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Detection the Impact of Chlorophyll Index and Global Environmental Monitoring Index on Water Separation in Swansea in Wales, United Kingdom Through Analysing the Spectral Wavelengths of Landsat 8-OLI

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ABSTRACT

Understanding the condition, spatial arrangement, and changing patterns of vegetation cover holds significant scientific and economic importance. Satellite platforms offer a highly convenient means to study how vegetation reacts to atmospheric influences by gauging reflectance in the visible and near-infrared spectra. Given the numerous potential origins of environmental land cover variability, this study seeks to examine how vegetation cover influences water separation. This is achieved by identifying the chlorophyll index (CIG) and global environmental monitoring index (GEMI) to enhance the vital safeguarding of water sector against the encroachment of excessive vegetation. To gain deeper insights into the impact of extensive vegetated areas, we have analyzed the CIG and GEMI within Swansea County, situated in Wales, United Kingdom. These underlined indices have been implemented and their performance has been assessed by ArcGIS and Remote Sensing technique. The results of the analysis of CIG and GEMI indices show that the minimum and maximum of these indices are -1 and 38 respectively, and 1.75105 and -9.61413e+008 respectively. The vast areas of greenery are associated with considerable emissions of chlorophyll, which are more reflected due to the fresh nature of vegetation. Dispersion of the chlorophyll concentration throughout the world poses a serious threat to the water sector. This may lead to severe water shortages in the future. The high value of CIG and GEMI indices shows that the surface of the earth is more covered with vegetation. Vegetation cover with Chlorophyll and more fresh water resources at the surface of the earth can be a significant impact on the earth's water resources, as it may lead to water stress in the future. Therefore, it is always wise to conserve the primary energy which is water energy and use it critically in such a manner that it is available for future generations.

Keywords: GIS, remote sensing technology, CIG, GEMI, Swansea, United Kingdom.

INTRODUCTION

The vegetations chlorophyll content, as shown through plant reflection can be estimated by utilizing sensing technology to determine the chlorophyll index (CIG) or green index. The plants. Spatial well being, reflected in photosynthesis serve as an indicator, for assessing its pigment. The green index enables the measurement of absorption or reflection by plant leaves within specific wavelengths (Anatoly et al., 2002). Advancements in sensing technologies provided by satellites and drones have significantly expanded the capacity to monitor and detect environmental and climatic factors over large areas. The CIG stands out as an indicator, for measuring plant chlorophyll levels amidst these advancements. According to Penuelas et al., 1995, the effectiveness of plant ecosystems can be accurately determined based on the RS and thus can be relied upon by researchers, decision makers, and land managers. CIG can evaluate the reflection of light emanating from plant leaves within different and specific wavelengths, the most important of which are near infrared (NIR) and red (R). The NIR contains multiple wave bands, so by collecting and analyzing ground reflections emanating from these bands, it is possible to extract the CIG, which indirectly reflects the concentration levels of health and stress to which the vegetation is exposed, as the CIG is considered one of the most important plant indicators through which the dynamics can be understood. Ecosystems and plant well-being in different environments with the aim of monitoring and subsequent evaluation (Nathalie et al., 2009).

The global environmental monitoring index (GEMI) represents one of the effective and important environmental indicators in many environmental studies, which can be relied upon in determining policies related to evaluating the global vegetation cover in terms of its well-being and the sustainability of its greenery, which is reflected in the provision of global sustainability requirements, as it can be relied upon in creating climate and environmental indicators. With a high degree of accuracy. These indicators enable environmental policy makers and researchers interested in the environment and climate to comprehensively assess the state of the planet by monitoring the progress in sustainable development and its goals sought by the United Nations Environment Organization (2002) and the Millennium Ecosystem Assessment (2005). GEMI refers, by its nature, to those environmental factors of all kinds, including the quality of water and the purity of the air for human use, as well as the changes that may occur to biodiversity and indicators that indicate weather and climate change, which enables it to carry out a comprehensive assessment of the terrestrial ecosystems, environmental and climatic systems and their interrelationships together. GEMI provides a modern platform through which ecological patterns can be scrutinized and those that need attention and intervention identified (World Health Organization, 2016). To measure the value of GEMI we need extraordinary global collaborative efforts between scientists, organizations and governments. This indicator can be relied upon as an effective and distinguished tool in studying: (1) the priorities of environmental initiatives, (2) determining optimal environmental policy paths, and (3) stimulating scientific cooperation globally to serve the face of pressing challenges that are likely to ravage the environment. GEMI is considered an important indicator through which our understanding of global environmental conditions can be shaped, which helps increase efforts towards a future more concerned with resilient environmental sustainability (Intergovernmental Panel on Climate Change, 2014).

