RESEARCH ARTICLE

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Exploring Bangladesh's Soil Moisture Dynamics via Multispectral Remote Sensing Satellite Image

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ABSTRACT

Accurate monitoring and mapping of soil moisture are essential for sustainable agricultural practices, water resource management, and climate studies. This study aims to explore the mapping of soil moisture in Bangladesh using multispectral remote-sensing satellite images. The purpose of this study is to prepare a map of soil moisture aiming to help government authorities in developing agricultural activities to accelerate the sustainable development of the rural economy in Bangladesh. A total of 14 Landsat scenes of paths 135-139 and rows 42-46 covers the entire Bangladesh. Thus, a set of Landsat imagery (a total of 14 scenes) for the year 2022 was used in this study to map the soil moisture of Bangladesh through the application of Geographical Information System (GIS) and Remote Sensing. Satellite Image preprocessing, correction, and analysis were done with ENVI software (version 5.1, developed by Research Systems, Inc., USA) and the ArcGIS software (version 10.6, developed by Environmental Systems Research Institute, USA). For the study of the long-term variation of soil moisture over Bangladesh and its seasonal characteristics, a soil moisture map can be used. In addition, to improve the climate model over Bangladesh, an up-to-date soil moisture map will be very helpful. The objective of this study is to provide accurate and detailed up-to-date spatial soil moisture information at reduced cost and time which is essential for environment modeling, risk assessment, decision-making for different government agencies and development partners, and help toward socio-economic development. In this study, the map shows soil moisture as very wet, wet, dry, and very dry soils of Bangladesh. The overall land cover classification accuracy was 92.56%, with a Kappa value 0.90 for Random Forest and the overall soil classification accuracy was 87.27%, with a Kappa value 0.858 for maximum likelihood classification indicating good consistency.

Keywords: agriculture, GIS, Landsat, Remote Sensing, Satellite Image, Soil Moisture Dynamics.

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I. INTRODUCTION

Accurate monitoring and mapping of soil moisture are essential for sustainable agricultural practices, water resource management, and climate studies. The objective of this research is to investigate the process of mapping soil moisture in Bangladesh by utilizing satellite images captured through multispectral remote sensing. Soil moisture plays a crucial role in influencing soil nutrients and supplements. In lower precipitation, the dirt dampness hold ought to be considered while picking manure rates [1]. Soil moisture over specific levels will for the most part give a more noteworthy financial comeback to manures [2]. In a general sense, soil moisture pertains to the water that is held within the gaps present among particles of soil. The upper 10 cm of the soil is mainly referring to the soil moisture, and the upper 100 cm of the soil refers to the root zone soil moisture which good for crops.

The health of our crops depends, among other things, on sufficient moisture and soil amendments. Typical plant performance and development are disrupted, and crop yields are reduced as moisture availability decreases. The accessibility of moisture is also becoming an increasingly important factor as our atmosphere changes. The volume of soil moisture is small compared to other parts of the water cycle, but it is critical for many hydrologic, natural, and biogeochemical processes. This information holds significance for various government entities and private enterprises involved in matters related to climate and atmospheric conditions, flood prevention and assessment, land stability, landfill management, geotechnical construction, and water quality. It is also considered as a key variable for controlling warmth vitality between the land surface and climate, trading of water and climate through dissipation with plants happening [3].

