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SOIL FERTILITY MAPPING IN SOILS OF AMTUR-3 MICRO-WATERSHED DERIVED FROM SCHISTOSE LANDSCAPE IN BAILHONGAL TALUK OF BELAGAVI DISTRICT, KARNATAKA, INDIA

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ABSTRACT

The study aimed to address soil fertility challenges by leveraging GIS technology, known for its precision in spatial analysis and mapping. Soil fertility varies significantly across landscapes due to factors such as land use, topography, climate and geology. GIS enables a detailed visualization of soil nutrient distribution, facilitating targeted agricultural interventions. By integrating analytical data with GIS, the research focused on identifying critical soil fertility constraints and optimizing land management practices in the Amtur-3 micro-watershed (4D5B8t04). Soil samples from the Amtur-3 micro-watershed (4D5B8t04) in the northern transition zone of Karnataka were drawn at 320 m x 320 m grid interval during March 2023 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 for each parameter were prepared using GIS technology with ArcGIS v 10.4.1. The soils were neutral to slightly alkaline and non-saline. Soil organic carbon content was medium. Available nitrogen (N) was low, available phosphorus (P) was low to medium. Both available potassium (K) and sulphur (S) were medium to high. Among available micronutrients; iron, manganese and copper were sufficient, while zinc was deficient to sufficient. The available boron content was medium to high. Nutrient mapping using GIS techniques revealed that available nitrogen, phosphorus and zinc are important soil fertility constraints in the Amtur-3 micro-watershed.

Key words : GIS, Soil fertility constraints, Soil fertility maps, Watershed.

Introduction

The identification of soil nutrient constraints using Geographic Information System (GIS) techniques represents a cutting-edge approach in agricultural and environmental management. As agricultural productivity and environmental sustainability become increasingly critical, understanding and addressing soil nutrient limitations is essential. Traditional methods of soil analysis, while effective, are often time-consuming and labor-intensive, making them less practical for large-scale assessments (Prabhavati *et al.*, 2015).

GIS, a robust suite of tools for capturing, storing, analyzing and visualizing spatial data, offers a powerful alternative. By integrating various data sources such as remote sensing imagery, soil surveys and land use maps, GIS enables a comprehensive spatial analysis of soil properties. This approach allows for the identification of nutrient deficiencies and other soil constraints across extensive areas with high precision and efficiency. Through GIS techniques, soil nutrient constraints can be mapped and analyzed in relation to specific geographical and environmental factors. This spatial perspective helps in understanding the variability in soil fertility within a given region, identifying areas that require targeted interventions and optimizing the application of fertilizers and soil amendments (Belal *et al*., 2021). Consequently, GIS-based soil nutrient analysis supports precision agriculture practices, enhancing crop yields, reducing input costs and minimizing environmental impacts.

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 Amtur-3 micro-watershed in northern transition zone of Karnataka.

Materials and Methods

Study area and site characteristics

The study area *i.e.*, Amtur-3 micro-watershed (4D5B8t04) is located in Bailhongal taluk of Belagavi district (Fig. 1), which falls under northern transitional zone of Karnataka. The geo-coordinates of the micro-watershed are 15°47'0" – 15°49'0" North latitudes and 74°49'30" – 74°51'0" East longitudes with total area of about 824.82 ha. The climate of the area is semi-arid to sub-humid with mean maximum and minimum temperatures in the range of 28-38°C and 16-23°C and the average annual rainfall of the zone ranges from 620 to 1025 mm (Anonymous, 2023). The soils are shallow to medium deep with texture ranging from sandy loam (red soil) to clay (black soil). The main cropping season is *kharif*. Maize, rice, jowar, pulses, groundnut, cotton, wheat, sugarcane and some vegetable crops like chilli, potato, peas and onion are the major crops grown in the micro-watershed.

