

An iks-based comparative analysis of soil properties and microbial diversity : a study across northern, central & southern telangana

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ABSTRACT

Agriculture and ecosystem sustainability are fundamentally dependent on healthy soil, a principle deeply rooted in Indian Knowledge System (IKS) that emphasizes balance between land, biodiversity, and human activity. Traditional ecological knowledge has long recognized soil fertility and biological activity have a key role in sustainable agriculture. In this study, we scientifically examine these principles through a comparative assessment of physicochemical properties and culturable microbial diversity in paddy-cultivated black soils across Telangana. Surface soil samples (0–15 cm depth) were collected from paddy fields at two locations each in Adilabad (north), Medchal (central), and Nalgonda (south), ensuring uniform land use and sample depth. Composite samples were analyzed for pH, soil texture, moisture, electrical conductivity, organic matter, and macronutrients (N, P, K). Culturable bacteria and fungi were isolated using Nutrient Agar and Sabouraud Dextrose Agar, and their abundance and morphology were preliminarily examined microscopically. Distinct regional microbial patterns were observed, influenced by soil texture, nutrient status, salinity, and local management practices. Adilabad soils exhibited lower salinity and higher microbial activity, while Medchal and Nalgonda showed varied bacterial and fungal diversity. A strong correlation between soil properties and microbial abundance highlights the role of organic matter and region-specific management in sustaining soil health. This district-level baseline integrates contemporary (modern) soil microbiology with indigenous agricultural knowledge, promoting site-specific fertility control and environmentally sustainable farming methods. Future research can extend this study to seasonal changes, subsurface soils & beneficial microbes, etc .

Keywords: *Indian knowledge system (IKS), Paddy soil, Black soil , Microbial diversity, Sustainable farming.*

INTRODUCTION

Soil fertility is one of the most critical factor which determine the agriculture productivity and long-term sustainability. Healthy soil promotes crop growth by regulating water retention, supplying essential nutrients, and maintaining a stable environment for microbial activity. Its physicochemical composition and biological communities has a major impact on soil health. Microorganisms, such as bacteria and fungi, play a key role in decomposing organic matter, nutrient cycling, and preserving soil structure, making them a major indicators of soil fertility. (Chen *et al*, Mohamed *et al*). Traditional Indian Knowledge Systems (IKS) have long recognized soil as a living system, emphasizing practices that support microbial activity, nutrient recycling, and ecological balance (Paul & Paul).

In India, 58% of the population is dependent on agriculture, making soil health intrinsically linked to food security and economic well-being. Telangana, with its diverse agricultural zones, relies deeply on black soils, known for their water retention and nutrient-holding capacity (Bindu *et al*). Paddy, a high nutrient demanding crop, particularly nitrogen, is widespread in these soils. Conversely, overuse of chemical fertilizers without proper soil assessment has led to nutrient imbalances, soil degradation, and reduced microbial diversity (Brindha & Elango, Reddy *et al*). Historically, indigenous farming practices emphasized organic amendments, crop residue recycling, and ecological feedback mechanisms—principles now recognized in IKS as essential for sustainable soil management.

Several studies have examined soil fertility in Telangana, but most are limited to specific regions or focus only on either physicochemical properties or microbial communities. For example, forage-growing soils in Nalgonda (Bindu *et al*), while physicochemical properties of soil in Adilabad (reddy *et al*) and spatial analysis of soil fertility in Nalgonda were studied by Brindha and Elango. While, studies on microflora in selected districts of Andhra pradesh were also done (Hindumathi and Reddy). Despite these studies providing valuable insights, they do not offer a district-level comparison integrating soil properties with microbial diversity in paddy-cultivated black soils. IKS emphasizes such local, context-specific knowledge, highlighting the importance of adapting agricultural practices to the specific ecological and social environment.

Microbial communities are sensitive to soil texture, pH, moisture, and nutrient availability reflecting regional environmental and management conditions (Tan *et.al*). Some microbes, such as nitrogen-fixing bacteria, phosphate-solubilizing microbes and plant-growth- promoting rhizobacteria increase the soil fertility and nutrient availability (paramasivan *et.al*). Moreover, mycorrhizal fungi such as vesicular arbuscular mycorrhizae (VAM), play an important role in enhancing the phosphorus uptake and plant resilience (Hindumathi and Reddy). Traditional farming practices have long promoted such interactions by supporting biodiversity and natural nutrient cycles which are the core principle of IKS.

