Journal of Environmental Impact and Management Policy
ISSN: 2799-113X
Vol : 03 , No. 05 , Aug-Sept 2023
http://journal.hmjournals.com/index.php/JEIMP
DOI: https://doi.org/10.55529/jeimp.35.39.55

Detecting Wetlands within the Gomoa East District of Ghana through the Lenses of Sentinel-1 SAR Data Using Google Earth Engine for Ecosystem Conservation and Water Resource Management

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Received: 24 May 2023 **Accepted:** 09 August 2023 **Published:** 22 September 2023

Abstract: This study presents a comprehensive analysis of wetlands within The Gomoa East District of Ghana using the powerful synergy of Sentinel-1 Synthetic Aperture Radar (SAR) data and the Google Earth Engine platform. The primary objective was to assess the status of wetlands in the region and evaluate their implications for ecosystem conservation and water resource management. Through the integration of multi-temporal SAR data, the study identified wetland areas and changes in their spatial distribution over time. Notably, the results revealed a concerning degradation of wetlands, with a loss of 260040 square meters in wetland areas, underscoring the critical need for conservation efforts. The study showcases the potential of Sentinel-1 SAR data and Google Earth Engine as valuable tools for monitoring wetlands, emphasizing their pivotal role in environmental sustainability and community well-being. Conservation strategies are imperative to safeguard these vital ecosystems and ensure a sustainable future. This research contributes to the knowledge base for wetland preservation and supports informed decision-making for the environmental management and ecological health of Gomoa East District in Ghana.

Keywords: Wetland Conservation, Sentinel-1 SAR, Google Earth Engine, Land Degradation, Sustainable Land Management.

1. INTRODUCTION

Wetlands, distinguished by their dynamic balance of water and land, are vital ecosystems that provide numerous ecological, economic, and social advantages (Alikhani et al., 2021). Wetlands provide critical habitat for many plant and animal species, help to preserve biodiversity and provide a variety of ecosystem services such as water filtration, flood control, and climate management. Wetlands also serve an important role in sustaining local lives and agriculture, maintaining the availability of water resources, and increasing global carbon sequestration (Alikhani et al., 2021). However, these priceless ecosystems are constantly threatened by human activity, resulting in habitat loss, degradation, and decreasing ecosystem services. The Gomoa East District, located in the coastal region of Ghana, is an important area of significance for wetland protection (Charuka et al., 2023). Wetlands in this district are particularly valuable due to their vast ecological diversity and critical significance in the support of livelihoods, agricultural output, and the protection of water resources. Wetlands in the region are critical for supporting local communities and maintaining biodiversity, making it critical to monitor and conserve these regions for long-term development and ecological health. In this context, the use of remote sensing technology is critical for efficiently analysing and maintaining wetlands. Sentinel-1 Synthetic Aperture Radar (SAR) data is one such strong technology, with the ability to acquire high-resolution images of the surface of the earth regardless of precipitation or sunshine (Tzouvaras et al., 2019). Google Earth Engine is an excellent platform for data processing and analysis, allowing researchers and conservationists to track changes in wetland extent, health, and dynamics across time (Tamiminia et al., 2020). Several studies have been conducted within this area of wetland detection. In a study conducted by Gulácsi & Kovács (2020), Sentinel-1 SAR data was employed to monitor saline wetlands, offering a valuable approach for continuous monitoring of vulnerable ecosystems. The validation of the method through multispectral indices like MNDWI demonstrates promising correlations ($\rho = 0.54$ to 0.80) but faces potential limitations in accuracy due to the classification approach and data resolution. A study conducted by Pham et al. (2023) presented a novel remote sensing approach using Google Earth Engine to automate the extraction of water bodies and map growing lotus wetlands in central Vietnam. Sentinel-1 and Sentinel-2 data, along with machine learning models, achieved high accuracy in water and lotus mapping. The methodology demonstrates the potential for scalable and reliable mapping of various wetland types globally, contributing to effective wetland conservation and management. Gxokwe et al. (2022) focused on leveraging Google Earth Engine (GEE) and Sentinel-2 data to accurately assess small, seasonal wetlands in semi-arid areas. It evaluates machine learning algorithms within GEE for wetland mapping, demonstrating the platform's capability for characterizing these ecosystems with acceptable accuracy. However, one limitation is that the Naïve Bayes (NB) method had lower classification accuracy compared to other algorithms. Additionally, the study relies on data from 2016 to 2020, which may not capture longer-term wetland dynamics or changes. Amani et al. (2019) did a study which showcased the efficient use of Google Earth Engine and machine learning to process extensive satellite data for provincial wetland mapping in three Canadian provinces. The high classification accuracies, reaching up to 84%, demonstrate the method's potential for large-scale wetland inventory. However, the assumption of similar wetland characteristics across provinces could be a limitation, as wetland ecosystems may vary between regions.

This study aims to detect wetlands in the Gomoa East District of Ghana using Sentinel-1 SAR data and the capabilities of Google Earth Engine. The study intends to accomplish the following goals by utilising modern image processing and analysis techniques: Locate wetland areas throughout the district, Examine the current extent of wetlands in the district and identify wetlands that have been degraded in the district. The findings of this research will be

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instrumental in advancing our understanding of wetland dynamics, promoting their sustainable management, and contributing to the United Nations Sustainable Development Goals (SDGs), particularly Goal 15: Life on Land, and Goal 6: Clean Water and Sanitation (Küfeoğlu, 2022). Moreover, the study will serve as a valuable resource for local communities, governmental bodies, and environmental organizations in the pursuit of wetland conservation and improved water resource management in the Gomoa East District of Ghana.

