International Journal of Plant & Soil Science

Volume 36, Issue 6, Page 918-937, 2024; Article no.IJPSS.117128
ISSN: 2320-7035

Soil Fertility Mapping Using GIS in Sirur Sub-Watershed of Kundagol Taluk of Dharwad District, Karnataka, India

Suhani [a++*], V. B. Kuligod [a#], M Hebbara [a†], M. B. Doddamani [b†] and Ashoka P. [c#]

[a] Department of Soil Science and Agricultural Chemistry, University of Agricultural Sciences, Dharwad- 580 005, Karnataka, India.
[b] Department of Crop Physiology, University of Agricultural Sciences, Dharwad- 580 005, Karnataka, India.
[c] Department of Agronomy, University of Agricultural Sciences, Dharwad- 580 005, Karnataka, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2024/v36i64700

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/117128

Original Research Article

Received: 19/03/2024
Accepted: 23/05/2024
Published: 28/05/2024

ABSTRACT

Aims: To identify available nutrient constraints in soils and to generate soil fertility maps using remote sensing and GIS of Sirur sub-watershed in northern dry zone of Karnataka.
Place and Duration of Study: The study was carried out in the Sirur sub-watershed (4D5B5j) located in Kundagol *taluk* of Dharwad district, Karnataka during 2022-24.

[++] Ph.D. Scholar;
[#] Professor and Head;
[†] Professor;
**Corresponding author: E-mail: sbsuhani3@gmail.com;*

Cite as: *Suhani, Kuligod , V. B., Hebbara , M., Doddamani , M. B., & Ashoka P. (2024). Soil Fertility Mapping Using GIS in Sirur Sub-Watershed of Kundagol Taluk of Dharwad District, Karnataka, India. International Journal of Plant & Soil Science, 36(6), 918–937. https://doi.org/10.9734/ijpss/2024/v36i64700*

Methodology: Soil samples (601) from Sirur sub-watershed in northern dry zone of Karnataka were drawn at 320 m x 320 m grid interval and assessed for fertility parameters. Analytical data was interpreted and statistical parameters like range, mean, standard deviation and coefficient of variation were calculated for each parameter. Soil fertility maps were prepared for each parameter using interpolation technique.
Results: Soils were neutral to alkaline in reaction and non-saline. Soil organic carbon content was low to medium. Available nitrogen and phosphorus were low to medium, available potassium was high and sulphur was medium to high. Regarding available micronutrients, iron, copper and manganese were sufficient in the soils whereas Zn was deficient in about half of the sub-watershed area and B content was medium to high.
Conclusion: The major constraints in sub-watershed are low content of OC, poor status of available N, P_2O_5 and Zn indicating their immediate attention for sustained crop production.

Keywords: GIS; nitrogen; soil fertility status; sub-watershed.

1. INTRODUCTION

Soil is a remarkable gift bestowed upon us by nature, serving as a crucial foundation for various ecosystems and essential for sustaining life on Earth. Soil holds immense importance in environmental and agricultural contexts, symbolizing fertility and abundance. However, in India ~120.7 M ha of land suffers from various forms of degradation [1] largely due to human activities such as unsustainable agricultural practices and indiscriminate land use. In India, Recognizing the urgent need for conservation efforts, stakeholders including farmers, builders and the general public must actively engage in soil protection initiatives to safeguard its quality and productivity. In response to these challenges, the current study focuses on evaluating the soil fertility of the Sirur sub-watershed for sustainable agricultural productivity. Through the utilization of advanced technologies such as remote sensing and GIS, we aim to establish effective and sustainable soil management practices. In contemporary times, the watershed-based approach has emerged as a promising avenue for achieving sustainability in agricultural production, particularly in rainfed regions. However, the intensification of agriculture to optimize land usage has led to either rapid depletion or occasional accumulation of soil fertility [2,3], emphasizing the importance of periodic monitoring to ensure soil health maintenance. Therefore, the integration of georeferenced data concerning land location, extent and quality is indispensable.

Remote sensing and GIS technologies have emerged as a potent instrument for examining soil resources, enabling the study of soils in spatial dimensions in a manner that is both time and cost-effective [4]. It is regarded as the most effective tool available to geo-scientists for mapping geological, geomorphological and soil resources, providing insights into their characteristics, spatial extent, distribution, potentials and constraints. Geographic information system (GIS) is described as a robust suite of instruments for gathering, storing, converting and visualizing spatial data obtained from the real world [5]. Precision agriculture (site-specific farming) incorporating remote sensing, global positioning system and geographic information system proves highly beneficial for evaluating and managing soil fertility [6]. This enables farmers to ascertain the appropriate inputs at the right time and in the correct quantities, thereby preventing input wastage and minimizing pollution arising from excessive input usage.

Soil fertility constraints in Karnataka lead to low crop yields due to inadequate nutrient levels, soil erosion, acidity and salinity. These constraints limit plant growth, impairing their ability to uptake essential nutrients. Consequently, farmers face decreased productivity, impacting food security and economic stability in the region. Addressing soil fertility issues through sustainable agricultural practices and soil management strategies is crucial for enhancing crop yields and ensuring food sufficiency. The current study was planned with the objective of identifying available nutrient constraints in soils and to generate soil fertility maps using remote sensing and GIS of Sirur sub-watershed in northern dry zone of Karnataka.

2. MATERIALS AND METHODS

2.1 Location of the Study Area

The study area Sirur sub-watershed (4D5B5j) is located in Kundagol *taluk* of Dharwad district

(Fig. 1) and falls under northern transitional zone of Karnataka. The geo-coordinates of the sub-watersheds are 15° 10' 30" N -15° 14' 0" North latitudes and 75° 12' 30" -75° 19' 30" East longitudes with total area of about 6,446.14 ha. The climate of the area is semi-arid with mean maximum and minimum temperatures in the range of 28-38°C and 16-23°C and the average rainfall of 737.80 mm [7]. A total of 601 surface soil samples (0-15 cm) were collected along with GPS points from the respective grids (320 m x 320 m) using WorldView-2, a high-resolution 8-band multispectral commercial satellite imagery [8]. Micro-watershed wise soil sample details are depicted in Table 1.

2.2 Soil Sample Preparation and Laboratory Analysis

The soil samples were air-dried, ground (to pass through 2 mm sieve) and analyzed for chemical and fertility parameters. The pH (1:2.5), electrical conductivity (EC) of soils were measured using standard procedures as described by Jackson [9]. Organic carbon (OC) was determined by Walkley-Black method [10]. Available nitrogen (N) was analyzed by modified alkaline permanganate method [11]. Available phosphorus (Olsen P) was measured using sodium bicarbonate (NaHCO3) as an extractant [12]. The available potassium (K2O) was