In addition, it plays an important role in improving climates and generating precipitation. Simulations conducted using climate prediction models indicate that significant enhancements can be achieved through better modeling of surface moisture, vegetation, and temperature. Additionally, the moisture level in the soil distinctly affects the quantity of precipitation that drains into nearby streams and waterways. Board storing, the early admonition of dry season, harvest yield anticipating, and water system planning are commonly used soil moisture data. Various remote sensing techniques employ different types of data, including visible, infrared, thermal, and microwave data, to acquire soil moisture information [4]. Bangladesh has ample water supply with a fertimprovesl which improve the different crops grow in easy ways. There is a huge arable land in Bangladesh which is more than 60% and it's called more valuable than gold or diamond reported by the World Bank [5], [6]. Most of the areas in Bangladesh have agro-suitable soil in the rate which is the greatest resource in the world [7]. Bangladeshi soil consists of five fundamental components: minerals, water, organic matter, gases, and microorganisms. Among these components, soil water holds the utmost significance for plant growth, along with other factors associated with the atmosphere [8]. Specifically, soil misters consist of 2-50% water including minerals, organic matter, microorganisms, and gases. Soil moisture is defined as the quantitative amount of water that occupies the pore spaces between soil particles by volume or mass. In rain-fed agricultural systems like Bangladesh, soil moisture serves as a crucial water source for plants and crops [9]. The availability of soil moisture plays a vital role in facilitating plant growth and overall crop production [10]. While the relationship between water supply and crop yield can be established under irrigated conditions, it should be noted that not all water capacities yield equal results for different crops [11].

The main drawback of the existing studies is that they did not demonstrate the recent information about soil moisture in Bangladesh. Although there are some automatic systems for mapping soil properties in Bangladesh such as Digital soil mapping (DSM). The problem is it needs a large amount of terrain point data which has huge complexity due to high cost, and rear to be found in many countries. In addition, it is not feasible to collect up-to-date information. In this study, we successfully map the soil salinity of Bangladesh via a multispectral remote sensing satellite image that shows soil moisture in four different categories namely *very wet*, *wet*, *dry*, and very *dry*. The major contributions of this research are:

- In the process of digital soil mapping, Remote Sensing data is utilized as a secondary source of information. A comprehensive set of 14 Landsat-8 OLI/TIRS imagery scenes, covering the entire Bangladesh area within path 135-139 and rows 42-46, were acquired from the USGS Earth Explorer site and images were then digitally analyzed, discussed in Section III (A and B).
- Landsat 8 Satellite Image preprocessing, correction, and analysis were done with ENVI and the ArcGIS desktop software using a high-performance computing facility (Microsoft Azure Windows Virtual Desktop), discussed in Section III (C).
- Provide a detailed guideline (Methodology) to map the soil moisture of Bangladesh using Multispectral Remote Sensing Satellite Image, discussed in Section III (G).
- Show the distribution of different soil properties in Bangladesh. Map the soil moisture of Bangladesh in four different categories: very wet, wet, dry, and very dry, discussed in Section IV (A).
- Examine the effectiveness of the proposed model using Multispectral Remote Sensing Satellite Image along with a detailed result analysis discussed in Section IV (B).
- Minimize cost and time associated with soil property mapping while delivering precise and current comprehensive spatial soil data, which is essential for environment modeling, risk assessment, and decision-making.

The remaining sections of the paper are structured as follows: Section II reviews relevant literature pertaining to the exploration of soil moisture in Bangladesh. Section III provides details about the data, materials, and methodology employed in the study. Section IV presents the research findings, including a comprehensive analysis and discussion of the results. The testing and evaluation process for the proposed model is also outlined in Section IV. The paper concludes in Section V, followed by a discussion of limitations and recommendations for future research in a dedicated section to assist fellow researchers in their future endeavors.

II. Literature Review

Remote sensing has emerged as a valuable tool for exploring soil moisture dynamics in various regions worldwide. In the context of Bangladesh, studies investigating soil moisture using multispectral remote sensing satellite imagery have gained prominence over the past few years. With the advancement of modern technologies, especially with the availability of remote sensing high dimensional satellite data, a number of research have been carried out on soil moisture in the last two decades. This section presents a literature review of key studies conducted between 2000 and 2023, focusing on the exploration of Bangladesh's soil moisture dynamics through multispectral remote sensing satellite image mapping. These studies mainly focus on the relationship among soil moisture and biophysical variables, vegetation indices, land surface temperature, water stress, etc. for various geographical regions of Bangladesh.

