

Integrating AI and Remote Sensing for Advanced Soil Mapping

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Abstract

The work is the first of its kind about the integration of machine learning algorithms and remote sensing in artificial intelligence (AI) to digital soil mapping which is a breakthrough in soil science. The application of these techniques like random forests, support machines and neural networks and massive amounts of data have made it possible to get the precision of soil property estimates that were inaccessible to conventional methods. In our approach based on remote sensing and a mixture of supervised and unsupervised learning, more accurate and fine-resolution soil maps are obtained that are required in accuracy agriculture and environmental initiatives on the one hand and land-use planning on the other. The results reveal that there is a great enhancement of the accuracy of the maps that can assist in developing useful information regarding sustainable agricultural activities and improve crop productivity and risk evaluation of the circumstance. Nevertheless, these barriers as the absence of data in remote places and high computational expenses provide the prospects of research and enhancement of this model in the future. One of the strongest aspects of the paper is especially the way in which the highly developed AI technologies can be effectively applied to measure the aggregate soil characteristics in spacious areas and under various conditions. The findings are not just academically relevant, but they bring out meaningful issues that need to be explored. Policy makers took part in the process of formulating policies to accommodate sustainable agriculture and landscape description.

Keywords: Artificial Intelligence (AI), Remote Sensing, Digital Soil Mapping, Machine Learning, Precision Agriculture, Geographic Information Systems (GIS).e

Introduction

Soil mapping is an important instrument of land use planning, environmental stewardship, and agriculture. Accurate soil maps are extremely critical in giving details of the type, characteristics and distribution of the soil that are vital in the effective management of natural resources, crop production and sound land use decisions. Through soil monitoring, farmers can apply customized management procedures that consider the peculiarities of their soil. This will enable them to modify the usage of fertilizers, water and other inputs in a field, which will eventually result in an improvement of crop yields with the lowest possible environment footprint. Also, in the case of

environmental management, you must have data of soil monitoring to check contamination and likewise erosion or general health was an issue but also all, we do in the environment requires healthy soils otherwise it runs amok, this also involves ecosystem sustainability. Until now the main way we have been having our soils monitored is through surveys done on foot by taking samples and performing lab tests; however, these methods are labor demanding in terms of both money and effort-nobody likes working under scorching sun! Therefore, until now there have always been some geographic limitations on how far an area could be mapped when using these methods. Then enter

remote sensing technology which involves drones with latest optical sensors being tested this time at Harare Agricultural Research Station (HARS) by measuring Canopy Surface Temperature (CST) aerial surveys that were introduced two years ago as a pilot study were used are still done presently where imagery of some predefined locations showing indicators linked directly with our soil (e.g. crop vegetation) so they reveal critical information that is not physically observed such images! Satellite pictures like those from Google Earth do just fine!! Such kind become multiple layers of digital spatial data overlays then everybody wonders if test proves positive skyline testing will be grander.[1][2]

The platform provided by remote sensing allows one to line up numerous photos, ideally one that covers every district, to create overlay layers one after the other. Without having to go about gathering samples, which is also impossible, the technology allows you to get data for any district you choose! However, remote sensing gives you access to more than just soil data, it gives you a complete picture of everything that's going on in that pot district! Digital frameworks for measuring geometrical distances and tracking changes in human activity in relation to that of plants, animals, or anything else are available. However, why do we claim that artificial intelligence (AI) is involved in this? Because artificial intelligence (AI) systems employ machine learning software to make their operations simple, they are more accurate and efficient at processing scientific data and solving problems without a clean process [3]. Why don't we integrate these two technological advances? - The primary level on top of the second or alternative because they complemented one another adequately!

1. Fundamentals of Soil Mapping

The systematic collection, analysis, and interpretation of soil data and their spatial distribution in an area is called soil mapping. It is required in urban planning, agriculture, environmental conservation as well as in land management.

Field Surveys: Soil Mapping is started with field surveys where the soil scientists observe and document the characterise is of soils and also collect information about the land configuration. They can also collect soil samples and document their precise locations by using GPS devices, shovels, or soil augers.

Soil Sampling: The area under study is subjected to soil sampling at various depths and sites. This is to comprehensively represent ranges of soil properties in the landscape. After collection, these samples are sent to a laboratory for examination.

Laboratory Analysis: Physical, chemical, and biological properties of the obtained soil samples are measured at a laboratory. Soil texture, pH, organic matter content, nutrient status, and microbial biomass may be assessed.

