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A Conceptual Approaches to Assessment of Soil Quality Parameters Using Remote Sensing, GIS, Google Earth and Drone Imagery Techniques

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Abstract: *Soil Quality (SQ) is a cornerstone of sustainable agricultural ecosystem functioning and environmental sustainability. While traditional field sampling and laboratory methods are accurate they are constrained by high costs time consuming processes and limited geographical coverage. This conceptual review examines modern geospatial approaches such as Remote Sensing (RS), Geographic Information Systems (GIS), Google Earth Engine (GEE), and drone (UAV) imagery to assess key soil quality parameters, including physical (texture, moisture, erosion), chemical (pH, salinity, nutrients, soil organic carbon), and biological indicators. Assessing soil quality is crucial for sustainable agriculture, land management, and environmental conservation, as it directly impacts productivity ecosystem services and resilience against degradation. Traditional field methods for evaluating parameters like pH, organic matter content, nutrient levels (N, P, K), texture, salinity, moisture, and erosion risk are often labour intensive, time-consuming, and limited in geographical scope. This paper presents a conceptual approach for efficient, scalable, and non-invasive soil quality monitoring by integrating Remote Sensing (RS), Geographic Information Systems (GIS), Google Earth, and drone (UAV) imaging technologies. These geospatial technologies enable multi-level analysis: satellite remote sensing and Google Earth provide extensive regional data on vegetation indices (e.g., NDVI, SAVI), soil moisture, and landforms; GIS facilitates the geospatial modelling and integration of multi-source data for the Soil Quality Index (SQI), while high-resolution drone imaging enables detailed, site-specific mapping of properties such as organic carbon and surface variations. To estimate and predict soil properties, these conceptual*

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frameworks often incorporate spectral indices, machine learning algorithms, Digital Soil Mapping (DSM) and terrain attributes derived from Digital Elevation Models (DEMs). This approach overcomes the limitations of traditional methods by providing cost-effective timely and repeatable assessments, particularly over heterogeneous or large landscapes. The text also discusses challenges such as atmospheric interference, the need for calibration, and the integration of multi-sensor data, as well as future directions involving the incorporation of AI-enhanced models to improve accuracy and decision support in precision agriculture.

Keywords: *Soil Quality Assessment, Remote Sensing, GIS, Google Earth Engine, Drone imagery, Soil Quality Index, Digital Soil Mapping.*

Introduction

Soil is a fundamental natural resource that serves as the foundation for food security, biodiversity, water regulation, and climate change mitigation. Amidst pressures arising from intensive agriculture, urbanization, climate change and land degradation, soil quality has become a matter of serious concern. Soil quality refers to the soil's capacity to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health. Parameters of soil quality include physical e.g., texture, bulk density, aggregate stability moisture and chemical Parameters e.g., pH, electrical conductivity, organic matter, nutrient availability, salinity and biological Parameters e.g., indicators of microbial activity properties. While traditional laboratory and field assessment methods are accurate at specific locations, they face challenges regarding spatial variability and scalability. These methods require extensive sample collection, which is costly and impractical for large areas or frequent monitoring. The advent of geospatial technology has revolutionized soil science, enabling comprehensive, non-destructive, and dynamic assessment of soil properties across vast areas and at various scales. By utilizing optical, thermal, and microwave sensors on satellites such as Landsat and Sentinel, remote sensing (RS) technology acquires data on spectral reflectance and emissivity associated with soil properties. Vegetation indices such as NDVI and EVI, along with soil adjusted indices (SAVI, MSAVI) indirectly indicate soil organic carbon, moisture and fertility through vegetation response, whereas bare soil indices help directly estimate properties like texture or salinity. Geographic Information Systems (GIS) serve as an integrated platform for combining remote sensing data with supplementary information such as topography derived from DEMs, climate data, and legacy soil maps. GIS-based models incorporating techniques like geo-statistical interpolation e.g., Kriging, Fuzzy Logic, the Analytic Hierarchy Process (AHP), and Machine Learning (ML) algorithms facilitate the development of spatial Soil Quality Indices (SQI) for mapping and decision making. Platforms like Google Earth provide free high-resolution imagery and 3D visualization tools, which prove useful for preliminary surveys, landform analysis and change detection in data scarce regions. Drone (UAV) imagery bridges the gap between satellite and ground based measurements offering multispectral and hyperspectral data with centimetre level resolution ideal for precision agriculture and site-specific management. Drones are highly effective for capturing surface features e.g., slope, aspect, TPI and spectral bands; these are utilized to model variables such as SOC and erosion risk. Assessing soil quality is crucial for sustainable agriculture, land management, and environmental conservation as it directly impacts productivity ecosystem services and resilience against degradation. Traditional field based methods for evaluating soil parameters such as pH organic matter content nutrient levels (N, P, K), texture, salinity, moisture, and erosion risk are often labour intensive time consuming and limited in geographical scope. Soil possesses various properties, primarily categorized into physical, chemical, and biological groups. Physical properties include factors such as soil texture, structure, bulk density and moisture content. Chemical properties encompass factors like pH, electrical conductivity, nutrient status and organic carbon, while biological properties include factors such as microbial activity and organic matter dynamics. Traditional assessment of soil quality relies primarily on collecting samples directly from the field and conducting laboratory analysis although accurate for specific locations, these methods are time-consuming, costly and labour intensive, and they have limited scope. Consequently these methods prove impractical for monitoring large areas or conditions that are constantly changing.

In recent decades advancements in geospatial technology have revolutionized soil quality assessment. Remote Sensing (RS) provides extensive, multi-temporal, and multi-spectral data, enabling the indirect estimation of soil properties through reflectance, vegetation indices, and microwave signals. Geographic Information Systems (GIS) facilitate data integration, spatial analysis, multi-criteria decision making and the mapping of Soil Quality Indices (SQI). Google Earth Engine (GEE), a cloud-based platform, offers powerful processing capabilities to handle large scale satellite datasets (e.g., Sentinel-2, Landsat, MODIS) alongside machine learning algorithms for predictive modelling. Drone (UAV) imagery provides ultra-high-resolution, centimetre level data bridging the gap between satellite observations and ground truth data for site specific analysis. Conceptual approaches integrate these technologies into a unified workflow data acquisition pre-processing e.g., calculating indices like NDVI and SAVI, modelling e.g., via multivariate analysis, Random Forest or geometric mean algorithms and validation. Frameworks such as MEDALUS or Digital Soil Mapping (DSM) are commonly adopted, often incorporating Digital Elevation Models (DEMs) to account for terrain characteristics. These methods support precision agriculture, land degradation monitoring, sustainable land management and policy formulation, particularly in data scarce or rugged terrains such as arid and semi-arid regions.