Recent studies have proven that reflected or absorbed active light radiation can be detected and extracted using two basic methods: (1) by relying on extracting vegetation indicators (VIs) (Gitelson et al., 2014; Ogutu et al., 2014) and (2) using the canopy reflectance model (Frédéric et al., 2007; Verger et al., 2011, Dong et al., 2012). In general, using Vis is the most widely used and widespread compared to the second method. VIs depend in their extraction on spectral reflections reflected to the atmosphere through the mathematical functions performed by the ground vegetation, represented by near-infrared rays. The green color reflected into the air space can be captured and its visible chlorophyll content analyzed, while NIR reflectance can help determine characteristics related to the plant canopy, such as leaf angle distribution (Pinty et al., 2009; Viña et al., 2011). Recently, significant reliance has been placed on elements related to chlorophyll concentration resulting from the reflection of the red edge of a plant leaf, which is of great importance in estimating the percentage of chlorophyll present in plant leaves or the entire plant cover (Haboudane et al., 2008; Wu et al., 2008; Delegido et al., 2011; Peng et al., 2011; Hunt et al., 2013). An example of previous studies related to estimating the proportion of chlorophyll in vegetation is estimating the ratio between the transformed chlorophyll absorption indices in reflectance to modified soil vegetation (TCARI/OSAVI) (Daughtry et al., 2000) and the modified chlorophyll absorption ratio index (MCARI) to OSAVI ratio (MCARI/OSAVI) (Zarco-Tejada et al., 2004), as each of these indicators showed high sensitivity to plant leaves containing chlorophyll. Therefore, it is necessary to carefully study these indicators to understand their meanings, as they are highly sensitive to environmental changes and various climatic factors. These factors include the atmospheric conditions and the angles of illumination and observation. In the context of global monitoring endeavors, where the goal is to describe the Earth's surface through the examination of the spatial or temporal patterns of these indices, it is assumed that, except in cloudy regions, alterations in surface characteristics are responsible for the observed variations, rather than shifts in atmospheric circumstances (Holben and Fraser, 1984; Holben, 1986; Holben et al., 1986; Lee and Kaufman, 1986).

The science of remote sensing has developed to be characterized by its high and accurate ability to monitor various environmental changes in addition to the changes experienced by the climate, as it has become a powerful and very effective tool in detecting terrestrial changes. Through remote sensing technology, scientists and researchers have been able to collect various data from a remote place using different and diverse sensors, such as self-piloted aircraft that do not require a pilot, satellites, and various ground devices linked to remote sensing technology. This advanced technique and technology has greatly improved the ability to understand and see the various dynamic processes that occur across time and space on the surface of the Earth (Duy et al., 2023).

Environmental sciences have developed widely based on remote sensing technology, as this technology has been able to collect various data related to the Earth's surface or atmosphere without direct human contact, collecting that data in addition to analyzing it accurately and extracting the information hidden in it. This technology is distinguished by its high-capacity electromagnetic radiation, which contains a wide range of wavelengths, which makes it capable of having a profound impact on transformative technologies for deducing various variables, as it has been able to monitor natural environmental events in addition to those events resulting from human interactions on the surface of the Earth. Remote sensing technology is represented by obtaining data and spectral images with multiple wavelengths, which gives it the ability to detect and supervise changes that occur in the land cover, the atmosphere, and even the interior of the earth, through which human activities on the surface of the earth, change in vegetation cover, can be monitored. Population and urban expansion, water quality, and changes occurring in forests in an accurate and systematic manner that can be analyzed scientifically and its results can be relied upon. In respect of climate change studies, RS provides critical information about shifts in the Earth's climate system. It facilitates the monitoring of temperature variations, sea level rise, glacial retreat, and changes in greenhouse gas concentrations. With the ability to observe remote and challenging-to-access regions, RS contributes to a comprehensive understanding of the complex interactions driving climate change and its consequences (Blaga et al., 2023).

Occasionally, the extensive vegetation cover can lead to a reduction in soil moisture levels, exacerbating the demand for irrigation water and further amplifying the already pressing requirement for water in an environment marked by severe scarcity of water. Consequently, due to the lack of studies specifically addressing the CIG and GEMI and their relationship with water sector, this study lays the foundation for enhancing and maintaining verdant vegetation within the worldwide ecosystem. It achieves this by employing RS and geospatial methods (such as ArcGIS) to assess the CIG and GEMI using Landsat 8 imagery within a designated region of interest, Swansea County in Wales in the United Kingdom, to assess the impact of these indexes on the reduction of water that will separate from land surface cover.

Swansea region of interest

Swansea, situated on the coast, holds the position of being Wales' second-largest city. It constitutes a key administrative region known officially as the County of Swansea. In the United Kingdom, it ranks as the twenty-fifth largest city. Positioned by Swansea Bay in the southwestern part of Wales, the primary area encompasses the Gower Peninsula, thus becoming an integral component of both the Swansea Bay locale and the historical Glamorgan county. Additionally, it is rooted in the ancient Welsh commote of Gŵyr. With an estimated populace of 246,563 in 2020, Swansea stands as the second most densely inhabited local governing body in Wales. Swansea has a population about 300,352 in 2011. Furthermore, it plays a significant role within the Swansea Bay City Region (Largest Cities in the UK, 2017).

Swansea exhibits division into four distinct physical regions, each characterized by intricate geological formations that contribute to its diverse and captivating landscapes. Notably, the Gower Peninsula holds the distinction of being the first location in the United Kingdom to attain the prestigious status of an Area of Outstanding Natural Beauty (AONB), encompassing the entirety of the peninsula except for its southeastern corner. Swansea boasts a multitude of both urban and rural parklands, a fact that has led to consistent recognition in the Wales in Bloom awards.