One notable study conducted by Rahman *et al.* [7] employed multispectral satellite data to map and monitor soil moisture levels across different regions of Bangladesh. The study demonstrated the effectiveness of multispectral remote sensing in capturing temporal and spatial variations in soil moisture, highlighting its potential for agricultural water management and land resource planning. Jin *et al.* [8] carried out an extensive study to examine the relationships between soil moisture, soil temperatures (Tsoil), and surface temperatures (Tskin). The investigation utilized data obtained from Atmospheric Radiation Measurement (ARM) observations and offline simulations conducted with the Community Land Model (CLM4) in Lamont, Oklahoma. Their study revealed notable findings, indicating that the soil moisture data derived from CLM4 exhibited a stronger correlation between Tsoil and Tskin ($r = 0.96$) compared to the results obtained from ARM observations ($r = 0.64$). Furthermore, the study noted that the predicted night-time Tskin values were consistently 0.5–2 °C higher than the corresponding observed temperatures.

Hunt [12] conducted a study investigating the correlation between soil moisture and biophysical variables during both wet and dry seasons in an agricultural field located in eastern Nebraska, USA. The research highlighted a specific drought case that emphasized the significance of irrigation in mitigating the impact of prolonged dry periods. Additionally, the study demonstrated the practicality of employing short-term drought indices as a means of identifying water stress in rainfed fields.

Rahmani *et al*. [13] conducted an extensive investigation involving the multiyear monitoring of soil moisture across Iran, employing satellite-based and reanalysis soil moisture products. Within this research, surface soil moisture (SSM) datasets from six distinct subregions in Iran, each characterized by different climate conditions, were obtained from various sources, including satellite-based passive and active microwave observations, as well as reanalysis products such as ERA-Interim and ERA-Interim/Land. The findings revealed a high level of agreement among all SSM products, with correlation coefficients exceeding 0.5. Particularly noteworthy were the Northeast and Southwest regions, which displayed notably strong agreement, indicated by average correlation values of 0.88 and 0.91, respectively. Furthermore, most SSM products exhibited robust correlations with maximum, minimum, and average temperatures, along with total monthly precipitation.

Asharaf *et al.* [14] conducted a research study focused on examining the soil moisture-precipitation feedback processes during the Indian summer monsoon season. The study revealed compelling evidence demonstrating the substantial impact of pre-monsoonal soil moisture on monsoonal precipitation.

Shrivastava *et al.* [15] conducted an analysis of soil moisture fluctuations using remotely sensed and reanalysis datasets in the context of weak monsoon conditions in central India and central Myanmar. The study findings indicated that day-to-day variations in soil moisture in these regions during weak monsoon periods were influenced by the deficit in rainfall. Specifically, the observed values of soil moisture from the European Space Agency (ESA) and the climate forecast system reanalysis (CFSR) datasets were reduced by up to 0.1 m^3m^{-3} compared to the climatological values, which typically exceeded 0.35 m^3m^{-3}.

Sen *et al.* [16] conducted a comprehensive investigation into the impact of various soil moisture regimes on onion yield. Their study aimed to determine the most suitable soil moisture conditions for optimal onion production in the grey terrace soil of Gazipur. After analyzing the data, the researchers concluded that a soil moisture regime with a ratio of 1.00 IW/CPE (Irrigation Water/Cumulative Pan Evaporation) was found to be the most favorable for maximizing onion yields.

Nahar *et al.* [17] investigated the impact of water stress on both moisture content distribution across various soil layers (pot) and the morphological characteristics of tomato plants. Their findings highlighted that maintaining a moisture level equivalent to 70% of the field capacity (FC) provided sufficient moisture supply for the tomato plants under examination. The researchers recommended this specific moisture threshold as it resulted in higher fruit yields and improved fruit size.

Parinussa *et al.* [18] conducted an analysis of different remotely sensed soil moisture products across various spatial scales over the Iberian Peninsula. The study utilized soil moisture (SM) data obtained from active microwave (AM), passive microwave (PM), and thermal infrared (TIR) observations, each offering distinct spatial and temporal coverage. Results indicated a strong agreement between all three remotely sensed SM products and ground observations. The comparison, based on correlation coefficient (r) and root mean square error (RMSE), demonstrated the consistency between the ground observations and satellite data.

