Soil Nutrient Variability Mapping Using Geospatial Techniques for Sustainable Agriculture in Chodavaram Mandal, Anakapalli District, A.P, India.

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Abstract: Agricultural plays a vital role in a farming country's economic development of food security. However, the farming sector is going through a difficult phase due to a lack of awareness of farming activities in India. Sometimes, in most cases, the farmers are unaware of the suitable crops according to their soil quality and structure. The system considers various parameters such as weather forecast and soil condition and gives the best crop ideal for cultivation. Soil nutrient availability is a critical factor influencing crop productivity. This study aims to analyze the spatial distribution of soil nutrients potassium (K), nitrogen (N), phosphorus (P), pH, electrical conductivity (EC), and organic carbon (OC) using geospatial techniques. Spatial interpolation methods were applied to generate detailed nutrient maps and field soil sampling from 66 locations. The results provide insights into nutrient variability and recommend sustainable agricultural practices.

Keywords: Soil nutrients, spatial interpolation, geospatial analysis, sustainable agriculture.

INTRODUCTION:

The Agricultural sector is one of the world's oldest and most important economic sectors. This sector is crippled by the lack of awareness, resources, and improper infrastructure in most third-world countries. These factors lead to more severe problems like less land yield, farmer suicides, an economic downturn for farmers, etc (Kartik Ahad et al., 2022). India is traditionally known as an agrarian country as more than 60% of people depend on agriculture both directly and indirectly for their livelihood (Lopamudra Lenka Samanta Ray 2015). Indian agriculture has continued to grow but at a little slower rate (2.3% per annum), but still, it is at a high level. Modern inputs such as HYV seed, fertilizer, and irrigation were major contributors to TFP growth in Indian agriculture. The rapid adoption of new technologies and improved rural infrastructure induced productivity growth, (Ramachandra Murthy K et al., 2014). Today, the Agriculture Sector is a major contributor to the Indian Economy. In a country like India, which has an ever-increasing demand for food due to a rising population, advances in the agriculture sector are required to meet the needs. Soil is an important ingredient of agriculture. Soil quality may include the capacity of water retention, carbon sequestration, plant productivity, waste remediation, and other functions or, it may be defined narrowly. the development of the concept of land quality and explores the use of soil chemical and physical attributes as determines of soil quality (M. Lokeswari et al., 2024). There are several kinds of soil. Each type of soil can have different features and crops grow on different types of soils. We need to know the features and characteristics of various soil types to understand which crops grow better in certain soil types.

Agricultural productivity heavily depends on soil health, which is determined by the availability of essential nutrients. The variability of soil nutrients across landscapes necessitates precise mapping and analysis to guide effective agricultural management. Crop yield prediction is critical in achieving these goals, enabling farmers and policymakers to make informed decisions regarding crop management and resource allocation (M. Lokeswari et al., 2024). This study employs geospatial techniques to map the spatial distribution of soil nutrients in Chodavaram Mandal, Andhra Pradesh and evaluates their implications for sustainable agriculture.

Study Area:

Chodavaram Mandal is located in Anakapalle District, Andhra Pradesh, India, with coordinates 17°82′77” latitude and 82°93′45” longitude. The area spans approximately 145.5 km² and features diverse soil types, including clayey soils, and supporting crops such as paddy, sugarcane, and vegetables.

Soil Sampling and Analysis:

Soil samples were collected from 66 georeferenced locations across the study area. Laboratory analysis determined the physio-chemical properties of the soil, including nitrogen, phosphorus, potassium, soil pH, electrical conductivity, and organic carbon content.

