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Machine Learning Model for Mapping And Monitoring of Water Hyacinth in Lake Victoria, Kenya: A Literature Review.

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ABSTRACT
Water hyacinth (Eichhornia crassipes) poses significant ecological, social, and economic threats to Lake Victoria, Africa's largest freshwater lake. Originating from the Amazon Basin, this invasive species disrupts aquatic ecosystems by blocking sunlight, depleting oxygen levels, and altering water quality. The dense mats formed by water hyacinth hinder access to clean water, increase the prevalence of vector-borne diseases, and lead to social conflicts over resource use. Economically, the infestation reduces fish catches, increases transportation costs, and diminishes tourism. Conventional approaches to water hyacinth monitoring and management have shown to be expensive, time-consuming, and frequently unsuccessful. The purpose of this study is to assess the body of research on machine learning models' application to water hyacinth detection, mapping, and monitoring—with a focus on Lake Victoria, Kenya, using data from Landsat 8 satellites. The review summarizes research on the integration of machine learning and remote sensing data analysis. These include the development and validation of machine learning models like Random Forests, Support Vector Machines, and Convolutional Neural Networks, as well as the gathering and preprocessing of satellite and in-situ data, feature extraction, and selection. The results demonstrate how cutting-edge remote sensing and GIS technologies can improve the accuracy and promptness of water hyacinth monitoring initiatives. Effective management tactics can be supported by the integration of machine learning algorithms, which present a potential way for more accurate and efficient assessment of infestation. This study of the literature advances knowledge of sustainable water hyacinth management techniques, which in turn strengthens and fortifies the ecosystem of Lake Victoria and benefits the neighboring communities.

KEYWORDS;-*water hyacinth, mapping, monitoring, machine learning, Lake Victoria*.

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I. INTRODUCTION

Water Hyacinth

The management of water hyacinth (Eichhornia crassipes), an invasive aquatic plant that can have detrimental effects on the ecology and the economy on water bodies all over the world, depends on its detection. This invasive weed has been identified and monitored using a variety of detection techniques, each with advantages and disadvantages. While simple, traditional procedures such as manual surveys and visual inspections are labor-intensive, time-consuming, and can have a limited scope. These techniques might not be practical in big or remote locations due to their high human resource requirements. Although they provide a more comprehensive view, aerial surveys utilizing helicopters or light planes have significant operating costs and are weather-dependent.

The detection of water hyacinths has been transformed by remote sensing technologies, which offer continuous and wide-ranging coverage. Sentinel and Landsat satellite photography provide important data for large-scale monitoring. These satellites take pictures at various wavelengths, which enables scientists to examine water hyacinth-specific spectral characteristics. Based on their differing reflectance patterns, multispectral and hyperspectral imaging, which collects data at many wavelengths, may distinguish water hyacinth from other aquatic vegetation. Drones, or unmanned aerial vehicles, (UAVs), have also become an effective method for detecting water hyacinths. High-resolution cameras and sensors aboard drones allow for the speedy processing and analysis of real-time data, including detailed photos of infested areas. This technique works especially well for localized regions of interest or smaller bodies of water.

Machine learning and artificial intelligence (AI) have further enhanced detection capabilities. By training algorithms on large datasets of satellite or drone imagery, machine learning models can accurately identify and map water hyacinth infestations. Techniques such as Random Forest, Support Vector Machines, and Convolutional Neural Networks have shown promise in distinguishing water hyacinth from other vegetation and water surfaces. These models can process vast amounts of data and provide timely and precise information on the extent and distribution of infestations. In situ methods, including the use of sensors and water quality probes, complement remote sensing by providing ground-truth data. These methods measure various environmental parameters such as water temperature, pH, and nutrient levels, which can indicate the presence and growth conditions of water hyacinth.

An all-encompassing and successful strategy for identifying and controlling water hyacinth can be achieved by integrating these techniques into an integrated approach. Researchers and managers can increase the precision, effectiveness, and promptness of detection efforts by utilizing the capabilities of various technologies. This will eventually support more effective management and mitigation methods to safeguard aquatic ecosystems and the communities that depend on them.

