BILINGUAL PUBLISHING GROUP

Journal of Environmental & Earth Sciences

https://journals.bilpubgroup.com/index.php/jees

ARTICLE

A New Method to Calculate Soil Water Content by Imaging and Testing the Color of the Soil Surface

Emad Ali Al-Helaly [1*], ***Ali H. Al-Rammahi*** [1], ***Israa J. Muhsin*** [2], ***Hussein S. Echbear*** [1], ***Hassen R. Jasim*** [1], ***Eman Ali Abed*** [3]

[1] *Faculty of Civil Engineering, University of Kufa, Najaf 54001, Iraq*

[2] *College of Science, Department of Remote Sensing and GIS, University of Baghdad, Al-Jadriya, Baghdad 10071, Iraq*

[3] *Department of Life Sciences. College of Education for Women, Al-Shatrah University, Dhi-Qar 64007, Iraq*

ABSTRACT

Soil color changes with water content due to chemical and physical reactions, making it a potential indicator for moisture estimation. By analyzing soil surface images and comparing color variations against laboratory-measured water content, a rapid and cost-effective method for moisture determination can be developed. Traditional moisture measurement techniques are time-consuming, so an imaging-based approach would be highly beneficial for quick decision-making. Soil color is also influenced by factors such as particle coarseness, which creates shadows and alters perceived darkness. This research introduces a novel method to isolate true soil color by analyzing the maximum color response in image pixels, minimizing shadow effects. Several equations were derived to correlate color changes with moisture content and were validated against lab measurements to ensure accuracy and simplicity. The most effective equation can be further adapted for satellite imagery by accounting for atmospheric light scattering differences between ground and satellite sensors, enabling large-scale moisture monitoring. The derived equations can be programmed into a software tool, allowing moisture estimation from simple soil surface images. The study involved controlled experiments where soil samples at varying moisture levels were imaged to establish an empirical color-moisture relationship. This method provides a fast, economical, and practical alternative to conventional techniques. However, the approach requires further refinement to account for different soil types globally. Future work should focus on adjusting the model with variables that adapt the color-moisture

*CORRESPONDING AUTHOR:

Emad Ali Al-Helaly, Faculty of Civil Engineering, University of Kufa, Najaf 54001, Iraq; Email: imada.alhilali@uokufa.edu.iq

ARTICLE INFO

Received: 11 May 2025 | Revised: 30 May 2025 | Accepted: 4 June 2025 | Published Online: 26 June 2025

DOI: https://doi.org/10.30564/jees.v7i6.9961

CITATION

Al-Helaly, E.A., Al-Rammahi, A.H., Muhsin, I.J., et al., 2025. New Method to Calculate Soil Water Content by Imaging and Testing the Color of the Soil Surface. Journal of Environmental & Earth Sciences. 7(7): 35–48. DOI: https://doi.org/10.30564/jees.v7i6.9961

relationship for diverse soils, ensuring broader applicability. Once optimized, this could significantly improve moisture assessment in agriculture, environmental monitoring, and land management.

Keywords: Soil Water Content; Soil Color; Spectral Reflectance of Soil; Satellite Imagery

1. Introduction

The changing soil color with increased water content is a known phenomenon. It is noted that the darkness of the soil's color rises with increasing water percentage. This is a natural visual phenomenon, and this research will use this phenomenon to measure the humidity of color and compare the results with laboratory tests.

The color of the soil surface is not only affected by its mineral content but also by the smoothness of the surface, the size of the particles, and their shapes, which scatter light and create shadows, which affects the overall color of the soil surface, and makes it difficult to relate the color of the soil to its components with a mathematical equation from mere color reflection. This difficulty is increased by the interaction of the soil with water and the change in the texture of the soil surface [1].

This research aims to develop a new, rapid method for calculating soil moisture content. This method involves photographing the soil surface and detecting the moisture content from the surface color. An empirical mathematical relationship linking the apparent soil color to the moisture content was deduced, and the results were confirmed by laboratory testing. This is a new, practical, and rapid method that is useful for determining soil moisture in situations where rapid information is required.

It is essential to develop this method to be flexible and applicable to all soil types worldwide. By repeating the same steps, we will eventually have programmable application equations to design universal software that measures moisture simply by imaging the soil surface. This method reduces the cost and time required for laboratory measurements. It can be further developed to increase its accuracy.

Dealing with soil and transforming its properties into practical mathematical expressions is very complicated due to the soil's composition, the large number of materials formed, their chemical reactions, their physical changes, and the different grain sizes and shapes.

Knowing the soil moisture is essential to determining its resistance to loads and predicting the collapses that may occur due to increased moisture levels during floods and rains. In 2024, Martin Wijaya et al. pointed out the effect of salinity on the soil water characteristic curve (SWCC). To anticipate future slope failures due to rainfall, they proposed a procedure to obtain SWCC using a polymer tensiometer [2].

A. M. Daramola and his research group studied the effect of soil moisture content on the hydraulic and mechanical behavior of the soil (SWCC). They tried assessing the hysteretic behavior of residual soil slope using old alluvium by combining field instrumentation and laboratory tests to determine the real-time measurement for the scanning curve of SWCC for unsaturated soil [3].

The classical methods for measuring moisture content involve taking soil samples to a laboratory and performing measurements. However, these laboratory measurements can be distorted and inaccurate. In 2023, Orazayeva et al. pointed out the effect of sample size on the soil-water characteristic curve (SWCC), void ratio, and degree of saturation [4].

In 2024, Prakoso, W. A. et al. proposed using a polymer-based tensiometer, which uses a ceramic disc at 15 bar, to measure water content. The desalinated water conversion efficiency (SWCC) generated by the polymer-based tensiometer is verified using a centrifugal test. They noted the effect of plant content on the tests [5].

In this research, we developed a method to overcome these difficulties through which we can calculate moisture from the color response of the soil after subjecting the surface image to a software analysis by calculating the color change between the highest color value in the pixels of the surface image with the measured change in the water content of the soil in the laboratory. The method proposed in this research is faster because it requires nothing more than photographing the soil surface and determining the moisture content based on the effect of water content on color. Therefore, it outperforms previous methods, especially when converted to a computer program. We tested the accuracy of the color index with the results of laboratory soil moisture tests, demonstrating the reliability of the method's results. In addition, this method is less expensive, avoids the drawbacks of previous examination methods, and is more accurate. It is expandable and adjustable for all soil types.

