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Monitoring the Ecological Component of Sustainable Development Goals using Geospatial Information Tools: A Review

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***Abstract*—** The Sustainable Development Goals (SDGs) comprising 17 goals and 169 targets is a global strategy for guiding all nations in the course of changing and managing the social, economic, and ecological dimensions of the world. Quantifying a set of measurable indicators for all the goals is essential for monitoring the progress in accomplishing the SDGs. In this regards, geospatial technology is of great importance. Yet, there is less awareness and understanding specifically at the strategic or decision-making level, of the vital and integrative role of geospatial information in implementing the SDGs. Thus, this article focuses on the role of geospatial information tools in monitoring the ecological component of SDGs. The study is guided by parts of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A thorough search was conducted in reputable electronic databases using specific search keywords. A total of 2,192 papers were gathered, which were subjected to exclusion and inclusion criteria resulting into the selection of 104 papers for review. Furthermore, the topical and methodological trends of geospatial technology studies relating to SDGs were discussed. In the conclusion, limitations were identified and future scope was provided.

***Keywords*—** *environmental, GIS, GPS, remote sensing, SDGs, socioeconomic, technology, United Nation*

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I. INTRODUCTION

Contemporary problems concerning global sustainability require urgent action at local, regional and international communities. It is meant to solve critical world problems, as a result of the global environmental concerns that started in the 1970s [1]. Consequently, the necessity to support the priorities connected to society-nature interaction was determined in 2002. The result is the emergence of a set of Sustainable Development Goals (SDGs) comprising 17 goals and 169 targets. The SDGs represent a worldwide call for towards ending poverty, hunger, protecting the planet, and safeguarding peace and justice by 2030 [2,3]. It builds on the Millennium Development Goals (MDGs) that were in place during 2000–2015 [4] and expand them in thematic and geographic scope [5]. The MGDs was used to reduce many challenges confronting humanity particularly in the Global South [6,7,1]. While MDGs encompassed the notion of development as the North-South project to meet basic needs to end poverty, SDGs reconceptualised development as the universal aspiration for human progress that is inclusive and sustainable [8].

Monitoring the progress of SDGs over time requires quantifying a set of measurable indicators of different targets specific to each goal [9]. This is a function of potent data acquisition capabilities and adequate data quality for optimum measurement of the indicators. Yet, the absence of dependable data in appropriate or integrated format for decision-making and progress monitoring is a problem. The geospatial data sources including remote sensing, GNSS, and GIS is an essential source of data for monitoring the SDGs. Remote sensing is concern with the use of sensors in capturing geospatial data; GNSS captures locations on Earth; and GIS is used for capturing, storing, manipulating, processing, analysing, and displaying geospatial data [10-13].

Remote sensing is the only cost-effective technology that can provide data at a global scale. Its data affords information about the bio-physical and chemical indices of the planet which is valuable in achieving the SDGs [14,15]. Of course, satellite-based data is advantageous in producing and supporting official statistics to complement traditional sources of socio-economic and environmental data [16]. Also, the readily accessible GNSS equipment and network has greatly influenced the advancement in the geospatial world as it gives precise information of certain position on earth at a high speed. GNSS observation is used for monitoring the atmosphere, disasters, sea level, and water distribution, etc. GIS is characterized with remarkable spatial analytical strength. Therefore, it can support sustainability planning, decision-making, and management because of its sophisticated ability to map, combine, and analyse different data into spatial layers.

This paper offers a systematic examination of geospatial information technology for implementing and monitoring of SDGs. Section II contains the related work on the topic; Section III deals with the methodology used in the study; Section IV presents the results and discussion; and Section V concludes the study with future directions.

II. Related Work

The concept of SD was developed in 1960 when it became apparent that economic and industrial advancement can result to ecological issues. The first report concerning SD (Meadows Report) was published in 1972. In 2000, MDGs was established with 8 objectives to tackle poverty and hunger, achieve gender equality and improve the health sector [17]. In 2012, new objectives designated as SDGs were established [18] as a policy paradigm [19], defining 17 unique objectives that symbolizes an urgent call to shift the world onto a more sustainable route [20] (see table 1).

