

Assessing Nigeria's Spatial Data Infrastructure (SDI) Readiness Index

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ABSTRACT

Geospatial Data Infrastructure (GDI) or Spatial Data Infrastructure (SDI) plays a vital role in developmental activities, whether in natural resource management or in socio-economic development. The GDI/SDI-readiness approach aims to measure the extent to which countries are prepared to deliver geographical information. It evaluates whether a country is ready to embrace the development of a National Geospatial Data Infrastructure (NGDI) within a specific administrative unit, such as a nation. This study assesses the SDI readiness index of Nigeria for the year 2025. Primary data, supplemented with the United Nations Department of Economic and Social Affairs (UN DESA) 2018 data, were collected for the multi-criteria analysis used to calculate Nigeria's GDI/SDI readiness index for 2024. The results revealed that for the year 2024, Nigeria had a GDI/SDI readiness index of 0.8434 (84%), higher than 0.58 obtained for 2017. Although Nigeria has made some strides toward developing its own National Geospatial Data Infrastructure (NGDI), the country still faces numerous challenges in developing and implementing an effective NGDI.

Keywords— Fuzzy Logic, NGDI, Nigeria, GDI/SDI, Readiness Index.

I. INTRODUCTION

Geospatial Data Infrastructure (GDI) / Spatial Data Infrastructure (SDI) is a comprehensive framework comprising technology, policies, standards, and human resources designed to facilitate the efficient collection, storage, sharing, and use of spatial data. It provides an "invisible backbone" for decision-making, allowing governments, organizations, and citizens to access reliable geographic information [1], [2]. GDI/SDI is a global phenomenon, evolving from inertia to necessity, especially in developing countries. So far, several GDI/SDI assessments have been conducted to measure the state of effectiveness of the GDI/SDI worldwide. The assessment of GDI/SDI performance has been a focal point in numerous studies, with a primary aim to enhance the effectiveness and efficiency of GDI/SDI initiatives [3]. These assessments are crucial for understanding the challenges and opportunities in the development and

implementation of GDI/SDIs, particularly in the context of improving data sharing and integration across various sectors [4]. The studies highlight different methodologies and frameworks used to evaluate GDI/SDI performance, emphasising the importance of evaluation in improving GDI/SDI systems. However, many of these studies have focused on assessing performance [5] or operational status [6], without considering the basic or pre-existing conditions. Aside from the study of Mwungu (2017) that evaluated Nigeria's GDI/SDI-readiness index for 2017, no other related up-to-date studies exist. This is the gap that this study intends to fill. It assesses Nigeria's GDI/SDI readiness index for 2024, taking into consideration the basic conditions necessary to undertake GDI/SDI. The findings can be utilised to respond to inquiries regarding contrasting the development of the implementation of GDI/SDIs in various nations. It can also aid in discovering implementation challenges for GDI/SDI programmes.

Over the past decade, GDI/SDIs have become a crucial component of geo-information research and practice. This has been demonstrated by numerous initiatives at global, regional, national, and local levels [8]. As an increasing number of GDI/SDIs have been established, it is increasingly vital to determine whether they have achieved their goals and delivered benefits. GDI/SDI appraisal serves several purposes, including: to ascertain whether GDI/SDI is functioning, to gauge if GDI/SDI is on track, and to ensure accountability. A GDI/SDI assessment is becoming an essential part of most GDI/SDI policies.

According to Kufoniyi (2013), the inception of GDI/SDI in Nigeria can be traced back to 1990, marked by an unsuccessful endeavour to establish a national land information system. An initiative was also undertaken to establish a national geographic information system in 1999, which was envisioned as a component of what was then termed a national geoinformation infrastructure (NGII). Committees were constituted to formulate a policy for this undertaking, as well as to address technical concerns and financial frameworks; moreover, an effort was initiated to inventory the existing geospatial datasets within the nation prior to the discontinuation of the NGII initiative in 1999. Nigeria's GDI has seen significant progress over the years, but it still faces challenges in terms of completeness, accessibility, and standardisation. While Nigeria has made strides in developing its GDI, the country still faces challenges related to data quality, accessibility, and institutional coordination. Further investment, policy reform, and technological integration are essential for achieving a robust geospatial infrastructure capable of supporting sustainable development and efficient governance.