2. MATERIALS AND METHODS

Materials and Data Used

In this study, a diverse set of materials and data sources were employed for wetland detection and mapping. The primary data source was Sentinel-1 SAR GRD (C-band Synthetic Aperture Radar Ground Range Detected) imagery, obtained from the COPERNICUS program, which provided a spatial resolution of 10m x 10m. Google Earth Engine (GEE) Code Editor played a pivotal role in processing and analysing the satellite data, making use of the cloud-based GEE platform. The study also relied on QGI 3.16 software and Google Earth Pro for geospatial data manipulation and visualization. Furthermore, the utilization of shapefiles for district boundaries facilitated the delineation of specific study areas. This comprehensive array of materials and data sources allowed for a robust and detailed investigation into wetland ecosystems. Table 1 shows the materials used with their sources.

Table 1: Materials used with their sources

Number	Material/ Data Used	ID	Spatial Resolution	Source
1	Sentinel-1 SAR GRD: C-band Synthetic Aperture Radar Ground Range Detected	COPERNICUS/S1_GRD	10m x10m	https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/
2	GEE Code Editor	GEE		https://code.earthengine.google.com/
3	QGI 3.16 Software	QGIS		https://www.qgis.org/en/site/forusers/download.html
4	Google Earth Pro	GE		https://earth.google.com/

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5	Shapefile of District boundary			https://www.diva-gis.org/datadown
6	Copernicus LULC dataset			https://lcviewer.vito.be/2015

Study Area
Gomoa East District is one of the twenty-two districts in Ghana. Originally it was part of the then-larger Gomoa District in 1988 until the eastern part of the district was split off to create the first Gomoa East District, with Gomoa Afransi as its capital town, on 29 February 2008 (which was later split off into two new districts on 15 March 2018: Gomoa Central District (capital: Gomoa Afransi), and the present Gomoa East District (capital: Potsin)); thus, the remaining part has been renamed as Gomoa West District. Potsin, the district assembly's capital city, is located in the southeast corner of the Central Region as shown in Fig. 1.

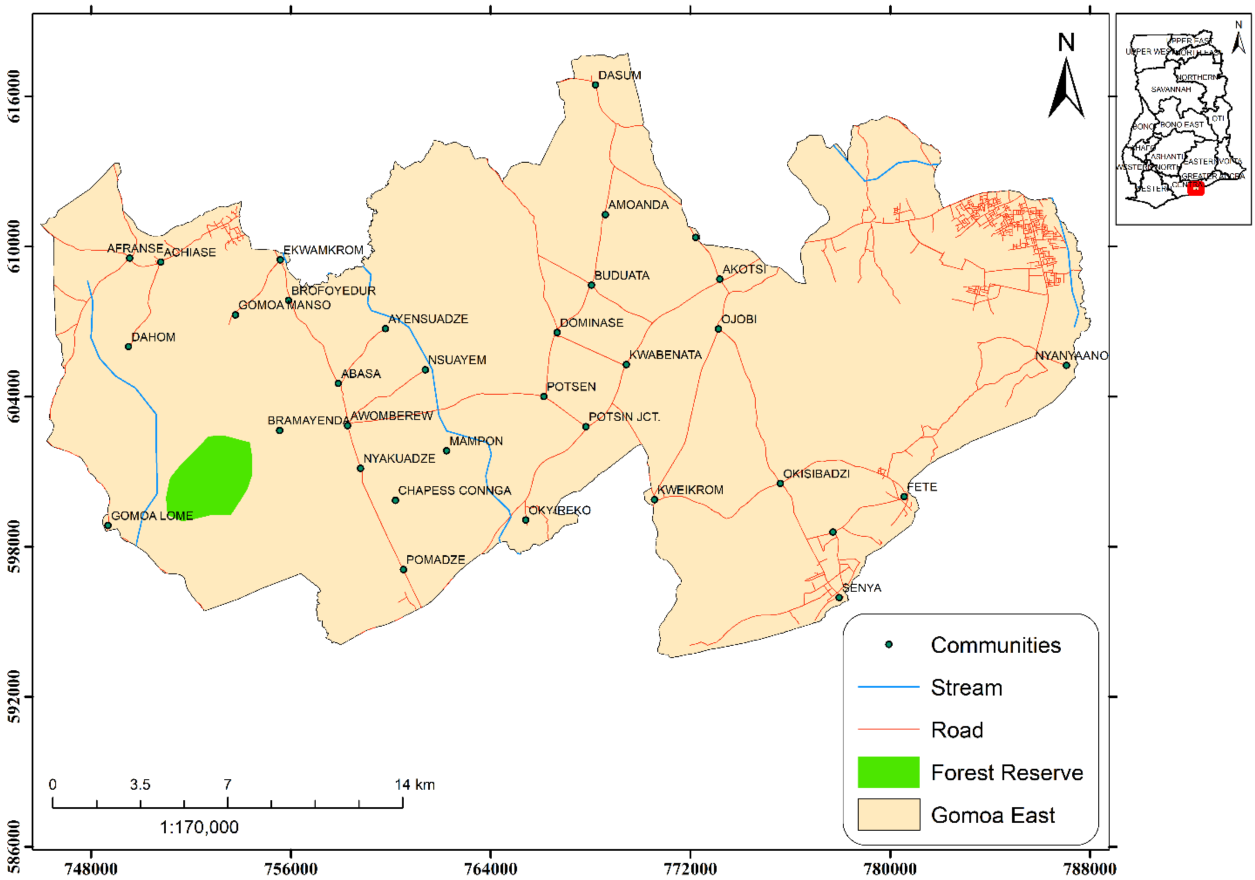

Fig. 1 A Map of Gomoa East in the Central region of Ghana

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3. METHODS

Data Acquisition (Sentinel-1 SAR GRD)

Sentinel-1 Synthetic Aperture Radar (SAR) Ground Range Detected (GRD) is a satellite mission developed by the European Space Agency (ESA) to provide continuous all-weather, day-and-night radar imaging for a wide range of applications, including environmental monitoring, disaster management, and security. It operates in the C-band (5.405 GHz) and is known for its ability to capture high-resolution radar imagery (Nagler et al., 2015).

