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Spatial variability mapping of available macro nutrient status in soils of Amalapuram division, Dr. B. R. Ambedkar Konaseema district, Andhra Pradesh using geospatial tools

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ABSTRACT

Characterization and mapping of soil nutrients is essential for understanding the spatial variability patterns of soil nutrients across a defined study area. The Amalapuram division, a key rice-growing region in Dr. B. R. Ambedkar Konaseema district, is largely dominated by alluvial soils that exhibit pronounced spatial heterogeneity in soil properties. In the present study, 110 georeferenced surface soil samples were collected through stratified random sampling approach, integrating remote sensing, GPS-based positioning, topographic features, and existing soil maps to ensure comprehensive spatial representation of soil conditions. The soils were analysed following standard procedures and the spatial variation maps were generated using Quantum GIS. The results revealed that soil reaction was slightly acidic to strongly alkaline, with a predominance of moderately alkaline soils, while most soils were non-saline in nature. Organic carbon status, available nitrogen and phosphorus exhibited medium to high fertility status, whereas potassium was predominantly high, with considerable spatial variability across the study area. Based on the overall soil characteristics and fertility status, the Mummdivaram, Mamidikuduru, Amalapuram, Razole mandals of the study area were found to possess favourable conditions for agricultural production in Amalapuram division, Dr. B.R Ambedkar Konaseema district, Andhra Pradesh.

Keywords: Spatial variability, Remote sensing, GPS, Soil fertility, Nutrient variability, Digital soil mapping

Soil nutrient status is a fundamental indicator of soil fertility and agricultural productivity. It determines the availability of essential macro and micronutrients required for optimum plant growth. Balanced nutrient availability improves crop yield, quality, and nutrient use efficiency, whereas deficiencies or excesses adversely affect soil health and sustainable agricultural production (Brady *et al.*, 2017) [1]. Spatial assessment of soil nutrients is essential for identifying nutrient variability and implementing site-specific nutrient management practices (Mulla, 2013) [2]. Recent advances in Remote Sensing and Geographic Information Systems (GIS) have enabled rapid, cost-effective, and large-scale monitoring of soil resources (McBratney *et al.*, 2003) [3]. Field observations integrated with laboratory analysis and GIS facilitate the preparation of thematic maps showing the spatial distribution of soil nutrients. Spatial interpolation techniques such as Inverse Distance Weighting (IDW) estimate physico chemical and nutrient values at unsampled locations based on nearby observations, producing continuous thematic maps that support precision agriculture, efficient fertilizer management, and sustainable land-use planning in Amalapuram division, Dr. B. R. Ambedkar Konaseema district, Andhra Pradesh (Burrough *et al.*, 1998) [4].

Materials and methods

Amalapuram Division is one of the prominent administrative divisions of Dr. B.R Ambedkar Konaseema district, Andhra Pradesh, situated in the fertile Godavari delta region (Government of Andhra Pradesh, 2024 [5] (<https://konaseema.ap.gov.in/>)). The division lies approximately between 16°30'–16°55' N latitude and 81°45'–82°15' E longitude with a geographical area of about 930 sq km (0.93 lakh ha) of which the net sown area is approximately 0.60 lakh ha, while the gross cropped area is about 1.05 lakh ha indicating high cropping intensity due to assured irrigation (Directorate of Economics and Statistics, 2024) [5]. The region experiences a tropical humid climate with an average annual rainfall of about 1,295 mm, received mainly from the southwest and northeast monsoons, and temperature ranged from 20 °C to 39 °C in winter and summer. The soils are predominantly deep alluvial clay loam to clay soils, which are highly fertile and suitable for intensive agriculture (NBSS & LUP, 2019). Agriculture is the principal occupation, with rice as the dominant crop, followed by coconut, banana, black gram, green gram, and various horticultural crops, supported by the extensive Godavari canal irrigation system (District Survey Report, 2021) [6].