Furthermore, Hossain *et al.* [19] utilized a fusion of multispectral and thermal infrared satellite data to estimate soil moisture content in Bangladesh. The study highlighted the advantages of combining different spectral bands to enhance the accuracy of soil moisture mapping, particularly in areas prone to water stress and drought conditions.

In a recent study, Islam *et al.* [20] investigated the potential of using high-resolution multispectral satellite images to map soil moisture at a fine-scale level in Bangladesh. The authors utilized advanced image processing techniques to extract soil moisture information from satellite data, offering valuable insights into local-scale soil moisture dynamics and its implications for agriculture and water resource management.

These studies collectively demonstrate the significance of multispectral remote sensing satellite image mapping in exploring and monitoring soil moisture dynamics in Bangladesh. But most of these previous studies conducted in Bangladesh have primarily focused on the impacts of soil moisture on crops and vegetables. However, a comprehensive analysis of the long-term variations and seasonal characteristics of soil moisture across Bangladesh remains unexplored. Furthermore, the development of an up-to-date soil moisture map is crucial for enhancing climate models specific to the region. This study aims to address these research gaps by primarily focusing on the creation of an updated soil moisture map to improve our understanding of soil moisture dynamics in Bangladesh.

III. Data Set and Environmental Setup

A. *Remote Sensing Data*

In the study, we used 14 in total scenes which were collected from the Landsat 8 Operational Land Imager (OLI) sensor with the help of the Landsat 8 satellite. This sensor captures the imagery of the Earth's surface including bi-dimensional bands. OLI mainly captures the reflectance and radiance of the object. After that, this imagery has been digitally analyzed. Our dataset scenes cover paths 135-139 and rows 42-46, covering the whole of Bangladesh. The Landsat 8 image used in the study was downloaded from USGS Earth Explorer site http://earthexplorer.usgs.gov, with <10% cloud cover. The spatial resolution varies with wavelength: 15 m in the OLI Panchromatic band, 30m in the OLI Multispectral bands, and 100 m in the TIRS Thermal bands (resampled to 30 m to match multispectral bands).

B. Satellite Image Correction

Radiation calibration and atmospheric correction using the ENVI 5.1 Radiation Correction tools have been applied to hand the soil moisture data. Algorithms and processes that enhance Landsat data are used in radiometric calibration. It converts Digital Number to radiance using calibration coefficients. It has been performed in necessary bands as the raw images are not best suited to calculate indices. In atmospheric correction, the radiance will be converted to reflectance. In order to minimize the influence of the atmosphere on Landsat 8 imagery, particularly aerosols, and water vapor, and to improve the accuracy of the estimation and classification, this procedure was applied only to the visible and near-infrared bands. All the necessary data for the calibration and correction process has been found in the header file (metadata) downloaded with the satellite images.

C. Environmental Setup

In the study, we used ArcMap and ENVI 5.1 software in the Microsoft Azure High-Performance Cloud-based systems. The ArcMap mainly comes from the ArcGIS Desktop suite which is mainly used as commercial software for the geographic information system (GIS) developed by Esri [21]. This software is very effective in analyzing geographic data including creation, management, analysis, and demonstration. Moreover, it provides good tools with diverse functionalities to analyze a wide range of geographical data. There are various application areas of this software including urban planning, natural resource management, and environmental analysis. We used it in our study aiming to analyze the soil moisture in Bangladeshi areas.

We used ENVI 5.1 software in version 5.1 to analyze the Landsat 8 satellite image. This is mainly developed as a commercial software system to analyze the remote sensing dataset including satellite images with Landsat dataset. It was developed by Harries which composed data import a visualization, image processing with enhancing tools, feature extraction and classification tools, change detection, geospatial analysis, integration with GIS system and customization automation tools. As we needed high computational power to analyze the satellite image using the ArcMap and ENVI software and by considering this we used Microsoft Azure Windows Virtual Desktop.