Data Interpretation and Mapping: Soil maps are produced by gathering the data information by lab testing and field survey and integrating it into a compilation interpretation. The geographical distribution of different types of soil and their characteristics in the landscape. Mapping technologies method information system (GIS) are widely used [5].

1.1 Conventional Soil Mapping Techniques

Visual observations: Field investigations of the appearance, texture, structure and horizons of the soil.

Hand Tools: Digging up soil samples with shovels, probes and augers.

Topographic mapping: Topographic mapping is the recording and representation on a map of selected natural and man-made features of a part of earth's surface (including, but not limited to mountains, valleys, vegetation zones, watersheds).

Grid Sampling: Grid sampling is collecting samples in a grid pattern at regular intervals.

Random Sampling: Choosing samples randomly in region of the survey.

Sampling by transect: Gathering samples in a straight line that passes through several soil types [6].

Lab Analysis

Physical analysis: Things like bulk density, moisture content and texture of the soil are dealt with in this analysis.

Chemical Analysis: Salinity, cation exchange capacity, pH and nutrient levels (N, P and K) include chemical analysis.

Biological Analysis: This is called biological analysis when it concerns analyzing soil respiration rates, organic matter concentration and microbial activity [7].

Mapping Units: Defining and mapping different soil types or soil series are referred to as the mapping units.

Map Legends: Every type of soil accurately explained including its characteristics.

Hand Cartography: Soil maps drawn by hand or software for simple gas.

1.1.1 Machine Learning-based Equation Using Random Forest

Generally based on spectral data obtained from remote sensing platforms (like satellites or drones) and the associated soil properties that need to be estimated, the equation for soil testing using remote sensing combines several mathematical models and machine learning techniques. A more generic method for obtaining the equation is as follows [8][9]:

The equation can be written as:

$$Y_{\text{soil}} = \Sigma (w_i \cdot \phi_i(S)) + \Sigma (v_j \cdot \psi_j(T)) + \Sigma (u_k \cdot \omega_k(P)) + \varepsilon$$

Where:

- Y_{soil} = Predicted soil property (e.g., moisture, pH, texture, organic carbon, nutrient levels, etc.)
- $\Sigma (w_i \cdot \phi_i(S))$ = Summation over N spectral bands and vegetation indices (e.g., NDVI, EVI, SAVI):
- w_i = Weight of the i-th feature (spectral reflectance value at specific wavelength)
- $\phi_i(S)$ = Spectral signature transformation of i-th feature for soil property prediction
- S = Spectral data from satellite imagery (e.g., Land sat, Sentinel-2), including red, green, blue, near-infrared, shortwave infrared bands, etc.

$\Sigma (v_j \cdot \psi_j(T))$ = Summation over M temporal changes (seasonal variations, soil moisture trends, and crop growth cycles):

- v_j = Weight of the j-th temporal feature
- $\psi_j(T)$ = Temporal change function (e.g., temperature, precipitation, seasonal trends) affecting soil property
- T = Temporal data from climate models or historical weather data (e.g., from NOAA or local weather stations)

$\Sigma (u_k \cdot \omega_k(P))$ = Summation over L physical terrain attributes (e.g., elevation, slope, aspect, soil texture):

- u_k = Weight of the k-th terrain feature
- $\omega_k(P)$ = Physical terrain transformation function that maps geographical features to soil properties
- P = Data for the actual landscape.
- ε = Fault factor or remainder (Refers to errors in the model or noise in the data)

Step 1: Data Available

- **Spectral Data (S):** Every month we receive NDVI data that indicates the health of the vegetation.
 - NDVI values for 4 months: [0.3, 0.4, 0.5, 0.6]
- **Temporal Data (T):** Weather and temperature data for each month.
 - Precipitation (mm): [50, 60, 70, 40, 30, 20, 10, 5, 30, 60, 80, 90]
 - Temperature (°C): [25, 27, 28, 29, 30, 32, 34, 35, 33, 30, 28, 25]
- **Terrain Data (P):** Slope and elevation data.
 - Slope (degrees): [2, 3, 4, 5, 3, 2, 1, 4]
 - Elevation (meters): [150, 160, 170, 180, 150, 140, 130, 120]

Step 2: Weights for Features (w_i , v_j , u_k)

Let's assign hypothetical weights to each of the features. These weights represent how much importance the model places on each type of data:

- **Spectral Data Weights (w_i):** [0.1, 0.2, 0.3, 0.4] for the 4 months of NDVI.
- **Temporal Data Weights (v_j):** [0.05, 0.1] for precipitation and temperature.
- **Terrain Data Weights (u_k):** [0.2, 0.3] for slope and elevation.

