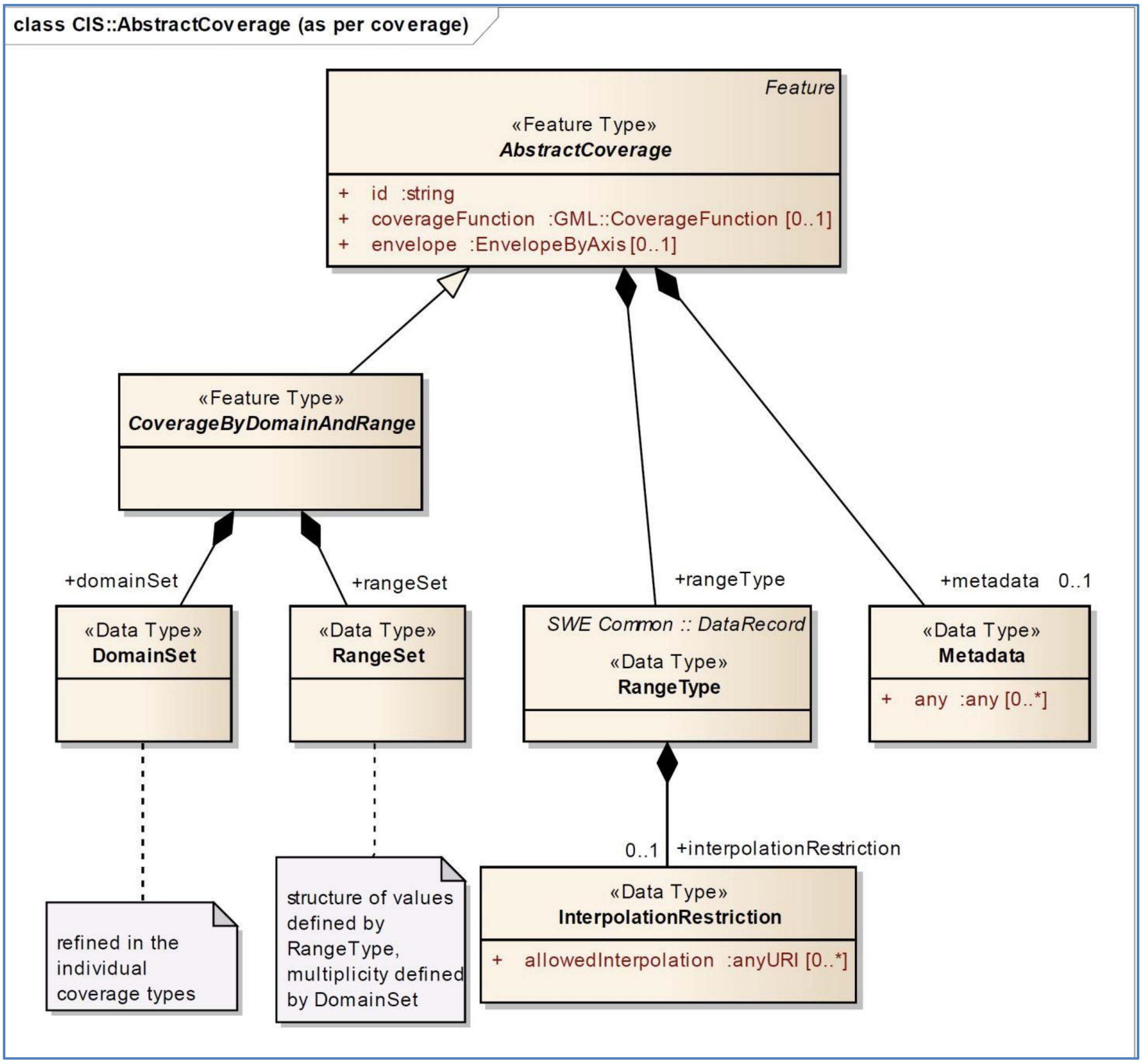

Figure 8: Abstract Coverage

4.3.2 API behavior model

The Coverages API is compatible, but not compliant, with the OGC Web Coverage Service. This allows API coverage and WCS implementation to coexist within a single processing environment.

OGC Web Coverage Service Standard Version 2 has an internal model for storing classic operations such as GetCapabilities, DescribeCoverage, and GetCoverage. This model includes a single CoverageOffering similar to the full WCS data store. In addition, some service metadata describes service properties such as encodings, WCS extensions, supported interpolations and CRSs, etc. This service also includes many OfferedCoverages.

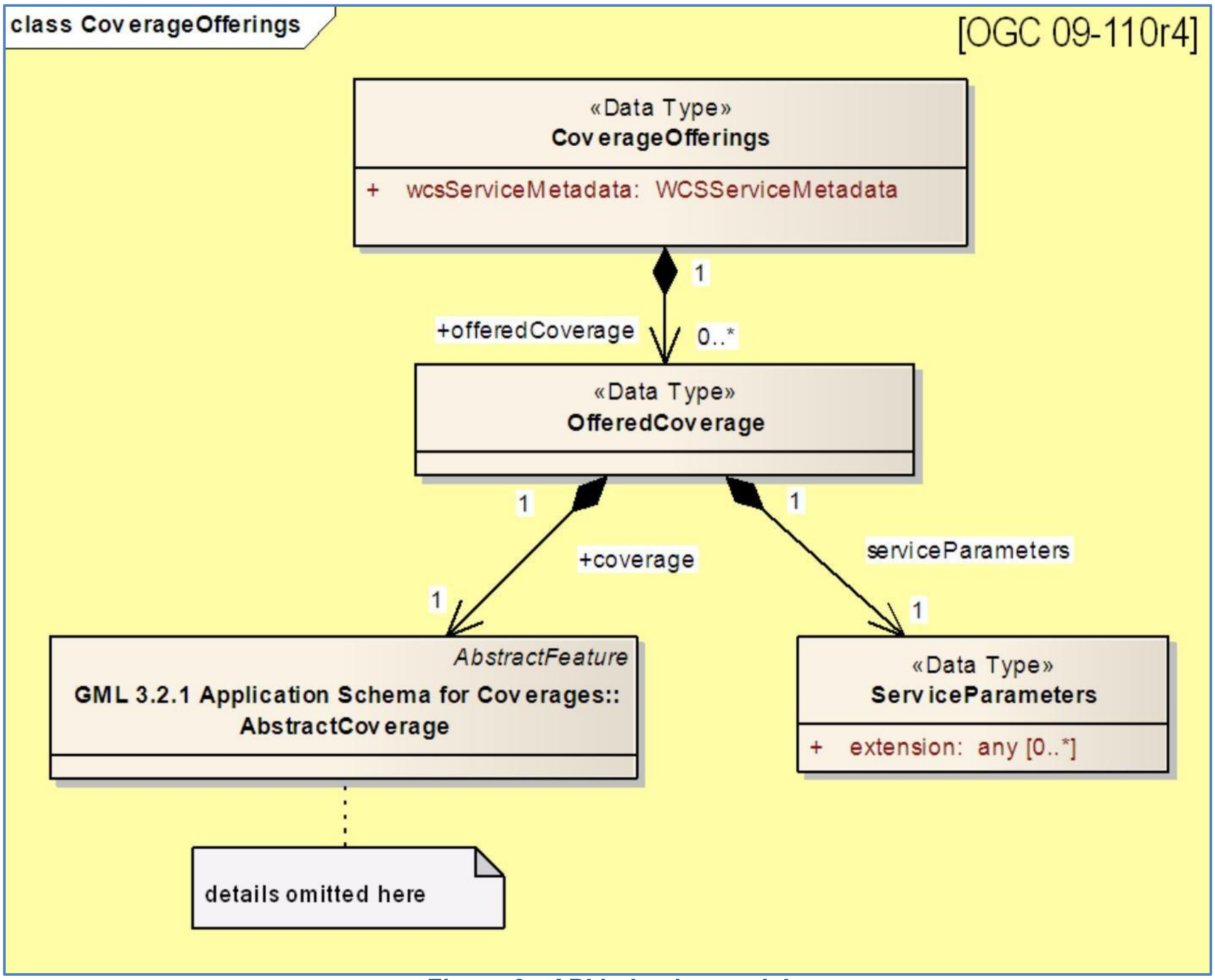

Figure 9: API behavior model

4.4 Free and open source software

The term "free and open source software" implies licensed permission for users to freely use, modify and redistribute software. In the developing world, particularly in Southern African countries, SDI development is still in its infancy. For this reason, access to FOSS provides an alternative to proprietary software. The biggest obstacle to using this software is the lack of adequate training and maintenance among users.

The FOSS used for spatial data application can be divided into spatial database management systems (DBMS), desktop GIS, web GIS clients, GIS extensions, openlayers, PostGIS, geoservers, PHP/Ajax, remote sensing software, GIS extensions, and spatial data analysis software. However, the open source geospatial community has its standard through the Open Source Geospatial Foundation (OSGEO) and an active user community that promotes its use and development. Currently, many FOSS projects collaborate; these projects include Geometry Engine Open Source (GEOS), Java Topology Suite (JTS), NetTopologySuite (NTS), and interoperability libraries such as the Geospatial Data Abstraction Library (GDAL).

4.5 Software Consideration

This section outlines the software considerations used to develop the SDI application. However, the application also includes technological trends that can be used to promote spatial data infrastructure in Africa. The tools are free and open source, such as OpenStreetMap layer (baseMap), OpenLayers, PostGIS, CSS, HTML, geoserver, and Ajax. Another important consideration is the implementation process.

As with any other standard geospatial application, decisions were made about the web server, client-side interaction, server-side geoservices, and spatial DBMS.

- Geoserver

This is a free Java-based software tool used for geospatial services. The software can be used to publish geospatial data using OGC standards such as WFS, WMS, WCS, CSW, WPS, and WMTS (Web Map Tile Service). The geoserver is a reference implementation of the OGC.

- OpenLayers

This is a JavaScript library and API that provides easy access to interactive maps on the web page. OpenLayers provides information about map tiles, markers, and vector data from various sources. The software tool is designed to manage different types of geographic information. It is an open-source JavaScript, which means that it can be used for commercial purposes (OpenLayers, 2019).

- JavaScript (JS).

This is a compiled programming and scripting language used for rendering web pages and is compatible with non-browser sites such as Adobe Acrobat, Apache CouchDB, and Node.js. However, JavaScript is a prototype-based and dynamic language that supports imperative, object-oriented, and declarative programming styles (MDN 2019).

- Cascading Style Sheets (CSS).

CSS is a programming language used to enhance the appearance of HTML or XML content. It is one of the programming languages that follows the W3C specification across platforms. The chosen technology stack (Geoserver, Openlayers, JS, PostGIS and Ajax) is completely FOSS.

4.6 Overview of the system architecture

Technological advances have changed the way data is collected and disseminated. A web mapping framework provides advanced and powerful data storage. Open source and commercial tools provide a great way to represent the spatial data infrastructure (Sadeq 2020). However, potential libraries for creating and customizing interactive maps are still under development (Leaflet, OpenLayers, QGIS, ArcGIS, Mapbox, and OpenStreetMap, etc.).

For this research project, the prototype system architecture is based on the client-server model (Figure 4). The first side (client) sends requests that are processed by the second component (server) to provide a fast and reliable response. Moreover, the server side was developed using Django REST framework (Geodjango extension), while Leaflet was used to set up the presentation and web GIS interfaces. The main advantage of using Geodjango is that it allows service providers to perform queries using Python codes instead of repetitive SQL statements (Lopatin 2020). Apart from the stored data, it can be easily managed through the Django administration interface. This sophisticated geographic web framework in Python supports object-relational procedures on datasets that can be stored in various databases such as MySQL, PostgreSQL, SQLite, and Oracle. For this project, the data was imported into a PostgreSQL geodatabase.

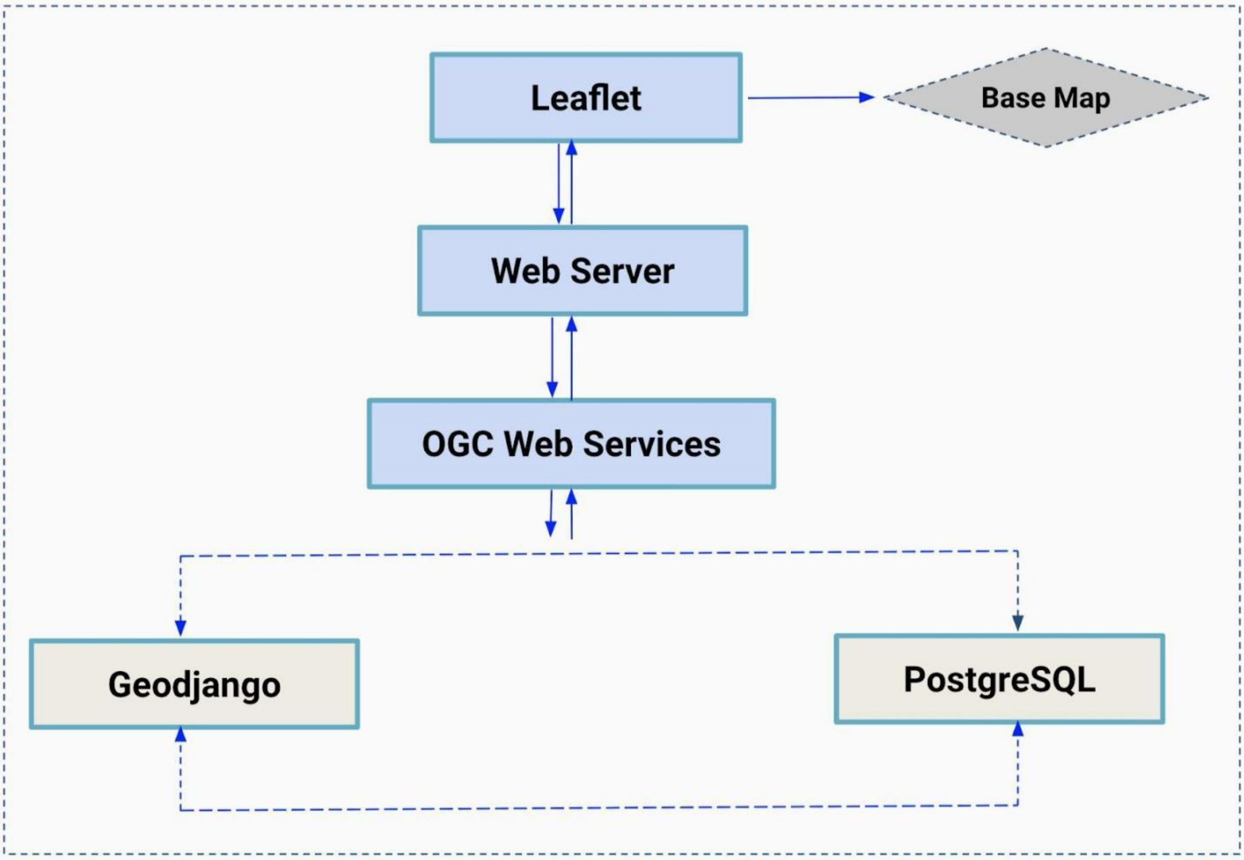

Figure 10: Overview of the SDI application design

4.6.1 General structure and components

The main interface of the SDI application is shown in Figure 11. Basic functions include a dynamic scale, zoom options (zoom in and zoom out), measurements, and accessibility via small icons on the left side. On the right side is a legend for monitoring user location and distance. Base maps and layers are organized in an expandable and collapsible panel located at the top right of the user interface.

