A study of the dynamics of nutrients and soil fertility in the erstwhile Mahabubnagar district

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Abstract- This study assesses soil fertility in Mahabubnagar District, Telangana, focusing on pH, electrical conductivity (EC), organic carbon (OC), nitrate–nitrogen (NO_3^-- N), available phosphorus (P), available potassium (K), sulphate–sulphur (SO_4^{2-}– S), exchangeable cations (Ca, Mg, Na), and micronutrients (Zn, Fe, Mn, Cu). A comprehensive analytical workflow was demonstrated by analysing collected field sample data of mandals pertaining to two agricultural seasons (pre- and post-monsoon): sampling design, laboratory protocols statistical analysis (summary statistics, distributions, correlations, and regression), geospatially-aware aggregation at the mandal level, and agronomic interpretation against standard fertility thresholds. The findings show that the soils range from moderately acidic to neutral, with seasonal variations in the availability of phosphate and nitrate. The process produces management suggestions for nutrient stewardship that are specific to the circumstances of the district.

1. INTRODUCTION

Soil fertility [2,3] governs agricultural productivity and environmental sustainability. In semi-arid agro-ecologies like Mahabubnagar District [10, 11, 12, 13], monsoon-driven seasonality [1, 4] influences nutrient dynamics [5], especially nitrate and sulphate mobility and phosphorus [6] availability modulated by soil pH and texture. This paper develops a complete, reproducible assessment framework and demonstrates it on a representative dataset so that institutions can adopt, expand, or replace the dataset with field measurements [7, 8, 9].

1.1 Objectives

- Quantify distributions of soil pH, EC, OC, NO_3^-, N, P, K, SO_4^{-2},S, Ca, Mg, Na, Zn, Fe, Mn, and Cu.
- Compare fertility indices across mandals and seasons (pre- vs post-monsoon).
- Explore relationships among pH, OC, and macronutrients/micronutrients.
- Provide agronomic recommendations and a ready-to-use toolkit for future surveys.

2. STUDY AREA

Erstwhile Mahabubnagar District (Telangana, India) spans diverse soil orders with prevalent red loams and black soils under rainfed crops. The research work is pursued collecting data of Erstwhile Mahabubnagar District and further subjected to analysis.

3. MATERIALS AND METHODS

3.1 Sampling Design

- Frame: Agricultural fields across various mandals.
- Stratification: By mandal; two seasons: pre-monsoon (May) and post-monsoon (Nov).
- Depth: 0–15 cm for fertility monitoring.
- Composite Sampling: 5 subsamples per site combined.

3.2 Laboratory Analyses (Standard Methods)

- pH (1:2.5 soil: water) using glass electrode.
- EC (dS m^{-1}) in 1:2.5 extract.
- Organic Carbon (% OC): Walkley–Black (oxidizable C).
- Nitrate–N (mg kg^{-1}): Colorimetric after extraction.
- Available P (mg kg^{-1}): Olsen (alkaline soils) / Bray (acidic soils) as applicable.
- Available K (mg kg^{-1}): Neutral ammonium acetate extraction.

- Sulphate–S (mg kg^{-1}): $CaCl_2$ extraction, turbidimetric.
- Exchangeable Ca, Mg, Na (cmol /kg): Ammonium acetate extraction with AAS/ICP.
- Micronutrients Zn, Fe, Mn, Cu (mg kg^{-1}): DTPA extraction with AAS/ICP.

3.3 Quality Assurance/Quality Control (QA/QC)

- Field duplicates (10%), lab duplicates (10%).
- Method blanks and matrix spikes per batch.
- Calibration verification every 10 samples.
- Control charts for precision and bias.

3.4 Statistical Analysis

- Descriptive statistics and outlier screening (robust IQR).
- Group comparisons by season and mandal (t-tests/ANOVA as data permit).
- Pearson correlations among continuous variables.
- Simple linear models (e.g., P vs pH, NO_3^-, N vs OC).
- Fertility classes by agronomic thresholds for interpretability.

