European Journal of Environment and Earth Sciences
Vol 5 | Issue 5 | October 2024
ISSN 2684-446X

RESEARCH ARTICLE

The Adoption and Applications of Earth Observations and Allied Geoinformation Systems for Environmental Management in Ghana

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ABSTRACT

Earth Observations (EOs) and allied technologies were initially adopted and applied to inform sustainable environmental resource management in Ghana. This paper examines the initial adoption of EOs in the early 1990s and subsequent applications. It highlights the transformative potentials of EO technologies in addressing critical environmental issues while also identifying barriers to their widespread adoption and options for optimal up-scaling. Literature review, in-depth interview, and personal experiences of the author were analyzed. The initial optimism bias generated may have masked the need for establishing the necessary sustainability arrangements. The adoption of EOs was driven by the need to generate data to inform natural and environmental resource management in the mid-1990s. Initially, EOs facilities were established in public organizations, including the Council for Scientific and Industrial Research (CSIR), Survey Department, and the University of Ghana. Since then, EOs have been applied in various sectors for research and environmental resource management. Granted, there have been successes. Yet, challenges undermine the optimization and scaling-up of actual benefits. These include the misconceived technocentric view of EOs, which is a restricted domain for the technically initiated and map-making tool. Others, such as unfavourable organizational processes, unsustainable funding, and limitations in research and applications, have adversely contributed to suboptimal outcomes. Suboptimal institutionalization of EOs into management decisions has constrained EOs infrastructure acquisition, maintenance and data procurement. To sustainably enhance EOs applications in resource management, research, and governance, a shift from present misconceptions for effective mainstreaming and a leveraging of EOs as integral parts of decision-making processes are prerequisites. Decision-makers and management personnel should be educated on the relevance of EOs' functionalities to the core strategies of environmental management.

Keywords: Earth observations, Environmental, Geoinformation, Ghana.

Submitted: August 17, 2024

Published: October 24, 2024

10.24018/ejgeo.2024.5.5.484

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1. Introduction

Natural resources make important contributions to production systems and development in sub-Saharan African countries, including Ghana [1], [2]. For instance, evidence indicates that the mining and agriculture sectors (including forestry) make substantial contributions to the national economy and employment generation in Ghana [3], [4]. Anim-Sakey [5] has found a positive relationship between the mining sector and GDP growth. In Ghana, the primary sector continues to make significant contributions to employment generation [6]. Consequently, over-dependence and unsustainable exploitation have resulted in environmental resource degradation in Ghana [7]–[12]. Over the years, efforts have been made to manage environmental resource exploitation by international and national policy interventions. Yet, the desired expectations have not been sufficiently realized. Inadequate spatial data and information on environmental resources at the right scales, amounts, and timeliness have rendered management policies defective. With the emergence of EOs and allied technologies, it was hoped that spatially multi-scale data would inform policy and management applications that

would drive sustainable environmental resource exploitation. Yet, there is a dearth of information on the successes and challenges since the initial deployment and subsequent applications. This paper examines the case of Ghana.

In the early 1980s, the prevailing intensification of land degradation and the global trends in advocacy for a sustainable development trajectory stimulated the preparation of the Ghana National Environmental Action Plan (NEAP), which was adopted in 1991 [13], [14]. Further to that, Ghana's first overarching Environmental Policy was enacted in 1995 for environmental governance. Since then, other environmental and natural resource policies have been developed: the Land Policy, the Forest and Wildlife Policy [15], and the National Climate Change Policy [16]. It was acknowledged that the inherent spatio-temporal nature of environmental and natural resource dynamics required the capacity to target and address environmental challenges over space and time [14]. There was a felt need for the generation of timely spatial information that captures the time-space dynamics of environmental resource exploitation and the corollary challenges for management priority attention.

With the advent of EO technologies and subsequent transfer to Africa during the early 1990s, Ghana decided to adopt and deploy them in environmental and natural resource governance decisions, particularly regarding the implementation of the NEAP [14]. The adoption was largely project-based and donor-funding driven. Selected government agencies and public institutions benefited from the investments in EO infrastructure development and capacity building. These included the University of Ghana, the Survey Department, and CSIR (Ghana). Awareness was created for the use of EOs and leveraging the utilities of geo-technology. In 2000, with the support of the World Bank and other donors, a National Framework for Geospatial Information Management (NAFGIM) was established, which served as the *de facto* Spatial Data Infrastructure (SDI). It was considered one of the earliest in Africa.

