IDeaMapSudan: Geo-Spatial Modelling of Urban Poverty

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***Abstract*—Khartoum, Sudan, is one of the fast-growing African metropolises, with a massive increase in its population from around 245,000 in 1956, to over 8 million in 2022 (Khartoum State). This urban growth is driven by rural-urban migration instigated by climate change, conflicts, and forced displacement, pushing rural populations into urban areas. The growing population often ends up in deprived urban areas that lack adequate housing, services, infrastructure, etc. Spatial data to support sustainable urban development strategies are limited. In response, IDeaMapSudan was launched in 2020 as a collaboration between the Sudan Urban Development Think-Tank, Ministries of Social Development, Physical Planning (Khartoum State), Infrastructure and Transport, and the Faculty Geo-Information Science and Earth Observation Science (ITC) at the University of Twente and partners from the Université Libre de Bruxelles and the African Population and Health Research Center. IDeaMapSudan aims to develop a geospatial information system for mapping deprived areas. For this purpose, a multi-level deprivation model based on open geospatial data is created. Data as part of the information system are made available via standard web services (e.g., OGC WMS/WFS) and web applications (Geoserver and Geonode) to support local stakeholders and encourage data exchange on urban development questions.

Keywords—Informal settlements, open geospatial data, urban poverty, urban assets, urban risks, multi-level deprivation

I. Introduction

Sudan, with a population of almost 45 million people (2021), has an estimated urbanization rate of 36% [1]. The rapid urban development has distinct regional differences, driven by various push and pull factors [2]. Generally, the massive rural-urban migration is driven by economic opportunities and the search for security and safety, which relates to the country's recent history, impacted by conflicts and climate-related risks (droughts and floods). Generally, decreasing returns from agriculture (e.g., low crop prices) and rural poverty are main push factors for migration to urban areas [3], where migrants mostly end-up in deprived areas (lacking basic services and infrastructure). Besides the major transport and economic hubs, waterbodies are the lifelines in a warm desert climate. Thus, Sudan's urbanization is also driven by water (scarcity), which is more complex than proximity to rivers and includes groundwater availability [4]. Another major risk in Sudan relating to water is regular floods, which disrupts human activities (Fig. 1). Intense convectional storms and seasonal floods of the Nile trigger floods in Sudan.

Fig. 1. Sentinel-2 image of Khartoum floods in September 2020 (left) and November 2020 (right), false-colour composite.

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Generally, seasonal floods (between July and September) have an essential role in agriculture and land fertility, but they also threaten urban areas that encroach on agricultural land due to the rapid growth of urban spaces [5].

Thus, Sudan, like many Low-and-Middle-Income Countries (LMICs) is rapidly urbanizing. Most of this growth occurs in deprived urban areas (commonly called slums and informal settlements) [6]. The terms slums and informal settlement are either used interchangeably or refer to the UN-Habitat definition, where slum is a household concept and informal an area concept of deprivation [7]. Generally, both (deprived households and areas) do not benefit from the achievements of urbanization (e.g., in terms of living conditions). They commonly lack access to services, infrastructure, and durable housing, among other things. The SDG Target 11.1 prioritizes the importance of access to adequate, safe, and affordable housing and basic services and to upgrade slums. In Sudan, rapid urbanization combined with economic and political instabilities caused the growth of such areas, often located in hazardous locations with high poverty rates [8-10]. Conditions in these areas are often poorly understood and considered in urban policies due to a massive lack of data on urban poverty [11-14]. Typically, data in support of local actors (e.g., government and civil society) is missing in a country with large political instability [15]. The increasing availability of open-access Geospatial and Earth Observation data can bridge such data gaps [16]. Therefore, IDeaMapSudan developed an open-access data model and information system on urban deprivation in support of local stakeholders.

II. Methodology

A. Modelling Urban Deprivation

To model multiple deprivations of neighbourhoods, the Index of Multiple Deprivation (IMD) is tailored for Greater Khartoum based on the IDEAMAPS Domains of Deprivation Framework [17]. Deprived areas lack various aspects of physical, environmental, or socio-economic assets. This is reflected in the Domains of Deprivation Framework [17] by nine aspects of urban deprivation (domains) that are typically experienced across cities (Fig. 2). For each domain, the framework includes examples of indicators, similar to other frameworks (e.g., the English Deprivation Index ([18]).