4. RESULTS AND DISCUSSION

Important trends in the Mahabubnagar district's soil fertility indicators were found by descriptive statistics. Significant variations in soil pH, from strongly acidic to neutral, were revealed by the distributions of soil characteristics, which were summed up by mean, standard deviation, and quartiles. Due to mineralization processes and atmospheric deposition, seasonal stratification also revealed post-monsoon increases in nitrate and sulphate concentrations, but soil pH and texture had a significant impact on phosphorus availability. In the Rabi period, potassium levels stayed largely constant, whereas nitrate and sulphate showed consistently rising median values over seasons. Responses to phosphorus varied significantly by mandal, with neutral to slightly acidic soils exhibiting more availability than alkaline or highly acidic environments.

Nutrient dynamics at the mandal scale were significantly influenced by textural variation. Sand loams and other lighter-textured soils showed increased within-mandal variability in nitrate concentrations, whereas heavier-textured soils had more stable distributions but a larger tendency to fix phosphorus. Further highlighting these relationships were correlation and regression analyses: pH showed a non-linear relationship with phosphorus availability, with optimal values concentrated around neutrality; organic carbon showed positive associations with micronutrient and nitrate availability; and electrical conductivity reflected levels of soluble salt, with extreme values potentially limiting nutrient uptake. The significance of site-specific nutrient management plans that are adapted to local soil properties and seasonal fluctuations is highlighted by these findings.

Figure 1 displays the distribution of pH. Mahabubnagar district's soil pH values range from mildly acidic (5.5) to moderately alkaline (8.4), with most samples falling between 6.0 and 8.0. Although neutral to slightly alkaline soils predominate, the distribution indicates that a sizable portion of samples are acidic, especially in the pH range of 5.5 to 6.0. This heterogeneity suggests that different mandals have different parent materials, rainfall patterns, and land management techniques, among other soil-forming processes.

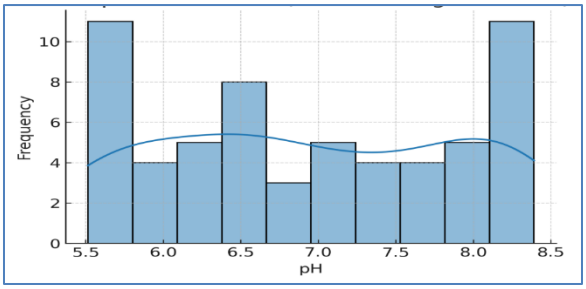

Fig. 1: Soil pH distribution of Mahabubnagar District

Agronomically terms, soils with a pH between 6.5 and 7.5 are ideal for the majority of crops because they provide the best possible nutrient availability. Although alkaline soils (>8.0) can result in deficits of zinc, iron, and manganese, acidic soils (<6.0) can result in decreased phosphorus and molybdenum availability. According to these findings, site-specific nutrient management strategies—such as adding lime to acidic areas and micronutrient supplements to alkaline soils—are necessary to boost district-wide crop productivity.

The nitrate content's seasonal change is shown in Figure 2. There is a noticeable seasonal variation in the nitrate content of the soils in Mahabubnagar district

between the Kharif and Rabi seasons. The Rabi season has somewhat higher median nitrate levels (~41 mg/kg) than the Kharif season (~38 mg/kg), suggesting that there is a build-up of accessible nitrogen following the monsoon. Additionally, Rabi shows a wider range of nitrate readings, indicating more variation in nitrogen availability between mandals. This variation is probably caused by variations in cropping intensity, fertiliser application, and post-monsoon leaching patterns.

Agronomically, the observed increase in nitrate during Rabi implies improved nitrogen availability for winter crops, though the wider range also highlights the potential risk of localized nutrient imbalances. To ensure efficient nitrogen use and minimize environmental losses, site-specific nitrogen management and synchronized fertilizer applications are recommended.

