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GPS and GIS based soil fertility maps of Khadambe Bk. village, Rahuri tehsil, Ahilyanagar district

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Abstract

The present study was undertaken in 2025-26 to assess the status of soil reaction, salinity, organic carbon, calcium carbonate and available nitrogen, phosphorus, potassium and sulphur in Khadambe Bk. village of Rahuri tehsil, Ahilyanagar district, and to present their spatial distribution as GIS-based fertility maps. A total of 135 geo-referenced surface soil samples (0-22.5 cm) were collected on a 250 m grid, representing 843.75 ha of cultivable land, and analysed by standard procedures. Maps were prepared in ArcGIS 10.8 by ordinary kriging. Soil pH ranged from 7.57 to 8.81 (mean 8.25); the soils were slightly (16.30%), moderately (62.96%) and strongly alkaline (20.74%). Electrical conductivity ranged from 0.16 to 1.27 dS m^{-1}, and 97.78% of the area was normal. Organic carbon ranged from 0.21 to 0.62% (mean 0.40%) and was low in 39.26%, moderate in 60.00% and moderately high in 0.74% of the area. Calcium carbonate ranged from 5.13 to 12.88% (mean 9.60%), with 49.63% of the area medium and 50.37% high. Available nitrogen (135-267 kg ha^{-1}) was low in 97.78% and very low in 2.22% of the area. Available phosphorus (6.91-26.01 kg ha^{-1}) ranged from very low to moderately high, with 60.00% of the area moderate. Available potassium (258-728 kg ha^{-1}) was high in 9.63% and very high in 90.37% of the area. Available sulphur (7.73-38.12 mg kg^{-1}) was sufficient in 82.22% and deficient in 17.78% of the area. The maps identify where nitrogen and phosphorus need to be supplemented and where potassium can be reduced, and can support balanced, site-specific fertilizer use in the village.

Keywords: GPS, GIS, Soil pH, Electrical conductivity, Organic carbon, Calcium carbonate, Available N, P, K, S, Khadambe Bk.

Introduction

Soil is the most important natural resource supporting agricultural production, providing nutrients, water, air and physical support for plant growth (Das *et al*., 2020) [1]. Soil fertility, the capacity of soil to supply essential nutrients, exhibits considerable spatial variability arising from differences in physical, chemical and biological processes, and its assessment is fundamental to developing sound soil management strategies (Brady *et al.*, 2002) [2].

Geographic Information System (GIS) and Global Positioning System (GPS) technologies have become indispensable tools for site-specific nutrient management. GPS allows accurate georeferencing of soil sampling locations, while GIS facilitates integration, spatial analysis and mapping of soil fertility data, helping identify nutrient deficiencies and generate prescription maps for balanced fertilization (Sharma, 2004) [3]. Such geospatial approaches allow fertilizer use to be customized to actual local requirement rather than blanket recommendation, thereby optimizing input cost and improving productivity.

Increasing population pressure and intensive cultivation have accelerated the decline of soil fertility in many parts of Maharashtra. Therefore, periodic assessment of soil fertility status is essential for recommending appropriate nutrient management practices. The present study was undertaken to characterize the soils of Khadambe Bk. village, Rahuri tehsil, Ahilyanagar district, Maharashtra, with the objectives of (i) determine the status of soil pH, electrical conductivity (EC), organic carbon (OC), calcium carbonate ($CaCO_3$) and available *N*, *P*, K and *S* (ii) prepare GIS-based fertility maps of the village.

Study area

Khadambe Bk. village lies at about 19.32° N latitude and 74.66° E longitude at an elevation of about 500 m above mean sea level. It is 12 km from Rahuri and 30 km from Ahilyanagar. The total geographical area is 1027.22 ha, of which 848.83 ha is cultivable. The cultivated area carries gram (161.07 ha), kharif crops (259.09 ha), horticultural crops (117.56 ha), sugarcane (168.82 ha) and wheat (142.29 ha). Irrigation is from wells, borewells, channels and a stream. The terrain is mostly flat with some undulating parts.