The overuse of pesticides, chemical fertilizers, & industrial effluents has increased the concern for soil degradation, in turn highlighting the urgent need for ecofriendly management practices (Zhuang *et al.*). Integrating soil fertility analysis with microbial monitoring can minimize the environmental risks by enhancing productivity. (Aimrun *et al.*, Lopez- Castaneda *et al.*). These approaches align with IKS principles, emphasizing sustainable soil management (long term soil fertility), ecological balance, and minimizing external influence.

The aim of this study is to provide a comparative analysis of paddy cultivating black soils across three contrasting districts of Telangana- Adilabad (north), Medchal (central), and Nalgonda (south). Particularly, it focuses on (i) analysing important physicochemical properties such as electrical conductivity, pH, organic matter, macro and micro nutrients (ii) identification and isolation of bacterial and fungal populations using standard laboratory techniques (iii) evaluating the effect of regional variations on microbial diversity and (iv) correlating soil properties with microbial distribution establishes a district-level baseline for sustainable soil management practices. This study aims to promote environmental sustainability and regional-specific agricultural practices by combining scientific studies with IKS-aligned principles.

MATERIALS AND METHODOLOGY

❖ Study area and soil sampling:

The present study evaluates three districts across Telangana - Adilabad (north), Medchal (central), Nalgonda (south) which differ in agro-climatic conditions. To maintain uniformity, paddy-cultivated black soils were specifically selected. Two samples of paddy-cultivated black soil from two representative locations were collected from each district, which include - Ankoli and Utnoor (Adilabad), Turkapally and Majeedpur (Medchal), and Maktha Anantharam and Kothagudem (Nalgonda). To prevent contamination, sterile techniques were used to collect soil samples within the depth of 0-15 cm from the surface. Samples collected were sealed in sterile bags as shown in fig.1, sample bags were labelled and transported for further analysis.

❖ Materials required:

Laboratory equipments: basic instruments such as analytical balance, hot air oven, incubator, autoclave, sterile glassware, petriplates, micropipettes, , laminar airflow, and Microscope.

Microbial assessment: Culture media were prepared in required amount – For Bacteria- Nutrient agar (peptone, NaCl, beef extract, agar, pH 7.2 ± 0.2 and for fungi Sabouraud Dextrose Agar (peptone, dextrose, agar, pH 5.6 ± 0.2 , chloramphenicol).

Staining method: Gram's staining reagents (crystal violet, Gram's iodine, acetone/alcohol, saffranin) used for bacterial identification; for fungal identification, lactophenol blue stain was used.

❖ **Analysis of soil physicochemical characteristics:**

Analysis of samples was done in **ZEAL Biologicals Environment Testing Lab and CRO**, Hyderabad, for physicochemical parameters to determine nutrient availability and soil fertility. Parameters such as pH, moisture content, electrical conductivity (EC), organic carbon, macronutrients (available nitrogen, phosphorus, potassium); & micronutrients (Ca, Mg, Zn, B, Fe, CaCO₃). Standard laboratory procedures were followed, and results were compared for three districts.

❖ **Isolation and preliminary identification of soil microbiota:**

Both medias (Nutrient agar, Sabouraud dextrose agar) were prepared according to the requirement and sterilized in an autoclave under 121°C, 15 psi pressure for 15 minutes and then plated on petri plates under sterile conditions (inside a laminar air flow chamber) to avoid contamination. According to the laboratory protocol, Plates were labelled.

Microbes were cultured in respective media by using serial dilution and plating method shown in fig.2. For each soil sample, 1g of soil was suspended in 10 ml sterile saline solution and serially diluted (10⁻¹ to 10⁻⁴). For each sample, aliquotes of each dilution were inoculated onto respective nutrient agar plates (for bacteria) and sabourauds dextrose agar plates (for fungi) and incubated under controlled conditions. This process was conducted in two independent trials to ensure reproducibility.

Analysis of Data:

- Post incubation, colony count and morphology on each diluted plate were observed and recorded.
- Colony counts of each diluted plate of every sample were done and recorded.
- Bacterial colonies were observed under a microscope after Gram staining as seen in fig.3 and after lactophenol blue staining for fungi, as seen in fig.4. The microorganisms were identified based on colony morphology, staining pattern and microscopic observation. This study was limited to preliminary identification only.
- The recorded data of physicochemical properties (ZEAL lab report) and microbial analysis were analyzed, compared and correlated as shown in **Table 1** to explore the relationship between soil fertility & soil microbial diversity.