The accuracy of this method can be increased to match the laboratory measurements and MS-Excel at an excellent point of strength, which is the broad, comprehensive measure of a large piece of land. In the laboratory, only soil samples can be measured, giving statistical insight based on the number and distribution of samples. Visual moisture and water content can be measured in a way that is closer to reality and more representative of the work site.

In 1995, Thomas J. Jackson and his researchers presented a large-scale study of the application of remote sensing techniques to hydrology conducted at the Washita watershed / Oklahoma watersheds in Southwest Oklahoma. The researchers observed significant differences in the level and rate of change in soil surface moisture over regions depending on the different soil composition, even if exposed to similar hydrological conditions [6].

In 2006, Ammarin Makkeasorn et al. presented an estimating method to find the soil moisture of the Chuck Canyon Water Complex, a semi-dry water complex of more than 14,200 square kilometers in South Texas, using a set of radar images. In this study, new models for estimating soil moisture derived from genetic programming were developed and applied to support data that estimates the distribution of soil moisture [7].

Soren-Nils Haubrocka et al. conducted a study in 2008 to measure surface moisture in high-resolution spectral measurements of remote sensing devices for sandy land cover and light vegetation cover. Then, they comprehensively validated the results of their research in the study area using the enhanced sensor (NSMI), which was developed for the application of ultra-structural data. The study area was in the south of Brandenburg, Germany [8].

In 2008, C. Ormeci and S. Ekercin used microwaves in remote sensing systems to determine soil moisture, salinity, and the permeability of the soil's surface to a small extent. As long as moisture and salinity affected the permeability of micro-rays, the researchers concluded a good relationship between observed and predicted reflection spectra and moisture content in the study area near Lake Malha in Turkey [9].

Jan M.H. Hendrickx and his team of researchers investigated in 2009 the effect of soil moisture on the military activities of the military and how it affected its activities, the discovery of unexploded landmines and military engineering activities, dust and man flight and reviewed a new method of high-precision soil moisture mapping (2.7 meters) Portable on Landsat and QuickBird [10].

Jan Haas submitted a master's thesis in 2010 at Geoinformatics to the Institute of Architecture & the Built Environment Royal Institute of Technology and has a model for estimating the humidity in his study area in Stockholm, Sweden, using techniques of remote sensing and comparing them with the results of the Topical Surface Humidity Index (T.W.I.) based on digital elevation maps [11].

L. Pasolli and his team of researchers in 2011 recognized that the knowledge of soil moisture from remote sensing sensors was one of the most challenging problems among biophysical parameters. They pointed to the difficulty of using microwave waves to measure moisture due to the influence of vegetation, especially in the Alps. The presence of vegetation and the heterogeneity of topography significantly affect the microwave signal, which complicates the process of estimating humidity. They conducted a study to demonstrate the accuracy of RADARSAT2 SAR photosensor in estimating soil moisture in the alpine chain. They proposed a technique for estimating soil moisture using a complex algorithm [12].

In 2016, Patrizia Savi and Yan Jia conducted an aerial survey of the remote sensing instrument GNSS-Reflectometry, an effective tool that is key in many applications. This tool was used to estimate the soil moisture or vegetation in the study area. The satellite channel had good results in estimating soil moisture content and was largely independent of biomass for soil cover or vegetation [13].

In 2023, A.N. Amantay et al. reviewed various moisture sensing technologies for real-time estimation of slope collapses brought on by rainfall; they explained standard moisture sensing techniques, such as soil water potential (SWP) and volumetric water content (VWC). SWP is the most common parameter for slope stability and can be measured using tensiometers and resistance blocks (gypsum blocks). However, these devices are expensive and require extensive maintenance. They are also highly affected by salinity, which makes readings from gypsum blocks inaccurate, and sensor life spans are limited in saline environments [14].

In 2020, Samuel N. Araya et al. used multispectral imagery from drones combined with machine learning (e.g., boosted regression trees) to predict surface soil moisture in grasslands. The model achieved a mean absolute error of 3.8% volumetric moisture content. Key variables included red-wavelength reflectance, precipitation, and topographic indices [15].

In 2024, Michelle Stern et al. tested an L-band radiometer system mounted on drones to map soil moisture at a high resolution (3–50 meters) in California's oak woodlands. The method addressed limitations of satellite-based sensing, which often lacks resolution for rugged terrains. The drone-based system successfully improved spatial resolution and provided data useful for wildfire risk assessment and hydrological modeling [16].

In 2025, Junfei Cai et al. introduced a downscaling method to enhance the resolution (1 km) of coarse satellite-derived soil moisture data (e.g., ESA CCI) by integrating MODIS land surface temperature (LST) and NDVI data. The method corrected for topographic effects and showed strong validation against ground measurements (RMSE = 0.103 m^3/m^3) [17].

2. Materials and Methods

Soil samples were taken from the study area, which is located in the Al-Najaf Governorate, near the University of Kufa, at the coordinates (longitude 44.371083 north, latitude 32.028593 east). The soil in this place was sandy clay. **Figure 1** shows the location of the study on the map.

Figure 1. The Study Area: Al-Najaf Governorate, Iraq (from Chat GPT Browser).

The field tools were a camera without any color enhancement and wooden blocks with little absorption. The moisture content was checked in the soil laboratory of the Civil Engineering Department at the University of Kufa.

Field photographs were taken of the change in soil color during rain in areas near the University of Kufa at different times of the year, depending on the occurrence of rain in this region.

The primary method of measuring water content was laboratory analysis using the gravimetric method, which is done by taking a soil sample (from the site) and recording its weight. At the same time, it is wet, so let the weight be (w_1), and then the sample is placed in an oven to dry for 24 hours. The soil is then weighed after drying (w_2), and through the difference of the two weights, the weight of the water is calculated, and thus the moisture content of the soil, as modified below:

$$Water\ Content = (w_1 - w_2)/w_1 \times 100 \quad (1)$$

2.1. Soil Color Change Experiment with Water Saturation

The experiment aims to measure the soil surface's color change when watered with water at different rates, ranging from complete saturation (100%) to dryness (0%). The soil surface is the visible part of the soil, and saturation is related to the water content, depending on how water spreads in the soil, which was studied in the third chapter. This experiment is completed with the following experiment.