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The climate is semi-arid, with hot summers (temperatures often above 40 °C in April-May), a mild dry winter and moderate rainfall from June to September; the average rainfall of Rahuri tehsil is 511 mm. During 2025 the mean weekly maximum and minimum temperatures were 31.91 °C and 17.57 °C respectively. The soils are derived from basalt (Deccan trap), which is basic in nature and rich in feldspars and augite.

Materials and methods

Soil sampling

Geo-referenced surface soil samples (0-22.5 cm) were collected from the cultivable area at 250 m grid intervals. The latitude, longitude and elevation of each point were recorded with a GPS-enabled smartphone application. A total of 135 samples, representing 843.75 ha, were drawn with a stainless steel auger to avoid iron contamination and were brought to the laboratory of the Department of Soil Science and Agricultural Chemistry, MPKV, Rahuri, for analysis.

Soil analysis

The methods used are given in Table 1. The results were grouped into classes using the standard ratings for pH, EC and $CaCO_3$ and the six-tier ratings for OC, *N*, *P* and K (Bangar *et al.*, 1978; Katkar *et al.*, 2010) [4, 5]. The mean, range, standard deviation and coefficient of variation were worked out as described by Panse *et al.* (1985) [6].

Table 1. Analytical methods used for soil analysis

Parameter	Method	Reference
pH (1:2.5)	Potentiometry	Jackson (1973)
EC (1:2.5)	Conductometry	Jackson (1973)
Organic carbon	Wet oxidation	Nelson and Sommer (1982)
Calcium carbonate	Acid neutralization	Allison and Moodie (1965)
Available nitrogen	Alkaline permanganate	Subbiah and Asija (1956)
Available phosphorus	0.5 M $NaHCO_3$ (Olsen)	Watanabe and Olsen (1965)
Available potassium	Neutral normal NH_4OAc, flame photometry	Jackson (1973)
Available sulphur	0.15% $CaCl_2$ extraction	Williams and Steinbergs (1959)

Preparation of maps

The sample coordinates and analytical values were imported into ArcGIS 10.8 as .csv files and projected to a suitable coordinate system after checking for missing values and coordinate errors. Values at unsampled locations were estimated by ordinary kriging. A semivariogram was fitted for each parameter, and the kriging model was checked by cross-validation. The interpolated surfaces were then classified according to the critical limits and the area under each class was calculated. The location map of Khadambe Bk. village showing GPS-based sampling locations presented in Fig. 1 and GPS-based grid soil sampling locations in Khadambe Bk. village presented in Fig. 2.

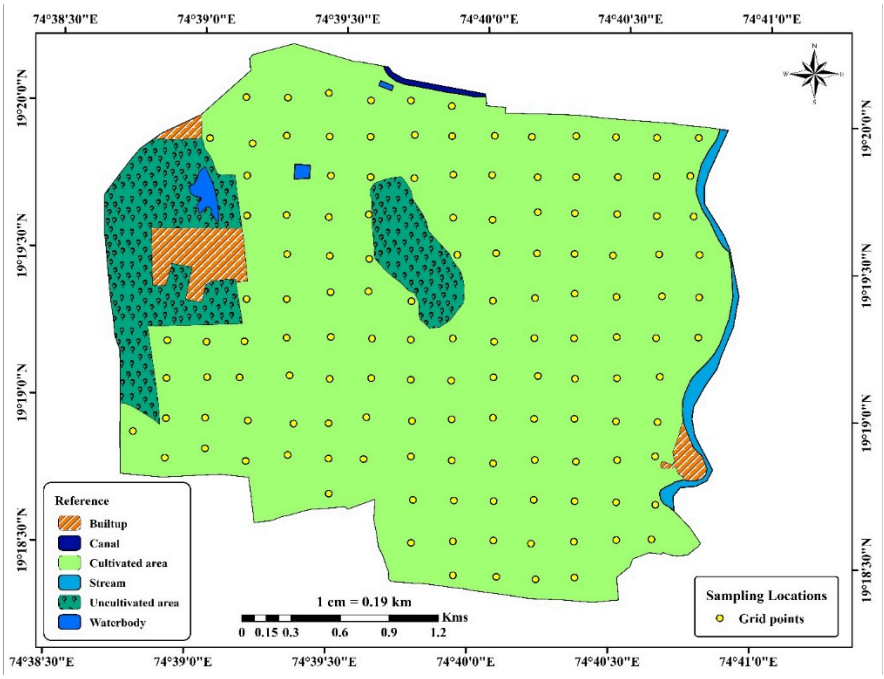


Figure 1. Location map of Khadambe Bk. village, Rahuri tehsil, Ahilyanagar district

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Results and discussion

The results for the 135 samples are given in Tables 2 and 3 and Fig. 3 to 10.