After years of adoption and application of spatial technologies, the objectives of sustainably managing environmental resource exploitation in Ghana have not been fully achieved. To benefit optimally from EOs applications and enhance the sustainability of environmental policy and governance processes, it is deemed critical to examine the potential spaces and opportunities available in geo-technologies, and the functionalities that can be deployed in environmental governance and policy processes. It is equally crucial to identify weaknesses, challenges, and constraints in the existing organizational decision-making processes, mainstreaming paradigms, and applications. This will help optimize the benefits of applications of EOs in environmental and resource management by effective uptake and upscale processes. Hence, the paper answers the questions relevant to the opportunities, environmental context and motivation for the adoption, the nature of adoption, organizational structure, the policy and management relevance of EOs adoption. Others are the challenges of the adoption and applications. We also propose actionable strategies to optimize the use of EO applications, ensuring they effectively contribute to sustainable environmental management.

2. Opportunities for Transformative Application of EOS

Environmental governance is the interactions among structures, processes and traditions that determine how power is exercised, decisions are taken on issues of public concern, and citizens or other stakeholders have their say [17], [18]. Governance encompasses policies, institutions, processes, and power. The perspectives of the processes of decision-making and implementation in natural and environmental resources provide a wider scope for the analysis of opportunities for deploying spatial technology in environmental governance and policy processes. Environmental governance presumes good governance processes, which are characterized by participation/inclusiveness, accountability, transparency, responsiveness, effectiveness, etc. [19]–[21].

Good governance offers expansive opportunities by deploying and embedding the tools, functionalities, information/data, and platforms of geo-technology in policy-making, decisions, and implementation processes. Haider *et al*. [22] echo the broader view that ICTs have the potential to positively impact government transparency, responsiveness, and accountability and to empower citizens by improving information flows between government and citizens. Thus, the benefit that is accrued from the strong mutual and complementary inter-relationship of good governance and Geo-technology is enormous for sustainable development. These mutual and complementary inter-linkages provide a definitive and comprehensive framework for critically examining and evaluating the significance of geospatial technologies in policy processes and decisions for environmental governance at all levels, namely international, regional, national, and local.

Policy formulation for good governance begins with analysis and evaluation, or inventorying of natural and environmental resources for quality and availability. These are basic managerial and decision functions. According to some estimates, 70%–80% of government work involves geographically related issues or tasks [23]. For instance, environmental and natural resources, human needs, and socio-economic activities are widely distributed differentially in space. Given the diverse spatial distribution of natural and environmental resources, governance and policies are challenged to effectively identify and evaluate these resources as they are distributed in space. This makes for the right priority setting in development and management decisions.

Localities vary significantly in resource availability and challenges of environmental issues, hence would demand an appropriate mix of remedial management strategies and actions. Clearly, there must be efficient targeting of limited management and developmental efforts and resources to ensure efficiency in resource use, spatial equity, and sustainable resource management and utilization. The identification of geographical "hot spots" is particularly relevant for determining where particular problems exist in relation to socio-economic activities and to what extent natural resources are being overly exploited and degraded, and to undertake prompt measures to minimize, if not

reverse the degradation. Temporal variation of quality and quantity in response to use is an inherent attribute of natural and environmental resources. Largely, countries with high dependency on natural resources degraded or depleted them. Many Sub-Saharan countries, including Ghana, have had their resources either depleted or degraded for over-exploitation and poor management. For effective governance, timely and regular innovative monitoring and analysis is possible with the application of EOSs that regularly provide information on the earth's resources.

The processes of various ecosystems, including biological, climatological, geological, social, and economic elements, are interlinked. Besides, natural and environmental resources are allocated to multi-sectoral activities that involve different groups and individuals at different localities. Communities make specific and differential uses of resources, which may be determined by distinct contexts of local mix of market demands, culture, quantities of resources availability, technology, government policies, etc. Therefore, integration aptly defines the mode of analysis of natural and environmental resource utilization. Sound environmental and natural resource management and policy require an integrated and holistic approach to avoid conflicts in use objectives and degradation. The growing range of actors/stakeholders and cross-cutting issues concerned with natural resource issues demands an integrated, inter-sectoral, and multi-stakeholder participatory approach to policy processes for good governance. Geo-information technologies provide platforms for integrated and inclusive resource use policy formulation framework essential for all aspects of governance and administration [23].