The experimental tools and measurement mechanisms:

- A square wooden mold (40 × 40 cm) intended to hold water until the soil absorbs it (**Figure 2**).
- Graduated flask for water.
- A trowel to level the ground and remove obstacles.
- Pure water.
- A precision photographic camera that does not include any color enhancers.

Figure 2. Wooden Mold That Retains Water.

2.2. The Soil Contents

Soil is the fragile or crumbled surface layer covering the Earth's surface. Soil consists of crumbled rocky materials that have previously changed due to exposure to environmental, biological, and chemical factors, including weathering and erosion factors. It is worth noting that soil differs from its essential rock components due to its change in the interaction processes between the ground surface's four covers: the lithosphere, atmosphere, hydrosphere, and biosphere [18].

Soil development has been considered a naturally evolving entity that has developed over a long period due to the combined influence of climate and living organisms on the soil's original material [19].

It is clear that all types of soil share several characteristics, have tertiary systems (solid, liquid, and gas), and can be added to or removed from. However, all types of soil have distinctive characteristics.

Soil has been considered an ecosystem with major biological processes, such as roots, microbes, organic matter, water content, chemical components, dead tree leaves, and current human pollutants. Other basic biological processes, such as transformations of nitrogen, phosphorus, sulfur compounds, and iron compounds, are also considered [20].

The development of soil took place from the carving of the parent rocks in the beginning by weather factors, which accumulated in their place or were moved to other areas by wind, water, gravity, or the combined effect of climate and living organisms. The original rocks' impact appears on each soil's components even if they are moved from their place.

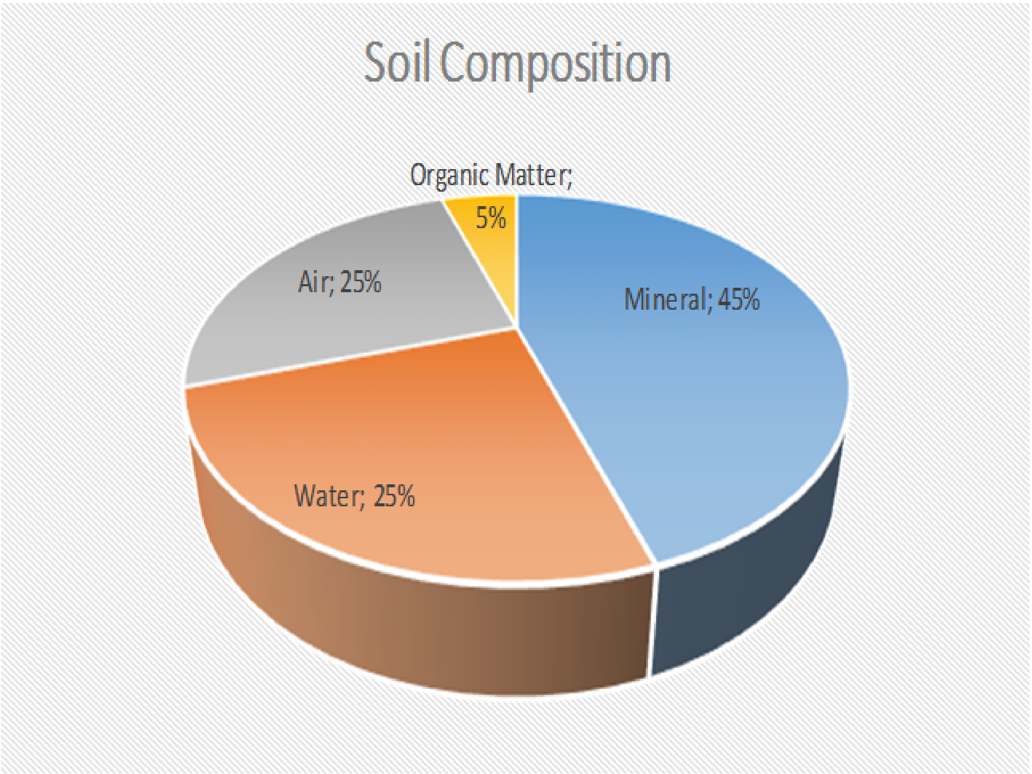

Figure 3. Approximate Diagram Summarizing the Proportions of Soil Components.

2.3. The Color of Soil

Color is one of the physical characteristics of soil and is one of several standard methods used to describe soil. It is our first impression when looking at bare soil. Soil colors and other characteristics, including composition, structure, and consistency, distinguish and identify soil layers. Hence, soil color has been used for years to qualitatively assess many soil components, such as organic matter, iron oxides, and carbonates, in remote sensing and soil science [21].

Image classification and identification from a satellite image depend on knowing the original color of the soil. The color of the soil is one of its physical properties related to the soil's spectral behavior and the interaction of visible light with soil materials. Soil scientists have long used soil color to describe it and its properties, to help classify soil, and to infer its characteristics from satellite images [18].

2.4. Spectral Reflectance of Soil

Knowing the spectral behavior of soil is the key to identifying and characterizing it using remote sensing techniques. The soil reflects all types of solar radiation within the visible range falling on the soil surface, reflecting and absorbing a percentage.

The surface of solid soil consists of irregular particles covered with organic matter and minerals (mostly clay, iron oxides, and calcium carbonate). These determine the soil's spectral reflectivity, which is affected by its physical and chemical properties. The direction of the incident radiation and the direction the sensor looks at also affect reflectivity. The roughness of the soil surface also affects reflectivity, noting the spatial resolution of the image [14].

Soil reflectivity is usually measured in the laboratory through careful observation and recording of the incident rays and the rays reflected from them at different wavelengths. Then, it is expressed by an iterative curve that describes the ratio of the soil's spectral reflectivity or radiative response to the wavelengths of the incident rays.

The spectral response pattern of soil changes with soil composition, environmental conditions, and topography, regardless of sensor power. The spectral response is affected by several factors. They may interfere with each other in a problematic way to calibrate, so it is essential to know all the influencing factors and repeat the experiment to control error rates. Soil consists mainly of minerals (mostly clay and iron oxides, living and decomposed organic matter, and water in its three states: solid, liquid, and gaseous, and these components have a direct or indirect effect on the spectral reflectivity of the soil. In what follows, we will focus on factors directly affecting spectral reflectivity [14].

Soil roughness affects the color response. The lower the roughness of the soil surface, the greater its spectral reflectivity. It has been observed that the reflectance in smooth, dry soil is about 50% greater than the reflectance from soil, which includes some cracks in its surface.

