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Web-Based Platform and Remote Sensing Technology for Monitoring Mangrove Ecosystem

Evelyn Anthony Rodriguez[1*], John Edgar Sualog Anthony[1], Randy Anthony Quitain[2], Wilma Cledera Delos Santos[2], Ernesto Jr. Benda Rodriguez[1]

[1]College of Computer Studies, Mindoro State University, Victoria, Philippines
[2]College of Arts and Sciences, Mindoro State University, Victoria, Philippines
Email: *reynaevyrodriguez@gmail.com

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Abstract

Remote sensing and web-based platforms have emerged as vital tools in the effective monitoring of mangrove ecosystems, which are crucial for coastal protection, biodiversity, and carbon sequestration. Utilizing satellite imagery and aerial data, remote sensing allows researchers to assess the health and extent of mangrove forests over large areas and time periods, providing insights into changes due to environmental stressors like climate change, urbanization, and deforestation. Coupled with web-based platforms, this technology facilitates real-time data sharing and collaborative research efforts among scientists, policymakers, and conservationists. Thus, there is a need to grow this research interest among experts working in this kind of ecosystem. The aim of this paper is to provide a comprehensive literature review on the effective role of remote sensing and web-based platform in monitoring mangrove ecosystem. The research paper utilized the thematic approach to extract specific information to use in the discussion which helped realize the efficiency of digital monitoring for the environment. Web-based platforms and remote sensing represent a powerful tool for environmental monitoring, particularly in the context of forest ecosystems. They facilitate the accessibility of vital data, promote collaboration among stakeholders, support evidence-based policymaking, and engage communities in conservation efforts. As experts confront the urgent challenges posed by climate change and environmental degradation, leveraging technology through web-based platforms is essential for fostering a sustainable future for the forests of the world.

Keywords

Mangrove Ecosystems, Monitoring, Remote Sensing, Web-Based Platform

1. Introduction

The Biogeochemical cycle plays a significant role in maintaining life on earth by facilitating the movement of vital nutrients and elements necessary for the consumption of living organisms. These cycles involve both biotic factors, such as plants and animals, and abiotic components, which interact to support various processes essential for life forms. For instance, the hydrological cycle regulates the weather conditions on planet's surface by facilitating evaporation and precipitation, ensuring a balanced temperature and pressure in the environment. Similarly, the carbon and oxygen cycle, driven by photosynthesis, regulates the exchange of gases between plants and animals [1]-[3].

One of the known functions of biogeochemical cycle is the regulation of Greenhouse Gases (GHGs) in the atmosphere via autotrophic photosynthesis. These GHGs include water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Carbon dioxide is the most prevalent among the Greenhouse Gases due to its numerous sources. Greenhouse Gases trap the heat emitted by the sun in order to maintain a warm environment for the living organisms, and energy generation. However, it is essential to maintain balance in the amount of GHGs in the atmosphere to prevent global warming. The consequences of global warming include unfavorable changes in temperature and weather patterns, extreme storms, and the gradual melting of glaciers leading to rising sea levels. Notably, the biogeochemical processes, particularly the carbon-oxygen cycle, naturally regulate the greenhouse effect. This involves recapturing GHGs in the atmosphere to maintain the necessary amount of heat during the day. Plants as carbon storage are the initiators of the abovementioned cycle. They utilized the atmospheric carbon dioxide to produce their own food through photosynthesis, releasing oxygen as a by-product. This oxygen was used by animals for cellular respiration, generating carbon dioxide that plants need for further growth, creating a continuous and essential cycle for the survival of other living organisms. However, these carbon sinks were exploited due to industrialization. There is a need to regulate activities that directly remove the trees from its ecosystem considering their role in the biogeochemical process that mitigates GHG emissions [4] [5].

Mangroves can be considered as one of the most effective carbon storages yet exploited ecosystem despite their capacity in mitigating excessive Greenhouse Gas (GHG) emissions. These Greenhouse Gases (GHGs) emitted in the atmosphere from anthropogenic activities were the culprit of global warming reinforcing climate change. Conservation and restoration projects for this ecosystem were implemented in regions of the world to establish carbon sinks to back up climate change mitigation. But still these activities were not transferred into information that is accessible and comprehensive. Moreover, the same conditions to prove their efficiency as habitat and breeding ground of marine organisms were not translated in a readily available platform [6]-[9].