B. The Study Area Delineation

The initial step was to delineate the urban extent of Greater Khartoum, a metropolitan area composed of 3 cities. Based on the results of an expert workshop (held in Khartoum, in January 2021), recent satellite imagery (Sentinel-2, September 2020) and other open data sets (e.g., GRID3 settlement extents and Africapolis), the study area was delineated to include the urban area of Greater Khartoum (Fig. 3).

C. Modelling Multiple Deprivation

During another expert workshop held in Khartoum in Aug. 2021 (urban poverty, urban planning and geospatial experts), six locally relevant domains of deprivation were identified, together with a list of indicators for each domain. Based on further expert consultations, open datasets have been identified following the IDEAMAPS Framework and combining Earth Observation data (e.g., VIIRS night lights, air pollution), open geospatial datasets such as OpenStreetMap and the Google AI Open Building dataset, and locally accessible data (e.g., water network) (Table I).

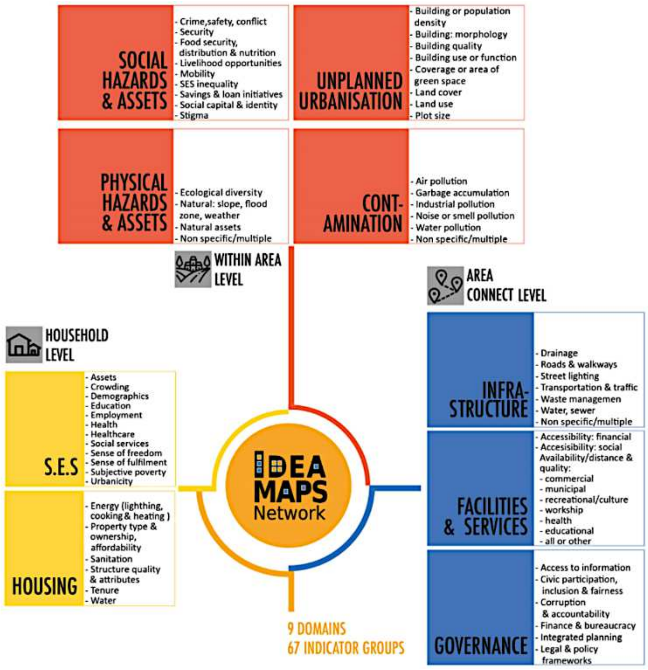

Fig. 2. IDEAMAPS Domain of Deprivation Framework [17].

The indicators were extracted using a 100x100m grid and scaled into a standard range (0 to 1), where values close to 1 indicate higher deprivation levels. Then, the indicators were weighted (based on an online expert survey) and summed by an expert-weighted multi-criteria analysis method to produce six domains deprivation index maps and the final IMD map on a continuous scale from most to least deprived. Thus, indicators were combined based on the expert weights to produce domain maps. The six domain maps were combined using the expert weights into the overall IMD. The reason for using a simple summative index is driven by the aim to produce an explainable outcome for stakeholders in Sudan. The use of data driven approaches (e.g., deep learning [19]) has been discussed but was not preferred by local experts.

TABLE I. COLLECTED DATASETS TO MODEL DEPRIVATION.

Domains	Indicators	Data models
Unplanned Urbanisation	*Building density*	*Building density using EO-based building footprints*
	Building: morphology	*Buildings adjacency & Equivalent Rectangular Index*
Services	*Education*	*Distance to Schools*
	Health	*Distance to health services*
	Recreation/culture	*Distance to culture and recreation (clubs, parks etc.)*
	Commercial	*Distance to commercial areas (open data)*
	Finances	*Distance to financial services (banks, ATMs etc.)*
Infrastructure	*Main roads*	*Distance to main roads*
	Transportation & Traffic	*Distance to transport stations*
	Water	*Distance to public water sources*
	Electricity	*Electricity network coverage (NTL from EO)*
	Communication	*Mobile phone network coverage*
Physical Hazard & Assets	*Natural: Flood, slope*	*Distance to flood areas (EO-based)*
		Flash flood water accumulation areas
	Natural assets	*Vegetation cover areas (EO-based)*
	Temperature	*Land surface temperature (Google Earth Engine)*
Social Hazards & Assets	*Security*	*Distance to police station*
		Availability of Street Lights (NTL from EO)
	Livelihood opportunities	*Distance to employment opportunities (commercial centers, factories, etc.) (open data)*
	Food security, distribution & nutrition	*Distance to markets/supermarkets (open data)*
Contamination	*Air pollution*	*Concentration NO2(EO-based)*
	Industrial Pollution	*Distance to industrial areas (digitised via Google Maps)*
	Smell pollution	*Distance to sewage plants and landfills (only Khartoum)*
	Garbage accumulation	*Distance to the landfills (only Khartoum)*
	Noise pollution	*Distance to city centres, main roads, etc.*