II. MATERIALS AND METHODS

A. Study area

Nigeria is located in West Africa and is the most populous country on the continent, with an estimated population of over 200 million people [10]. It is a diverse nation with over 250 ethnic groups, the largest of which are the Hausa, Yoruba, and Igbo. The country is made up of 36 states and the Federal Capital Territory (FCT), where the capital, Abuja, is situated. Nigeria has a varied landscape that includes coastal plains, savannas, tropical forests, and mountainous regions. The south is characterised by rainforests and wetlands, while the north consists of arid and semi-arid regions, including the Sahel. The Niger and Benue rivers meet in the central part of the country, providing fertile land for agriculture. The climate varies from tropical in the south, with a rainy season from April to October, to semi-arid in the north, where rainfall is limited. The north experiences a dry season with harmattan winds from December to February. Nigeria is one of Africa's largest economies, largely driven by its oil reserves, which are among the largest in the world. Agriculture, telecommunications, and services also contribute significantly to the economy. Major cities include Lagos, the largest city and economic hub; Abuja, the political capital; Kano, a key commercial centre in the north; and Port Harcourt, an important oil industry city [11].

To evaluate an GDI/SDI readiness index, a wide range of elements that can impact GDI/SDI development must be identified. These factors must then be prioritised, and their prevalence in nations about NGDI implementation must be ascertained. Several GDI/SDI assessment approaches exist that can inform the nature and type of data to be collected. Examples include the Clearinghouse Suitability [12], [13], State of Play [14], Organisational (Institutional) [15], Performance-Based [16], Cadastral [17], and GDI/SDI-Readiness [19], [18]. This study has adopted the GDI/SDI-Readiness approach. This approach has not been widely applied in GDI/SDI assessment studies in Africa; therefore, favouring its adoption.

Primary and secondary data were collected for this multi-criteria analysis using a self-administered questionnaire, supplemented with the UNDESA 2018 data. The survey questionnaire was divided into four main sections: identifying information, respondent details, information about the NGDI (including the geoportal web address, the name or organisation coordinating the NGDI, and its website address), and factors affecting GDI/SDI readiness such as information, human resources, access to technology, and financial resources. Additionally, respondents were asked to share their opinions regarding the availability of core datasets in Nigeria within the questionnaire. The questionnaire was administered between October 2023 and March 2024 to experts in public sector geospatial information organisations operating in Nigeria

and academic institutions involved in teaching geoinformation-related courses in Nigeria, both at the national and state levels. These organisations are located in different parts of the country and were purposefully selected because they are stakeholders in geoinformation products. The response rate was 83%.

Table 1 illustrates the distribution of questionnaire responses by variables. The three variables: human capital index, web connectivity index, and communication infrastructure index, obtained from the UNDESA survey, were excluded from this table.

B. Data Analysis

(i) The GDI/SDI-Readiness Model

Three metrics can be used to measure GDI/SDI readiness: “why,” “what,” and “how”, as captured by [19], [21]. These metrics were adopted in this study. The “what” index is a composite measurement of the capacity and willingness of a country to use GDI/SDIs. The index incorporates organisational, informational, human resources, technological, and financial resources factors, and the index value was determined based on a survey questionnaire that was administered to academic experts. The factors for the GDI/SDI readiness index model were built on the organisational, information, human resources, technology, and financial resources indices [19], [21]. Therefore, making it more qualitative rather than quantitative.

The five components enabling GDI/SDI development—organisation, information, technology, people, and financial resources, were the explanatory variables, while the dependent variable was the state of GDI/SDI [21]. The adopted global GDI/SDI readiness parameters were decomposed into decision criteria (Table 2) for the purpose of effectively assessing and enhancing the development of GDI/SDIs, particularly in developing regions.

