Visualizing the Philippines' SDG 11.3.1 Status and Progress Using Open-Source Geospatial Software and Earth Observation Datasets

Jojene R. Santillan [1, 2], Christian Heipke [1]

[1] Leibniz University Hannover, Institute of Photogrammetry and GeoInformation, Nienburger Straße 1, 30167 Hannover, Germany – (santillan, heipke) @ipi.uni-hannover.de
[2] Caraga State University, Caraga Center for Geo-Informatics & Department of Geodetic Engineering, College of Engineering and Geosciences, Ampayon, 8600 Butuan City, Philippines – jrsantillan@carsu.edu.ph

Keywords: Sustainable Development Goals, SDG Monitoring, SDG Visualization, SDG 11.3.1, Land Use Efficiency, Web GIS

Abstract

This paper presents the development and implementation of a web GIS-based application designed to visualize the status and progress of Sustainable Development Goals (SDGs). Focusing specifically on SDG 11.3.1, which pertains to sustainable urbanization, we propose a prototype (accessible at https://ccgeoinformatics.github.io/sdg1131ph/) that leverages open-source geospatial software and earth observation (EO) datasets. By following the "where-when-what-how" framework of SDG visualization system development, we address the need for effective visualization methods while showcasing the potential of accessible datasets and technology in supporting sustainable development monitoring efforts across different administrative levels. We demonstrate the feasibility of the system in aiding policymakers and stakeholders in their decision-making processes toward achieving the SDGs by 2030. Additionally, our work exemplified how open-source software and EO datasets can address the challenges associated with SDG reporting, particularly in areas where both data and visualization tools are scarce or inaccessible. This paper also contributes to the ongoing discourse on SDG visualization and underscores the importance of localized analysis and visualization in understanding and addressing the challenges of sustainable urbanization using the example of the Philippines.

1. Introduction

The United Nations Sustainable Development Goals (SDGs) provide a comprehensive framework for tackling global challenges, including poverty, inequality, environmental degradation, and climate change (United Nations Department of Economic and Social Affairs, 2022a). Adopted by all UN Member States in 2015, the SDGs aim to mobilize efforts to build a more equitable, prosperous, and sustainable world by 2030. There are 17 SDGs; each SDG comprises a set of targets which are evaluated through indicators. All UN member states are mandated to report their status and progress of achieving these SDGs at various intervals between 2015 and 2030. With a total of 169 targets and 248 indicators in the global indicator framework (United Nations Statistics Division, 2024), SDG reporting has been considered a challenging task. This has driven efforts to identify effective strategies not only to visualize the SDG indicators' status and progress but also to convey the findings to policymakers and other relevant stakeholders (Gong, 2019; Kraak et al., 2018; Li et al., 2020).

In this paper, we present the development and implementation of a prototype web GIS-based application for visualizing the status and progress of SDGs, using the Philippines as an example. Focusing on the SDG 11.3.1 indicator, we propose a prototype that utilizes open-source geospatial software and earth observation (EO) datasets, following the "where-when-what-how" framework (Li et al., 2020) of SDG visualization system development. Through our prototype, we aim to demonstrate its feasibility in aiding policymakers and stakeholders in their decision-making processes toward achieving the SDGs by 2030. Additionally, we aim to promote the utilization of open-source geospatial software and publicly available EO datasets. Aside from raising awareness among stakeholders and public entities of their availability, we exemplify how these tools and datasets can address the challenges associated with SDG reporting, particularly in areas where data and visualization tools are limited or difficult to access.

The remainder of this paper is arranged as follows. We discuss related work in Section 2, highlighting SDG visualization concepts and approaches, open-source software and datasets, and recent global efforts in visualizing the SDG status and progress, including that of the Philippines. Section 3 details the methodology employed in developing our web-based application for visualizing SDG indicators, focusing on SDG 11.3.1. Section 4 presents the outcomes of our prototype implementation. Finally, in Section 5, we offer concluding remarks on our study's contributions, reflect on limitations, and suggest future research directions and applications.

2. Related Work

2.1 SDG Visualization Concepts and Approaches

Visualization is essential in sustainable development as it simplifies complex data. It also enables stakeholders to comprehend interconnected sustainability challenges and the impacts of interventions. By translating data into intuitive visual representations, such as charts and maps, visualization enhances understanding and awareness among policymakers, researchers, and the public (Rist and Masoodian, 2022; Siekierska et al., 2004). This could then facilitate informed decision-making and engagement in sustainability efforts (Isaacs et al., 2009). Moreover, visualizations serve as powerful communication tools that promote collaboration and dialogue among a wide range of stakeholders, and, in turn, fosters consensus-building and collective action towards common sustainability objectives (Metabolic, 2019; Rist and Masoodian, 2022).

The use of maps, especially digital maps created using Geographic Information System (GIS), is a common approach employed for SDG visualization (Gong, 2019; Gorte and Degbelo, 2022; Kraak et al., 2018; Li et al., 2020; Rist and Masoodian, 2022). However, the wide range of goals and indicators along with their specific data characteristics makes it challenging to prescribe a universal cartographic representation (Kraak et al., 2018). Furthermore, an SDG visualization system must address the needs of policymakers, administrators, and the broader public. While some individuals may concentrate on the progress within their own countries or regions, others may seek to compare development levels across various regions or localities (Li et al., 2020). It follows that SDG visualization should extend beyond maps to encompass other forms of visualization and analysis. A visualization system with basic analytical capabilities is deemed essential for its utility and relevance (Gong, 2019; Li et al., 2020). The functional requirements for such a system have been proposed by Li et al. (2020), classified into graphical representation requirements and analysis capacity requirements. The first set of requirements focuses on the capability of the system to effectively visualize the three dimensions of SDG data, i.e., “the location” (where), “the time” (when) and “the object or attribute” (what), according to different potential scenarios (e.g., where-when-what, where-what, when-what, where-what-when, etc.) (Li et al., 2020). The second set of requirements focuses on the basic analytical capabilities that the system can provide to its user, such as identifying, comparing, ranking, associating, and delineating SDG indicator data. When these requirements are met, an effective SDG visualization system can be implemented, featuring functions that visualize the "where," "when," "what," and "how," along with analytical tools to provide insights into the "why" behind the data (Li et al., 2020). An example of this system is the SDG Viz (Gong, 2019), which has the capacity of producing various kinds of thematic maps of SDG indicator data, along with visual interaction functions.