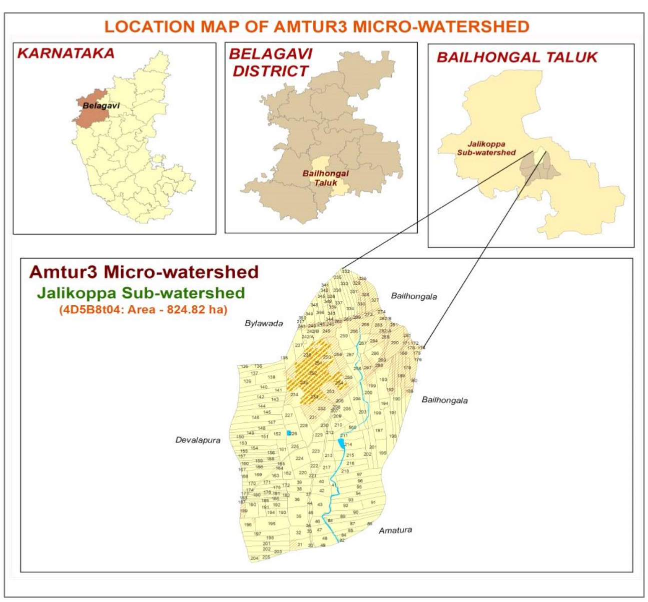

Fig. 1 : Location map of Amtur-3 micro-watershed.

Table 1 : 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
Available macro-nutrients (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
Available secondary nutrient (mg kg^{-1})			
Sulphur	<10	10-20	>20
DTPA extractable 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

Geology of study area

The Archaen schist, an extension of the Dharawar schist belt is observed in Amtur-3 MWS of Bailhongal taluk. Dharawar schist is mainly made up of Argillite (Composed of sediments with more of fine silt and sand-sized particles) and greywackes/ phyllites (Clay dominated by kaolin).

Collection of soil samples and laboratory analysis

Sampling was carried out at a grid interval of 320 m × 320 m during March 2023. A total of 65 surface composite soil samples drawn from 0-20 cm depth were collected using grids overlaid WorldView-2, a 50 cm spatial resolution with 8-band multispectral commercial satellite imagery (Liu *et al*., 2006).

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) and electrical conductivity (EC) (1:2.5) of soils were measured using standard procedures as described by Jackson (1973). Organic carbon (OC) was determined by Walkley-Black method (Nelson and Sommers, 1996). Available nitrogen (N) was analyzed by modified alkaline permanganate method (Sahrawat and Burford, 1982). Available phosphorus (Olsen P) was measured using sodium bicarbonate ($NaHCO_3$) as an extractant (Olsen and Sommers, 1982). The available potassium (K_2O) was determined using the ammonium acetate method (Helmke and Sparks, 1996). The available sulphur (S) was extracted using 0.15% calcium chloride and estimated using spectrophotometer (Tabatabai, 1996). Available micronutrients (Fe, Zn, Cu and Mn) were extracted using DTPA as explained by Lindsay and Norvell (1978). The available boron was determined using Azomethine-H colorimetric method (John *et al*., 2007). 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, S and B in soils were interpreted as low, medium and high and that of available iron (Fe), copper (Cu), zinc (Zn) and manganese (Mn) were interpreted as deficient and sufficient by following the criteria given in Table 1.

A geo-database (GDB) 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 Amtur-3 micro-watershed area was created in Arc GIS 10.3.1 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 Amtur-3 micro-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 Amtur-3 micro-watershed and the interpolation method applied was ordinary kriging. Following this, a map was generated and classified based on the ratings of the individual nutrients outlined in Table 1 (Patil *et al*., 2016). Finally, the area for each nutrient category was calculated.

Results and Discussion

Soil reaction and electrical conductivity

The soils of Amtur-3 micro-watershed exhibited neutral to slightly alkaline reaction, with pH ranging between 6.51 and 7.85 and mean pH of 7.03. The standard deviation of the pH was 0.43 and the coefficient of variation was 6.08 per cent (Table 2). 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 two reaction classes:

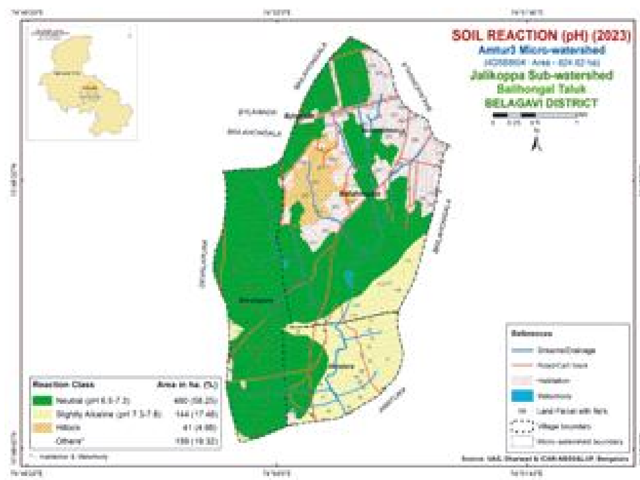

Fig. 2 : Soil reaction status of Amtur-3 micro-watershed.