A truth scale per category was utilised to evaluate each choice criterion (Table 3). Group procedures were used to assign values to reduce the subjectivity of singular points of view. As suggested in the study of [22], real value was assigned to a category scale (or categorisation). As a result, a seven-tier categorisation system was obtained (Table 3) where the given values were spaced apart by 0.15 units and span from 0.1 to 1.0.

Table 1: Distribution of responses by variables

Variable	Tier							Total
	7	6	5	4	3	2	1	
Vision	4	5	4	3	2	5	4	27
Institutional	5	5	6	2	4	2	3	27
Legal	4	6	5	4	3	3	2	27
Fundamental Datasets	5	3	4	5	3	5	2	27
Metadata Availability	3	5	4	3	3	4	5	27
Culture / Education	6	5	4	4	3	3	2	27
GDI/SDI Champion	3	4	3	3	5	4	5	27
Commercial Software	3	4	3	4	5	3	5	27
Open Source Software	4	2	3	5	3	4	6	27
Government Funding	5	5	5	3	4	2	3	27
Cost Recovery Funding	4	3	3	5	3	4	5	27
Private Funding	3	5	4	3	3	4	5	27

Note: 7 = Extremely high, 6 = Very high, 5 = High, 4 = Medium, 3 = Low, 2 = Very low, and 1 = Extremely low

Table 2: Decomposing global GDI/SDI readiness parameters into decision criteria

Factor Decision Criteria	Decision Criteria
Organisational (O)	Politician's vision (Ov)
	Institutional Leadership (Ol)
	Umbrella legal agreement(s) (Oa)
Information/ Data availability (I)	Digital cartography availability (Ic)
	Metadata availability (Im)
People (P)	Human Capital (Pc)
	GDI/SDI culture-education (Ps)
	Individual leadership (Pl)
Access network (A) / Technology	Web connectivity (Aw)
	Telecommunication infrastructure (At)
	Geospatial software availability (As) /
	Own development (Ad)/ open source (Ao)
Financial Resources (F)	Government central funding (Fg)
	Data Policy aimed to return on investment (Fr)
	Private sector activity (Fp)

Table 3: The fuzzy model's seven-tier classification scheme values (after Espin-Andrade et al., 2016).

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

C. Fuzzy logic application to the GDI/SDI-Readiness model

A fuzzy-based model backed by a novel multivalent logic system called Compensatory Logic was adopted in line with the suggestion of [22]. The only situation where there is a need for care is when the value is 0 (which is entirely incorrect), since it represents a veto. The basic concept of the model is outlined below:

In Boolean logic, a predicate p is a mapping from the universe set X to $\{0, 1\}$. For example, the sentence ‘ x was born in year y ’ declares a model in which the predicate p from the set of pairs (x, y) to $\{0, 1\}$ assigns 1 if x was effectively born in year y and 0 if it cannot be assured that x was born in year y . The propositional connectives \wedge , \vee , \neg and \rightarrow denote operations [22].

$p \wedge q$ is true when and only when both p and q are true. It is called conjunction and symbolises the inclusive use of “and” in natural language.

$p \vee q$ is false when and only when both p and q are false. It is called disjunction and symbolises the use of “or” in natural language

$\neg p$ is true when p is false and conversely. It is called the negation of p .

The fuzzy-based model was used to consider some of the elements' qualitative character. In line with [19] model, the following propositions were assumed:

A nation is prepared to implement an GDI/SDI if and only if it possesses the necessary levels of the global factors: organisational, informational, human, and financial resources, as well as any degree of access network.

$$\text{GDI/SDI Readiness} = O \wedge I \wedge P \wedge A^{0.5} \quad (1)$$

A nation is prepared to embrace an GDI/SDI if it has an appropriate level of worldwide elements: Information, people, financial and organisational resources, and any level of access networks.

$$O = O_v \wedge O_I \wedge O_a \quad (2)$$

If and only if digital cartography and metadata are appropriately available, a country will have the necessary amount of information to carry out GDI/SDI; if neither is available, it will still have a strong level of metadata.