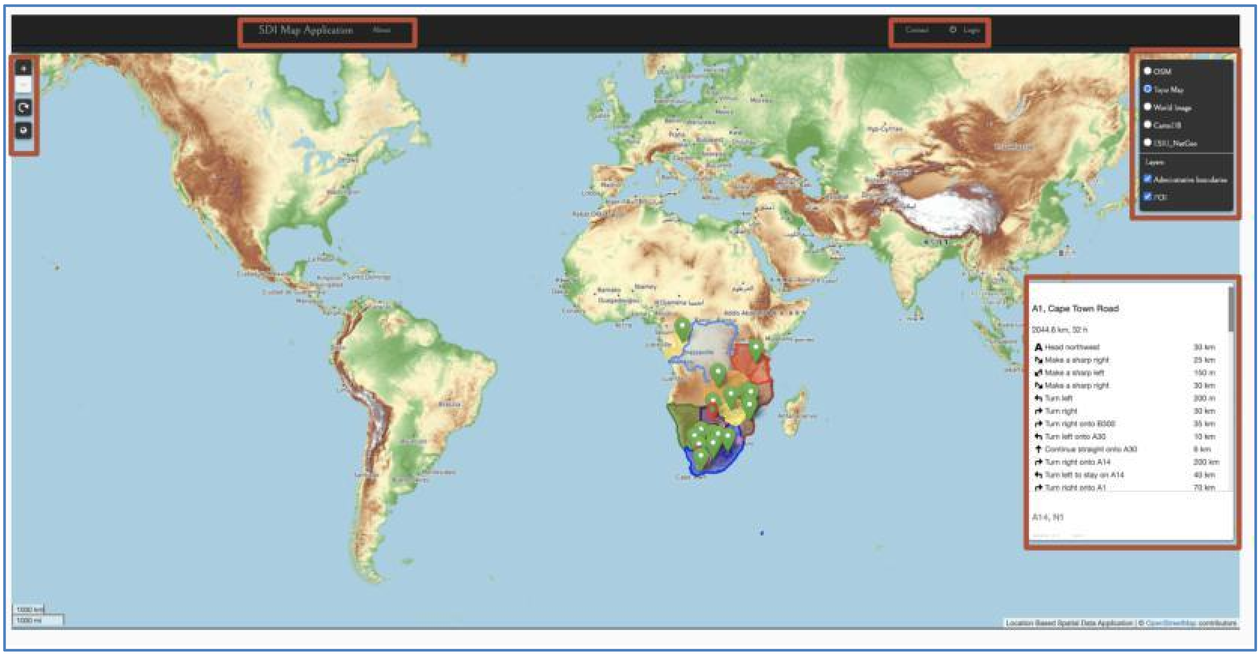

Figure 11: overview and functionality of the SDI application

The prototype framework allows SDI stakeholders to add their analysis tools and datasets through the admin panel, as shown in Figure 12. To this end, users can easily define their functions in the Geodjango framework. These new functions receive the procedures specified in the Leaflet-based interface, perform the appropriate operations on the models (for more information on setting up Geodjango, see https://docs.djangoproject.com/en/3.2/)

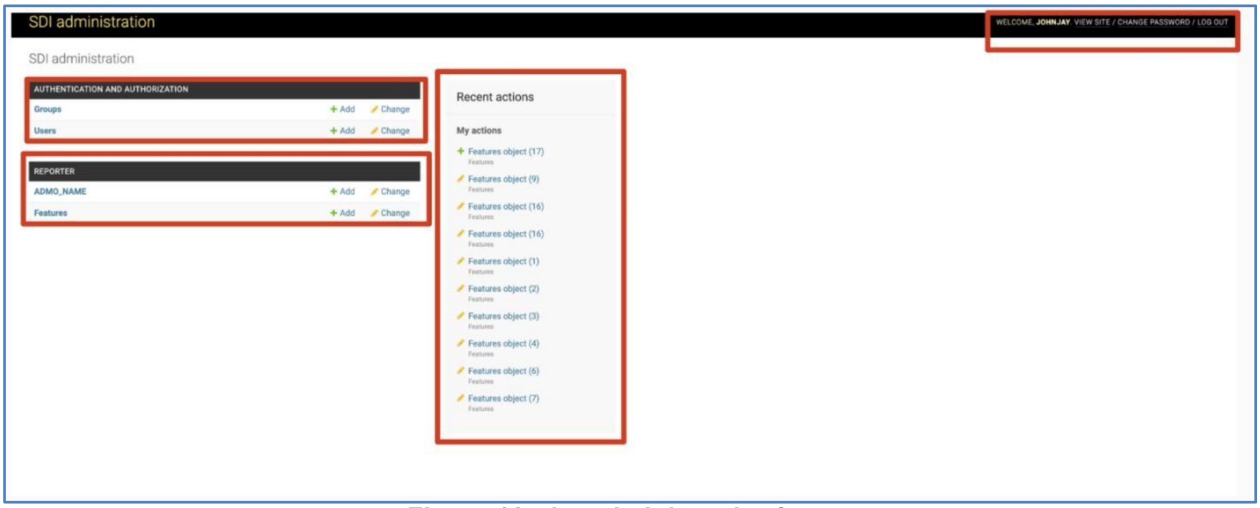

Figure 12: the administrative layout

4.6.2 Main functionalities

The administrative boundaries allow visualization and point location of the international organization in each country. The query is performed by several functions written in Python and the Javascript library. Another functionality used is the map styling of the country boundaries. Among these options was the choice of map classification in the feature space. The color schemes used consisted of selected ColorBrewer color schemes (Brewer 2012), with 256 color intervals.

Other aspects of the SDI application include data access and map layer generation, including querying, processing, styling, accessing, and displaying the map legend. In addition, the application allows the user to select various options and specify a query, color space with options relevant to the point of interest (POI).

4.7 Conclusion

This section provides an overview of the dynamic web mapping implementation that provides valuable services on how SDI stakeholders can implement the process to effectively facilitate the decision-making process. The prototype also provides the ability to add new functionality at no cost, as it is free and open source.

The Geodjango platform offers scalability so that computing resources can be scaled as needed. In the context of SDI, scalability at the national and higher levels is important. This can be exploited to reach large audiences through effective geospatial services.

Aside from the trends for SDI implementation, this concept can also be applied in the education sector to perform spatial analysis of existing geospatial data. The same principles can also be applied to other sectors such as climate and agricultural monitoring.

Chapter 5 Research Methodology

5.1 Introduction

This section focuses on the methodological approach and indicators used to assess the spatial data infrastructure within the selected countries. To understand the current status and implementation of SDI, it is important to conduct an in-depth study of SDI within the basins (South Africa, Tanzania, Botswana, Malawi, and Zimbabwe). Relevant materials were reviewed for this research, including a website search, documentation, and questionnaires. The results and discussion were covered in Chapter 6. The map below (fig 13) shows the five selected case study countries.

Figure 13: Map showing case study countries

5.2 Methodology used

A multi-view assessment approach (Grus et al., 2011) was adopted for this study to assess the status of NSDI development in the selected countries. The two multi-view assessments used for this study include the organizational approach and the modified state of affairs approach similar to the INSPIRE methodology. Relevant data were collected from stakeholders in various organizations such as academia, NGOs, government agencies, international organizations, private and public sectors. The research steps undertaken can be visualized in the following flowchart (Figure 14).

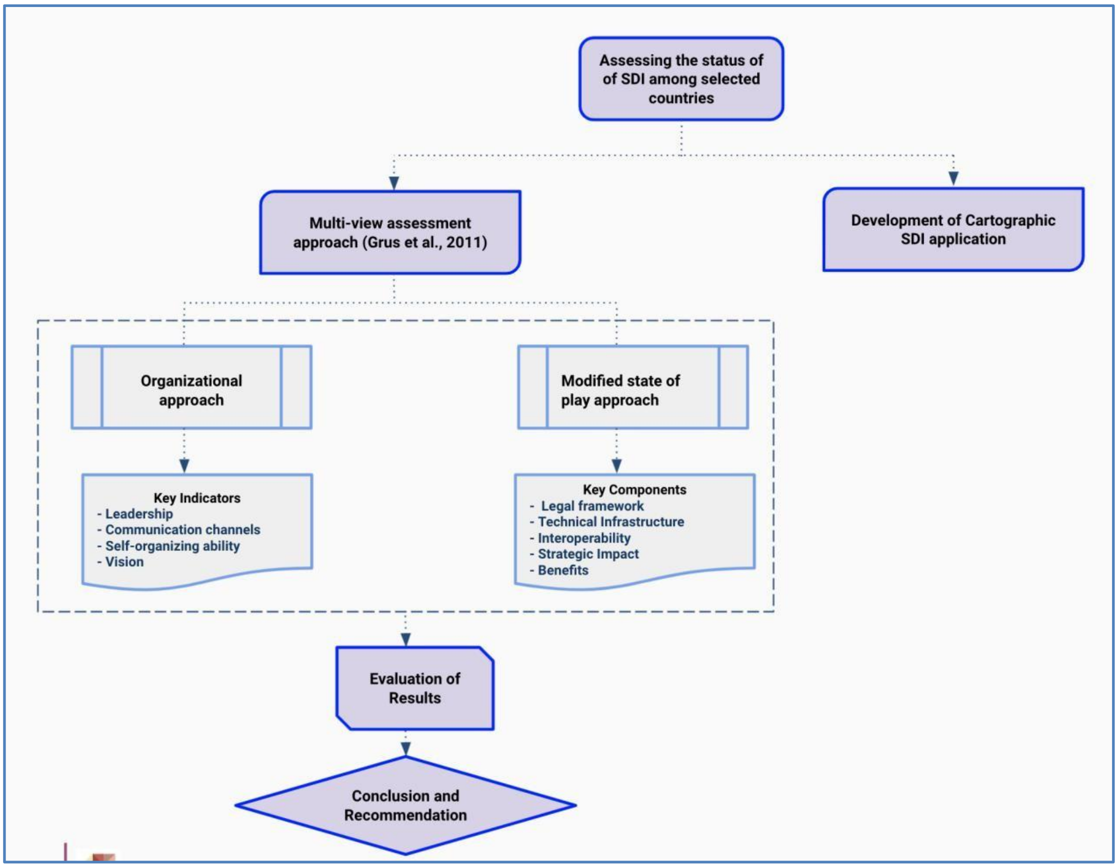

Figure 14: Methodology flowchart

5.2.1 Organizational approach

The organizational assessment approach focuses on measuring the institutional development aspects of SDI through four components: Leadership, Communication Channels, Self-Organization Capability, and Vision (Grus et al., 2011). The main objective of this assessment is to evaluate the improvement performance (outcome) and organizational results within NSDI activities in the selected countries.

The data collection process includes documents, web searches, and reports from international institutions (e.g., UNECA 2020).

- Documents

According to Silverman (2020), documents are critical in a research context. In most cases, they generate relevant ideas, questions, and assessments. From an SDI perspective, documents provide relevant information about countries, organizations, or regional institutions. In most cases, this includes economic endeavors and social systems associated with the implementation of spatial data infrastructures (Bui et al., 2020).

In the context of qualitative research, documentary research is divided into three main categories, namely (a) physical evidence (b) public records and (c) personal documents. Physical evidence is mainly used to prove or disprove a fact (Guest et al., 2020). In this study, public records include feasibility studies, country laws, assessment and implementation reports related to SDI. In selecting relevant content, great emphasis was placed on the content of the SDI assessment and the year of publication. Some of the valuable information includes:

- **Country reports on SDI technical infrastructure:** these reports provide relevant information on what has been done in implementing SDI at the national level. The reports are important for assessing the current SDI status and organizational framework in the selected countries.
- **Institutional Framework:** Previous studies have shown that a lack of institutional framework has slowed the progress of SDI. For this reason, it is important to understand the current status and accessibility for SDI development.
- **SDI feasibility studies:** feasibility studies provide information and detailed research on the national SDI implementation process. This includes information on existing SDI activities and implementation processes.
- **Internet Search:** In recent years, the Internet has become an important platform for accessing information quickly and efficiently. Geospatial platforms such as geoportals, national SDI websites, and organization websites are primary sources for information retrieval.

The websites and geoportals studied were used to retrieve information on past and current SDI activities in the selected countries. This research study is similar to the work of (Sjoukema et al., 2020) in that it uses web searches to gather relevant information on SDI development. Thus, the web site searches include the following information;

- History of national SDI implementation (Inception Date).
- Basic geospatial data sets.
- Actors and stakeholders involved in SDI activities.

5.2.2 Modified State of Play Approach

The assessment approach using the modified state of play approach was taken from the state of play approach used in Europe (INSPIRE). For this study, the assessment considered searching websites, country reports, and contacting relevant in-country stakeholders for data collection. The approach was modified and divided into subgroups based on the SDI key indicators, as shown in Table 6.