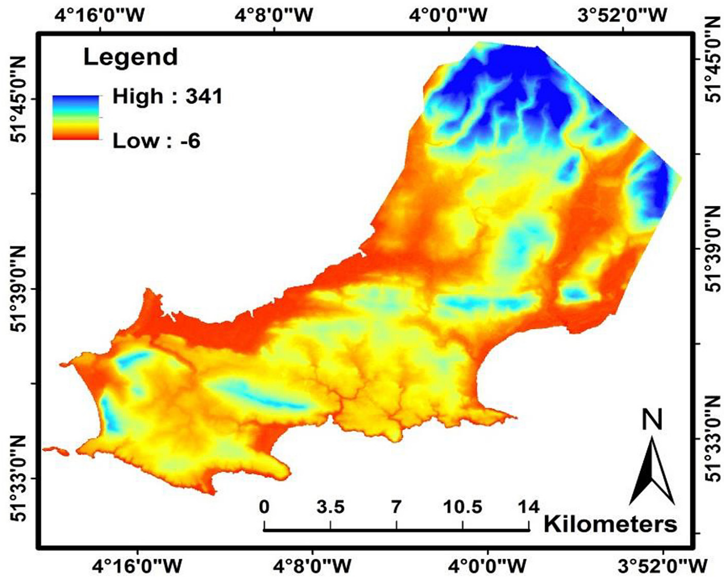


Figure 1. DEM of Swansea

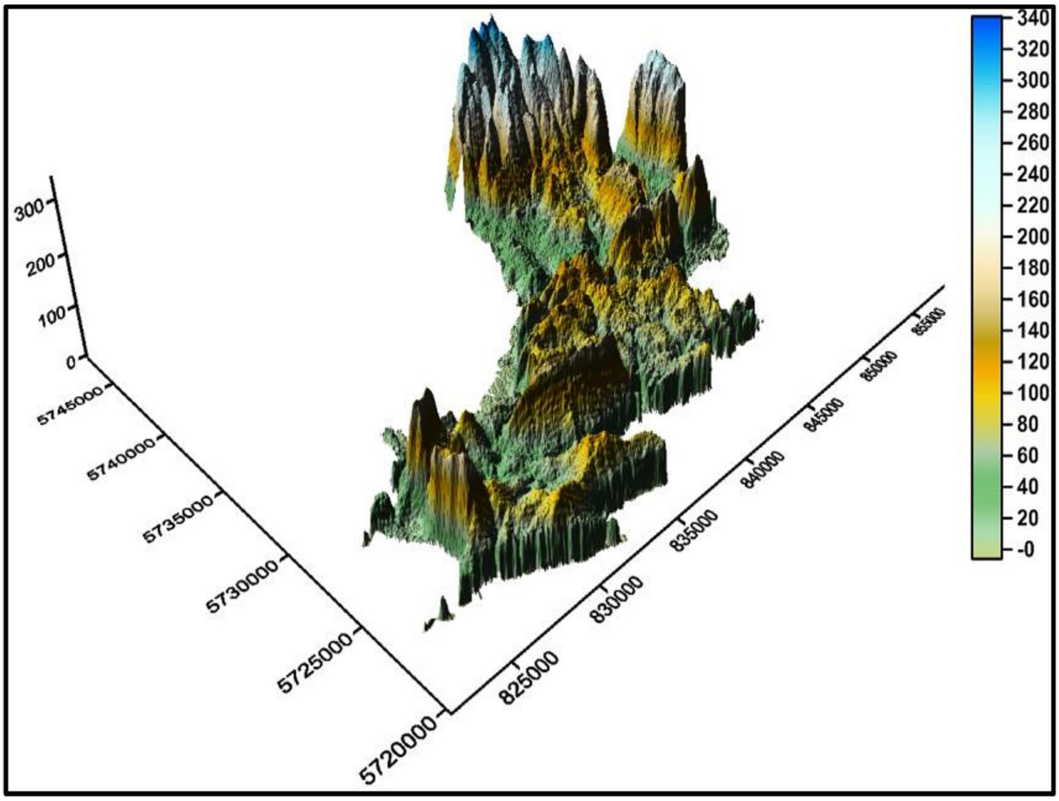


Figure 2. 3-Dimensional sketch showing the ground surface levels of Swansea

Swansea's topography is predominantly undulating, with notable elevations occurring within the Mawr council ward. The central portion of the city features elevation fluctuations of up to 185 meters. This central area is demarcated by prominent geographical features such as Kilvey Hill, Townhill, and Llwynmawr, which serve to delineate the core of Swansea from its northern suburban areas (Student information – Swansea geography, 2007).

