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INVESTIGATING LANDSAT DATA FOR CONTINUOUS MONITORING OF GROUND ELECTRICAL CONDUCTIVITY: IMPLICATION FOR PROPAGATION AT MEDIUM FREQUENCY IN ONDO WEST

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ABSTRACT

Ground electrical conductivity (GEC) has many applications, which makes it worthy of continuous research. Apart from the configurations of the radio transmitter and receiver, it is a major determinant of the electric field intensity of radio waves in the Medium Frequency (MF) band. It is usually measured in such a way that both the researcher and the measuring instrument are in direct contact with the ground, and measurements are made at some predetermined constant intervals to ensure good spatial coverage and even spatial distribution. The direct method becomes cumbersome when the field of study is large because the GEC over the licensed coverage area must be known such that electric field intensity can be predicted. At the planning stage, this ensures all parts of the licensed region are reached by useful signals that can suppress interference at all times and seasons. The study is motivated by the possibility of using Landsat to estimate GEC. This study utilizes Landsat images to first estimate the normalized difference salinity index and then, with the aid of map algebra, generate another raster whose pixels' values are the GEC. The study covers a landmass of 967 km^2 in the Ondo West Local Government Area (OWLGA). During analysis, the GEC was divided into five classes. The results reveal that the ranges of very low, low, moderate, high, and very high GEC are 0.124 to 0.437, 0.438 to 0.937, 0.938 to 1.635, 1.636 to 2.524, and 2.525 to 3.600 mS/m, which have mean values of 0.346 ± 0.109, 0.754 ± 0.103, 1.071 ± 0.089, 1.351 ± 0.067, and 1.564 ± 0.106 mS/m, and are dispersed over 176.45, 202.24, 214.14, 374.17, and 228.56 km^2, respectively. The values of GEC, their respective coverage, and spatial distribution recorded in this study are strong enough to sustain the propagation of useful electric field intensity over the entire landmass of Ondo West Local Government if a medium wave network is not established. The study recommends that the change in GEC with time in this field be studied.

Keywords: Landsat, GEC, Medium frequency band, Electric field intensity, Spatial, Salinity.

INTRODUCTION

The interplay between ground electrical conductivity and the intensity of electromagnetic waves at the medium frequency (MF) band stands as a pivotal factor shaping the performance and reliability of radio communication systems. The MF band, encompassing frequencies between 300 kHz and 3 MHz, is particularly significant in applications like Amplitude Modulated (AM) radio broadcasting. Ground electrical conductivity profoundly influences the propagation characteristics of MF waves, acting as a key determinant of signal strength, coverage range, and overall system efficiency (Adenodi *et al*., 2013). As radio waves traverse the Earth's surface in the MF band, the electrical properties of the underlying ground play a crucial role in governing the attenuation, reflection, and refraction of these waves. An in-depth exploration of the impact of ground conductivity is essential for engineers, researchers, and policymakers seeking to optimize the design and functionality of communication systems operating within the MF spectrum.

Ground Electrical Conductivity

Electrical conductivity results from the movement of electrically charged particles in metals, and electrons and holes in semiconductors. GEC is a measure of how well the ground can move electricity or charges through it. This movement takes place along the solid-liquid, liquid, and solid pathways in the ground (Corwin and Lesch, 2005; Corwin and Yemoto, 2017). The electricity is carried by dissolved ions in groundwater flowing through these pathways. Processes such as evaporation and plant transpiration that cause water to be extracted from the ground bring about the accumulation of ions (Harja *et al*., 2023). Fertilizers and many other salts are sources of dissolved ions that contribute to electrical conductivity. When no electric fields are present in water or soil, ions move about at random, and no net electric current is detected. When an electric field is provided, on the other hand, cations migrate to lower potentials and anions move to higher potentials, allowing the water or soil system to transfer electricity. Salinity is a measure of the amount of dissolved ions in the ground. Dissolved salt contributes to both salinity and conductivity.