Geo-information systems are socio-technological units of different scales and complexities, with appropriate operational interactions, rules of engagement, processes, and methodologies for sustainability. From a toolbox or functional perspective, geo-information technologies provide enormous functionalities for the generation and storage, analysis, modeling, integration, and visualization of data and information. Collective or communal engagement in these activities creates platforms and environments in the policy space and process for multi-stakeholder participation and engagement [24]. It offers the opportunity for communities and individuals to share their views on matters related to governance.

As a decision-making and support tool, geospatial technologies support managerial activities of planning, resource allocation, inventorying, monitoring, and evaluation. If well deployed in an organizational setting, the information provided (e.g., in a two or three-dimensional representation) on environmental resources enables collective stakeholder engagements in discussions, managing power play as it creates platforms for multi-stakeholder participation and encourages teamwork. Thus, spatial and integrated management involves processes and activities that are best supported by logic in the applications of geo-technology. At the community level, the processes of participatory GIS have enabled collective data generation and management of resources in rural communities [25].

3. Methodology

The paper adopted a qualitative approach. It reviewed the appropriate context and opportunities for EOs applications in Ghana, relevant technical reports and articles on the processes of adopting EOs and allied technologies, and the initial implementations in Ghana. Additionally, we identified and reviewed some research and management applications of EOs, including land use and land cover, forestry, carbon assessment, oceanography, agroforestry, etc. In-depth interviews and discussions were conducted with relevant officials of state agencies and organizations that have EOs and allied facilities. These included EPA, LUPSA, NADMO, CSIR, the University of Ghana, CERSGIS, and the Survey Department of Ghana. The discussions were centered on the adoption of EOs, capacity, funding, management, applications, benefits, and challenges. Data gathered was organized and discussed thematically and according to the evolutionary trends of EOs adoption in Ghana. The author's experiences and lessons from several years of project implementation, teaching, and participation in different forums contributed to the discussion.

4. Findings and Discussions

4.1. The Contexts and Motivation of Adoption

Coincidentally, the earliest efforts to adopt EOs started when Ghana was initiating the formulation and implementation of environmental policies as part of the global framework for sustainable development during the late 1980s and the early 1990s. Thus, EOs adoption in Ghana was largely driven by the need to formulate informed environmental policies for sustainable environmental management in Ghana. In the late 1970s, the inadequacy of the state of natural resource information was highlighted in a Land Use Planning Committee report of a study commissioned by the Ministry of Lands and Natural Resources in October 1978 [26]. The report called for the setting up of databases and identification of focal points to be linked together with a national information network. After the publication of the report, efforts were made to coordinate activities related to different types of natural resource information.

The adoption of EOs in Ghana was within the wider context of a global, regional, and national need to support the generation of information on natural and environmental resources to support policy decisions for sustainable development. In 1980, a National Remote Sensing Committee was established as part of the African Remote Sensing Council (ARSC), which Ghana ratified and signed in March 1980. Its main objective was to create awareness of the beneficial uses of remote sensing by drawing the attention of national governments to the use of remote sensing in natural resources and environmental management. Concurrently, the World Bank and other international donor agencies initiated a program to promote the development of Environmental Information Systems in Sub-Saharan Africa (EIS-SSA) to support a series of National Environmental Action Plans (NEAPs) in Africa [27]. This was in response to the challenges of

striking imbalances between economic development and sustainable management of renewable resources. In March 1988, the Government of Ghana initiated the preparation of the NEAP. In the preparation of the NEAP, information availability was identified as a critical priority for the success of the implementation of the environmental policy. A formal information framework on environment and natural resources management, the National Environmental Information System (NEIS), was proposed to ensure the success of NEAP.

The first organizational structure that marked the actual adoption of Geo-information technology in Ghana was initiated by the University of Ghana, which established the Remote Sensing Unit in 1986. In 1988, the Environmental Protection Agency (EPA), then Environmental Protection Council (EPC), established a directory of agencies and organizations responsible for all aspects of environmental management in Ghana and available information within these institutions. In 1989, workshops were organized by the National Remote Sensing Committee to promote EOs and the associated technologies in Ghana, to provide a basis for funding, and to demonstrate the potential for the applications of GIS and remote sensing in Ghana.