2.2 Open-source Geospatial Software and their Potential for SDG Monitoring and Visualization

Open-source geospatial software have become widely available and extensively used for a variety of purposes over the past few decades (Bocher and Neteler, 2012; Coetzee et al., 2020; Mobasheri et al., 2020). Continuous collaboration and development by the open geospatial community has resulted in the availability of a comprehensive suite of geospatial tools and libraries, including desktop GIS applications like QGIS and GRASS GIS as well as WebGIS software and essential libraries like GDAL/OGR (Mobasheri et al., 2020).

Web GIS, also known as "browser-facing GIS," (Coetzee et al., 2020) has become a popular platform for visualizing geospatial data, particularly aimed at the general public. There are several software options for browser-facing GIS such as OpenLayers, Leaflet, and GeoNode, all of which support interactive and comprehensive geospatial data visualization and analysis (Coetzee et al., 2020). The interactive tools not only provide access to data attributes but also enable various levels of analysis to extract information. In terms of user-friendliness and intuitiveness, Web GIS often matches or even surpasses the capabilities of desktop GIS applications, making it accessible for non-specialist users. This accessibility makes Web GIS very suitable for SDG visualization, allowing a broader audience to engage with and understand sustainable development goals (Tsai and van Gasselt, 2022).

2.3 Platforms and Dashboards for SDG Reporting and Visualization

In recent years, several platforms have emerged for managing and sharing data and statistics related to the UN SDGs. One such platform is OpenSDG (open-sdg.org), developed through collaboration between the members of the Open SDG community, the Center for Open Data Enterprise (CODE), the UK Office for National Statistics (ONS), and the US government. OpenSDG is a customizable, open-source platform offering features like data visualizations through graphs, tables, maps, and embedded content (openSDG, 2024). It has been adopted by over 20 countries and utilized in more than ten cities and regions (open-sdg.org/community). While OpenSDG provides detailed pages for SDGs, targets, and indicators, its map feature is often underused. This is due to its limitation in supporting disaggregation, resulting in generalized visualizations at the country level.

Other online dashboards, such as the Sustainable Development Report (SDR; previously known as the SDG Index and Dashboards, accessible at dashboards.sdgindex.org/) and the Global Data Lab (globaldatalab.org/sdgs/), offer visual representations of the progress made by UN member states towards the SDGs. These dashboards typically present generalized metrics, including SDG score, rank, and trends for each goal. While these metrics are conveyed through charts, tables, and interactive maps, users are only provided state/country-level insights into the overall performance in achieving the SDGs.

2.4 SDG Status and Progress Reporting in the Philippines

The Philippines, as a UN member state, actively pursues the SDGs. General information on its status and progress toward achieving the SDGs are reported in the SDR (dashboards.sdgindex.org/profiles/philippines) and in the global data lab (GDL, globaldatalab.org/sdgs/PHL). For more detailed insights into the Philippines' SDG progress, two websites by the Philippine Statistics Authority (PSA) serve as valuable resources, namely psa.gov.ph/sdg and openstat.psa.gov.ph/Database/Sustainable-Development-Goals. The former includes an "SDG Watch" section enabling users to select a specific SDG, and then provides a summarized report in portable document format (PDF), displaying indicators and their corresponding values (e.g., baseline, latest, and target). The latter allows users to select indicators and view tabular data. In both websites, the indicators are only reported at the national levels. Neither of them offers interactive maps that can display the variability of each indicator across different administrative divisions. There is an online, interactive dashboard available at psa.maps.arcgis.com, however, the said dashboard is not available publicly. It is also worth noting that not all indicators have been included for monitoring thus far. Based on published official documents in the PSA website (www.psa.gov.ph/sdg/philippines/resolutions), the Philippine government currently monitors only 159 indicators. Of this number, 97 are global indicators, 36 are proxy indicators, and 26 are supplemental indicators (Balisacan, 2023).

2.5 SDG 11.3.1 Monitoring in the Philippines

One of the indicators that the Philippines is not currently monitoring but is important in the framework of sustainable urban development is SDG 11.3.1. As outlined in its metadata, indicator 11.3.1 represents the “ratio of the land consumption rate (LCR) to the population growth rate (PGR)” (United Nations Statistics Division, 2021). This indicator, also referred to as "LCRPGR," is recognized as a metric for assessing land use efficiency (LUE) (Estoque et al., 2021; Melchiorri et al., 2019;

https://doi.org/10.5194/isprs-annals-X-5-2024-173-2024 |

Schiavina et al., 2019). If an area's LCRPGR, such as that of a city, is 1 or below, it indicates high land use efficiency. This suggests that the city is compact and well-planned, minimizing the costs of providing basic services and infrastructure while conserving surrounding land for other uses. When the LCRPGR nears 1, it implies that the city's urban expansion is nearly proportional to its population growth. However, an LCRPGR above 1 indicates that the city is using more land than necessary for its population growth, leading to inefficient land use (UN-Habitat, 2018). Indicator 11.3.1 is a key measure for assessing the advancement of target 11.3, which aims to promote inclusive and sustainable urbanization. Meeting this target supports the achievement of SDG 11, i.e., to ensure that cities and human settlements are "inclusive, safe, resilient and sustainable" by 2030 (United Nations Department of Economic and Social Affairs, 2022b).