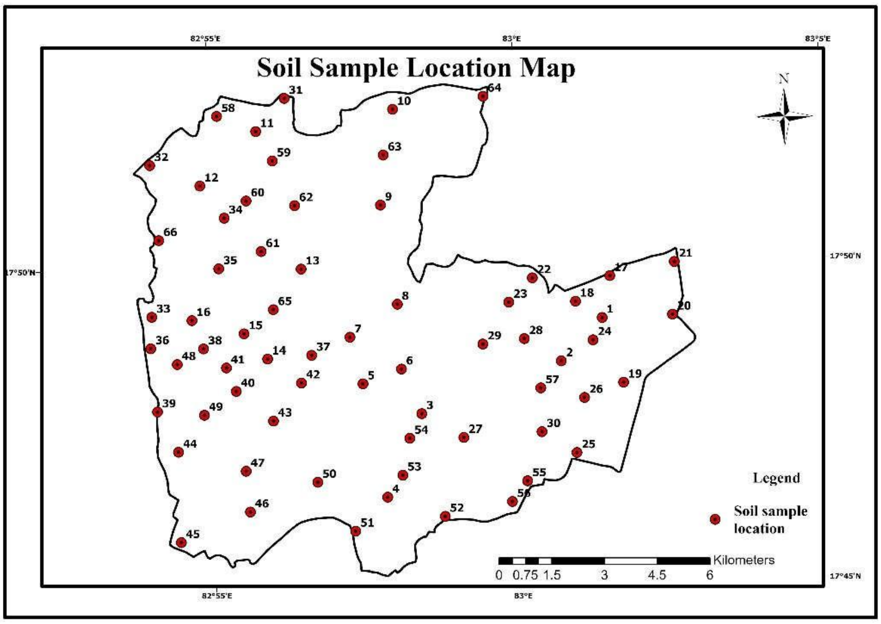

Fig 1. Soil Sample Location Map

The sample collection villages are Ankupalem, Lakkavaram, Amberupuram, Gavaravaram, Govada, Chodavaram, Chakipalle, Gowripatnam, Pakirsahebpeta, Laxmipuram, Venkayyagaripeta, Venkannapalem, Rayapurajupeta, Juttada, Adduru, Khandipalle, Duddupalem, Gajapathinagaram, Muddruthi, Narasayyapeta, Bhoagapuram, Bennavolu, Jannavaram, Gandhavaram, Dumunapalle, Maycheralapalem, Seemunapalle, Annavaram, M. Kothapalle, Thimmannapalem, Sreerampatnam. These collected samples underwent a thorough examination in the laboratory to assess essential soil parameters such as pH, electrical conductivity, nitrogen, phosphorus, potassium, and total organic carbon. Soil testing is an essential component of soil resource management. Each sample collected must be a true representative of the area being sampled. The utility of the results obtained from the laboratory analysis depends on the sampling precision. Hence, the collection of a large number of samples is advisable so that a sample of the desired size can be obtained by sub-sampling. In general, sampling is done at the rate of one sample for every two-hectare area. However, at least one sample should be collected for a maximum area of five hectares. For soil survey work, samples are collected from a soil profile representative of the soil of the surrounding area.

Spatial Interpolation Techniques:

Spatial interpolation techniques are essential tools in geographic information system (GIS) analyses, particularly for predicting and visualizing spatial patterns of environmental variables. Geostatistical interpolation methods, such as Inverse Distance Weighting (IDW), are commonly used to estimate unknown values at unsampled locations based on the values measured at known locations.

In this study, Inverse Distance Weighting (IDW) was applied using ArcGIS Pro software to generate spatial distribution maps for each soil nutrient. IDW is a deterministic geostatistical method that assumes that the value of an unsampled point is influenced more by nearby sampled points than those farther away. The influence decreases as the distance increases, which is controlled by a power parameter in the IDW algorithm. A higher power parameter gives greater weight to closer points, producing a more localized result, while a lower power parameter smoothens the interpolated surface. The nutrient variability maps generated through IDW interpolation in ArcGIS Pro are invaluable for understanding the spatial distribution of soil nutrients, enabling better agricultural decision-making. These maps can also serve as inputs for machine learning models to improve crop yield predictions.

Results and Discussion:

The essential findings were obtained from laboratory tests conducted on soil parameters. The results of these tests have been meticulously mapped across the study area in Chodavaram Mandal using the spatial interpolation technique Inverse Distance Weighted. The objective behind conducting agricultural soil tests is to assess and analyze the specific characteristics of the soil, comparing them against the permissible limits. After analyzing the test results, deficiency nutrients were identified and subsequently recommended to maintain soil fertility.