Some researchers have measured and highlighted the applications of GEC in MF applications. Ajewole and Arogunjo (2000) opined that GEC measurement is usually done to improve the coverage of MF transmitters. In their study, the Vertical Electrical Sounding technique based on the Wenner Array geophysical prospecting method was used to determine the GEC around the transmitters of the then Ondo State Radio Corporation located at Irese, Oba-Ile, Okitipupa, and Ido-Ani, respectively, Ekiti State Broadcasting Service located at Ifaki-Ekiti, and Osun State Broadcasting Corporation at Osu. The mean values of GEC range between 1.99 ± 0.30 and 5.41 ± 0.81 mS/m. Ajayi (2005) reported that the average GEC for different soil types around the Ondo State Radio Corporation was 3.02 ± 0.29 mS/m. Adenodi (2019) shows the contribution of GEC to the coverage area of amplitude modulated broadcasting radio. The International Telecommunication Union Report (ITU-R, 1968) outlined some methods of estimating GEC which exclude the use of remotely sensed data. This study is aimed at estimating GEC from Landsat imagery. The MF ranges between 300 to 3000 kHz and it finds application in broadcasting such as amplitude modulation; mobile such as ship-to-ship and ship-to-shore communications; and radio navigation such as LORAN and others.

The wetness of the ground significantly impacts its electrical conductivity. When the ground is wet, water molecules facilitate the movement of ions, increasing conductivity, and allowing ions to move more freely through the soil (Ratshiedana *et al.*, 2023). Consequently, wet ground exhibits higher electrical conductivity compared to dry ground. This is crucial in various fields such as agriculture, geophysics, and environmental monitoring, where measuring soil conductivity helps in assessing soil moisture levels and identifying areas prone to flooding or erosion. The optical properties of the ground surface depend largely on the concentration of dissolved ions within it. According to Slonecker *et al.* (2016), dissolved ions are optically measurable by remote sensing techniques because they reflect some radiation, such as red and near-infrared, while absorbing others. They are therefore measured as part of the surface reflectance. Gad *et al.* (2022) also claimed that spectral reflectance indices are an effective technique for estimating the quality of water. Some of the Landsat 8 OLI bands were used in this study to estimate the electrical conductivity of the ground.

Landsat Program

The Landsat program, which is jointly managed by the National Aeronautics and Space Administration (NASA) and the United States Geological Survey (USGS), began providing repetitive multispectral observations of the Earth's surface in 1972, and it has since been the longest and most consistent source of space-based, reasonable spatial resolution land remote sensing data for measuring physical parameters and recognizing and distinguishing changes over time (Archaya and Yang, 2015). The program is a series of Earth-observing satellite missions that have developed from Landsat 1 to Landsat 9 (Wulder *et al.*, 2019). The timeline of the Landsat program which began in 1970 with mission acquisition and has since been used for many other applications, is already being proposed beyond the present. According to Maini and Agrawal (2014), Landsat imagery has been used for a variety of purposes, including studying changes in biophysical and biochemical settings; observing how people and the environment interact; and examining the impacts of global warming on forests and deforestation, to mention a few. In this study, Landsat 8 imagery will be used to estimate the GEC of the OWLGA. The Landsat 8 satellite carries two sensors, namely the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). OLI provides nine bands at a 30 m resolution, except the panchromatic band, which has a 15 m resolution, while TIRS measures Earth's thermal energy, which is presented in only two bands at a 100 m resolution.

Remote Sensing

Remote sensing is an art in which the characteristics of an object are measured without actually being in contact with it but by sensing, recording reflected or emitted energy, processing, analyzing, and applying that information. The components of remote sensing are platforms and sensors. The sensors are placed on a platform at a vantage distance and height above the target whose characteristics are required. Earlier remote sensing platforms were pigeons, balloons, and kites (Adenodi, 2021). The primitive camera-platform combination was used to access inaccessible places like wild animal-invested areas, locations of enemies during wars, and a host of other dangerous places. In 1859, Gaspard Tournachon took a photograph of a village near Paris from a balloon. Thereafter, many people all over the world did the same. During the Civil War in the United States, aerial photography from balloons was used to reveal the defense positions in Virginia (Colwell, 1983). This technology has over time developed into placing sensors on land-based, air-based, and space-based platforms. Satellites provide space-based platforms to research the Earth and space. Before its development, access was mainly from ground-based observations. The use of satellites provides an opportunity for scientific research that is global (Maini and Agrawal, 2014). Aerial platforms include kites, manned and unmanned aircraft, and balloons, with mounted sensors for research purposes (Tian-Zhu *et al*., 2019). The aerial platform delivers rapid and reliable spatial data useful for scientific research and can also complement data from either space-based or ground-based sources (Anderson *et al*., 2016). Ground-based platforms involved cranes, masts, and skyscrapers (Kolle *et al*., 2021).