Table 6: Spatial Data Infrastructure components and measurable indicators

Components of SDI	Number	Measurable Indicator
Legal Framework	1A	Existence of national SDI bodies to facilitate decision making and policy.
	1B	There is a legal framework for geospatial data implementation at the national level
	1C	Existence of central organization responsible for coordinating NSDI implementation
Strategic Impact	2A	There is a strategic approach to promoting innovative geospatial solutions

	2B	There is a strategic method for researching, discovering and implementing new technological functions
	2C	The officially recognized coordinating body for NSDI is responsible for the national data producer (e.g., CSI in South Africa)
Technical Infrastructure	3A	Most of the data created are captured via Metadata
	3B	Web mapping services exist for all core spatial data.
	3C	There is an SDI standard for metadata (ISO 19115) at the national level.
Interoperability	4A	The process of datasets creation is formally standardized.
	4B	There are no restrictions in accessing spatial data

Benefits	5A	The use of SDI has brought measurable benefits to businesses, citizens and society
	5B	The country uses SDI to deploy cross-border eGovernment activities
	5C	Public organizations and private users use SDIs to drive decision-making and service delivery processes.

To ensure that all relevant aspects are explored and examined, SDI perspectives include key indicators:

- **Legal framework:** This indicator covers policy and legal requirements for SDI implementation. This includes e-government services and open data regulations.
- **Strategic Influence:** this indicator includes the strategy developed for advancing the public sector, citizens, organizations, and education.
- **Technical infrastructure:** this indicator covers the development of advanced components.
- **Interoperability:** this indicator focuses on promoting interoperability of data, integrating data collections, and establishing connections between different portals and platforms.
- **Benefit:** This is about the benefits of SDI development among government, businesses, and citizens.

A total of 15 questionnaires were distributed to relevant stakeholders in the selected countries: Professionals (government and private sector), users and producers, academia and NGOs.

5.3 Problems encountered

The main challenge in this research project was that most respondents did not respond to emails in real time. Email communication was considered the easiest means of interaction due to geographic barriers. Other problems included the lack of accessibility to the NSDI website, e.g., the Botswana website http://www.ngis.gov.bw/ (no longer available).

5.4 Conclusion

This chapter explained the data collection processes and approaches within this study. The case study methodology and associated methods were explained in relation to the research questions and objectives. In addition, the questionnaire provides insight into the assessment of the current state of SDI in the selected countries. Document and website search was used to extract information about SDI in the selected countries.

Chapter 6 Results and Discussion on the status of NSDI

6.0 Introduction

This chapter presents the results of the organizational assessment and modified state of play approach used to assess the SDI status in selected Southern African countries. The objective is to assess the progress and enabling environment for SDI development in these countries.

The organizational assessments include four components related to the status of SDI development. Among the selected countries, South Africa is the only country with advanced legal indicators that support the progress of organizational SDI activities. As mentioned in Chapter 5, the modified State of Play approach was adopted from the State of Play approach (INSPIRE). The State of Play approach was also modified into 5 main components: Legal Framework, Strategic Influence, Technical Infrastructure, Interoperability, and Utility to reflect the nature of the NSDI framework in Southern Africa. These components were grouped into 14 measurable indicators for further analysis.

6.1 Results for Organizational Assessments

The results of the organizational assessments show that the selected countries are at different stages of spatial data infrastructure development. There is a lack of infrastructural and technical facilities at the national level. Each organization is building its own "infrastructure" based on the availability of data models and specific standards. Organizational outputs and collected information are not dependent on other organizations. Thus, individual organizations may have organizational visions. Nevertheless, there is no shared vision for SDI in the Southern African region.

Among the selected countries, few understand the potential value of the SDI concept. Organizations lack the resources to convince potential stakeholders to participate in SDI. In addition, SDI is not considered a priority by the organizations responsible for NSDI activities. Communication among relevant SDI organizations is not open, and top management does not see the need to change the inward-looking organization by becoming more outward-looking.

The organizational assessment focused on four main components, similar to the Multi-View

Assessment Framework of Grus et al. (2011). The organizational components include:

- Leadership
- Communication channels
- Self-organizational capability
- Vision

6.1.1 Organizational Assessment of South Africa

- Leadership: the Committee for Spatial Information (CSI) provides leadership for the spatial data infrastructure in South Africa. The CSI's work is primarily supported by six subcommittees, including Data Systems, Policy and Legislation, Marketing, Standards, and Education. In addition, the spatial data infrastructure in South Africa has an institutional, national technical and policy framework to support the collection, management, integration, maintenance, distribution and use of spatial data. Currently, the electronic data collection facility or geospatial data portal is operational (http://www.sasdi.gov.za/sites/SASDI/). Nevertheless, it needs additional capabilities, such as innovative impact, to achieve the goal of data managers and users, as shown in Figure 10.

- Self-organization capability: to improve the management of land reform and rural development, South Africa has initiated policy changes. These support the SDI department's commitment to update a mandate that meets citizens' expectations. Some of the legislative and self-organizational capabilities include:

- Geomatics Profession Act, Act 19 of 2013: the Act replaces the Surveyors and Technical Surveyors Act, 40 of 1984, and is aimed at SDI stakeholders and geographic professionals.

- Spatial Data Infrastructure Act, 54 of 2003: the SDI Act promotes the South African Spatial Data Infrastructure and the Committee for Geographic Information. It also enables the open sharing of geospatial data within various government institutions.

Vision: The vision for the South African Spatial Data Infrastructure is that the country's geo-referenced data, products and services are accessible and available to all users. This can be achieved by:

- Promoting the relevance and benefits of a national spatial data infrastructure.
- Creating awareness among stakeholders of the South African spatial data infrastructure.
- Improving SDI activities through governance, data accessibility, integrability, interoperability, and quality.
- Encourage private and public sector organizations to adopt and support the activities of the national spatial data infrastructure.

Communication Channels: Some of the objectives of the South African Spatial Data Infrastructure communication channels are:

- Improve coordination and cooperation among stakeholders and the spatial data community.

- Create awareness through implementation of the SDI Act and regulations among government agencies.

- Improve communication between CSI and other regional and global partners.

- Facilitate CSI activities and services.

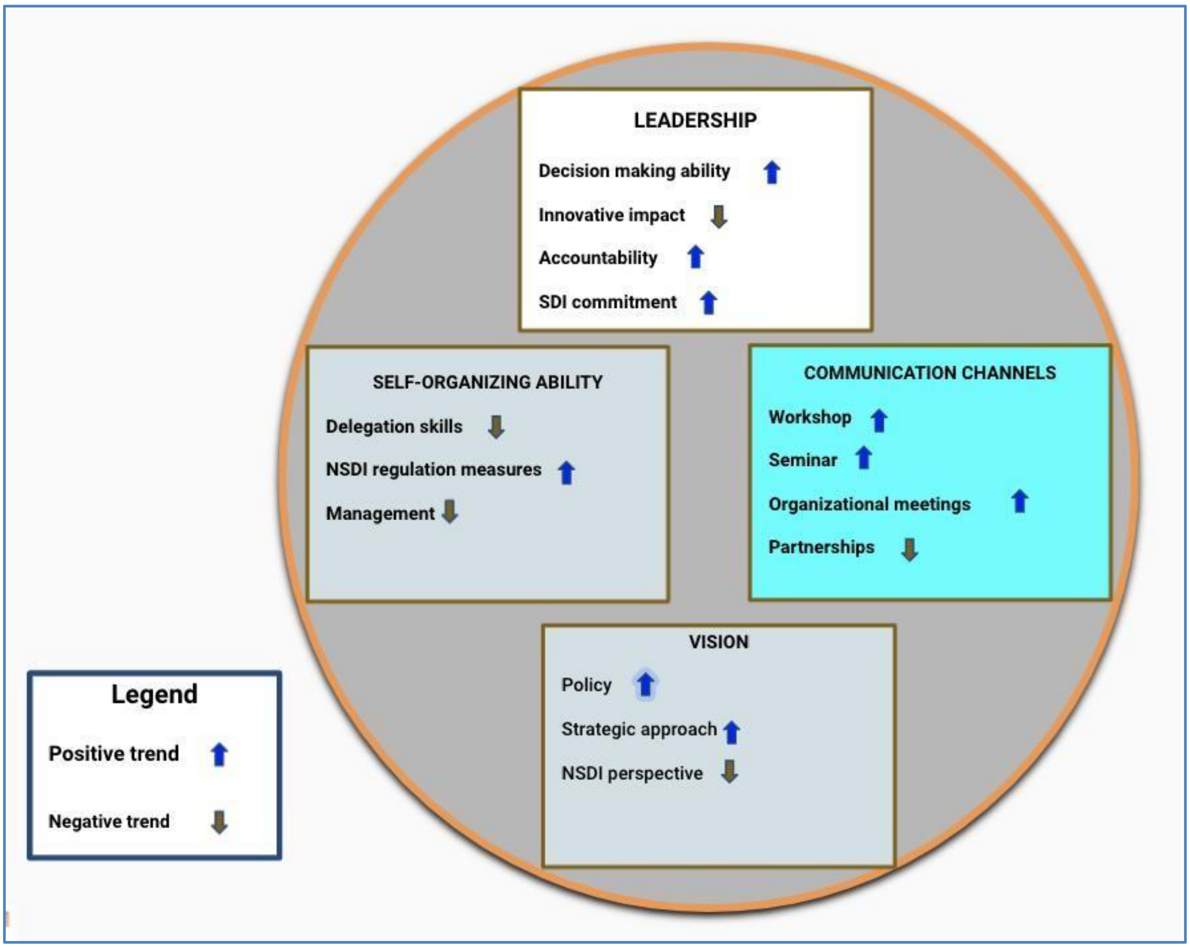

Figure 15: showing the trends in organizational assessment results in South Africa

6.1.2 Botswana Organizational Assessment

Leadership: the Department of Survey and Mapping leads the activities of the Botswana Spatial Data Infrastructure. Despite the lack of adequate activities, the initiatives have made progress in collecting geospatial data to facilitate socioeconomic development in line with the BSDI goal of "providing land and housing for socioeconomic development."

Self-organization capability: the government is still in the early stages of implementing an e-governance strategy to advance the initiatives of the GIS Cluster and the Land Information Center. In addition, the NSDI committee in Botswana has signed an Enterprise License Agreement (ELA) with ESRI South Africa to promote sharing/integration of spatial information and address data compatibility issues.

Vision: Botswana has developed a land policy that addresses economic development, equitable land distribution, gender, and access to land. In addition, the Land Tribunal Bill was passed to empower existing tribunals to address land use planning appeals and spatial data infrastructure implementation.

Some of the future policy activities include:

- Review and formulate policies for national planning and land management initiatives.
- Incorporate available technology and support from international organizations to develop a meaningful NSDI framework.
- Digital mapping of the land to facilitate planning and sustainable economic development.

Communication Channels: The Survey Department has formulated a public-private partnership (PPP) strategy to promote land reform by engaging the private sector in land-related services.

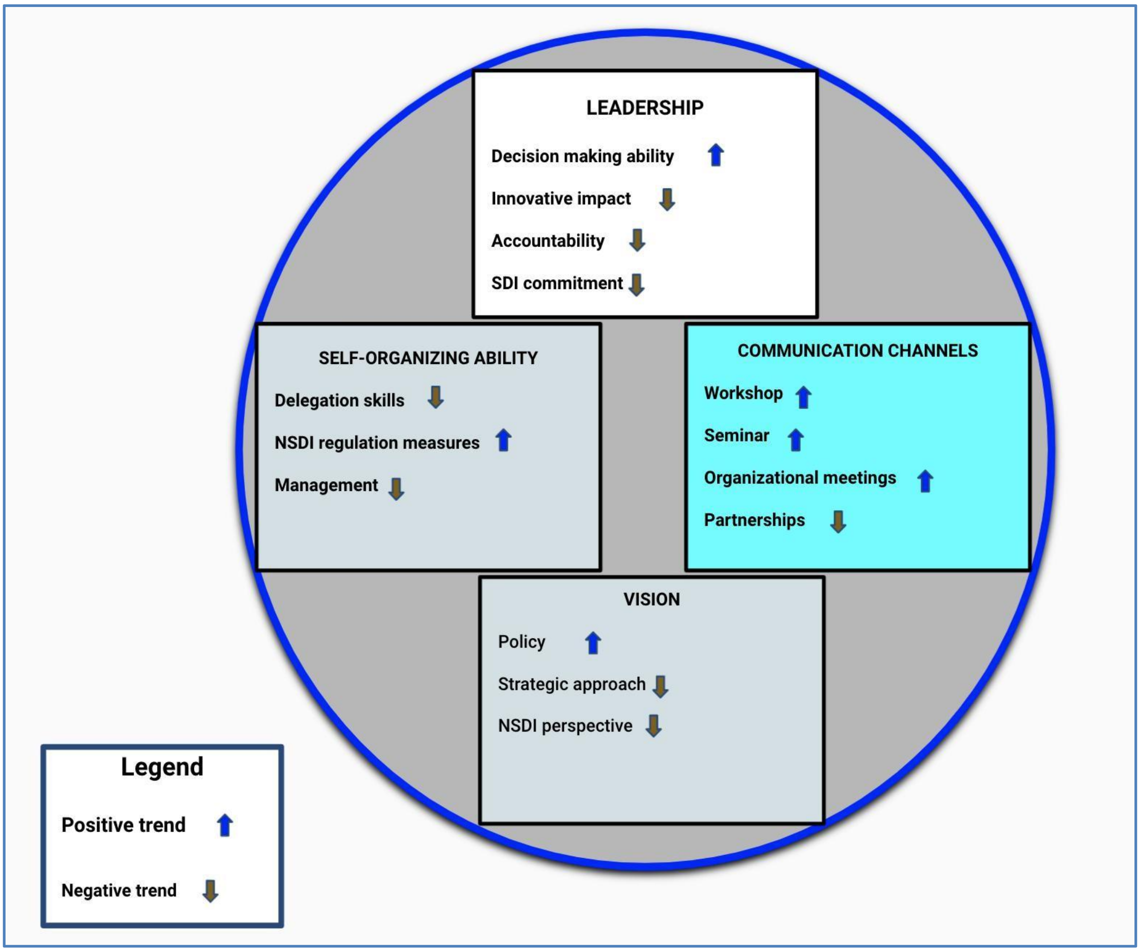

Figure 16: showing the trends in organizational assessment results in Botswana

6.1.3 Organizational Assessment of Tanzania

Leadership: The Ministry of Lands, Housing and Human Settlements Development under the Department of Surveying and Mapping leads the spatial data infrastructure activities in Tanzania. However, the development of spatial data infrastructure in Tanzania has been slow due to lack of financial and human resources. In addition, the country's surveying laws have been written since 1957 without taking technological advances into account, necessitating a revision of the law. Since 2002, attempts have been made to revise the law by formulating a new directive, but this has been neglected due to a lack of political interest. Currently, with funding from the World Bank, work is underway under the Private Sector Competitiveness Project (PSCP) to implement a new guideline for the spatial data infrastructure in the country.