Spatial Distribution of Soil Nutrients:

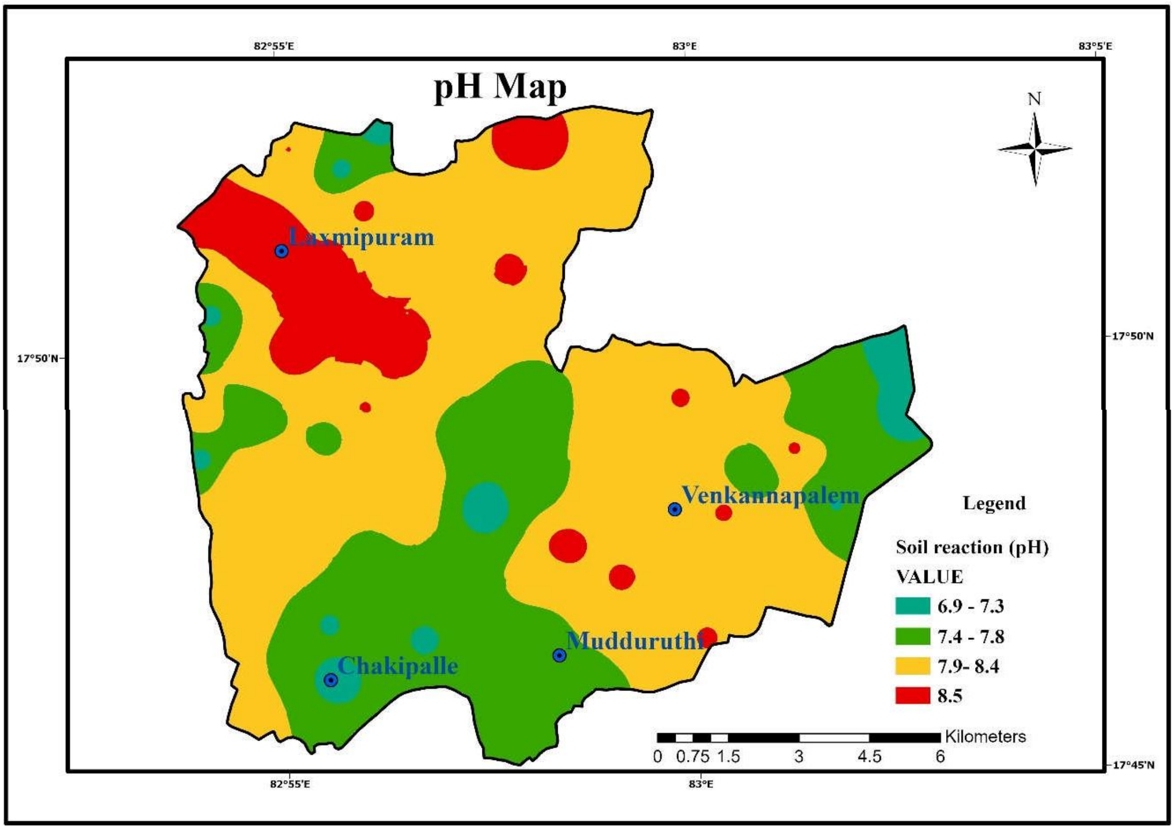

Fig 1. Spatial Distribution of pH Map

Soil pH: The soil pH values (6.91-8.56) fall within the neutral to moderately alkaline range. All samples are within permissible limits as per IS standards.

Recommendations:

For Acidic Soil (pH < 6): Apply agricultural lime (calcium carbonate or dolomite lime) to increase pH and reduce aluminum toxicity. Determine lime application rates based on soil testing and the buffer pH.

For Alkaline Soil (pH > 8.5): Use elemental sulphur or acidifying fertilizers like ammonium sulfate to lower pH gradually. Introduce organic matter (compost, manure) to buffer pH and enhance soil microbial activity. Monitor pH levels regularly to maintain balance and ensure crop-specific suitability.