Based on the above scenario, this study discussed the efficiency of developing a Web-based monitoring platform that provides results regarding the Biogeochemical activities of mangroves. Primarily it will utilize remote sensing technology to gather data in terms of mangrove biomass weight, carbon stock (sequestration), Carbon Dioxide Equivalent (CO_2-Eq) and net oxygen release. Exhibiting the results of their Biogeochemical process in the web and mobile application will justify their importance in resolving GHG emissions. As these data are presented in the community level, policymaking and decision-making will be efficient because the beneficiaries and stakeholders have a reliable reference in administering conservation and protection activities. Moreover, the community people will realize the importance of mangroves in climate mitigation through a spectrum of figures accessible and available through the internet.

2. Methods

In this study, the researchers adopted an internet-based research approach that utilized reputable data from different sources available in the internet, including established research journals, credible websites, and scientific proceedings. By employing search engines efficiently, the researchers were able to compile a comprehensive information that reflects the advantage of remote monitoring in different forest ecosystems. This method not only streamlines secondary data collection but also facilitates access to a vast array of information that would otherwise be challenging to gather through physical library research.

The significance of literature review in the context of utilizing remote sensing technology for mangrove monitoring lies in its ability to synthesize existing research and highlight the potential benefits of digital tools in environmental management. By critically analyzing previous studies, a literature review can reveal gaps in knowledge and demonstrate how remote sensing can enhance the accuracy and efficiency of monitoring mangrove ecosystems. This not only increases awareness of the ecological importance of mangroves but also fosters greater interest among researchers, policymakers, and conservationists in integrating advanced technologies into environmental practices.

The review of literatures concerning remote sensing and mangrove monitoring from 2005 to 2024 illustrates a significant evolution in this field, transitioning from rudimentary applications to sophisticated methodologies that yield impactful results. Initially, remote sensing was primarily used to gather basic data about mangrove health and distribution, relying on simplistic imaging techniques. As technology advanced, researchers began to employ more complex satellite imagery and aerial drones equipped with high-resolution sensors, enabling detailed analysis of mangrove ecosystems. This progression has allowed for enhanced understanding of mangrove dynamics, such as their responses to climate change, coastal erosion, and human activity. The integration of machine learning and artificial intelligence into remote sensing practices has further refined data interpretation, providing real-time insights that are crucial for effective conservation efforts. By 2030, remote sensing has emerged as an indispensable tool in the sustainable management of mangrove forests, demonstrating the profound potential of this technology in environmental monitoring and ecological research.

The fact being discussed in this study were primarily sourced from reputable journals indexed in Scopus and Web of Science, highlights the importance of utilizing specific key terminologies such as “remote sensing”, “satellite”, “unmanned vehicle”, and “live biomass” to delineate the focus of research in this field. These terms not only facilitate a clearer understanding of the technologies employed but also enhance the precision of data collection regarding mangrove health and distribution. Meanwhile, in the evaluation of literature concerning remote sensing applications for mangrove monitoring, researchers employ a full-text evaluation for relevance approach. This methodology ensures that the studies assessed provide pertinent data on the effectiveness of remote sensing technologies, such as satellite imagery and aerial photography, in capturing the dynamics of mangrove health, extent, and changes over time. By analyzing these texts, researchers can identify trends, challenges, and advancements in the field, ultimately contributing to better conservation strategies and sustainable management of mangrove resources.

The important information from the literature review of remote sensing utilized in mangrove monitoring were extracted through thematic approach. This method involves categorizing and analyzing data based on specific themes, such as vegetation health, land cover changes, and hydrological impacts. By focusing on these distinct aspects, researchers can better understand the complexities of mangrove environments, which are vital for coastal protection, biodiversity, and carbon sequestration.