Table 1. United Nations Sustainable Development Goals

SDGs	Goal
SDG 1	End poverty in all its forms everywhere
SDG 2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
SDG 3	Ensure healthy lives and promote well-being for all at all ages
SDG 4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
SDG 5	Achieve gender equality and empower all women and girls
SDG 6	Ensure availability and sustainable management of water and sanitation for all
SDG 7	Ensure access to affordable, reliable, sustainable and modern energy for all
SDG 8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
SDG 9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
SDG 10	Reduce inequality within and among countries
SDG 11	Make cities and human settlements inclusive, safe, resilient and sustainable
SDG 12	Ensure sustainable consumption and production patterns
SDG 13	Take urgent action to combat climate change and its impacts
SDG 14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
SDG 15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
SDG 16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
SDG 17	Strengthen the means of implementation and revitalize the global partnership for sustainable development

Evidence in the literature demonstrates significant effort on SDGs by researchers. For example, Mensah [21] clarified the sustainable development paradigm and its implications for humanity. He believes that SD centres on inter- and intra-generational equity with regards to the environment, economy, and society.

Application of geospatial information technology have improved the proficiency for governments, international organizations and researchers in evaluating, modelling, monitoring and making reports in relation to SD, and other global concerns. Therefore, Yuan [22] highlighted the rational significance of GIScience to the SDGs. He concluded that GIScience knowledge and knowledge creation is important for addressing the gaps identified by the 2019 UN Forum on SD. Also, Nabiyeva and Wheeler [23] determined the areas of sustainable development where GIS has been used for implementing SDGs and potential areas where it might be used more. It was discovered that SDGs, which are most frequently addressed with GIS are 15, 11, and 13 while SDGs 2, 8, and 16 are least addressed with GIS. Acharya and Lee [13] presented the geospatial methods and their utilization in assessing SDGs with emphasis on prospects and problems. They suggested that remote sensing demonstrates considerable progress with innovative satellites having better abilities, and less restriction by Unmanned Aerial Vehicles (UAVs). Ferreira1 et al. [24] evaluated various Earth Observation (EO) methods and their input to accomplishing SDGs. They observed that with the importance and rising volume of data derived through EO, a new technique specifically the use of Machine Learning is required for attaining the SDGs. Baumgart et al. [25] carried out a comprehensive mapping of the alignments among space agencies and other organizations (as regards their projects) to the SDG structure. The purpose is to measure the benefits of the projects and tools to each SDG. It was indicated that many projects and tools differs across the range of the goals with specific emphasis on industrial growth, hunger removal, and better healthcare.

Though, various research indicate the significance of geospatial technology in monitoring SDGs, Scott and Rajabifard [26] shows that its role in contributing to sustainable development has not been adequately described. Hence, this study is aimed at emphasising the significance of geospatial technology in monitoring the SDGs with specific interest in the ecological component of SDGs.

III. Methodology

This review is focused on papers that deal with the application of geospatial technology for monitoring SDGs. It was guided by parts of the “Preferred Reporting Items for Systematic Reviews and Meta-Analyses” (PRISMA) guidelines (see [27]). Systematic reviews are characterized with transparency and repeatability, maximizing objectivity and minimizing bias [28].

A thorough search was executed in electronic databases including Scopus, Web of Knowledge, Science Direct, and Google Scholar. Relevant articles were identified through a combination of searches using specific keywords– "Sustainable Development Goals", "Geospatial Technology AND SDGs", "Geospatial Data AND SDGs". The search was not limited by any specific period as precedence was given to the significance of the materials in terms of their substantial contribution to the on-going discourse on SDGs. Yet, more recent papers were gathered to reflect the rising importance of the topic.

The search terms and criteria for inclusion/exclusion of articles were established. Articles that are not linked to SDGs were excluded while those that are coherent with the subject matter were included in the review. The main inclusion conditions were significance, authority and currency [29]. Significance is concerned with degree of contribution of the paper to the research on SDGs, with emphasis on geospatial technology; authority deals with whether the paper had been published by a reputable source or the material had been peer-reviewed or professionally edited; and currency was defined in terms the current influence of the material regarding the debate on SDGs [30].

The literature search produced 2,192 references, which were subjected to further screening and eligibility processes. Consequently, articles were identified for full-text retrieval, out of which 104 met the final inclusion criteria and were thus retained, read thoroughly, reviewed in full detail, and analysed. The relevant information were summarised repeatedly, guided by the keywords and phrases mentioned earlier.

IV. Results and Discussion

The formulation of SDGs considered the global ecological, economic, and social connections. In other words, social and economic development must be performed such that the environment is protected [31] for both the present and future generations. Of course, the SDGs imply a progression from an economic perspective toward an ecological perspective [32]. The following subsections deals with the goals that are directly related to ecological aspect of SDGs.