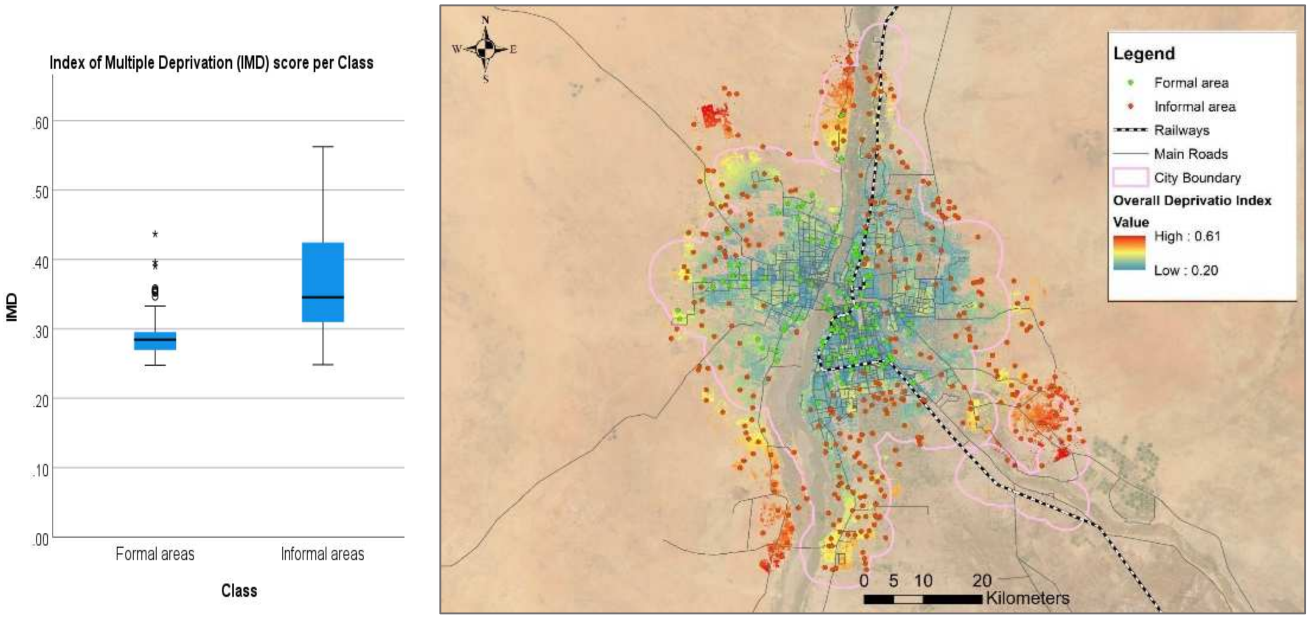

Fig. 3. Greater Khartoum - Index of Multiple Deprivation (IMD) and validation with ground reference points.

D. Validation of the Index

Validating deprivation indices is a complex task, particularly in data restricted environments. To provide insight into gaps and uncertainties of the index, quantitative and qualitative validation was performed. For quantitative validation, a random sample of 450 points was labelled by local experts (including ground verification). For a qualitative assessment, an expert workshop held in Khartoum in February 2023 was used to gain feedback on the relevance of the index.

III. Results

The expert meeting selected the six most relevant domains where data are accessible. The resulting domains included social hazards and assets, physical hazards and assets, unplanned urbanization, contamination, infrastructure, and facilities and services. For each domain, an index map showing the variation in living conditions was generated. The combination of all domains into an overall deprivation index is shown in Fig. 3. The final index ranges from 0.20 (least deprived) to 0.61 (most deprived), as shown in Fig. 3.