Self-organization capacity: due to the lack of SDI commitment within the country, there are few spatial data infrastructure projects. Regardless, international organizations such as the World Bank are assisting Tanzania in integrating the land management system. The project was implemented to improve data sharing and storage.

Vision: The clear vision of Tanzania's spatial data infrastructure is to solve the problems associated with sharing and managing spatial data. However, the development of the NSDI requires long-term collaboration to support the integrity and continuity of activities. Given the complexity of SDIs, the country needs to develop a clear vision to achieve the goal of the spatial data infrastructure.

Communication Channels: In recent years, efforts have been made to identify areas where human interaction requires collaboration to promote cross-border transactions and procedures. For example, Nakonde/Tunduma is one of the areas where communication channels impact the One-Stop Border Post (OSBP). Other areas with cross-border communication and cooperation are Holili (Tanzania/Kenya border) and Namanga, which is also between Tanzania and Kenya. However, this form of communication channels will promote the adoption of SDI activities and strengthen cross-border relations.

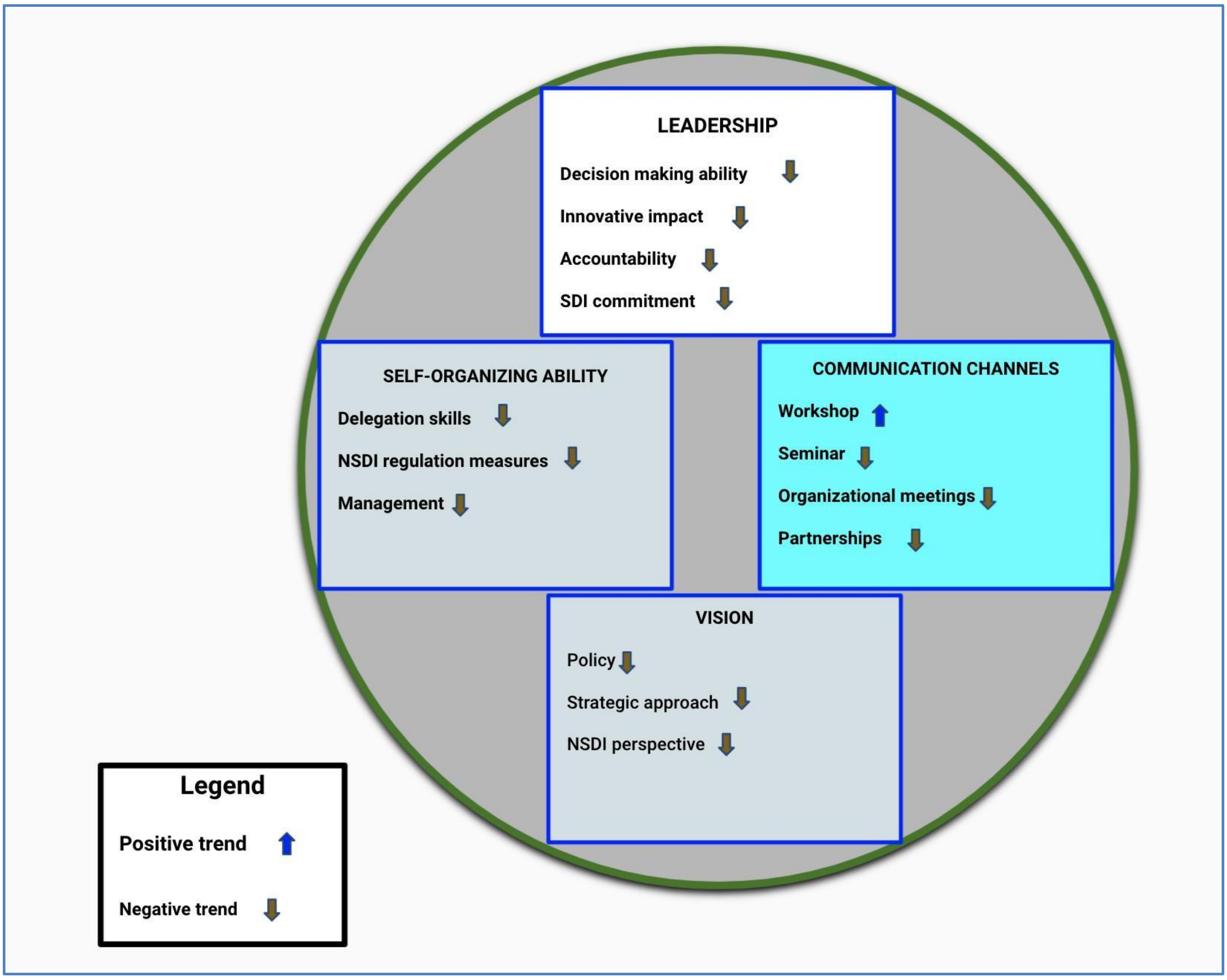

Figure 17: showing the trends in organizational assessment results in Tanzania

6.1.4 Organizational Assessment of Malawi

Leadership: the Department of Survey (DoS) manages spatial data infrastructure activities in Malawi. However, due to high poverty, diverse cultures, and population growth, innovation, accountability, and decision-making in the country are low.

Vision: the country tends to address many issues related to SDI, such as capacity building, surveying, international boundary compliance, and digital geospatial data production.

Communication channels: mainly through workshops and support from the international organization.

Self-organization capacity: the country lacks adequate management, delegation capacity and regulatory measures. In recent years, many institutions have proposed to implement the land reform program within community organizations, non-governmental organizations and civil society. Some of the notable achievements of the program are:

- The reform of land resources in Malawi to facilitate rural and income-generating livelihoods.
- Stakeholder participation in the ineffective use and management of Malawi's land resources.
- Implementing land-related programs.

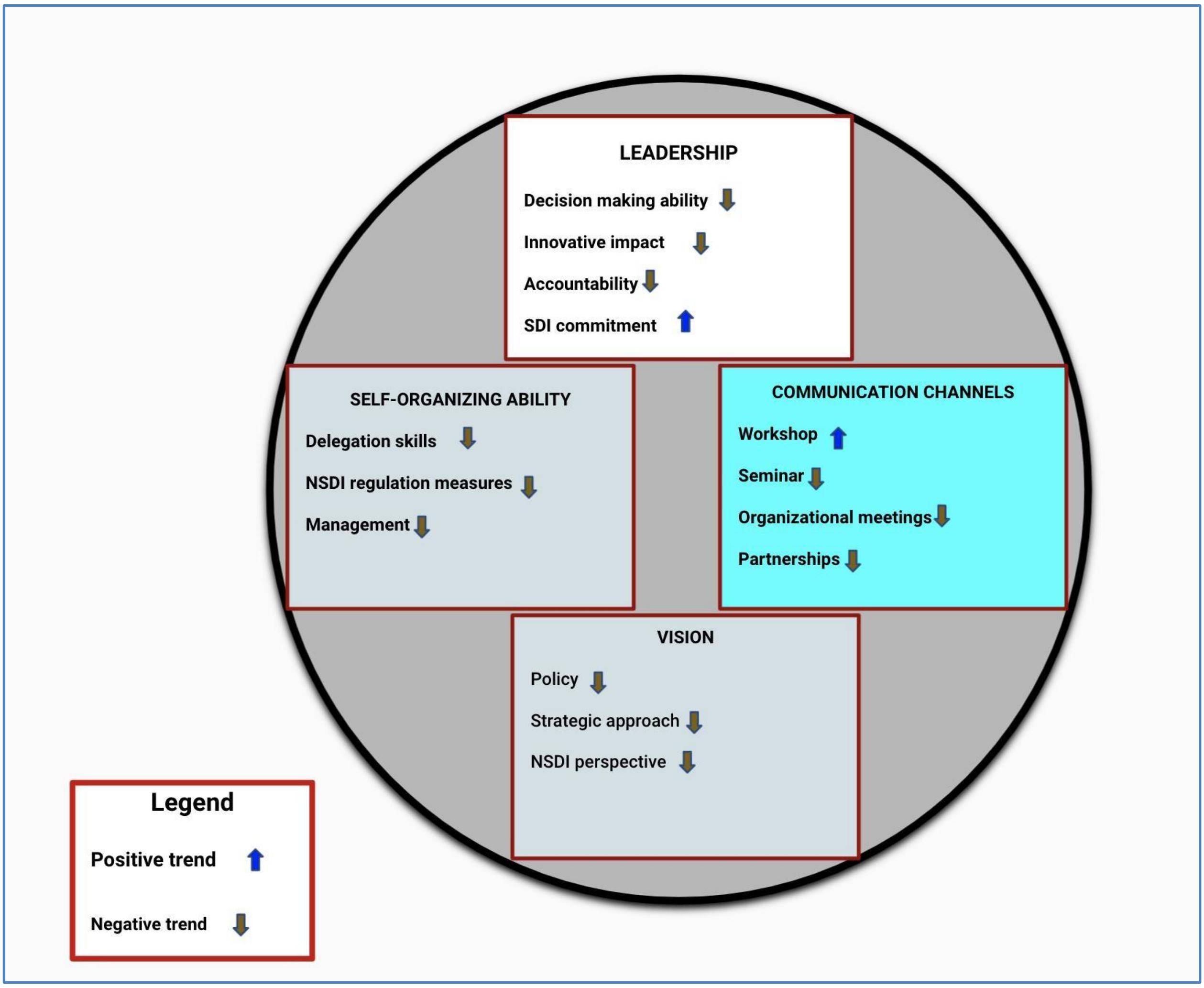

Figure 18: showing the trends in organizational assessment results in Malawi

6.1.5 Organizational Assessment of Zimbabwe

Leadership: the Department of Surveying under the National Mapping Agency manages the spatial data infrastructure activities in Zimbabwe. The department is divided into three technical divisions: the Mapping Division, the Cadastral Division, and the Geodesy Division, which support spatial services and task fulfillment. There are also supporting departments such as Human Resources, Finance, and IT.

Self-Organization Capability: The County has included several mandates to meet geospatial services and shared facilities requirements. These include:

-Cadastral survey of state land under Section 25 of the LSA.
-Maintenance and commissioning of Zimbabwe's international boundary.
-Review and approval of survey data.
-Maintenance and densification of the national geodetic control network.
-Production of thematic maps and topographic base maps.

Vision: The mission of the Zimbabwe Spatial Data Infrastructure is to promote geospatial data and build capacity through interaction and collaboration with the center and member states. Currently this is not being achieved, mainly due to constraints associated with the spatial data infrastructure in Zimbabwe.

Communication Channels: In recent years, Zimbabwe has actively participated in workshops, seminars, and organizational meetings on spatial data infrastructure. In addition, the department has participated and contributed to UN-GGIM forums. Participation has helped the country in terms of external communication, collaboration and sharing of experiences with various organizations and governments. Some of the organizations have shown interest in working with Zimbabwe in the areas of spatial data development.

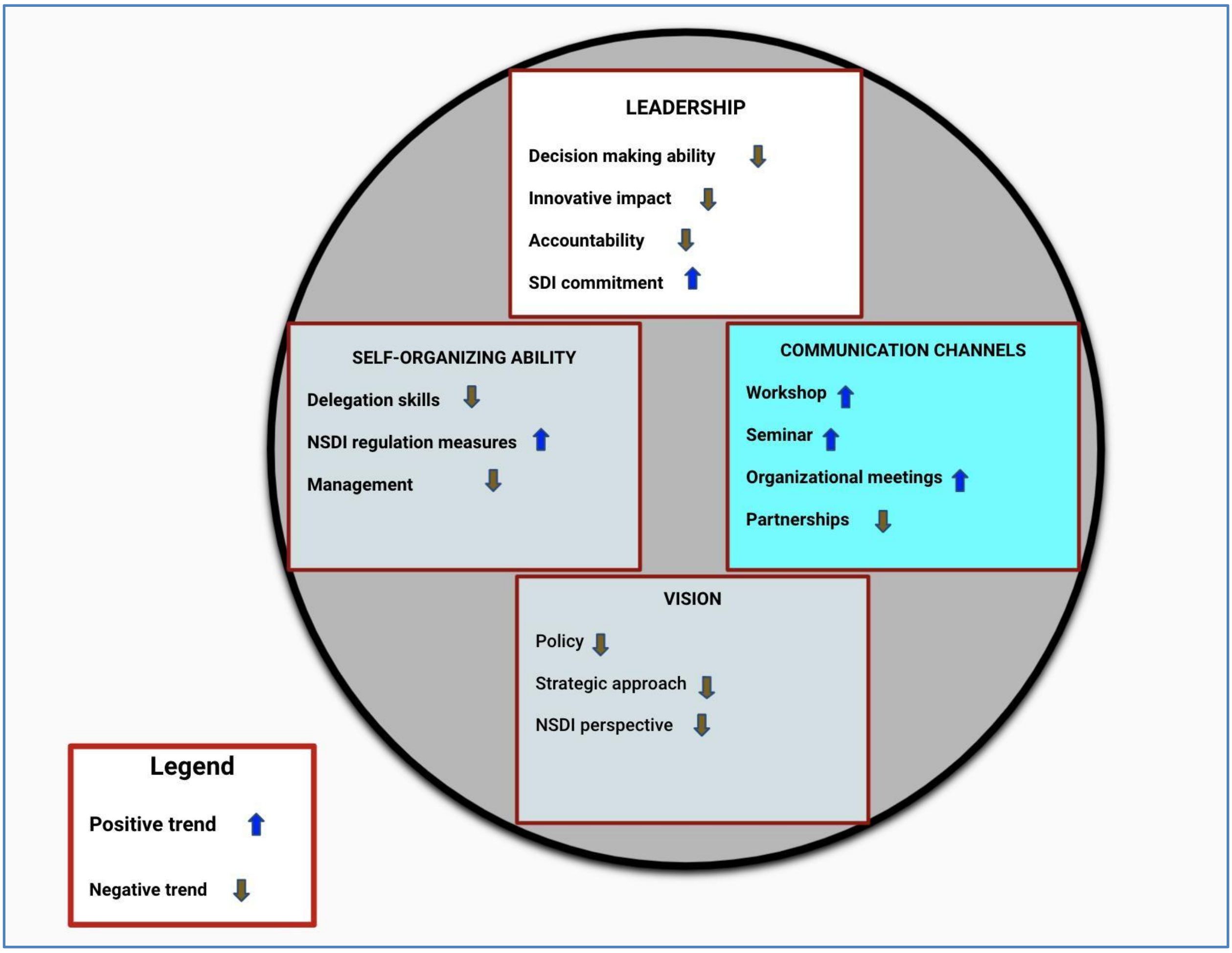

Figure 19: showing the trends in organizational assessment results in Zimbabwe

6.2 Organizational assessment of United Nations Global Geospatial Information Management in African countries

Some of the UN-GGIM activities for geospatial information infrastructure development include:

- **Implementing the Geospatial Information Policy for Africa:** The Economic Commission in Africa (ECA) Division has offered assistance in formulating an overarching geospatial information policy for Africa. The document outlines the common geospatial strategy, vision, organizational capacity, and communications for Africa. The meeting was held in 2016 in Côte d'Ivoire 2016.