Swansea experiences a warm and temperate climate, characterized by consistent rainfall even during the least wet months. This climate falls under the Cfb classification (warm temperate, fully humid, with warm summers) according to the Köppen and Geiger system. The annual average temperature in Swansea measures 13.1 °C, accompanied by an annual precipitation of approximately 587 mm. Situated in the southern hemisphere, the summer season spans from the end of January through December, encompassing the months of December, January, February, and March. Notably, June exhibits the highest relative humidity at 76.91%, whereas December records the lowest relative humidity at 65.24%. In terms of precipitation, November stands as the wettest month, while May is the driest (Peel et al., 2007; UK climate extremes, 2023). Figures 1 and 2 demonstrate the downloaded digital elevation model (DEM) of Swansea and a 3-dimentioal sketch of the ground surface elevations, respectively.

CIG and GEMI fundamental description

The CIG is a RS-derived parameter used to assess the chlorophyll content and health of vegetation. CIG is extracted through the vegetation that reflects more green light and less near-infrared light due to the absorption of red and blue light for photosynthesis. The CIG provides valuable insights into plant health, stress, and chlorophyll concentration, which in turn can indicate factors like nutrient deficiencies, water stress, and overall vegetation vitality. This information is particularly useful for precision agriculture, crop monitoring, and environmental assessments. The CIG is often calculated using various bands of satellite or airborne RS data. Eq. (1) is the only one common formula to calculate CI or CIG is (Gitelson et al., 1996):

$$CIG = \frac{Band5}{Band3} - 1 \tag{1}$$

where: *Band3* – the reflectance of green wavelength of Landsat 8-OLI. *Band5* – the reflectance of near infrared wavelength of Landsat 8-OLI.

Incorporating environmental monitoring should be a fundamental component within a country's biodiversity management framework, serving as a key resource to educate both decision makers and the general population. National systems for monitoring biodiversity (referred to as NBMSs) ought to emphasize the evaluation of stressors, influential elements, and policy actions using defined indicators. The efficacy of these NBMSs hinges upon the degree to which biodiversity indicators are directly aligned with officially stated national objectives concerning the preservation of biodiversity and the responsible utilization of natural resources. The GEMI approach constitutes a nonlinear vegetation index utilized in worldwide environmental surveillance via satellite images. While akin to NDVI, it demonstrates reduced susceptibility to atmospheric influences. It does respond to exposed soil, thus making it unsuitable for application in regions characterized by limited or moderately concentrated vegetation. The GEMI can be estimated using Eqs. (2) and (3) illustrated below (Pinty and Verstraete, 1992).

$$GEMI = ETA * (1 - 0.25 * ETA) - \left(\frac{Band4 - 0.125}{1 - Band4}\right) \tag{2}$$

$$ETA = \frac{\left(2 * \left(Band5^2 - Band4^2\right) + 1.5 * Band5 + 0.5 * Band4\right)}{\left(Band5 + Band4 + 0.5\right)} \tag{3}$$

where: *Band4* – the reflectance of red wavelength of Landsat 8-OLI.

METHODOLOGY

Given the significant advantages of vegetation in contemporary contexts, it is imperative to integrate a precise scientific methodology with geospatial instruments for ascertaining both the condition and geographic scope of vegetation coverage. This preliminary understanding will serve as a foundation for devising forward-thinking tactics concerning land utilization and the stewardship of ecosystems. A pertinent tool poised to lead in gauging the ecological equilibrium of the biosphere via plant monitoring is satellite imagery (Solano-Correa et al., 2018).

NASA's recent endeavors encompass the Landsat 8 mission, an orbiting satellite engineered to meticulously map the Earth's terrain and document spatial transformations from its vantage point in space, amassing invaluable RS data. Decades after it was first established, NASA in partnership, with the U.S. Geological Survey introduced Landsat 8. This satellite is crucial for gathering data on changes in the Earths geography. Its main focus is observing Earth. Monitoring changes on the planets surface caused by processes and human actions. With rapid geographical transformations happening scientists aim to observe how the Earth is evolving. Landsat 8 uses the Operational Land Imager (OLI) sensor as a tool, for collecting data capturing images at a spatial resolution of 30 meters (Pettorelli et al., 2014).

Geographic Information Systems (GIS) and RS are powerful and synergistic technologies changing our approach to spatial data gathering, analysis, and interpretation. Together they have a potential for the advanced understanding of complex real-world processes, help make informed decisions, and contribute to addressing various environmental and societal issues. The integration of GIS and RS analyses allows researchers, policymakers, and professionals to shed further light on the mechanisms governing our planet and consequently facilitate better and more informed decision-making. The birth of GIS technologies and applications has played a large part in helping to identify, measure, and solve problems. It is critically important that GIS provides a future-looking approach to developing solutions through modeling potential occurrences and facilitating preventative measures. Through the years, GIS has become an invaluable tool in the lives of people and organizations working in the telecom industry, event planning, social services and policy, environmental assessment, awareness of flood risk, the management of natural resources, environmental health and safety, and vegetation monitoring (to name just a few).