In the Philippine context, monitoring SDG 11.3.1 can help assess whether urban development in the country is proceeding in a sustainable manner. This information is crucial for making well-informed decisions regarding land use planning and management, particularly as the country has undergone significant urban expansion in recent decades. Although urbanization offers economic advantages, its rapid progression in the Philippines has led to numerous challenges, such as problems with land use, infrastructure development, environmental degradation, and the quality of life for urban populations (Berse, 2024). UN-Habitat reports highlight significant challenges in many Philippine cities, including limited land access, inadequate housing, expanding slums, poverty, unemployment, and the worsening impact of natural disasters due to climate change and conflict, among others (UN-Habitat, 2024).

At present, not enough attention is given to monitoring SDG 11.3.1 in the Philippines, more so with its visualization. A recent analysis by Santillan and Heipke (2023) using global EO datasets provided "evidence of the developmental progress and urbanization" in the Philippines, revealing "a decline in land consumption, a deceleration in population growth, and an overall enhancement in land-use efficiency within the country". In Santillan and Heipke (2024), an assessment of indicator 11.3.1 showed highly variable progress across Philippine cities and municipalities. Given that the Philippines is an archipelagic country with cities and municipalities dispersed across various islands and regions, both national and local visualizations of indicator 11.3.1 are essential for effective monitoring and analysis. For policymakers and administrators, presenting and visualizing a city or municipality's status and progress regarding indicator 11.3.1 can provide a deeper understanding of the challenges and opportunities tied to urban development in their area. Additionally, this approach could provide insights on the factors that drives urbanization and land-use efficiency. This, in turn, facilitates the development of spatial planning strategies and well-structured policy interventions aimed at promoting inclusive and sustainable urbanization (Santillan and Heipke, 2023).

2.6 EO Data for Monitoring and Visualizing SDG 11.3.1

There are two key datasets essential for tracking SDG 11.3.1, namely built-up area, and population. These data need to be a function of time. Typically, they should be available at intervals like one year or five years, depending on the desired temporal scale. With built-up area and population data available for different years, the SDG 11.3.1 variables LCR and PGR can be calculated, including its ratio (UN-Habitat, 2018).

Built-up area mapping commonly relies on EO data analysis, mostly using satellite imagery and a variety of approaches (Chaves et al., 2020), while population data are often sourced from government agencies and gathered through census surveys (Qiu et al., 2022). However, built-up area mapping presents challenges, especially over large areas that encompass country boundaries, such as archipelagic countries. This task requires analysing numerous images; in tropical countries, cloud cover often complicates the process further especially when working with optical satellite imagery. Maintaining data consistency across spatiotemporal scales is also an issue. In the Philippines, accessing built-up area data is particularly challenging, while population data often require manual encoding from census reports. These obstacles significantly hinder the monitoring of SDG 11.3.1, including visualizing its status and progress.

The availability of global EO datasets for monitoring SDG 11.3.1 has been made possible by recent progress in remote sensing and geospatial technologies. These datasets, including land cover and impervious surface maps such as GlobeLand30, ESA CCI Land Cover, Global Artificial Impervious Area (GAIA), and others (Liu et al., 2021; Wang et al., 2023), offer multi-temporal built-up area information, which is particularly beneficial for countries like the Philippines. Likewise, datasets such as WorldPop and the Gridded Population of the World (GPW) offer spatially detailed population data with global coverage (Yin et al., 2021). However, these datasets often require harmonization in terms of spatial resolution, and not all of them cover multiple time periods, which is necessary for effective SDG 11.3.1 monitoring.

The Global Human Settlement Layers (GHSL) is a key data source for monitoring SDG 11.3.1. GHSL provides extensive multi-temporal data at various spatial resolutions, with unrestricted access to gridded built-up area and population datasets from 1975 to 2020 (European Commission, 2023). The GHSL has been employed in numerous studies focused on monitoring SDG 11.3.1 (e.g., Estoque et al., 2021; Melchiorri et al., 2019; Schiavina et al., 2019). Despite its widespread application, there remains untapped potential for using it as a primary dataset for SDG 11.3.1 visualization. This study aims to advocate for the broader utilization of the GHSL dataset in both monitoring and visualizing SDG 11.3.1 progress, using the Philippines as an example.

3. Developing the SDG 11.3.1 Indicator Visualization System

3.1 Development Framework and System Requirements

For developing our system, we adapted the "where-when-what-how" framework of SDG visualization system development described by Li et al. (2020). In this framework, there are nine potential scenarios of graphically representing an SDG indicator (i.e., the "where-when-what") (Table 1) and five representational requirements for analysis capacity (i.e., the "how") (Table 2). As the visualization we are developing is specific for indicator 11.3.1, the scenarios requiring all other SDG indicators were excluded in our requirements, i.e., S5 and S8.

3.2 Web Application Development

Figure 1 depicts the general workflow of developing a prototype web GIS-based visualization system for SDG 11.3.1 status and progress monitoring in the Philippines across four administrative divisions (national, regional, provincial, and city/municipal).