Soil pH

Soil pH ranged from 7.57 to 8.81 with a mean of 8.25 (SD 0.29; CV 3.55%), showing little variation (Table 2). Among 135 samples, 62.96% were moderately alkaline, 20.74% strongly alkaline and 16.30% slightly alkaline. The highest pH (8.81) was recorded at 19.333834° N, 74.652491° E and the lowest (7.57) at 19.309550° N, 74.675295° E. The alkaline reaction can be attributed to the calcareous, base-rich basaltic parent material, low rainfall and poor leaching of basic cations under the semi-arid climate. Similar results were reported by Shelke *et al.* (2022) [7] in the command area of a sugar factory at Rahuri and by Surwase *et al.* (2024) [8] in sugarcane soils of Rahuri tehsil.

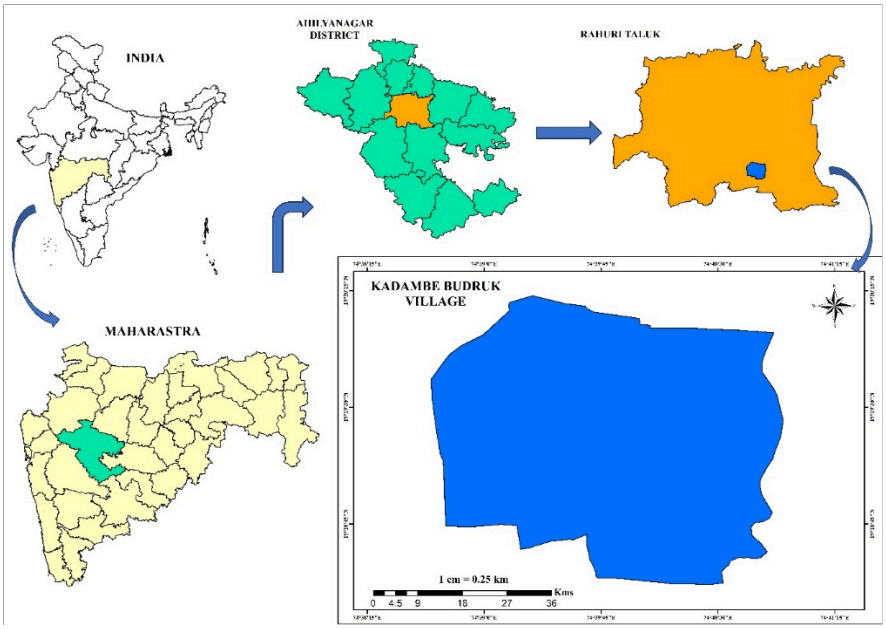


Figure 2. GPS-based grid soil sampling locations in Khadambe Bk. village

Electrical conductivity

EC ranged from 0.16 to 1.27 dS m^{-1} with a mean of 0.49 dS m^{-1} and a high CV of 40.32%, so salt content varied considerably from place to place. About 97.78% of the samples had normal EC, indicating soils free from salinity hazard and suitable for healthy plant growth. The remaining 2.22% exceeded 1.0 dS m^{-1} and were critical for seed germination; the highest value (1.27 dS m^{-1}) occurred at 19.333910° N, 74.659849° E and may be due to local accumulation of soluble salts and differences in drainage. Comparable results were reported by Ammannawar *et al.* (2017) [9] in Pathardi tehsil, where all samples were non-saline.