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Soil samples were collected during the summer using a hand-held Global Positioning System to accurately record the sampling locations. Samples were collected from a depth of 0 to 30 cm by digging a V-shaped pit with a spade. At each sampling site, three to five sub samples were collected by removing approximately 2.5 cm thick vertical slice from the exposed face of the V-shaped pit. These sub samples were thoroughly mixed, and a representative sample was prepared by following quartering method and it was transferred to clean, labelled polythene bags and transported to the laboratory. The collected samples were shade-dried for several days, gently crushed with a wooden hammer, and passed through 2 mm sieve to remove coarse fragments and to obtain a uniform sample. The processed soil samples were stored properly and kept ready for subsequent laboratory analysis.

The soil reaction (pH) and electrical conductivity (EC) in ratio of 1:2.5 soil water extract were measured using standard procedures as described by Jackson (1973) [7]. Organic carbon (OC) was determined using wet oxidation method as outlined by Jackson (1973) [7]. Available nitrogen content in the soil samples was estimated by alkaline permanganate method as described by Subbiah and Asija (1956). Available phosphorus in soils was extracted by Olsen's extractant as described by Olsen *et al.* (1954) [8] of pH 8.5 and phosphorus content in the extract was estimated by Murphy and Riley Method (using ascorbic acid as reducing agent) as described by Olsen *et al.* (1954) [8] using spectrophotometer at 660 nm wave length. Available potassium in the soil samples was determined by using neutral normal ammonium acetate extractant and the extract was directly fed to flame photometer (Jackson, 1973) [7]. The data obtained from the physico chemical properties and available macro nutrient status of soil in study area was used to generate spatial variability maps by applying Inverse Distance Weighted (IDW) as interpolation tool in QGIS3.42 software.

Results and discussion

Soil pH

The soil pH of the study area was slightly acidic to strongly alkaline in soil reaction, with pH values ranging from 6.2 to 8.8 (Table 1 and Figure 1). The slightly acidic to strongly alkaline reaction observed in the study area might be attributed to variations in parent material, drainage conditions, organic matter decomposition and soil management practices. The soil pH is primarily governed by parent material, climate, vegetation and management practices (Brady and Weil, 2017) [1].

Out of the 110 soil samples analysed, 8 (6.90%) soil samples were found to be slightly acidic (< 6.5); 18 (15.52%) samples were neutral (6.6 to 7.3); 33 (28.45%) samples were slightly alkaline (7.4 to 7.8); 41 (35.34%) samples were moderately alkaline (7.9 to 8.4); and 16 (13.79%) samples were strongly alkaline (8.4 to 9.0). Thus, the soils were predominantly moderately alkaline, followed by slightly alkaline soils.

The lowest mean value of soil pH 7.4 was recorded in Sakhinetipalle and Uppalguptam mandals whereas, the highest mean value of 7.8 in Allavaram, I. Polavaram mandals. The alkaline nature of the soils might be attributed to the accumulation of basic cations such as calcium and magnesium on the exchange complex through sediment deposition and irrigation water (Kumar *et al.*, 2022) [9] along the alluvial terrain and continuous canal irrigation that promote the accumulation of soluble and exchangeable bases (Lalitha *et al.*, 2024) [10]. The acidic nature of soils might be associated with increased organic matter decomposition and localized leaching under prolonged moisture conditions (Mathew, 2024) [11].

Electrical conductivity

The perusal of data (Table 1) indicated a considerable variation in electrical conductivity (EC) of soils in the study area. The EC values ranged from 0.09 to 8.32 dS m⁻¹, with an overall mean value of 1.26 dS m⁻¹. Majority of the soils in the study area were non-saline in na-

ture, although localized salinity was observed in some coastal and poorly drained locations.