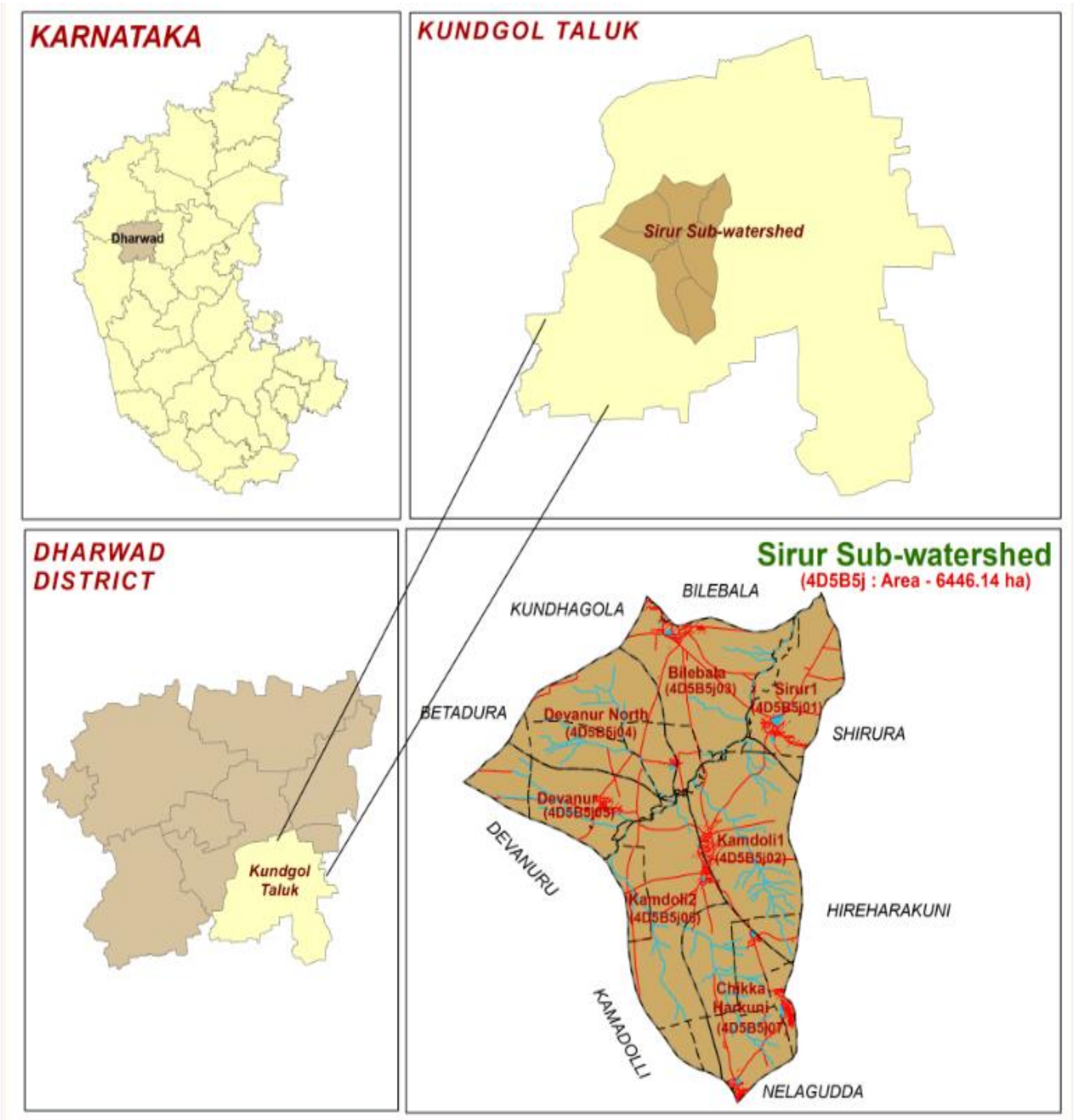

Fig.1. Location map of Sirur sub-watershed

Table 1. Details of soil sampling in Sirur sub-watershed

Micro-watershed	Code	Area (ha)	No. of samples
1. Sirur -1	4D5B5j01	641.36	57
2. Kamdolli-1	4D5B5j02	1076.89	103
3. Bilebala	4D5B5j03	1008.46	90
4. Devanur North	4D5B5j04	978.46	94
5. Devanur	4D5B5j05	697.29	66
6. Kamdolli-2	4D5B5j06	1126.72	108
7. Chikkaharkuni	4D5B5j07	916.96	83
Total		6446.14	601

Table 2. Soil fertility ratings for available nutrients

Nutrients	Fertility ratings		
	Low	Medium	High
Organic carbon (g kg^{-1})	<5.0	5.0-7.5	>7.5
Macronutrients (kg ha^{-1})			
Nitrogen	<280	280-560	>560
Phosphorus (P_2O_5)	<22.5	22.5-55.0	>55.0
Potassium(K_2O)	<140	140-330	>330
Sulphur (mg kg^{-1})	<10	10-20	>20
Micronutrients (mg kg^{-1})	Deficient	Sufficient	Excess
Iron (Fe)	<2.5	2.5-4.5	>4.5
Zinc (Zn)	<0.6	0.6-1.5	>1.5
Manganese (Mn)	<2.0	2-4	>4.0
Copper (Cu)	<0.2	0.2-5.0	>5.0

determined using the ammonium acetate method [13]. The available (S) was measured using 0.15 % calcium chloride ($CaCl_2$) as an extractant [14]. Micronutrients (Fe, Zn, Cu and Mn) were determined using DTPA extractable method as explained by Lindsay and Norvell [15]. The available boron was determined using Azomethine-H colorimetric method [16]. Variability of data was assessed using mean, range, standard deviation and coefficient of variation for each set of soil sample data. Availability of N, P_2O_5, K_2O and S in soils are interpreted as low, medium and high and that of exchangeable Ca and Mg as well as available iron (Fe), copper (Cu), zinc (Zn) and manganese (Mn) were interpreted as deficient and sufficient by following the criteria given in Table 2.

A database file consisting of data for X and Y co-ordinates in respect of sampling site location and a shape file (vector data) showing the outline of Sirur sub-watershed area was created in Arc GIS 10.4.1 Software. The database file was accessed within the project window, where the "longitudes" were assigned to the X-field and the "latitudes" to the Y-field. The Z field was utilized for various nutrients. Additionally, the Sirur sub-watershed file was opened and the "geo statistical wizard" option from the "Surface menu" in ArcGIS geostatistical Analyst was selected. In the subsequent "grid specification dialogue, "the output grid extension was set to match that of the Sirur sub-watershed and the interpolation method applied was ordinary kriging method. Following this, a map was generated and cclassified based on the ratings of the individual nutrients outlined in Table 2 [17]. Finally, the area for each nutrient category was calculated.

3. RESULTS AND DISCUSSION

3.1 Soil reaction and Electrical Conductivity

The soils of the Sirur sub-watershed exhibited a neutral to alkaline reaction, with a pH range between 6.52 and 8.83 and a mean pH of 7.97. The standard deviation of the pH was 0.35 and the coefficient of variation was 4.37 per cent (Table 3). The elevated soil pH in the sub-watershed is predominantly a result of the calcareous characteristics and presence of exchangeable Na. Spatially, the soil pH did not vary significantly as indicated by the coefficient of variation. Mapping of soil pH using GIS techniques categorized the soil into four reaction classes: neutral (6.5–7.3), slightly alkaline (7.3–7.8), moderately alkaline (7.8–8.4) and strongly alkaline (8.4–9.0). The distribution of these classes in the sub-watershed area (Fig. 2) was moderately alkaline (72.28%) followed by slightly alkaline (18.43%), strongly alkaline (3.86%) and neutral (0.3%). The higher pH of soils could be explained by low intensity of leaching, thereby less removal of basic elements from the soil, leading to the accumulation of bases and subsequently increasing soil pH levels. The findings align with the results documented by different workers for soils in the northern dry zone [18,19,20,21,22].

The electrical conductivity (EC) of soils in the sub-watershed ranged from 0 to 0.88 dS m^{-1}, with a mean value of 0.17 and a standard deviation of 0.11. The coefficient of variation (CV) of EC values was 60.46 per cent, indicating spatial variability in salt content within the sub-watershed. The slightly elevated levels of soluble salts in the study area could be attributed to semi-arid climatic conditions, also may be due to undulating nature of the terrain coupled with fairly good drainage conditions, which favored the removal of released bases by the percolating drainage water. Analysis of soluble salt content in the sub-watershed indicated that the area was non-saline (EC remained lesser than 4 dS m^{-1}, [23]. On the basis of area, total of 6,115 ha (94.86%) was non- saline in nature (Fig. 3).

3.2 Organic Carbon

Soil organic carbon (OC) content of Sirur sub-watershed ranged from 1.17 to 11.67 g kg^{-1} with mean and standard deviation value of 6.23 and 2.41, respectively. The coefficient of variation (CV) for OC content was 38.71 per cent, indicating spatial variability in OC within the sub-watershed (Table 3). GIS mapping of OC revealed that 80.73 per cent of the study area had medium OC levels, 13.13 per cent had low OC levels and 1 per cent had high soil OC status (Fig. 4). The values obtained in the present study are in agreement with those reported by Ravikumar et al*.* [19] for black soils of Malaprabha command area of Karnataka. The low organic carbon content in soils is influenced by semi-arid and warm conditions speeding up organic matter degradation, insufficient organic manure additions and intensive cropping practices. These factors collectively impede organic carbon accumulation, resulting in diminished soil organic carbon levels [24,25,26]. Similar findings were also documented by Prabhavati et al. [21] for the soils of northern dry zone of Karnataka.

3.3 Available Macronutrients

Available N in soils of the sub-watershed ranged from 84 to 273 kg ha^{-1} with a mean of 156.94 and SD of 35.15. The CV value of 22.40 per cent indicated that available N in soils varied spatially. The study revealed that the entire sub-watershed was low in the available N (Table 3). On the area basis majority of soils are low in available nitrogen 4305 ha (66.78%) (Fig.5). The low nitrogen content in the soil may stem from diverse soil management practices, inconsistent application of farmyard manure (FYM) and fertilizers in previous crop cycles. In black soils, nitrogen becomes a critical limiting nutrient due to decreased availability caused by fixation and volatilization losses. Additionally, the low organic matter levels in these regions, influenced by scant rainfall and high temperatures, accelerated organic matter breakdown and removal, contributing to nitrogen deficiency. Similar trend was recorded by Basavaraju et al. [27] and Shankaraiah et al. [28] in non-saline clay to sandy loams and calcareous soils.

The available P_2O_5 content in the sub-watershed ranged from 5.15 to 55.25 kg P_2O_5 ha^{-1}, with an average of 15.90 kg ha^{-1} and a standard deviation of 7.23. The coefficient of variation (CV) of 45.47 per cent for available P_2O_5 distribution indicates spatially variable. GIS mapping showed that 77.12, 12.87 and 4.87 per cent of the area had low, very low and medium in available P_2O_5, respectively (Table 3 and Fig. 6). The low availability of P_2O_5 in these soils is linked to their elevated pH, calcareous nature and low organic matter levels. Ravikumar et al. [19] noted that the low available P status in black soils of the Malaprabha command area in Karnataka was attributed to high calcium carbonate content. These results align with the findings of Shivaprasad et al. [23] and Bopathi and Sharma [29], indicating that most soils in Karnataka exhibit medium phosphorus content.