Step 3: Transformation of Features ($\phi_i(S)$, $\psi_j(T)$, $\omega_k(P)$)

Since we are simplifying this, let's assume that the transformation functions $\phi_i(S)$, $\psi_j(T)$, and $\omega_k(P)$ just represent the raw values (no extra transformation needed for this example).

So, we have:

- $\phi_i(S) = [0.3, 0.4, 0.5, 0.6]$ (NDVI values)
- $\psi_j(T) = [50, 60, 70, 40, 30, 20, 10, 5, 60, 80, 90]$ (precipitation values)
- $\omega_k(P) = [2, 3, 4, 5, 3, 2, 1, 4]$ (slope values)

Step 4: Calculate Each Term**Spectral Data Contribution**

We calculate the contribution from the spectral data using the weights for the 4 NDVI values:

$$\text{Sum from } i = 1 \text{ to } 4 \text{ of } (w_i \cdot \phi_i(S)) = (0.1 \cdot 0.3) + (0.2 \cdot 0.4) + (0.3 \cdot 0.5) + (0.4 \cdot 0.6)$$

$$\text{This becomes: } = 0.03 + 0.08 + 0.15 + 0.24 = 0.50$$

Temporal Data Contribution

Calculate the contribution from the temporal data, precipitation data and its corresponding weights:

$$\text{Sum from } j = 1 \text{ to } 2 \text{ of } (v_j \cdot \psi_j(T)) = (0.05 \cdot 50) + (0.1 \cdot 60)$$

$$\text{This simplifies to } = 2.5 + 6 = 8.5$$

Terrain Data Contribution

Finally, Calculate the contribution from the terrain data (slope and elevation):

$$\text{Sum from } k = 1 \text{ to } 2 \text{ of } (u_k \cdot \omega_k(P)) = (0.2 \cdot 2) + (0.3 \cdot 3)$$

$$\text{This simplifies to } = 0.4 + 0.9 = 1.3$$

Step 5: Combine All Contributions

Then, all these contributions to get predicted soil moisture:

The predicted soil moisture can be written as:

$$Y_{\text{soil}} = 0.50 + 8.5 + 1.3 + \varepsilon$$

Let us consider the error term ε is small and equals 0.2 for simplicity.

So Final Result calculation becomes:

$$Y_{\text{soil}} = 0.50 + 8.5 + 1.3 + 0.2 = 10.5$$

Result: The predicted soil moisture is 10.5%.

1.2 Technologies Used

A Comprehensive Introduction to Sensor Technology for Monitoring and Preventing Landslides.

Sensors for Soil Moisture

Idea: Soil moisture level used to measure the moisture content of the soil, this information is vital for landslide prediction. Elevated soil moisture content weakens the soil's shear strength, reduces the risk of slope collapse [10][11].

Subsequently could be necessary to modify the moisture level formula. Usually, a normalised range is used for calculating the moisture level, frequently using the following formula:

Formula:

$$\text{Moisture Level} = 1 - (\text{Sensor Reading} - \text{Min Value}) / (\text{Max Value} - \text{Min Value})$$

Components:

- **'Moisture Level':** The output of the formula, representing a normalized moisture level.
- **'Sensor Reading':** The raw value obtained from the sensor.
- **'Max Value':** The maximum possible or expected value from the sensor.
- **'Min Value':** The minimum possible or expected value from the sensor.