- **Report on the Third UN-GGIM Meeting:** The meeting provided an opportunity to launch the African Action Plan on Global Geospatial Information Management, also known as Geospatial Information for Sustainable Development in Africa (GI4SD). The document outlines actions associated with costs, responsibilities, and timelines that will guide future SDI initiatives in Africa.

- **Capacity Development:** to ensure sustainable geospatial information development, attention must be paid to capacity building so that no country in Africa is left behind. With support from UN-GGIM, the Regional Committee organized an international workshop on basic geospatial data sets for monitoring the Sustainable Development Goals. The workshop was held in Addis Ababa, Ethiopia in April 2018.

6.2.1 Organizational assessment challenges and remedial actions identified by UN-GGIM

Many African countries face constraints that affect the full implementation of SDI activities and continental action plans. Based on the recommendations of the third meeting;

- African countries should promote the commitment of member states to participate in UN-GGIM meetings and activities, and in regional SDI in general.
- Identify alternative means of communication and conduct meetings, taking into account available electronic communication channels among member states.
- Ensure that the Economic Commission for Africa, regional and national organizations are actively engaged in the geospatial information community by actively participating in meetings and activities to provide a mechanism for disseminating relevant geospatial information community knowledge in Africa.

6.3 Summary of the assessment of the organizational approach in the selected countries

The results of the organizational assessment approach represent the critical values required to implement a spatial data infrastructure. However, successful implementation of the outcomes depends on the approach taken by each country. Human resources are another potential barrier identified for effective implementation and maintenance of the spatial data infrastructure in the selected countries. Some of the recommendations for an effective organizational approach in Southern African countries include:

Leadership: SDI implementation requires strong commitment and leadership activities to promote the long-term value of investments in geospatial data. This can only be achieved through prioritization and sequencing to create an action plan that applies to short-, medium-, and long-term interventions. This can only be achieved through government support and advocacy.

Vision: the vision for a national spatial data infrastructure should be clear, sustainable, and transparent to relevant stakeholders. However, there should be transparency guidelines and accountability for all citizens, academics, government organizations, and the private sector to encourage research and development.

Self-organizability: the spatial data infrastructure implementation framework should be designed to promote national productivity and be sustainable over the long term. As a priority, organizations should be actively involved in the legal and policy structures to form an effective system for managing the spatial data infrastructure and its use.

Communication channels: Effective communication and collaboration (between civil society, organizations, government, and industry) improves the implementation and sharing of geospatial data between providers and users; it also reduces duplication of data within the government sector and clarifies the roles and responsibilities of organizations.

6.4 Modified State of Play Results Analysis

In these sections, most responses focused on the constraints affecting SDI development in Southern African countries. To further explore these findings, they were summarized using measurable indicators to see the frequency of occurrence in the responses. For example, are there national SDI bodies that promote decision-making and policy? The results summaries were presented in Figures 10, 11, 12, 13, and 14. For each measurable indicator, they were converted to percentages by dividing the frequency of each item by the total number of respondents. The bar graphs show whether respondents strongly agree (dark gray color), partially agree (light blue), and disagree (red) with the measurable indicators.

Modified state-of-play components assessed include regulatory framework, strategic impact, technical infrastructure, interoperability, and utility.

The distributions of respondent sample sizes are shown in Figure 20. Almost half of the respondents were selected from national institutions (38.5%), 23.1% from international organizations (UNECA and UN-GGIM), and 23.1% from academia, while 15.4% were from non-governmental organizations

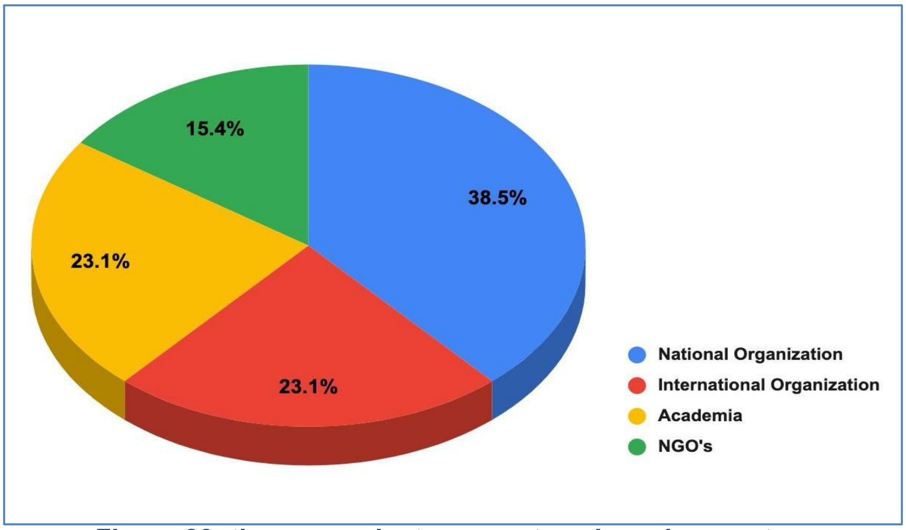

Figure 20: the respondents percentage based on sectors

- Legal framework

Analysis of the results of the questionnaire on the legal framework shows that 69% strongly agree. In comparison, 23% partially agree and 8% disagree that there is a national SDI governance body that promotes decision making and policy. The result of the analysis also shows that 54% of the respondents strongly agree that there is a legal framework for SDI activities in Southern African countries. In addition, 38% partially agree and 8% disagree that there is a legal framework. The possible reason for the high score of "agree" on the legal framework is the active awareness of NSDI initiatives among international organizations such as UN-GGIM and UNECA to promote SDI development in Africa.

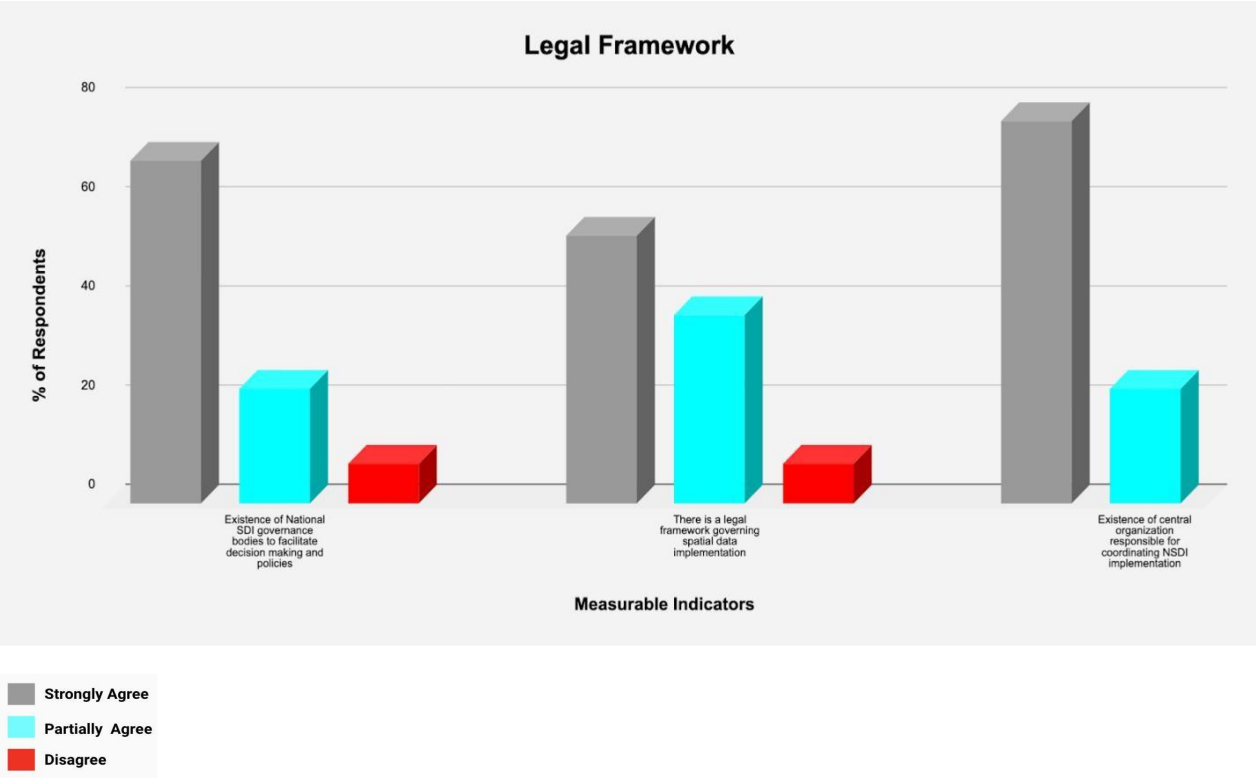

Figure 21: Legal Framework of NSDI results based on modified state of play approach

- Strategic approach

In terms of strategic approach, 43% of respondents indicated that there is a strategic approach to promoting innovative geospatial solutions. Many respondents also partially agree (31%) and disagree (23%) that there is a strategic approach to SDI development services. When asked if there is a strategic approach to researching and implementing technology capabilities, 54% agreed (disagreed). In addition, most respondents identified the need for a strategic influence on SDI development in Southern African countries. Accordingly, strategic influence, which includes technical capacity and national policies, needs to be better aligned with the regulatory framework in order for Southern African countries to develop and contribute positively to the ecosystem of national spatial data infrastructure development. Other findings show that Southern African countries can benefit from the strategic guidance developed by UN-GGIM. The strategic drivers include: Multilateral Trade Agreements, United Nations Ocean Conference: Call for Action, Transforming our World: 2030 Agenda for sustainable development and National Transformation Programme etc. (Crompvoets 2019).

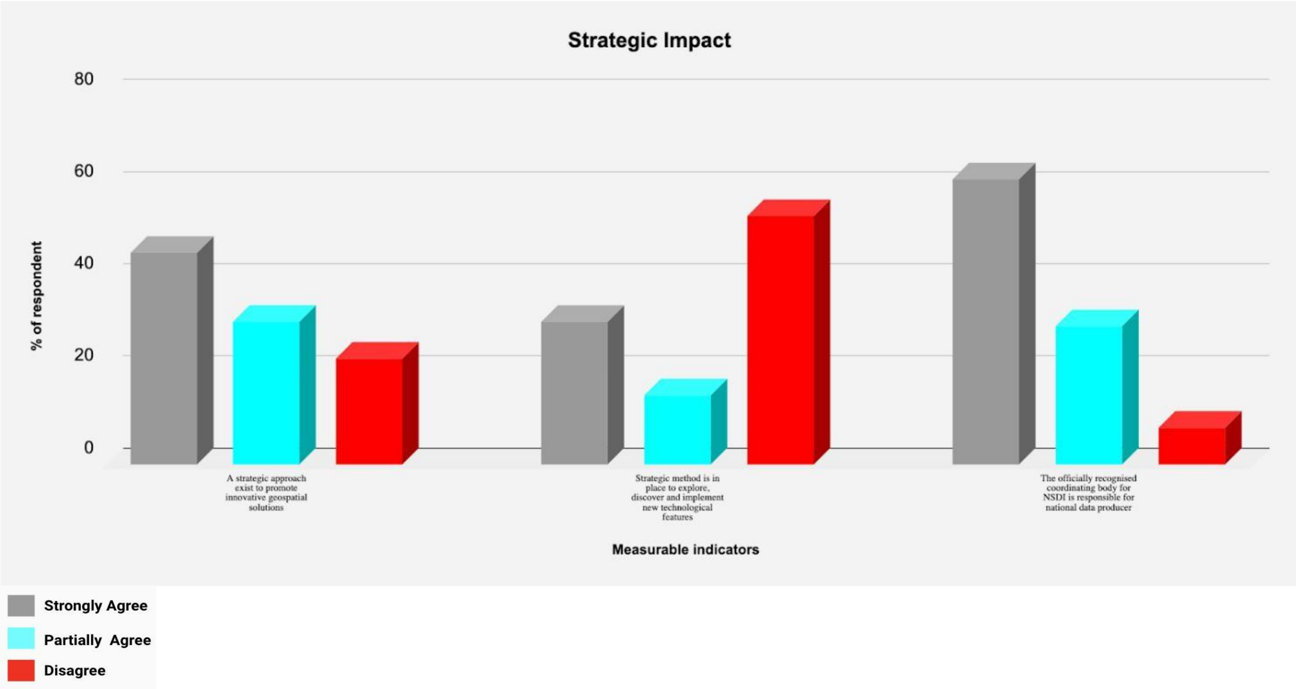

Figure 22: Strategic Impact of NSDI results based on modified state of play approach

- Technical Infrastructure

The results on technical infrastructure show a lack of digital data and a lack of data quality control measures within the selected countries. Regarding the collection of metadata for data creation, 46% of respondents strongly agree. At the same time, other indicators show that most of the spatial data infrastructure in Southern Africa exists in analog form. As a result, it is indicated that 62% of respondents partially agree with the SDI standard for metadata. With respect to web mapping services for geocore data, only 31% of respondents strongly agree with the statement, while 46% partially agree. These results show that NSDI does not have an adequate technical framework in the selected countries.