The available K_2O content in the sub-watershed ranged from 113.04 to 997.20 kg K_2O ha^{-1}, with a mean of 592.90 kg ha^{-1} and a standard deviation of 179.22. The coefficient of variation (CV) of 30.23 per cent for available K_2O content indicated spatial variability within the sub-watershed. GIS mapping showed that 70.34 per cent of the study area fell into the high category, while 24.54 per cent was classified as very high available K_2O content (Table 3 and Fig. 7). The higher concentration of water-soluble and exchangeable potassium (K) in surface soils in Karnataka could be attributed to the ability of soils to maintain adequate or elevated levels of exchangeable K, ensuring a consistent supply to plants over time. This phenomenon is likely due to the presence of potassium-rich micaceous and feldspar minerals in the parent material of the soil, as suggested by Basavaraju et al. [27] and Somasundaram et al. [30]. Additionally, high to very high availability of potassium in the soils of the Sirur sub-watershed aligned with findings by Vara Prasad Rao et al. [31] and Patil et al. [17], further emphasizing the influence of mineral composition on potassium levels in the soil.

The available S content of soils of the sub-watershed ranged from 3.13 to 82.50 mg kg^{-1} soil with mean and SD values of 25.64 and 17.60, respectively. The CV of 68.64 per cent for available S content highlights the spatial variability of sulfur levels in the sub-watershed. The GIS mapping of available S revealed that, the area under study was medium to high in available S in 17.91 and 76.96 per cent, respectively (Table 3 and Fig. 8). The high sulphur content in the study region could be attributed to the predominance of potash-rich micaceous and feldspar minerals in the parent material of the soil. Additionally, the gypsiferous nature of sulphur in black soils, which is non-available, may lead to higher sulphur content in certain areas. Past studies by Srikanth et al. [32], Pulakeshi et al. [33], Patil et al. [17] and Patil et al. [34] have reported similar findings, highlighting the significance of these factors in determining sulphur levels in the study area.

3.4 Available Micronutrients

The available Fe in the sub-watershed ranged from 0.68 to 39.40 mg kg^{-1} with mean and SD value of 10.11 and 4.98, respectively (Table 4). The CV of 49.26 per cent for available Fe content indicates that, it varied spatially in the sub-watershed. Mapping of available Fe by GIS revealed that, it was sufficient in 94.86 per cent of the area (Fig. 9). The available iron in surface soils has no regular pattern of distribution as also reported by Nayak et al. [35]. This type of variation may be due to the soil management practices and cropping pattern adopted by different farmers. Similar results were also observed by Patil et al. [36] and Ravikumar et al. [37].

The available Mn in the sub-watershed was sufficient and ranged from 2.01 to 41.42 mg kg^{-1} with mean and SD value of 14.52 and 5.98, respectively (Table 4). The CV of 41.16 per cent for available Mn content indicates spatial variability in the sub-watershed. Sufficient content of Mn was also observed by Ravikumar et al. [37] in Vertisols of Malaprabha command area, Pulakeshi [33] in the soils of northern transition zone of Karnataka derived from chlorite schist and Manojkumar [38] in the soils of northern transition zone of Karnataka derived from basalt.

Table 3. Chemical properties and available major nutrients status in Sirur sub-watershed

Particulars	pH	EC (dS m^{-1})	OC (g kg^{-1})	N	P_2O_5	K_2O	S (mg kg^{-1})
				(kg ha^{-1})			
Range	6.52-8.83	0-0.88	1.17-11.67	84.00-273.00	5.15-55.25	113.04-997.20	3.13-82.50
Average	7.97	0.17	6.23	156.94	15.90	592.90	25.64
SD	0.35	0.11	2.41	35.15	7.23	179.22	17.60
CV (%)	4.37	60.46	38.71	22.40	45.47	30.23	68.64

Table 4. Available micronutrients status in Sirur sub-watershed

Particulars	Fe	Mn	Cu	Zn	B
			(mg kg^{-1})		
Range	0.68-39.40	2.01-41.42	0.24-8.06	0.09-4.39	0.20-4.50
Average	10.11	14.52	1.93	0.62	1.56
SD	4.98	5.98	0.98	0.42	0.64
CV (%)	49.26	41.16	50.62	67.50	40.97