Electromagnetic radiation from the sun is reflected and scattered by the object, while objects at temperatures above absolute zero emit radiation. During interaction between an object and incident radiation, the radiation can be absorbed, reflected, transmitted through, or scattered. The radiation also experiences alteration in polarization, magnitude, direction, phase, and wavelength. These changes depend on the combined properties of the target and the wavelength of incident radiation, which carry both the spatial and spectral information of the object and are detected by the sensor. The combined properties of the object and the incident wavelength that determines which portion and percentage of incident radiation is reflected by the object of interest after the interaction is called the spectral signature (Capoloupo *et al*., 2020). The spatial information includes shape, size, and orientation, while the spectral information contains color, tone, and spectral signature. The sensor extracts spatial and spectral information from the emitted and reflected radiation to build the image data of the object. Landsat, Sentinel, and Meteosat are some of the imagery resulting from spectral signatures that are in the public domain. Landsat imagery will be used in this study.

MATERIALS AND METHODS

The material for this study is the bands of Landsat 8 OLI imagery, which was downloaded from the USGS website. These are the bands that have information about the dissolved ions in the ground. This information will be used to estimate the salinity, and then map algebra will be used to convert the salinity to GEC.

Study Area

Ondo West is one of the eighteen local government areas (LGAs) in Ondo State. It has a landmass of about 970 km^2. The LGA is blessed with industrious, hospitable, and resourceful Yoruba people as well as a tropical rainforest. Apart from the indigenes, it is a home for many people from other parts of the state and nation, who are engaged in large and small-scale farming, trading, and crafting. Located within the LGA are three citadels of learning, namely, Adeyemi Federal University of Education, Ondo (formerly Adeyemi College of Education, Ondo), University of Medical Science, Ondo, and Westley University, Ondo. Students and staff of these institutions are sourced from all over the nation. The teaching hospital attracts people from within and outside the country who come for medical research or treatment. Her well-educated elites have made the LGA one of the best-educated in the whole state. There are three broadcasting radio stations, namely EKI FM, SUNCITY FM, and MUSIC and CULTURE FM. Apart from enhancing electric field intensity at the MF band, GEC has proved profitable in many other fields of study, such as agriculture (Corwin and Yemoto, 2017; Corwin and Lesch, 2005), the conduction of atmospheric electrical discharge (Rohan and

Kausha, 2020; Fortov et al., 2015) and a host of others.

Map Algebra

The visible red and the near-infrared bands of Landsat 8 imagery, in the wavelength range of 0.630 to 0.680 µm and 0.845 to 0.885 µm, respectively, each having a resolution of 30 m, downloaded from the USGS website, will be used for the estimation of salinity. The bands were first projected to the WGS 1984 UTM Zone 31 coordinate system, the null value portions were removed and then they were clipped to cover the extent of the study area. The Raster calculator facility was used to estimate the normalized difference salinity index (NDSI) with the following equation (Nguyen *et al.*, 2020; Garcia-Reyes *et al.*, 2021):

$$NDSI = \frac{Red - NIR}{Red + NIR} \quad (1)$$

The raster containing the GEC was then generated with the aid of raster calculator using the relationship (El-Battay *et al.*, 2017; Garcia-Reyes *et al.*, 2021):

$$GEC = 627.45(NDSI)^2 + 147.16(NDSI) + 9.71 \quad (2)$$

The values of GEC were divided into five, namely very high ground electrical conductivity (VHGEC), high ground electrical conductivity (HGEC), moderate ground electrical conductivity (MGEC), low ground electrical conductivity (LGEC) and very low ground electrical conductivity (VLGEC). Some named locations were identified and overlaid on the GEC raster for ease of explanation.

RESULTS AND DISCUSSION

The generated raster of GEC presented in Figure 1, has five ranges of values. The ranges of values of salinity that were transformed by the map algebra to GEC are presented in Table 1. The least and maximum values of GEC are 0.124 and 3.600 mS/m, respectively. The VLGEC value ranges between 0.124 and 0.437 mS/m, has a mean of 0.346 ± 0.109 mS/m, and covers a total area of 176.45 km^2, mostly within parts of Ondo city in the northeastern region; Omisoro and Arotundun in the northwestern region; below Bolodunro 1 and Igbindo in the southwestern region; and Erinla in the southwestern region of the LGA. It is less evenly distributed compared to other ranges of the GEC. This range of values of GEC, presented in Figure 2, though weak, can boost weak signals at some considerable distance from the transmitter.