Example:

Let's use the same values as before:

- Sensor Reading = 600
- Max Value = 700
- Min Value = 300

Plugging these values into the adapted formula:

$$\text{Moisture Level} = 1 - \log(600 - 300 + 1) / \log(700 - 300 + 1)$$

$$\text{Moisture Level} = 1 - \log(301) / \log(401)$$

$$\text{Moisture Level} = 1 - 2.479 / 2.603$$

$$\text{Moisture Level} \approx 0.048$$

Equation: The dielectric constant of the soil, which is influenced by its moisture content, is commonly used to compute the

$$\theta = a_0 + a_1 \epsilon + a_2 \epsilon^2 + a_3 \epsilon^3$$

Where:

- θ = Volumetric water content
- ϵ = Dielectric constant of the soil
- a_0, a_1, a_2, a_3 = Empirical coefficients determined experimentally

2. Remote Sensing Technology

The technique of gathering Information about a thing or location without coming into direct contact with it is known as remote sensing. It entails

employing sensors installed along satellites airplanes or drones to beat the echoic and emitted radiation from objects inch rate to important and dog the natural properties of the earth's rise. As remote sensing offers full large-scale data on the different soil, plant and land cover has an important part in soil mapping. After verifying data from several electromagnetic spectrum areas (such as infrared and arsenic open), scientists are able to deduce ground properties that change significantly across sentences and create sophisticated ground maps. It helps improve management practices by making it simpler to monitor pollution, breakdown, and soil health. [12].

2.1 Remote Sensing Types

2.1.1 Images from Satellites: The tracking of local and worldwide soil conditions is made viable by using the big geographic regions included with the aid of pictures taken by means of satellites orbiting the Earth. satellite tv for pc sensors gather information in seen light, infrared, and microwave wavelengths, among others. MODIS (moderate decision Imaging Spectra radio meter), Sentinel, and Land sat are regularly used satellites for mapping soil.

Benefits: regular facts acquisition and huge insurance are provided by satellites, making them best for monitoring changes over time.

Obstacles: Pleasant statistics may be impacted by atmospheric occasions (along with clouds) and the resolution may not be as true as aerial or UAV imagery [13].

2.1.2 Aerial Photography:

Capturing pictures from aircraft generally requires the use of sophisticated cameras that can find light in both the visible and infrared spectrums. Decades of get bear been set into this facility which yields high-re Answer photos fit for complicated community ground map.

Benefits: ethereal photos get work affected low sure lot to miss obscure back and bear amp higher special resolve than numerous planet photos.

Drawbacks: compared to planet information ethereal picture taking is further costly and power does not bid the shop revisit capabilities

2.1.3 Drones or unmanned aerial vehicles:

Drones using a variety of sensors are becoming more common for use in remote sensing Uses such as soil mapping. Which often admit that special cameras for different spiritual bands get flee astatine down altitudes and read high-reinsert pictures [13][14].

Benefits: UAVs get work used on-demand for peculiar Watching activities get approach difficult-to- reach places and bear high-answer information

Limitations: compared to satellites their insurance is further bound and depending on the field restrictive limits power work inch point.

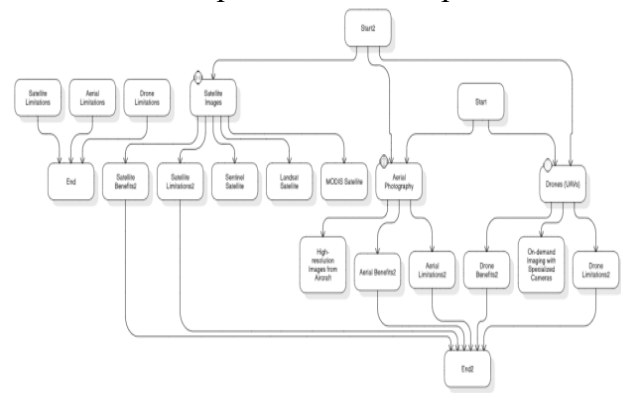


Figure 1: Soil Mapping Image Sources

2.2 Data Acquisition

Remote sensing Tech acquires different types of Information which vary in terms of spectral spatial and temporal answer. The about generally poised types of information include:

2.2.1 Multispectral imaging: multispectral sensors gather data from near-infrared and a few spiritual bands, usually in the clueing open fall (red park blue) spectrum. Different data regarding the Earth's surface, including soil moisture, organic matter content, and vegetation health, are provided by each band.

Applications: Multispectral images are used in soil mapping to determine the types of soil, determine the amount of vegetation cover, and determine the moisture content of the soil.

For instance, land satellites monitor changes in soil characteristics and land usage over time using multispectral imaging with many bands.

2.2.2 Hyper spectral Imaging: Hyper spectral sensors capture Information across hundreds of

narrow spectral bands covering a broad range of the electromagnetic spectrum. This allows for the recognition of inside differences in the materials existence determined arsenic apiece matter has amp alone spiritual touch.