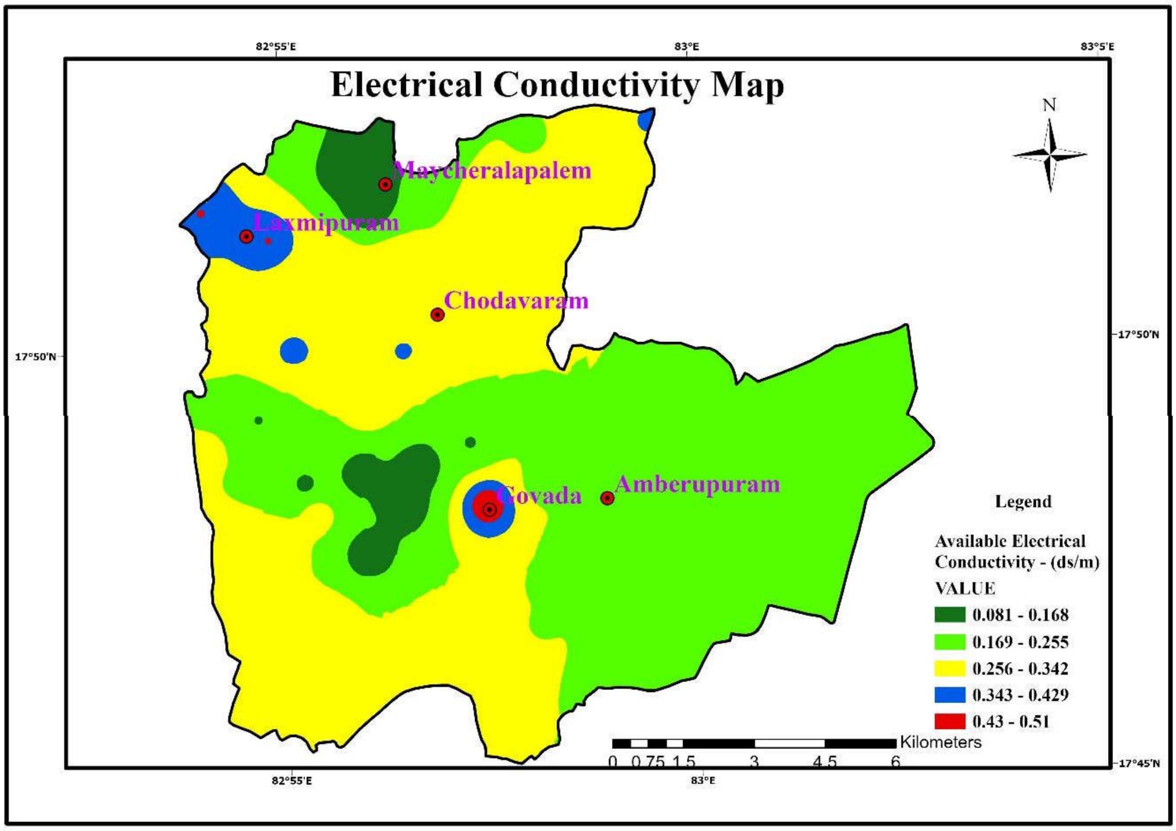

Fig 2. Spatial Distribution of Electrical Conductivity Map

Electrical Conductivity (EC): The EC values range from 0.08-0.517 dS/m, with most samples suitable for cultivation. Values above 0.99 dS/m indicate salinity issues requiring treatment.

Recommendations:

For EC < 0.42 dS/m: Ensure optimal fertilization, as extremely low EC may indicate low nutrient availability.

For EC 0.42-0.99 dS/m (Optimal Range): Maintain irrigation water quality and ensure balanced fertilization to sustain the suitability for cultivation.

For EC > 0.99 dS/m (High Salinity): Improve drainage to leach salts below the root zone. Use salt-tolerant paddy varieties or implement crop rotation with salt-resistant crops. Avoid over-fertilization with saline-based fertilizers. Apply gypsum or soil conditioners where appropriate to mitigate salinity.