The LGEC, as shown in Figure 3, covers a surface area of about 202.24 km^2 and its values range between 0.438 and 0.937 mS/m with a mean value of 0.754 ± 0.103 mS/m. This is better distributed compared to VLGEC. It can be located on the outskirts of Ondo city, some areas around Epe in the north, Ilunla and Bolorunduro 2 in the southeastern and eastern regions, respectively, and some places around Litaye.

Figure 4 shows the MGEC with the best even distribution over the OWLGA. It ranges between 0.938 and 1.635 mS/m and occupies a total area of 214.14 km^2. Its mean value is 1.071 ± 0.089 mS/m. It covers almost all parts and is likely to be the dominant in the study area.

The HGEC is fairly evenly distributed but much more concentrated in the eastern region of the study area, except for Ondo City. As shown in Figure 5, it covers a total area of 374.17 km^2, and its value ranges between 1.636 and 2.524 mS/m. It has a mean value of 1.351 ± 0.067 mS/m.

Figure 6 presents the VHGEC with a mean value of 1.564 ± 0.106 mS/m and it is spread over a total area of 228.56 km^2. It ranges between 2.525 and 3.600 mS/m. It is much more concentrated in the southwestern regions of the study area.

The enhancement of electric field intensity increases with an increase in the value of the GEC. The higher the conductivity, the greater the coverage distance and the strength of the signal to suppress interference, including noise. Similarly, the larger the landmass covered by considerably high GEC, the wider the coverage area of the transmitter. This implies that a high GEC value increases the fidelity and, consequently, the patronage. The ranges of GEC reported in this study have good spatial coverage and even spatial distribution that will enhance the electric field intensity of surface waves' propagation in the MF range and sustain useful electric field intensity over the landmass of OWLGA. Table 2 shows the

Table 1: Ranges of salinity and its equivalent GEC

Classes	Range of Salinity (dS/m)	Range of GEC (mS/m)
Very Low	0.017 – 0.143	0.124 – 0.437
Low	0.144 – 0.267	0.438 – 0.937
Moderate	0.268 – 0.391	0.938 – 1.635
High	0.392 – 0.515	1.636 – 2.524
Very High	0.516 – 0.639	2.525 – 3.600

Table 2: Spatial statistics of GEC

Classes of GEC	Area (km^2)	Mean (mS/m)	STD
Very Low	176.45	0.346	0.109
Low	202.24	0.754	0.103
Moderate	214.14	1.071	0.089
High	374.17	1.351	0.067
Very High	228.56	1.564	0.106

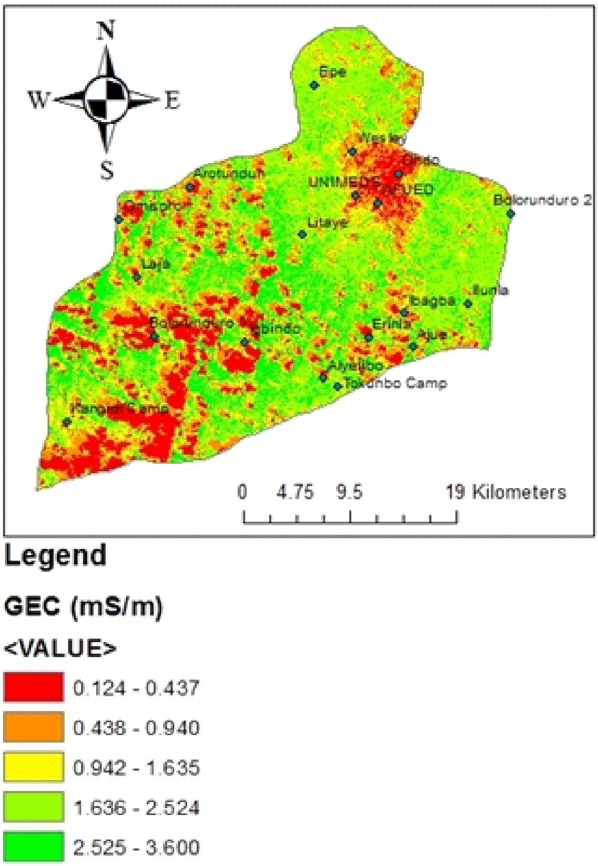

Figure 1: Ground Electrical Conductivity.