From a conceptual standpoint these technologies integrate processes such as data acquisition, pre-processing e.g., calculating indices like NDVI and SAVI modelling e.g., via multivariate analysis, Random Forest, or geometric mean algorithms and validation. Frameworks such as MEDALUS or Digital Soil Mapping (DSM) are commonly adopted often incorporating Digital Elevation Models (DEMs) to account for terrain characteristics. These methods facilitate precision agriculture land degradation monitoring, sustainable land management, and policy formulation particularly in data scarce or rugged terrains such as arid and semi-arid regions.

This review outlines the conceptual framework, applications, challenges, and scale discrepancies, as well as future directions such as field validation, atmospheric interference, AI-enhanced integration, and real time monitoring. This integrated geospatial framework offers a scalable, cost-effective, and non-destructive alternative to traditional methods, thereby supporting precision agriculture, land degradation assessment, and informed policy decisions across diverse agro-ecological contexts. These geospatial technologies enable multi-level analysis satellite remote sensing and Google Earth provide extensive regional data on vegetation indices (e.g., NDVI, SAVI), soil moisture, and landforms GIS facilitates the geospatial modelling and integration of multi-source data for the Soil Quality Index (SQI); while high-resolution drone imagery enables detailed, site-specific mapping of properties such as organic carbon and surface variations. To estimate and predict soil properties, the conceptual frameworks often incorporate spectral indices, machine learning algorithms, Digital Soil Mapping (DSM) and terrain attributes derived from Digital Elevation Models (DEMs). This approach overcomes the limitations of traditional methods by providing cost-effective, timely and repeatable assessments, particularly over heterogeneous or large landscapes. Challenges such as atmospheric interference the need for calibration and the integration of multi sensor data are discussed alongside future directions involving AI enhanced models for improved accuracy and decision support in precision agriculture. This conceptual article outlines integrated frameworks that combine these technologies for a comprehensive assessment of soil quality. It highlights integration e.g., Multi Sensor Fusion, (DSM), practical applications in agricultural and barren lands, methodological aspects, and emerging opportunities in AI and cloud computing. By moving beyond mere point measurements toward spatially explicit and dynamic monitoring these approaches support evidence-based sustainable land management and policy making. This paper presents a conceptual approach for the efficient scalable and non-invasive monitoring of soil quality by integrating remote sensing (RS), Geographic Information Systems (GIS), Google Earth, and drone (UAV) imagery technologies.

Aim:

The primary objective of this conceptual study is to explore and synthesize integrated geospatial methods for the efficient, scalable, and non-destructive assessment of soil quality parameters. The study aims to demonstrate how remote sensing, GIS, Google Earth Engine, and drone imagery can complement or replace traditional techniques, thereby fostering a better understanding of soil health dynamics for sustainable agriculture and environmental management.

Objectives

1. To review the fundamental concepts and theoretical frameworks underlying soil quality assessment using geospatial technology and leveraging new technologies in this context.
2. To Conceptual Approaches study the specific capabilities and applications of remote sensing optical, hyperspectral, SAR, GIS-based spatial modelling, Google Earth Engine for big data processing, and drone/UAV platforms to derive key soil quality indicators e.g., organic carbon, moisture, salinity, erosion risk, nutrients.
3. To Conceptual study integration methods such as multi-sensor fusion machine learning algorithms, vegetation indices, and landscape metrics to develop a composite Soil Quality Index (SQI).
4. To propose conceptual integration models combining multi-source geospatial data (Satellite Imagery, Drone Multispectral, Hyperspectral data, DEMs, and Ancillary Layers) within a GIS environment for generating Soil Quality Indices (SQI).

Methodology

To fulfil the research aims and objectives the following research methodology has been adopted. The study relies primarily on secondary data utilizing various journals and websites. As part of a systematic literature review and conceptual synthesis methodology this research relies entirely on secondary data sources. No primary data e.g., new field sampling, original UAV flights or new satellite imagery were collected or analyzed. To develop an integrated conceptual approach for soil quality assessment, this study synthesizes existing published knowledge, established methodologies, and publicly available geospatial datasets.

Types of Secondary Data

The following categories of secondary sources were utilized:

1. Peer-reviewed Journal Articles and Review Papers : For this research paper, information was gathered by studying how various modern technologies such as remote sensing, GIS, Google Earth, and drones are utilized to assess soil quality parameters, with these serving as the most crucial secondary data sources.

2. Technical Reports and Grey Literature: Documents from organizations like FAO, ESA, NASA, USGS, and research institutions detailing standard protocols, datasets, and best practices e.g., MEDALUS framework, Digital Soil Mapping guidelines.

3. Based on a study of all these factors illustrative diagrams have been created to visualize how this modern approach can be applied to assess soil quality; these diagrams are conceptual and intended to demonstrate the potential utility of the method for this purpose.

Selection Criteria

1. Relevance to integration of RS, GIS, GEE, and UAV for soil quality indicators (physical, chemical, biological). Consideration has been given based on a conceptual study.
2. Publication in reputable peer-reviewed venues.
3. Coverage of diverse agro-ecological especially arid or semi-arid regions.
4. Emphasis on conceptual pipelines, challenges, and validation approaches rather than site-specific primary results. Based on all these secondary studies, various conceptual images have been created to illustrate how remote sensing, GIS, Google Earth, and drones can be utilized for soil quality assessment.

Result and Discussion

Figure 1 primarily illustrates how remote sensing, GIS, Google Earth, and drones are utilized for Conceptual Framework for Soil Quality Assessment. This image illustrates a step-by-step conceptual methodology for assessing land quality criteria using modern geospatial technologies primarily remote sensing (satellites and drones), GIS, Google Earth, and high-resolution imagery. It outlines a systematic and integrated approach, ranging from planning to final recommendations. The framework is showing visualized as a linear 7 stage process.