4.1 SDG 6: Clean water and sanitation.

The global population is expected to reach 8.5 billion in 2030 [33]. Hence an enhanced management of water and sanitation will sustain human wellbeing, while conserving the resilience of the environment. The growing worldwide demand for water is resulting from various factors including the increasing global population, improving living standards, changing consumption patterns, and extension of irrigated agriculture [34]. Studies have shown a great number of people worldwide still have issues with access to water (see [35-38]) due to manifold factors. In consequence, water crises have become a prevalent global threat in terms of probable impact [39].

The World Health Organization (WHO) [40] reported that 2 billion people still do not have basic sanitation facilities of which 673 million still defecate in the open such as in the street gutters, behind bushes or open bodies of water. Of course, poorly managed dumping of waste is frequently practiced in many metropolises, which result to severe ecological degradation [41]. The major consequence is prevalence of disease (see table 2), economic problem (see figure 1), and various social-related issues.

Table 2. Disease burden related to insufficient sanitation.

DISEASE	DEATHS	DALYS (1,000S)	POPULATION ATTRIBUTABLE FRACTION
Diarrhoeal	828,651	49,774	0.60
Soil-transmitted helminth	6,248	3,431	1.00
Malnutrition	28,194	2,995	0.16
Trachoma	<10	244	1.00
Schistosomiasis	10,405	1,096	0.43
Lymphatic filariasis	<10	782	0.67

Source: Author's modification from the WHO [42]

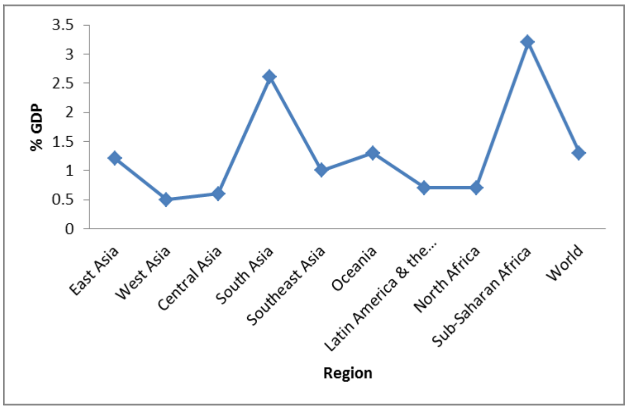

Figure 1. Economic losses associated with inadequate sanitation by region, as a percentage of GDP in 2012.
Source: Author's input based on data from the WHO [43]

The spatiotemporal discrepancy between demand and availability of freshwater is the crux of global water scarcity [44]. This can be measured in physical or social or economic terms based on adaptation capability [45]. Geospatial tools specifically remote sensing and GIS can be used to address the issues associated to availability and sustainable management of water and sanitation. For instance, Machiwal et al. [46] generated a groundwater map showing potential zones of Udaipur district of Rajasthan, Western India using RSGIS and Multi-Criteria Decision Making Techniques. Furthermore, one significant phenomenon that has greatly influenced water-related negative consequence such as reduced water supply, declined water quality, and desertification is drought. Drought is a dangerous natural risk resulting from insufficient rainfall [47,48]. Satellite data provides a potent tool for spatiotemporal evaluation of droughts and its underlying drivers [49,50]. Thus, Eguaroje et al. [51] conduct satellite-enhanced assessment of drought over Kano State, Nigeria for 2018. They used MODIS Normalized Difference Vegetation Index (NDVI), and ancillary data. Results indicate a near normal condition in the study area.

4.2 SDG 7: Sustainable energy solutions.

Significant improvements in energy supply have been made since 2010. More people were connected to electricity in 2019 [52]. Yet, a huge number of people still live without electricity especially in fragile and conflict affected areas. Another critical problem is related to the quality of global energy supply, still consists of pervasive use of fossil fuels. Therefore, finding an effective approach to deal with resource depletion and climate change require a complete change of the prevailing energy systems [53] to the renewable energy sources

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The primary renewable technologies used in developing regions are solar photovoltaics (PV), wind turbines, hydroelectric power, and biomass combustion. For instance, studies suggest that there is a theoretical annual electricity generation potential of 660,000 TWh for Solar PV in Africa [54]. Also, the World Energy Council [55] estimates that worldwide wind capacity could grow from 435 GW in 2015 to 977 GW in 2030. Similar records indicate that China, India, and Brazil are prominent in installed wind capacity and constant sector growth among developing countries [56]. Also, many other nations have demonstrated intentions for wind energy developments, such as the Philippines with a goal of 2.3 GW of capacity by 2030 [57] and Kenya with addition of 0.4 GW capacity by 2020 [58]. One of the main advantages associated with solar PV and wind energy sources lies in their simplicity to operate off-grid. Thus several studies have estimated prospects of solar energy [e.g., 59– 60] and wind energy [e.g., 61–64] in different sites.