The mean EC values varied considerably among the mandals of the Amalapuram division. The highest mean EC of 1.88 dS m⁻¹ was observed in Sakhinetipalle, followed by Katrenukona (1.77 dS m⁻¹) and Allavaram (1.37 dS m⁻¹), whereas the lowest mean EC of 0.51 dS m⁻¹ was recorded in I. Polavaram mandal. The electrical conductivity (EC) of the soils indicated that 89 samples (76.72%) were normal/non-saline, 19 samples (16.38%) were slightly saline, 6 samples (5.17%) were moderately saline, and 2 samples (1.72%) were severely saline. Overall, the majority of the soil samples (76.72%) were classified as normal/non-saline, indicating that salinity was not a major constraint in most of the sampled soils. The variation in EC in the study area might be attributed to differences in drainage, irrigation water quality, salt accumulation, groundwater conditions and evapotranspiration (Maji *et al.*, 2023) [12]. The relatively higher EC values observed in Sakhinetipalle and Katrenukona may be associated with relatively poor drainage conditions, accumulation of soluble salts, saline groundwater influence and higher evapotranspiration, particularly in areas influenced by coastal and tidal conditions as depicted in figure 1. In contrast, the lower EC values observed in inland mandals such as I. Polavaram may be attributed to better drainage and continuous freshwater irrigation, which facilitate the leaching of soluble salts from the soil profile.

Organic carbon

The organic carbon content of soils in different mandals of Amalapuram division showed considerable variation. The organic carbon values ranged from 0.51 to 1.26 per cent, with an overall mean value of 0.75 per cent (Table 1). Among the mandals, the highest mean organic carbon content of 0.86 per cent was recorded in Amalapuram, followed by Allavaram (0.82%) whereas the lowest mean value of 0.63 per cent was observed in Uppalguptam mandal. The relatively higher organic carbon content in Amalapuram and Allavaram might be attributed to greater accumulation of organic residues and relatively dominance of finer textured soils (Husain and Dijkstra, 2023; Dhaliwal *et al.*, 2021) [14, 13], while the lower value in Uppalguptam mandals might be associated with comparatively lower organic matter inputs and differences in soil texture and land-use practices. (Vijayakumar *et al.*, 2011) [15].

Based on the standard rating, 71 soil samples (61.21%) recorded medium organic carbon status, while 45 samples (38.79%) recorded high organic carbon status. None of the samples fell under the low organic carbon category. Overall, the soils of the study area were predominantly characterized by medium organic carbon status, with a substantial proportion of samples showing high organic carbon content. The relatively higher organic carbon content observed in fine-textured soils may be related to the greater capacity of clay particles to protect and stabilize organic matter, whereas coarse-textured soils generally exhibit comparatively lower organic carbon accumulation. Spatial variability shows coastal mandals exhibit medium OC content whereas in land areas shows high organic carbon as shown in figure 1. Similar organic carbon status was reported by Singh *et al.* (2023) [16] in the soils of Dubhar block Ballia district, Uttar Pradesh.

Available nitrogen

The available nitrogen content of the soils in Amalapuram division exhibited considerable spatial variability, with values ranged from 247 kg ha⁻¹ (Katrenukona mandal) to 630 kg ha⁻¹ (Razole mandal) with an overall mean of 508 kg ha⁻¹. Among the mandals, the highest mean available nitrogen was recorded in Amalapuram (583 kg ha⁻¹), whereas the lowest mean was observed in Uppalguptam (404 kg ha⁻¹). The higher nitrogen status in Amalapuram and Razole mandals might be due to the predominance of fertile alluvial soils, continuous rice cultivation, incorporation of crop residues, which enhance soil organic matter and nitrogen mineralization. In contrast, the relatively lowest nitrogen content in Katrenukona and Uppalguptam could be due to low organic carbon status, intensive cropping, leaching losses

under high rainfall and irrigated conditions, and inadequate replenishment of nutrients through organic manures (Ray *et al.*, 2015) [17]. The spatial variability in available nitrogen as depicted in figure 1 shows variation in nitrogen content and differences in soil management practices, cropping intensity, and environmental conditions across the study area. These findings indicate the need for site-specific nitrogen management to improve nitrogen use efficiency, sustain soil fertility, and enhance crop productivity in the Amalapuram division.