The most deprived areas in Greater Khartoum are found in the North, South-East and South extensions of the city (Fig. 4). Differently to many other LMIC cities, many deprived areas are not extremely dense built-up, e.g., as compared to Kibera in Nairobi (Kenya), a very prominent example of a very dense built-up area [20]. Deprived areas in Khartoum generally lack access to services, infrastructure, and social assets (e.g., related to security and livelihood opportunities). Several parts are impacted by regular flood events (e.g., the South and North). Parts of the East outskirts also show relatively high deprivation values. However, these areas are not impacted by fluvial floods but have issues with access to services, social assets, and often high built-up density (unplanned urbanization domain). Besides deprived areas towards the outskirts, smaller clusters of high deprivation values are found in central areas that are commonly impacted by a combination of high built-up density and high contamination values (central deprived clusters) (Fig. 5).

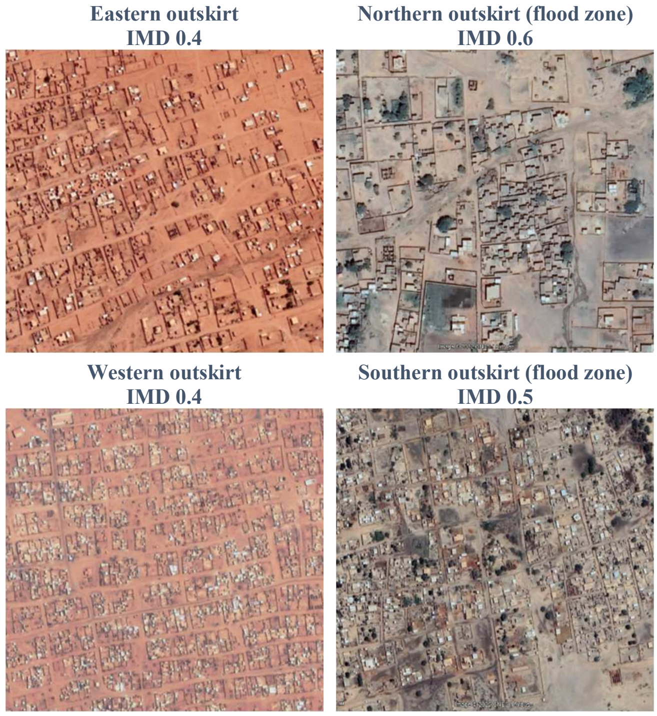

Fig. 4. Outskirts of Khartoum zoom-in examples of the deprivation index.

Fig. 5. Khartoum zoom-in examples of a deprived area in the centre.

The quantitative and qualitative validation showed that the deprivation index can capture the major patterns of deprivation (Fig. 3), e.g., highly deprived areas towards the south (e.g., Jebel Aulia) are confirmed via ground verification. However, some locally detailed patterns of deprivation within central areas of Khartoum are only partially captured, due to data gaps in open data on environmental and physical conditions (e.g., smell pollution caused by sewage lines). The deprivation index and the datasets compiled and produced, are made publicly available online at http://geonode.idea-maps.net via a GeoNode-based [18] spatial data infrastructure in an effort to promote open access and exchange of data in Sudan between various stakeholder groups that share an interest on urban poverty alleviation. The initial plan was to develop a local server to access data for local stakeholders. However, the political instability and resource constraints (e.g., common power cuts) led to the deployment of GeoNode on a server hosted by the University of Twente, but managed by the local team of IDeaMapSudan. Through GeoNode, data are made accessible to view and download, and useful metadata are also provided. The main innovation of this work sits in the co-creation of open-access data together with local stakeholders. The data are built on available Geospatial and Earth Observation data. The approach provides a pathway for building locally relevant data systems and promotes open-access data in an environment where up-to-date data are often not available or not shared to promote sustainable urban development.

IV. Conclusions

Building on a localization of knowledge on deprived areas in Khartoum, we developed a locally-adapted geospatial information system to combine relevant data that reflect different aspects of deprivation and provide an overall deprivation map at city scale. The IDeAMapSudan data ecosystem was developed within a GeoNode to provide access to data in a data-restricted urban landscape. IDeAMapSudan addresses two significant gaps in relation to urban deprivation data. First, we use available data (global and local) to provide data, which are locally of high demand but do not exist, to support planning and policy making to address SDG 1 (“No Poverty”) and SDG 11 (“Sustainable Cities”). Second, we build the capacity of local stakeholders (from ministries and NGOs) to work with the data ecosystem depicted to support these policies. The process of curating the required data, making it accessible to local stakeholders and training them to use the data promotes evidence-based policy making to address SDGs in resource-constrained environments.

Acknowledgment

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