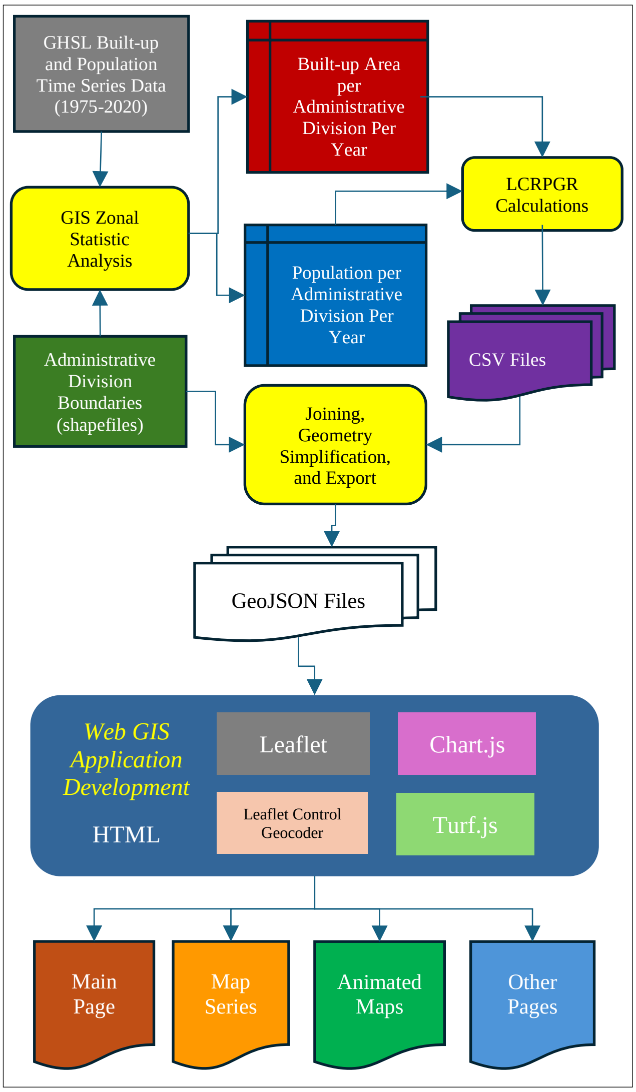

Figure 1. Workflow for the development of the SDG 11.3.1 indicator visualization system.

3.2.1 Data Preparation and LCRPGR Calculations: Following the methodology outlined by Santillan and Heipke (2023, 2024), we used GIS shapefiles of the administrative boundaries of the Philippines and time-series raster datasets (1975-2020, in 5-year intervals) for built-up areas and population from the GHSL – GHS Package 2023. These freely available datasets were accessed via the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) Humanitarian Data Exchange (HDX, data.humdata.org/dataset/cod-ab-phl) and the GHSL website (ghsl.jrc.ec.europa.eu/). Using ArcGIS Pro 2.7, we performed a "Zonal Statistics as Table" analysis to extract total built-up area and population data for the entire Philippines and its regions, provinces, cities, and municipalities for each year. The extracted data were compiled into an MS Excel spreadsheet for LCRPGR calculations, based on the formulae provided in Table 3. The results were then exported as Comma Separated Value (CSV) files, with each file containing the unique identifier of the administrative unit and the calculated values for LCR, PGR, and LCRPGR for each 5-year interval (1975-1980, 1980-1985, up to 2015-2020). These CSV files were imported back in ArcGIS Pro for joining with their corresponding administrative boundary shapefiles, and then exported to GeoJSON files. Prior to export, geometry simplification using the Douglas-Peucker algorithm was employed to the shapefiles to reduce the file sizes while retaining critical points (and hence, preserving the essential shape) of each polygon corresponding to an administrative unit. This was done using the "Simplify Polygon" tool in ArcGIS Pro software.

Scenarios	Interpretation	Examples for Indicator 11.3.1	Representational Requirements
S1 *"where-when-what"*	A specific attribute at a given location and point in time.	Ratio of LCR to PGR (LCRPGR) in a place (e.g., Metro Manila) during a period (e.g., 2015-2020)	A symbol with visually enhanced characteristics designed to emphasize a particular attribute at the location
S2 *"where-what"*	A specific attribute at a given location	LCRPGR of a place	A dynamic map that visually animates the LCRPGR changes at a specific location over time
S3 *"when-what"*	A specific attribute at a given point in time	LCRPGR of all places (e.g., all cities and municipalities of the Philippines) during a period (e.g., 2015-2020)	A map displaying the variation of a specific attribute at a given time across a selected geographical area
S4 *"where-what-when"*	The times when a specific attribute at a given location reaches a certain value	The time (periods) when LCRPGR exceeded a value of 1 in a place (e.g., Metro Manila)	A series of maps illustrating the instances where the attribute reaches a specific value (e.g., greater than 1) at a particular location
S5 *"where-when"*	The attributes at a specific location and point in time	The behaviour or status of various indicators in a specific location (e.g., Metro Manila) during a particular year (e.g., 2020)	An animated dynamic map showcasing the 17 SDGs over time
S6 *"what-when"*	An attribute attains a specific level at a particular point in time	The LCRPGR exceeds a value of 1 during a period (e.g., 2015-2020)	A map displaying the variation of attributes at a specific time across a chosen geographical area
S7 *"when-what-where"*	The location where an attribute reaches a specific level at a particular time	The location where the LCRPGR exceeds 1 within a specified period (e.g., 2015-2020)	A symbol with enhanced visual features to emphasize the location
S8 *"when-where"*	The attributes at a specific location and point in time	The status or changes in various indicators in a specific location (e.g., Metro Manila) during a particular year (e.g., 2020)	An animated dynamic map showcasing the 17 SDGs over time
S9 *"what-where"*	A specific location characterized by a particular attribute	The periods when the LCRPGR exceeds a value of 1 at a particular location (e.g., Metro Manila)	An animated map that displays changes over time

Table 1. Scenarios for indicator 11.3.1 interpretation and graphic representation requirements (adapted from Li et al., 2020).

3.2.2 Web GIS Visualization System Development: The web visualization system was designed to compose of a main page and pages that each contains LCRPGR series maps and animated maps, respectively. We developed these web pages using HyperText Markup Language (HTML) in combination with open source software and plugins such as Leaflet (leafletjs.com/), Chart.js (www.chartjs.org/), Leaflet Control Geocoder (github.com/perliedman/leaflet-control-geocoder), and Turf.js (turfjs.org/).

Leaflet, an open-source JavaScript library, was used to create interactive web maps from GeoJSON files that visualizes the LCRPGR values at different administrative levels and at different time periods with basic analytical capabilities as previously listed in the system requirements tables (Tables 1 and 2). In all these maps, the choropleth format is adapted, where each feature is symbolized based on its LCRPGR value, following the categories proposed by Jiang et al. (2021) (see Table 4 for the descriptions). We utilized the HTML and JavaScript codes from Leaflet’s “Interactive Choropleth Map” tutorial (leafletjs.com/examples/choropleth/) as our starting point, wherein it was modified and expanded to meet our requirements. The line charts showing the trends in LCR, PGR and LCRPGR values were added using Chart.js to complement the choropleth maps. The web maps also include a “Search” tool to search and zoom-in to specific localities. This functionality was implemented using a combination of Turf.js and Leaflet Control Geocoder.