IV. Materials and Methods

The proposed methodology uses Band-5 (NIR) & Band-6 (SWIR) of Landsat-8 to calculate soil moisture. The outline of the proposed methodology is shown in Fig. 1. The position of Bangladesh in the world map is visualized in Fig. 2 which shows that it lies between the 20.74˚ and 26.63˚ north latitudes and 88.01˚ and 92.67˚ east longitudes. Fig. 1 demonstrates the working flow graph of the proposed model where we first used the dataset which is collected by Landsat 8 OLI. This dataset is composed of a high-dimension or many number bands and all bands do not contain effective information. Based on the study first few bands contain the most important information. To collect effective information, we applied the PCA approach to select the effective bands by discarding unnecessary bands. After that, we used ENVI software to preprocess the data.

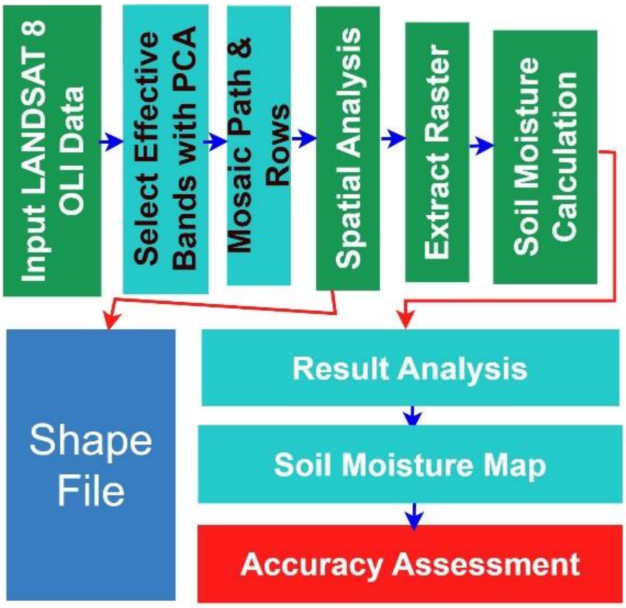

Fig. 1. Proposed working flow architecture.

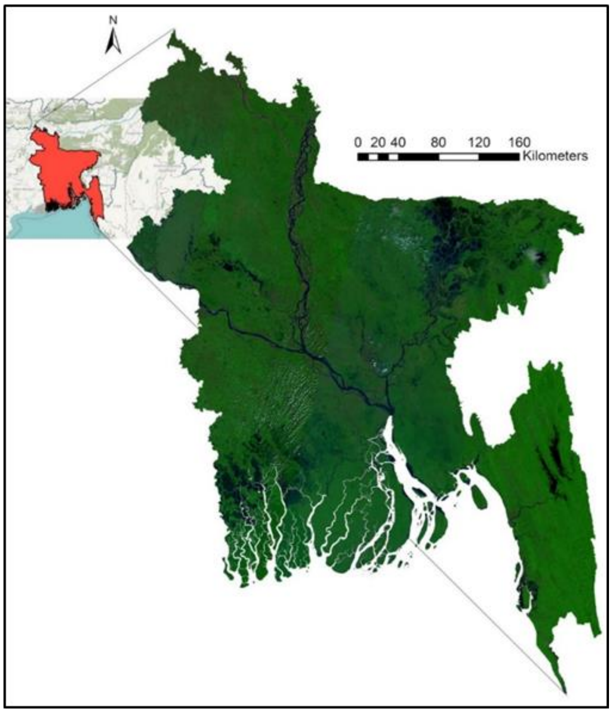

Fig. 2. Study area shown in false-color composite (RGB 753) of a Landsat 8 image in 2019.

Once individual bands complete to preprocess then we mosaic them together. This mainly aligns the bands and makes some overlapping areas aiming to create a seamless mosaic. Then we applied a spatial analysis to extract the pattern and relationship within the geographic components.

A. Preprocessing

Satellite Raw images needed to be clipped to remove the background black color from the images. This can be done by the raster clip tool in Data Management of ArcToolbox in ArcMap. An example is shown in Fig. 3.