The European Space Science (ESA) is using its satellite system to generate safe power that can replace natural emissions producing greenhouse gasses. Similar efforts by the National Aeronautics and Space Administration (NASA) is providing a robust enhancement for our planet's clean energy programs while advancing in highly technological research for science, aeronautics and space exploration tasks [65] through Earth Observation satellites. Of course, when talking about space technologies for clean energy generation, it is necessary to look at EO satellites for maximizing renewable energy production [66]. First and foremost, satellite data is important for viability analysis of renewable energy systems including solar energy resource assessment, management of PV installations, wind power estimation and wind farm siting, and environmental impact assessment. Furthermore, Thermal Infrared (TIR) data, surface wavelength measurements, and gravity anomalies generated from EO are of great significance in geothermal prospecting of large land areas. EO data are also frequently used to evaluate water quantity and accessibility for designing and monitoring hydroelectric power resources.

4.3 SDG 7: Climate change.

Anthropogenic activities, especially the burning of fossil fuels have caused the atmospheric concentrations of GHGs to increase over the past geological time. For instance, the ice record data of the past 420,000 years shows that the concentrations of carbon dioxide have risen from 280 to 400 ppm [67]. These gases usually hamper the outward infrared radiations more than they block inward solar radiations [68,69]. So, the growing GHGs concentrations are increasing the natural greenhouse effect, causing Earth's surface temperature to increase [70]. Also, human-induced aerosols increases the quantity of sunlight that is reflected back to space, a cooling effect that offsets some of the warming induced by increasing GHG concentrations. The impact of this change in climate is being felt all over the world including changing weather patterns, more extreme weather events, drought, desertification, rising sea levels, and flooding, etc.

Comprehending the climate change requires creating a framework to take several pieces of past and future data from a range of sources and merging them in a single system using GIS [71]. Furthermore, the application of remote sensing in climate monitoring and analysis is now prevalent. Remote sensing is highly effective in climate change studies as it affords data on Essential Climate Variables (ECVs) at local, regional, and global coverage. On the other hand, the conventional ground-based approach is limited due to the lack of a dense network of ground-based measurements for the ECVs in many regions. Satellite-derived information can improve the accuracy of gridded climate datasets from dense ground-based networks. Apparently, the use of remote sensing has enhanced the manner by which climate change is being monitored in recent time (see [73-75]).

4.4 SDG 14: Sustainable use and conservation of ocean, seas and marine resources.

Coastal zones are extremely productive, supplying living aquatic and other natural resources. However, more than 40% of the world's oceans are influenced by anthropogenic factors, including marine contamination, loss of habitats and livestock depletion, over-exploitation of marine resources, and others. Marine pollution is currently high and a considerable percentage of coral reefs have been destroyed irreversibly. Without concerted efforts, coastal eutrophication is expected to increase in 20 per cent of large marine ecosystems by 2050 [76]. There is a global decline in marine biodiversity at present demonstrated by disappearances, invasions, hybridizations and decrease in the species abundance [77]. This may be associated with poor decisions in resource management, which normally compromise conservation, local livelihood, and resource sustainability goals [78]. Of course, the sustainable management of our oceans relies on the capacity to guide human utilization of the marine ecosystem [79].

Contaminants such as oil, toxic chemicals, heavy metals, bacteria, viruses, nutrients, and sediments can adversely impact human health and coastal ecosystems and thus have significant environmental and socio-economic ramifications (see [80]). Geospatial techniques provide an enhanced means of monitoring the ocean, seas and marine resources. For instance, Dahdouh-guebas [81] used integrated remote sensing and GIS to study the sustainable utilization and management of tropical coastal ecosystems including coral reefs, mangrove forests, and seagrass beds. An improved coastal management and proper knowledge of change in location and areal extent of seagrasses can be achieved by spatial monitoring [82] in GIS environment. Mapping the extent of seagrasses is benefiting from remote-sensing technologies, high-resolution satellite imagers, lower-orbit and airborne earth looking camera technology [83].