Objective	Purpose	Examples of presentational function as implemented in this work
Identify	To analyze a specific map feature, such as: • Identifying a location, • Determining an attribute value, and • Pinpointing a particular time.	• A "mouse-click" function to display an attribute value (LCRPGR) at a specific location (e.g., Butuan City) • A "hover" function to mark (“highlight”) areas of interest (e.g., the boundary of Butuan City).
Compare	To identify the similarities and differences between two map features	• A "mouse-click" function to display attribute values that can be compared at specific locations. • Choropleth maps with distinct color of map features to enhance recognition.
Rank	To determine the order and relative position of map features	Choropleth maps with distinct colors representing the magnitude of attribute values, along with a 'click' function to display detailed information. The color scheme helps users easily compare and rank map features based on their attribute values.
Associate	To describe the relationships between multiple map features.	Dynamic (animated) choropleth maps and pop-up to display attribute changes over time.
Delineate	To arrange map features in a coherent and logical structure.	A drop-down selection option that allows users to selectively display specific map layers or classes.

Table 2. SDG indicator 11.3.1 representational requirements for analysis capacity (adapted from Li et al., 2020).

$LCRPGR = \frac{LCR}{PGR}$	*Where:* BU_{t+n} *and* BU_t *represent the total built-up area for the final year (t+n) and initial year (t), respectively.* Pop_t *and* Pop_{t+n} *represent the total population for the initial and final years. n is the number of years between the initial and final years.*
$LCR = \frac{BU_{t+n} - BU_t}{BU_t} \cdot \frac{1}{n}$	
$PGR = \frac{ln\left(\frac{Pop_{t+n}}{Pop_t}\right)}{n}$	

Table 3. SDG 11.3.1 indicator formulae, from United Nations Statistics Division (2021). Variable notations and definitions are adapted from Santillan and Heipke (2024).

4. Results

The SDG 11.3.1 visualization system we developed is accessible online at https://ccgeoinformatics.github.io/sdg1131ph/. In the subsequent sections, we discuss its features, specifically addressing the graphical and analytical representation requirements essential for SDG visualization.

4.1 Main Visualization and Analysis Page

In the main page, the user must select the desired geographical level of analysis (national, regional, provincial, city/municipal) and the period (1975-1980, 1980-1985, etc.). Then, an interactive web map will be displayed. The interactivity includes “mouse-over” functions such as highlighting each feature, displaying their placenames, and corresponding LCR, PGR, and LCRPGR values. Clicking a feature will display line charts that allow the user to see the trends in their LCR, PGR, and LCRPGR values. We have integrated LCR and PGR values alongside LCRPGR to enhance its interpretability. This is in accordance with recommendations from scholarly sources on SDG 11.3.1 (e.g., Estoque et al., 2021).

The main page functionalities, illustrated in Figure 2, would satisfy four scenarios of graphical representational requirements (S1, S3, S6, S7). By employing choropleth maps with a symbology classification tailored to facilitate indicator interpretation, we ensure that the LCRPGR values are prominently emphasized at a location. Also, the maps can show the variation of the LCRPGR at a particular period across a selected geographical area. By merely visualizing the LCRPGR values using the choropleth maps, the users can see, for example, at which localities and at what periods the LCRPGR exceeds the ideal value of 1, which, in turn, would inform them where land utilization is inefficient. For S2, S4 and S9, the graphical representation requirements set by Li et al. (2020) include a series of maps and a dynamic map to show the times or periods that the attribute reaches a certain value. However, our use of interactive line charts to show the temporal trends of indicator values for a selected locality can still satisfy these requirements, albeit in a different manner.

Regarding analysis capabilities, the functionalities provided on the main page aid users in conducting basic analyses, including identification, comparison, association, ranking, and delineation of mapped features and their corresponding indicator values.

4.2 Map Series Page

The map series page, accessible via a button in the main page, was specifically created to satisfy S4, including basic analytical capability to identify, compare, associate, and delineate. As illustrated in Figure 3, a series of maps of the same geographical area or locality is displayed to show how the LCRPGR changes and reaches a certain value.

Category	Range	Description
1	LCRPGR ≤ 0	Spatial expansion occurs simultaneously with demographic decline.
2	0 < LCRPGR ≤ 1	Population density increases (alongside minimal spatial expansion).
3	1 < LCRPGR ≤ 2	The rate of spatial expansion exceeds the demographic growth rate.
4	LCRPGR > 2	The rate of spatial expansion is more than twice as fast as population growth rate.

Table 4. LCRPGR classification (adapted from Jiang et al., 2021).

4.3 Animated Maps

Animated maps of LCRPGR values (Figure 4) are also available to satisfy S9 representational requirement, i.e., to visualize a particular location and how its LCRPGR value changes through time. To access this functionality, the user first selects the geographical level in the main page via the “Animated Maps” button. For each selected level, the user has the option to show all features or select a locality. Animation buttons are available to play, pause, stop, or rewind the animation. Before, or even while animating, the user can click on the selected feature to display the LCRPGR values, which also updates simultaneously with the period. The user can also zoom-out while animating to visualize the changes in LCRPGR values around the selected locality.