Polarization Modes

Sentinel-1 SAR data is available in different polarization modes. The two primary polarization modes are:
Vertical-Vertical (VV): In VV mode, both the radar transmitter and receiver are polarized vertically. This configuration is suitable for many applications, such as terrain mapping and monitoring of natural resources.
Horizontal-Horizontal (HH): In HH mode, both the transmitter and receiver are polarized horizontally. This mode is often used for applications like soil moisture estimation and forest mapping.
In addition to VV and HH, Sentinel-1 also provides dual-polarization modes, including:
Vertical-Horizontal (VH): One polarization is vertical, and the other is horizontal. VH mode can be beneficial for tasks like detecting changes in land cover.
Horizontal-Vertical (HV): Similar to VH, but with the polarizations reversed. HV is also valuable for various applications, particularly for identifying vegetation types and moisture content.

Radar Equation

The radar equation describes the relationship between the power received by the radar (received power) and various parameters that govern the radar system's performance (Bole et al., 2014). The basic radar equation is as follows:
Received Power (P_r) = Transmitted Power (P_t) * Radar Cross-Section (σ) * Antenna Gain (G_a) * (Wavelength^2) * (Transmit-Receive Distance)$^{-4}$ * Losses (1)
P_r: Received power, the power received by the radar antenna.
P_t: Transmitted power, the power emitted by the radar antenna.
σ (Sigma): Radar Cross-Section, a measure of the target's reflectivity. It quantifies how well a target scatters radar waves.
G_a: Antenna Gain, a measure of the radar antenna's focusing ability.
Wavelength (λ): The radar signal's wavelength, which is inversely proportional to its frequency (C-band in the case of Sentinel-1) (Bole et al., 2014).
Transmit-Receive Distance: The distance between the radar antenna and the target.
Losses: Includes losses due to atmospheric absorption, terrain, and other factors.
The received power is used to generate radar images, and the radar cross-section is a critical parameter that characterizes how a target scatters radar wave. Sentinel-1 uses these radar equations to capture radar imagery in different polarization modes and to interpret the information about the Earth's surface. By utilizing the radar equation and the multiple

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polarization modes of Sentinel-1, it becomes possible to derive valuable information about the Earth's surface and perform various applications, including monitoring land cover changes, detecting surface water, and estimating soil moisture content.

Backscatter in Sentinel-1 Synthetic Aperture Radar (SAR) Ground Range Detected (GRD)

Backscatter in Sentinel-1 SAR GRD data is a fundamental concept that plays a crucial role in radar remote sensing. Backscatter refers to the power of the radar signal that is reflected back to the antenna of the satellite after interacting with the surface of the Earth. It is a key parameter used to characterize the properties of different surfaces and objects on the ground (Yuan et al., 2022).

Key Points about Backscatter in Sentinel-1 SAR GRD data

Intensity and Brightness

Backscatter intensity is often referred to as radar brightness. It is measured in decibels (dB) and represents the strength of the radar signal that is returned from the ground. A brighter area in a SAR image indicates higher backscatter, while a darker area corresponds to lower backscatter (Yuan et al., 2022).

Dependence on Surface Properties

Backscatter depends on various surface properties, including surface roughness, composition, and geometry. Different surfaces or objects reflect radar waves differently. Smooth surfaces tend to produce lower backscatter, while rough surfaces can result in higher backscatter.

Polarization and Backscatter

The polarization of the radar signal (e.g., VV, HH, VH, HV) significantly influences backscatter. For example, VV polarization represents radar waves transmitted and received in the vertical direction. Backscatter in VV polarization is sensitive to surface roughness (Yuan et al., 2022).

HH polarization, with horizontal transmission and reception, is often used for vegetation monitoring because it provides good penetration of vegetation canopies. The combination of polarization modes (e.g., VV/VH) can be used to distinguish different types of surfaces, like soil, water, and vegetation (Yuan et al., 2022).

Temporal Changes

Backscatter values can change over time due to factors such as seasonal variations, changes in land cover, and weather conditions. Monitoring temporal changes in backscatter is valuable for applications like land cover classification and crop monitoring.

Image Interpretation

Radar images, including Sentinel-1 SAR GRD data, are typically displayed in grayscale, where lighter shades represent higher backscatter and darker shades indicate lower backscatter (Zhang et al., 2020). The interpretation of radar images often involves identifying features or changes in land cover based on variations in backscatter.

Quantitative Analysis

Backscatter values can be quantitatively analysed to derive information about surface properties. For instance, changes in backscatter can be used to estimate soil moisture content or detect the presence of water bodies (Zhang et al., 2020).

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Calibration and Correction
Sentinel-1 SAR data undergo calibration and radiometric correction to ensure consistency and accuracy in backscatter values. Radiometric correction removes noise and artefacts from the data. Backscatter in Sentinel-1 SAR GRD data is a key parameter that reflects the interaction between radar waves and the Earth's surface. It provides valuable information for a wide range of applications, from land cover classification to environmental monitoring, and is a fundamental component of radar remote sensing (Zhang et al., 2020).