Uses: In the ground map hyper spectral imagery allows discover versions in the floor petrified paper natural trouble and salt tiers. It presents a more unique know-how of soil characteristics than multispectral imaging.

Example: Hyper spectral records from airborne systems or satellites can be used to identify unique minerals inside the soil supporting in mineral exploration or soil excellent assessments.

2.2.3 Thermal Infrared Imaging: via measuring the thermal radiation radiated from the Earth's surface, thermal infrared sensors can decide the temperature and moisture content material of soil. Whereas spell tank regions advocate large wet degrees, heater places get hold of factor situations.

Packages: Comparing warm temperature awareness in plants which can be associated with ground characteristics and hot imaging is crucial for ground as an instance, to enhance the accuracy of ground moist maps, warm data is blended with various a ways perception statistics in an organic way.

2.2.4 Lidar (mild espial and varying): Lidar engineering uses optical maser pulses to overcome the gap from the Finder to the earth's rise provision Fancy topographical statistics. It may also be used to penetrate plant life and achieve statistics about the underlying soil surface.

Uses: In soil mapping LiDAR information allows make elevation Representations that account for panorama results on soil residences and water distribution.

Instance: LiDAR statistics is often used together with multispectral or hyper spectral imagery to refine soil maps and improve the precision of soil assets estimations [15][16].

3. Artificial Intelligence in Soil Mapping

Growing machines that can carry out duties that commonly require human intelligence is the problem of the technological know-how discipline known as artificial intelligence (AI). trouble-fixing,

pattern recognition, language comprehension, and decision-making are a few examples of such obligations. Artificial intelligence (AI) structures are distinctly powerful in analyzing records and figuring out patterns due to the fact they can manner big volumes of data and discover hidden correlations, tendencies, and patterns within. This feature is important, particularly in fields like soil mapping, which makes use of remote sensing, laboratory analysis, and aerial and ground surveys to recognize the homes of soil over big regions.

3.1 AI strategies

A ramification of synthetic intelligence strategies may be leveraged for processing the information and making intelligent interpretation within the soil mapping. several of them are:

Machine gaining knowledge of (ML): machine studying is a technique where a prediction or assessment is made based on records that have already been processed via algorithms. Those models can use datasets with surroundings variables and soil traits to expect soil parameters at unstapled locations. These information processing and sensible interpretation techniques may be carried out to soil mapping in several ways.

Random Forests: Useful for classification jobs such as differentiating between types of soil. For instance, Support Vector Machines (SVM) help with these classifications by evaluating different soil salinity levels.

K-Nearest Neighbors (KNN): KNN is a technique that uses known neighboring data points to estimate a feature of interest, in these instance soil qualities [17].

3.2 Deep Learning

Simulated neural networks that employ learning in more than three layers of processing are often referred to as deep learning. The design of these networks allows the deep learning algorithms to work with complex data, such as images taken from satellites or hyper spectral imagery, and store the data in a productive manner. Deep learning will find its use in soil mapping as follows:

- Study the images and identify small differences in the soils.

- Use the time series sensor data and predict the soil health index.
- Retrieve relevant information from large data sources without a tedious process of feature engineering [18].

3.3 Networks of Neural Systems

Neural networks are like the structure and function of the human brain since they are composed of connected nodes, or neurons. They are especially useful for activities requiring pattern identification in soil mapping, such as:

- Understanding the connections between environmental influences and soil characteristics.
- Calculating soil moisture content using both historical and current data.
- Utilize tagged training data to classify soils into various categories [19].

4. Integration of AI and Remote Sensing in Soil Mapping

General Equation for Soil Mapping using AI and Remote Sensing.

Let

- **R(x,y,λ)**: Be the remote sensing data as a function of wavelength λ and geographic coordinates (x,y).
- **P(x,y)**: Preprocessed data, such as dereferencing and noise reduction.
- **F(X,Y)**: Attributes extracted from AI algorithms are represented by F(x,y).
- **M(x,y)**: Predicting a soil map.
The following equation can be used to illustrate the general flow:

The formula is

$$M(x,y)=f(F(x,y))=f(g(P(x,y)))=f(g(h(R(x,y,\lambda))))$$

Where:

- **h**: Preprocessing function.
- **g**: Feature extraction function using AI.
- **f**: Prediction function (e.g., classification or regression).