This part aims to demonstrate the utilization of meteorology in estimating crucial indicators, namely CIG and GEMI. The Geographic Information System will process the satellite images (captured by Landsat 8) of Swansea in Wales, UK, to derive CIG and GEMI values. Landsat 8 comprises eleven spectral bands. The satellite incorporates the operational land imager being linear

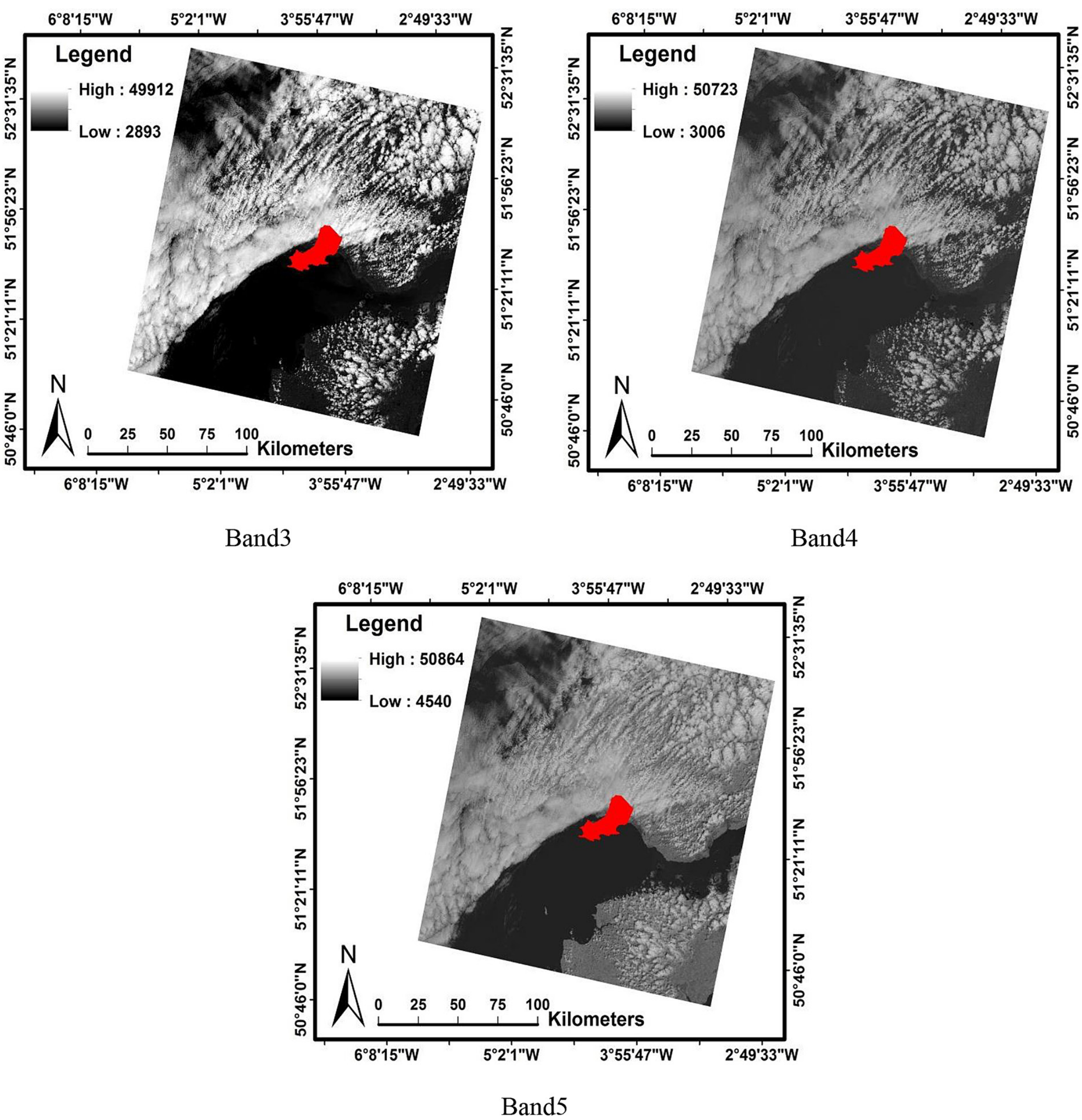
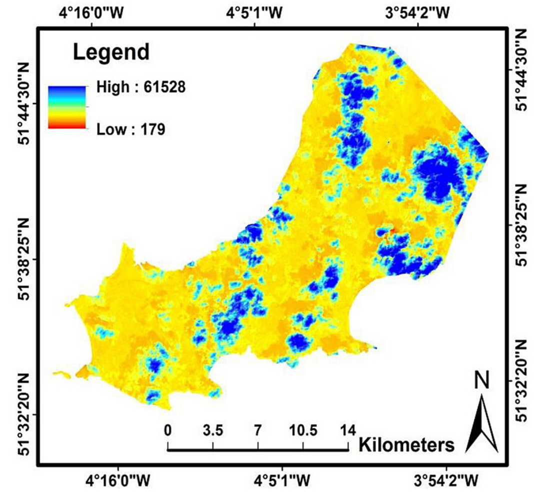
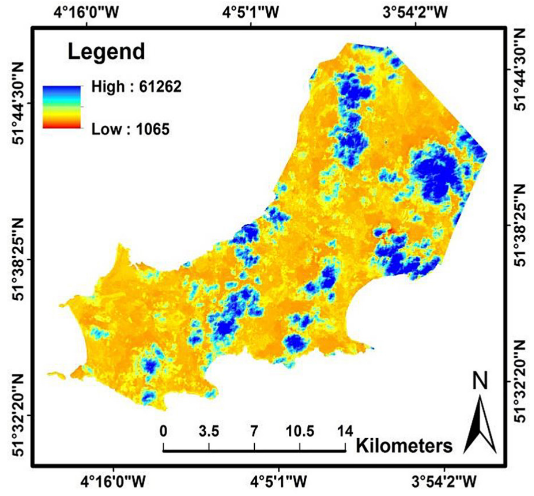