RESULT

The results of soil profile (physicochemical analysis) and microbial analysis in paddy cultivating black soil of three districts of Telangana - Adilabad (north), Medchal (central), Nalgonda (south) were compared with each other as shown in table 1. The test result showed that all soils were alkaline (pH 7.5-8.0), but Nalgonda showed the highest salinity. Electrical conductivity spread wide, with Adilabad getting bottom values (60-65 $\mu\text{S}/\text{cm}$), Medchal in the middle (208- 210 $\mu\text{S}/\text{cm}$) and Nalgonda higher than that (448-450 $\mu\text{S}/\text{cm}$). This implies that the southern site of Telangana has greater soil salinity. Organic carbon was consistently low (0.5-0.7%), with Medchal being slightly higher; phosphorus availability was excessively high in Nalgonda compared to Adilabad and Medchal. The micronutrients such as iron and boron were severely absent in all the districts. Medchal soil was only deficient in zinc compared to Adilabad and Nalgonda having moderate levels.

Fig.3 and 4 shown in the appendix are the microbial diversity across these three selected districts, which reveals that Adilabad soils were rich in actinomycetes and mixed bacterial populations such as gram negative bacilli, whereas medchal showed balanced bacterial diversity with sporulating rods. In contrast, Nalgonda exhibited reduced bacterial diversity and abundant gram negative bacilli due to salinity stress. Fungal diversity was similar characterized by *Penicillium*, *Aspergillus*, *Fusarium* at all sites. Adilabad soils were more prevalent in *Penicillium* and *Fusarium*, Medchal was dominated by *Aspergillus* whereas, Nalgonda soils showed stress-adapted black *Aspergillus* colonies.

Overall, Adilabad soils were characterized by greater microbial richness likely due to low salinity while having slightly lower organic carbon than Medchal, Balanced microbial diversity and moderate fertility were observed in Medchal soils, whereas Nalgonda exhibited high salinity and reduced microbial diversity.

Table 1

District-wise comparative analysis of physicochemical properties and microbial diversity of paddy-cultivated black soils across three districts of Telangana

Parameters	Adilabad (North)	Medchal (Central)	Nalgonda (South)	Observation/ Interpretation
pH	7.5-7.6 (alkaline)	7.7-7.8 (alkaline)	7.9-8.0 (alkaline)	Soils are moderately alkaline across all districts
Electrical conductivity (µs/cm)	60-65 (low)	208-210 (moderate)	448-450 (high)	Higher salinity recorded in Nalgonda
Organic carbon (%)	0.5-0.6 (low)	0.6-0.7 (moderate)	0.5-0.6 (low)	Moderate across all districts
Ammonical N (kg/acre)	14.0-15.0 (very high)	10-11 (moderate)	14.5-15.0 (very high)	High across all the districts
Nitrate N (kg/acre)	9.5-10.0 (moderate)	14.5-15.0 (high)	14.8-15.0 (high)	Higher levels in Medchal & Nalgonda
Available P (kg/acre)	15-16 (low)	19-20 (low)	78-80 (very high)	Excessively high P accumulation in Nalgonda
Available K (kg/acre)	~3000 (minimum)	~3150 (minimum)	~3400 (minimum)	All the soils showed adequate range across districts
Micronutrients (ppm)	Fe= 0.1-0.2ppm Zn= ~1.0	Fe =0.2-0.3ppm Zn 0.3-0.4	Fe= 0.5-0.6ppm Zn= 1.1-1.2	Deficiency of Fe & Zn in all districts
Bacterial diversity (Dominant groups)	Actinomycetes, Gram-negative bacilli	Actinomycetes, sporulating rods, clusters of bacilli	Gram-negative bacilli (Dominant), few actinomycetes	Bacterial diversity reduced in Nalgonda due to salinity stress
Fungal Diversity (Dominant genera)	Aspergillus, Penicillium, Fusarium	Dominant Aspergillus, some Penicillium	Aspergillus (Black colonies), Fusarium	Aspergillus was dominant in Nalgonda soils.

DISCUSSION

This study clearly validates regional differences in soil physicochemical properties and microbial diversity across paddy cultivated black soils in Telangana, emphasizing the strong influence of soil salinity, organic matter and nutrient content on soil biological activity. Adilabad soil showed lower electric conductivity with rich microbial diversity (especially actinomycetes & mixed bacterial population) due to favorable conditions that supported microbial activity. In contrast, Nalgonda soil was characterized by high salinity and high phosphorus levels, which led to lower bacterial diversity and dominance of stress tolerant gram negative bacilli and black *Aspergillus* spp. High salinity created a nutrient imbalance of soil, which led to the suppression of sensitive microbes and disrupted the soil's biological balance. Medchal soils exhibited moderate salinity, comparatively higher organic carbon and a balanced bacterial and fungal population indicating that the microbial population adapted to intermediate soil conditions and local management practices. This highlights the impact of organic matter and salinity on soil microbial communities across different agro-climatic zones in Telangana.