Step 1: Research Objectives & Study Area Delineation

The primary objective of this first stage is Define what you want to assess and where. For this, as follows Activities need to be taken. First is Identify important soil quality parameters e.g., Soil Organic Carbon (SOC), pH, nutrients, moisture, salinity, texture, erosion risk. Second is Select and delineate the study area.

Step 2: Multi-Source Data Acquisition

The primary objective of this second stage is Gather diverse datasets for comprehensive analysis. For this, as follows Activities need to be taken. First is Satellite Remote Sensing (Landsat, Sentinel) second is Drone/UAV Multispectral & Hyperspectral Imagery third is Google Earth Engine (historical & high-resolution imagery) and last fourth is Ancillary data (field samples, Digital Elevation Model - DEM)

Step 3: Data Pre-processing & Correction

The primary objective of this third stage is Clean and prepares raw data for reliable analysis. For this, as follows Activities need to be taken. First is an atmospheric geometric and radiometric correction second is Orthomosaic generation from drone images and list third is Image enhancement & mosaicking.

Step 4: GIS Integration & Spatial Database Creation

The primary objective of this forth stage is Organize all data into a usable spatial system. For this, As follows **Activities** need to be taken. First is Layer stacking, second is Overlay analysis in ArcGIS/QGIS and last third is base map integration.

Step 5: Index Derivation & Soil Quality Modelling

The primary objective of this fifth stage is Extract meaningful information and builds models. For this, as follows Techniques need to be taken. First is Compute spectral indices (NDVI, SAVI, NDMI, BSI, LST, etc.) second is Spectral analysis and

Statistical & Machine Learning methods (Random Forest, Regression, etc.) and lastly Calculation of Soil Quality Index (SQI).

Step 6: Validation & Accuracy Assessment

The primary objective of this fifth stage is Ensure the results are reliable. For this, the as follows Methods need to be taken. The first is Ground truthing with field soil samples second is Cross-validation and lastly Accuracy metrics e.g. Root Mean Squared Error (RMSE), R^2(R-Squared), Cohen's Kappa (Kappa).

Step 7: Soil Quality Mapping, Analysis & Recommendation

The primary objective of this fifth stage is Produce actionable outputs. For this, the following Outputs need to be taken. The first is Generate thematic maps second is Perform spatial variability & hotspot analysis, third is Provide sustainable soil management recommendations and lastly Create final outputs e.g., in QGIS or similar.

To complete the aforementioned seven stages it is necessary to conduct an analysis and breakdown using the following factors. Remote Sensing Satellite (Landsat, Sentinel) Drone or UAV. GIS Software, ArcGIS, QGIS. Imagery Platforms, Google Earth, Google Earth Engine. Advanced Analysis, Spectral indices, Machine Learning, Statistical modelling.

Fig no 01: Soil quality assessment Using Remote sensing, GIS, Google Earth and Drone Imagery Techniques

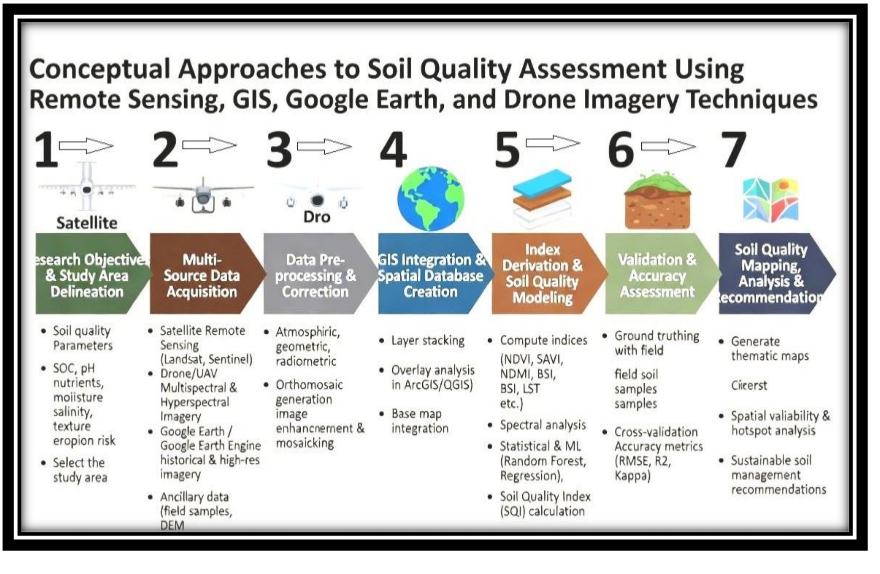

Fig no 02: Integrated Framework for Soil Quality Index Assessment Using GIS Techniques