2.5. The Soil Water

Gravity, capillary action, and soil porosity control the water movement within the soil. The water reserve in the soil is affected by several different forces, the strongest of which is the molecular strength of the elements and compounds present on the surface of soil minerals. The water this force holds is called water and consists of water contained within 0.0002 mm of the soil particle surface. The highest extent of this water around soil particles is named the hygroscopicity coefficient. Hydrogenated water is immobile and can only be removed from the soil by heating due to the strong adhesion to the soil particles.

2.6. How Does Water Affect Soil Color

Figure 4 illustrates the different light scatter ways for the soil surface with water content. Water affects soil color in two ways. First, if the soil is saturated with water, it reflects light, making it appear opaque, and the water's color overpowers the soil's color (**Figure 4**). This occurs at high humidity levels that reach saturation (see **Figure 4**(**a**)). The water's surface reflects much light, not toward the camera (**Figure 4**(**b**)). Second, when water interacts with soil components, the color changes without the water's color overpowering the soil's color. The soil scatters incident light rays randomly because the soil's rough surface allows it to be photographed from multiple directions. Shadows may appear between soil particles, resulting in a lack of color response (**Figure 4**(**c**)).

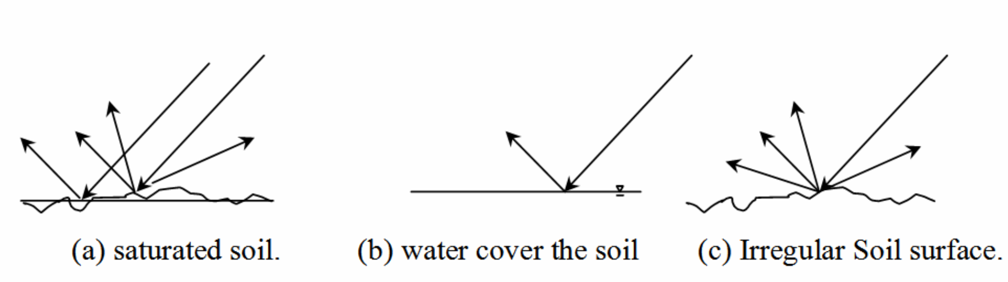

Figure 4. The Effect of Soil Surface on the Color Response. (**a**) Saturated Soil. (**b**) Water Covers the Soil. (**c**) Irregular Soil Surface.

This interference causes a loss in reflected rays because water is taken from the soil's surface. Depending on the water-to-soil ratio, the total rays reflected from the wet spot will be the sum of the two spectral responses.

2.7. Moisture Retention Time in the Soil

Weather factors play a role in reducing some types of moisture present in the soil. Several places on the ground surface were photographed at varying periods after rain fell and the soil was saturated (**Figure 5**). These images enable future or past predictions of water content (Extrapolation) or during the period (**Figure 5** (**a**)–(**d**)). It was not observed between the two recorded periods (interpolation) after comparing them with the soil color difference plots varying from water contents.

Figure 5(**d**) clearly shows that the soil in the study area has dried out after three days of rain in a clear atmosphere with normal humidity, and the soil's color has changed.

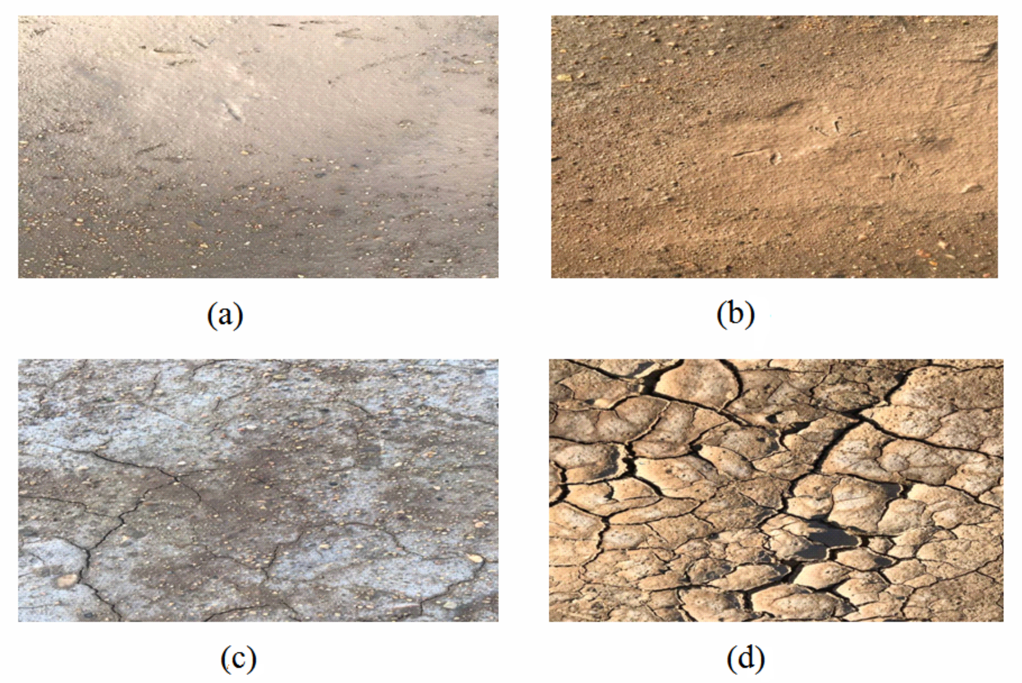

Figure 5. The Change of the Soil Surface with Time. (**a**) Pictures of Ground Wet with Rain Water in the First Hours After the Rain Stopped, (**b**) Picture After a Day of Rain, (**c**) After Two Days of Rain, (**d**) After Three Days of Rain.

3. The Procedure of the Work and Results

The work took the following steps:

Choose a suitable place for the experiment. The place must be level so that shadows do not affect its accuracy.

Take an initial photo of the dry land.

Wet the edges of the mold to reduce water losses due to water absorption from the mold.

Place the mold on the ground to be studied and pour water until the soil is completely saturated. Record the amount of water required to make the saturation rate 100%, then measure the amount of that water (630 milliliters). Our method for achieving 100% saturation was to slowly flood the soil in the mold with water until it stopped absorbing water.

After saturating the soil, a photo of its surface was taken.