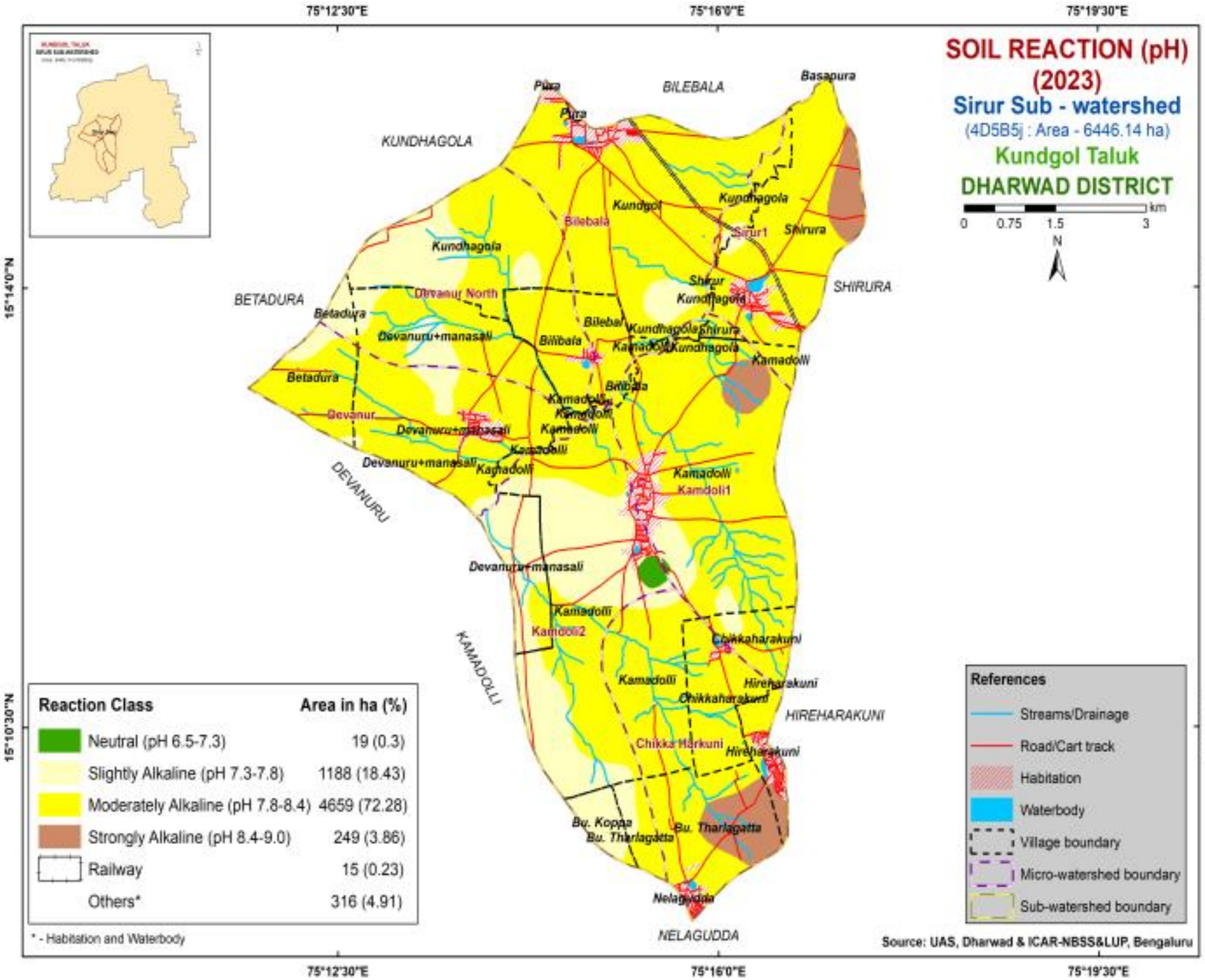

Fig. 2. Soil reaction status of Sirur sub-watershed

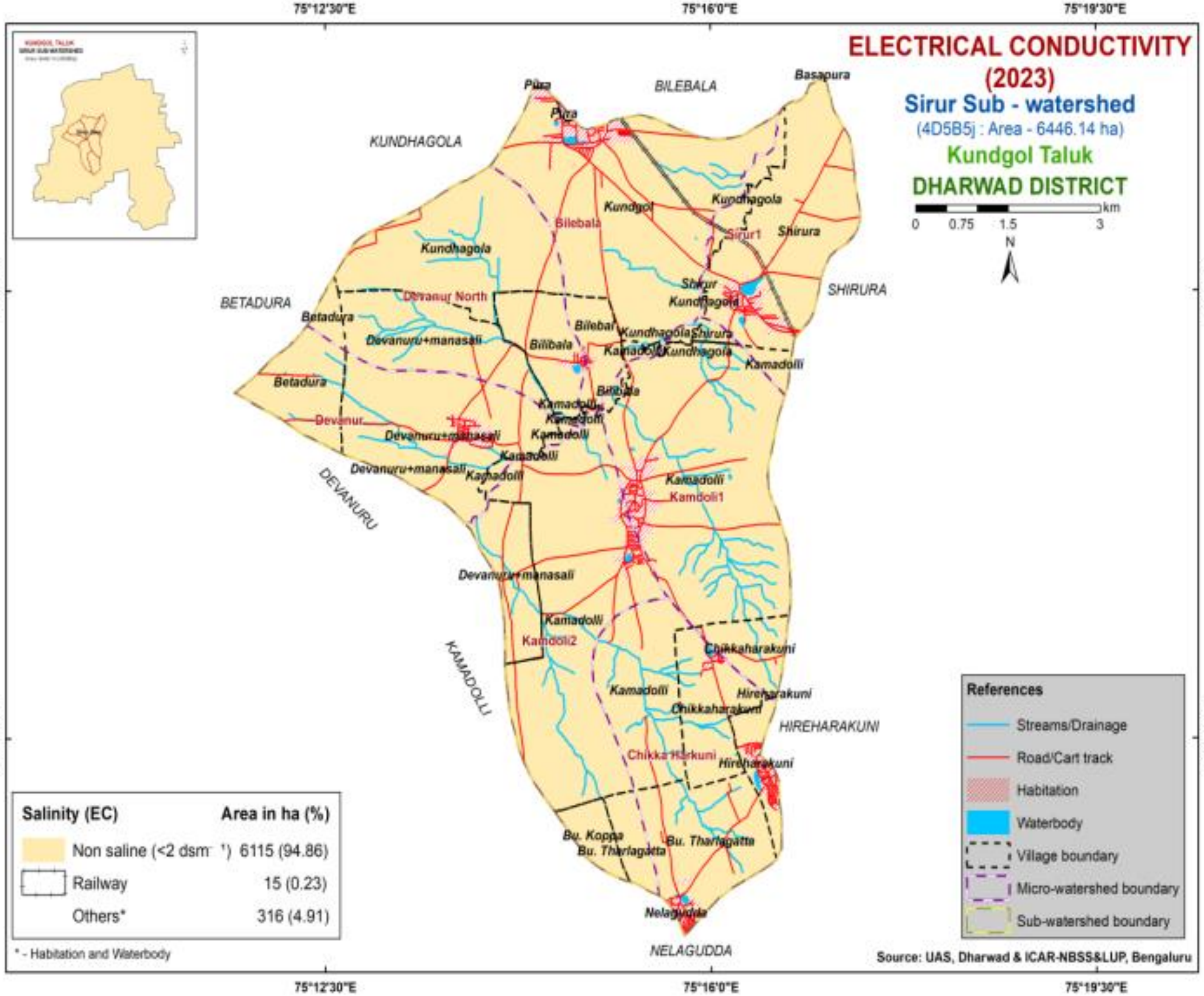

Fig. 3. Soil EC status of Sirur sub-watershed

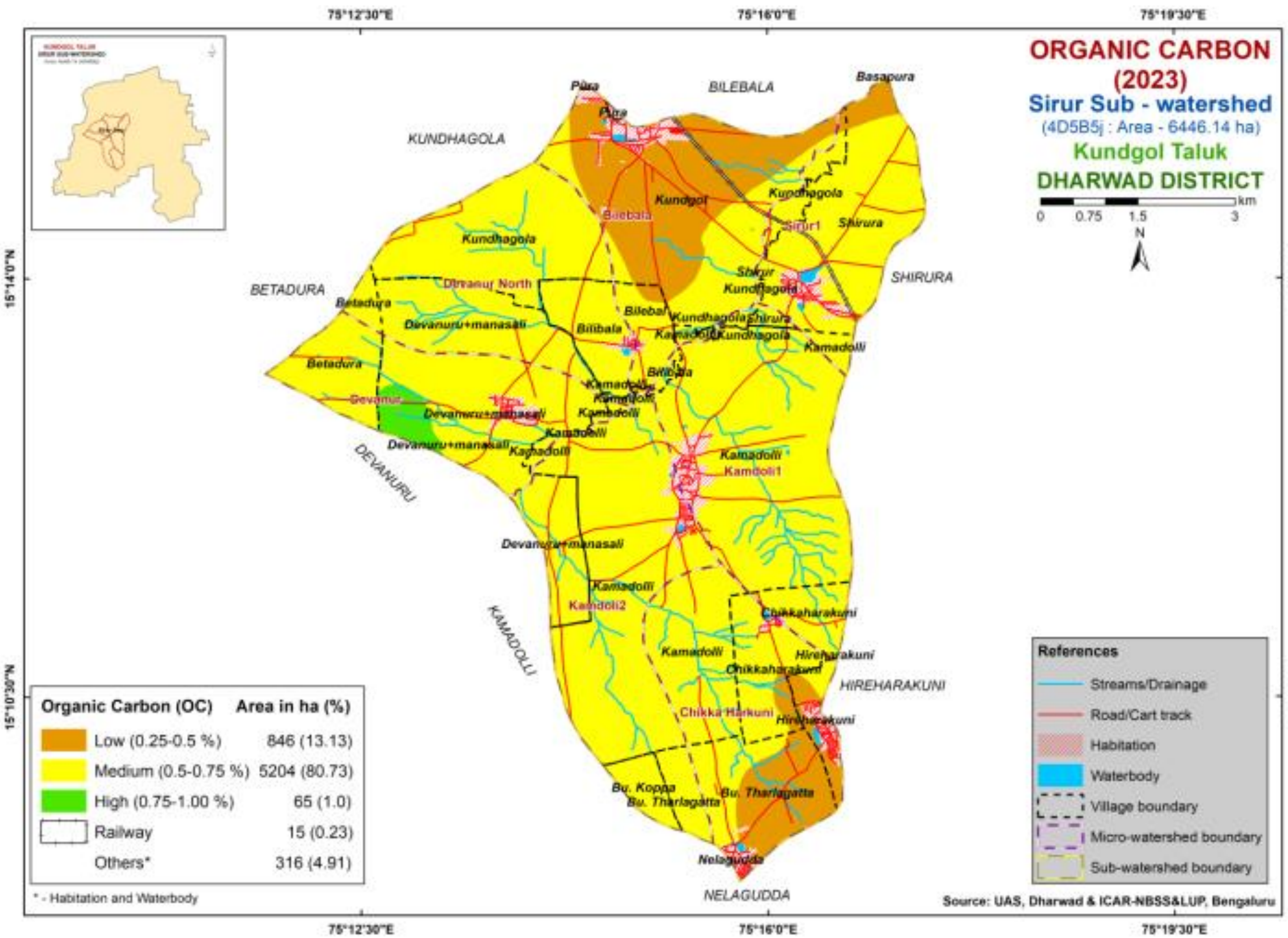

Fig. 4. Soil OC status of Sirur sub-watershed

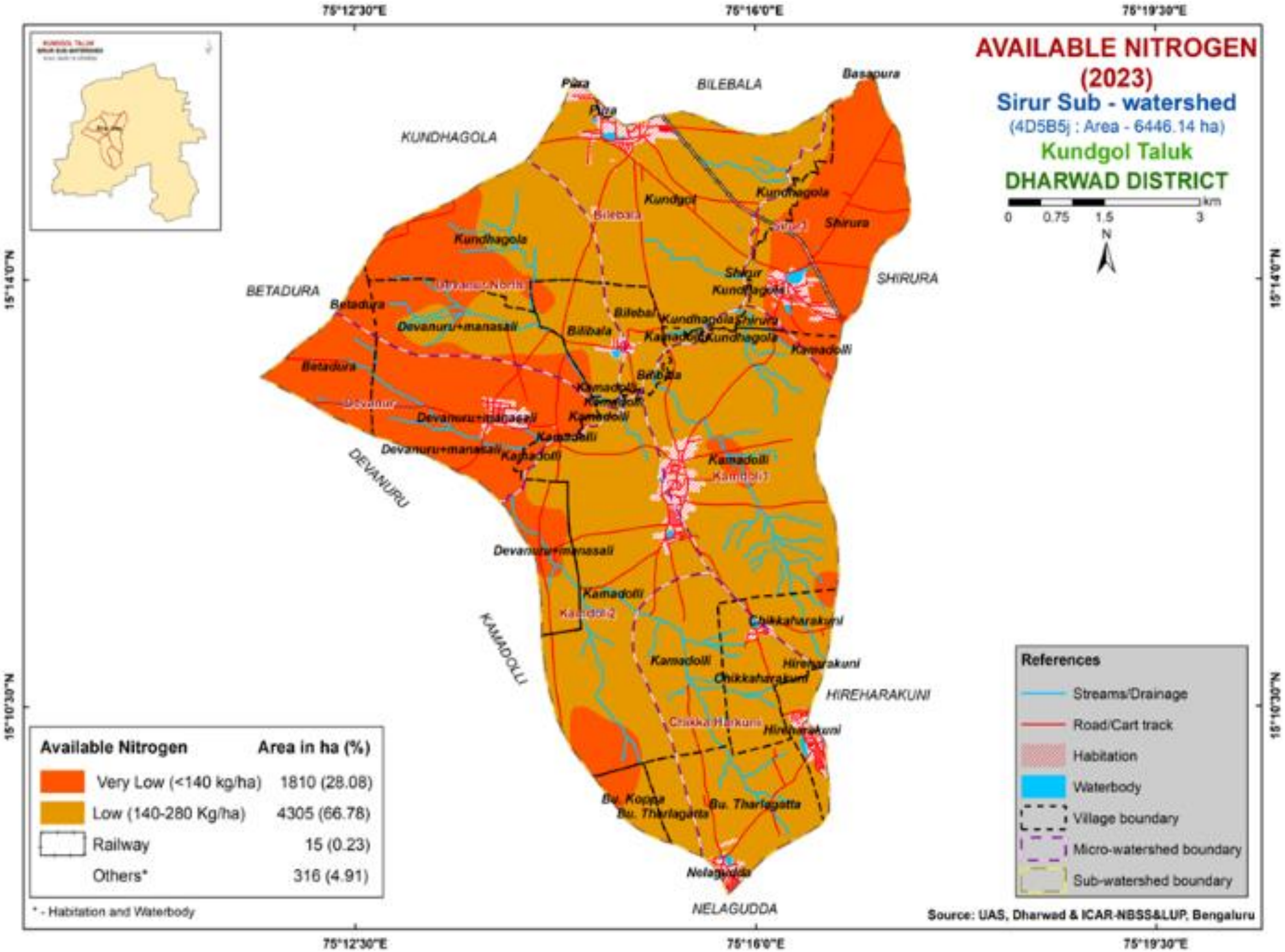

Fig. 5. Available nitrogen status of Sirur sub-watershed

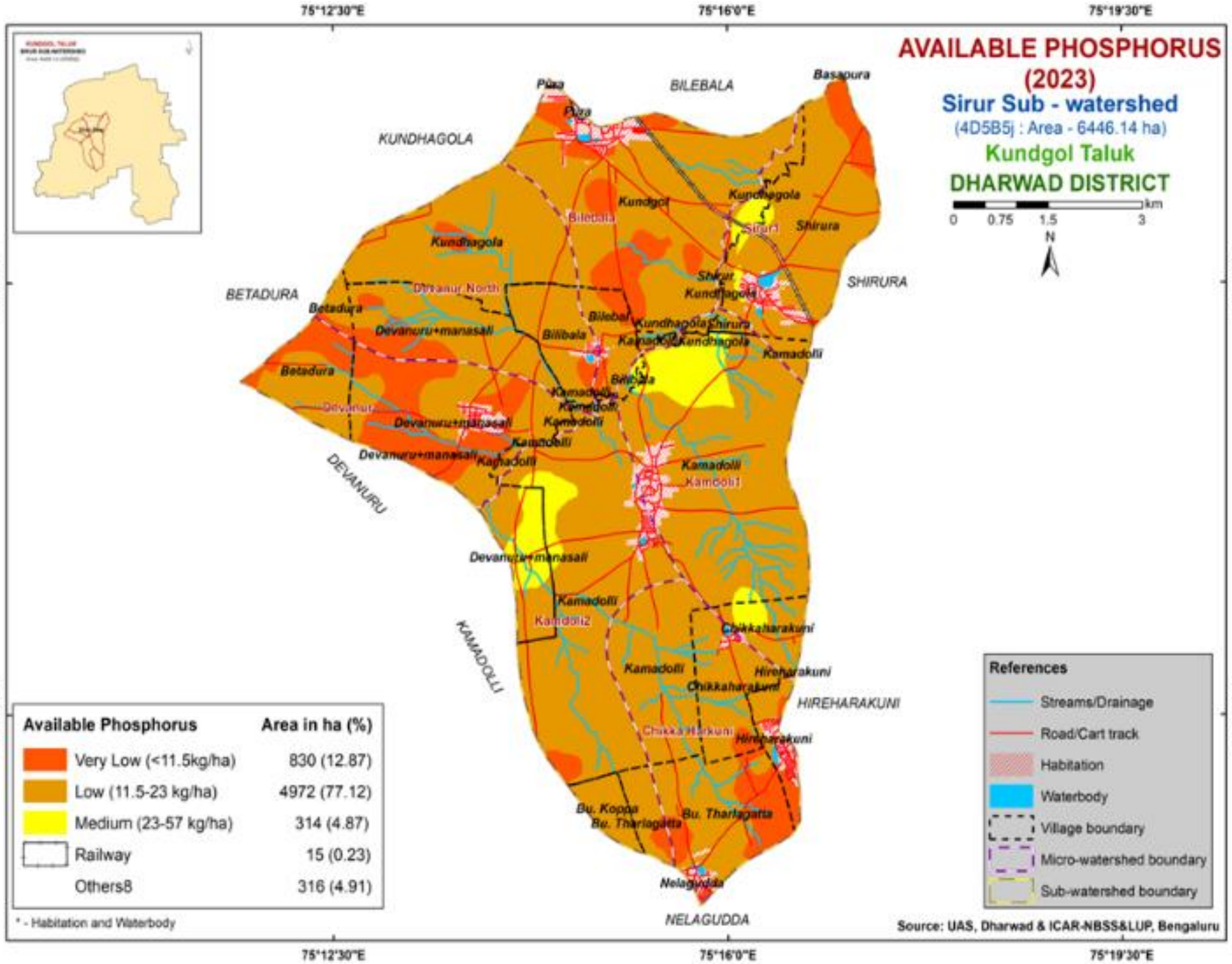

Fig. 6. Available phosphorus status of Sirur sub-watershed

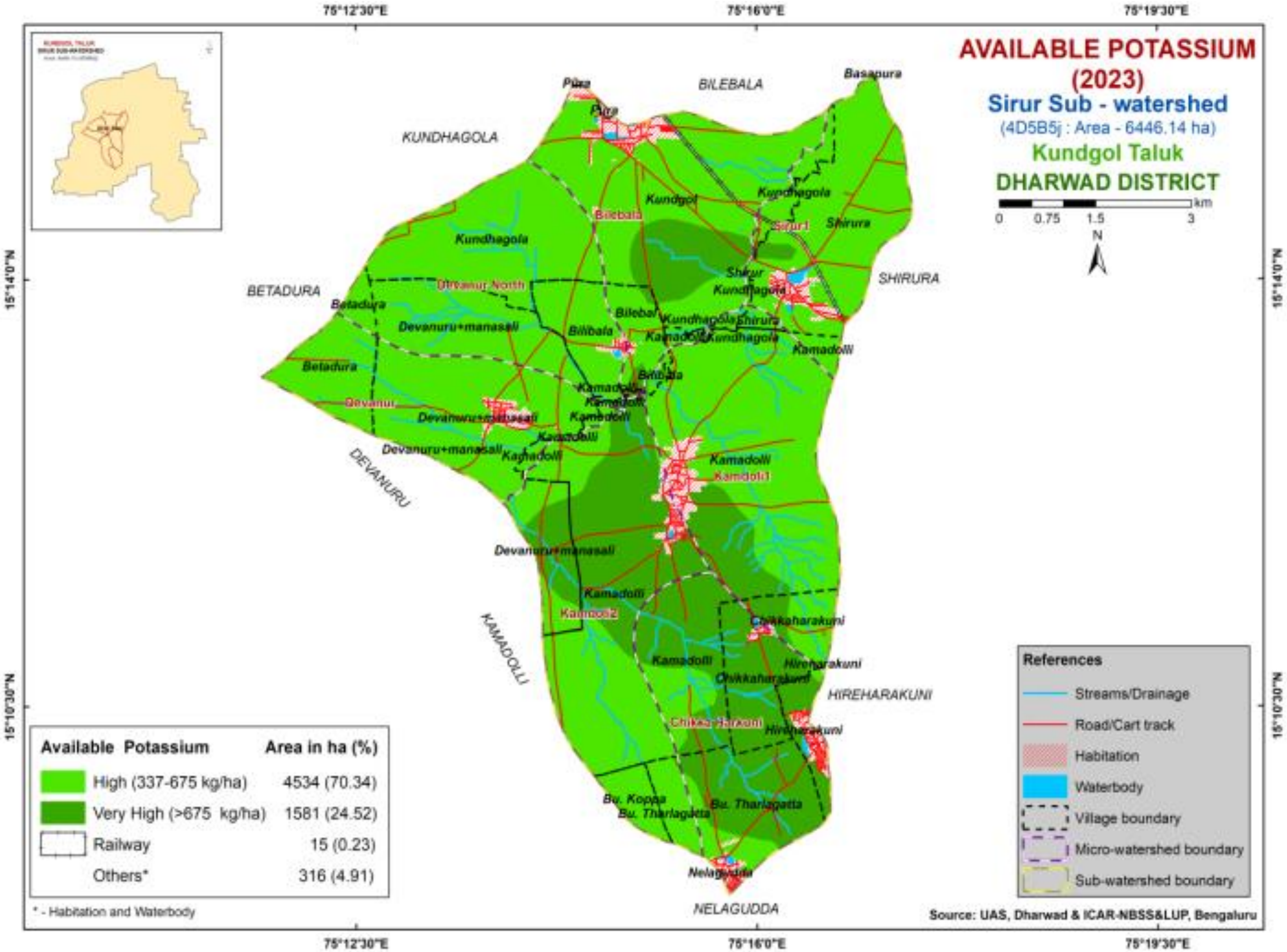

Fig. 7. Available potassium status of Sirur sub-watershed

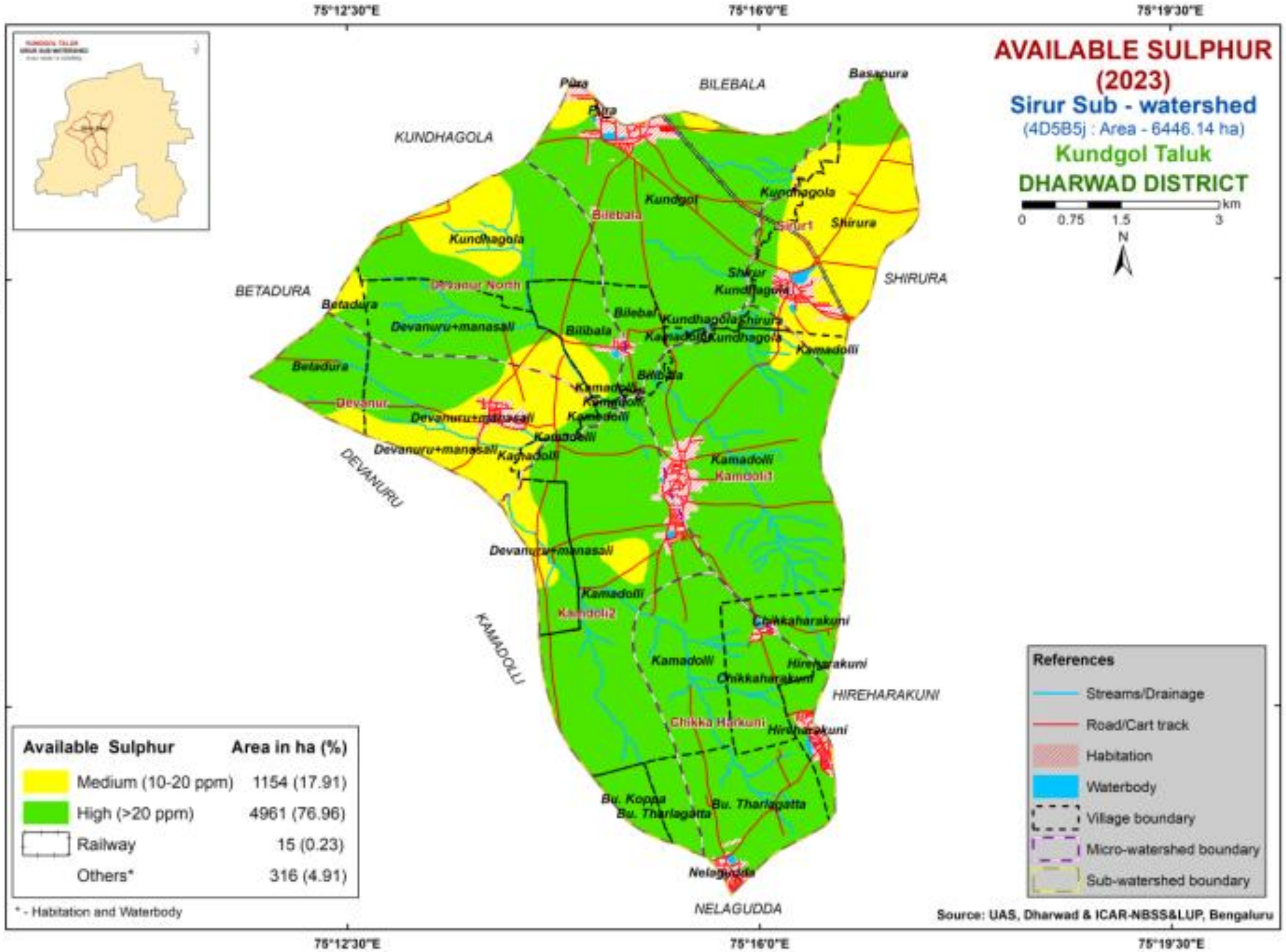

Fig. 8. Available sulphur status of Sirur sub-watershed

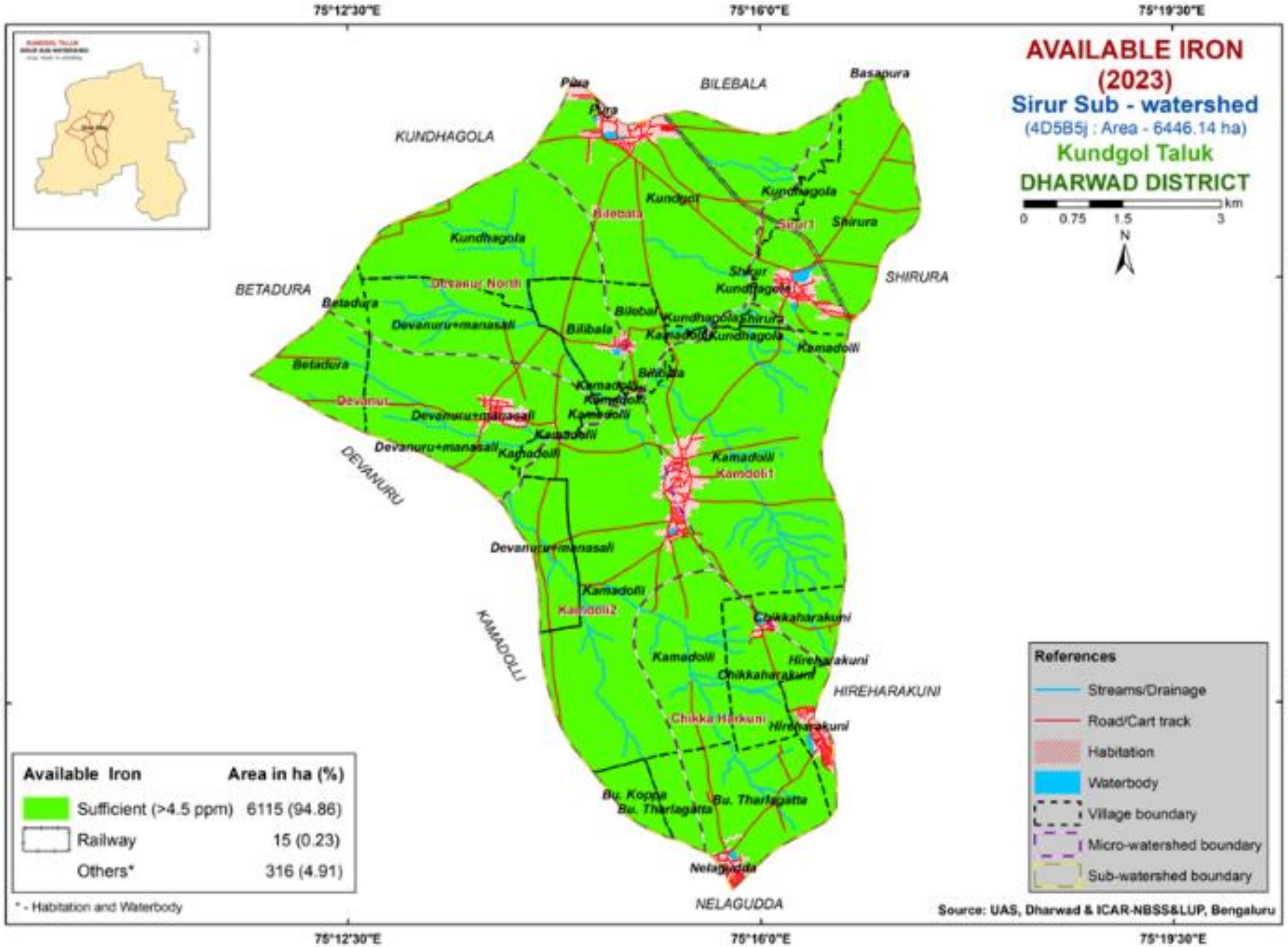

Fig. 9. Available iron status of Sirur sub-watershed

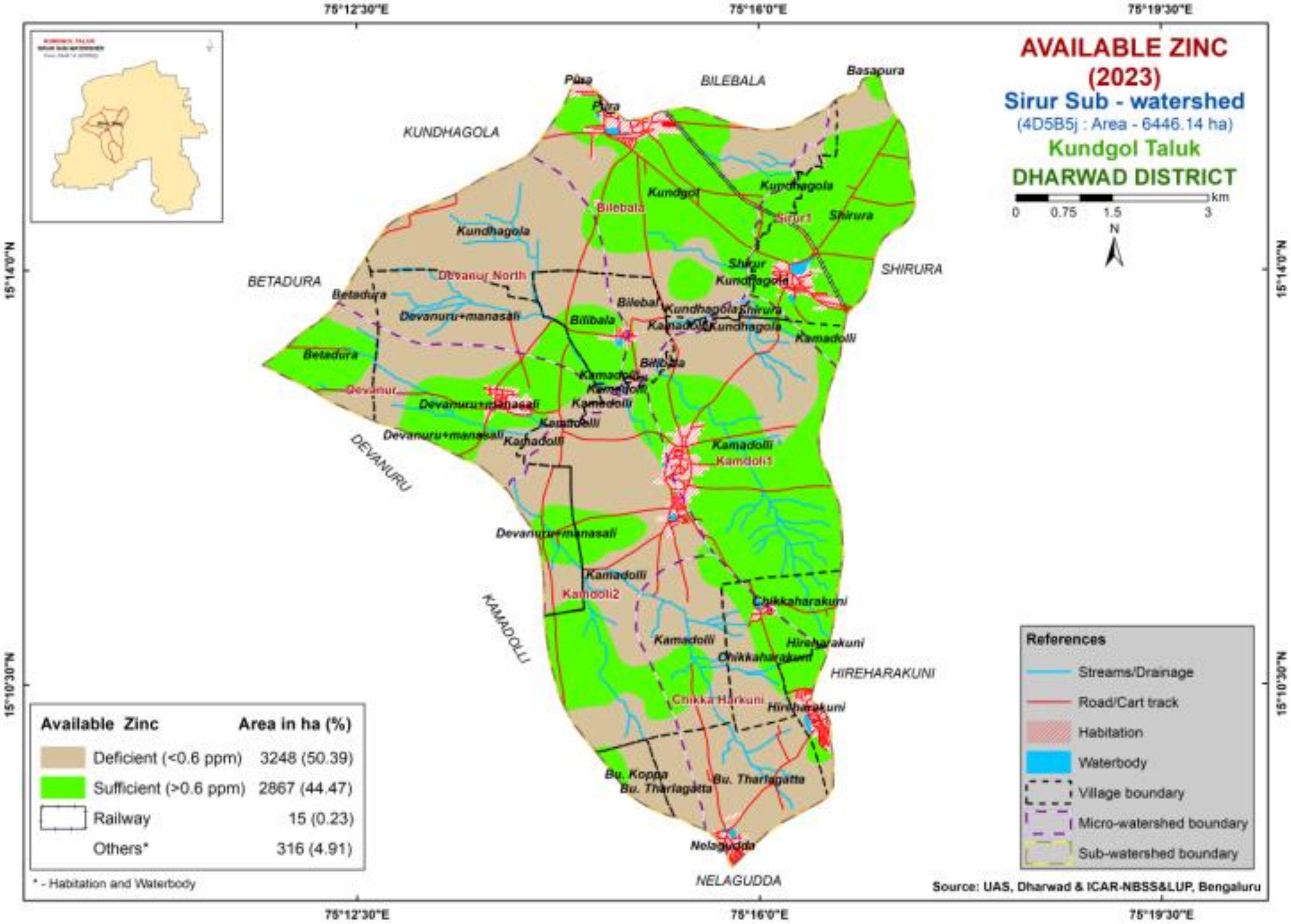

Fig. 10. Available zinc status of Sirur sub-watershed

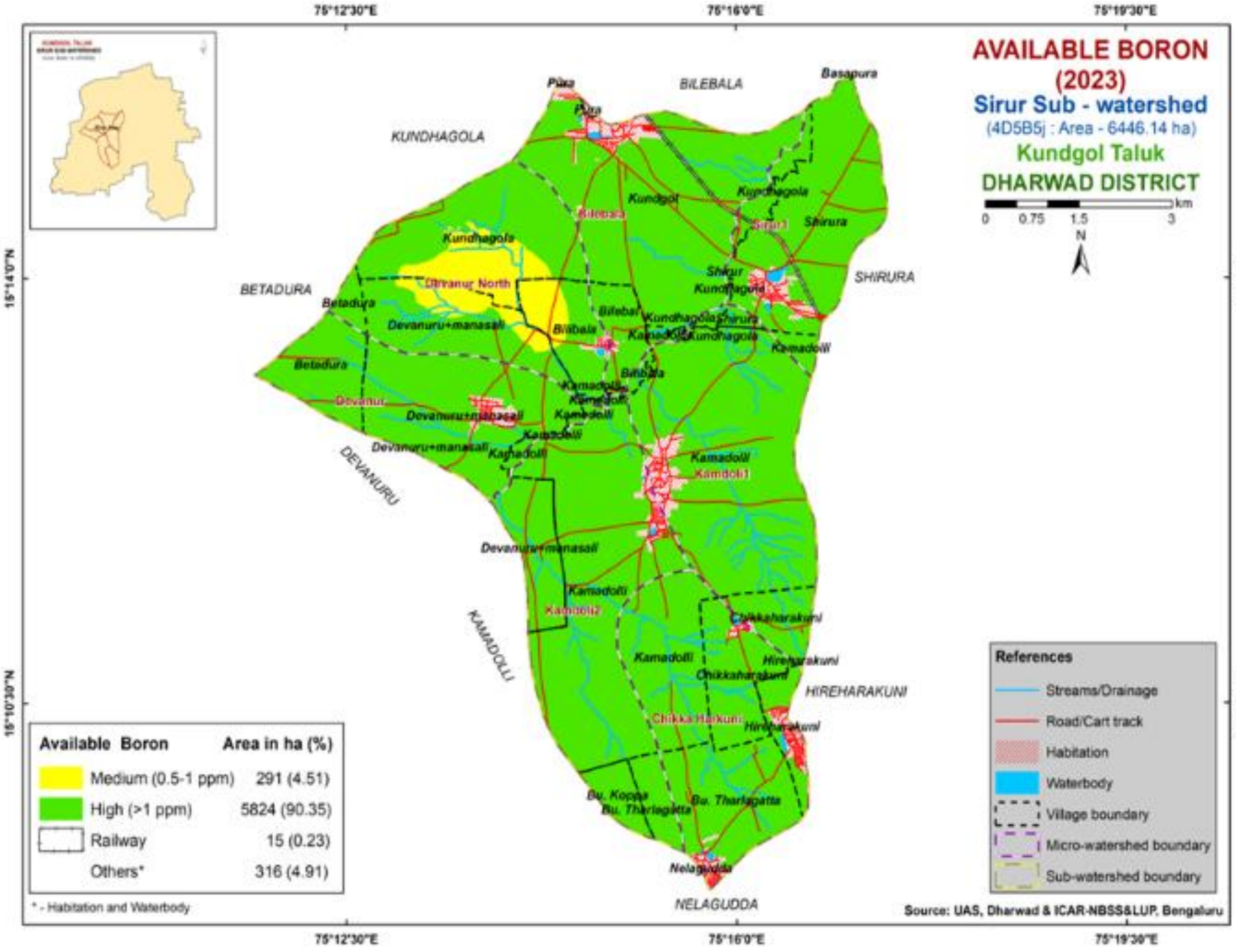

Fig. 11. Available boron status of Sirur sub-watershed

The available Cu in the entire sub-watershed showed sufficient levels ranging from 0.24 to 8.06 mg kg^{-1} with mean and SD value of 1.93 and 0.98, respectively (Table 4). The CV of 50.62 per cent for available Cu content highlights spatial variations within the sub-watershed. Consistent findings of sufficient copper status in soils of northern Karnataka were also noted by Ravikumar et al. [37], Pulakeshi [33] and Manojkumar [38].