B. Creating a Subset of Bands

PCA is one of the most effective feature extraction and dimension reduction algorithms which can select potential features from the large dimensionality of the features [22]. It can accurately select an effective number of bands from the high-dimensional multi-band images by removing the correlation among the bans. In our cases, output images of the dataset mainly concentrated on the first few bands of the image. We need to identify the first few bands to extract the grain features of the image by selecting. In addition, we need to enhance the first few bands and discard the rest bands. In our study, we used PCA in the ArcMap to select the effective few bands by considering the first few bands and removing the rest bands.

C. Mosaic Path and Rows

Then we need to mosaic all clipped images of each band individually to create a single raster of our study area (Fig. 4). Mosaics are combinations or merges of two or more images and using ArcGIS, we can mosaic multiple raster data sets to create a single raster data set.

The Area of Interest (AOI) has been extracted from the output of the mosaic image using the shape file of Bangladesh (Fig. 4).

D. Spatial Analysis

This has been done using the Extract by mask of Spatial Analysis Tools in ArcGIS. The shape file was downloaded from GeoDASH (https://geodash.gov.bd) website.

We need to use a multiband image layer for image classification. The Composite Bands function in ArcGIS allows us to combine rasters to form a multiband image. Therefore, we need to use the Combine Bands tool to load individual bands into a new multiple-band image. An example is shown in Fig 6.

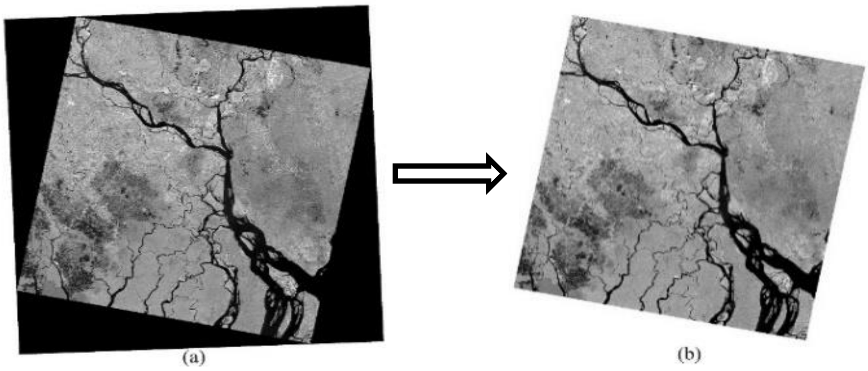

Fig. 3. Path 137 Row 44 of Band 6 (a) Before Clipping, (b) After Clipping.

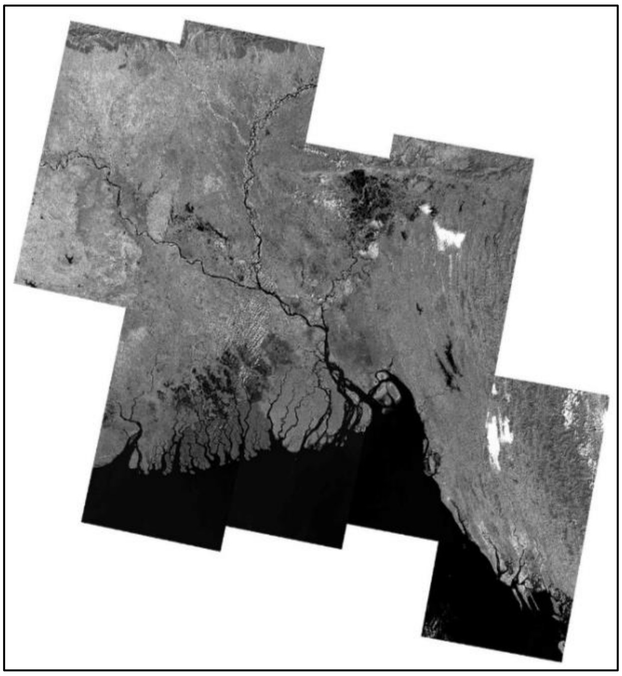

Fig. 4. Mosaic of 14 Path Rows of band 6.