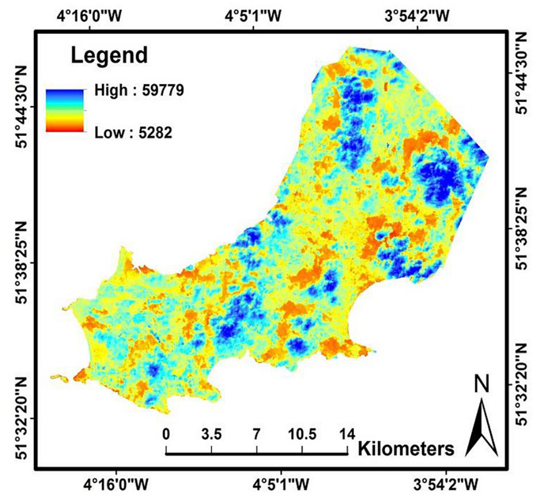
Figure 3. Downloaded bands 3, 4, and 5 of Landsat 8-OLI of Swansea



Band3



Band4



Band5

Figure 4. Extracted bands 3, 4, and 5 of Landsat 8-OLI of Swansea

array systems. The spectral bands of OLI sensor can optimally assess water resources, vegetation cover, coastal regions, and many environmental phenomena. Band 9 of Landsat 8-OLI is designed for the new infrared range, optimized to identify and map areas with cirrus clouds (thin and high) that can obscure clouds, water bodies, and snow.

The downloaded Landsat 8-OLI of Swansea that essential to estimate CIG and GEMI are bands 3, 4, and 5, are illustrated in Figure 3. The highlighted area of interest depicted in Fig. 3 will be processed to extract Bands 3 (green wavelength), 4 (red wavelength) and 5 (near infrared wavelength) of Swansea County. These bands will be then processed to enable the detection of CIG and GEMI. The extensive coverage of the area introduces various challenges, notably concerning reflectivity values, processing time, and effort. Consequently, the GIS program is employed to selectively extract Swansea area of interest, addressing these issues. The outcome of this extraction process is illustrated in Figure 4.

RESULTS AND DISCUSSION

Understanding the condition, spatial arrangement, and changing patterns of vegetation holds significant scientific and economic importance. Satellite platforms offer a highly convenient means of observing the Earth's biosphere on a global scale and with regularity. So far, deriving precise quantitative insights from these observations can pose challenges. Utilizing measurements of reflectance within the visible and near-infrared spectra, straightforward yet effective indices have been developed to amplify distinctions between vegetation and other surface categories. Nonetheless, these indices prove to be quite susceptible to the effect of atmospheric conditions. In recent times, the widespread adoption of GIS and various RS methodologies has resulted in the popularization of applications for processing satellite images. The techniques employed for computing vegetation indices (VIs) and their broad application across diverse landscapes have proven to be highly valuable for the examination of plant life and the analysis of biophysical factors within both forests and agricultural fields. The foundation of VIs in Landsat 8 images is rooted in the selection of combinations of spectral bands that capture surface reflectance across multiple wavelengths. These combinations, either through specific band selections or mathematical formulations, serve to accentuate distinct plant attributes. The specifics of each VI differ based on the methodology employed in its creation and the specific plant feature (such as pigments, water, carbon, chlorophyll, nutrients) being emphasized. Nonetheless, all techniques involving Landsat 8 band combinations rely on the reflective properties exhibited by plants or surface land cover.

Chlorophyll content and global environmental monitoring index values were computed and extensively illustrated in Figures 5 and 6 for the purpose of comparison. The presence of vegetative cover in various regions was determined using the extracted values of chlorophyll index green and GEMI. Analysis of Landsat 8-OLI images focused on bands 3, 4, and 5, namely green (0.53–0.59), red (0.64–0.67), and near infrared (0.85–0.88) bands. Examination of Figure 5 revealed that CIG indicated vegetation chlorophyll levels ranging from -1 to 38, signifying abundant green areas contributing to increased chlorophyll emissions into the atmosphere. Visual assessment of the classification outcomes highlighted GEMI's effectiveness in capturing emission impacts reflected in the atmospheric domain, with values spanning from 1.75105 to -9.61413e+008. Overall, the visual inspection distinctly showcased extensive vegetation coverage, influencing the atmosphere through heightened chlorophyll reflectance into space. These findings have the potential to provide quantitative metrics and visual depictions aiding researchers, policymakers, and stakeholders in making well-informed choices.