Seasonal Analysis
Defining date ranges corresponding to different seasons in the context of wetland detection helps account for temporal variations in water extent. In the provided methodology, three specific seasons were defined: spring, late spring, and summer. Here, are more details about how to define these date ranges for each season were defined:
Spring
Spring is a season characterized by the transition from winter to summer. It is often marked by an increase in temperature and the beginning of plant growth. To define the date range for spring, the local climate and vegetation patterns in the study area were considered. In Gomoa East, spring occurs from March to May. The *ee.Filter.date()* function in Google Earth Engine was used to specify the date range. That is *ee.Filter.date('2023-03-01', '2023-05-31')* for a typical spring season in Gomoa East.
Late Spring
Late spring is a continuation of the spring season, often characterized by further vegetation growth and warmer temperatures. The date range for late spring typically extends beyond the initial spring months. To define the date range for late spring (April – June), *ee.Filter.date('2023-04-21', '2023-06-10')* was used in GEE to filter the Sentinel-1 SAR data.
Summer
Summer is the warmest season of the year, marked by high temperatures and peak vegetation growth in many regions. The date range for summer based on the local climate in Ghana was defined. That is *ee.Filter.date('2023-06-11', '2023-08-31')* for the typical summer season in Gomoa East.

Computing Multi-Temporal Means
Calculating multi-temporal means for each season using ascending orbit data is a crucial step in the wetland detection process. It is used to analyse the changes in the environment across different seasons and observe patterns of wetland dynamics. Here is a more detailed explanation of this process:
Ascending Orbit Data
Ascending orbit data from satellite sensors like Sentinel-1 provides imagery acquired as the satellite passes from south to north (ascending relative to the Earth's surface). Ascending orbit data is valuable for observing wetland changes because it captures a different angle of the surface of the earth compared to descending orbit data. This reveals unique information about water bodies and wetlands (Zhang et al., 2020).

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Seasonal Means

To calculate multi-temporal means for each season, you're interested in understanding the average or mean condition of the study area during specific time intervals (i.e., the defined seasons). In your provided code, you've defined three seasons: spring, late spring, and summer.
Steps for Calculating Seasonal Means
Using ascending orbit data, you should first filter the images that correspond to each season. This is done by applying the *ee.Filter.date()* function, which was already demonstrated in your code.
For the spring season, the filter used is: *ee.Filter.date('2023-03-01', 'YYYY-04-20').*
For late spring, the filter used is: *ee.Filter.date('2023-04-21', 'YYYY-06-10').*
And for summer, the filter used is: *ee.Filter.date('2023-06-11', 'YYYY-08-31').*
These filters were applied to the ascending orbit data and the *mean()* function was used to calculate the average values for each season. This resulted in multi-temporal means. Analysing the seasonal means was useful to identify patterns of change in the wetland extent, including when wetlands expand, contract, or remain relatively stable over different seasons. This information was vital for detecting the wetlands in the study area, assessing their ecological health, and making informed decisions for conservation and resource management.

Detection of Wetland

The process of applying a threshold to SAR (Synthetic Aperture Radar) data and subsequently extracting wetlands and water extent is essential for identifying water bodies within the region of interest (ROI). Here is a detailed flow of this process:
Applying a Threshold
Synthetic Aperture Radar (SAR) data provides backscatter values for each pixel in the image. These backscatter values are indicative of the intensity of the radar signal reflected from the surface of the Earth. To distinguish water bodies and wetlands from other land cover types, a threshold was applied to the backscatter values. In the GEE code, a threshold of -20 dB was used (Zhang et al., 2020). This means that any pixel with a backscatter value less than or equal to -20 dB is considered part of the waterbody and wetlands. Pixels with values below the threshold are likely to represent calm water surfaces, while other land cover types (e.g., vegetation, and urban areas) tend to have higher backscatter values. Applying a threshold and extracting water extent from SAR data is a fundamental step in mapping and monitoring water bodies. It is also useful to identify the spatial distribution and extent of water features within the study area, which is essential for various applications, including wetland mapping, hydrological studies, and environmental monitoring.
Extracting Water Extent and wetlands
Pixels below the threshold (-20 dB in this case) are identified as waterbodies and wetlands. This process resulted in a binary water extent map, where water pixels were set to a value of 1, and non-water pixels were set to 0.
Clipping to the ROI
To focus on the study area or region of interest (ROI), the water and wetland extent map was clipped so that it only covers the area of interest. In the GEE code, the *clip(ROI)* method was used to achieve this. The water and wetland extent map are restricted to the geographical boundaries of the ROI.

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Detecting Degraded Wetlands within the Study Area

The use of Copernicus Land Use/Land Cover (LULC) data is instrumental in detecting and assessing the effects of urbanization on wetlands within the study area. Analysing this comprehensive dataset, the built-up areas, representing urban or infrastructural development (Fig. 6), were extracted and overlayed with the detected wetland areas within the study area. This facilitated the identification of wetlands that have been adversely impacted by urbanisation as shown in Fig. 7. Comparing the extent of wetlands in the study area with the extent of built-up areas enabled the quantification of degradation and the transformation of wetlands into built environments. The results served as a powerful tool to evaluate the extent of wetland degradation, understand the repercussions of urbanization on wetland ecosystems as shown in Fig. 7 and Fig. 8, and subsequently formulate conservation strategies and land use policies. Furthermore, the Copernicus LULC data allows for the continuous monitoring of urban growth, providing insights into the rate and patterns of urbanization and its corresponding effects on wetlands.

Mapping and Geo-visualization

It is a good practice to visualize the water extent and wetland to ensure that the extraction process works correctly. The clipped water extent and wetland layer were overlayed on the ROI to observe the extent and distribution of water bodies and wetlands. The conceptual framework of this study is shown in Fig. 2.