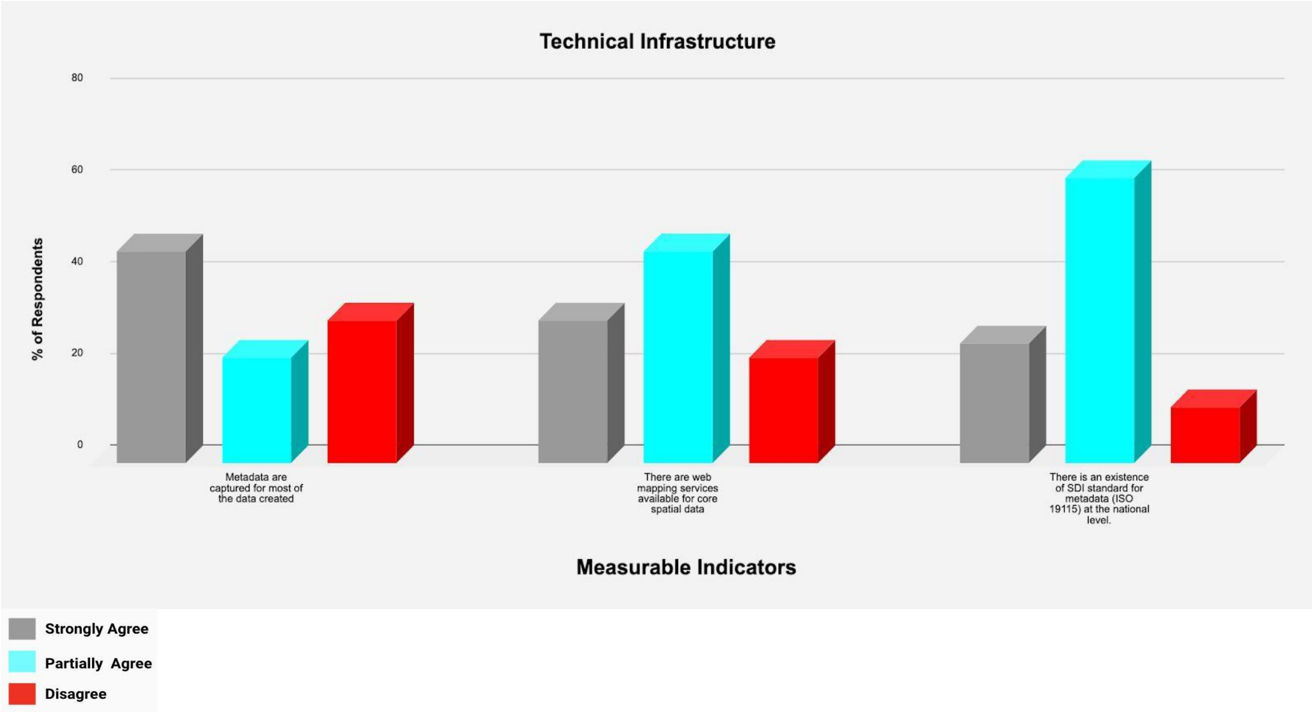

Figure 23: Technical Infrastructure of NSDI results based on modified state of play approach

- Interoperability

Among the selected countries, the interoperability component did not receive much attention compared to the other identified components. As shown in the figure below, the data creation process is partially answered due to formal standards and geospatial constraints. The reason for the low score is not only a lack of human resources, but also a lack of infrastructural constraints such as telecommunication facilities.

Regarding the data creation process, 48% partially agree that there is a data creation process through formal standards, while 26% agree. This contrasting result is due to a lack of awareness among SDI stakeholders about the existence and benefits of interoperability.

The result is consistent with Maphale (2019). This is attributed to either a lack of functioning infrastructure development or fewer technical experts. In addition, most geospatial datasets in Southern African countries do not exist in digital form.

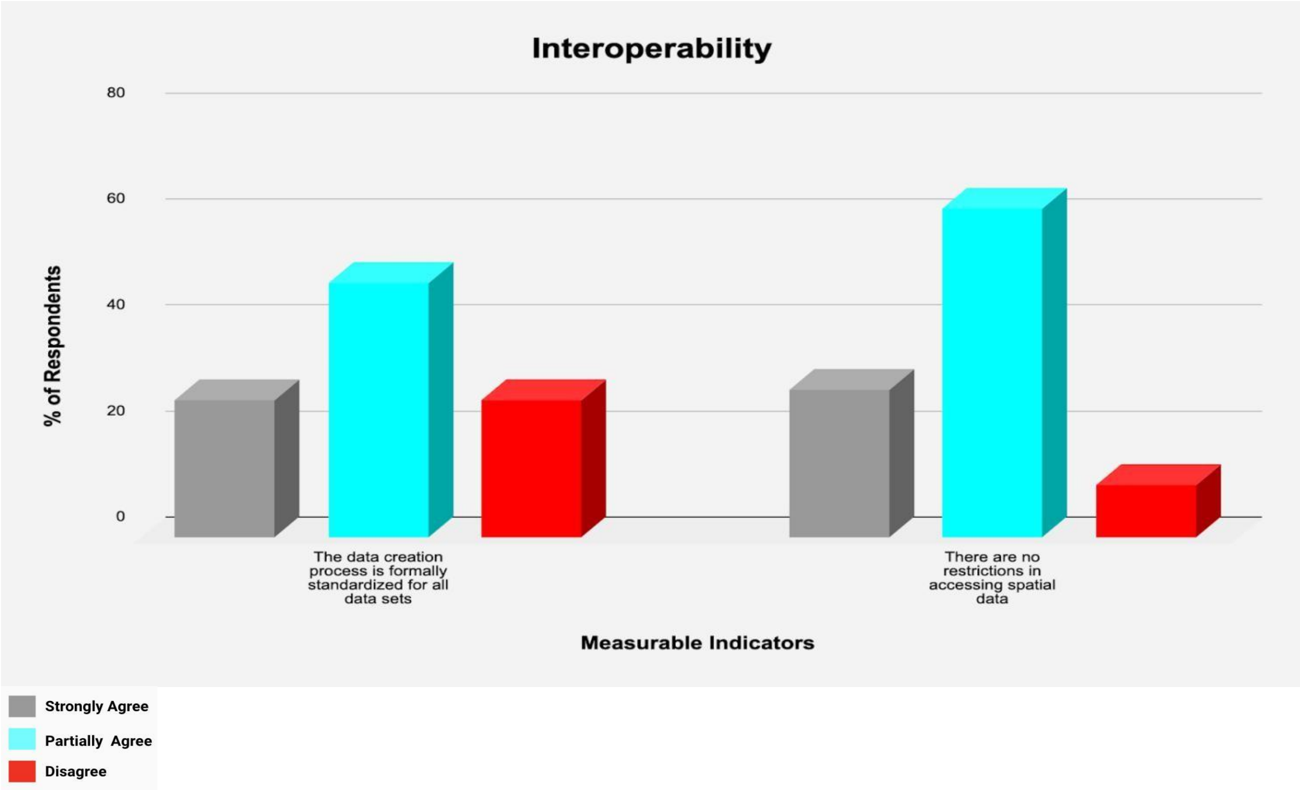

Figure 24: Interoperability of NSDI results based on modified state of play approach

- Benefits

In terms of benefits, 69% of respondents (strongly agree) felt that the spatial data infrastructure brings significant benefits to businesses, citizens, and society, and 46% partially agreed that the NSDI enables cross-border eGovernment activities. 23% of respondents (disagree) cited limitations associated with the use of SDI, such as data sharing limitations, lack of standards, and a conventional way of working. In addition, respondents emphasized the weak connection to SDI development among the selected countries.

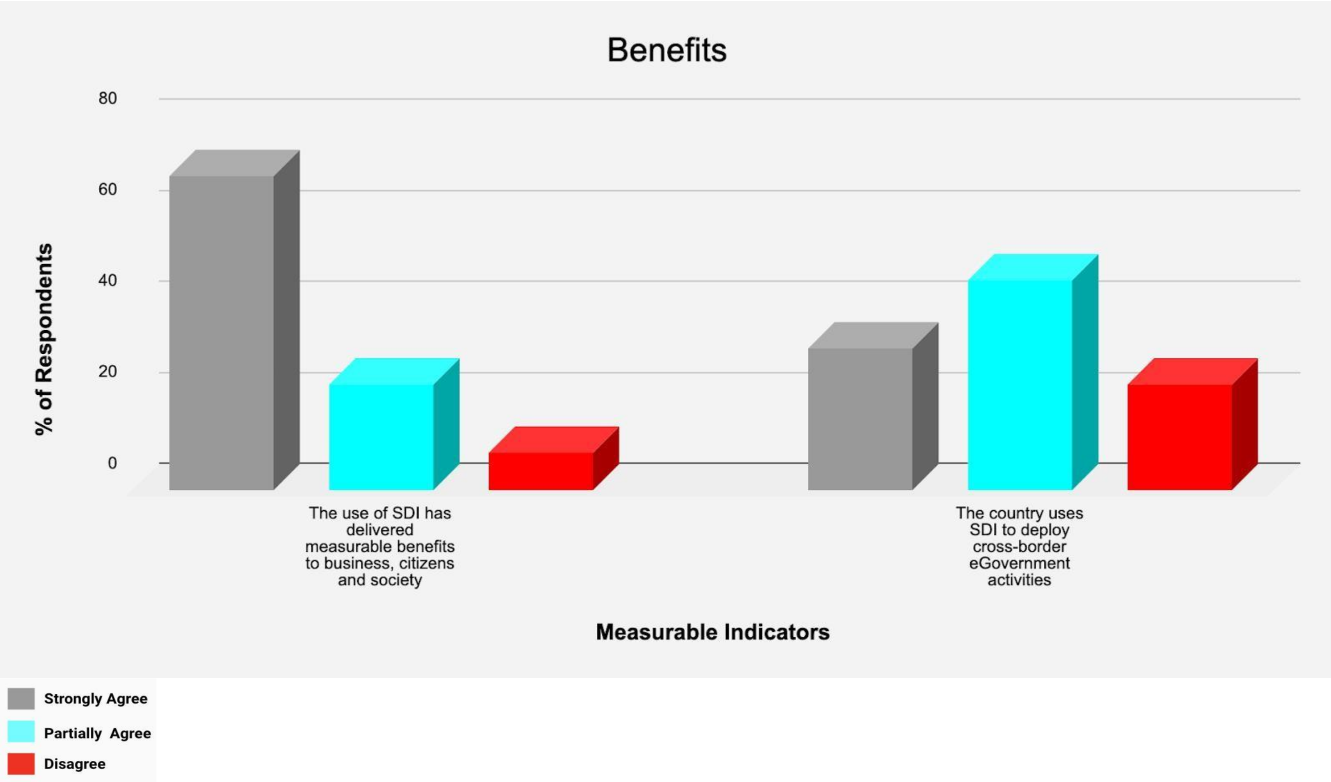

Figure 25: Benefits of NSDI results based on modified state of play approach

6.4.1 Constraints associated with SDI implementation in Southern African countries

In a developing country, implementing a spatial data infrastructure is not an easy task; there are negative impacts associated with successful SDI implementation. Some of the barriers include:

- Lack of financial resources (the financial cost of implementing NSDI is expensive).
- Inadequate knowledge and awareness of geospatial technologies among decision makers (stakeholders).
- Lack of willingness on the part of government to invest in geospatial data acquisition
- Lack of government commitment: in most cases, SDI should be initiated and implemented by the government; if there is no political intent, SDI cannot be realized

6.5 Discussion

Over the years, the impact of SDI has led to the sharing of geospatial data among various organizations (private and public) and citizens. Despite the progress, the implementation of a National Spatial Data Infrastructure (NDI) in developing countries, especially in Southern African countries, has struggled to achieve tangible results. Lack of technical infrastructure, basic datasets, strategic impact, and interoperability are among the challenges affecting the selected countries.

Apart from South Africa, other selected countries also struggle with duplication of datasets as many stakeholders create data for their own needs using different data formats, standards, specifications, data redundancy, and different sources of basemaps. In addition, stakeholders involved in NSDI implementation have had problems with political support for integration and sharing of baseline datasets.

The results of the modified state-of-play approach within the selected countries also indicated that access to and sharing of data within NSDI government departments remains one of the main obstacles involving technical infrastructure, legal framework, and strategic policy implications. Privacy and national security issues are also barriers. However, the technical means to achieve interoperability are still in the early stages in Southern African countries, while human and political issues exist. The desire of government departments to implement their mandates and budget allocations prevents mechanisms for sharing and effectively distributing spatial data infrastructure (UN-GGIM 2020).

In conclusion, the study suggests that more attention should be paid to the following areas of spatial data infrastructure in the selected countries:

-Redefining geospatial resource metadata and provenance in the selected countries.

-Increase the visibility of spatial data infrastructure on the web and develop a national framework for access to open public data such as geospatial datasets.

Chapter 7 Conclusions and recommendations

7.1 Conclusion

Spatial Data Infrastructure has been identified as a best practice for addressing development challenges in Africa. Unfortunately, the implementation of SDI in the selected countries has been slow compared to the experience in developed countries.

This study highlights key findings from the assessment, including:

- The adoption of new technologies such as FOSS, cloud computing, and VGI in African countries was highlighted in Chapter 4. These include the integration of scalable geospatial services and cost-effective SDI implementation. As part of this research, an application was developed to highlight the importance and potential of the emerging trends.

- Review of the organizational aspects of the NSDI results shows that the status of leadership, vision, self-organization capacity, and communication channels is relatively good in some selected countries (South Africa and Botswana). Other selected countries (Malawi, Zimbabwe, and Tanzania) are still in the process of developing a long-term strategic plan in accordance with the draft policy to promote SDI organizational activities.

- The results of the Modified State of Play approach indicate that SDI key components and measurable indicators are underutilized. This approach also identifies a lack of digital data, a lack of data set policy, and inadequate control measures

- The assessment found that most countries in Southern African regions lack human and financial resources. Other identified constraints include lack of political support, limitations in access to basic geospatial datasets, and national policy and guideline issues.

In summary, the status of NSDI development in Southern African countries is low, but there is a great opportunity to improve in the future.

7.1.1 Answers to the research questions

Answers to the questions posed in Chapter 1 are provided, based on the results analysis in Chapter 6.

Question 1: What are the barriers affecting the implementation of SDI in the selected countries?

At the national level, SDI implementation has been affected by several issues. In the case of Botswana, SDI was first introduced in 2000 by the national Ministry of Environment. Unfortunately, the country is still struggling to establish advanced SDI activities. In other words, the implementation of SDI has been insufficiently successful mainly due to the lack of basic data sets (metadata, competent geoportals, and standards) and supportive legal frameworks. Thus, the mandate of BSDI remains unclear.