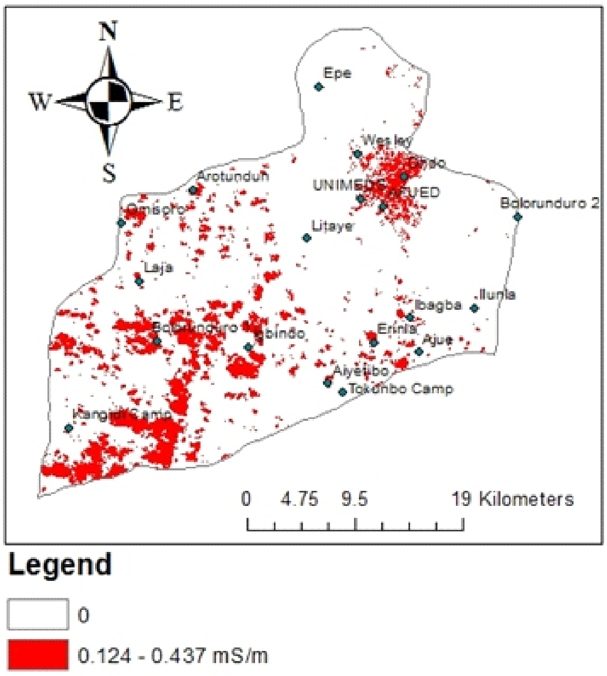

Figure 2: Very Low Ground Electrical Conductivity.

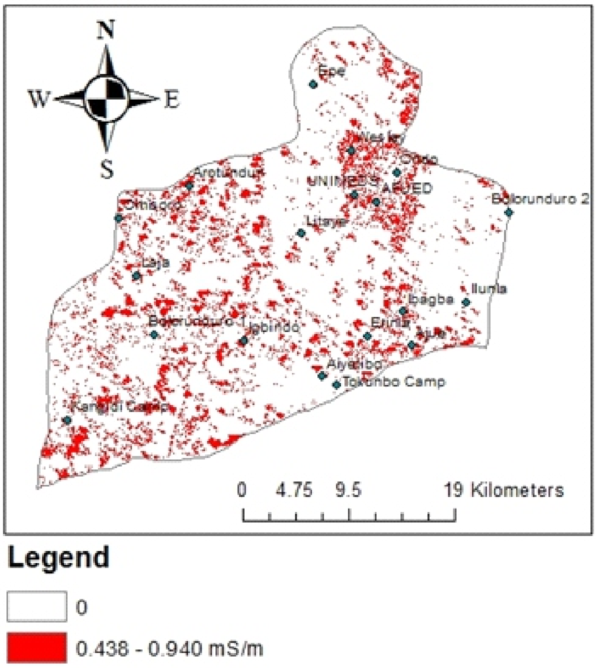

Figure 3: Low Ground Electrical Conductivity.

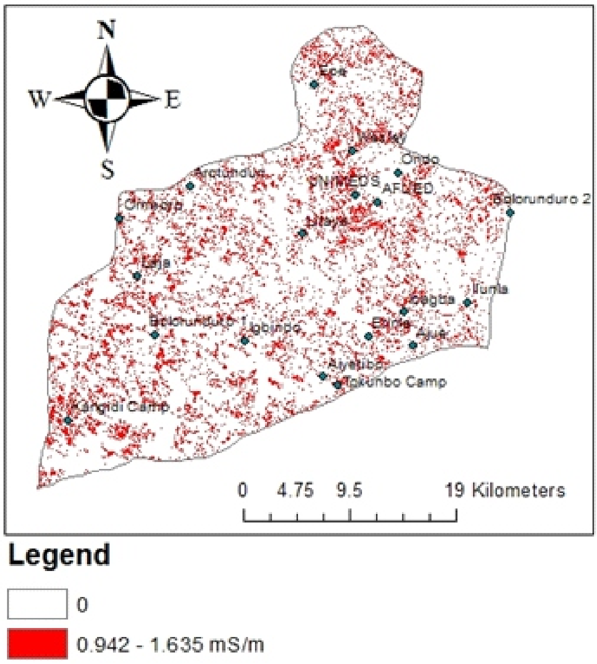

Figure 4: Moderate Ground Electrical Conductivity.

