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# Development of an Integrated Physicochemical and Biological Soil Quality Assessment Method for Evaluating Soil Health and Agricultural Suitability

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**Abstract:**

Soil quality is an essential determinant of agricultural productivity, ecosystem stability and environmental sustainability. Conventional soil testing primarily focuses on physicochemical characteristics, including pH, electrical conductivity, organic carbon and nutrient concentrations. However, these parameters alone may not adequately represent the biological condition and functional capacity of soil.

The present research project was designed to develop an integrated soil quality assessment method combining physicochemical, biological and physical indicators. Soil samples representing three different land-use conditions were considered: agricultural soil, garden soil and roadside soil. Parameters including soil pH, electrical conductivity, moisture content, organic carbon, nitrogen, phosphorus, potassium, microbial activity and water infiltration capacity were evaluated.

An integrated Soil Quality Index (SQI) was developed by combining normalised measurements of the selected indicators. The illustrative experimental findings demonstrated that garden soil exhibited the highest overall soil quality, followed by agricultural soil, whereas roadside soil demonstrated comparatively lower biological activity and organic carbon content.

The proposed assessment method provides a framework for evaluating soil health through multiple indicators rather than relying exclusively on conventional nutrient measurements. It may contribute to sustainable agricultural management, environmental monitoring and soil restoration programmes.

**Keywords:** Soil Quality, Soil Health, Environmental Biotechnology, Soil Microbiology, Organic Carbon, Soil Fertility, Microbial Respiration, Sustainable Agriculture.

## 1. Introduction

Soil is a complex biological and physicochemical system that supports terrestrial ecosystems and agricultural production. It provides essential nutrients, retains water, supports microbial communities and participates in several biogeochemical cycles.

Increasing urbanisation, excessive fertiliser application, industrial contamination, deforestation and inappropriate agricultural practices have contributed to the deterioration of soil quality in several regions. Traditional soil analysis generally involves the measurement of pH, nitrogen, phosphorus, potassium and organic carbon. Although these parameters are important, soil quality is influenced by several additional

characteristics, including microbial diversity, biological respiration, aggregate stability and water infiltration.

Soil microorganisms play a particularly important role in maintaining soil functionality. Bacteria, fungi and other microorganisms participate in organic matter decomposition, nitrogen cycling, phosphorus solubilisation and nutrient transformation.

Therefore, evaluating soil quality requires an integrated approach that considers the physical, chemical and biological properties of soil.

### 1.1 Research Gap

Many conventional soil assessment approaches focus predominantly on chemical fertility. Consequently, a soil sample with adequate nutrient concentrations may still exhibit poor biological activity or physical degradation.

The present project addresses this limitation by introducing an integrated assessment framework that combines:

1. Physicochemical soil characteristics.
2. Biological soil activity.
3. Physical soil properties.
4. A composite Soil Quality Index.

### 1.2 Research Objectives

The primary objectives were:

- To evaluate the physicochemical properties of different soil samples.
- To determine soil moisture and organic carbon concentrations.
- To investigate microbial respiration as an indicator of biological activity.
- To compare soil fertility indicators across different land-use conditions.
- To develop an integrated Soil Quality Index.
- To establish a practical framework for sustainable soil monitoring.

## 2. Materials and Methods

### 2.1 Experimental Design

A comparative experimental study was designed using three categories of soil:

- Sample A: Agricultural soil.
- Sample B: Garden soil.
- Sample C: Roadside soil.

Three independent sampling locations were considered for each land-use category. At each location, multiple subsamples were collected from the upper 0–15 cm soil layer and combined into a representative sample.

The collected samples were transported in clean, labelled containers and processed using standard laboratory procedures.

### 2.2 Soil Sample Preparation

Large stones, roots and visible plant debris were removed manually.

Samples intended for chemical analysis were air-dried and passed through a 2 mm sieve. Separate fresh subsamples were maintained for moisture determination and microbial respiration analysis.

**2.3 Measurement of Soil pH**

Soil pH was determined using a calibrated digital pH meter.
A soil-water suspension was prepared using a 1:2.5 soil-to-distilled-water ratio. The suspension was mixed thoroughly and allowed to equilibrate before measurement.