Place the mold in another nearby place and reduce the percentage of water by 10%. (567 milliliters) were placed, and a picture was taken after the soil had been saturated. Thus, the rate of water added was reduced (10%) until it reached 63 milliliters.

Analyzing the color components of images according to saturation ratios and creating a chart. **Figure 6** describes the sequence of the study:

3.1. Pictures Taken to the Ground Surface in the Site

The images in **Figure 7** represent the soil surface with different moisture contents (**Figure 7**(**a**)–(**k**)).

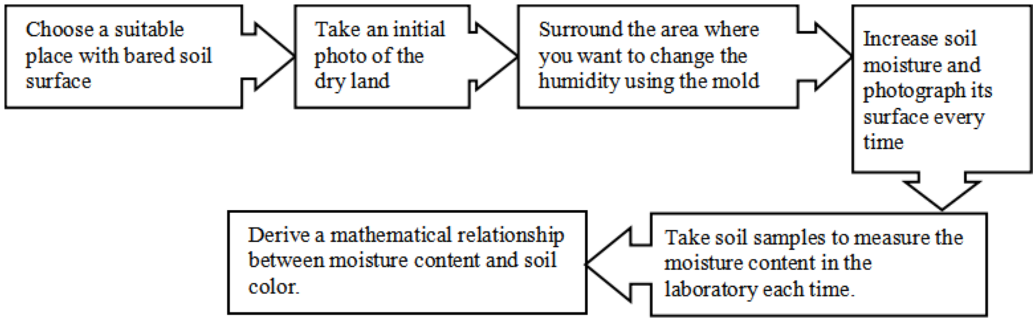

Figure 6. The Study Sequence.

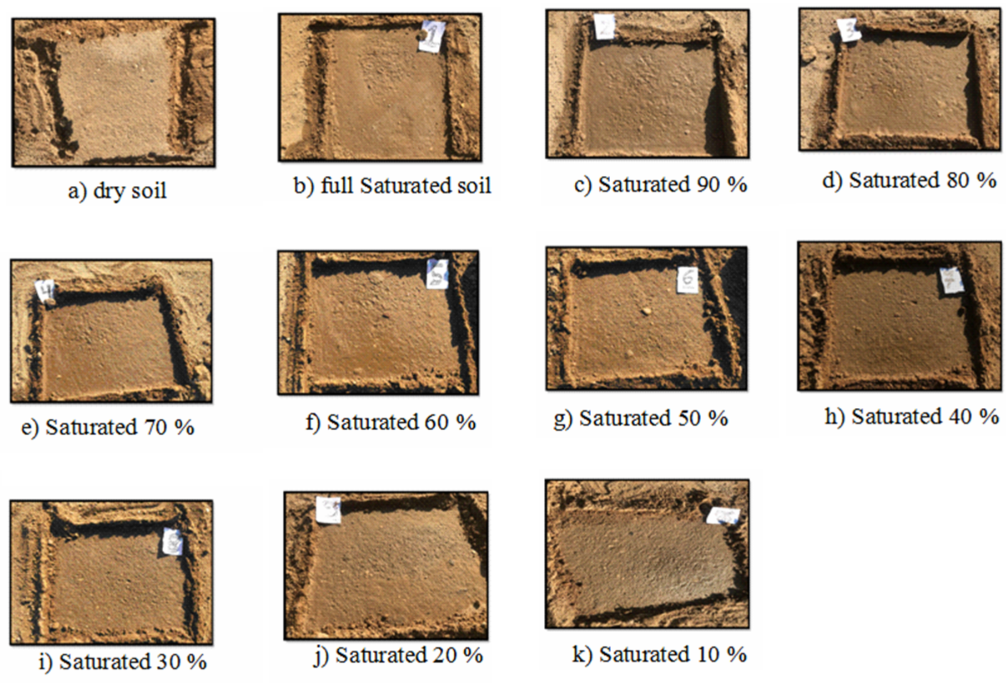

Figure 7. Images of the Surface of Soil with Different Moisture Contents. (**a**) Dry soil, (**b**) Fully saturated soil, (**c**) Saturated 90%, (**d**) Saturated 80%, (**e**) Saturated 70%, (**f**) Saturated 60%, (**g**) Saturated 50%, (**h**) Saturated 40%, (**i**) Saturated 30%, (**j**) Saturated 20%, (**k**) Saturated 10%.

After the fieldwork, we worked on the computer to select several pixels in a flat image area that represents the soil's surface and does not include shadows. We read each color component (red, green, and blue).

After that, we converted our calculations to an Excel chart, as shown below (see **Figure 8**). Using the trend line tool, we developed new equations to show the color and moisture content relation.

The relationship in **Figure 8** is not strictly linear, but for speed and brevity, we represented it with a first-degree equation with a reasonable accuracy factor.

$$Red = -39.5x + 200.7, R^2 : 0.99 \quad (2)$$

$$Green = -34.6x + 156, R^2 : 0.98 \quad (3)$$

$$Blue = -35.7x + 116, R^2 : 0.99 \quad (4)$$

The data can be re-represented according to the spectral response percentages and develop new equations:

$$Red = -15.2s + 78, R^2 : 0.99 \quad (5)$$

$$Green = -13.5s + 60.6, R^2 : 0.98 \quad (6)$$

$$Blue = -13.9s + 45, R^2 : 0.99 \quad (7)$$

Where s: Saturation percent.

The R^2 is a statistical factor representing the proportion of variance explained by an independent variable in the regression model.