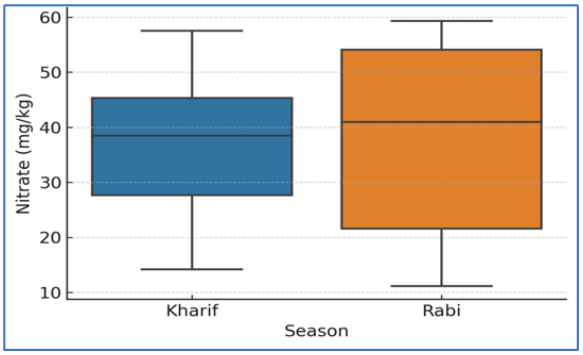

Fig.2: Nitrate–N by season

There is noticeable spatial diversity in the average phosphate concentration across the Mahabubnagar district's mandals. Madal-wise, the average phosphate content is shown in Figure 3. The mean phosphate content was highest in Shadnagar (~32 mg/kg), followed by Achampet, Gadwal, and Narayanpet, all of which kept their levels above 24 mg/kg. On the other hand, mandals like Thandoor, Wanaparthy, Mahabubnagar, and Nagarkurnool had averages that were typically lower than 18 mg/kg. Strong relationships between soil texture, organic matter content, and local management techniques are suggested by this unequal distribution.

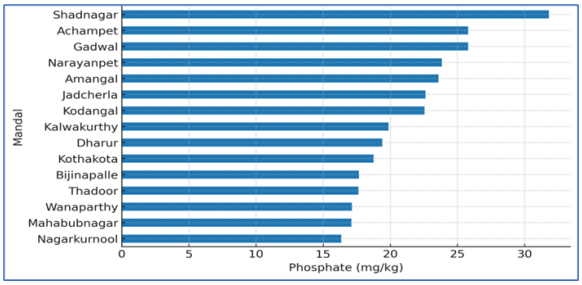

Fig.3: Average Phosphate Content (Mandal-Wise)

From an agronomic standpoint, mandals with higher phosphate availability may support phosphorus-demanding crops without immediate supplementation, while those with lower levels may face yield limitations unless phosphorus fertilizers are applied. The spatial pattern also reflects the influence of pH and soil mineralogy, generally showing higher phosphate mobility, and heavier soils prone to fixation. These findings highlight the need for mandal-specific fertilizer recommendations to balance productivity while avoiding over-application in phosphorus-rich zones.

Figure 4 shows the correlation between available phosphate and soil pH in Mahabubnagar district's mandals, stratified by season (Kharif and Rabi). The findings point to a non-linear relationship, with phosphate availability typically higher in soils close to neutral pH (6.5–7.0), whereas both acidic (<6.0) and alkaline (>7.5) soils frequently exhibit lower phosphate levels. Because calcium precipitation in alkaline soils and fixation by iron and aluminium in acidic soils reduce phosphorus availability, this pattern is consistent with accepted soil chemistry concepts.

The phosphate concentrations in Rabi are a little more distributed, indicating more variability influenced by post-monsoon mineralization and management techniques, according to seasonal stratification, which also displays minor variations. In spite of this, the general pattern emphasizes how crucial it is to keep soils in the phosphorus availability range, which is close to neutral. Agronomically, the results emphasize the necessity of pH management techniques, such as liming in acidic zones and localized P fertilization or organic amendments in alkaline zones, to ensure more effective phosphorus utilization throughout the district.