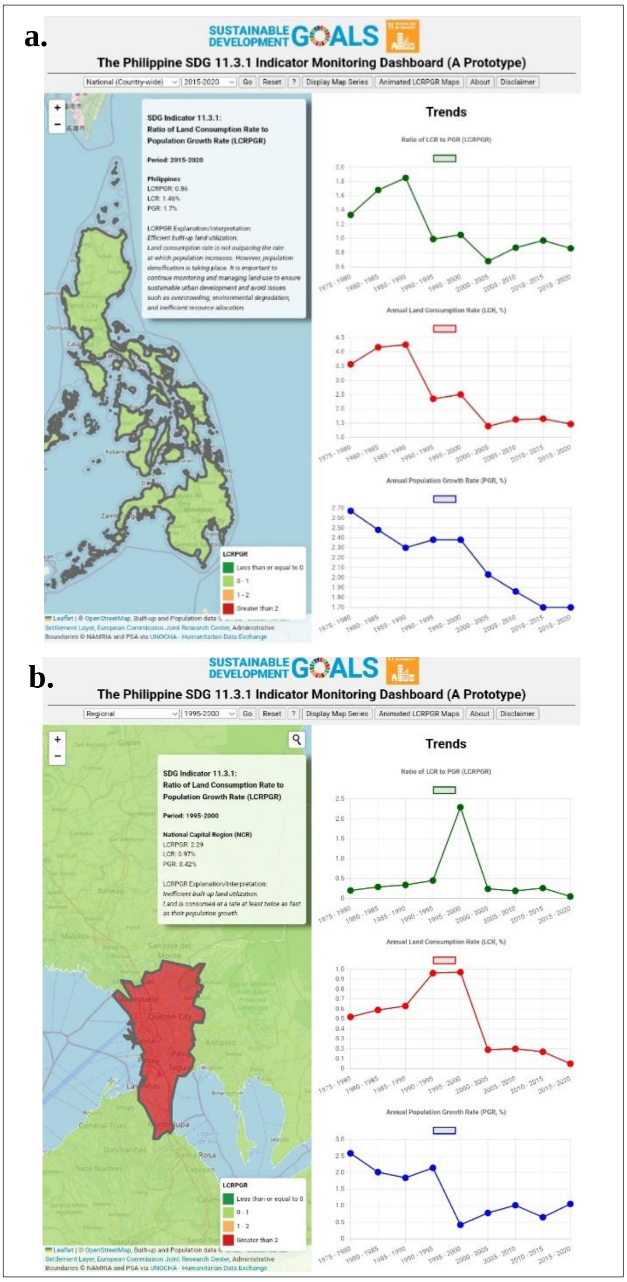

Figure 2. The main visualization and analysis page. In these illustrations, the user selects the geographical level and period using drop-down selection buttons; (a) demonstrates an example for the entire country, while (b) shows an example for a specific region. Hovering the mouse cursor over a feature will display information on LCR, PGR, and LCRPGR, along with a brief explanation. Clicking on a feature will bring up detailed line charts for further analysis.

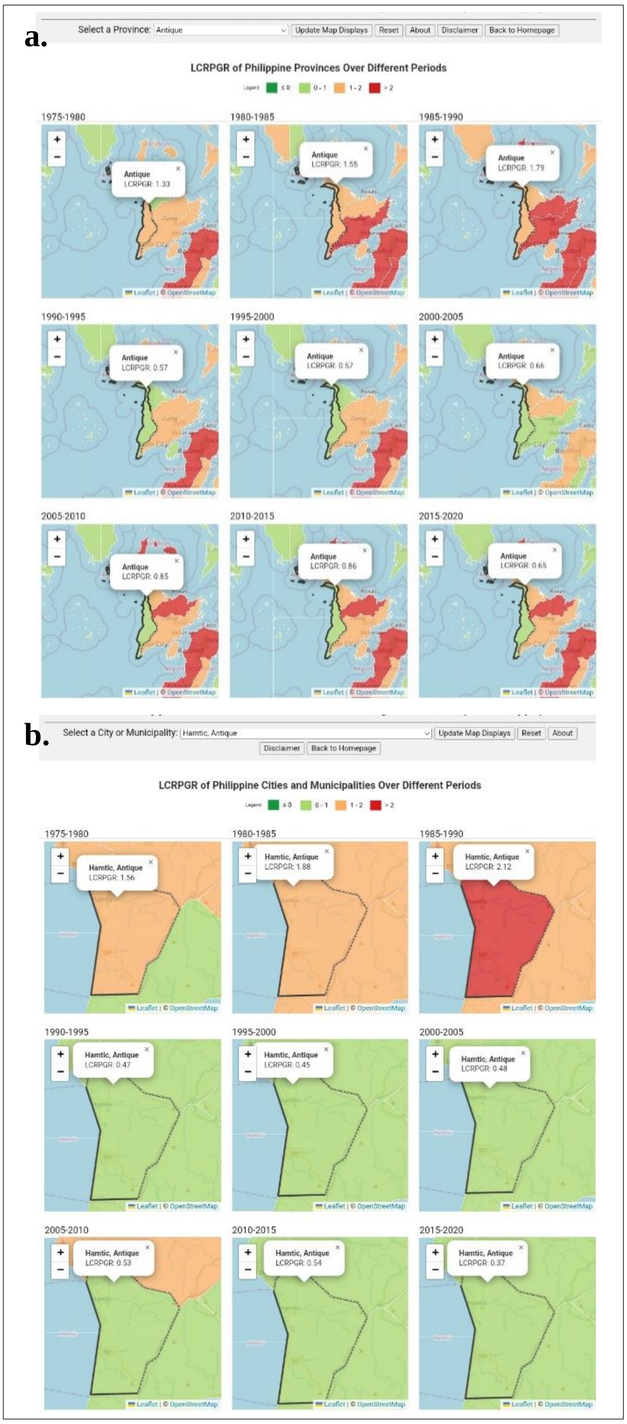

Figure 3. The “map series” page. To access this functionality, the user first selects the geographical level in the main page via the “Map Series” button; (a) demonstrates an example for a specific province, while (b) shows an example for a specific municipality. For each selected level, the user has the option to show all features or select a locality. After selection, the map displays will simultaneously zoom-in to the selected locality, and the LCRPGR values can be displayed as well by clicking on the feature.