Deficiency of essential micronutrients such as iron, zinc were evident across all three districts which may have a negative impact on microbial metabolism and crop productivity. The consistent occurrence of fungal genera i.e., *Aspergillus*, *Penicillium*, *Fusarium* across the districts highlights their important role in nutrient cycling and decomposition of organic matter in black soil paddy cultivation. The correlation of soil physicochemical properties and microbial abundance emphasizes the importance of organic matter and local soil management practices, which directly aligns with the principles of Indian Knowledge Systems (IKS). IKS has long ago recognized soil as a living entity and emphasized organic inputs, biodiversity conservation and region-specific soil management practices. This correlative study, along with both scientific methods and IKS principles, provided a sustainable approach for improving soil health, long-term agriculture productivity, and ecological balance.

CONCLUSION

This comparative study of paddy-cultivated black soils from three distinct agro-climatic zones of Telangana—Adilabad (north), Medchal (central), and Nalgonda (south)—combined with a correlative analysis of soil fertility and microbial diversity, provides a deeper insight into soil management strategies to improve crop productivity. The study revealed that regional variations significantly influence soil health and microbial communities. Adilabad soils exhibited low salinity, supporting higher microbial diversity, whereas Nalgonda soils, with higher salinity, showed nutrient imbalances and reduced microbial abundance. Medchal soils

displayed moderate nutrient levels and microbial populations. These findings underscore the importance of regular soil health assessment to ensure long-term fertility and productivity.

Microbial analysis highlighted the predominance of Gram-negative bacilli, Actinomycetes, and fungal colonies such as *Aspergillus*, *Penicillium*, and *Fusarium*. The relationship between microbial abundance and organic content emphasizes the role of microorganisms in nutrient cycling, organic matter decomposition, and maintaining soil fertility. Linking microbial diversity with soil physicochemical properties provides actionable insights for sustainable agricultural practices. Indigenous knowledge systems (IKS) have historically promoted similar practices, emphasizing the maintenance of soil fertility through organic amendments, crop rotation, and biodiversity management (Sharma & Das, 2021; Rajendra et al., 2021).

The study illustrates the complex interplay between soil properties and microbial communities, both of which influence crop productivity. It advocates integrating microbial monitoring into soil management strategies for sustainable agriculture. Traditional practices such as rotational cultivation, organic matter incorporation, and site-specific fertility management—core elements of IKS—can enhance ecological balance and long-term soil health. Furthermore, decentralized and community-based approaches, as highlighted in indigenous systems, foster participatory stewardship and resilience against environmental challenges (Singh, 2022).

This research was limited to surface soil analysis and preliminary microbial identification. Future studies may extend to subsurface soils, seasonal and multi-site sampling, and exploring microbial roles in nutrient cycling, metabolite production, and bioremediation. Investigating industrially important microbes for agricultural and pharmaceutical applications and integrating IKS principles with modern scientific tools can further strengthen sustainable practices, biodiversity conservation, and climate resilience.