Organic carbon

Organic carbon ranged from 0.21 to 0.62% with a mean of 0.40% (CV 24.17%). Low, moderate and moderately high classes accounted for 39.26%, 60.00% and 0.74% of the samples respectively. The highest value (0.62%) was at 19.313909° N, 74.670316° E and the lowest (0.21%) at 19.331228° N, 74.652961° E. Moderate values in some fields probably reflect the use of organic manures and crop residues, while the low values reflect intensive cultivation with little addition of farmyard manure under a warm semi-arid climate that favours rapid decomposition. Low organic carbon in the Baragaon Nandur village of the same taluka was reported by Vaddepally *et al.* (2017) [10], and low organic carbon associated with erosion was reported by Jadhav *et al.* (2024) [11] in Nashik district.

Table 2. Status of pH, EC, organic carbon and calcium carbonate in soils of Khadambe Bk. (n = 135)

Statistic	pH (1:2.5)	EC (dS m^{-1})	Organic carbon (%)	$CaCO_3$ (%)
Mean	8.25	0.49	0.40	9.60
Range	7.57-8.81	0.16-1.27	0.21-0.62	5.13-12.88
Standard deviation	0.29	0.20	0.09	2.07
CV (%)	3.55	40.32	24.17	21.59
Classes (% of samples)	Slightly alkaline 16.30; moderately alkaline 62.96; strongly alkaline 20.74	Normal 97.78; critical for germination 2.22	Low 39.26; moderate 60.00; moderately high 0.74	Medium 49.63; high 50.37

Calcium carbonate

$CaCO_3$ ranged from 5.13 to 12.88% with a mean of 9.60% (CV 21.59%). Half of the samples (50.37%) were in the high class and 49.63% in the medium class; none was in the harmful class. The highest value (12.88%) was recorded at 19.315494° N, 74.648475° E and the lowest (5.13%) at 19.309267° N, 74.668051° E. Accumulation of carbonates is typical of semi-arid soils where low rainfall and high evaporation favour precipitation of calcium carbonate in the profile. Similar medium to high $CaCO_3$ was reported by Patil *et al.* (2017) [12] at Kadegaon, Sangli district, and by Surwase *et al.* (2024) [8] in Rahuri tehsil.

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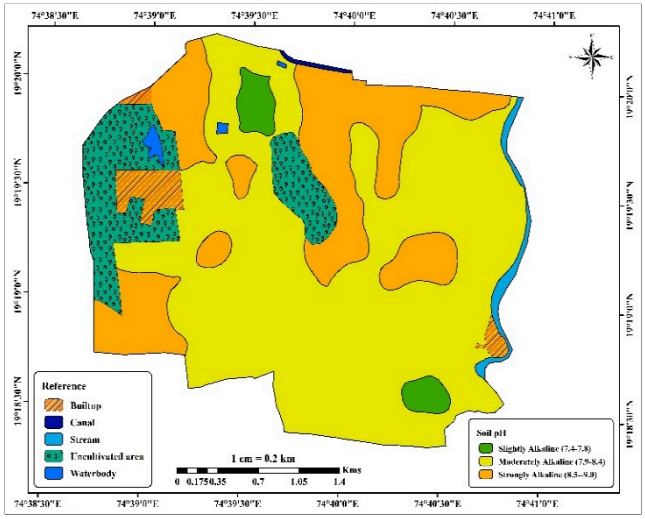


Figure 3. GPS based soil fertility map of pH in Khadambe Bk. village

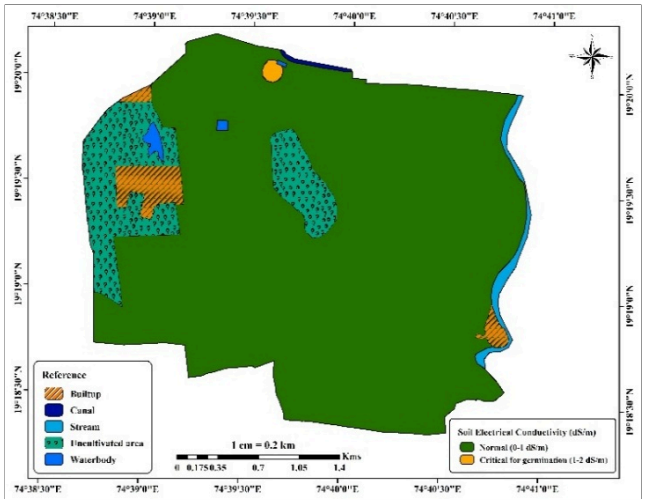


Figure 4. GPS based soil fertility map of Electrical Conductivity in Khadambe Bk. village