**2.4 Electrical Conductivity**

Electrical conductivity was measured using a calibrated conductivity meter.
The parameter was used to estimate the concentration of soluble ionic substances present in the soil suspension.

**2.5 Soil Moisture Content**

Soil moisture was determined through the gravimetric method.
A known quantity of fresh soil was weighed, dried in an oven at approximately 105°C until constant mass and weighed again.
Moisture content was calculated using:
Moisture content (%) = [(Fresh soil weight − Dry soil weight) / Dry soil weight] × 100

**2.6 Soil Organic Carbon**

Organic carbon was determined using an appropriate laboratory soil organic carbon method, such as the Walkley–Black wet oxidation method.
The estimated organic carbon concentration was used to assess the contribution of organic matter to soil fertility and biological functioning.

**2.7 Available Nitrogen, Phosphorus and Potassium**

Available nitrogen, phosphorus and potassium were estimated using suitable soil analytical procedures.
Nitrogen was assessed using an appropriate available-nitrogen method, phosphorus through a soil-appropriate extraction and colorimetric determination, and potassium through an appropriate extraction followed by flame photometry or an equivalent validated technique.

**2.8 Soil Microbial Respiration**

Biological activity was estimated through a soil respiration experiment.
Fresh soil samples were incubated under controlled moisture and temperature conditions. Carbon dioxide released during incubation was captured using an appropriate alkali-trapping method and quantified through titration.
The results were expressed as $CO_2$-C released per unit mass of dry soil per unit time.
This measurement provided an estimate of microbial metabolic activity.

**2.9 Water Infiltration Capacity**

Water infiltration capacity was evaluated using a standardised infiltration procedure.

A known volume of water was introduced into a defined soil column or field infiltration ring. The time required for water to infiltrate was recorded.
Higher infiltration rates generally indicate better water movement through the soil, although interpretation depends on soil texture and structure.

### 2.10 Development of the Soil Quality Index

A composite Soil Quality Index was developed using the selected indicators.
Each parameter was normalised to a score between 0 and 1.
For indicators where higher values generally represent better soil quality:
Score = (Observed value − Minimum value) / (Maximum value − Minimum value)
For indicators where lower values represent better soil quality within a defined assessment range, an inverse scoring approach was applied.
The final index was calculated using:
$SQI = \Sigma (Wi \times Si)$
Where:

- SQI = Soil Quality Index.
- Wi = Weight assigned to the individual indicator.
- Si = Normalised indicator score.

The weights were assigned according to the predefined assessment framework and should be validated for the intended soil type and application.

## 3. Results

**Note: All numerical values in this section are hypothetical demonstration data. They do not represent completed laboratory measurements.**

### 3.1 Physicochemical Characteristics

| Parameter | Agricultural | Garden | Roadside |
|---|---|---|---|
| pH | 6.8 | 6.6 | 7.8 |
| EC (dS/m) | 0.42 | 0.35 | 0.78 |
| Moisture (%) | 18.5 | 24.2 | 11.8 |
| Organic carbon (%) | 1.42 | 2.15 | 0.68 |
| Available N (mg/kg) | 245 | 285 | 112 |
| Available P (mg/kg) | 18.5 | 22.4 | 9.2 |
| Available K (mg/kg) | 168 | 195 | 105 |

The illustrative dataset indicated that garden soil possessed comparatively higher organic carbon and moisture content than the other two soil categories.
Roadside soil demonstrated comparatively higher electrical conductivity and lower organic carbon concentration.

### 3.2 Biological Activity

Microbial respiration was used as an indicator of biological activity.

| Soil category | Illustrative respiration rate (mg $CO_2$-C/kg soil/day) |
|---|---|
| Agricultural | 42 |
| Garden | 61 |
| Roadside | 19 |

Garden soil demonstrated the highest estimated microbial respiration, whereas roadside soil exhibited the lowest value.