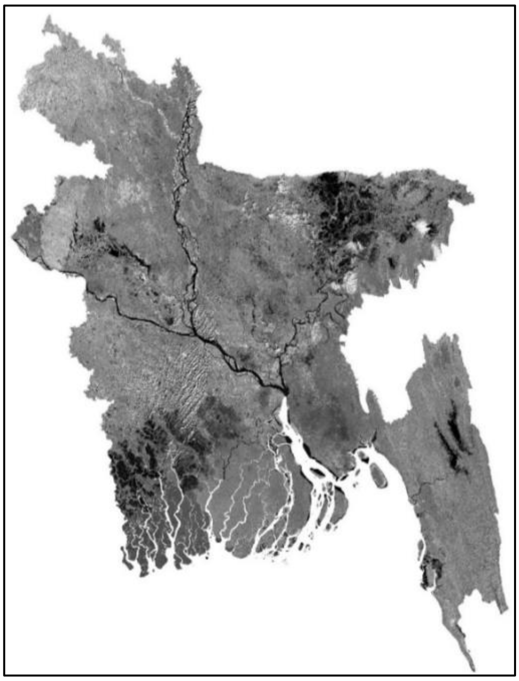

Fig. 5. Extracted Area of Interest (EOI) of band 6.

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Fig 6. Example Band Composite (RGB 543) called Color Infrared.

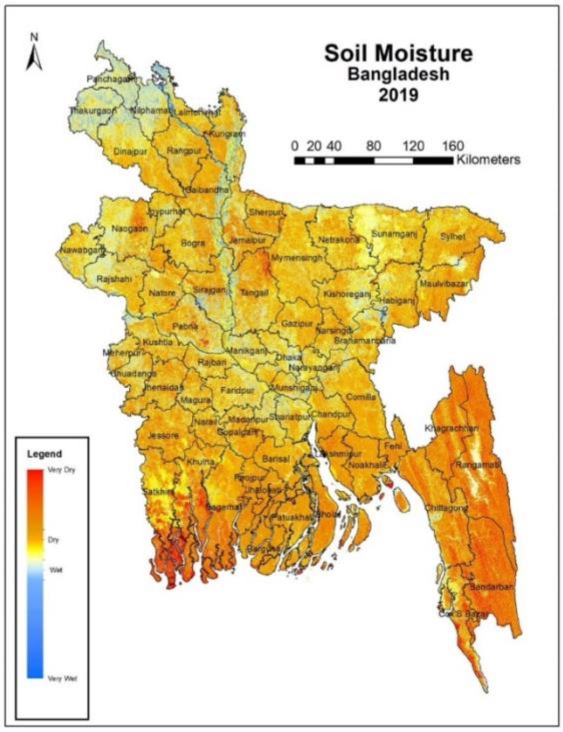

Fig. 1. Soil Moisture Map of Bangladesh 2022.

E. Soil Moisture Calculation

To create a Soil Moisture Map, Near Infrared (NIR) and Short Wavelength Infrared (SWIR) were used which are Band-5 and 6 of Landsat-8 images, respectively [23]. It is calculated as a ratio between the Near Infrared (NIR) and Short Wavelength Infrared (SWIR) values in traditional fashion as follows:

$$Soil\ Moisture = \frac{NIR-SWIR}{NIR+SWIR} = \frac{Band\ 5-Band\ 6}{Band\ 5+Band\ 6} \qquad (1)$$

V. Results

To assess the performance of the prediction model we utilized Accuracy and Kappa value as evaluation metrics. The metrics mentioned are the standard evaluation measures utilized to assess the performance of algorithms on binary and multi-class classification datasets. The outputs of Soil Moisture and Soil Classifications are shown in maps. This section also includes the analysis of the results including the accuracy and kappa value of the results.

A. Soil Moisture Map

Band-5 (NIR) & Band-6 (SWIR) of Landsat-8 were used to create the Soil Moisture Map. The calculation has been done using equation (1) [23]. The calculation provides a moderate accuracy for the Soil Moisture map. Map of Bangladesh is shown in Fig. 1. The map shows Soil Moisture as *Very Wet, Wet, Dry,* and *Very Dry* soils of Bangladesh. The task estimating soil moisture becomes more difficult when the study area is land covered with intense vegetation or snow and when there are significant topographical changes in the area. The most accurate results are achieved when there is no or low soil cover, especially when the test area is flat.