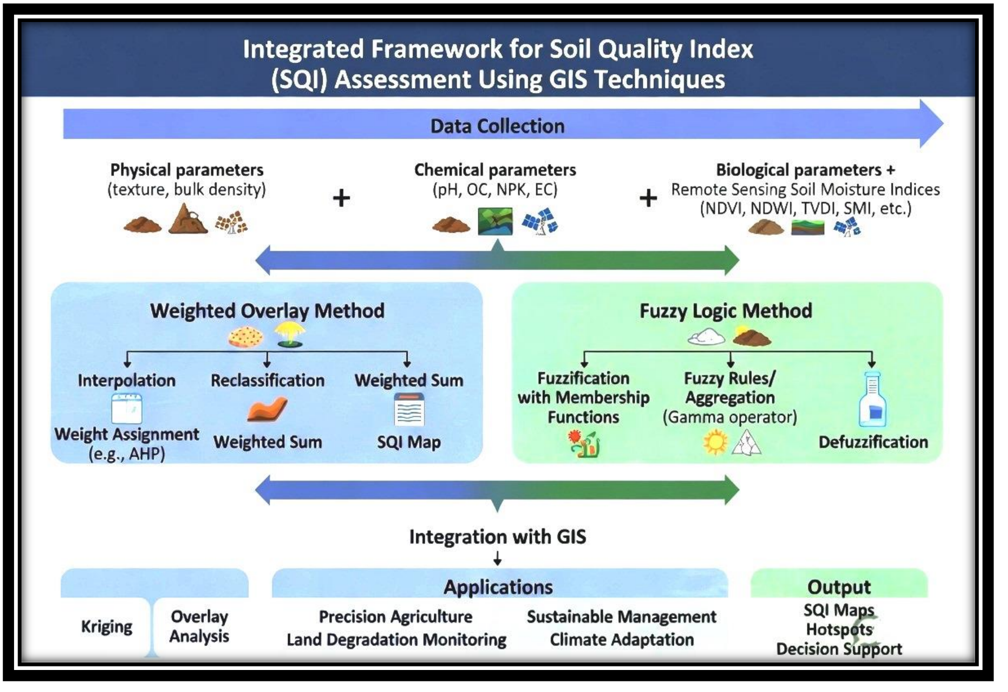

Figure 2 presents a comprehensive, integrated methodological framework for calculating and mapping the Soil Quality Index (SQI) using GIS. It incorporates an integrated study of various data types and analytical methods to generate reliable soil quality assessments for practical applications. Figure 2 is divided into three sections. The first section describes soil data collection, specifically focusing on three types of parameters: physical, chemical, and biological. The second stage outlines the methodologies based on these parameters specifically the Weighted Overlay method and logic-based methods and discusses which approach is most suitable. Finally, the third stage focuses on integration with GIS, illustrating the application process and the nature of the resulting output. The analysis in this regard can be presented as follows.

1. Data Collection:

Soil quality is assessed using **three complementary categories** of parameters Soil quality is evaluated using parameters from three complementary categories as follows.

1. **Physical Parameters**: Texture, bulk density, etc. represented by soil icons. It is represented by the component.

2. **Chemical Parameters**: pH, Organic Carbon (OC), NPK (Nitrogen, Phosphorus, Potassium), Electrical Conductivity (EC) etc. It is represented by the component.
3. **Biological Parameters, Remote Sensing and Soil Moisture Indices**: NDVI, NDWI, TVDI, SMI, etc. combines field or lab data with satellite or drone-derived indices. It is represented by the component.

***2.* Analytical Approaches:**

The framework offers **two major GIS based methods** running in parallel. This section is divided into two parts one presents the **Fuzzy Logic Method** and the other presents the **Fuzzy Logic Method** as follows.

A. Weighted Overlay Method

Four steps are shown in this method. First of all, in this **Weight Assignment** e.g., using Analytic Hierarchy Process (AHP), second method is **Interpolation** to create continuous surfaces from point data as well as third is Reclassification of layers and last Weighted **Sum** operation. These four steps are utilized in this system.

B. Fuzzy Logic Method

Three types of methods are used in these steps. First of all **Fuzzification** converting crisp values into membership functions second method is **Fuzzy Rules or Aggregation** using Gamma operator and the third and most important method is **Defuzzification** converting fuzzy results back to crisp values.

3. GIS Integration:

'Kriging' is a geostatistical method that estimates values at un-sampled locations using observed data from nearby points.'Kriging' is a geostatistical method that estimates values at un-sampled locations using observed data from nearby points.

4. Applications:

The resulting Soil Quality Index (SQI) can support: These four factors are primarily considered important for the Soil Quality Index: Precision Agriculture, Sustainable Soil Management, Land Degradation Monitoring, and Climate Adaptation.

4. The fourth and most important process is outputs, this involves three processes. First of all SQI Maps second Spatial Hotspots identification and last third Decision Support tools for policymakers and farmers. Soil quality assessment can be carried out using all these processes.

Fig no 03: Conceptual Research Methodology for soil quality Assessment using Goggle Earth and Drone

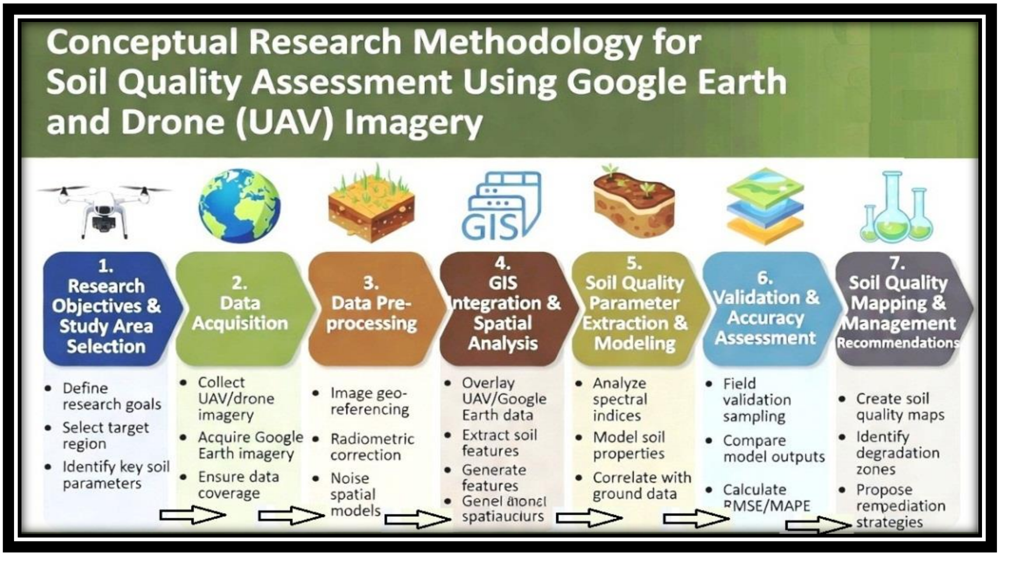

Fig no 03 mainly shows Conceptual Research Methodology for soil quality Assessment using Goggle Earth and Drone. Seven stages regarding soil quality are shown in this. This approach integrates remote sensing, GIS technology, and field verification to generate reliable soil quality maps and management recommendations.

1. In the initial stage, it is important to determine the research object and select the study area; this involves defining the objectives, choosing the study region, and studying the soil parameters.
2. In the second stage, the process primarily involves an initial study using Google Earth and drones to establish connections regarding soil data; this entails acquiring Google Earth imagery and ensuring sufficient spatial and temporal data coverage.
3. Data pre-processing is carried out in the third stage; this includes image geo-referencing, radiometric correction, noise reduction, and the development of spatial models.
4. GIS integration and spatial analysis techniques are crucial in the fourth stage. This stage involves overlaying UAV and Google Earth data layers, extracting soil-related features, generating additional features, and performing general spatial analysis activities that prove highly beneficial for assessing soil quality.
5. The fifth stage encompasses the extraction of soil quality parameters and modeling. In this stage, it is essential to analyze spectral indices (such as NDVI,

SAVI, etc.), model key soil properties, and correlate remote sensing outputs with ground-truth data to ensure accurate soil quality results.