### 3.3 Soil Quality Index

Following normalisation and application of the illustrative weighting framework, the following composite scores were obtained.

| Soil category | Illustrative SQI |
|---|---|
| Agricultural | 0.72 |
| Garden | 0.86 |
| Roadside | 0.39 |

The illustrative findings suggest the following soil quality ranking:

1. Garden soil.
2. Agricultural soil.
3. Roadside soil.

These values are demonstration scores and would need to be recalculated using actual measurements.

## 4. Discussion

The proposed research framework demonstrates the importance of evaluating soil through multiple interacting characteristics.

### 4.1 Relationship Between Organic Carbon and Soil Health

Organic carbon is an important component of soil functionality. It contributes to nutrient retention, aggregate formation, water-holding capacity and microbial growth.

The illustrative results indicated that garden soil contained higher organic carbon concentrations than agricultural and roadside soil.

This difference could be associated with variations in organic matter input, vegetation cover, decomposition and land-management practices.

### 4.2 Importance of Soil Microbial Activity

Microorganisms contribute to nutrient cycling and the decomposition of organic substances.

The comparatively higher illustrative respiration rate in garden soil suggests greater microbial metabolic activity under the assumed experimental conditions.

However, respiration alone cannot establish microbial diversity or ecological health. Additional investigations involving microbial enumeration, enzyme activity and community analysis would provide stronger biological evidence.

### 4.3 Soil Salinity and Electrical Conductivity

Electrical conductivity provides information about soluble salts in soil.

Higher EC values may indicate increased salt accumulation, which can influence plant water uptake and microbial functioning.

The comparatively higher illustrative EC value of roadside soil suggests that further investigation of possible salt accumulation and external contamination may be warranted.

However, electrical conductivity alone cannot identify specific contaminants or establish pollution.

### 4.4 Importance of Integrated Soil Assessment

One of the principal contributions of the proposed project is the integration of biological and physicochemical indicators.

A soil sample may contain sufficient nitrogen, phosphorus and potassium but still exhibit poor microbial activity or water infiltration.

Therefore, the Soil Quality Index offers a broader assessment framework than individual chemical measurements.

The index should be interpreted as a comparative tool rather than a universal measurement of soil health.

## 5. Proposed Applications

The integrated soil assessment framework may be useful in:

1. Agricultural land fertility assessment.
2. Monitoring soil degradation.
3. Environmental biotechnology research.
4. Urban soil quality evaluation.
5. Sustainable farming management.
6. Soil restoration and rehabilitation.
7. Preliminary screening of land for agricultural suitability.

## 6. Limitations of the Study

The proposed framework has several limitations.

First, soil characteristics vary according to season, rainfall, temperature and land-management practices.

Second, microbial respiration does not directly measure microbial diversity.

Third, a composite index may simplify complex interactions among soil indicators.

Fourth, the selected parameters cannot independently identify heavy-metal contamination, pesticide residues or pathogenic microorganisms.

Future investigations should incorporate microbial diversity analysis, soil enzyme assays, heavy-metal determination and repeated seasonal sampling.

## 7. Future Research Directions

Further development of the project may involve the construction of a portable soil quality testing device.

Such a device could integrate:

- A digital pH sensor.
- An electrical conductivity sensor.

- A soil moisture sensor.
- A temperature sensor.
- A nitrate-sensitive measurement system.
- A microbial respiration measurement module.

The collected measurements could be processed using a predefined mathematical Soil Quality Index without requiring artificial intelligence.

A subsequent research phase could investigate the relationship between soil microbial activity and nutrient availability across different agricultural environments.

## 8. Conclusion

The present project proposes an integrated approach for evaluating soil quality through physicochemical, biological and physical indicators.

The proposed methodology combines conventional soil testing with microbial respiration assessment and a composite Soil Quality Index.

The illustrative results demonstrate how this approach can distinguish between soil samples with different characteristics and identify potential differences in biological activity, organic carbon content and nutrient availability.

The study establishes a foundation for developing practical soil monitoring methodologies that may support agricultural sustainability and environmental management.

Importantly, the proposed framework emphasises that soil quality should not be determined exclusively by nutrient concentrations. Biological activity, organic matter, physical structure and water-related characteristics must also be considered.

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