neutral (6.5–7.3) and slightly alkaline (7.3–7.8). The distribution of these classes in the micro-watershed area (Fig. 2) was neutral (58.25%) followed by slightly alkaline (17.46%). The neutral to slightly alkaline soil reaction observed in the Amtur-3 micro-watershed, despite being inherited from schist parent material, could potentially be attributed to several interconnected factors. The schist, composed mainly of mica, quartz and feldspar, might have exhibited low weathering rates compared to other rock types, resulting in fewer acidic ions being released into the soil solution and contributing to a near neutral pH environment. Additionally, the presence of buffering minerals like calcite in schist could have stabilized soil pH, while weathering of minerals within schist may influenced soil pH dynamics. Moreover, the low intensity of leaching in the study area might have prevented the removal of basic elements like calcium and magnesium, allowing them to accumulate, which could have resulted in slightly alkaline soil pH (Chytry *et al*., 2007; Ravikumar *et al*., 2007a; Patil *et al*., 2017; Prabhavati *et al*., 2015 and Yan *et al*., 2019). These factors collectively seemed to contribute to the observed soil reaction characteristics in schist-derived landscapes.

The electrical conductivity (EC) of soils in the micro-watershed ranged from 0.15 to 0.37 dS m^{-1}, with the mean and standard deviation values of 0.26 and 0.04 dS

Table 2: Chemical properties and available major nutrients status in Amtur-3 micro-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	6.51-7.85	0.15-0.37	1.95-9.73	105.00-287.00	4.29-159.16	94.35-403.20	5.00-43.13
Average	7.03	0.26	5.94	188.89	48.09	190.97	17.72
SD	0.43	0.04	2.12	43.99	32.01	75.55	8.93
CV (%)	6.08	14.19	35.64	23.29	66.57	39.56	50.38

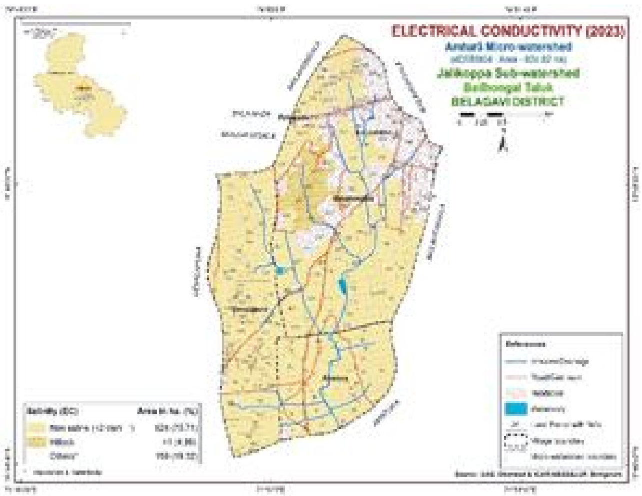

Fig. 3 : Soil EC status of Amtur-3 micro-watershed.

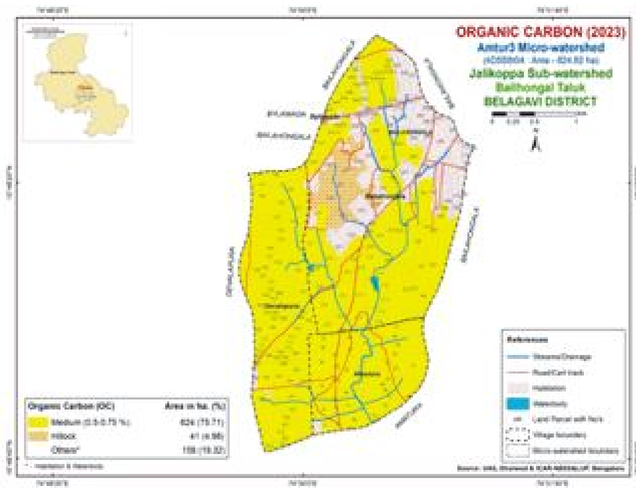

Fig. 4 : Soil OC status of Amtur-3 micro-watershed.