Soil moisture estimation has become complex when land is covered with vegetation or snow. In addition, significant topographical changes badly impacted to estimate this. Soil moisture estimation can demonstrate high performance when the test area is flatter without including snow, vegetarians, or forest fields.

B. Confusion Matrix for Maximum Likelihood

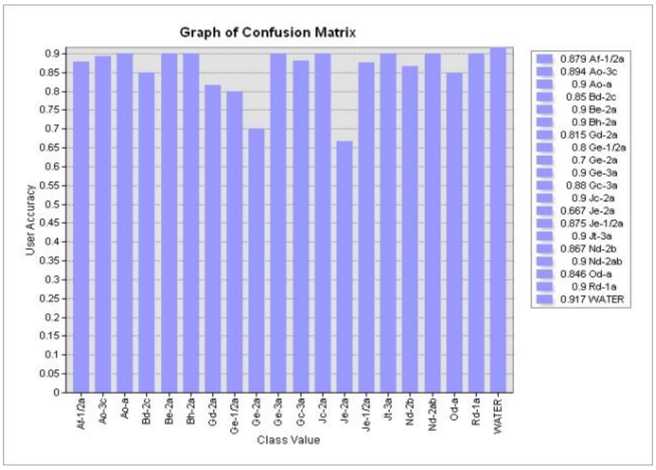

Fig. 8. Graph of Confusion Matrix for Maximum Likelihood Classification.

User accuracy refers to the measurement of false positives, which occurs when pixels are incorrectly classified as belonging to a known class instead of another class. It is also known as an error of commission or a type 1 error. The data required for calculating this error rate are extracted from the rows of the table provided, displaying the total number of points that should have been identified as a specific class according to the reference data.

On the other hand, the producer's accuracy represents the false negatives, which are observed when pixels of a known class are erroneously classified as something other than that class. It is also referred to as an error of omission or a type 2 error. The columns of the table contain the data necessary to compute this error rate, indicating the total number of points identified as belonging to a particular class based on the classification map. The Kappa agreement index provides an overall assessment of the classification's accuracy.

VI. Conclusion

Data from Remote Sensing (RS) have become successful secondary sources for improved electronic land modeling on all scales in recent decades. This research work describes the use of LANDSAT 8 OLI/TIRS satellite image for the study of soil moisture where precise preprocessing has an important influence on the results. The availability of soil moisture data holds significant importance in the domains of disaster prediction, environmental monitoring, and hydrological applications. Analysis found that Landsat 8 OLI/TIRS images had the potential to detect soil moisture of Bangladesh. In this study, the research utilizes the Geographic Information System (GIS) technique, a robust tool that enhances the precision of soil moisture and land use mapping through the analysis of remote sensing data. Certainly, this work explores the use of high spatial resolution satellite (Landsat 8 data) to map the moisture of soil and provide accurate and detailed up-to-date soil moisture information. The findings of this study demonstrate the effectiveness of multispectral remote sensing satellite imagery in mapping soil moisture at a regional scale. The integration of satellite data with ground-based measurements and advanced modeling techniques enhances the accuracy and reliability of the soil moisture estimates. The developed methodology can be applied in other regions with similar environmental characteristics to monitor and manage soil moisture levels effectively.

VII. Future Recommendation

Until now, remote sensing techniques have not been effective in estimating soil moisture from deep soil layers, specifically the root zone. However, additional research is required to investigate the possibility of obtaining soil moisture information from surface layers. The applicability of other free-accessed satellite images to detect the soil moisture of Bangladesh can also be evaluated. In future, we want to conduct research work to map the overall soil properties of Bangladesh using remote sensing high dimension satellite data. In future work may include normalizing the dataset and uplifting the recently developed map with tremendous data to achieve appetite exactitude. Subsequent studies are required to validate the findings and conclusions drawn from this research. Researchers interested in the field are encouraged to explore the utilization of satellite images for predicting underground natural resources, such as minerals.

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