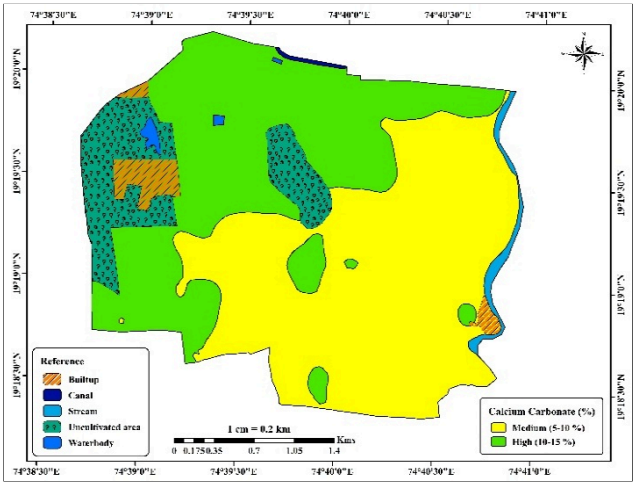


Figure 5. GPS based soil fertility map of Organic Carbon in Khadambe Bk. village

Available nitrogen

Available *N* ranged from 135 to 267 kg ha^{-1} with a mean of 194 kg ha^{-1} (CV 16.22%) (Table 3). It was low in 97.78% and very low in 2.22% of the samples; no sample reached the moderate class. The highest value (267 kg ha^{-1}) was at 19.313706° N, 74.665423° E, probably where heavy nitrogen fertilization is practised, and the lowest (135 kg ha^{-1}) at 19.331440° N, 74.650437° E. The widespread deficiency reflects the low organic carbon, which is the main reservoir of soil nitrogen, together with losses by leaching, volatilization and denitrification. Gosavi *et al.* (2016) [13] in Shirpur tehsil and Pranav *et al.* (2025) [14] at Parbhani reported similar low status.

Available phosphorus

Available *P* ranged from 6.91 to 26.01 kg ha^{-1} with a mean of 15.77 kg ha^{-1} (CV 30.18%). Of the samples, 2.96% were very low, 31.11% low, 60.00% moderate and 5.93% moderately high. The highest value (26.01 kg ha^{-1}) was at 19.313628° N, 74.667865° E and the lowest (6.91 kg ha^{-1}) at 19.329609° N, 74.662579° E. The low status in about one-third of the area is associated with the alkaline reaction and high $CaCO_3$, which precipitate phosphorus as calcium phosphates

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and reduce its availability. The wide range (CV 30.18%) also reflects variation in pH, calcareousness, organic matter and management. Bhoyar *et al.* (2023) [15] reported similar status in Saoner tehsil of Nagpur district.

Table 3. Status of available nitrogen, phosphorus and potassium in soils of Khadambe Bk. (n = 135)

Statistic	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	S (mg kg^{-1})
Mean	194	15.77	467	16.51
Range	135-267	6.91-26.01	258-728	7.73-38.12
Standard deviation	31.49	4.76	119.28	5.89
CV (%)	16.22	30.18	25.54	35.69
Classes (% of samples)	Very low 2.22; low 97.78	Very low 2.96; low 31.11; moderate 60.00; moderately high 5.93	High 9.63; very high 90.37	Deficient 17.78; sufficient 82.22

Available potassium

Available K ranged from 258 to 728 kg ha^{-1} with a mean of 467 kg ha^{-1} (CV 25.54%); 90.37% of the samples were very high and 9.63% high, and none was low. The highest value (728 kg ha^{-1}) was at 19.315973° N, 74.660288° E and the lowest (258 kg ha^{-1}) at 19.324942° N, 74.660104° E. The abundant potassium can be attributed to release from the lattice of silicate clay minerals and to the fine texture of the soils: 37.78% of the samples were clay and 32.59% silty clay. Ammannawar *et al.* (2017) [9] recorded 302.4-571.2 kg ha^{-1} in Pathardi tehsil, and Shelke *et al.* (2022) [7] found similar status at Rahuri.