In a similar context, Tanzania lacks a legal framework for SDI. This has resulted in a weak organizational mandate, inadequate funding, and poorly developed infrastructure. In other selected countries (Zimbabwe and Malawi), strategic impact and political support are lacking. Therefore, strategic impact is considered an important component to the SDI framework.

On the other hand, South Africa has had the SDI Act since 2003 with the goal of implementing a national SDI. In recent years, the country has faced many challenges, which include cooperation and coordination despite the mandate of the DRDLR (Department of Rural Development and Land Reform). Although South Africa has an active website that addresses issues related to NSDI activities (http://www.sasdi.net/), it is not sufficient to provide access to geospatial data as required by the SASDI Act.

In summary, the main constraint affecting SDI components is the slow pace of development; this needs to be identified and scaled at the national level.

Question 2: Who are the main actors/departments responsible for coordinating SDI activities and how can they work together to achieve a similar goal?

Existing documents and questionnaire responses indicated that there are SDI efforts at the national level. For example, in Botswana, two departments are recognized to have made decisions related to SDI activities at different times. From 2002 to 2009, the Department of Information Technology (DIT) managed SDI-related activities. Since 2010, the Department of Surveys and Mapping (DSM) has had control of Botswana SDI. During both departmental phases, SDI was considered to be in a better position for successful implementation in the country. After SDI implementation progressed slowly under the DIT department, it was moved to the Department of Land and Housing (Departments of Surveys and Mapping). The Botswana scenario shows that despite coordination of SDI by relevant stakeholders, SDI efforts have not produced acceptable results.

In the case of South Africa, the implementation of SDI is accomplished through the SASDI Act 2003. The organizing act for SDI implementation took place within the Department of Rural Development and Land Reform (DRDLR). The department was further divided into two divisions, namely the National Spatial Information Network (NSIF) and the Committee for Spatial Information (CSI), to facilitate the implementation of the national spatial data infrastructure. The results of this work show that SDI implementation should focus on an independent organization to raise funds and other organizational frameworks such as regulations, guidelines, and policies for effective implementation.

At the national level, there are no sustainable SDI practices among stakeholders. However, this research emphasizes the importance of national SDI mandates, assessments, and organizational structures in defining principles. The proposed structure to facilitate basic SDI implementation includes: Adequate funding, policy formulation, central organization, metadata, fundamental datasets, research, and innovation.

RQ3: How can SDI implementation be successfully implemented in the selected countries?

This study examined the status of SDI development within the selected countries. However, some barriers to successful SDI implementation were identified. These barriers were examined for South Africa, Botswana, and Tanzania. Within the selected countries, most of the

SDI barriers in the selected countries occurred most often in the latter stages of implementation. Thus, if some of the problems were conclusively identified, then proposed solutions should have been introduced in the early stages. For example, Botswana struggled with SDI implementation, primarily because of a lack of legal framework and mandates from relevant stakeholders. Therefore, had Botswana advocated for an effective legal framework (regulations, laws, guidelines, and policies) under SDI, it would have made progress compared to South Africa.

7.1.2 Research Contribution to Knowledge

This study made a positive contribution to the existing research knowledge on SDI. These include;

1) Legal framework of spatial data infrastructure: the scope of this study covered the components of SDI development and implementation within the selected countries. However, selected countries (Botswana and South Africa) with legal frameworks have robust SDI implementation compared to Malawi, Zimbabwe and Tanzania without legal frameworks. This study suggested that a legal framework for SDI should be a prerequisite for SDI implementation in African countries.

2) Barriers to SDI implementation: in most cases, the identified SDI barriers improve the planning processes and the status of spatial data infrastructure. When the problems are understood among relevant stakeholders, it is easier to solve them at national, regional, and global levels, depending on the core values. The results show that national SDIs face challenges mainly due to the lack of a legal framework or SDI awareness. In South Africa, for example, the main constraints are due to inadequate coordination and organization of SDI concepts. In Tanzania, on the other hand, SDI implementation is slow due to many factors identified in Chapter 6.

7.2 Recommendations

Based on the assessment results and study limitations, the following recommendations are proposed for NSDI development in Southern African countries:

- Technological trends (such as FOSS, cloud computing, and VGI) should be embraced by developing countries as they contribute positively to the successful implementation of the National Spatial Data Infrastructure. These platforms will also enable African countries to develop SDI that meets international standards.

- African countries should consider improving their SDI implementation practices by providing sustainable funding and sufficient human resources. Other essential SDI components such as metadata, data, standards, policies, and legal frameworks need to be improved for successful SDI development.

- Developing countries, especially African countries, should consider developing human resources and providing more funding to support the development of the SDI technical and legal framework, the development of SDI components (standards, metadata, data, and guidelines), the development of the institutional framework, and the search for political support.

7.3 Areas for Further Study

The main limitation for this study was the lack of readiness and adequate information related to SDI implementation activities within the selected countries. For this reason, many gaps were identified that can be improved in future studies.

The study could be improved by exploring the approaches and opportunities of African countries to adopt new technological trends in SDI. Second, the response rate to the questionnaire was low, but other data sources such as UNECA reports and national SDI documentation were considered.

In future studies, it will be important to see if key organizations responsible for geospatial information on the African continent (for example, UNECA) can contribute to the collection of SDI datasets at the national level.

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Appendix 1: UN-GGIM Integrated Geospatial Information Framework

Integrated Geospatial Information Framework

The Integrated Geospatial Information Framework recognized eight (8) goals to achieve effective use of geospatial information in developing countries.

Future achievement of these goals will enable countries to improve conditions for building capacity and use geospatial information to improve government policy, decision-making, environmental management, and socio-economic development. The eight goals includes;

Goal 1: Efficient Geospatial Information Management.
It is about enabling governance and institutional arrangements to ensure effective spatial data management and organizational arrangements that are aligned with national and global policy frameworks.

Goal 2: Increased Capacity buidling and Knowledge Transfer
Many mechanisms should be in place to create great awareness and use of geospatial information, to promote capacity building, and to strengthen ingenuity in government, academia, and the private and community sectors.

Goal 3: Integrated Geospatial Information Systems and Services

This includes community information, integrated within the governmental organization and evidence-based policy.

Goal 4: Economic Return on Investemnt
Economic return can be actualized through best practice management, innovation, and use of integrated geospatial data within developing countries.

Goal 5: Sustainable Training and Education Programs
Training and education programs should be conducted by professionals in the fields of cartography, geospatial information technology, and data science to develop spaital skills related to policy, law, financial systems, and project management.

Goal 6: International Partnerships and Cooperation
This goal can be achieved by sharing and managing geospatial information in support of national development interests.

Goal 7: National Engagement and Communication
All relevant stakeholders, led by high-level decision makers, should fully integrate geospatial information for socioeconomic development and decision-making.

Goal 8: Improved Societal Value and Benefits

Socio-economic development and environmental sustainability can be achieved by incorporating geo-information products and services.

Source: http://ggim.un.org/UN-GGIM-publications/

Appendix 2: Modified State of Play Assessment Indicators adopted by Grus et al., (2011)

Measurable Indicators	Strongly Agree	Partially Agree	Disagree
Legal framework			
Existence of National SDI governance bodies to facilitate decision making and policies			
There is a legal framework governing spatial data implementation			
Existence of central organization responsible for coordinating NSDI implementation			
Strategic Impact			
A strategic approach exist to promote innovative geospatial solutions			
Strategic method is in place to explore, discover and implement new technological features			
The officially recognised coordinating body for NSDI is responsible for national data producer (e.g CSI in South Africa)			
Technical Infrastructure			
Metadata are captured for most of the data created			
There are web mapping services available for core spatial data			
There is an existence of SDI standard for metadata (ISO 19115) at the national level.			
Interoperability			
The data creation process is formally standardized for all data sets			
There are no restrictions in accessing spatial data			
Benefits			
The use of SDI has delivered measurable benefits to business, citizens and society			
The country uses SDI to deploy cross-border eGovernment activities			

Appendix 3: Questionnaire

Cartography M.Sc.

Reviewing the Status of National Spatial Data Infrastructure: A Case Study in Southern African Countries.
For: MSc Thesis-
Cartography A
Questionnaire Survey

By

John Ogunbiyi

Introduction

The study aimed to assess the current status of National Spatial Data Infrastructure among selected Southern Africa countries (Botswana, South Africa, Malawi, Zimbabwe and Tanzania).

The general objective of this study is to provide an overall view of what has been implemented, organizational process and technological advancement in national spatial data infrastructures.

Organization of the Questionnaire

The SDI components assessed are grouped into three headings and questions are asked on specific aspects. They include:

i) Policy and legal issues

a. Legal framework

b. Leadership

c. Strategic impact

ii) Technical Infrastructure

a. Data access mechnaism

b. Metadata

c. Interoperability

d. Technical standard

iii) People

a. Communication channels

b. Benefits

c. Communication channels

The first part of the questionnaire contains information about the respondents and the organization. Respondents are asked to tick the appropriate answers to the question (X). At the end of the questions, a field is provided for comments on the status and development of the NSDI.

PART 1

1. Name of Organization/Institution

2. Status of Institution

(a) Public ☐ (b) Private☐(c) Non-governmental agencies ☐ (d) Others(please specify)

3. Organizational Website

(a) Internationaal level☐ (b) Regional level ☐ (c) National level☐ (d) Others(please specify)

PART 2: Policy and Legal issues

4. There is a legal framework governing spatial data implementation

(a) Strongly Agree ☐ (b) Partially Agree ☐ (c) Disagree ☐ (d) Not sure ☐

5. Existence of National SDI governance bodies to facilitate decision making and policies

(a) Strongly Agree ☐ (b) Partially Agree ☐ (c) Disagree ☐ (d) Not sure ☐

6. Existence of central organization responsible for coordinating NSDI implementation

(a) Strongly Agree ☐ (b) Partially Agree ☐ (c) Disagree ☐ (d) Not sure ☐

7. A strategic approach exist to promote innovative geospatial solutions

(a) Strongly Agree ☐ ☐ ☐

8. Strategic method is in place to explore, discover and implement new technological features

(a) Strongly Agree ☐ (b) Partially Agree ☐ (c) Disagree ☐ (d) Not sure ☐

9. The officially recognised coordinating body for NSDI is responsible for national data producer (e.g CSI in South Africa)

(a) Strongly Agree ☐ (b) Partially Agree ☐ (c) Disagree ☐ (d) Not sure ☐

PART 3: Technical Infrastructure

10. Metadata are captured for most of the data created

(a) Strongly Agree ☐ (b) Partially Agree ☐ (c) Disagree ☐ (d) Not sure ☐

11. There are web mapping services available for core spatial data

(a) Strongly Agree ☐ (b) Partially Agree ☐ (c) Disagree ☐ (d) Not sure ☐

12. There is an existence of SDI standard for metadata (ISO 19115) at the national level.

(a) Strongly Agree ☐ (b) Partially Agree ☐ (c) Disagree ☐ (d) Not sure ☐

13. The data creation process is formally standardized for all data sets

(a) Strongly Agree ☐ (b) Partially Agree ☐ (c) Disagree ☐ (d) Not sure ☐

14. There are no restrictions in accessing spatial data

(a) Strongly Agree ☐ ☐

PART 4: People

15. The use of SDI has delivered measurable benefits to business, citizens and society

(a) Strongly Agree ☐ (b) Partially Agree ☐ (c) Disagree ☐ (d) Not sure ☐

16. The country uses SDI to deploy cross-border eGovernment activities

(a) Strongly Agree ☐ (b) Partially Agree ☐ (c) Disagree ☐ (d) Not sure ☐

17. Public organization and private users use SDIs to promote decision-making and service delivery processes.

(a) Strongly Agree ☐ (b) Partially Agree ☐ (c) Disagree ☐ (d) Not sure ☐

18. The NSDI initiative incorporate self-organizing ability

(a) Strongly Agree ☐ (b) Partially Agree ☐ (c) Disagree ☐ (d) Not sure ☐

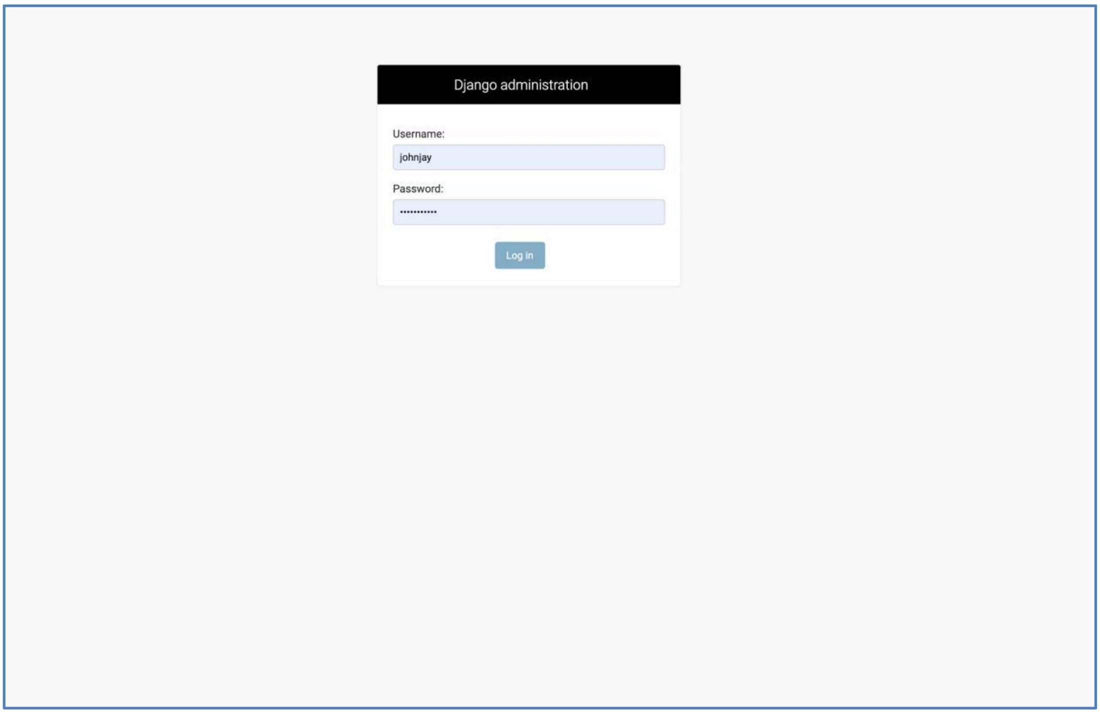
If you have any further comments, please feel free to write them in the box below.