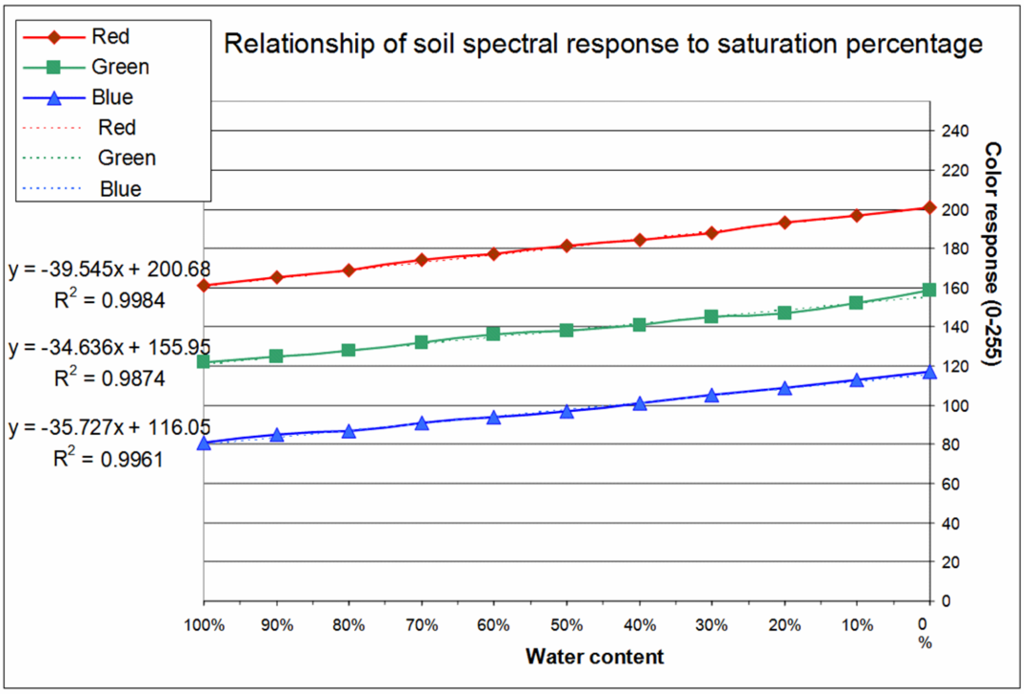

Figure 8. The Three Compounds' Relationship to the Soil's Saturation Percentage.

3.2. Measurement of Soil Water Content

After photographing the areas irrigated with water in the previous experiment, soil samples were taken to the laboratory to calculate the water content and convert the spectral response change relationship from the percentage of saturation to the percentage of water content according to Eq. (1).

Table 1 brings together the results of the previous experiment and the current experiment:

Table 1. Results of the Two Experiments Linking the Saturation Percentage, the Moisture Percentage, and the Spectral Response of the Soil.

% Saturation	Red	Green	Blue	% Red	% Green	% Blue	Water Content %
0%	201	159	117	78	62	45	0.6
10%	197	152	113	77	59	44	3.3
20%	193	147	109	75	57	42	5.7
30%	188	145	105	73	56	41	8.5
40%	184	141	101	72	55	39	11.2
50%	181	138	97	70	54	38	13.9
60%	177	136	94	69	53	36	16.5
70%	174	132	91	68	51	35	18.7
80%	169	128	87	66	50	34	21.7
90%	165	125	85	64	49	33	24.1
100%	161	122	81	63	47	31	29.5

The equations were applied to images of the soil in **Figure 7(a)–(k)** to test their accuracy.

The computer measured the percentage of color compounds for red (67.85%), green (66.3%), and blue (56.5%).

From equations (5) to (7), we have three percentages of water content (18.6% of red color), (11.4% of green color), and (22.7% of blue color).

After taking samples from that soil to measure the moisture percentage in the laboratory, it was found to be 17.6%, the same as before, which is close to the calculated rate of red color. However, the result of the equation extracted from the green compound appears unnatural, perhaps due to the presence of phytoplankton in the soil with a green color. Also, the blue color equation seems less accurate.

Therefore, the equation extracted from the red color will be adopted more than the other two.

When comparing the laboratory result with the equation, it becomes clear that the error rate = 17.6/18.6 = 94.6%.

Applying the equation to the image in **Figure 5** shows that the humidity percentage decreased one day after the rain and the cessation of weather factors, reaching 14.5% in the laboratory measurement and 15.1% according to the red component equation, with an error rate of 96%.

After two days, the humidity decreased further to 12.6% in the laboratory and 13.0% according to the red component equation, with an error rate of 97%.

After three days, the humidity dropped to 10.7% in the laboratory and 12.1% based on the equation, with an error rate of 88.4%.

The varying error percentage is expected to result from the non-homogeneity of the moisture distribution between the soil surface and its interior, the difficulty of selecting pixels in the image representing the total color response, and other technical difficulties.

3.3. Applying Equations to the Satellite Image and Deriving New Equations

The previous relationship represents the color response of the ground image, and the color response does not reach the satellite sensors as it is. There is a loss rate of (45%) for the red component, (52%) for the green component, and (54% for the blue component)[22]; this means that the color response will decrease between the satellite image and the ground image[23]. The results will be as follows for the satellite image (**Table 2**):

Table 2. The Relationship Between Water Content and the Color Response Recorded from the Satellite.

Water Content %	Sat-Red	Sat-Green	Sat-Blue
0.6	35.1	27.9	20.25
3.3	34.65	26.55	19.8
5.7	33.75	25.65	18.9
8.5	32.85	25.2	18.45
11.2	32.4	24.75	17.55
13.9	31.5	24.3	17.1
16.5	31.05	23.85	16.2
18.7	30.6	22.95	15.75
21.7	29.7	22.5	15.3
24.1	28.8	22.05	14.85
29.5	28.35	21.15	13.95

Using the Trendline technique in MS Excel, we can extract the following equations:

$$Red - Sat = -0.2477w + 35.165, R^2 : 0.99\% \quad (8)$$

$$Green - Sat = -0.2198w + 27.33, R^2 : 0.98\% \quad (9)$$

$$Blue - Sat = -0.2271w + 20.274, R^2 : 0.99\% \quad (10)$$

Where:

Red, Green, Blue-Sat: the response percent from a satellite image.

w: water content.

A satellite image of the area was used to test these equations, which appear in the ArcView interface below (**Figure 9**).

The ArcMap program enables you to look at each component individually, and it can isolate the three bands in the image, which represent red, green, and blue[24, 25].

Although the satellite image is old, the surface or nature of the soil has remained unchanged since it was taken.

We will take color samples in the satellite image and measure their values using Adobe Photoshop from areas close to the study area, so we can obtain an average value for the red component and apply the previous equations to it:

Red component 31.45%, green 23.2%, blue 16.3%.

To calculate the percentage of humidity from each, we obtain three results: 15% of the equation for the red compound.

18.8% of the equation of the green component and 17.5% of the equation of the blue component are close percentages.

We cannot know the humidity percentage from when the satellite image was taken. Still, it is close to the humidity percentage measured (17.6%) on the date of our experiment (11/28/2018) in terms of the rainy season.