Step-by-Step Graph Components:

- **Remote Sensing Data:**
 - $R(x,y,\lambda) \rightarrow$ (Input: Satellite, UAV, or Aerial Data)

- **Preprocessing:**
 - $P(x,y)=h(R(x,y,\lambda)) \rightarrow$ (Noise Removal, Dereferencing)
- **Feature Extraction:**
 - $F(x,y)=g(P(x,y)) \rightarrow$ (Extract Soil Features via AI Models, e.g., CNN)
- **Soil Mapping:**
 - $M(x,y)=f(F(x,y)) \rightarrow$ (Generate Soil Map using ML Models)

5. Visualization of the Equation Graph

X-Axis: Coordinates in space (x, yx, yx, y).

Y-Axis: Value of Soil Properties (moisture, organic content, etc.).

Data Flow: Illustrates the changes between unprocessed data, processed data, and predicted maps.

Let me generate a conceptual equation graph for this.

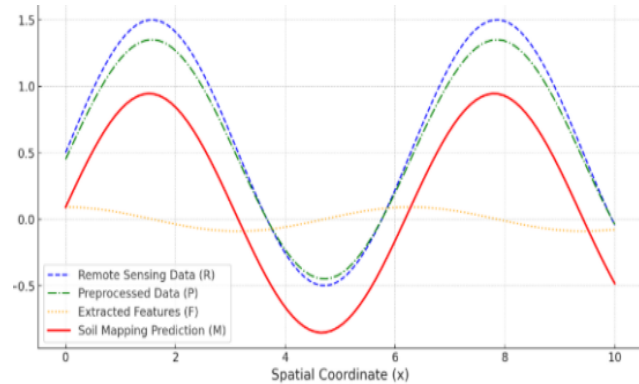


Figure 2. Integration of AI and Remote Sensing in Soil Mapping

The graph above illustrates the flow of data in the integration of AI and remote sensing for soil mapping:

- **Remote Sensing Data (R):** Unprocessed input data obtained from aerial photography, UAVs, or satellites.
- **Preprocessed Data (P):** Data following alignment and noise reduction.
- **Extracted Features (F):** Features found by employing artificial intelligence methods such as spectral indecisions.
- **Soil Mapping Prediction (M):** The ultimate anticipated classification or characteristics of the soil [20].

6. Enhancing Precision Agriculture through Advanced Soil Mapping

In giving full information on the physical and chemical characteristics of the soil, including its texture, pH, organic matter content, moisture content, and nutrient availability, advanced soil mapping is essential to precision agriculture.

Optimized Fertilizer Use: Usage of fertilizers in optimum manner: When the farmers understand the nutrient content of the soil, they can use fertilizers in a better way by applying them to the locations whose soil is lacking in certain nutrients. This practice of nutrient application on a particular site saves on costs of fertilizers and conserves the environment from negative aspects brought about by over application of fertilizers use such as soil and water nutrients pollution.

Water-saving irrigation techniques: Accurate soil moisture monitoring can encourage crop irrigation programs to be implemented in the most efficient manner, supplying the right amount of water to the plant and at the appropriate time, thereby eliminating excess water use. It is very water efficient and prevents excessive watering of crops or drought, which affects the yield more. This is very water efficient and prevents excessive watering of crops or drought which affects yield in higher.

Soil Health Monitoring and Management: Sustainable Soil Management and Monitoring: Soil mapping enables the assessment of the changing status of soil health over periods. The farmers can monitor changes to soil characteristics and change their farming methods, for example using crop rotation or cover cropping systems that preserve the soil base [21].

Variable Rate Seeding and Planting: Allele-Specific Seeding and Planting. The knowledge of soil property variation within most farms enables farmers to manipulate the quantity of village seed enrolled in the system to the expected level of soil fertility, to achieve desired stand density and yield. This approach also enhances resourced use and general farm production efficiency.

Combating the Threat of Insect Pests and Fungus: Maps of soils can also show potential

locations of infestation by insects or plant diseases depending on the available soil moisture and pH values and therefore support the zoning and timing of the agricultural chemical control against pests [22].

5.1 Environmental Management Monitoring, Land Reclamation, and Conservation

Environmental management benefitted from advanced soil mapping in diverse ways including monitoring of ex situ ecosystems, land rehabilitation, and natural resource preservation.