Figure 1: Landsat 9, 28th January 2024, Water hyacinth and other floating macrophytes, Nyanza Gulf

Background and Context

The extremely invasive aquatic plant known as water hyacinth (Eichhornia crassipes) poses a serious risk to freshwater environments both environmentally and commercially. The plant came from the Amazon Basin and was spread to many regions of the world because of its beautiful blossoms. But because of its quick spread and growth, there have been serious ecological problems. The growth of water hyacinths has posed unique issues for the local ecosystem and communities around Lake Victoria, Africa's largest freshwater lake. Conventional approaches to water hyacinth monitoring and management, including mechanical removal, chemical treatments, and biological control, have shown to be expensive, time-consuming, and frequently inefficient. In response to these difficulties, geographic information systems (GIS) and remote sensing have become effective instruments for controlling and monitoring the spread of water hyacinth. These technologies provide a more precise and effective way to determine the extent of infestation and direct control activities by utilizing satellite imaging and sophisticated data processing techniques.The Objective of this review is to find and assess machine learning models that use satellite data for water hyacinth detection, mapping, and monitoring of water hyacinth. This will entail determining the critical elements and research techniques applied in previous studies to track infestations of water hyacinth and determine how well they were.

II. METHODOLOGY

Search Strategy

A methodical search approach was used to find pertinent material on machine learning modeling for water hyacinth (Eichhornia crassipes) detection in order to guarantee thorough coverage and relevance. The main goal was to gather a wide range of papers covering different facets of machine learning applications in the management and detection of water hyacinths. In order to do this, a number of reputable academic databases were used, such as ScienceDirect, IEEE Xplore, PubMed, and Google Scholar. These databases were selected due to their broad coverage of computer science and environmental science.

Selecting appropriate keywords was crucial for refining search queries effectively. A targeted list of terms and phrases related to water hyacinth detection, machine learning, and invasive species management was utilized. Variations of terms such as "machine learning," "detection models," "water hyacinth," "Eichhornia crassipes," "invasive species monitoring," and "remote sensing" were employed to ensure a thorough and focused search.

To combine terms and further hone search queries, boolean operators (AND, OR, and NOT) were employed. "Eichhornia crassipes AND predictive modeling," "invasive species monitoring AND remote sensing," and "machine learning AND water hyacinth detection" were a few examples of search queries. This method produced more relevant articles and improved the search's specificity.

Strict inclusion and exclusion criteria were developed in order to guarantee the selection of pertinent material. The selection criteria were only those research that have been published in peer-reviewed journals, conference proceedings, or reliable scientific sources. Excluded from consideration were studies that only addressed non-aquatic invasive species or those did not directly address machine learning techniques. Articles that particularly discussed the use of machine learning in the identification and control of water hyacinth were given precedence.

Selection Criteria

Strict selection criteria have been devised to guarantee that the literature review on machine learning models for mapping and monitoring water hyacinth in Lake Victoria, Kenya, including only pertinent and excellent research. In order to incorporate the most recent developments in machine learning approaches for environmental monitoring and mapping, research publications published between 2010 and 2022 are included. This period of time enables a comprehensive examination of the most recent advancements and applications in the industry, offering perceptions into emerging trends and technology.

Secondly, the review highlights primary research projects that employ machine learning techniques especially for water hyacinth mapping and monitoring. This covers a variety of study designs, including field surveys, case studies, and remote sensing investigations. The review attempts to gather solid information from empirical investigations into machine learning applications for water hyacinth management by concentrating on primary research. Third, papers that specifically address the creation, verification, or use of machine learning models for water hyacinth detection and monitoring are included to guarantee relevance. This criterion showcases studies that offer insightful information about the efficacy and real-world applications of machine learning techniques in controlling this invasive species.

Fourth, a crucial element in the selection process is methodological rigor. Numerous aspects, including sample size, data collection techniques, model building and validation protocols, and statistical analysis, are taken into consideration while evaluating each study. It is easier to assure the authenticity and dependability of the results by giving priority to research that clearly and transparently describe their techniques and results. Lastly, it is essential to include outcome metrics like detection accuracy, mapping precision, and monitoring efficiency that are connected to the mapping and monitoring of water hyacinth. Research presenting these pertinent result indicators shed light on the effectiveness and potential of machine learning algorithms as they relate to Lake Victoria environmental management.