The available Zn in the sub-watershed ranged from 0.09 to 4.39 mg kg^{-1} with mean and SD value of 0.62 and 0.42, respectively (Table 4). The CV of 67.50 per cent for available Zn content indicates that, it varied spatially in the sub-watershed. Mapping of available Zn by GIS revealed that, it was deficient in53.8 per cent and sufficient in 45.70 per cent of the study area (Fig. 10). The zinc content in soils tends to increase with a decrease in pH and an increase in organic carbon (OC) content. Satyavathi and Suryanarayana Reddy [39] similarly noted that zinc content decreases as soil pH increases. Given that most soils are alkaline, low in OC and rich in $CaCO_3$, zinc may have precipitated as hydroxides and carbonates, leading to reduced solubility and mobility, thereby decreasing its availability [36,40].

The available B in the sub-watershed was sufficient and ranged from 0.20 to 4.50 mg kg^{-1} with mean and SD value of 1.56 and 0.64, respectively [41,42] (Table 4). The CV of 40.97 per cent for available B content indicates that, it varied spatially in the sub-watershed. The sub-watershed area was high in 5824 ha (90.35%) and medium in 291 ha (4.51%) in available boron content (Fig. 11). Like sulphur status, available boron status is also closely followed by organic carbon status in these soils [43]. A similar result was reported by Gurumurthy et al. [44] and Katti et al. [40].

4. CONCLUSION

The soils of Sirur sub-watershed in the northern dry zone of Karnataka exhibited neutral to moderately alkaline and non-saline characteristics. They were very low to low in available nitrogen and available phosphorus, high in available potassium and medium to high in available sulfur. Micro-nutrients such as manganese, copper and iron were found to be sufficient, while zinc was deficient. Available boron content ranged from medium to high in the sub-watershed area. GIS mapping highlighted significant deficiencies in available nitrogen, phosphorus and zinc across the study area, demanding immediate attention for sustained crop production. Balanced fertilization, precision agriculture techniques like variable rate fertilization based on GIS-derived maps and the integration of organic amendments and cover cropping methods are recommended to address these soil fertility constraints effectively and promote resilient agricultural systems.