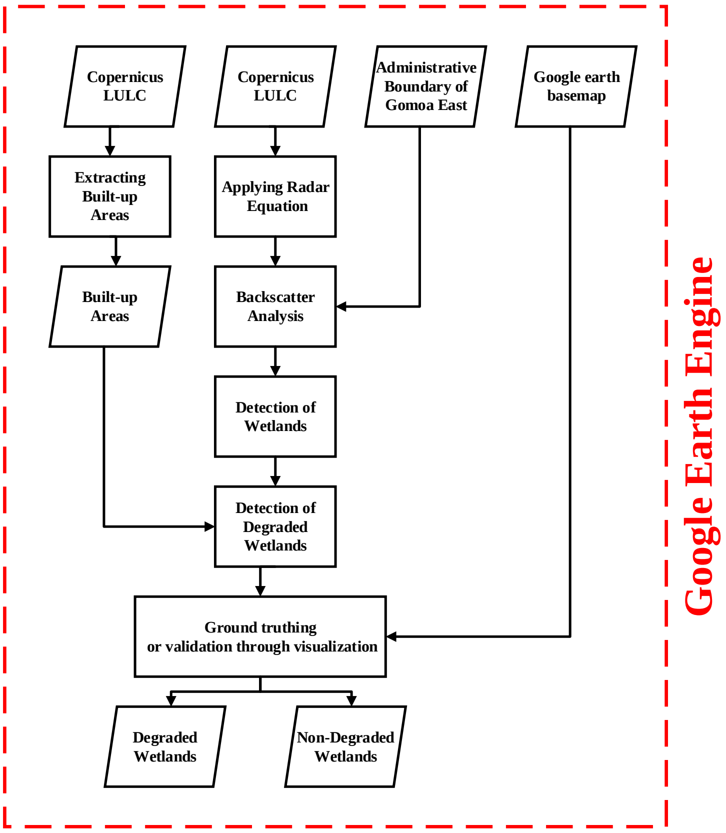

Fig. 2 Conceptual Framework of the method used in this study

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4. RESULTS

The results of this study, which focused on detecting wetlands within The Gomoa East District of Ghana using Sentinel-1 Synthetic Aperture Radar (SAR) data in conjunction with the powerful geospatial analysis capabilities of Google Earth Engine. This research aimed to contribute to ecosystem conservation and effective water resource management by identifying and characterizing wetlands in this region. Through the utilization of state-of-the-art technology and remote sensing, valuable insights have been obtained into the extent and degradation of wetlands over time. The results presented herein provide a comprehensive overview of wetland distribution, seasonal variations, and any potential impacts of urbanization and land use changes on these vital ecosystems. Understanding the wetland dynamics, these findings can inform sustainable land management practices and support the preservation of these ecologically significant areas.

Fig. 3 Multi-temporal Mean of Ascending Orbit in the Study Area

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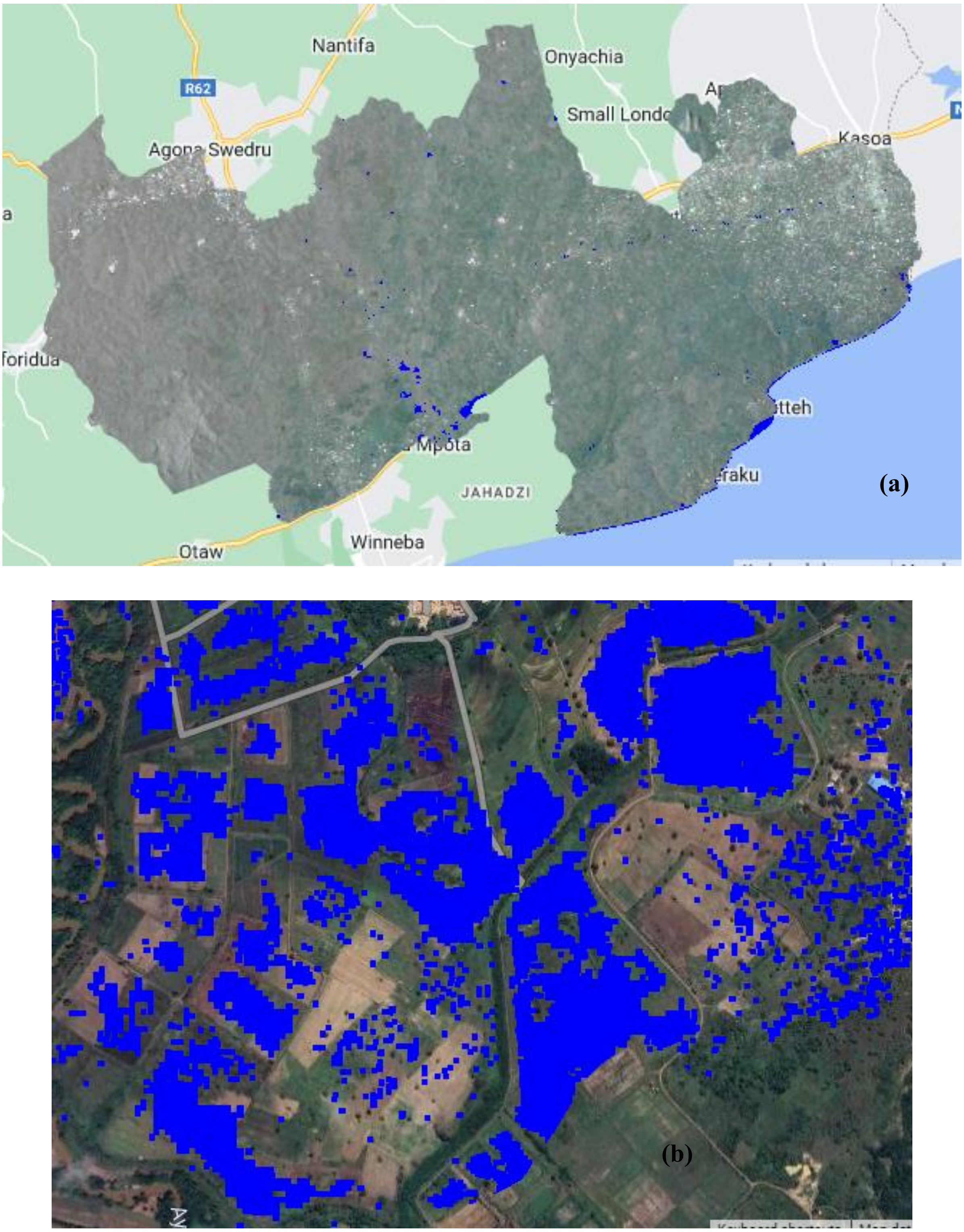