In the given paragraph, the chlorophyll index green is specifically mentioned, which likely employs spectral bands sensitive to green light (Band 3 in Landsat imagery). There are practical applications of the chlorophyll Index which can be concluded to: (1) ecosystem health: monitoring changes in chlorophyll content provides insights into the overall health and stress levels of vegetation. Anomalies in chlorophyll levels may indicate nutrient deficiencies, disease, or environmental stressors, enabling timely interventions to mitigate

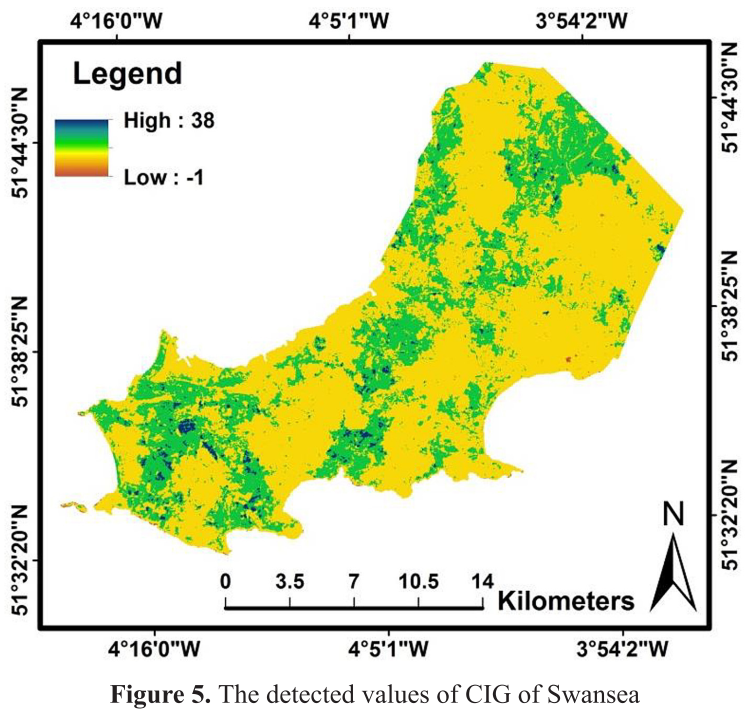
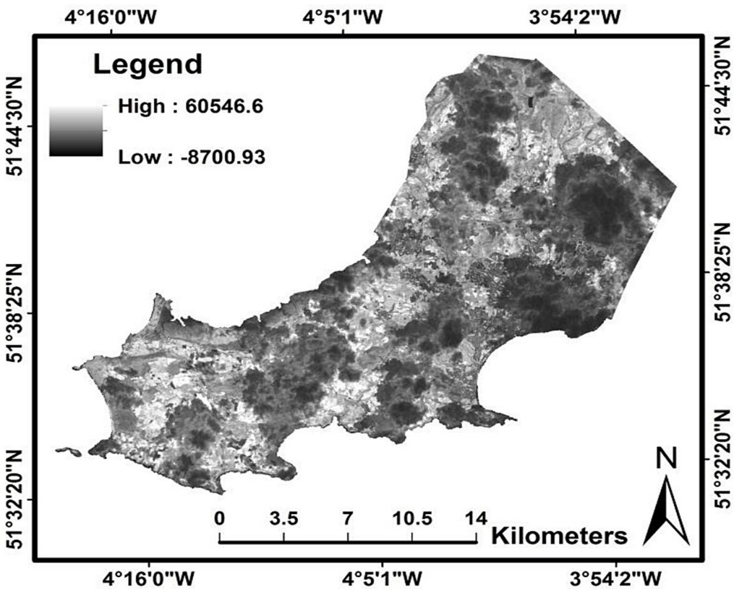
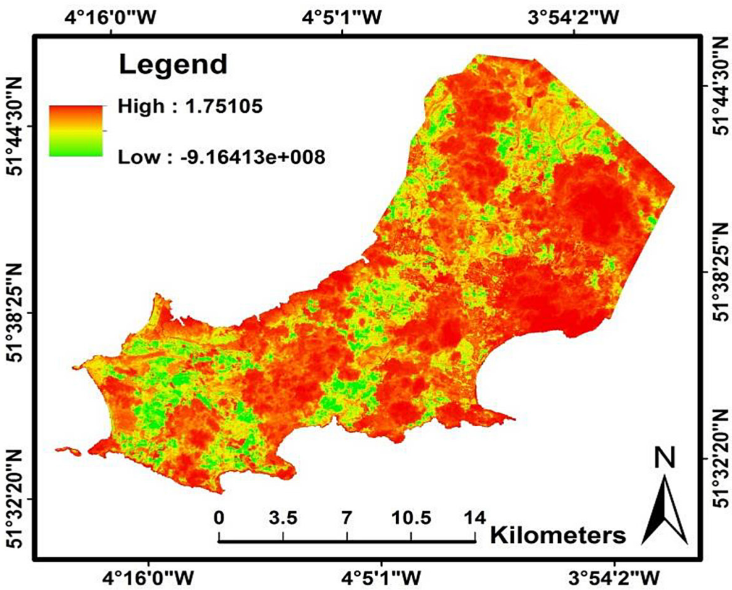