Many organizations have been involved in education and sensitization on the relevance of the applications of EOs in Ghana. Educational institutions, especially the tertiary, are key in training and equipping students with the requisite skills and knowledge in EOs in environmental management applications. With support from DANIDA, the Remote Sensing Application Laboratory (RSAL), now RS/GIS LAB, and Remote Sensing Applications Unit (RSAU), now CERGIS, was established at the University of Ghana, to train students and generate EOs products, respectively. Presently, spatial technologies are incorporated in several natural resources and environmental applied academic programs in Ghana. For instance, at the University of Ghana, remote sensing is taught at the departments of Marine and Oceanography, Earth Science, Geography and Resource Development, Institute for Environment and Sanitation Studies (IESS). Courses are also taught by other universities at the Kwame Nkurmah University of Science and Technology (KNUST), UMMAT, Wisconsin University (Ghana), etc.

Other research institutions and organizations have adopted EOS for applications. These include the Forestry Research Institute of Ghana (FORIG) and Soil Research Institute (SRI) of CSIR; LUSPA, EPA and Survey Department. Some local governments also have these facilities. It is necessary to underscore that not all the institutions and organizations that apply EOs products own the facilities. Some hire the services of institutions and experts to assist with the use of EOs in decision-making.

4.2. Applications of EOs and Allied Technologies

Earth Observation information products have received a high level of patronage in different aspects of the policy process at different levels for environmental governance. In terms of resources analysis and evaluation of the scope and nature of environmental problems, EOs has assisted in different issues. Apart from the use of EOs in generating land-use/cover maps, many sectors have made significant use of EOs. These have been information on the state of natural and environmental resources and the outcome of applied research. Again, there has been some amount of work in different ecological media, but the actual embedding of information and knowledge in policy formulation has been limited for reasons that are institutional and administrative rather than technical.

4.2.1. Land-Use/Cover and Land Suitability Mapping

Land degradation was an environmental challenge in Ghana due to intense land-based activities. Therefore, the initial applications involved the need to generate information requirements for land use management. A framework of a multi-institutional stakeholder committee of users and suppliers of environmental data and information was established. This was to lead the strengthening of national capacities in providing recommendations for the design of a sub-component of an Environmental Information System (EIS). This was part of a broad Environmental Resources Management System (ERMS), an integral aspect of the Ghana Environmental Resource Management Project (GERMP). This was a five-year project dedicated to the implementation the NEAP in 1993. The project was funded by Ghana and international development agencies, including the World Bank, DANIDA, ODA (DFID, UK), and the Government of Ghana. Major thematic environmental information generated was land-use/cover map. This was the first time major EOs products were used on a national scale. The Center for Remote Sensing and Geographic Information System (CERGIS), then the Remote Sensing Application Unit (RSAU) at the University of Ghana, was responsible for the exercise. Landsat 1990 was used to generate the maps. Besides, the Soil Research Institute of the CSIR was capacitated and tasked with the provision of digital soul and land suitability maps.

4.2.2. Carbon Mapping for REDD Implementation and Forestry

Ghana subscribed to REDD (Reduced Emissions from Deforestation and Degradation) strategies, which encouraged saving endangered forests, and REDD+ strategies, which encouraged forestation/reforestation by planting trees on land that has not been forested for a long time–if ever. To inform the national implementation strategies, useful applications of EOs were made for the production of the Ghana Carbon Map. In December 2009, as a joint initiative of the Katoomba Group's West Africa Incubator for Ecosystem Services, Nature Conservation Research Centre (NCRC), Oxford University, and Ghana's Forestry Commission, with technical support from NASA, and financial support by the Gordon and Betty Moore Foundation. Additional support was also provided by the Rockefeller Foundation, the Global Environment Facility (GEF), and the Norwegian Agency for Development Cooperation (NORAD). The carbon map of Ghana combined a range of satellite imagery, including radar from ALOS-PALSAR, optical imagery from MODIS, and LiDAR estimates of canopy height from GLAS (Geoscience Laser Altimeter System).