Fig. 4 (a) Multi-temporal Mean of Ascending Orbit with waterbodies and wetlands in blue patches (b)Validated Wetland from Google Earth in the Study Area

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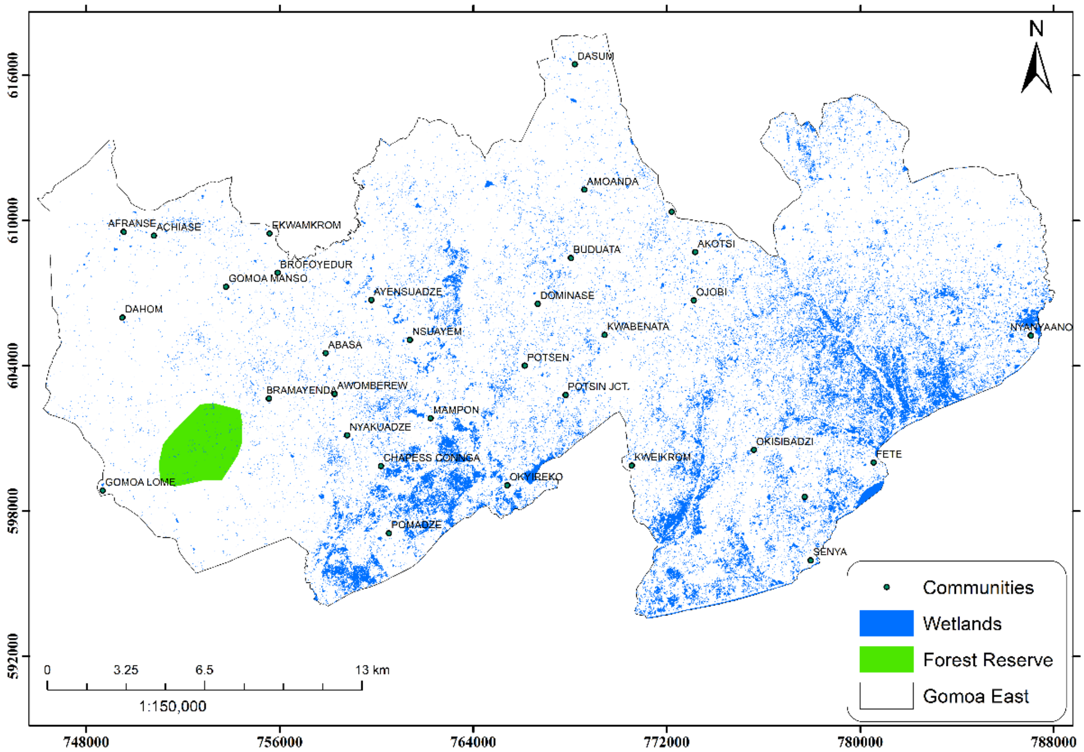