Figure 5. The detected values of CIG of Swansea



a) ETA



b) GEMI

Figure 6. The detected values for: (a) the extracted parameter ETA for Swansea, and (b) GEMI

potential risks to ecosystems; (2) crop monitoring and management: for agricultural purposes, chlorophyll indices are used to assess crop health, optimize irrigation, and manage fertilizer application. This helps improve crop yield and resource efficiency; (3) environmental monitoring: monitoring chlorophyll levels in aquatic ecosystems, such as lakes and oceans, offers insights into water quality and algae blooms. Chlorophyll is necessary for life, but like many other things, too much can be harmful. High amounts of chlorophyll can indicate too many nutrients coming into a body of water from runoff, which can lead to eutrophication and disrupt the natural balance of an ecosystem; (4) consequences of climate change chlorophyll indexes draw out information about land cover changes and the role of vegetation in mitigating and contributing to the effects of climate change. The detection of change of chlorophyll levels is an indication of the overall complex changes in ecosystem processes experienced by the vegetation, so it has a direct influence on its productivity.

GEMI is an instrument for analyzing and quantifying the reflection and absorption of emissions to the atmosphere, particularly from vegetated areas. Some key aspects and ramifications of the global environmental monitoring index are: (1) holistic view of the environment: GEMI is a way to monitor the environment more effectively than if only one variable or parameter is measured. This allows for concurrent changes in multiple environmental indicators, such as land cover, vegetation vitality, water quality, and air condition; (2) determining the environmental impact: If GEMI is plotted over time the progress of changes in the environment is indicating that the response time of environmental changes at an early stage can be achieved by identifying indicators of climate change, pollution, deforestation, and urbanization. Starting detecting is crucial for early protection and remediation; (3) monitoring of biodiversity and habitat: The implementation of GEMI detection vegetation changes, changes in vegetation cover may affect some species of habitats and migration patterns of the array, and 4) climate change research: A key aspect of climate change is the monitoring of changes in vegetation cover and the use of the land to ensure the type of energy, the normal cycle and the general climate of the Earth.

In general, and through the results obtained using the spatial and temporal analysis of the Landsat 8-OLI satellite image, we note that the values of chlorophyll levels reflected to the airspace are very large. Whereas, the global environmental monitoring index showed very high values for the rates of chlorophyll released to the atmosphere. Despite the environmental benefit that can be obtained from the provision of dense vegetation, as it reflects large levels of oxygen in the atmosphere and the absorption of carbon dioxide, this vegetation density clearly indicates the consumption of large quantities of water needed by the dense vegetation. As the high water consumption needed by the dense vegetation cover strongly affects the rates and quantities of fresh water available on the surface of the Earth, which is expected to strongly affect future water scarcity. Fresh water is used in all facilities of human life, and its shortage or scarcity will certainly affect its availability, especially since the world at the present time suffers from global warming, which generates high temperatures that increase evaporation rates, in addition to the high and unprecedented scarcity in low precipitation rates. Consequently, a prudent approach would involve managing water consumption by dense vegetation, utilizing groundwater, or scaling back vegetation cover to a level that doesn't compromise the availability of fresh water resources.

CONCLUSIONS

This study showcased the utilization of geographic information systems for environmental monitoring. Specifically, it highlighted the capabilities of Landsat 8-OLI in visualizing various vegetation indices. To assess sensitivity to different vegetation coverage scenarios, the CIG and GEMI were put to the test. This was achieved by analyzing a Landsat 8 image of Swansea county in Wales, UK, which contained comprehensive vegetation-related data. The resulting spectral VIs provided insights into the variations across vegetation conditions. By processing Landsat 8-OLI's Bands 3, 4, and 5 using GIS techniques, the CIG and GEMI were derived from RS data.

The research area exhibited pronounced vegetation characteristics as evidenced by the CIG and GEMI indices. The chlorophyll index spanned from -1 to 38, while the global environmental monitoring index ranged between 1.75105 and -9.61413e+008. Both indices effectively identified substantial vegetative land coverage. These extensive vegetated zones have the potential to influence the climate due to elevated chlorophyll emissions, thereby intensifying atmospheric impacts. Moreover, the substantial areas covered by vegetation will also contribute to heightened water demand, further impacting the water sector. Based on the findings, which highlighted substantial areas covered by vegetation, as evidenced by the CIG values and the GEMI environmental monitoring index, it is advisable to prioritize the utilization of GEMI due to its precise assessment of climate impacts caused by significant emissions. In regions prone to severe weather conditions, such as the United Kingdom and specifically Swansea County, employing various vegetation indices can serve as a valuable tool for estimating canopy health. To safeguard the water sector in Swansea from the repercussions of weather-related emissions reflected in land cover and land use, precautionary measures should be taken.

The proficiency of geographic information systems in interpreting cartographic data significantly aids in thematic mapping of global vegetation, offering visual insights into plant growth and well-being. The approach presented here holds potential for application in other studies with similar aims of environmental forest monitoring.

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