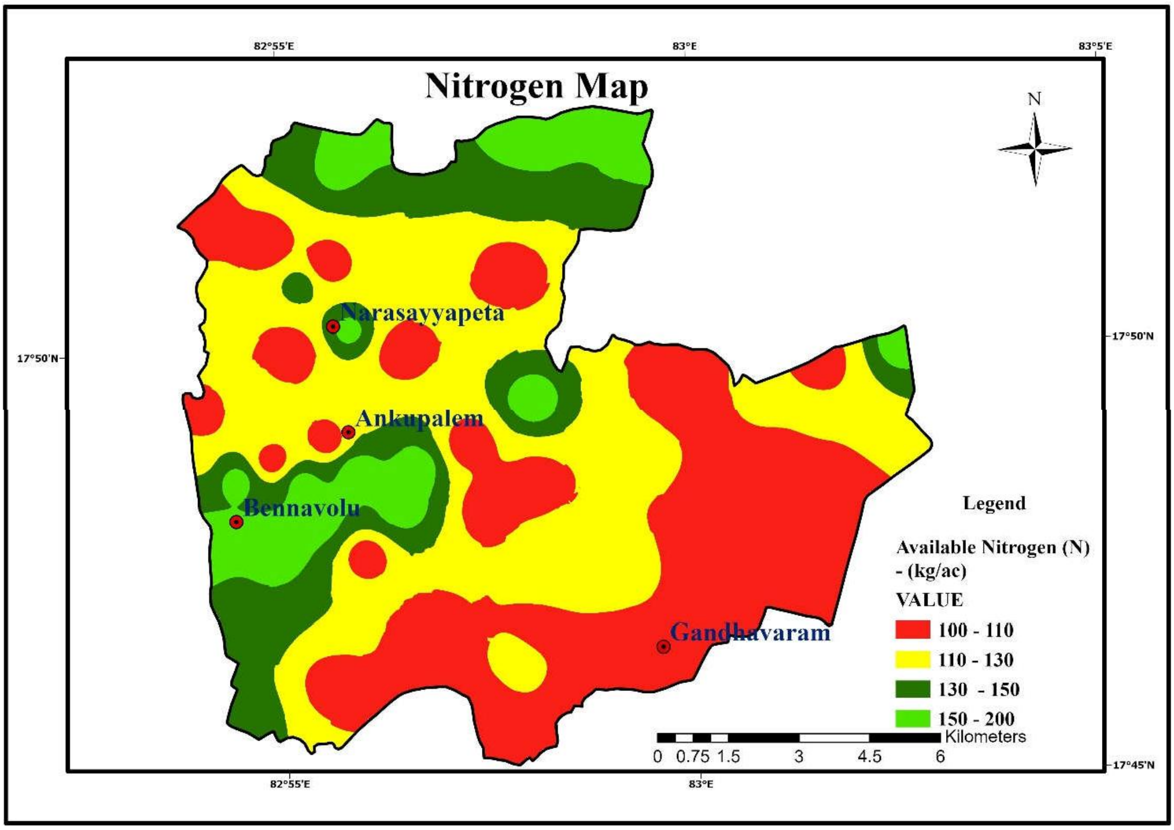

Fig 3. Spatial Distribution of Nitrogen Map

Nitrogen (N): Nitrogen levels range from 100-200 kg/ac, falling within low to medium levels. All samples are within permissible limits.

Recommendations:

For Low Nitrogen (100-150 kg/ac): Apply nitrogen-rich fertilizers like: Urea (41% nitrogen). Ammonium nitrate (34% nitrogen). Diammonium phosphate (DAP, 18% nitrogen). Incorporate green manure crops like clover or legumes to fix atmospheric nitrogen. Consider controlled-release fertilizers to reduce losses and improve efficiency.

For Medium Nitrogen (150-200 kg/ac): Balance fertilization with phosphorus and potassium. Avoid over-application to prevent nitrogen leaching and environmental issues.

For High Nitrogen (>200 kg/ac): Reduce nitrogen application and monitor levels carefully to prevent toxicity or imbalanced growth.