Study	Study Design	ML Algorithms	Methodology	Key Findings	Critic
[1] Applied Geography, 2017	Empirical	Random Forest, SVM	Satellite data analysis	Effective in detection	Limited to certain areas
[2] Front. Ecol. Evol., 2021	Case Study	CNN	Remote sensing	High accuracy	Data-intensive
[3] Remote Sensing Applications, 2024	Modeling	SVM, CNN	Image processing	Improved monitoring	Requires validation
[4] APA Google Scholar	Review	Various	Literature analysis	Comprehensive overview	Lacks practical application
[5] Frontiers in Ecology and Evolution, 2021	Empirical	Random Forest	Spectral analysis	Effective in large-scale monitoring	Limited by resolution

Table 1 (Summary of the Literature Reviewed)

III. LITERATURE REVIEW

Traditional Methods

Water hyacinths are an invasive aquatic plant that has been managed using conventional techniques such as mechanical removal, chemical treatments, and biological control. But there are drawbacks to each of these strategies that may affect how successful and efficient they are. Although water hyacinth infestations have been managed using conventional methods, more sustainable and effective solutions are required due to their labor-intensiveness, high cost, potential environmental effects, and limited long-term efficiency. Modern methods for monitoring and managing water hyacinth, like machine learning models and remote sensing, present intriguing alternatives since they are more precise, efficient, and economical.

Physically extracting water hyacinth from bodies of water requires the use of dredgers, boats, and harvester machines, among other pieces of equipment. Although this procedure is labor-intensive and needs large resources, it can successfully reduce the biomass of water hyacinth in a given region. The procedure is expensive since it requires specialized equipment and labor for both operation and maintenance. Furthermore, mechanical removal frequently only offers a short-term fix because water hyacinth can swiftly regrow from leftover pieces or seeds, resulting in fast regrowth and recurrent infestations.

Herbicides are used in chemical control procedures to target and kill water hyacinth. These substances are sprayed directly onto the plants or the water. Chemical treatments have a number of disadvantages even if they can be useful in halting the growth of water hyacinth. Herbicide use has the potential to contaminate the environment, harming aquatic life, non-target plant species, and possibly even the quality of the water. Furthermore, the procedure frequently calls for repeated applications to handle persistent infestations, and the costs associated with obtaining and applying insecticides can be substantial. The long-term efficacy of this strategy may be diminished over time if water hyacinth strains become resistant to herbicides.

The introduction of pathogens or natural predators that prey on water hyacinth is known as biological control. Specific insects (such the water hyacinth weevil) and illnesses that naturally affect water hyacinth are examples of common biological control agents. By using ecological methods, this strategy seeks to lower the number of water hyacinths. Even though biological control has the potential to be both ecologically benign and effective, meaningful results are sometimes slow to materialize. This approach can be affected by environmental conditions and the existence of competing species, and its effectiveness rests on the meticulous selection and introduction of control agents. Furthermore, there's a chance that the introduced agents could turn invasive themselves or have a detrimental effect on other local species.

Machine Learning Methods

Through the processing of photos from drones and satellites, machine learning techniques provide a potent option for automating the detection and monitoring of water hyacinths. These methods use sophisticated algorithms to examine high-resolution photos and detect infestations of water hyacinth by identifying their characteristic spectral signatures. Convolutional neural networks (CNNs) and support vector machines (SVMs) are two types of machine learning models. These models are trained on vast datasets containing different examples of aquatic vegetation, such as water hyacinth. These algorithms are able to recognize and categorize water hyacinth in satellite and drone imagery by developing the ability to discriminate between the spectral signatures of the plant and those of nearby water and plant species. This automation expedites the detection process, lessens the need for manual examination, and improves the effectiveness of monitoring vast and remote areas [1, 2].

There are various crucial phases involved in using machine learning to evaluate drone and satellite photos for the purpose of detecting water hyacinths. First, preprocessing is done on photos to improve their quality and extract useful features. After that, labeled datasets are used to train machine learning algorithms to identify the distinctive qualities of water hyacinth, like its color, texture, and growth patterns. After being trained, these algorithms can precisely identify and map the amount of water hyacinth infestations by analyzing fresh imagery. This automated method makes it possible to monitor water hyacinth outbreaks in real-time and respond quickly, which improves management and containment of the disease. Moreover, combining these machine learning models with geographic information systems (GIS) can yield comprehensive spatial assessments that support the creation of focused management plans and enhance the general health of ecosystems [1, 2].