It was anticipated that the maps produced would have multiple applications in Ghana's quest to mitigate climate change through forestry and agriculture. It is also expected to have extensive utility for establishing a baseline information against which future stock changes (whether deforestation, degradation, or biomass enhancement) can be assessed, but also the basis for determining which regions or districts in Ghana have the greatest potential for preserving carbon and the extensive ecosystem services the nation's forests provide. It also holds a potential, in combination with land-use modeling, in helping to establish a reference emissions baseline for REDD+ and related activities. The carbon stock map can also inform mechanisms for distributing incentive payments that account for carbon stocks, whether national or sub-national, thereby helping to ensure that effective, efficient, and equitable mechanisms are in place for reducing carbon emissions from deforestation and forest degradation.

In recent times, EOs and GIS have been used to develop decision support in fragmented forest reserves in the Western Region of Ghana. The purpose of the application was to develop a multi-disciplinary strategy for forest corridor connectivity in two protected areas to address the environmental and social (socio-economic) impacts of cocoa production. As part of the criteria for selecting locations for developing cocoa agroforestry corridors, biophysical assessments using satellite images for vegetation patterns. This was integrated with other spatial data in a GIS environment to select suitable areas that were used. A decision support system was used to select suitable candidate sites for the corridor within a GIS framework [28].

The sea is both an environment and an important source of resources that provide a variety of ecosystem services that support livelihood systems and food security. A wider EOs application was the Monitoring for Environment and Security (MESA) in Africa initiative in the ECOWAS sub-region. The ECOWAS Coastal and Marine Resource Management Center was established at the University of Ghana and coordinates initiatives of the 14 countries of the subregion. The Marine Thema is the aspect of MESA that provides operational services of EOs-based information to support fisheries, management, and the safety of artisanal fisheries. Apart from providing information for operational purposes, they recognize the need for broader policy strategies for sound governance of the marine environment and resources. The Gulf of Guinea faces challenges common to many oceans, including depleting fish stocks, degradation of the marine ecosystem, and the impacts of climate change. As part of their contribution to the wider regional and individual states' marine policy process, they enable a better understanding of the status of marine resources and processes. In Ghana, the Ministry of Fishery and Aquaculture Development is the focal point, hence the ability to leverage EOs information in sound policy formulations.

It has been argued that scientists can and should play key and useful roles in the environmental policy process [29]. Environmental science is critical in environmental governance and policy [29], [30]. In Ghana, EOs have provided evidence from studies to correct misconceptions about changes in landscapes, inform shifts in opinions and changes in policy trajectories. Analysis of land-use/cover change, with emphasis on identifying the nature and extent of deforestation or natural regeneration in the forest zones, has provided insight into the patterns of LULCC dynamics and possible drivers of change [31]–[34]. Remote sensing-based studies conducted in the forest-savanna transitional zone of Ghana have revealed significant negative impacts of decades of the implementation of state-owned commercial agricultural policies since the 1960s and shaped inaccurate policy discourses [33]. Other studies on urbanization have identified unsustainable land cover conversion of prime farmlands and green spaces to build-up areas, resulting in flood intensities and flooding [34], [35].

4.3. Challenges and Options for Optimal Uptake and Sustainable Benefits

Ghana's socio-economic development is, to a large extent, dependent on natural and environmental resource exploitation. Having identified the potential and real merits in the application of EOs and allied geo-technologies in governance and policy processes, efforts were made from the mid-1990s to adopt EOs for policy and governance processes in Ghana. Successes have been achieved, yet not adequate sustainable resource use management. To ensure the optimization of EOs applications for environmental policy processes and governance, challenges that hinder concrete achievements must be addressed. Closing the gap between rhetoric and reality requires addressing the issues below.

4.3.1. Policy and Management Relevance of EOs Research

Criticism of the inadequacy of science and technology relevance for development in Ghana is rife. It is argued that research outcomes are neither packaged nor communicated in ways that are more understandable or appreciated by policy-makers to enable uptake and application. This includes EOs-based research and application, especially given its relative novelty and sophistication. Therefore, it is important to train researchers to target EOs-based studies to real national and environmental issues of policy relevance rather than being obsessed with satisfying personal intellectual curiosities. Again, there is a need for training researchers to enable them to package and communicate research outcomes in a language and products that are more understandable to policy-makers and easy to deploy in management processes. They must keep themselves abreast with contemporary policy debates and challenges and be more proactive in engaging with the policy processes at all levels.

4.3.2. Sectoral and Integrated Environmental Information

The environmental policy and governance domain is multi-and inter-sectoral. Each sector requires relevant and current information developed from EOs for decisions. Much as sectoral activities and mandates are vital, integration is central to developing environmental policy decisions and implementations that are holistic. This will require the integration of multi-sectoral data extracted from EOs. Hence, it is a prerequisite to build institutional

capacities to integrate multi-sectoral data for inter-sectoral and integrated policy processes.