6. The sixth step involves validation and accuracy assessment. This primarily includes processes such as conducting field validation sampling, comparing model outputs with actual ground measurements, and calculating accuracy metrics like RMSE (Root Mean Square Error) and MAPE (Mean Absolute Percentage Error).

7. The final stage in this diagram is 'Soil Quality Mapping & Management Recommendations.' This stage primarily involves processes such as creating detailed soil quality maps, identifying zones of soil degradation, and proposing remediation and management strategies.

Fig no 04: *Conceptual approached to soil quality Assessment Using Remote Sensing and GIS*

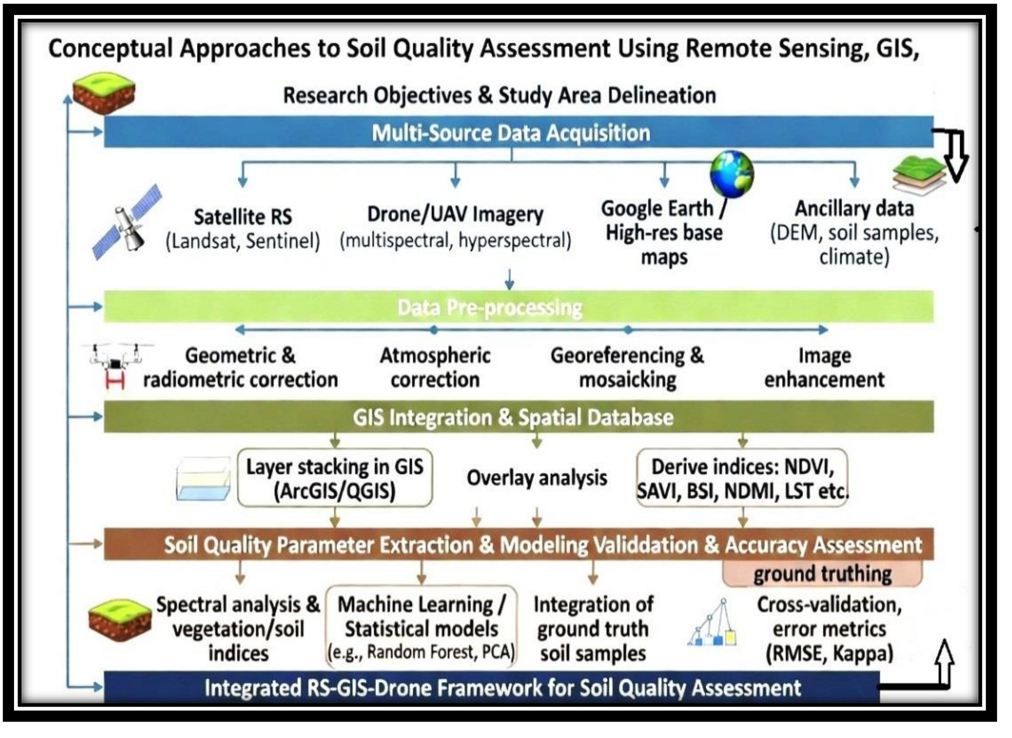

Figure 4 illustrates how conceptual approaches can be utilized for soil quality assessment. In this process, which primarily involves multi-source data acquisition, soil quality is analyzed using various tools. Key techniques employed for data processing include geometric and radiometric correction, atmospheric correction, georeferencing and mosaicking, and image enhancement. Following data processing for soil quality, GIS integration and the creation of a spatial database are carried out using the GIS system. Key methods employed in this process include layer stacking, overlay analysis, and the derivation of indices such as NDVI, SAVI, BSI, NDMI, and LST.

Conceptual Framework

The study follows an integrated multi-scale geospatial modeling approach for Soil Quality Index (SQI) assessment. It draws on the **SCORPAN** framework (Soil = f(s, c, o, r, p, a, n) — soil, climate, organisms, relief, parent material, age, spatial position) commonly used in digital soil mapping, enhanced with remote sensing covariates. soil quality parameters considered theoretically include:

1. **Physical**: Soil texture (sand, silt, and clay) bulk density and aggregate stability.
2. **Chemical**: pH, Electrical Conductivity (EC), Soil Organic Carbon (SOC)/Organic Matter (SOM), macronutrients (N, P, K), Cation Exchange Capacity (CEC).
3. **Biological/Integrated**: Indicators derived via vegetation proxies and spectral indices.

Soil Quality Index (SQI) is conceptualized using additive, multiplicative, or weighted scoring models (e.g., Minimum Data Set (MDS) or Total Data Set (TDS) approaches), often combined with Principal Component Analysis (PCA) for indicator selection. **Satellite Remote Sensing**, Multispectral data from Sentinel-2, Landsat-8/9, or higher-resolution platforms (e.g., RapidEye, PlanetScope). Focus on cloud-free imagery during bare soil periods. Use Google Earth Engine (GEE) for large-scale processing and time-series analysis. **Drone (UAV) Imagery**, High-resolution multispectral/RGB imagery (e.g., via MicaSense or similar sensors) processed through Structure-from-Motion (SfM) photogrammetry for orthomosaics, Digital Surface Models (DSM), and vegetation/soil indices. **Google Earth**, High-resolution historical and 3D imagery for visual interpretation, landform delineation, and ancillary validation. **Ancillary Data**, Digital Elevation Models (DEM SRTM/ASTER), topographic derivatives (slope, aspect, TPI, TRI), climate data, and existing soil/land use maps.

Limitations and Considerations

Theoretical limitations include dependency on data availability and quality, effects of atmospheric conditions, scale mismatches between sensors, and the need for ground-truth calibration in real applications. Advantages of the integrated approach:

cost-effectiveness, scalability, non-invasiveness, and multi-temporal monitoring capability. This theoretical methodology provides a comprehensive, reproducible framework grounded in established literature. It can be adapted for specific study areas or extended with case studies from published works.