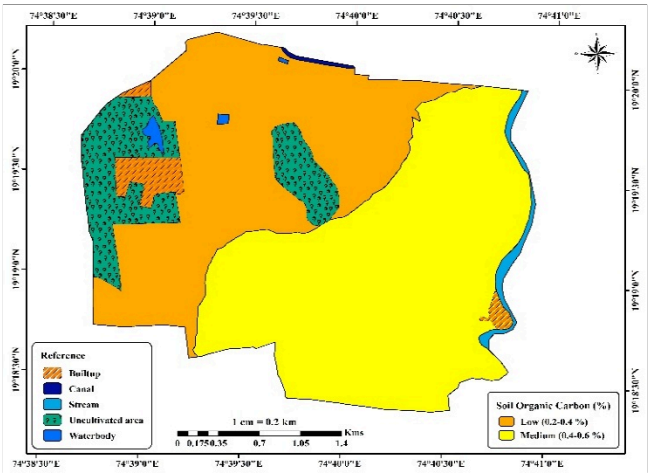


Figure 6. GPS based soil fertility map of Calcium Carbonate in Khadambe Bk. village

Available sulphur

Available *S* ranged from 7.73 to 38.12 mg kg^{-1} with a mean of 16.51 mg kg^{-1} and a high CV of 35.69%. With a critical limit of 10 mg kg^{-1}, 82.22% of the samples were sufficient and 17.78% deficient. The highest value (38.12 mg kg^{-1}) was at 19.321037° N, 74.674867° E and the lowest (7.73 mg kg^{-1}) at 19.331228° N, 74.652961° E, the same point that recorded the lowest organic carbon. Sufficiency over most of the area may be due to moderate organic carbon, fine texture and accumulation of sulphate in the surface layer, together with sulphur-bearing fertilizers such as single super phosphate and ammonium sulphate. Similar results were reported by Ghodke *et al.* (2016) [16] in soils of western Maharashtra and by Hadole *et al.* (2019) [17] in Jalgaon district.

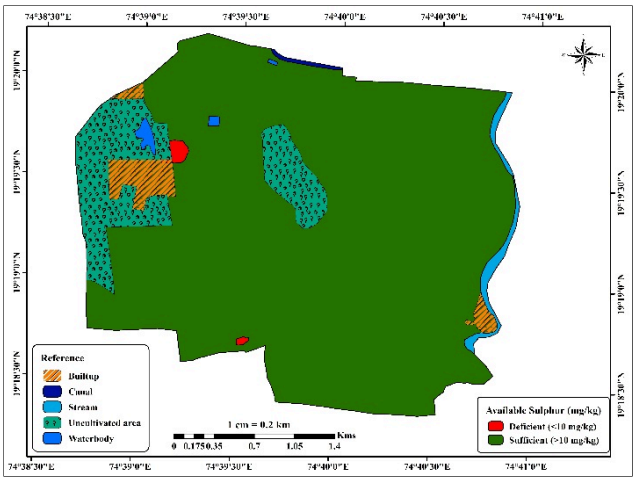


Figure 7. GPS based soil fertility map of available Nitrogen in Khadambe Bk. village

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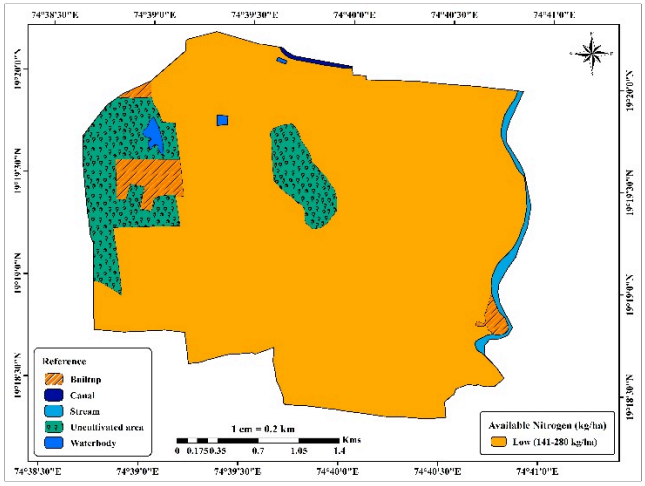