$$I = I_c \wedge (\neg I_c \rightarrow I_m) \quad (3)$$

Only when a nation's human capital, GDI/SDI culture, and individual leadership are at the proper levels do its citizens have the capacity to engage in GDI/SDI.

$$P = P_c \wedge P_s \wedge P_l \quad (4)$$

A nation has the necessary financial resources to carry out GDI/SDI if and only if there is a level of funding from the public or private sectors, as well as the necessary amount of return on investment from the geospatial industry.

$$F = F_g \vee F_p \vee F_r \quad (5)$$

Only if a country has an appropriate level of technological infrastructure, web connectivity, and the relevant availability of geospatial software or its own geoinformatics development or open-source culture can it undertake GDI/SDI.

$$A = A_t \wedge A_w \wedge (A_s \vee A_d \vee A_o) \quad (6)$$

The following model was used to formalise the GDI/SDI readiness index based on fuzzy logic.

$$\text{GDI/SDI Readiness} = (O_v \wedge O_I \wedge O_a) \wedge (I_c \wedge (\neg(\neg I_c) \wedge (\neg I_c \wedge I_m))) \wedge (P_c \wedge P_s \wedge P_l) \wedge (F_g \vee F_p \vee F_r) \wedge (A_t \wedge A_w \wedge (A_s \vee A_d \vee A_o))^{1/2} \quad (7)$$

To define the GDI/SDI-readiness as well as each of the GDI/SDI readiness elements, an iterative procedure using a proposition set was used (see Table 2). The GDI/SDI readiness index was formalised using the following disaggregated model, which is based on fuzzy logic:

$$\text{GDI/SDI Readiness} = (O_v \wedge O_I \wedge O_a) \wedge (I_c \wedge I_m) \wedge (P_c \wedge P_s \wedge P_l) \wedge (F_g \vee F_p \vee F_r) \wedge (A_t \wedge A_w \wedge (A_s \wedge A_d \wedge A_o))^{0.5} \quad (8)$$

The compensatory logic was applied, where the conjunction was solved by (Table 3):

$$c(x_1, x_2, \dots, x_n) = (x_1 * x_2 * \dots * x_n)^{1/n} \quad (9)$$

and the disjunction by:

$$d(x_1, x_2, \dots, x_n) = 1 - ((1-x_1) * (1-x_2) * \dots * (1-x_n))^{1/n} \quad (10)$$

Finally, the following expression was obtained:

$$\text{GDI/SDI Readiness} = (O_v * O_l * O_a)^{1/3} * (I_c * I_m)^{1/2} * (P_c * P_s * P_l)^{1/3} * (1 - ((1 - F_g) * (1 - F_p) * (1 - F_r))^{1/3}) * ((A_t * A_w * (1 - ((1 - A_s) * (1 - A_d) * (1 - A_o))^{1/3}))^{1/3})^{1/2} \quad (11)$$

Table 3: Propositions for GDI/SDI Readiness based on fuzzy-compensatory logic

Factors of readiness	Proposition	Logical model
Organisation	Only if a nation has an appropriate level of GDI/SDI vision (O_v), institutional leadership (O_l), and legal framework (O_a) does it have the organisational capacity (O) to carry out GDI/SDI.	$O_v \wedge O_l \wedge O_a$
Information	If digital cartography (I_c) and metadata (I_m) are available, a nation can conduct GDI/SDI at an appropriate level of information (I).	$I = I_c \wedge I_m$
Human Resources	If and only if there is an appropriate level of national human capital (P_c), GDI/SDI-culture (P_s), and individual leadership (P_l), a nation has the human resources necessary to implement GDI/SDI.	$P_c \wedge P_s \wedge P_l$
Financial Resources	Financial resources (F) to carry out GDI/SDI, provided that there is an adequate amount of funding from the government (F_g), the private sector (F_p), or the geospatial industry (F_r).	$F_g \vee F_p \vee F_r$
Technology	Only if a country has the necessary technological infrastructure, web connectivity, and access to geospatial software, as well as its own geo-informatics development and open-source culture, can it engage in GDI/SDI.	$A_t \wedge A_w \wedge (A_s \vee A_d \vee A_o)$
GDI/SDI	A nation is only prepared to conduct an GDI/SDI if and only if it possesses an appropriate level of the following general factors: Information, people, financial and organisational resources, and any level of access network.	$O \wedge I \wedge P \wedge F \wedge A^{0.5}$