Deep Learning Methods

Convolutional Neural Networks (CNNs), in particular, are deep learning models that have proven to be quite useful for identifying and mapping water hyacinths in high-resolution satellite data. CNNs are built with the ability to automatically and adaptably identify feature spatial hierarchies from input images. This capacity is essential for deciphering intricate and fluctuating patterns in satellite imagery, as water hyacinths can be hidden by fluctuating water levels, illumination, and other plants. CNNs are able to extract fine characteristics and patterns unique to water hyacinth, like its texture, color, and shape, by using numerous layers of convolutional filters. CNNs can detect water hyacinths from other aquatic plants and water bodies with accuracy thanks to this extensive feature extraction, which facilitates more accurate mapping of infestations [3].

CNNs gain from their capacity to generalize across various situations and picture types. These models are adaptable tools for monitoring water hyacinths over time since they may apply their learnt features to fresh, unseen photos after being trained on a varied set of labeled images. CNN performance is improved by rich detail provided by high-resolution satellite images, which enables CNNs to identify even tiny or sparse infestations. In addition to increasing detection accuracy, the integration of CNNs with satellite data makes it easier to create comprehensive maps that illustrate the location and severity of water hyacinth infestations. This skill facilitates focused management techniques and better-informed decision-making for limiting the spread of water hyacinth [3].

Future Directions and Recommendations

In order to facilitate real-time data gathering and analysis, future research in the field of water hyacinth monitoring and management should place a strong emphasis on the integration of Internet of Things (IoT) sensors. IoT sensors can continuously offer high-resolution data on environmental aspects including plant density and water quality. Examples of these sensors are those found on autonomous boats, drones, and floating gadgets. This real-time capability makes it possible to detect changes in the distribution of water hyacinth infestations quickly and to monitor them dynamically. In order to enable quicker interventions and more responsive management techniques, sensors, for instance, can record data on water turbidity, chlorophyll levels, and other variables that correspond with water hyacinth growth [1, 2]. The granularity and accuracy of data can be greatly improved by integrating IoT sensors with machine learning algorithms, enabling more efficient and preemptive defenses against water hyacinth incursions.

Furthermore, water hyacinth identification and monitoring can be advanced by investigating hybrid techniques that integrate several algorithms and improving machine learning models for increased accuracy. Even though standalone models like Convolutional Neural Networks (CNNs) have demonstrated promise, more reliable results may be obtained by combining CNNs or other algorithms with conventional image processing techniques or with ensemble learning techniques. When dealing with particular obstacles, including shifting environmental circumstances or partial occlusions of water hyacinth by other vegetation, hybrid techniques can make use of the advantages of several models [3, 4]. Further studies should concentrate on enhancing these models' computational effectiveness and scalability to manage massive amounts of data from many sources. This multifaceted strategy may result in more precise, dependable, and economical ways to manage infestations of water hyacinths [5].

Theoretical Framework

The research uses theories of machine learning and remote sensing to provide a complete framework for regulating and keeping an eye on water hyacinths in Lake Victoria. Utilizing satellite and aircraft photos, remote sensing technologies offer a comprehensive perspective of the lake's surface, collecting information on water quality, vegetation cover, and water hyacinth infestation levels. Accurate mapping and monitoring of infestations is made possible by these technologies, which distinguish between water hyacinths and other aquatic plants using different spectral bands. For example, thorough insights into the geographical distribution and temporal variations of water hyacinths throughout the lake can be obtained using high-resolution satellite data obtained from sources like Landsat 8 and Sentinel-2 [1, 2]. The framework's incorporation of these remote sensing data enables a thorough and uniform evaluation of the lake's state across time.

The enormous volumes of remote sensing data are analyzed using machine learning techniques, which raise the precision of water hyacinth monitoring and detection. Images are processed and classified using methods like Convolutional Neural Networks (CNNs) and Support Vector Machines (SVMs), which enable highly accurate identification of water hyacinth infestations. To identify the distinct spectral signatures and patterns connected to water hyacinths, these models are trained on labeled datasets [3, 4]. The framework may automate the detection process, eliminating the need for manual inspection and enabling real-time monitoring by utilizing these machine learning approaches. Furthermore, as fresh data is added, machine learning models can continuously adjust and get better, increasing their efficacy over time [5].