3.4. Design Software to Calculate the Moisture Content from the Image

All the previous equations can be converted into algorithms (**Figure 10**). Still, the most challenging problem that previous researchers could not overcome was determining the color of the soil, especially when photographing close-ups, due to the heterogeneity of the soil color and the effect of shadows. We propose a new method to calculate soil color: the Maximum value obtained from the image of the soil surface (**Figure 10**).

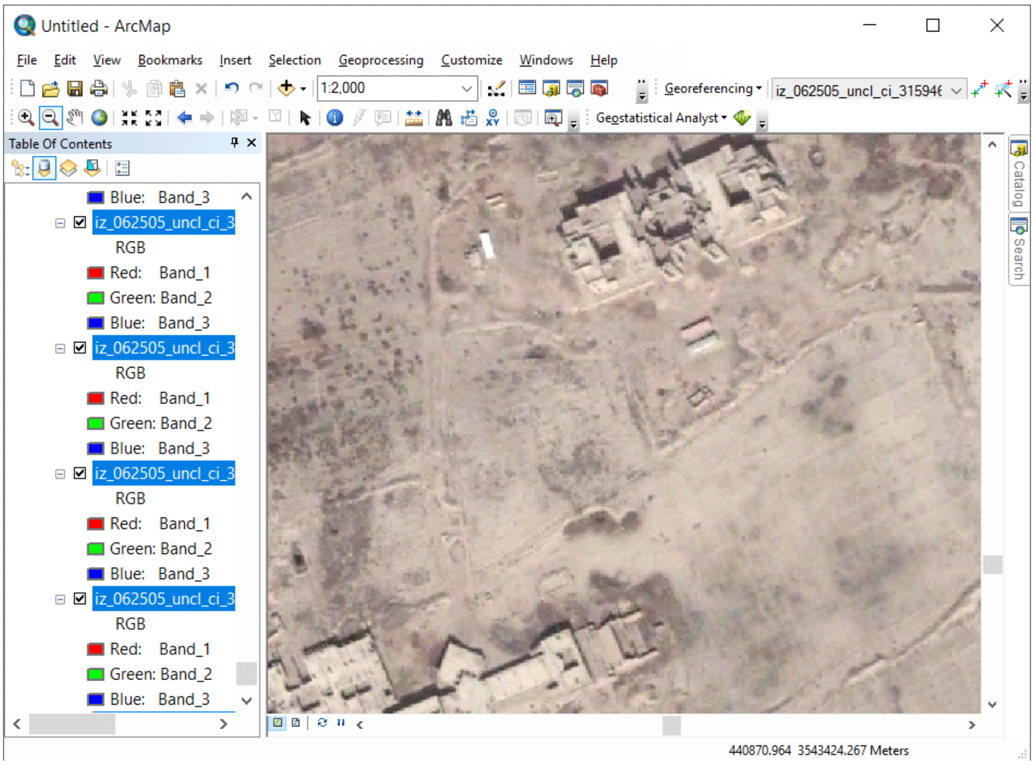

Figure 9. Dealing with the Satellite Image of the QuickBird Satellite Via the ArcMap 10.2 Program.

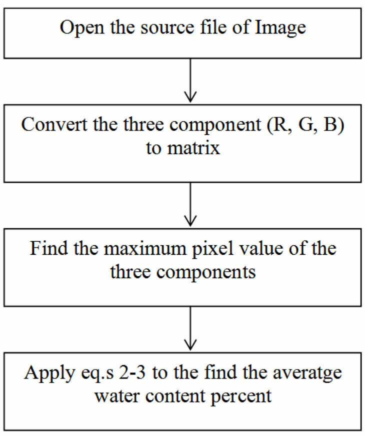

Figure 10. A Diagram for the Algorithm to Calculate the Soil Water Content from a Color Image.

4. Discussions and Recommendations

Through theoretical preparation, fieldwork, and laboratory measurements, we have revealed several significant results:

We can use the change in soil color to measure the moisture content of the soil.

We can use ground and satellite images to analyze the color response and deduce their moisture content.

We obtained several equations in the previous chapter that can be adopted with high accuracy.

The relationship between moisture content and color change is first-order linear or semi-linear, which means that it depends on one element in a simple and not complex manner.

Compared to the Martin Wijaya et al. method (2024) for estimating the moisture content measurement and the A. M. Daramola's method (2024) [2, 3], our method outperforms the previous two methods in terms of speed and practical feasibility, especially in conditions of natural disasters or in which soil collapse is expected.

In order to develop the work to be broader and more complete, we present these recommendations:

Due to their surface roughness, selecting samples of image pixels, especially the ground image, is complex.

There is a slight discrepancy between the percentage of water saturation and the water content of the soil that needs to be adjusted due to the non-homogeneity of the spread of water from the surface to all parts of the soil. Therefore, the error percentage in the measured water content increases due to the change in color of the soil surface, and the more samples we take from the soil and test them, the higher the error percentage. Still, it is. Do not go too far; later experiments can be conducted to control this change.

Soil undergoes many changes and influences, such as the influence of weather factors, chemical reactions, and molecular composition.

5. Conclusions

The estimate of soil moisture from its color depends on a linear relationship, but the difficulty was finding the color of the soil surface with uneven color and shadow effects. The method of maximum color succeeded in avoiding the shadow effect, but our experiment was conducted on a specific type of soil: sandy-clay soil.

For future work, we recommend:

I. Our experiment was on a specific type of soil, which was sandy-clay soil. To expand the results, future studies could repeat the same work on other types of soil and survey more expansive areas.
II. More experiments and samples can be performed to control for anomalies, especially with a complex compound such as soil.
III. The research idea can be expanded to include other terrestrial phenomena, such as vegetation, noting the differences.
IV. Measuring the effect of weather factors on soil color to consider it in satellite image classification.
V. A statistical filter can be designed to extract a result that represents the sum of the colors of the image pixels instead of the manual average calculations we perform.
VI. We recommend applying this method to multiple types of satellite images.

Author Contributions

All researchers participated in various works and contributed to all parts of the research.. All authors have read and agreed to the published version of the manuscript.

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

No new data were created.