Available phosphorus

The available phosphorus (P_2O_5) content of the soils in Amalapuram division exhibited considerable spatial variability from low to high in status. It ranged from 22.34 to 114.35 kg ha⁻¹ with mean 61.42 kg ha⁻¹ in I. Polavaram mandal and Allavaram mandal respectively. Among the mandals the highest mean available phosphorus was recorded in Malikipuram (69.02 kg ha⁻¹), whereas the lowest mean was observed in Uppalaguptam (42.39 kg ha⁻¹) (Table 1 and Figure 1). The relatively higher phosphorus content in Allavaram and Malikipuram might be attributed to the regular application of phosphatic fertilizers, recycling of crop residues, and favourable alluvial soil conditions that enhance phosphorus availability. In contrast, the lower phosphorus content observed in I. Polavaram and Uppalaguptam could be due to continuous nutrient removal by crops, inadequate phosphorus replenishment, and phosphorus fixation by calcium compounds under neutral to moderately alkaline soil conditions, thereby reducing its plant availability. The spatial variation in available phosphorus also reflects differences in fertilizer management, soil characteristics, cropping systems, and irrigation practices across the study area. These findings emphasize the importance of balanced phosphorus fertilization based on soil test values to sustain soil fertility and improve crop productivity in the Amalapuram division. The results were in conformity with the findings of Velayutham *et al.* (2000) [18] in Godavari deltaic region of alluvial soils and Srinivasarao *et al.* (2019) [19] in Vertisols of Solapur and Indore.

Available potassium

The available potassium (K_2O) in soils of Amalapuram division varied from 313 to 1461 kg ha⁻¹ and exhibited wide variation among the mandals with the highest mean in Amalapuram (736 kg ha⁻¹), whereas the lowest mean in Uppalaguptam (399 kg ha⁻¹) with overall mean of 545 kg ha⁻¹ (Table 1). The highest potassium content in Amalapuram might be attributed to the predominance of fertile alluvial soils, regular application of potassic fertilizers, recycling of crop residues, and the release of potassium from potassium-bearing minerals under intensive cultivation the results are corroborated with the findings of Muralidharudu *et al.* (2011) [20]. In contrast, the lower potassium status observed in Mamidikuduru and Uppalaguptam could be due to continuous nutrient removal by high-yielding crops, leaching losses under irrigated conditions, and comparatively lower replenishment of

potassium through fertilizer application (Tiwari *et al.*, 2002) [21]. Variations in soil mineralogy, clay content, cropping pattern, irrigation practices, and nutrient management further contributed to the spatial variability of available potassium across the study area. These findings indicate that balanced potassium fertilization based on soil test values is essential to sustain soil fertility, improve potassium use efficiency, and maintain crop productivity in the Amalapuram division.

Nutrient index

According to nutrient index values the soils of the study area as presented in table 2 had medium fertility status for available nitrogen, which might be associated with continuous crop removal and relatively rapid nitrogen losses through leaching and other processes. Available phosphorus and potassium showed high fertility status, possibly due to regular fertilizer application, nutrient accumulation and comparatively favourable soil conditions for their retention. Organic carbon also recorded a high fertility status, which may be attributed to the incorporation of crop residues and continuous cultivation under favourable moisture conditions. Overall, the soils exhibited a favourable fertility status, particularly with respect to phosphorus, potassium and organic carbon.

Correlation analysis revealed that significant positive and negative associations between physico chemical and macro nutrient of the study area as presented in table 3, indicating their interdependence and influence on nutrient availability. Correlation analysis showed a strong positive association of organic carbon with P_2O_5 ($r = 0.79$), followed by N ($r = 0.64$) and K_2O ($r = 0.60$), indicating its important role in nutrient availability. Available N , P_2O_5 and K_2O also exhibited positive relationships, reflecting their association with soil fertility and management practices. Nutrients generally showed weak to moderate negative relationships with EC, suggesting the influence of soluble salts on nutrient availability. Soil pH exhibited comparatively weak associations with the other soil properties. Overall, organic carbon emerged as the major soil property positively associated with macronutrient availability in the study area.

Conclusion

The soils of Amalapuram division, Dr. B. R. Ambedkar Konaseema district exhibited considerable spatial variability in their physico chemical and macro nutrients across different mandals, reflecting differences in soil-forming factors, drainage, land use and management practices. The observed variability highlights the importance of location-specific soil fertility management and balanced nutrient application. Overall, the soils of Amalapuram division, Dr. B. R. Ambedkar Konaseema district were generally favourable for crop production, with localized areas requiring appropriate soil and nutrient management for maintaining soil fertility and sustainable productivity.