3. Discussion

3.1. Scientific Basis for Mangrove Monitoring Using Remote Sensing

Mangrove swamps are difficult to access due to their remote locations and complex terrain. Conducting traditional field surveys in such areas can be time-consuming, expensive, and even unsafe. Moreover, the dynamic nature of mangrove ecosystems requires frequent monitoring to capture changes in their spatial distribution, ecological processes and health. Based on this scenario, remote sensing technology offers a reliable and efficient alternative to gather the necessary data for tracking their productivity. Remote sensing involves using aerial or satellite-based sensors to collect information about the Earth’s surface without physical contact. This technology allows for the acquisition of high-resolution imagery and data that provide a comprehensive view of mangrove ecosystems (**Figure 1**).

As an example, case of the abovementioned insights, a field surveys were conducted in Mauritius, a Small Island Developing State (SIDS) located approximately 900 km off the east coast of Madagascar in the southwest Indian Ocean. The research focused on two sites: Le Morne, a recently planted area in the south (20˚27'S and 57˚20'E), and Ferney, an older, mature mangrove region on the east coast (20˚22'S and 57˚42'E). The study of mangrove ecosystems in Mauritius reveals the essential role these habitats play in combating climate change and highlights the value of remote sensing technologies for effective management. By providing baseline data on the spatiotemporal distribution of mangroves, researchers can better understand how these ecosystems respond to environmental changes, particularly in relation to climate-induced threats like increased swell waves. Remote sensing techniques offer critical insights into mangrove distribution, carbon storage capacity, and vulnerability assessments, which are vital for developing mitigation and adaptation strategies [10].

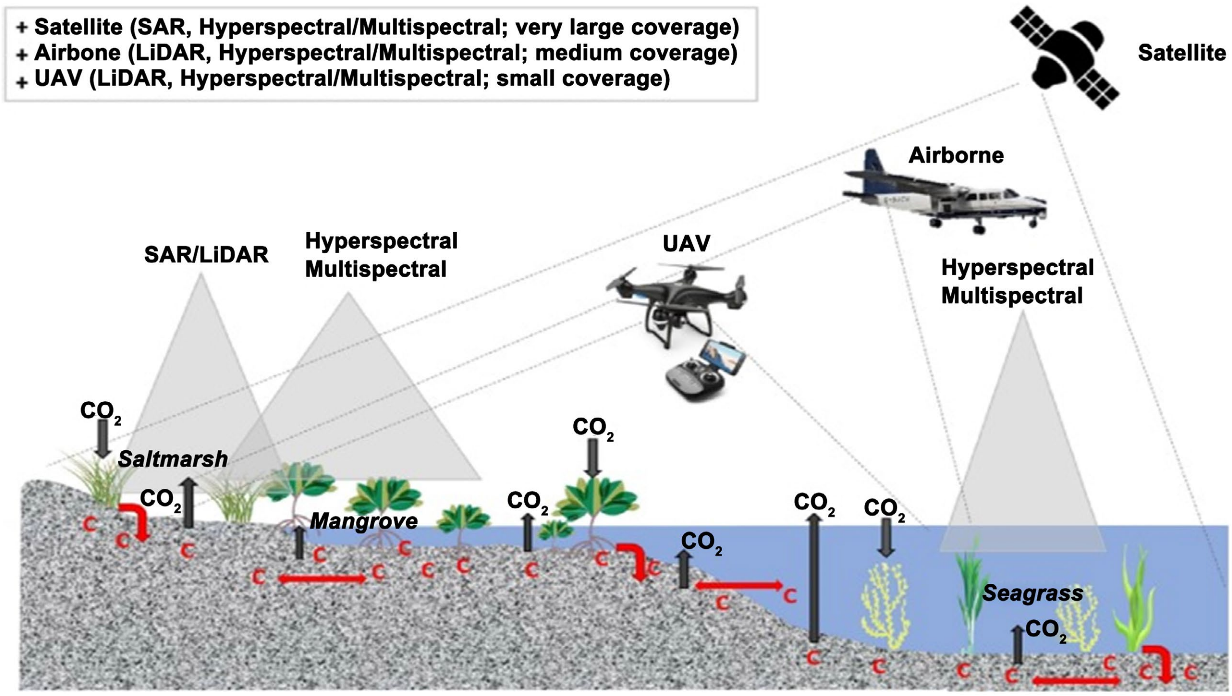

Figure 1. The conceptual diagram of remote sensing in mangrove ecosystem (image from Pham *et al.*, 2023).