5. Discussion, Conclusions and Outlook

Our paper presents the development and deployment of a prototype web GIS-based application aimed at visualizing the status and progress of SDG 11.3.1 in the Philippines. By leveraging open-source geospatial software and EO datasets within the "where-when-what-how" framework, we have demonstrated the potential of accessible technology in supporting sustainable development monitoring efforts up to the city/municipal levels. Through our prototype, accessible at https://ccgeoinformatics.github.io/sdg1131ph/, we showcase the feasibility of such tools in aiding policymakers and stakeholders towards achieving the SDGs by 2030. The system's functionalities, including interactive choropleth maps, line charts, map series, and animated maps, not only facilitate the graphical representation of indicator values but also enable basic analyses crucial for informed decision-making. Our approach not only addresses the need for effective visualization methods but also underscores the importance of technological accessibility in monitoring SDGs.

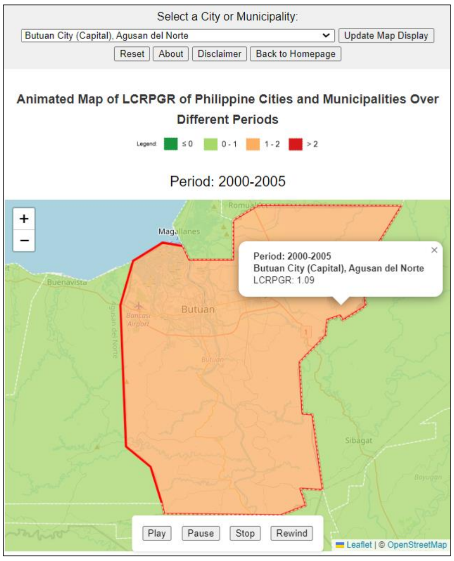

Figure 4. The "animated maps" page.

Aside from providing a system for visualizing SDG 11.3.1, another important contribution of this work is the ability to quantify and display the trends in LCR and PGR up to the city/municipal level. Previously, such detailed information (along with LCRPGR) was inaccessible. With our system, users can easily visualize these trends across four administrative levels through maps and charts. This represents a significant improvement over the currently available information on Philippine SDG status and progress, which is typically presented only in tables or graphs as part of reports or documents.
All these achievements were made possible by utilizing open datasets like the GHSL and coupling them with open-source software for visualization. Our work exemplifies how open data, and accessible technology can transform SDG monitoring; it provides a more interactive and detailed view of progress that is essential for informed decision-making and policy development.

In its current form, our visualization system is not yet capable of ranking localities based on their SDG indicator values. Future updates will include such functionality. Moreover, we emphasize that the system presented is a prototype, intended for demonstration purposes. While it showcases the potential of utilizing open-source geospatial software and earth observation datasets, its operational readiness for real-life applications may require further refinement and validation. Nevertheless, the system can be easily adapted by interested agencies through updating the primary input data consisting of GeoJSON files of LCR, PGR and LCRPGR calculations or can be modified to connect to geospatial databases. We also want to clarify that our prototype is not intended to replace official reports on SDGs produced by relevant Philippine government agencies or the United Nations. Rather, it serves as a supplementary tool to enhance understanding and engagement with SDG monitoring efforts.

Acknowledgements

The lead author gratefully acknowledges the Department of Science and Technology – Science Education Institute (DOST-SEI) for the doctoral scholarship, and Caraga State University for the fellowship. We also thank the European Commission – Joint Research Center, the UN Office for the Coordination of Humanitarian Affairs for the datasets, and the anonymous reviewers for their valuable feedback.

References

Balisacan, A.M., 2023. Approving and Adopting the Refined List of Philippine Sustainable Development Goal (SDG) Indicators. PSA Board Resolution No. 2 Series of 2023. Philippine Statistics Authority Board. https://www.psa.gov.ph/system/files/phdsd/PSA-Board-Resolution-No-02-Series-of-2023.pdf (12 April 2024).

Berse, K., 2024. Regional: Advancing Inclusive and Resilient Urban Development Targeted at the Urban Poor Philippines: Urbanization Trends, Hazard Exposure and Sectoral Realities: A Macro View of Philippine Cities (Supplementary Report). *ADB Technical Assistance Consultant's Report, Project Number: 51325-001*. Asian Development Bank. https://www.adb.org/sites/default/files/project-documents/51325/51325-001-tacr-en_5.pdf (17 March 2024).

Bocher, E., Neteler, M., 2012. *Geospatial Free and Open Source Software in the 21st Century: Proceedings of the First Open Source Geospatial Research Symposium, OGRS 2009*. Springer-Verlag Berlin Heidelberg. doi.org/10.1007/978-3-642-10595-1.

Chaves, M.E.D., Picoli, M.C.A., Sanches, I.D., 2020. Recent applications of Landsat 8/OLI and Sentinel-2/MSI for land use and land cover mapping: a systematic review. *Remote Sensing*, 12(18), 3062. doi.org/10.3390/rs12183062.

Coetzee, S., Ivánová, I., Mitasova, H., Brovelli, M., 2020. Open geospatial software and data: a review of the current state and a perspective into the future. *ISPRS International Journal of Geo-Information*, 9(2), 90. doi.org/10.3390/ijgi9020090.

Estoque, R.C., Ooba, M., Togawa, T., Hijioka, Y., Murayama, Y., 2021. Monitoring global land-use efficiency in the context of the UN 2030 Agenda for Sustainable Development. *Habitat International*, 115. doi.org/10.1016/j.habitatint.2021.102403.

European Commission, 2023. GHSL Data Package 2023. Publications Office of the European Union, Luxembourg. doi.org/10.2760/098587.

Gong, X., 2019. SDG Viz: a web-based system for visualizing sustainable development indicators. *Proceedings of the ICA*, 2, 39. doi.org/10.5194/ica-proc-2-39-2019.

Gorte, V., Degbelo, A., 2022. Choriented maps: visualizing SDG data on mobile devices. *Cartographic Journal*, 59(1), 35–54. doi.org/10.1080/00087041.2021.1986616.