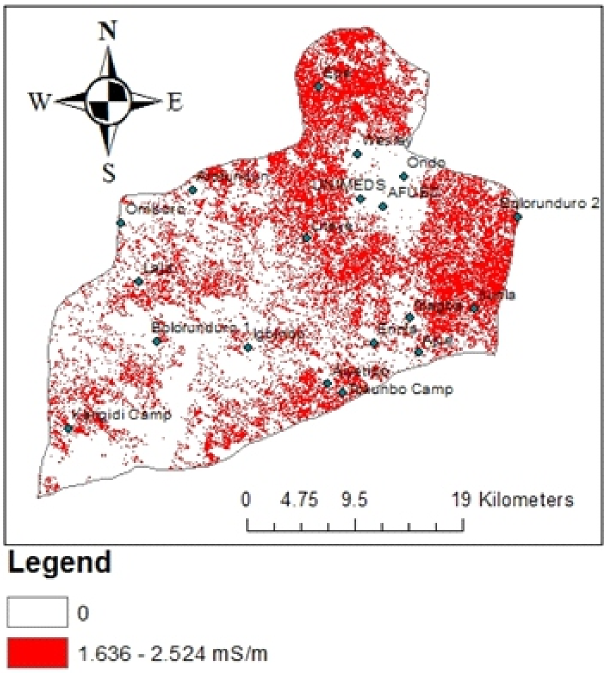

Figure 5: High Ground Electrical Conductivity.

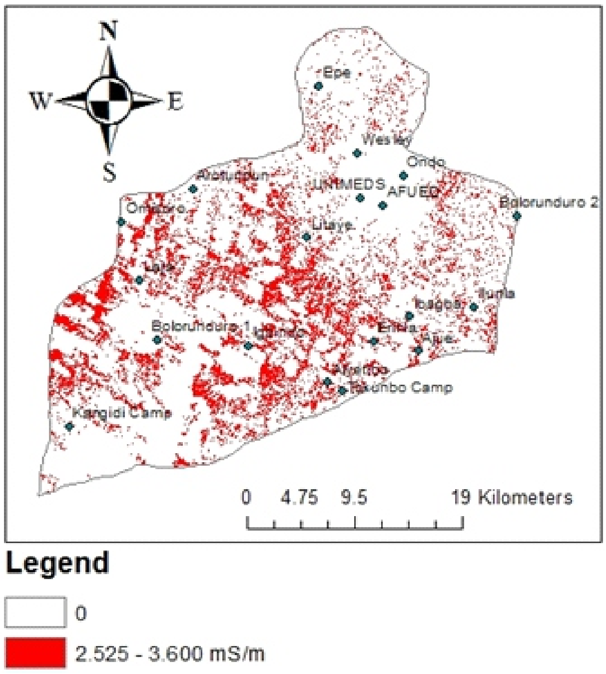

Figure 6: Very High Ground Electrical Conductivity.

CONCLUSION

In conclusion, the investigation into GEC undertaken in the OWLGA reveals significant findings with implications for radio wave propagation in the MF band. The study recognizes the importance of GEC as a crucial factor influencing the electric field intensity of radio waves, emphasizing its relevance in diverse applications. The traditional direct measurement method, while effective for smaller study areas, is acknowledged as impractical for large-scale studies due to its inherent complexity. As a response to this challenge, the research explores the potential of utilizing Landsat images to estimate GEC, presenting a novel approach to overcome the limitations associated with direct measurements. The methodology employed involves the estimation of the normalized difference salinity index from Landsat images, followed by the generation of a GEC raster using map algebra. The study covers a substantial landmass of 967 km^2, and the GEC values obtained were classified into five distinct ranges. These ranges, along with their corresponding mean values, coverage, and spatial distribution, provide a comprehensive understanding of the GEC variation across the study area. The results highlight the potential for sustaining the propagation of useful electric field intensity over the entire landmass if a medium wave is established. The spatial distribution of GEC values, categorized into different classes, underscores the importance of considering GEC variations in planning radio transmission to ensure reliable signal coverage across diverse terrains and under different environmental conditions.

The recommends further research to explore the temporal dynamics of GEC. Recognizing the dynamic nature of environmental factors, understanding how GEC changes over time will enhance the precision of radio wave propagation predictions, thereby improving the effectiveness of medium wave transmissions. In essence, this research not only advances our knowledge of GEC but also provides a practical methodology for large-scale GEC estimation using satellite imagery, opening avenues for continued exploration and application in the field of radio wave propagation.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this study.

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