APPENDIX

Fig 1: Soil samples collected from Adilabad, Medchal & Nalgonda

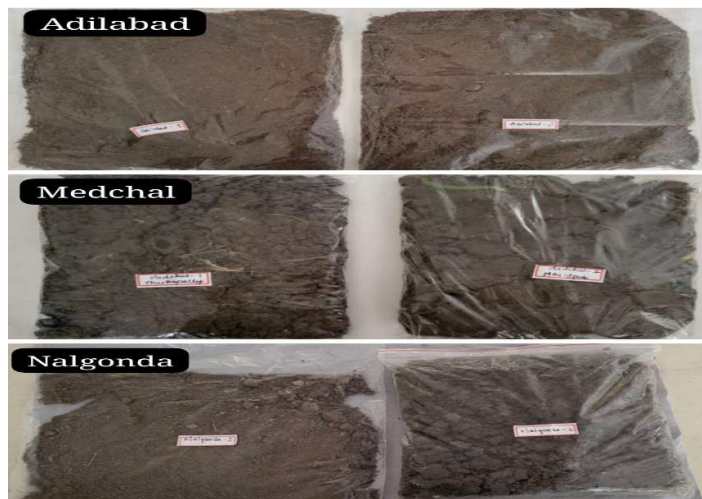


Fig 2: Media preparation & plating of soil microbes in laboratory



Microscopic observation of soil microbial communities

Fig 3: Bacterial isolates

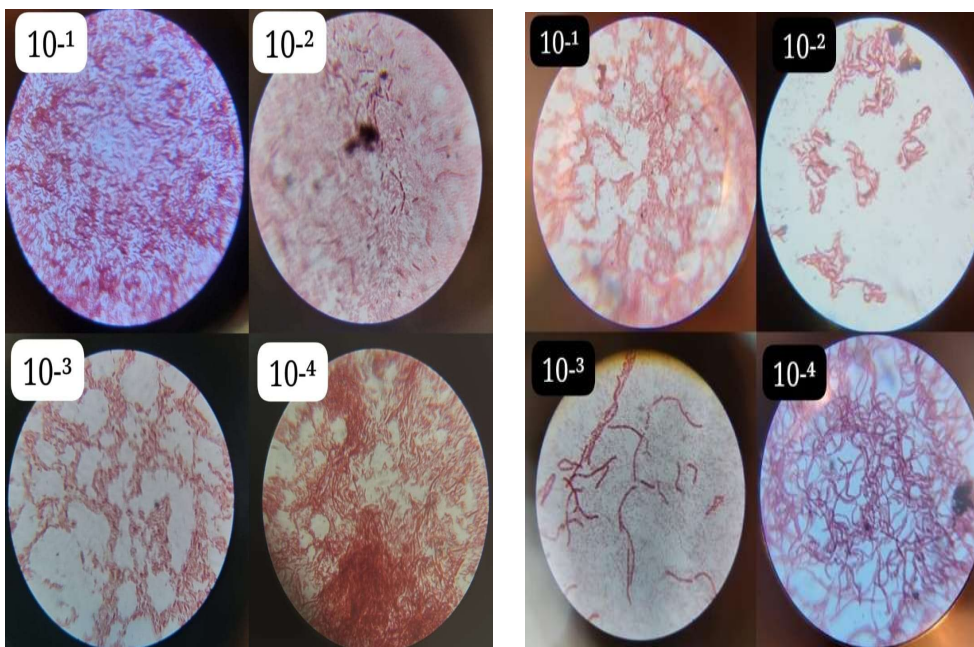
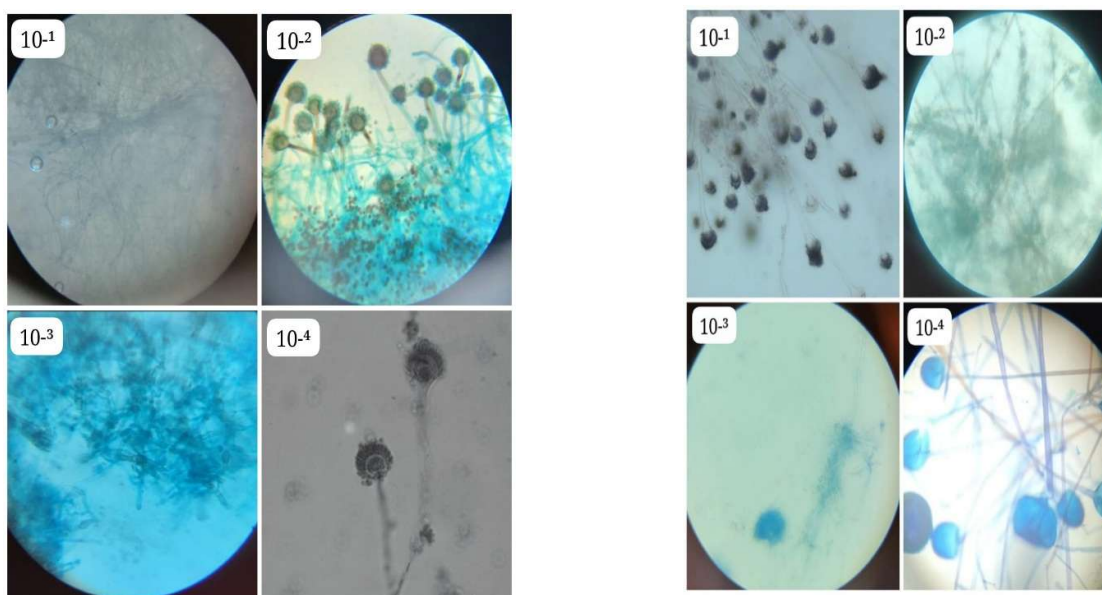


Fig 4: Fungal isolates



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