ACKNOWLEDGEMENTS

The manuscript is part of the REWARD project funded by Government of Karnataka. The authors duly acknowledge the technical support from the staff of REWARD project, UAS Dharwad.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. NAAS. Degraded and wastelands of India–status of spatial distribution. New Delhi: National Academy of Agricultural Sciences; 2010.
2. Bacilieri FS, Nicchio B, Lemes EM, Gurski BC. Compounded Biological Soil Conditioner for Soybean Crop Production at Brazil. Journal of Advances in Biology & Biotechnology. 2023;26(4):1–13.
   Available:https://doi.org/10.9734/jabb/2023/v26i4627
3. Diatta AA, Fike JH, Battaglia ML, Galbraith JM, Baig MB. Effects of biochar on soil fertility and crop productivity in arid regions: A review. Arabian Journal of Geosciences. 2020;13:1-7.
4. Saxena RK. Applications of remote sensing in soils and agriculture. Indian Society of Soil Science. 2003;51(4):431-447.
5. Raddy G, Lalitha BS, Jayadeva HM and Subbarayappa CT. Soil fertility assessment and balanced fertilizer recommendation for improved crop productivity in Hanjihalli micro watershed using GIS and GPS. Journal of Pharmacognosy and Phytochemistry. 2019;8(5):1125-1128.