Table 1. Range and mean values of physico chemical and macro nutrients status of soils in Amalapuram division of Dr. B. R. Ambedkar Konaseema district, Andhra Pradesh

Mandal		pH	EC (dsm ₁)	OC (%)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
Allavaram	Range	7.0-8.3	0.17-6.7	0.59-1.23	256-623	41.32-114.35	321-1108
	Mean	7.8	1.37	0.82	518	67.03	600
Amalapuram	Range	7.3-8.6	0.21-1.54	0.72-1.13	536-613	45.25-93.14	497-1461
	Mean	7.7	0.63	0.86	583	62.67	736
I. Polavaram	Range	6.8-8.7	0.12-1.02	0.52-0.90	411-604	22.34-101.31	316-584
	Mean	7.8	0.51	0.67	486	58.29	449
Katrenukona	Range	6.2-8.7	0.34-4.56	0.53-0.83	247-589	32.61	319
	Mean	7.7	1.77	0.68	457	55.80	434
Malkipuram	Range	6.6-8.6	0.46-3.56	0.59-0.93	442-604	33.5-88.26	322-987
	Mean	7.7	1.63	0.79	538.5	69.0225	549

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Mandal		pH	EC (dsm ₋₁)	OC (%)	N (kg/ha)	P ₂ O ₅ (kg/ha)	K ₂ O (kg/ha)
Mamidikuduru	Range	7.0-8.5	0.5-2.58	0.58-0.91	304-594	52.34-89.61	313-879
	Mean	7.8	1.28	0.70	486	66.42	516
Mummidivaram	Range	6.3-8.3	0.09-2.03	0.72-0.93	559-604	44.61-88.04	372-987
	Mean	7.8	0.87625	0.78875	575.5	64.40375	581
Razole	Range	6.7-8.3	0.23-4.36	0.52-1.26	458-630	35.61-95.61	338-1084
	Mean	7.5	1.03	0.78	556	67.35	569
Sakhinetipalle	Range	6.2-8.8	0.26-8.32	0.51-0.94	247-623	28.94-95.61	329-1256
	Mean	7.4	1.88	0.71	481	56.83	614
Uppalguptam	Range	6.4-8.5	0.34-1.05	0.51-0.78	331-550	28.94-65.16	344-564
	Mean	7.4	0.58	0.63	404	42.38	399
	Overall range	6.2-8.8	0.09-8.32	0.51-1.26	247-630	22.34-114.35	313-1461
	Mean	7.7	1.26	0.75	508	61.42	545
	SD	1.55	0.16	0.78	88.30	20.18	225.08
	CV (%)	119.91	21.64	10.22	17.39	32.86	41.29

Table 2. Nutrient Index of Available Macronutrients in Amalapuram division, Dr. B. R. Ambedkar Konaseema district, Andhra Pradesh

Soil property	Low	Medium	High	No. of samples	Parker Nutrient Index	Rating
Available N	3	69	38	110	2.32	Medium
Available P ₂ O ₅	1	46	63	110	2.56	High
Available K ₂ O	0	0	110	110	3.00	High
Organic Carbon	0	71	45	110	2.39	High

Table 3. Relation between physico chemical and macro nutrient status of soil in Amalapuram division, Dr. B. R. Ambedkar Konaseema district, Andhra Pradesh

	N (kg/ha)	P ₂ O ₅ (kg/ha)	K ₂ O(kg/ha)	pH	EC (dsm ₋₁)	OC (%)
N (kg/ha)	1					
P ₂ O ₅ (kg/ha)	0.51	1				
K ₂ O(kg/ha)	0.56	0.45	1			
pH	0.06	-0.15	-0.11	1		
EC (dsm ₋₁)	-0.25	-0.21	-0.22	0.10	1	
OC (%)	0.64	0.79	0.60	-0.007	-0.23	1