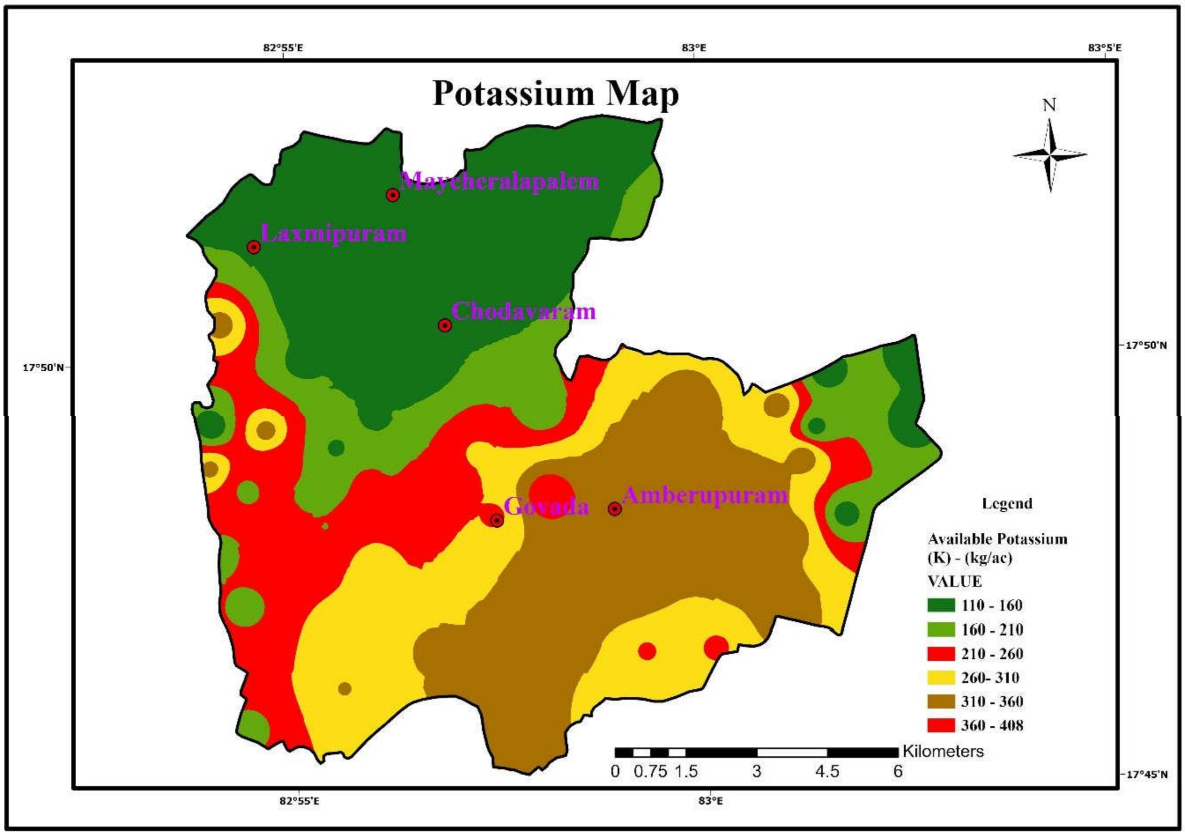

Fig 4. Spatial Distribution of Potassium Map

Potassium (K): Potassium levels range from 110-408 kg/ac, falling within low to high categories. All samples are within permissible limits.

Recommendations:

For Low Potassium (<150 kg/ac): Apply potassium-rich fertilizers like: Potassium chloride (MOP, 60-62% K2O). Potassium sulfate (SOP, 50% K2O), especially for chlorine-sensitive crops. Use crop residues (e.g., rice straw) to return potassium to the soil.

For Medium Potassium (150-300 kg/ac): Balance potassium with nitrogen and phosphorus for optimal plant growth. Use potassium fertilizers only if deficiencies are indicated by crop growth or testing.

For High Potassium (>300 kg/ac): Avoid excess potassium fertilization. Improve drainage to prevent leaching into groundwater. Monitor soil nutrient balance to prevent antagonistic effects on magnesium and calcium uptake.