Monitoring of Environment: Generally, soil maps do not offer only information that consists of soil and its levels of pollution. Such information is very useful for the monitoring of soil degradation/improvements where pollutants, man-made or natural, are introduced. That can allow relevant state institutions to devise strategies that will eliminate sources of pollution and rehabilitate the affected soils [23].

Land Reclamation: In post-operative mining sites or regions exposed to industry or even natural disasters, soil mapping is performed to establish the area of any degraded or contaminated soils. Then reclamation works enhance the restoration of soils by using specific soil amendments, planting, or other techniques.

Integrated Conservation Planning: Soil maps are useful in the process of assessing where there is a likelihood of erosion, landslides or desertification. Based on all these determinations, they can make decisions on the most needed actions towards the achievement of such objectives as vegetation cover, terraces construction, and soil erosion control. The use of such a creative approach makes it easy to protect biodiversity, restore watersheds and erosion control [24].

Carbon sequestration: The application of a complex soil mapping in a carbon sequestration scheme also involves the measurement of soil organic carbon that is an important component of carbon capture. The land managers can mitigate the problem of carbon mobility in the soil due to land use changes like no-till farming or planting trees in response to global warming mitigation [25].

7. Technical Issues to Be Solved to Combine AI And Remote Sensing to Soil Mapping

Quality and Availability of Data: The quality and availability of remote sensing data have a strong influence on the accuracy with which AI-based soil mapping is used. The accuracy of soil maps can be less in the event of noise, inconsistency of record resolution or insufficient coverage of facts. Satellite imagery can also be utilized to map by clouds, change in seasons of vegetation and sensor obstructions. Another difficulty is in combining the information of various sources (drones, satellites and floor sensors). The combination of this data is extremely hard due to its dissimilarity forms, scales and ranges of accuracy [26].

Computational Demands: The sorting of high-resolution remote sensing information and the training of multifaceted Artificial Intelligence algorithms demand computer resources. Massive soil mapping with system mastering models (e.g. deep neural networks) may absorb lots of PC resources which entail specialized equipment (e.g. GPUs or cloud computing) that not all people can afford. Hyperspectral sensors or LiDAR sensors today generate volumes of data, and even to do processing on the fly, it requires advanced hardware and garage [27].

Model Interpretability and Explain Potential: Numerous AI are fashions deep knowing algorithms, work like black packing containers, which may be hard to identify. These fashions are hard to tell how they predict the soil characteristics. This complicates the process of verifying whether the implications of the model are correct and making individuals think about them. [28]

Scalability and Generalization AI models are not consistent in their performance across extraordinary scalabilities or geographic areas, when trained on accurate datasets or areas. The functions of soil in various areas can be very different, and hence models must consider a lot of soil types and environmental factors. Applying AI-powered soil to large areas of land, instead of small patches of land, is even more difficult, including how to integrate various sources of records and address changes in soil and land cover. Ethical and

private aspects: Soil mapping with the aid of AI and remote sensing might provoke some privacy concerns in case high-resolution imaging tracks the land owned by individuals. The collection and analysis of information should be advised to be done in an ethical and legal way. Also, there is an issue of the actual access to generation in that the rural areas or less developed ones may be left behind to have access to better soil mapping tools [29][30].

8. CONCLUSION

The impact of the revolution of AI and remote sensing on soil mapping has varied effects on city planning, environmental control and precision farming. With the integration of data gathered by both hyperspectral, LiDAR and multispectral data collection and remote sensing technology as well as more advanced gadget mastering algorithms like Random Forest, Support Vegetable machines and deep knowledge techniques, nowadays, one can generate much more accurate and comprehensive soil maps in comparison to those produced by the traditional tools. The innovation will give important information on soil habitats, which allows high-yield management, sustainable agriculture, and land-use planning. Although the advantages are numerous, numerous technical difficulties remain, such as the correctness of the statistics, the problem of meeting the vexed needs of computers, and the enhancement of the understandability of AI models. Such issues should be rectified so that soil mapping technologies can be developed this way. Moreover, in rural settings or underdeveloped regions, ethical issues connected to the actual privacy and fair rights to access should be considered. The further development in soil mapping will be based on AI algorithm development, extensive statistical data, and better sensor technology. The further development of IoT-based soil monitoring and the combination of AI-based approaches and the conventional models of soil technology present tremendous opportunities to the future trends. The soil mapping can be made more precise and enable further efficient control of the land by adopting

these new trends and contributing to the solving of the current challenging situations.

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