D. Model for calculating the GDI/SDI readiness index

Modelling an GDI/SDI readiness index, the global elements must first be broken down into several decision criteria, which must then be broken down again until each choice attribute is described. Table 4 shows the decomposition produced as a result of this operation.

Table 4: GDI/SDI-Readiness Index variables (after [4])

Factor	Definition of Factor	Variable	Definition of Variable	Source
Organisation Index^a	Consists of GDI/SDI vision, institutional leadership, and legal framework	GDI/SDI Vision, O_v	Awareness of politicians on the importance and development of a National GDI/SDI	Survey Questionnaire
		Institutional Leadership, O_l	GDI/SDI coordination by one or more institutions	Survey Questionnaire
		Legal Framework, O_a	Existence of any national legal instrument (law, policy, directive, or agreement) to support GDI/SDI	Survey Questionnaire
Information Index^b	Availability of fundamental spatial data	Spatial Data Availability I_c	The availability of spatial data, e.g., foundation data, framework data, etc.	Survey Questionnaire
	Metadata availability	Metadata availability: I_m	Metadata availability	Survey Questionnaire
Human Resources Index^c	Incorporates the Human Capital Index, culture/education on GDI/SDI, and individual leadership	Human Capital Index, P_c	UNDP education index	UNDESA
		Culture/Education, P_s	The capacity building and awareness of the impact of GDI/SDI are evidenced through workshops or seminars.	Survey Questionnaire
		Individual Leadership, P_l	One or more champions who lead GDI/SDI development,	Survey Questionnaire
	Sources of funding for GDI/SDI	Government Funding, F_g	There is funding from the Government	Survey Questionnaire

Financial Resources Index^d		Private Sector Funding, Fp	There is funding from the private sector	Survey Questionnaire
		Geospatial industry funding, Fr	A high level of return on investment from the geospatial industry	Survey Questionnaire
Technology Index^e	Communication infrastructure, web connectivity, spatial software, and use of open-source resources related to GDI/SDI	Technology Infrastructure, At	An appropriate level of technology infrastructure	UNDESA
		Web connectivity index, Aw	There is an appropriate level of web connectivity	UNDESA
		Spatial Software, As	Availability of spatial software	Survey Questionnaire
		Geo-informatics development, Ad	Availability of own Geoinformatics development	Survey Questionnaire
		Open Source Resources, Ao	Evidence of open source culture	Survey Questionnaire

^a This factor has three main variables. They are GDI/SDI vision, institutional leadership, and legal framework. The GDI/SDI vision deals with political elites and GI Stakeholders' awareness of the importance and development of a National GDI/SDI. Institutional leadership can be expressed as the coordination by one or more institutions to develop a national GDI/SDI.

^b This factor incorporates two variables: fundamental (Core) datasets and availability of metadata. The core geospatial datasets are the foundation and framework of geospatial datasets (for example, geodetic controls, elevation, cadastral, administrative boundaries, hydrography, transport, satellite imagery, and place names). At the same time, metadata availability refers to data or information describing the geospatial datasets and other resources that can be used in developing GDI/SDI.

^c The factor incorporates these three variables: human capital index, culture/education on GDI/SDI, and individual leadership. The human capital index is a composite score from the UN Report of e-Government Readiness [24]. This quantitative index comprises adult literacy, gross enrolment ratio, expected and mean years of education. The culture/education on GDI/SDI refers to capacity building and the awareness of the impact of geospatial data on society, and lastly, a leader from existing coordination activities for the sustainability of the GDI/SDI initiative.