Applications

These approaches support precision agriculture, land degradation monitoring, reclamation planning, erosion risk assessment, and policy-making. Examples include spatial SQI mapping in arid regions (e.g., Egypt's El Fayoum) and integration with land capability classification.

Soil Quality Parameters Assessment Using Remote Sensing
Remote Sensing (RS) techniques offer non-invasive, synoptic, and repeatable methods for estimating key soil quality parameters. While direct measurement of some subsurface properties remains challenging, RS leverages spectral reflectance, emissivity, and derived indices from optical, multispectral, hyperspectral, thermal, and microwave sensors to provide both direct and indirect proxies. Satellite platforms (Landsat, Sentinel-2, MODIS, hyperspectral sensors like PRISMA or EnMAP) and airborne/drone-based systems are commonly used. Below is a systematic overview of major soil quality parameters and their RS-based assessment approaches.

1. Physical Soil Properties

- **Soil Moisture Content** Critical for plant growth, microbial activity, and erosion risk. **RS Methods**:

a) Thermal infrared (TIR) data using surface temperature–vegetation index (TVX) or triangle methods.
b) Microwave (active SAR: Sentinel-1; passive: SMAP, SMOS) for direct dielectric constant measurement, effective even under vegetation.
c) Optical indices like Normalized Difference Water Index (NDWI) and shortwave infrared (SWIR) bands. High accuracy in bare or sparsely vegetated soils; fusion with meteorological data improves estimates.

- **Soil Texture (Sand, Silt, Clay Content)** Influences water holding capacity, fertility, and erodibility. **RS Methods**:

a) Hyperspectral RS: Absorption features in visible-near infrared (VNIR) and SWIR regions (e.g., 2200 nm for clay minerals).

b) Multispectral indices and bare soil reflectance models.
c) Machine learning regression (e.g., Partial Least Squares Regression – PLSR) on continuum-removed spectra.

- **Erosion Risk and Soil Loss RS Methods**:

a) Multi-temporal change detection using vegetation cover (NDVI), bare soil exposure, and slope from DEM integration.
b) Revised Universal Soil Loss Equation (RUSLE) with RS-derived C-factor (cover-management) and LS-factor (topography).

2. Chemical Soil Properties

- **Soil Organic Carbon (SOC) / Organic Matter (OM)** One of the most important indicators of soil quality. **RS Methods**:

a) Direct estimation via hyperspectral sensors detecting absorption features around 1700 nm and 2300 nm.
b) Indirect via vegetation indices (NDVI, EVI) and crop productivity proxies in vegetated areas.
c) Bare Soil Index (BSI) and Soil Line concepts for exposed soils. Models often combine RS with terrain attributes in Digital Soil Mapping.

- **Soil pH** Affects nutrient availability and microbial activity. **RS Methods**:

a) Limited direct detection; indirect through correlations with reflectance in specific bands or via vegetation response.
b) Hyperspectral analysis of iron oxides and carbonates; proximal sensing (field spectrometers) for calibration.

- **Salinity / Electrical Conductivity (EC)** Major constraint in arid and semi-arid regions. **RS Methods**:

a) Salinity Index (SI) and combinations of blue, red, and NIR bands.
b) Thermal bands for salt-induced surface temperature changes.
c) Hyperspectral detection of specific salt mineral absorptions. Popular indices: Normalized Difference Salinity Index (NDSI), SI-T.

- **Nutrient Status (Nitrogen, Phosphorus, Potassium) RS Methods**:

a) Nitrogen: Strongly linked to chlorophyll via red-edge bands (e.g., NDRE); hyperspectral indices.

b) Phosphorus and Potassium: Weaker direct signals; primarily through vegetation vigor and crop stress indices. Multi-temporal RS data helps track nutrient dynamics.

3. Biological Soil Properties

Biological indicators (microbial biomass, enzyme activity, earthworm counts) are difficult to assess directly with RS.

a) Indirect proxies through vegetation health indices (NDVI, SAVI) and litter cover.
b) Hyperspectral RS for microbial-induced spectral changes or decomposition stages.
c) Integration with soil moisture and SOC estimates.

Table no 01: Remote Sensing Techniques and Indices

Parameter	Primary RS Data Source	Techniques	Strengths	Limitations
Soil Moisture	Microwave, Thermal, Optical	NDWI, TVX, SAR backscatter	Penetrates clouds/vegetation	Surface only, vegetation interference
SOC/OM	Hyperspectral, Multispectral	NDVI, BSI, Continuum Removal	Good for bare soils	Needs calibration
Salinity	Multispectral, Hyperspectral	SI, NDSI, Salinity Indices	Effective in arid areas	Mixed pixel issues
Soil Texture	Hyperspectral	PLSR, Spectral Libraries	High spectral resolution	Limited depth
Erosion Risk	Optical and DEM	NDVI time-series, RUSLE integration	Large area coverage	Requires ancillary data
Vegetation Proxy	Optical	NDVI, SAVI, EVI	Widely available, cost-effective	Indirect for soil properties

Soil Quality Parameters Assessment Using Google Earth

Google Earth (desktop or pro version) is a widely accessible, user-friendly 3D visualization tool that supports preliminary reconnaissance, visual interpretation, historical change detection, and integration with soil data layers. While it lacks advanced quantitative processing capabilities compared to GIS or Google Earth Engine (GEE), it excels in rapid spatial context analysis, landform identification, and overlaying ancillary soil information for qualitative and semi-quantitative soil quality assessment.

Soil Quality Parameters Assessable in Google Earth:

1. **Land Use/Land Cover (LULC) and Vegetation Cover** (Proxy for Soil Organic Matter & Fertility)

a) High-resolution historical and current imagery allows visual assessment of vegetation density, crop health, and bare soil exposure.
b) Sparse vegetation or degradation indicators suggest low soil organic carbon (SOC) and poor quality.
c) Time-slider feature enables change detection (e.g., deforestation, urbanization impacting soil).

2. **Erosion Features and Risk**

a) Visual identification of gullies, rills, sheet erosion, landslides, or degraded landforms.
b) Overlay with terrain (elevation, slope visualization) to assess erosion susceptibility.
c) Integration with RUSLE factors for preliminary hotspot mapping.