4.3.3. Decision-Making, Governance and Policy Process Mainstreaming

The policy process provides a range of activities, platforms, and spaces for deploying and embedding EOs and information products. Currently, the nature of the policy processes limits the use of data/information in the formulation, implementation, monitoring, and evaluation. Some of the constraints and challenges are inherently fundamental to the paradigms of policy processes that discourage data/information use. Other constraints to the mainstreaming and embedding of EOs in the policy processes are more structural and functional. Factors that characterise poor governance, namely, inadequate data/information sharing, and flow, openness, participation, and accountability undermine EO applications. Therefore, policy and governance processes and institutional structures should be adapted and re-oriented to institutionalize the use of EOs. The institutions need to change to allow for openness, democratization, inclusivity, accountability, readiness for data sharing, etc.

4.3.4. Awareness, Education, Knowledge and skill Training

Geoinformation technologies are perceived to have applications relevant only to Geography as a discipline, to the exclusion of others. It is also widely considered a mapping tool, capable of composing 'nice' maps. Teaching was essentially introductory and theoretical; practical and skill training was limited. The analytical and integrative functionalities were de-emphasized. The approach to teaching was more technocentric–with a high emphasis on technology rather than applications. This rendered it less attractive to students and potential users alike. The analytical, integrative, and modeling functionalities: the most research and policy-relevant capabilities of geo-technologies were masked. The situation has not substantially improved.

Deliberate and comprehensive initiatives on education on the multiplicity of potential environmental applications for policy and governance should be embarked upon. The elitist and technocentric views should be demystified: they should form part of the mainstream technologies for decision-making and support. The capacity to apply EOs in managerial policy-relevant activities such as planning, implementation, monitoring, and evaluation should be strengthened. Teaching and training should emphasize environmental policy-relevant applications of EOs rather than the technology itself. Researchers should be trained to appreciate the relevant environmental applications for policy and governance. The focus should shift from the technology to the policy applications.

4.3.5. Investment in Technology, Data and Training

EOs technology is a dynamic field of research and application. It keeps evolving, with more applications emerging. Ghana would not optimally benefit if it is constrained by skills and access to relevant technologies. Companies in EOs software should be involved in training for the use of their software to enable users to benefit from their investments and lessen the burden of data acquisition. Obviously, from the very outset, EOs adoption was donor-driven. However, there must be a determined effort to ensure dedicated budgetary allocations for investments in infrastructure, logistics, data acquisition, skill training, and technology for deploying sustainable EO systems implementation. We must also take advantage of the availability of open-source software and free EOs data.

5. Conclusion

For the purpose of answering the questions relevant to the opportunities, environmental context, and motivation for the adoption, the initial adoption of EOs in the early 1990s and subsequent applications in Ghana was examined. The process of adoption, organizational structures, policy and management relevance of EOs adoption, the challenges of the adoption, applications, and options for enhanced applications was examined. Apparently, the initial optimism bias generated may have masked the need for establishing the necessary sustainability arrangements. The adoption of EOs was driven by the need to inform natural and environmental resource management in the mid-1990s. Initially, EOs facilities were established in public organizations, including public universities, agencies, and research institutions. Granted, there have been successes. Yet, challenges undermine the optimization and scaling-up of actual benefits. These include the technocentric view of EOs, which is also a restricted domain for the technically initiated and map-making tool. Unfavorable organizational processes, unsustainable funding, and limitations in research and applications have adversely contributed to sub-optimal outcomes. Inadequate institutionalization of EOs into management decisions has constrained EOs infrastructure acquisition, maintenance, data procurement, skill development, etc. To enhance EOs applications in environmental resource management, research, and governance, there is a need for a shift from present misconceptions for effective mainstreaming and a leveraging of EOs as the integral part of decision-making processes. Decision-makers and management personnel should be educated on the relevance of EOs' functionalities to the core strategies of environmental management.

Acknowledgment

I acknowledge the contributions of the various individuals who made time for engagements and shared their views and experiences relevant to the study. Initial financial support from the National Aeronautics and Space Administration has been acknowledged.

Conflict of Interest

The author declare that he do not have any conflict of interest.

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