Also, the spatiotemporal extent of oil spill coverage revealed from satellite imagery offers essential information for assessing ecological impacts of natural and anthropogenic oils, such as inhibition of gas exchange at the air–water interface and changes in phytoplankton biomass [84,85]. The advanced RS technology regarding Synthetic Aperture Radar (SAR) has proven to be a significant tool in oil-spill monitoring [86]. Yet, colour radiometry data is conventionally used to detect the areal coverage of oil spills and natural oil seepages, complementing the coverage-limited Synthetic Aperture Radar (SAR) observations (e.g [87,88].

Remote sensing has also proved the feasibility of designing near-real-time fishery management boundaries using SST (sea surface temperature), modelled data, and thermal habitat signatures from pop-up satellite tags [89]. Though, observation of SST has been carried out using in–situ method in the past, satellite–based investigation of global temperature trends now prevails. More importantly, satellite-based SST products such as those from the AVHRR can complement the in–situ network, offering improved spatiotemporal sampling.

4.5 SDG 15: Life on land.

More than 120,000 designated Protected Areas (PAs) cover about 13% of the Earth's land surface and Marine protected areas cover 6.3% of territorial seas and 0.5% of the high seas. They are important in conserving biodiversity [90] as they frequently contribute to the persistence of biodiversity and are also the only remaining stronghold for many of the world's top species [91]. Well-managed protected areas can provide vital ecosystem services, such as water purification and retention, erosion control, and reduction of flooding and unnatural wild fires. Also, forests are significant components of the terrestrial ecosystem and are normally responsible for regulating the exchanges between vegetation and atmosphere [92]. For this reason, they are used for carbon sequestration thereby balancing the atmospheric concentration of carbon dioxide; which in turn mitigates global warming. Alterations or reduction in the forested area usually leads to emission of carbon into the atmosphere. Therefore, the REDD+ concept of the UNFCCC emphasize on reducing emissions from deforestation and forest degradation, promoting sustainable forest management as well as enhancing carbon sinks for mitigating GHG emissions. This requires accurate monitoring by mapping and estimating the net forests cover, deforestation, and degraded forest area and quantifying the Above Ground Biomass (AGB). In this regards, geospatial techniques have shown to be highly effective. Specifically, satellite remote sensing which offers high spatiotemporal coverage has been used to map deforestation and forest degradation [e.g., 93]. Satellite-based assessment of vegetation have shown that while PAs are losing forest, these losses on average are less inside than outside PAs [see 94-97]. Anthropogenic activities have caused a more rapid alteration in biodiversity within the last 5 decades more than at any other period in human history. Change in habitat due to the harvesting of natural resources for industrial production, and urbanization are obviously among the most significant sources of biodiversity loss and land degradation.

Global severity and spatial coverage of land degradation is increasingly affecting more than 30% of forests, 20% of croplands, 10% of grasslands [98], and an estimated 2.6 billion human population [99]. Land degradation results from both natural and human-induced drivers. The natural factors are drought and desertification, soil salinity, and water logging, [100], and others while anthropogenic factors include overgrazing, mining, deforestation, LULC alteration [101], etc. Land degradation features such as gully erosion, bare lands and degraded vegetation can be detected directly and analysed using satellite imagery and geographical information systems [see 102-104,101].

V. Conclusion and Future Scope

The SDGs are meant to improve human well-being, protect natural resources and reduce anthropogenic impact on the Earth for the current and future generations. The role of geospatial technology for monitoring the SDGs has been significant in terms of its capability for data acquisition, processing, storage, analysis, and display. In this paper, major recent trends about the ecological component of SDGs were covered. However, not all the identified recent trends were addressed in-depth. More empirical study on different trends is needed to know the rate of adoption of geospatial technology and validate the implications. Also, the choice of satellite imagery for any kind of monitoring is a function of the study objective. The result of this study demonstrates that optical remote sensing is limited by certain weather situations whereas microwave remote sensing is possible through all weather conditions and throughout the year.

Furthermore, the progress of emerging tools such as Artificial Intelligence, Digital Twins, Virtual Reality, Internet of Things, participatory sensing, and humans-as-sensors will certainly alter our overall orientation. Merging geospatial data and tools with these technologies will advance new tools for monitoring the SDGs. These big-data-driven systems and applications will be more appropriate than ever, combining users' habits and inclinations with circumstances and locations, to offer smart notification services and location-aware virtual assistants.

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