Acknowledgments

The Soil Laboratory in the Department of Civil Engineering at the College of Engineering at the University of Kufa undertook and supported this research and experiments. We wish to thank all department and laboratory members and technicians for cooperating with us in the experiments.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Miyazaki, T., 2006. Water Flow in Soil, 2nd ed. CRC Press: Boca Raton, FL, USA.
[2] Wijaya, M., Lim, A., Rahardjo, P.P., et al., 2024. Determination of soil-water characteristic curves by using a polymer tensiometer. Journal of the Mechanical Behavior of Materials. 33(1), 20240007. DOI: https://doi.org/10.1515/jmbm-2024-0007
[3] Daramola, A.M., Satyanaga, A., Adejumo, B.D., et al., 2025. Real-Time Scanning Curve of Soil-Water Characteristic Curve for Sustainability of Residual Soil Slopes. Sustainability. 17(5), 1803. DOI: https://doi.org/10.3390/su17051803
[4] Orazayeva, S., Satyanaga, A., Kim, Y., et al., 2024. Advanced scanning technology for volume change measurement of residual soil. Applied Sciences. 14, 10938. DOI: https://doi.org/10.3390/app142310938
[5] Prakoso, W.A., Hamdany, A.H., Wijaya, M., et al., 2024. Measurement of Soil-Water Characteristic Curve of Vegetative Soil Using Polymer-Based Tensiometer for Maintaining Environmental Sustainability. Sustainability. 17(1), 218-232. DOI: https://doi.org/10.3390/su17010218
[6] Jackson, T.J., Le Vine, D.M., Swift, C.T., et al., 1995. Large Area Mapping of Soil Moisture Using the ESTAR Passive Microwave Radiometer in Washita'92. Remote Sensing and Environment. 54(1), 27-37. DOI: https://doi.org/10.1016/0034-4257(95)00084-E

[7] Makkeasorn, A., Chang, N.B., Beaman, M., et al., 2006. Soil moisture estimation in a semiarid watershed using RADARSAT-1 satellite imagery and genetic programming. IEEE Transactions on Geoscience and Remote Sensing. Water Resources Research. 42(9). DOI: https://doi.org/10.1029/2005WR004033

[8] Haubrock, S.N., Chabrillat, S., Kuhnert, M., et al., 2008. Surface soil moisture quantification and validation based on hyperspectral data and field measurements. Journal of Applied Remote Sensing. 2(1), 023552. DOI: https://doi.org/10.1117/1.3059191

[9] Ormeci, C., Ekercin, S., 2008. Use Of Real-Time Remote Sensing Data For Evaluating Soil Moisture And Salinity Effects On Light Penetration Depth. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. XXXVII(B2), 167-174.

[10] Hendrickx, J.M., Harrison, B.J., Borchers, B., et al., 2010. High-Resolution Soil Moisture Mapping Using Operational Optical Satellite Imagery. Proceedings of the SPIE Defense, Security, and Sensing 2010 (SPIE Vol. 7664); 5-9 April, 2010; Orlando, Florida, USA. pp. 1-14. DOI: https://doi.org/10.1117/12.856462

[11] Haas, J., 2010. Soil moisture modeling using TWI and satellite imagery in the Stockholm region [Master's Thesis]. Royal Institute of Technology: Stockholm, Sweden.

[12] Pasolli, L., Notarnicola, C., Bruzzone, L., et al., 2011. Estimation of Soil Moisture in an Alpine Catchment with RADARSAT2 Images. Applied and Environmental Soil Science. 2011(1), 175473. DOI: https://doi.org/10.1155/2011/175473

[13] Jia, Y., Savi, P., 2017. Sensing soil moisture and vegetation using GNSS-R polarimetric Measurement. Advances in Space Research. 59(3), 858-869. DOI: https://doi.org/10.1016/j.asr.2016.11.028

[14] Amantay, A.N., Satyanaga, A., Moon, S.W., 2023. Moisture sensing technology for assessment of rainfall-induced slope failure. In: Zhussupbekov, A., Sarsembayeva, A., Kaliakin, V.N. (eds.). Smart Geotechnics for Smart Societies. CRC Press: Boca Raton, FL, USA. pp. 2042-2048. DOI: https://doi.org/10.1201/9781003299127-312

[15] Araya, S.N., Fryjoff-Hung, A., Anderson, A., et al., 2020. Advances in soil moisture retrieval from multispectral remote sensing using unmanned aircraft systems and machine learning techniques. Hydrology and Earth System Sciences Discussions. 25(5), 2739-2758. DOI: https://doi.org/10.5194/hess-25-2739-2021

[16] Stern, M., Ferrell, R., Flint, L., et al., 2024. Fine-scale surficial soil moisture mapping using UAS-based L-band remote sensing in a mixed oak-grassland landscape. Frontiers in Remote Sensing. 5, 1337953. DOI: https://doi.org/10.3389/frsen.2024.1337953

[17] Cai, J., Zhao, W., Ding, T., et al., 2025. Generation of High-Resolution Surface Soil Moisture over Mountain Areas by Spatially Downscaling Remote Sensing Products Based on Land Surface Temperature-Vegetation Index Feature Space. Journal of Remote Sensing. 5, 0437. DOI: https://doi.org/10.34133/remotesensing.0437

[18] Dwivedi, R.S., 2017. Remote Sensing of Soil. Springer: Berlin, Germany.

[19] Briaud, J.L., 2013. Geotechnical Engineering: Unsaturated and Saturated Soils. John Wiley & Sons: Hoboken, NJ, USA.

[20] Diestel, H., 1993. Saturated Flow and Soil Structure. Springer-Verlag: Berlin, Germany.

[21] Carranza, E.J.M., 2009. Geochemical Anomaly and Mineral Prospectivity Mapping. Elsevier: Amsterdam, Netherlands.

[22] Al-Helaly, E.A., 2017. Estimate of Buildings and Targets in Satellite Images Using Shadow Applications [PhD Thesis]. University of Baghdad: Baghdad, Iraq. Available from: website (cited Day Month Year) [unpublished PhD thesis].

[23] Muhsin, I.J., Hamid, A., 2017. Monitoring the Changes of Vegetal Cover of Karbala Province (Iraq) using Target Detection and Classification Techniques. International Journal of Science and Research. 6(7), 1408-1412. DOI: https://doi.org/10.24996/ijs.2017.58.3A.19

[24] Hussein, A.K., Kadhim, N.A., Jaber, A.S., et al., 2020. Landsat-8 Operational Land Imager Change Detection Analysis Using Remote Sensing and GIS Techniques in Al-Manathera District, Najaf, Iraq. Annals of Agri-Bio Research. 25(2), 278-283.

[25] Esri. Working with raster bands in ArcMap. Available from: https://desktop.arcgis.com