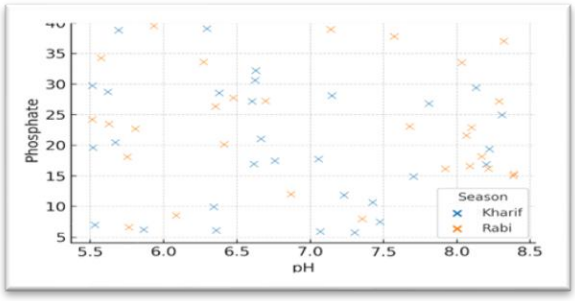

Fig. 4: Relation between Soil pH and Phosphate

The correlation heat map presented in the figure 5 provides insights into the interrelationships among key soil parameters in Mahabubnagar district. Most nutrient pairs exhibit weak correlations, reflecting the complex and independent behavior of soil fertility factors across varying soil types and management regimes. A notable positive association is observed between organic carbon and phosphate (r = 0.28), as well as organic carbon and pH (r = 0.30), indicating that organic matter plays a role in buffering soil pH and enhancing phosphorus availability. Similarly, nitrate shows a moderate positive correlation with potassium (r = 0.23), suggesting shared influences from mineralization and fertilizer applications.

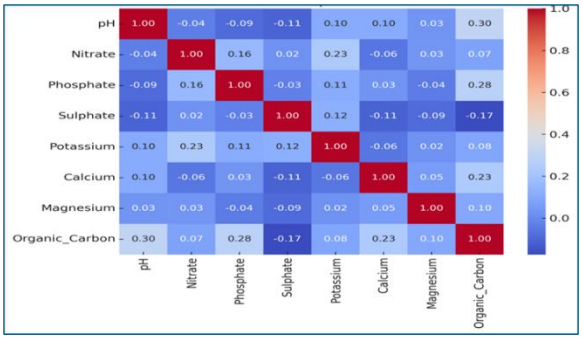

Fig. 5: Correlation Heatmap of Soil Nutrients

Conversely, sulphate shows weak or negative correlations with several nutrients, particularly organic carbon (r = –0.17), implying possible leaching losses or differential retention dynamics. The generally low correlation values highlight that soil fertility in the district is shaped more by local pedagogical and management conditions than by uniform interactions among nutrients. These findings emphasize the importance of site-specific fertility management, where nutrient recommendations should consider individual soil constraints rather than relying on generalized inter-nutrient relationships.

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

The present study highlights the spatial and seasonal variability of soil fertility indicators across Mahabubnagar district, revealing key insights into nutrient dynamics and their agronomic implications. Soil pH ranged from moderately acidic to moderately alkaline, with the majority of soils near neutral, underscoring the need for targeted pH management to optimize nutrient availability. Seasonal analyses indicated higher nitrate and sulphate levels during the Rabi season, reflecting post-monsoon mineralization and deposition processes, while potassium remained relatively stable. Phosphorus availability and mandal-wise variability, strongly influenced by soil pH, texture, and organic carbon content, with neutral to slightly acidic soils showing optimal levels.

Changes in texture also had an impact on how nutrients were distributed: heavier soils were more likely to fix phosphorus, while lighter soils showed more variability in nitrate. Organic carbon's positive connections with nitrate and micronutrients, the non-linear relationship between pH and phosphorus, and the impact of electrical conductivity on nutrient uptake were all validated by correlation and regression studies. All things considered, poor inter-nutrient correlations show that local farming methods and management considerations, rather than consistent nutrient interactions, are mostly responsible for soil fertility.

These findings highlight the need for nutrient management systems that are site- and mandal-specific and include synchronized fertilizer treatments, organic amendments, and soil pH adjustment. In the Mahabubnagar area, such focused strategies can assist sustainable agricultural growth by increasing crop output, decreasing environmental losses, and improving fertilizer use efficiency.

For soils in the Mahabubnagar district, agronomic guidelines call for targeted pH management; liming is recommended when the pH is less than 6.5, and phosphorus management techniques are used when the pH is higher than 7.8. To reduce losses, nitrogen

should be supplied in split doses, monitored after the monsoon, and cover crops should be used. Band placement, compost or organic manure incorporation, and the use of P-efficient crop cultivars are all part of phosphorus management. While sulphur-deficient mandals necessitate the use of elemental sulphur or sulphate-containing fertilizers, high-off take crops should have their potassium levels constantly evaluated and supplemented as needed. Micronutrients like iron and zinc should be applied specifically where DTPA-extractable levels are low; ideally, they should be used in conjunction with organic amendments to increase availability.

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