3. **Soil Salinity**

a) Identification of white/salty crusts or patches on bare soil surfaces in arid/semi-arid areas.
b) Visual correlation with poor vegetation growth or halophytic plants.

4. **Soil Texture and Landforms**

a) Interpretation of surface patterns, color tones, and drainage features (e.g., alluvial plains vs. hilly areas).
b) Overlay with global or regional soil maps (via KML imports) for texture classes, depth, and parent material insights.

5. **Soil Moisture and Drainage Patterns**

a) Observation of surface water pooling, dry patches, or wetland indicators.

b) 3D terrain view helps assess topographic wetness.

6. **Overall Soil Quality Zoning**

a) Integration of USDA Web Soil Survey or other public KML layers to view soil types, pH, water-holding capacity, organic matter estimates, and suitability ratings directly in Google Earth.

Soil Quality Parameters Assessment Using Drone (UAV) Imagery

Drone (Unmanned Aerial Vehicle – UAV) imagery provides very high-resolution (centimeter-level) multispectral, hyperspectral, thermal, and RGB data that bridges the gap between satellite remote sensing and ground-based measurements. Drones excel in site-specific, on-demand monitoring with flexible flight planning, making them ideal for precision agriculture and detailed soil quality assessment in heterogeneous landscapes.

1. Soil Organic Carbon (SOC) and Organic Matter

a) **Approach**: Multispectral/hyperspectral sensors detect reflectance in VIS-NIR-SWIR regions. Bare soil imagery combined with indices like BSI (Bare Soil Index) or continuum removal techniques.

b) **Advanced**: Machine learning models e.g., Random Forest trained on drone-derived spectra ground samples for high-resolution SOC maps.

2. Soil Moisture Content

a) **The approach** are thermal infrared sensors measure surface temperature; combined with vegetation indices (NDVI, SAVI) using TVX (Temperature-Vegetation Index) method.

b) Multispectral indices like NDWI (Normalized Difference Water Index).

c) Highly effective for detecting spatial variability and irrigation stress.

3. Soil Texture and Surface Properties

a) **Approach**: Hyperspectral data for clay, sand, and silt discrimination via specific absorption features.

b) RGB and multispectral imagery for surface roughness and crusting analysis.

c) Structure-from-Motion (SfM) photogrammetry generates ultra-high-resolution DEMs for micro-topography.

4. Soil Salinity and pH

a) **The approach** are Salinity indices derived from visible and NIR bands; detection of salt efflorescence on bare soil.

b) Thermal anomalies and vegetation stress patterns indirectly indicate salinity.
c) Limited direct pH detection, but correlated with spectral signatures of carbonates/iron oxides.

5. Erosion Risk and Soil Degradation

a) The Approach is High-resolution DEMs for deriving terrain attributes e.g. slope, LS-factor, Topographic Wetness Index e.g.TWI, (Terrain Position Index).
b) Visual and spectral detection of rills, gullies, and bare soil patches.
c) Multi-temporal flights for change detection and soil loss monitoring.

6. Nutrient Status (N, P, K)

a) **Approach**: Primarily indirect via crop/vegetation response chlorophyll indices like NDRE (Normalized Difference Red Edge).
b) Bare soil flights for direct soil nutrient proxies using hyper spectral data.

7. Biological Indicators (Indirect)

a) Vegetation health, litter cover, and microbial activity proxies through NDVI time-series and canopy density.

Table no 02: Soil Quality and Steps

Steps	Objectives	Techniques & Tools	Data Sources or Inputs	Soil Quality Parameters	Output
1. Study Area Delineation & Pre-processing	Define boundaries, gather baseline data, and prepare datasets.	GIS layering; DEM analysis; Google Earth for visual reconnaissance.	Satellite imagery (Sentinel-2, Landsat-8/9), SRTM/DEM, Google Earth Pro imagery, administrative boundaries.	Topography (slope, elevation, TWI), landforms.	Base maps, landform/physiographic units map, study area boundary.

2. Data Acquisition	Collect multi-scale imagery and ancillary data.	RS platforms: Satellites for broad coverage, Drones (UAVs) for high-res detail. Multispectral/ multispectral sensors.	Sentinel-2/Landsat (optical), Sentinel-1 (SAR for moisture), Drone RGB/multispectral (e.g., DJI with MicaSense), Google Earth high-res visuals. Field samples for ground truth.	Vegetation indices (NDVI, NDRE, SAVI), soil spectral reflectance.	Raw imagery stacks, drone orthomosaics, point cloud/DSM/ DTM.
3. Image Processing & Feature Extraction	Correct and derive indices/layers.	Radiometric/geometric correction, atmospheric correction, index calculation in GIS/RS software (e.g., QGIS, ArcGIS, Google Earth Engine - GEE). SfM photogrammetry for drones.	Processed satellite/drone bands.	Soil color, texture proxies, moisture (SAR/backscatter), salinity indices (SI, NDSI), organic matter proxies.	Corrected images, vegetation/soil indices maps, topographic derivatives (slope, aspect, TPI, TRI).

4. Soil Sampling & Laboratory Analysis (Ground Truth)	Validate remote estimates with direct measurements.	Stratified random sampling based on RS-derived units; lab methods (e.g., Walkley-Black for SOC).	Field GPS points, soil profiles.	pH, EC (salinity), SOC/OM, nutrients (N,P,K), texture, bulk density, aggregate stability (MWD).	Soil database with georeferenced properties.
5. Modeling & Spatial Integration	Develop indices/ models and integrate layers.	GIS overlay weighted sum; Machine Learning (Random Forest, etc.) in GEE or ArcGIS; PCA for parameter reduction; Soil Quality Index (SQI) calculation (e.g., Fertility, Physical, Chemical, Geomorphologic indices).	All layers from prior steps + lab data.	Integrated SQI components: physical (texture, structure), chemical (pH, salinity), biological (SOC, OM).	SQI/Suitability maps, predictive models for parameters.
6. Validation & Accuracy Assessment	Ensure reliability of outputs.	Cross-validation with independent samples; statistical metrics (R^2, RMSE); comparison	Ground truth data, existing soil maps.	Error in parameter estimates (e.g., SOC, salinity).	Accuracy reports, uncertainty maps, validated SQI.

		with NDVI/land capability.			
7. Mapping, Analysis & Visualization	Produce final products and interpret.	GIS cartography, GEE scripting for scalability, Google Earth for 3D visualization.	All processed layers.	Spatial variability of soil quality, degradation hotspots, erosion risk (e.g., RUSLE integration).	Thematic maps (soil quality classes: High/Medium/Low), reports, time-series analysis.