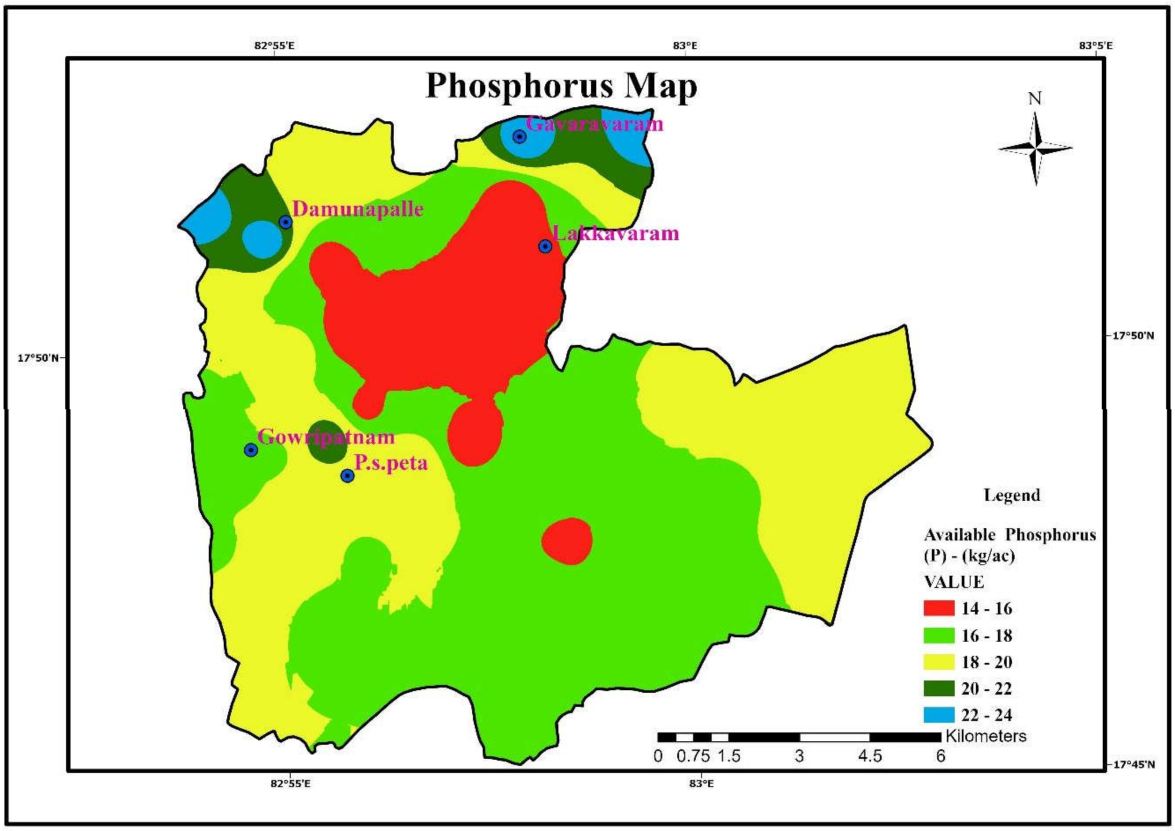

Fig 5. Spatial Distribution of Phosphorus Map

Phosphorus (P): Phosphorus levels range from 14-24 kg/ac, showing low to high levels. Most samples are within permissible limits.

Recommendations:

For Low Phosphorus (<15 kg/ac): Apply phosphorus-based fertilizers like: Diammonium phosphate (DAP, 46% P2O5). Monoammonium phosphate (MAP, 48% P2O5). Use rock phosphate for long-term phosphorus supply in acidic soils.

For High Phosphorus (>24 kg/ac): Reduce phosphorus application and focus on balanced fertilization. Introduce phosphorus-adsorbing materials like aluminum sulfate (alum) to immobilize excess phosphorus. Promote beneficial microorganisms (e.g., mycorrhizal fungi) that enhance phosphorus uptake efficiency.