By utilizing various remote sensing techniques, scientists and researchers can monitor mangroves on a large scale and identify areas that require immediate attention. One of the key advantages of remote sensing technology is its ability to capture precise spatial information. By analyzing satellite images and aerial photographs, experts can assess the extent and density of mangrove forests accurately. This data is essential for evaluating the health of mangrove ecosystems and identifying potential threats or areas at risk of degradation. With this knowledge, conservation efforts can be targeted towards the areas that need the most attention, maximizing the impact of limited resources. Furthermore, remote sensing technology allows for the monitoring of mangroves over time. By comparing satellite images captured at different intervals, scientists can track changes in mangrove distribution, biomass level, detect deforestation or degradation patterns, and evaluate the effectiveness of conservation strategies. This longitudinal data is invaluable in understanding the underlying factors affecting mangrove ecosystems and adapting conservation practices accordingly [11]-[13].

3.2. Remote Sensing in the Context of Environmental Monitoring

Remote sensing technologies have become indispensable tools for monitoring and understanding the surface of the planet. They provide valuable insights into environmental changes, natural resource management and disaster response. Furthermore, it is an emerging observation technology that uses various sensing instruments to collect, process, and finally image electromagnetic wave information radiated and reflected by distant targets. A standard analytical technique for environmental analysis by obtaining a quick, sensitive, and decentralized measurement to respond appropriately to contingency scenarios is highly desirable in remote sensing set-ups. Various remote sensing techniques were available which encompass visible light remote sensing, infrared remote sensing, multispectral remote sensing, ultraviolet remote sensing, and unmanned aerial vehicle (UAV) remote sensing. Visible light remote sensing relies on photosensitive film or photodetectors to record light in the 0.4 to 0.7-micron wavelength range, delivering high-resolution images primarily during daylight hours. Infrared remote sensing extends its capabilities with near-infrared (0.7 to 1.5 microns), mid-infrared (1.5 to 5.5 microns), and far-infrared (5.5 to 1000 microns) wavelengths. Multi-spectral remote sensing takes advantage of simultaneous data capture across various spectral bands, enhancing the depth of information about objects or areas. This technique employs devices like multispectral cameras and scanners to support more precise interpretation and identification. Additionally, ultraviolet and microwave remote sensing techniques offer specialized capabilities for unique applications. Unmanned Aerial Vehicle (UAV) remote sensing combines aerial platforms, remote sensing equipment, and advanced image processing to provide high-definition, large-scale, and precise aerial photography, making it a valuable tool in numerous fields, including environmental monitoring and land management [12] [14] [15].

3.3. Utilization of Remote Sensing Technology to Estimate Mangrove Carbon Stock

Remote sensing data provides numerous advantages for monitoring deforestation, aquaculture activity, and conducting environmental sensitivity analyses. In environmental sensitivity analysis, remote sensing data pinpoints ecologically sensitive areas, such as wetlands, mangroves, and coral reefs, facilitating environmental management and impact assessment for these vital ecosystems. Moreover, several studies have developed a model for estimating mangrove productivity and carbon sequestration using remote sensing data and machine learning algorithms study. Logarithmic regression of drone images provided the best estimation, with an R2 value of 0.7454 and an RMSE accuracy of 689.9 kg. The drone images provided valuable data for estimating above-ground and below-ground biomass, as well as soil carbon stocks in the mangrove areas. The research also involved volume measurements, comparison with carbon calculations, and modeling mangrove carbon stocks. This work contributes to our understanding of mangroves' carbon storage capacity, which is vital for conservation and management efforts. In summary, the integration of drones in this kind of research concept enabled both efficient and precise monitoring of mangrove carbon stocks, offering invaluable insights for conservation and management initiatives [14] [16]-[18].