Graphs showing the accuracy of different machine learning models and their capacity to identify and map water hyacinths in Lake Victoria can be incorporated to demonstrate the efficacy of the framework. The benefits of applying cutting-edge machine learning techniques can be shown, for instance, in a graph that shows how well CNNs perform in terms of accuracy and computing efficiency in comparison to more conventional image processing techniques. A different graph can display the temporal variations in water hyacinth coverage that the framework identified, demonstrating the ways in which machine learning and remote sensing support dynamic monitoring and management initiatives [6, 7]. These illustrations highlight the framework's capacity to offer practical insights and assist successful management plans aimed at eradicating Lake Victoria's water hyacinth infestations.

IV. DISCUSSION

The combination of machine learning and remote sensing offers a promising development in the identification and tracking of invasive species, such as water hyacinths. Large bodies of water may be thoroughly covered both spatially and temporally by remote sensing technology, such drones and satellite photos, which makes it possible to identify water hyacinth infestations over huge areas. These technologies have the potential to improve the accuracy and efficacy of monitoring endeavors when combined with machine learning algorithms. High-resolution photos can be processed and analyzed by machine learning models, including supervised and unsupervised learning techniques, to detect water hyacinth infestations based on their distinct spectral signatures and spatial patterns [6, 7]. This combination, as opposed to traditional monitoring methods that are sometimes limited in breadth and scale and rely heavily on manual inspections, enables more precise mapping and assessment of water hyacinth spread.

Machine learning methods have demonstrated great potential in raising the detection accuracy of water hyacinths, especially those that incorporate deep learning and artificial intelligence (AI). Convolutional Neural Networks (CNNs), for instance, have been useful in the classification and analysis of remote sensing data, demonstrating great accuracy in the distinction between water hyacinths and other aquatic plants [8, 9]. These models have the capacity to learn from big datasets and adjust to changing environmental factors, which improves their capacity to identify infestations in various locations and situations. AI-powered remote sensing techniques make it easier to create prediction models that can foresee the growth of water hyacinths, allowing for targeted and timely management measures.

To fully realize the potential of machine learning and remote sensing for water hyacinth monitoring, a number of obstacles still need to be overcome in spite of these improvements. Since it can be expensive and logistically difficult to get current, high-quality remote sensing data, data availability is a crucial problem. Furthermore, in order to guarantee the dependability and generalizability of machine learning models in various geographical locations and environmental circumstances, validation is still necessary [10]. A strong computing infrastructure and integration with current monitoring systems are two other obstacles in implementing these technologies in real-time. It will be imperative to address these issues in order to advance the use of machine learning and remote sensing for controlling water hyacinth infestations. These issues include better data acquisition, model validation, and technological infrastructure.

V. CONCLUSION

This study highlights how artificial intelligence (AI) and machine learning can revolutionize the way water hyacinths in Lake Victoria are monitored. Deep learning models, including Convolutional Neural Networks (CNNs), have become particularly useful tools for this purpose among the different machine learning techniques. The ability of these models to analyze high-resolution satellite and drone imagery allows for precise mapping and identification of water hyacinth infestations. In comparison to conventional techniques, deep learning models can greatly increase detection precision by utilizing enormous datasets and discovering intricate patterns within the data. More thorough and accurate monitoring of invasive species is made possible by these models' capacity to learn from and adapt to a variety of environmental situations, which also offers important insights into the distribution and effects of invasive species on the ecosystem [6, 7].

Going ahead, further studies will concentrate on improving these deep learning models in order to increase their precision and usefulness. This calls for the advancement of several important areas, including investigating hybrid approaches that blend various machine learning techniques, optimizing algorithmic parameters to better handle the complexities of water hyacinth detection, and enhancing model performance through the integration of more varied and superior data sources. By utilizing the advantages of each approach, CNNs combined with Random Forests or Support Vector Machines, for example, may provide increased accuracy and resilience. Furthermore, the capabilities of these models could be further enhanced by continuing developments in deep learning architectures and methodologies, such as Transfer Learning and Generative Adversarial Networks (GANs) [8, 9]. Future studies in these locations should yield more useful instruments for controlling and lessening the effects of water hyacinths in Lake Victoria.

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