6. Belal AA, El-Ramady H, Jalhoum M, Gad A, Mohamed ES. Precision farming technologies to increase soil and crop productivity. Agro-Environmental Sustainability in MENA Regions. 2021: 117-154.
7. Anonymous. A recap: meteorological centre, Bengaluru, Karnataka. 2023. Accessed 20 March 2024. Available: https://mausam.imd.gov.in.
8. Liu TL, Juang KW, Lee DY. Interpolating soil properties using kriging combined with categorical information of soil maps. Soil Science Society of America Journal. 2006;70:1200–1209.
9. Jackson ML. Soil Chemical Analysis. Prentice Hall of India (Pvt.) Ltd., New Delhi; 1973.
10. Nelson DW, Sommers LE. Total carbon, organic carbon, and organic matter. In Methods of Soil Analysis, Part 3. Chemical Methods (D.L. Sparks, Ed.), Madison, Wisconsin. 1996:961-1010.
11. Sahrawat KL, Burford JR. Modification of alkaline permanganate method for assessing the availability of soil nitrogen in upland soils. Soil Science. 1982;133: 53-57.
12. Olsen SR, Sommers LE. Phosphorus. In Methods of Soil Analysis (A.L. Page et al., Eds.), Part 2, 2nd edition, Madison, Wisconsin. 1982:403-430.
13. Helmke PA, Sparks DL. Lithium, sodium, potassium, rubidium and caesium. In Methods of Soil Analysis, Part 3, Chemical Methods (D.L. Sparks, Ed.). Madison, Wisc. SSSA and ASA. 1996:551-574.
14. Tabatabai MA. () Sulfur. In Methods of Soil Analysis, Part 3. Chemical Methods (D.L. Sparks, Ed.). Madison, Wisconsin. 1996: 921-960.
15. Lindsay WL, Norvell WA. Development of DTPA soil test for zinc, iron, manganese and copper. Soil Science Society of America Journal. 1978;4:421-428.
16. John R, Estefan G, Rashid A, Soil and Plant Analysis, Laboratory Manual, Scientific Publishers, Jodhpur, India. 2007: 111-114.
17. Patil PL, Kuligod VB, Gundlur SS, Katti J, Nagaral IN, Shikrashetti P, Geetanjali HM, Dasog GS. Soil fertility mapping in Dindur sub-watershed of Karnataka for site specific recommendations. Journal of the Indian Society of Soil Science. 2016; 64(4):381-390.
18. Chytry M, Danihelka J, Ermakov N, Hajek M, Hajkova P, Koci M. Plant species richness in continental southern Siberia: effects of pH and climate in the context of the species pool hypothesis. Global Ecology and Biogeography. 2007;16(5): 668–678.
19. Ravikumar MA, Patil PL, Dasog GS. Mapping of nutrients status of 48A distributary of Malaprabha right bank command of Karnataka by GIS technique. I-Major Nutrients. Karnataka Journal of Agricultural Sciences. 2007a;20: 735-737.
20. Patil PL, Bidari BI, Hebbara M, Katti J, Dilvaranaik, Khan S, Vishwanatha S, Geetanjali HM, Dasog GS. Identification of soil fertility constraints by GIS in Bedwatti sub watershed under Northern dry zone of Karnataka for site specific recommendations. Journal of Farm Sciences. 2017;30:206-211.
21. Prabhavati K, Dasog DS, Patil PL, Sahrawat KL and Wani SP. Soil fertility mapping using GIS in three agro-climatic zones of Belgaum district, Karnataka. Journal of the Indian Society of Soil Science. 2015;63(2):173-180.
22. Yan P, Peng H, Yan L Zhang S, Chen A, Lin K. Spatial variability in soil pH and land use as the main influential factor in the red beds of the Nanxiong Basin, China. PeerJ. 2019;6342.
23. Shivaprasad CR, Reddy RS, Sehgal J, Velayutham M. Soils of Karnataka for optimizing land use. NBSS Publications. 1998;47:15.
24. Bali S, Raj Kumar K, Hundal HS, Kuldeep S, Bhupinder S. GIS aided mapping of DTPA-extractable zinc and soil characteristics in the state of Punjab. Journal of Indian Society of Soil Science. 2010;58(2):189-199.
25. Mureva A, Ward D, Pillay T, Chivenge P; Cramer M. Soil organic carbon increases in semi-arid regions while it decreases in humid regions due to woody-plant encroachment of grasslands in South Africa. Scientific reports. 2018;8(1): 15506.
26. Chaitra BK, Dhananjaya BC, Gurumurthy KT, Soumya TM, Ashok LB. Distribution of secondary nutrients under different land use in Hebburu micro-watershed of Chikkamagaluru district, Karnataka.

Journal of Pharmacognosy and Phytochemistry. 2019;8(3): 3034-3037.

27. Basavaraju D, Naidu MVS, Ramavatharam N, Venkaiah K, Rama Rao G, Reddy KS. Characterization, classification and evaluation of soilsin Chandragiri mandal of Chittoor district, Andhra Pradesh. Agropedology. 2005;15: 55–62.
28. Shankaraiah M, Sreemannarayana B, Srinivasaraju A. Studies on the status and distribution ofsulphur in black soils (Vertisols) of Karimnagardistrict, Andhra Pradesh. Indian Journal of Dry Land Agricultural Research and Development. 2006;21:74-79.
29. Bopathi HK, Sharma KN. Phosphorus adsorption and desorption characteristics of some soils as affected by clay and available phosphorus content. Journal of the Indian Society of Soil Science. 2006; 54:111-114.
30. Somasundaram J, Singh RK, Prandiyal AK, Prasad SN. Micronutrient status of soils underdifferent land use systems in Chambal ravines. Journal of the Indian Society of Soil Science.2009;57:307-312.
31. Vara Prasad Rao AP, Naidu MVS, Ramavatharam N and Rama Rao G. Characterization, classification and evaluation of soils on different landforms in Ramachandrapuram mandal and Chittoor district in Andhra Pradesh and sustainable land use planning. Journal of the Indian Society of Soil Science. 2008;56: 23-33.
32. Srikanth KS, Patil, PL, Dasog, GS and Gali SK. apping of Available Major Nutrients of a Microwatershed in Northern dry Zone of Karnataka. Karnataka Journal of Agricultural Science. 2010;21(3):391-395.
33. Pulakeshi PHB, Patil PL, Dasog GS, Radder BM, Bidari BI and Mansur CP. Mapping of nuntrients status by geographic information system (GIS) in Mantagani village under northern transition zone of Karnataka. Karnataka Journal of Agriculture Science. 2012;25: 332-335.
34. Patil PL, Deepa Pawadashetti, Sunilkumar K, Renuka Nagarahalli, Ramachandraiah HC, Deepa Kalappanavar and Umme Salma Sanadi. Soil fertility mapping by GIS in Madhalli sub-watershed under northern dry zone of Karnataka for site specific recommendations. Journal of Farm Science. 2019;32(2):167-176.
35. Nayak RK, Sahu GC, Nanda SSK. Characterization and classification of the soils of Central Research Station, Bhubaneswar. Agropedology. 2002;12:1-8.
36. Patil PL, Radder BM, Patil SG, Aladakatti YR, Meti CB and Khot AB.Response of maize to micronutrients and moisture regimes in vertisols of Malaprabha Command, Karnataka. Journal of Indian Society of Soil Science. 2006;54: 261-264.
37. Ravikumar MA, Patil PL and Dasog GS. 2007b. Mapping of nutrients status of 48A distributary of Malaprabha right bank command of Karnataka by GIS technique. II-Micro nutrients. Karnataka Journal of Agricultural Sciences. 2007b;20:738-740.
38. Manojkumar D. Characterization and classification of soils of a microwatershed on basalt parent rock in northern transition zone of Karnataka. *M. Sc (Agri.) Thesis*, University of Agricultural Sciences, Dharwad (India); 2011.
39. Satyavathi PLA, Suryanarayana Reddy M. Distribution of DTPA extractable micronutrients in soils of Telangana Andhra Pradesh. Agropedology. 2004;14: 32-37.
40. Katti J, Gurumurthy KT, Ravikumar D, Girijesh GI, Sridhar CJ. Fertility assessment of soils of Nandipura micro-watershed under Chikkamagalur district, Karnataka. International Journal of Chemistry. 2020;8(5):977-984.
41. Black CA. Methods of soil Analysis, Part I and II. American Society of Agronomy, Inc, Madison, Wisconsin, USA; 1965.
42. Sahu D, Srivastava L, Porte SS, Jatav G, Baghel S. Evaluation of Soil Fertility Status of Research Farm, College of Agriculture and Research Station, Katghora, Korba, Chhattisgarh. International Journal of Environment and Climate Change, 2023; 13(10):2468–2473.
Available:https://doi.org/10.9734/ijecc/2023/v13i102913
43. Harshita S. Soil characterization of Hebbalagere micro watershed of Channagiri*taluk* in Davanagere district of Karnataka. *M. Sc. (Agri.) Thesis*, University of Agricultural and Horticultural Science, Shivamogga, Karnataka, India; 2018.

44. Gurumurthy KT, Ravikumar D, Priyanka AV, Patil A, Rudresh MD, Vasanthkumar KM, Raghavendra S, Raghu AN.Appraisal and Mapping of soil fertility status for Korasagu-4 micro watershed, by using Geo-spatial techniques. Int. J. Curr. Microbiol. App. Sci. 2019;8(5): 2339-2349.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/117128