^d This crucial index focuses on funding sources to develop an GDI/SDI activity. They can be obtained from the following sources: government, cost recovery, and the private sector. Funding is needed to finance, for example, the GDI/SDI management and coordination costs, institutional framework, legal environment, hardware (commercial) software, capacity building, metadata preparation, data collection, development of the institutional framework and the legal environment, training, and capacity building.

^e The access networks and technologies are critical from a technological perspective to facilitate the use of data and services from GDI/SDIs. They seek to facilitate access to relevant data sources and spatial information services by anyone, anywhere, in a ubiquitous environment. This index comprises communication infrastructure, Web connectivity, commercial or in-house geospatially-related software availability, and open-source resources related to GDI/SDI. The web connectivity index was from the UN Report on e-Government Readiness [24] and constitutes a score derived from a quantitative analysis of the national web presence of the UN member states. The availability of commercial or in-house spatially related software measures existing primary software platforms for developing GDI/SDIs. The measurement of the use of open-source software is fundamental in developing countries as it is a critical factor of technological sustainability, particularly when the financial scenarios change.

III. RESULTS AND DISCUSSION

The results of the computed GDI/SDI-Readiness Index for Nigeria are shown in Table 6. The 2024 NGDI-Readiness index status computed for Nigeria was 0.8434. In a broad sense, the GDI/SDI-readiness index had improved compared to the 0.58 reported by Mwungu (2017). Factors responsible for the improvements included a) Human Resources Index, b) Information Index, and c) Technology Index. Rajabifard (2008) has suggested that any country with such possible progress toward a higher index of 0.8 implies that such a country is completely GDI/SDI capable of a spatially enabled society.

The readiness index for the majority of other African countries for GDI/SDI implementation is generally low, with significant variability across the continent. This is due to several factors, including limited financial resources, inadequate data management structures, and a lack of cohesive geospatial data governance [26]. GDI/SDI readiness in selected African countries is characterised by varying levels of development and implementation challenges. Table 6 shows SDI readiness in some selected African countries, as compared to Nigeria, though characterised by varying levels of development and implementation challenges.

Table 6: GDI/SDI readiness in some selected African countries, (after Mwangi et al. 2018)

Country	GDI/SDI Readiness Index
Senegal	0.69
Rwanda	0.65
South Africa	0.64
Ghana	0.61
Kenya	0.56
Ethiopia	0.41
Malawi	0.38
Botswana	0.35
Tanzania	0.33
Zimbabwe	0.33

Table 7: Computed GDI/SDI-Readiness Index for Nigeria, 2024

Organization	Informational	Human Resource	Technology	Financial	GDI/SDI-Readiness Index (2024)
0.8534	0.7715	0.6856	0.6985	0.7985	0.8434

Higher scores indicate stronger institutional, technical, and policy frameworks for GDI/SDI development. Using a case study approach to assess the progress of GDI/SDI readiness in Cuba. Delgado et al. (2005) found the index to be 0.55

IV. CONCLUSION

This study evaluated Nigeria's NGDI readiness index, and the outcome revealed that to create a composite integrator readiness index, organisational, informational, financial, and human elements must be considered in addition to technology difficulties when evaluating the GDI/SDI readiness index. Information infrastructures, such as NGDI, are required to capture a range of geospatial datasets for socioeconomic and environmental development if Nigeria is to experience quick and sustained economic growth. Delgado et al. (2005) recommended that countries improve GDI/SDI readiness depending on their weak spots. This research showed that Human Resources at 0.6856 and Technology at 0.6985 were the main factors inhibiting NGDI development in the country, and ageing technology. Therefore, efforts should be put in place to improve these two factors. The organisation index for the country, 0.8534, was

high because GDI/SDI vision and institutional leadership had been established with the establishment of the National Space Research and Development Agency (NASRDA). This conclusion may be supported by the possibility that limited human resources will hinder the creation of the technologies and information resources (core datasets and metadata) required to develop and deploy NGDI. NASRDA should develop an encompassing NGDI for geospatial data access and exchange by building a collaboration network among GI organisations in the country.

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