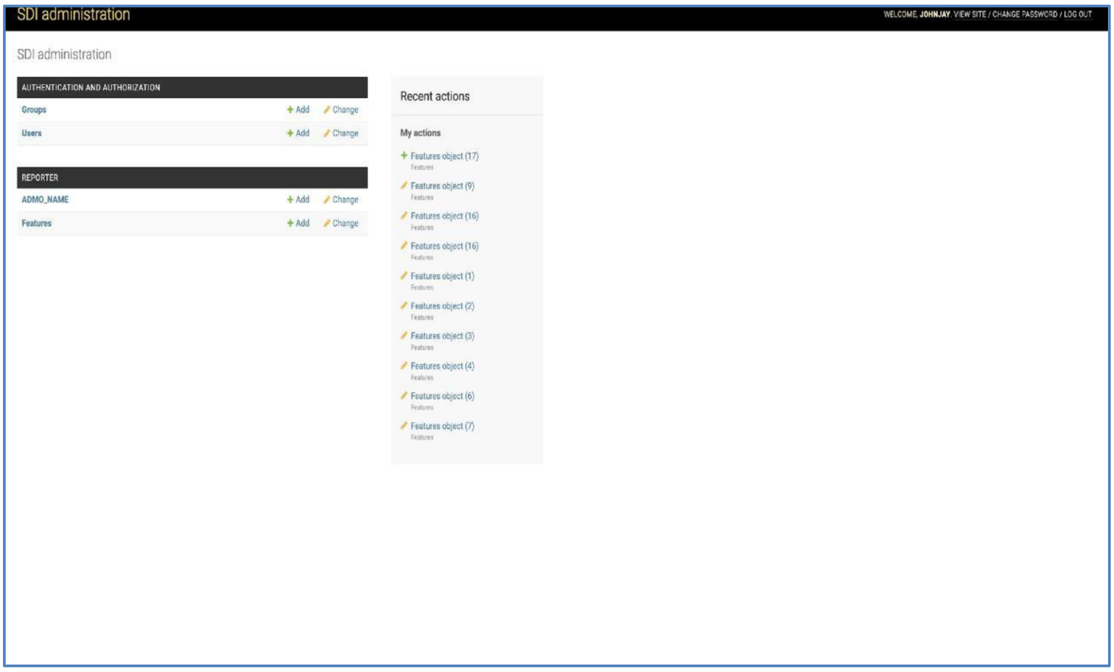
Please return the questionnaire as an attachment to this e-mail Johnogunbiyi01@gmail.com

Thank you for your support!

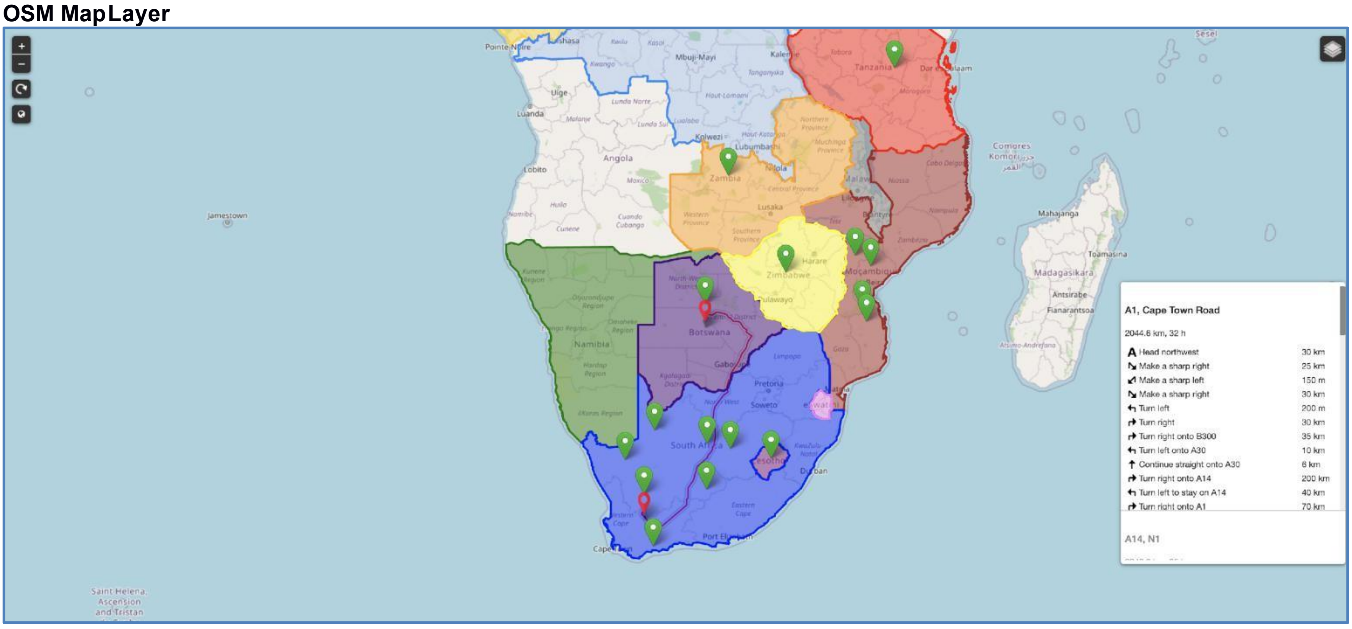
Some of the highlights and features of the geodjango app includes:

- Adminstrative layer of Django Application





OSM Map Layer



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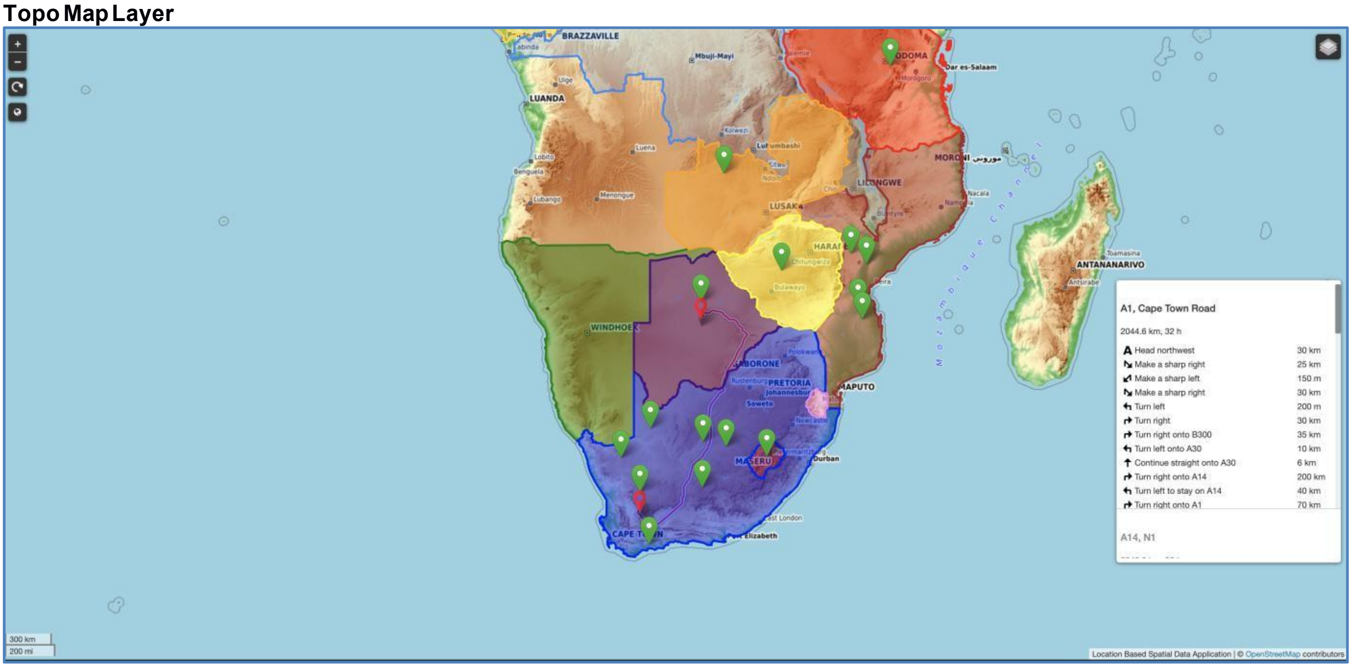
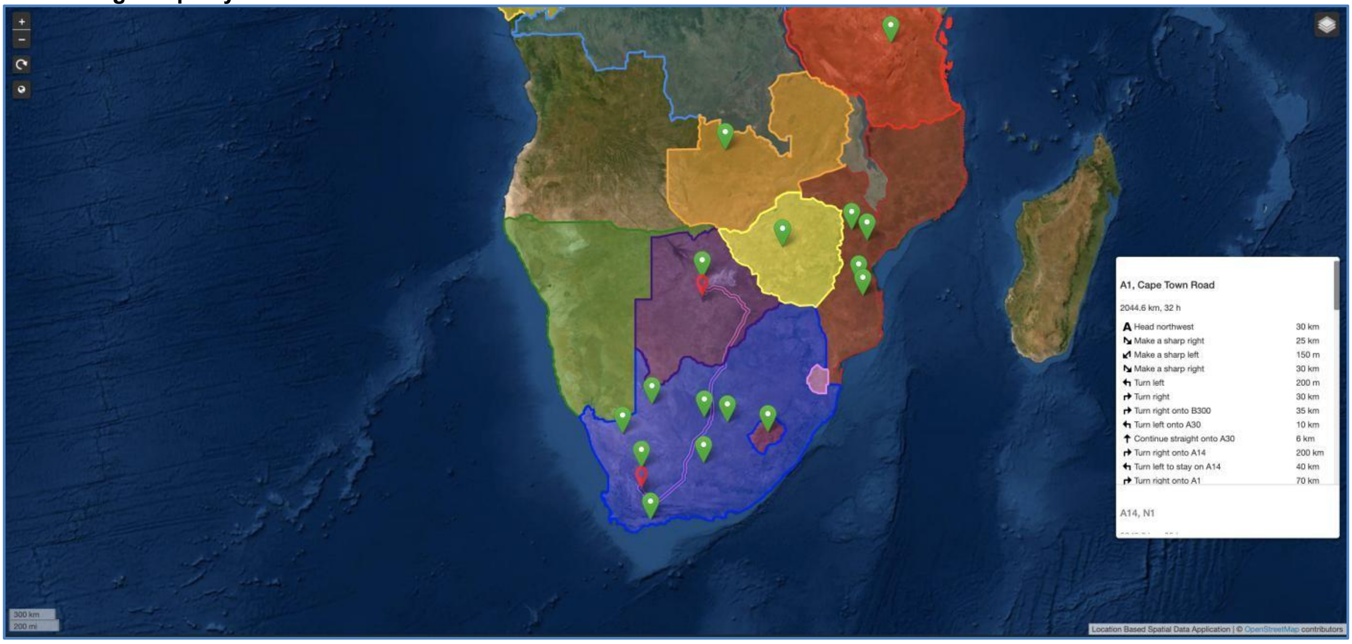
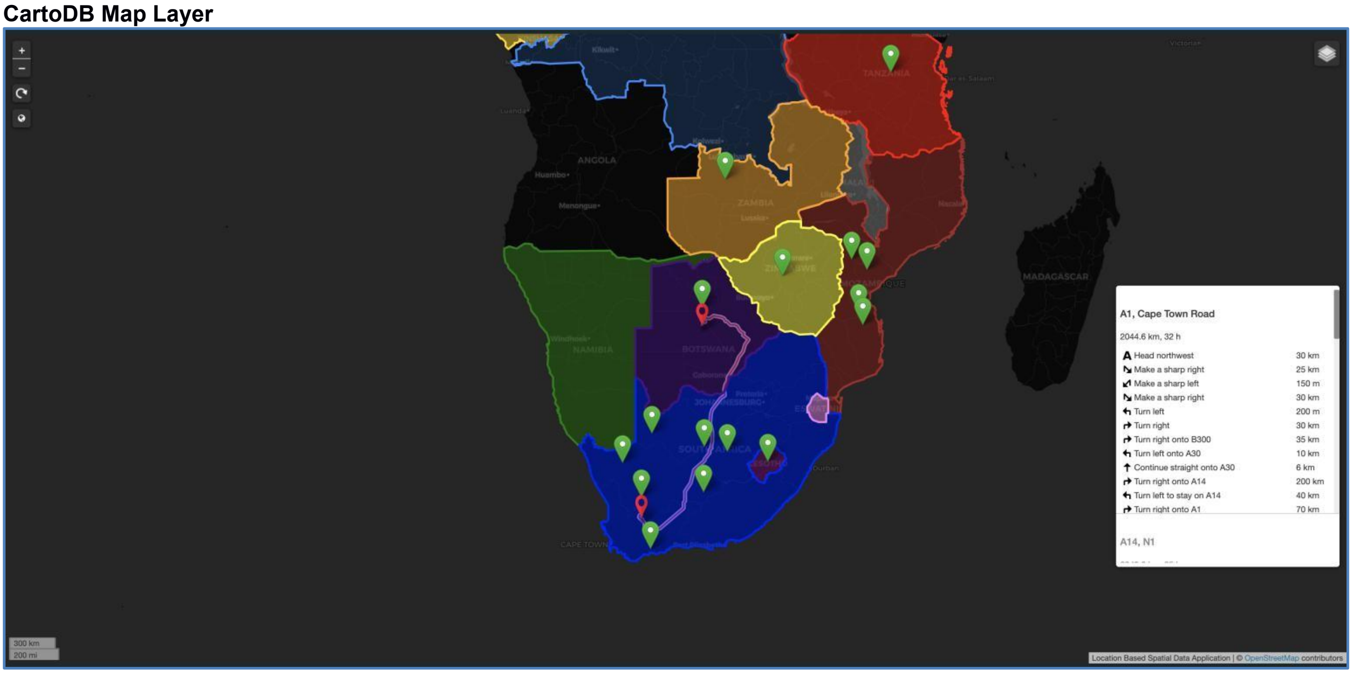


World Image Map Layer



CartoDB Map Layer



ESRI_NatGeo Map Layer