m^{-1}, respectively (Table 2). The coefficient of variation (CV) of EC values was 14.19 per cent, indicating spatial variability in salt content didn't vary significantly within the micro-watershed. Analysis of soluble salt content in the micro-watershed indicated that the area was non-saline (EC remained lesser than 4 dS m^{-1} (Kumar *et al*., 2019). The spatial distribution of EC values showed that a total of 824.82 ha (75.71%) was non- saline in nature (Fig. 3). The non-saline nature of the soils in the study area could be attributed to effective drainage systems, inherent soil properties like texture, mineral composition and the absence of saline parent materials or sources of saline water infiltration. These factors collectively might have minimized salt accumulation in the soil profile, ensuring its suitability for various crops (Wakwoya *et al*., 2023).

Organic carbon

Soil organic carbon (OC) content of Amtur-3 micro-watershed ranged from 1.95 to 9.73 g kg^{-1} with mean and standard deviation value of 5.94 and 2.12 g kg^{-1}, respectively. The coefficient of variation (CV) for OC content was 35.64 per cent, indicating spatial variability in OC within the micro-watershed (Table 2). GIS mapping of OC revealed that 75.71 per cent of the study area had medium OC levels (Fig. 4), which could be attributed to several factors. Firstly, the semi-arid to sub-humid and warm climatic conditions prevalent in the region might have accelerated the degradation of organic matter, limiting OC accumulation in the soil. Additionally, inadequate additions of organic manure and intensive cropping practices further contributed to the depletion of OC levels in the soil. The combination of these factors has limited the buildup of organic carbon, resulting in medium OC levels across the study area. These results are in corroboration with the findings reported by previous studies conducted in similar agro-ecological zones, such as the black soils of the Malaprabha command area of Karnataka (Ravikumar *et al*., 2007a) and the soils of the northern dry zone of Karnataka (Prabhavati *et al*., 2015), indicating the widespread influence of climatic and agricultural practices on soil organic carbon content.

Available macro-nutrients

Wide range of available nitrogen (N) levels was observed in the soils of the Amtu-3 micro-watershed, ranging from 105.00 to 287.00 kg ha^{-1} with a mean of 188.89 kg ha^{-1} and standard deviation of 43.99 kg ha^{-1}, indicated spatial variability in nitrogen availability. This variability was further highlighted by the coefficient of variation (CV) value of 23.29 per cent, signifying differences in nitrogen content across different locations within the micro-watershed (Table 2). The study's findings suggested overall low nitrogen availability in the micro-watershed, covering 75.71 per cent of the area (Fig. 5). The variation in N content might be related to diverse soil management practices, including inadequate crop rotation, monoculture farming, 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 medium organic carbon levels in these regions might be attributed to scanty rainfall and high temperatures causing accelerated oxidation of soil organic matter, resulting in low N status. Addressing these factors through improved soil and nutrient management strategies is essential for enhancing nitrogen availability and promoting soil fertility in the micro-watershed. Similar nitrogen status was reported by Srikant *et al*. (2008), Pulakeshi *et al*. (2012), Patil *et al*. (2016 and 2017a, 2017b, 2018a and 2018b) in clay to sandy loams and calcareous soils of northern Karnataka.

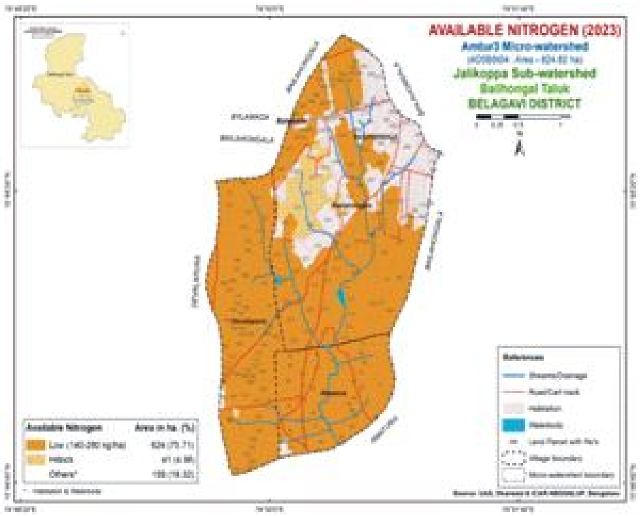

Fig. 5 : Available nitrogen status of Amtur-3 micro-watershed.