Isaacs, J.P., Falconer, R.E., Blackwood, D.J., Gilmour, D.J., 2009. Visualisation for sustainable decision making. *Eurographics/IEEE Symposium on Visualization*. https://rke.abertay.ac.uk/en/publications/visualisation-for-sustainable-decision-making (13 April 2024).

Jiang, H., Sun, Z., Guo, H., Weng, Q., Du, W., Xing, Q., Cai, G., 2021. An assessment of urbanization sustainability in China between 1990 and 2015 using land use efficiency indicators. *Npj Urban Sustainability*, 1(1), 34. doi.org/10.1038/s42949-021-00032-y.

Kraak, M.J., Ricker, B., Engelhardt, Y., 2018. Challenges of mapping sustainable development goals indicators data. *ISPRS International Journal of Geo-Information*, 7(12). doi.org/10.3390/ijgi7120482.

Li, Z., Gong, X., Chen, J., Mills, J., Songnian, L., Zhu, X., Peng, T., Hao, W., 2020. Functional requirements of systems for visualization of sustainable development goal (SDG) indicators. *Journal of Geovisualization and Spatial Analysis*, 4(1). doi.org/10.1007/s41651-019-0046-x.

Liu, L., Zhang, X., Gao, Y., Chen, X., Shuai, X., Mi, J., 2021. Finer-resolution mapping of global land cover: recent developments, consistency analysis, and prospects. *Journal of Remote Sensing*, 2021. doi.org/10.34133/2021/5289697.

Melchiorri, M., Pesaresi, M., Florczyk, A. J., Corbane, C., Kemper, T., 2019. Principles and applications of the global human settlement layer as baseline for the land use efficiency indicator—SDG 11.3.1. *ISPRS International Journal of Geo-Information*, 8(2). doi.org/10.3390/ijgi8020096.

Metabolic, 2019. Why data visualization is critical to driving sustainable change. https://www.metabolic.nl/news/why-data-visualization-is-critical-to-driving-sustainable-change/ (12 April 2024).

Mobasheri, A., Mitasova, H., Neteler, M., Singleton, A., Ledoux, H., Brovelli, M.A., 2020. Highlighting recent trends in open source geospatial science and software. *Transactions in GIS*, 24(5), 1141–1146. doi.org/10.1111/tgis.12703.

openSDG. (2024). openSDG Documentation. OpenSDG Documentation. https://open-sdg.readthedocs.io/en/latest/ (18 April 2024).

Qiu, Y., Zhao, X., Fan, D., Li, S., Zhao, Y., 2022. Disaggregating population data for assessing progress of SDGs: methods and applications. *International Journal of Digital Earth*, 15(1), 2–29. doi.org/10.1080/17538947.2021.2013553.

Rist, T., Masoodian, M., 2022. Interactive map visualizations for supporting environmental sustainable development goals. In: Ardito, C., et al. Sense, Feel, Design. INTERACT 2021. *Lecture Notes in Computer Science*, 13198. Springer, Cham. doi.org/10.1007/978-3-030-98388-8_4.

Santillan, J.R., Heipke, C., 2023. Using GHSL to analyze urbanization and land-use efficiency in the Philippines from 1975-2020: trends and implications for sustainable development. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 10(1-W1-2023), 413–422. doi.org/10.5194/isprs-annals-X-1-W1-2023-413-2023.

Santillan, J. R., Heipke, C., 2024. Assessing patterns and trends in urbanization and land use efficiency across the Philippines: A comprehensive analysis using global earth observation data and SDG 11.3.1 indicators. *PFG–Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, 92, 569-592. doi.org/10.1007/s41064-024-00305-y.

Schiavina, M., Melchiorri, M., Corbane, C., Florczyk, A.J., Freire, S., Pesaresi, M., Kemper, T., 2019. Multi-scale estimation of land use efficiency (SDG 11.3.1) across 25 years using global open and free data. *Sustainability*, 11(20). doi.org/10.3390/su11205674.

Siekierska, E., Williams, P., Mueller, A., 2004. Visualization and sustainable development decision making. https://www.codata.info/archives/2004/04conf/papers/Siekierska-paper.pdf (12 April 2024).

Tsai, M.C., van Gasselt, S., 2022. Framework and use case for a web-based interactive analysis tool to investigate urban expansion and sustainable development goal indicators. *GI_Forum*, 10(2), 18–31. doi.org/10.1553/giscience2022_02_s18

UN-Habitat, 2018. SDG Indicator 11.3.1 Training Module: Land Use Efficiency. https://unhabitat.org/sites/default/files/2021/08/indicator_11.3.1_training_module_land_use_efficiency.pdf (10 March 2024).

UN-Habitat, 2024. Philippines. United Nations Human Settlements Programme. https://unhabitat.org/philippines (17 March 2024).

United Nations Department of Economic and Social Affairs, 2022a. The 17 Goals. https://sdgs.un.org/goals (07 April 2024).

United Nations Department of Economic and Social Affairs, 2022b. The 17 Goals. https://sdgs.un.org/goals/goal11 (07 April 2024).

United Nations Statistics Division, 2021. SDG indicator metadata (Harmonized metadata template – format version 1.0). Last updated 2021-03-01. https://unstats.un.org/sdgs/metadata/files/Metadata-11-03-01.pdf (10 March 2024).

United Nations Statistics Division, 2024. SDG Indicators: Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development. United Nations Statistics Division. https://unstats.un.org/sdgs/indicators/indicators-list/ (12 April 2024).

Wang, Y., Sun, Y., Cao, X., Wang, Y., Zhang, W., Cheng, X., 2023. A review of regional and global scale land use/land cover (LULC) mapping products generated from satellite remote sensing. *ISPRS Journal of Photogrammetry and Remote Sensing*, 206, 311–334. doi.org/10.1016/j.isprsjprs.2023.11.014.

Yin, X., Li, P., Feng, Z., Yang, Y., You, Z., Xiao, C., 2021. Which gridded population data product is better? Evidences from mainland southeast Asia (MSEA). *ISPRS International Journal of Geo-Information*, 10(10). doi.org/10.3390/ijgi10100681.