Conclusion

Soil Quality (SQ) refers to the soil's capacity to function within an ecosystem framework, sustain biological productivity, maintain environmental quality, and support plant, animal, and human health. Soil quality (SQ) assessment is fundamental to sustainable agriculture, land management, and environmental conservation. It evaluates the soil's capacity to sustain productivity, maintain environmental quality, and support ecosystem functions through integrated physical, chemical, and biological indicators. Traditional field sampling and laboratory analysis are accurate but labour-intensive, costly and limited in spatial and temporal coverage. Modern conceptual approaches leverage Remote Sensing (RS), Geographic Information Systems (GIS), Google Earth Engine (GEE), and Unmanned Aerial Vehicles (UAVs or drones) for scalable, non-destructive, and spatially explicit monitoring.

Reference

Aggag, A.M., Alharbi, A. (2022) Spatial Analysis of Soil Properties and Site-Specific Management Zone Delineation for the South Hail Region, Saudi Arabia. Sustainability, 14, 16209. https://doi.org/ 10.3390/su142316209

Balasaheb Raghunath Chakor et.al (2024) Prognostication of Urbanisation Growth and Level in Pune District of Maharashtra State an Using GIS Technique, Journal of Computational Analysis and Applications, 33 (08) 473-482.

Deepak Janardhan Gadekar et al., (2025), Prognostication of Urbanisation Growth, Trend and Level in Maharashtra State, Using GIS Techniques, MSW Management Journal,35(2) Pp 1284-1302, https://doi.org/10.7492/gqpsq530

Diaz-Gonzalez, F. A., Vuelvas, J., Correa, C. A., Vallejo, V. E., & Patino, D. (2022). Machine learning and remote sensing techniques applied to estimate soil indicators – Review. Ecological Indicators, 135, 108517. https://doi.org/10.1016/j.ecolind.2021 .108517

Gadekar Deepak Janardhan (2016) A Hybrid Land Cover Classification of Landsat-7 & 8 (OLI) ETM+ Data for Resourceful Vegetation Mapping - Akole Thasil Dist-Ahmednagar, M.S, India, American International Journal of Research in Humanities Arts and Social Sciences,13(3) 217-221.

Gadekar Deepak Janardhan (2025) A GIS-Based Identification of Spatial Analysis of Road Density and Understanding the Pattern of Road Network in Ahilyanagar District of Maharashtra State, India, Asian Journal of Geographical Research, 8(9) Pp 34-48, DOI: https://doi.org/10.9734/ajgr/2025/v8i3274

Gadekar, D. J., Zine A. S., Ramdas, R.V., Sonawane, V.V., and Balu, S.P. (2024). Physical and Biological Characteristics of Soil: A Perspective Study. ShodhKosh: Journal of Visual and Performing Arts, 5(6), 219–228. doi:10.29121/shodhkosh.v5.i6.2024.1724

Gadekar, D.J. (2024). Calculation of Water Quality Index and Physico-Chemical Analysis of Pravara River Water Ahmednagar District (Maharashtra). ShodhKosh: Journal of Visual and Performing Arts, 5(3), 480–490. doi:10.29121/shodhkosh.v5 .i3.2024.2202

Kharde M. N (2022) Agricultural area and Food Nutrition in Akole tehsil, Ahmednagar District of Maharashtra State, India, India International Journal of Food and Nutritional Sciences, 11 (11) 1067- 1076

Medhe Ravindra Sampat et.al, (2024) Estimate the Rate of Change in Forest Cover and Its Impact on Soil by Using GIS And Remote Sensing, A Case Study of Gadchiroli District, Maharashtra, The Bioscan19(3) Pp08-18

Medhe Ravindra Sampat, et al. (2024) Land Use and Land Cover Mapping Using Digital Classification Technique in Dindori Tehsil of Nashik District, Maharashtra

State, India Using Remote Sensing, Journal of Computational Analysis and Applications 33(6) Pp 604-617

Sarkar A, Roy D, Mandal D. K. Assessment of Spatial Variability Mapping of Soil Properties and its Impacts on Agricultural Productivity using GIS Approach in Siliguri Sub-Division, West Bengal, India.Curr World Environ 2023;18(2). DOI:http://dx.doi.org/10.12944/CWE.18.2.28

Silvero, N. E. Q., Demattê, J. A. M., Minasny, B., Rosin, N. A., García Nascimento, J., Rodríguez Albarracín, H. S., ... & Gómez, A. M. R. (2023). Sensing technologies for characterizing and monitoring soil functions: A review. Advances in Agronomy, 177, 125-168.

Sonawane V. R. et.,al.(2020), "Analysis of Chemical Properties of Soil under Sugarcane Crop: A Case Study of Khandala, Shrirampur, Ahmednagar District, Maharashtra State, India". Our Heritage Vol. 68, Issue, 30, Pp.6522-6547

Sonawane V. R. et.,al.(2020), A Geographical Study of Crop Combination in Tribal Area of Nashik District, Maharashtra, India. Studies in Indian Place Names, 40(3) 3915-3940. Sonawane V. R. et.,al.(2020), Analysis of Chemical Properties of Soil under Sugarcane Crop: A Case Study of Khandala, Shrirampur, Ahmednagar District, Maharashtra State, India. Our Heritage 68(30) 6522-6547.

Soniya Sonkar (2021), Physico-Chemical Characteristics of Ground Water in Rahuri Tahsil of Ahmednagar District, M.S. India. International Journal of Scientific Research in Chemical Sciences 8(1) 4-8 Soniya Sonkar (2021) The Study of Physico-Chemical Characteristics OfPravara River, International Journal of Science, Engineering and Technology,9(2) Pp 1-6

Tupe B.K (2010), Agricultural land use and Crop Pattern in Rahata Tahsil of Ahmadnagar District in Maharashtra State, Maharashtra Bhugolshastra Sanshodhan Patrika 27(01).30-37