Fig. 5 Spatial Distribution of Wetlands in the study area

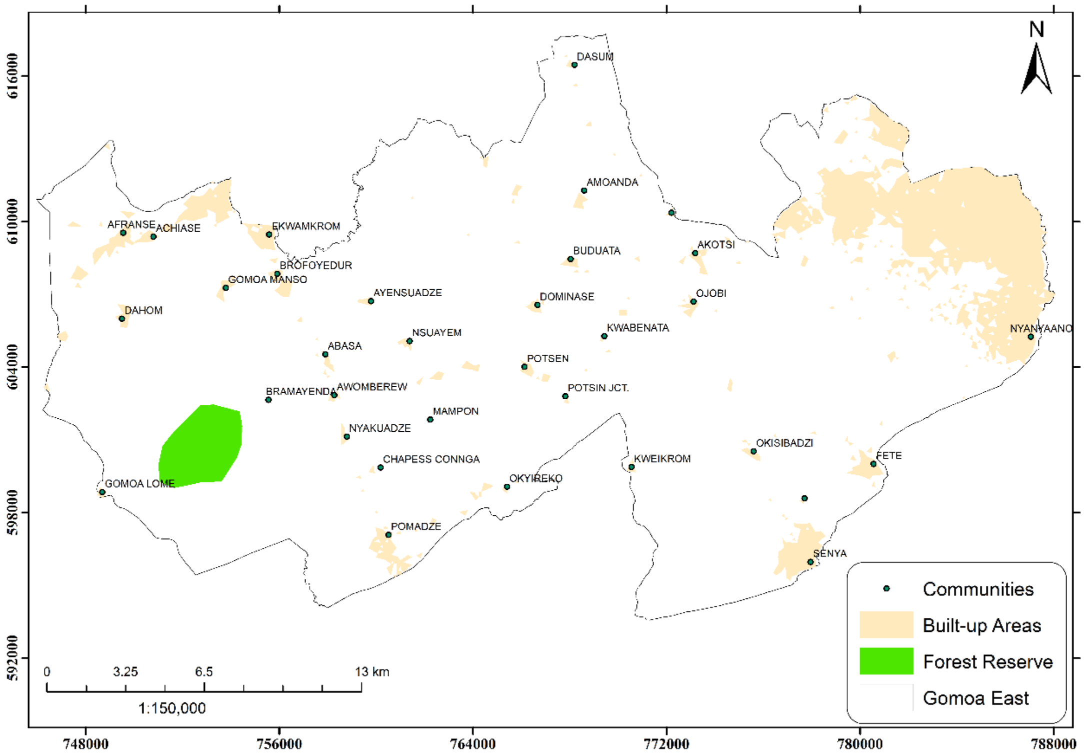

Fig. 6 Built-up areas within the study area

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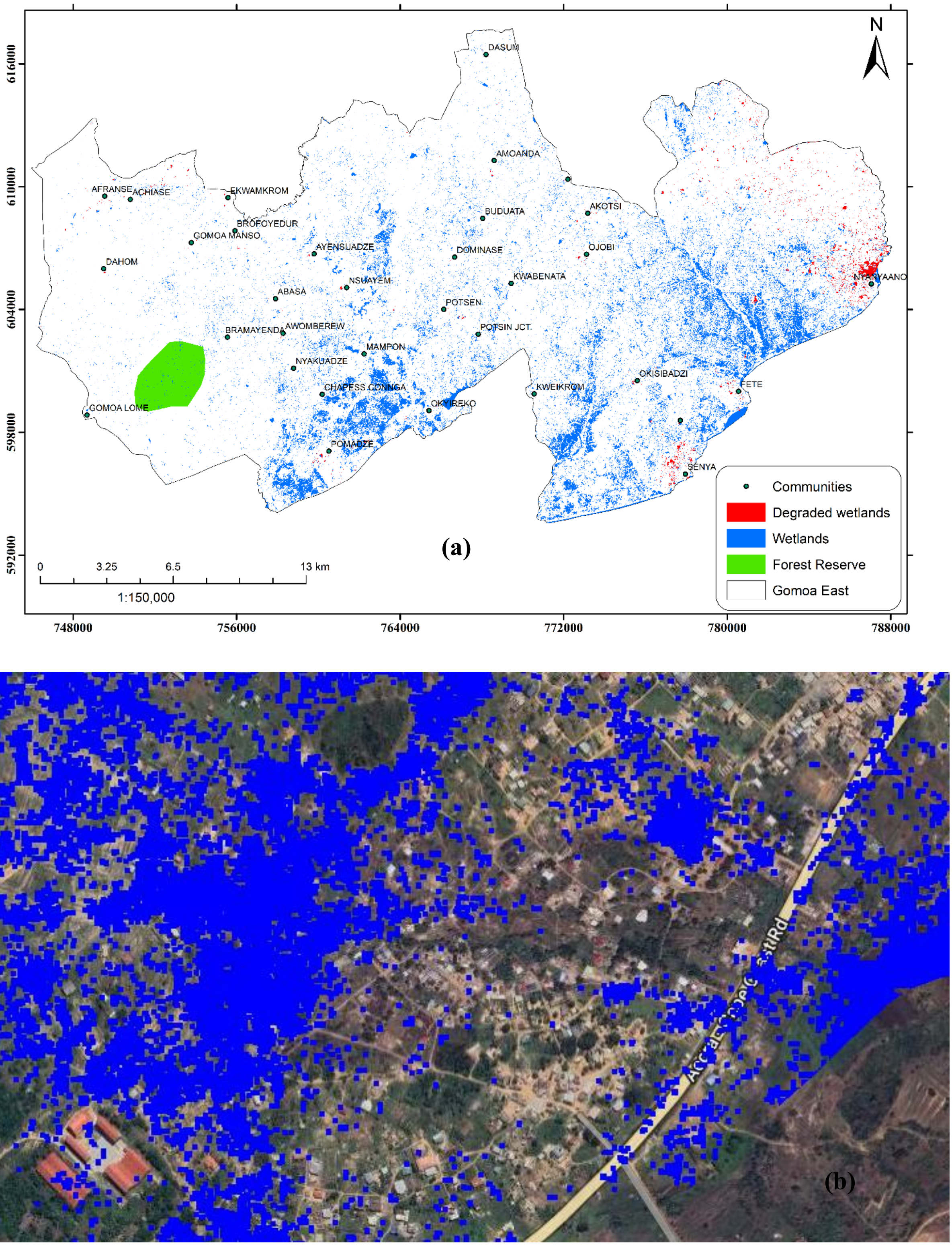

Fig. 7 (a) Spatial Coverage of Wetlands and Degraded Wetlands in Gomoa East District
(b)Evidence of Wetland Degradation in Gomoa East

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From Fig. 8, the change in the area of wetlands within the study area suggests that there has been a degradation of 260040 m^2 of wetlands, resulting in a decrease in wetland area from 56786058 m^2 to 56526018 m^2. This loss of wetland area is a concerning environmental issue, as wetlands provide critical ecosystem services and are essential for biodiversity and water resource management. Conservation efforts should be considered to mitigate further degradation and protect these valuable ecosystems.