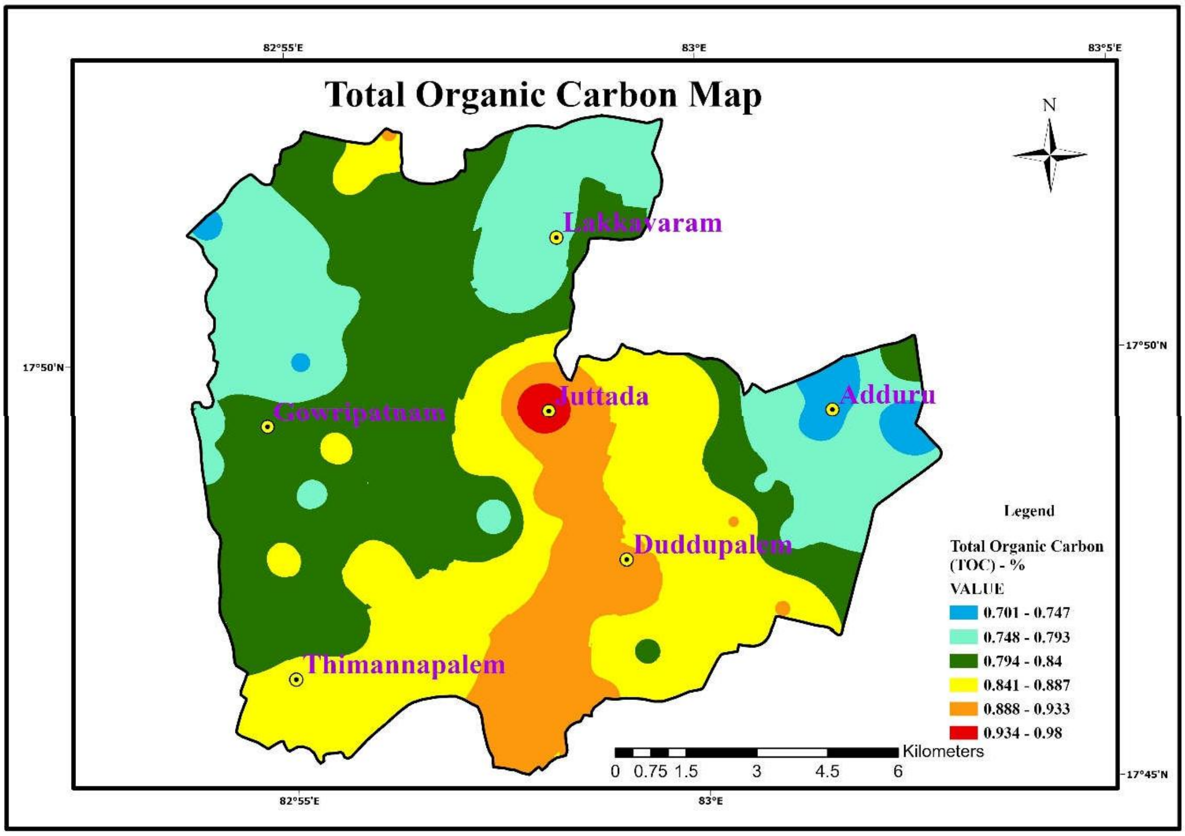

Fig 6. Spatial of Distribution Total Organic Carbon Map

Total Organic Carbon (TOC): The TOC ranges from 0.7-0.98%, with most samples showing medium to high levels.

Recommendations:

For Low TOC (<0.75%): Incorporate organic amendments such as well-rotted compost, farmyard manure, and cover crops (e.g., legumes) to improve soil structure and carbon content. Practice conservation tillage to reduce organic matter loss.

For High TOC (>0.75%): Monitor TOC levels to ensure they are balanced with other nutrients like nitrogen, phosphorus, and potassium. Promote microbial activity through regular organic matter additions and balanced fertilization.

Implications for Agricultural Practices:

The nutrient maps reveal significant spatial variability, emphasizing the need for site-specific soil management practices. For example, nitrogen-deficient areas could benefit from targeted fertilizer application, while regions with high EC values may require salinity mitigation measures.

Conclusion:

The application of spatial interpolation techniques, such as Inverse Distance Weighting (IDW), in assessing soil nutrient variability has proven to be a powerful tool for modern agricultural management. The generated maps provide a clear visualization of nutrient-rich and deficient zones, offering valuable insights for farmers and policymakers. These insights enable site-specific nutrient management, ensuring optimal fertilizer application, reducing wastage, and improving crop yields sustainably. By pinpointing areas of nutrient deficiency, these techniques help minimize environmental impacts such as nutrient runoff, leaching, and soil degradation, contributing to sustainable agricultural practices. Policymakers can also use these insights to allocate resources more effectively, ensuring targeted interventions in areas requiring immediate attention. Future research should explore integrating remote sensing data for more comprehensive soil health monitoring, Deploying IoT-based soil sensors for continuous monitoring of pH, electrical conductivity, and nutrient levels, and providing real-time data for decision-making.

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