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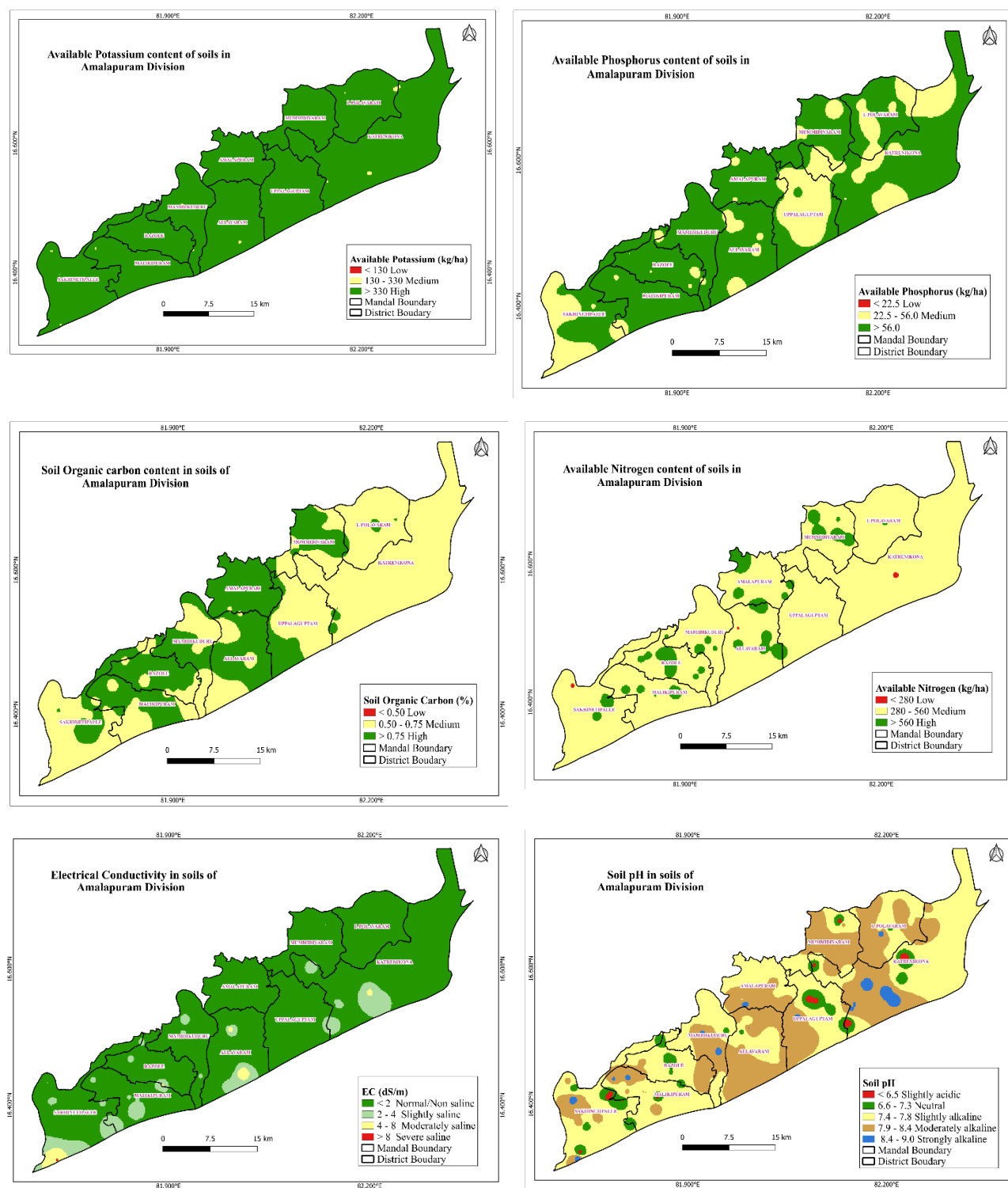


Figure 1. Spatial Variability mapping of Soil Physico chemical properties and available macro nutrient status in Amalapuram division of Dr. B. R. Ambedkar Konaseema district, Andhra Pradesh

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