Satellite remote sensing plays a critical role in monitoring mangrove forests through various methods. This includes assessing sea surface height time series using extensions like Jason-2 and TOPEX/Poseidon, which are vital for understanding the impact of sea-level rise on mangrove ecosystems. Meanwhile, using Unmanned Aerial Vehicle (UAV) imagery for estimating live biomass in mangroves, and image-based tree height measurements were highly accurate. This approach provides a quicker and broader data collection compared to traditional methods. This technique has potential to be a reliable tool for estimating mangrove biomass and carbon storage [19] [20].

3.4. The Advantage of Web-Based Monitoring Platform in Environmental Monitoring

The webGIS system, known as e-Pesisir, significantly enhances the capabilities of the Forestry Department of Peninsular Malaysia (FDPM) in evaluating the effectiveness of mangrove ecosystem rehabilitation and restoration efforts. Built using a combination of programming languages including PHP, JavaScript, HTML, and CSS, e-Pesisir integrates various ArcGIS Enterprise tools such as Portal, Server, and Web AppBuilder, which facilitates the development of a user-friendly graphical interface. The system adeptly supports both raster and vector data models, allowing for a comprehensive analysis of environmental data. Analytical results indicate that e-Pesisir delivers accurate and efficient information, making it a valuable management tool. Additionally, when combined with field monitoring techniques, this innovative system plays a crucial role in enhancing the protection and restoration of mangrove ecosystems, thereby contributing to ecological sustainability in the region [21]. The intersection of environmental science and digital innovation presents an opportunity to enhance the understanding and management of forest ecosystems. One of the most effective tools in this endeavor is the use of web-based platforms for sharing information derived from remote sensing images. These platforms not only facilitate the accessibility of critical data but also promote collaboration and informed decision-making among researchers, policymakers, and the public.

Remote sensing technology allows for the collection of vast amounts of data regarding forest conditions, including tree cover, health, and biodiversity. Through satellite imagery and aerial surveys, scientists can monitor changes in forest ecosystems over time, providing insights into the effects of climate change, deforestation, and natural disasters. However, the challenge lies in disseminating this complex information in a manner that is understandable and actionable for various stakeholders. Here, web-based platforms play a pivotal role.

Eventually, web-based platforms democratize access to environmental data.

Traditional methods of data sharing often involve complex reports that are not easily accessible to the general public. In contrast, web-based platforms can present this information visually through interactive maps, graphs, and dashboards. This visualization helps users comprehend intricate data sets quickly and effectively, fostering greater public engagement and awareness regarding environmental issues. When individuals understand the state of their local forests, they are more likely to advocate for sustainable practices and policies.

Moreover, these platforms enhance collaboration among researchers and organizations. By providing a centralized space for data sharing, scientists can contribute their findings, share methodologies, and compare results with peers across the globe. This collaborative approach accelerates the pace of research and innovation, leading to more effective strategies for forest conservation and management. As environmental challenges become increasingly complex, the ability to collaborate across disciplines and geographic boundaries is essential.

Additionally, web-based platforms can serve as a vital resource for policymakers. Access to real-time data on forest ecosystems enables informed decision-making and the development of evidence-based policies. For instance, if a web-based platform indicates a significant decline in forest health due to invasive species, policymakers can take immediate action to implement control measures. This proactive approach is crucial in mitigating the impacts of environmental degradation and ensuring the longevity of forest ecosystems.

Furthermore, the integration of community feedback into web-based platforms can enhance their effectiveness. By allowing users to report observations or concerns, these platforms can create a feedback loop that informs researchers and policymakers of grassroots issues. This engagement not only empowers local communities but also enriches the data available for analysis.

4. Conclusion

Web-based platforms and remote sensing represent a powerful tool for environmental monitoring, particularly in the context of forest ecosystems. They facilitate the accessibility of vital data, promote collaboration among stakeholders, support evidence-based policymaking, and engage communities in conservation efforts. As experts confront the urgent challenges posed by climate change and environmental degradation, leveraging technology through web-based platforms is essential for fostering a sustainable future for the forests of the world.

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Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this paper.

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