Figure 8. GPS based soil fertility map of available Phosphorus in Khadambe Bk. village

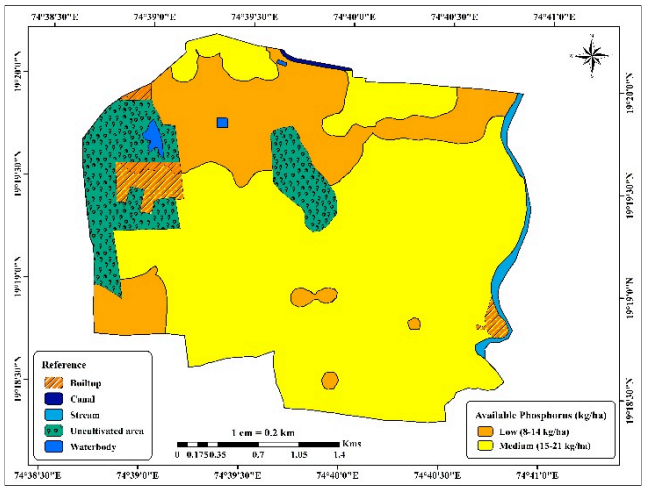


Figure 9. GPS based soil fertility map of available Potassium in Khadambe Bk. village

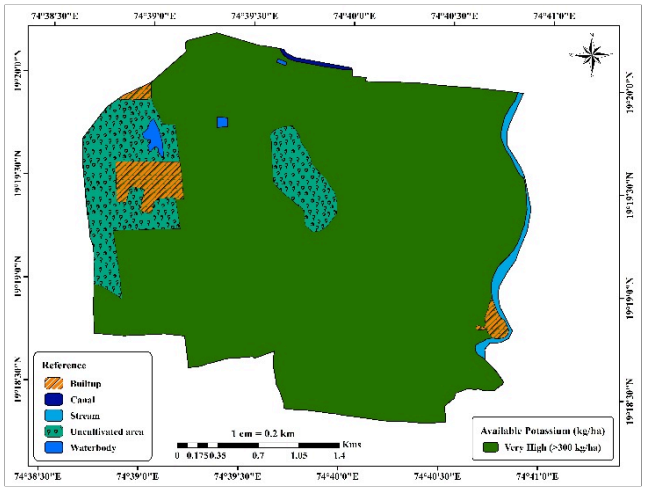


Figure 10. GPS based soil fertility map of available Sulphur in Khadambe Bk. village

Conclusion

The soils of Khadambe Bk. are slightly to strongly alkaline, calcareous and non-saline over almost the whole village. Organic carbon is low to moderate, available nitrogen is low over 97.78% of the area, phosphorus is low in about one-third of the area, and potassium is high to very high everywhere, and sulphur is deficient in 17.78% of the area. Because organic carbon favours, and calcium carbonate reduces, nutrient availability, regular addition of organic manures and green manures is needed. The maps indicate that nitrogen and phosphorus doses should be raised in the deficient parts of the village, whereas potassium can be applied at reduced rates, so that fertilizers are used in a more balanced and economical manner.

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The findings and conclusions presented in this research article are based on the soil samples collected and analysed during 2025–26 under the specific soil and environmental conditions of Khadambe Bk. village, Rahuri tehsil, Ahilyanagar district, Maharashtra. The results represent the soil fertility status of the study area during the investigation period. Further studies covering different seasons and locations may be necessary before making broader recommendations.

Conflict of interest

The authors declare no conflicts of interest, and no external funding or sponsorship influenced the study design, data collection, analysis, publication decision, or manuscript preparation.

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