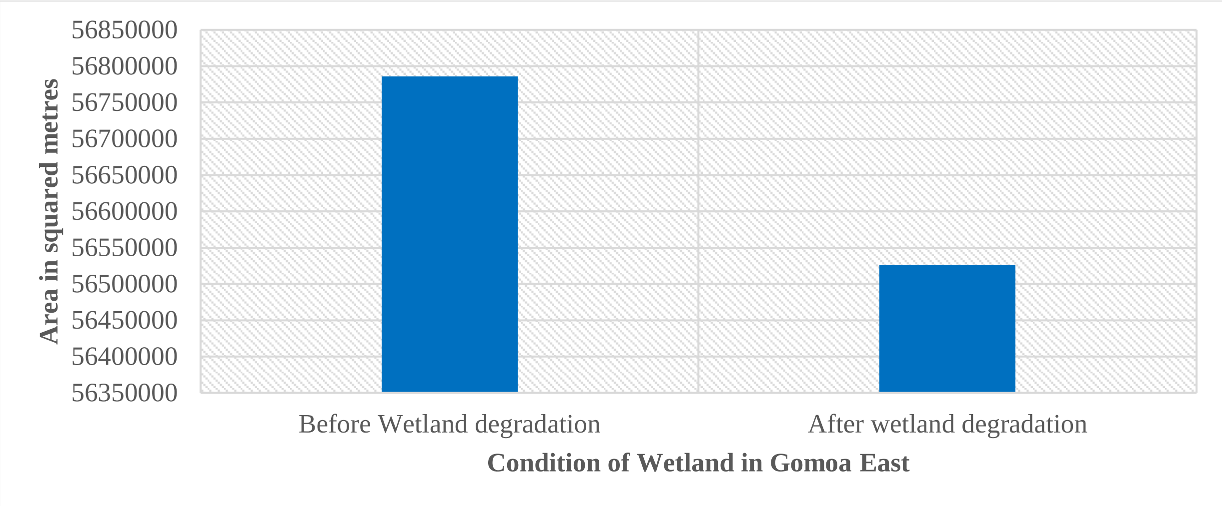

Fig. 8 Wetland Change (degradation) in the Gomoa East District

5. DISCUSSION

The results obtained from the analysis of wetlands in The Gomoa East District of Ghana using Sentinel-1 SAR data and Google Earth Engine reveal valuable insights into the dynamics of these vital ecosystems. The data shows significant changes in wetland areas over time, which have important implications for environmental conservation, ecosystem health, and water resource management.

Fig. 3 and 4 depict the multi-temporal mean of ascending orbit data derived from SAR data in the study area, highlighting the presence of waterbodies and wetlands in blue patches within the GEE environment. These figures illustrate the seasonal variations in the wetland extent and provide a visual representation of the wetland dynamics. Fig. 5 presents the spatial distribution of wetlands in the study area, showing the areas where these ecosystems are located. This map is crucial for identifying the geographical distribution of wetlands and their potential vulnerability to land use changes. In Fig. 6, there is a spatial distribution of built-up areas within the study area. This information is essential for understanding the impact of urbanization and land development on wetlands. The proximity of built-up areas to wetlands can result in their degradation, as observed in this study.

Fig. 7 provides an overview of the spatial coverage of wetlands and degraded wetlands in the Gomoa East District. The distinction between intact wetlands and degraded wetlands is crucial for conservation efforts. The data shows that 260040 square meters of wetlands have

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experienced degradation, resulting in a decrease in wetland area from 56,786,058 square meters to 56526018 square meters (as shown in Fig. 8). The loss of wetland area is a matter of environmental concern. Wetlands play a vital role in providing essential ecosystem services, such as water purification, flood control, and habitat for wildlife. They are also essential for maintaining biodiversity and supporting sustainable water resource management. The observed degradation underscores the need for conservation efforts to mitigate further loss of wetlands in the Gomoa East District. Possible measures may include land-use planning, wetland restoration, and policies aimed at safeguarding these ecologically significant areas.
The results of this study provide valuable data for understanding wetland dynamics and the impacts of land use changes within the Gomoa East District. These findings can serve as a foundation for informed decision-making in ecosystem conservation and water resource management, with a focus on preserving these essential wetland ecosystems for the benefit of both the environment and the local communities.

6. CONCLUSION

In conclusion, the study focused on detecting wetlands within The Gomoa East District of Ghana using Sentinel-1 SAR data in combination with Google Earth Engine. The analysis aimed to shed light on the status of wetlands in the region, with a particular focus on the impact of ecosystem conservation and water resource management. The results revealed several key findings, which have significant implications for environmental sustainability and local communities.
The study identified the existence and spatial distribution of wetlands in the study area, as shown in Figure 5. This mapping is invaluable for understanding the geographical extent of wetlands and identifying areas that are particularly ecologically significant. The data also provided a distinction between intact wetlands and those that have been degraded due to various factors, as depicted in Figure 7. It is evident from the results that approximately 260040 square meters of wetlands have experienced degradation, leading to a decrease in wetland area from 56786058 square meters to 56526018 square meters, as illustrated in Figure 8. This loss of wetland area is a pressing concern, given the critical role wetlands play in maintaining biodiversity, water resource management, and ecosystem services.
The study outcomes underscore the importance of conserving wetlands in the Gomoa East District. These ecosystems provide essential services such as water purification, flood control, and habitat for diverse wildlife. The observed degradation signals a need for immediate conservation efforts to mitigate further loss and to protect the invaluable resources provided by wetlands.
Moreover, the study emphasizes the utility of Sentinel-1 SAR data and Google Earth Engine in monitoring wetlands and ecosystem changes over time. These tools offer an efficient and accurate means of tracking and assessing the state of wetlands, which is vital for informed decision-making and sustainable land use planning. The findings call for a concerted effort to protect and restore wetlands in the Gomoa East District. Conservation strategies, local policies, and community engagement can collectively contribute to the preservation of these ecosystems. By safeguarding wetlands, we can ensure a healthier environment, improved water resource management, and a more sustainable future for both the ecosystem and the local

communities. The study serves as a critical step toward these conservation goals and underscores the importance of continued research and action in this vital field.

Acknowledgement
I would like to acknowledge the Google Earth Engine (GEE) for providing open access to cloud-based Remote sensing datasets and processing platforms for this work.

Declaration of Conflict of Interest
The author declares no conflict of interest.

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Journal of Environmental Impact and Management Policy
ISSN: 2799-113X
Vol : 03 , No. 05 , Aug-Sept 2023
http://journal.hmjournals.com/index.php/JEIMP
DOI: https://doi.org/10.55529/jeimp.35.39.55

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