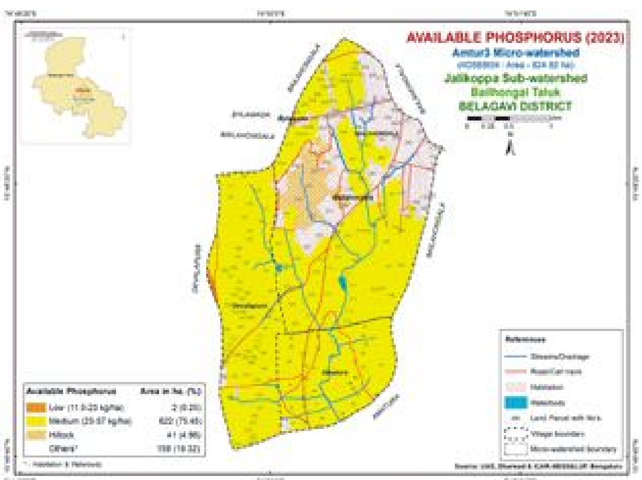

Fig. 6 : Available phosphorus status of Amtur-3 micro-watershed.

The available P_2O_5 content in the micro-watershed ranged from 4.29 to 159.16 kg P_2O_5 ha^{-1}, with an average of 48.09kg ha^{-1} and a standard deviation of 32.01kg ha^{-1}. The coefficient of variation (CV) of 66.57 per cent for available P_2O_5 distribution indicated higher spatially variability in respect of available P_2O_5. GIS mapping showed that 0.25 and 75.45 per cent of the area had low and medium available P_2O_5, respectively (Table 2 and Fig. 6). The low availability of P_2O_5 in these soils was linked to their elevated pH, calcareous nature and low organic matter levels. Ravikumar *et al*. (2007a) 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*. (1998) and Bopathi and Sharma (2006), indicating that most soils in Karnataka exhibit medium phosphorus content.

The available K_2O content in the Amtur-3 micro-watershed exhibited considerable spatial variability,

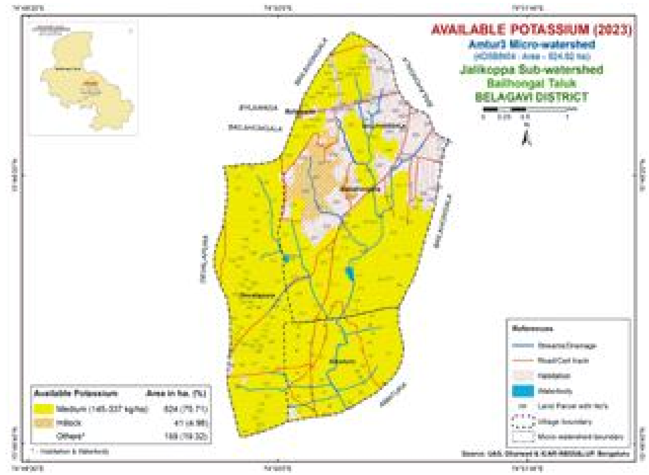

Fig. 7 : Available potassium status of Amtur-3 micro-watershed.

ranging from 94.35 to 403.20 kg K_2O ha^{-1}, with a mean of 190.97 kg ha^{-1} and a standard deviation of 75.55 kg ha^{-1}. GIS mapping indicated that 75.71 per cent of the study area fell into the medium category (Table 2 and Fig. 7). The medium availability of potassium (K) in the soils is consistent with findings from previous studies, suggesting a prevalent influence of mineral composition on potassium levels. The presence of potassium-rich micaceous and feldspar minerals in the schist parent material likely contribute to sufficient or even elevated levels of exchangeable K, ensuring a consistent supply to plants over time. This phenomenon aligns with research by Basavaraju *et al*. (2005), Vara Prasad Rao *et al*. (2008), Somasundaram *et al*. (2009) and Patil *et al*. (2016), which emphasized the significant role of mineral composition in determining potassium content in soils.

The available sulphur (S) content in soils of the micro-watershed ranged from 5.00 to 43.13 mg kg^{-1} soil, with a mean of 17.72 mg kg^{-1} and a standard deviation of 8.93 mg kg^{-1}. The CV of 50.38 per cent emphasized this variability. GIS mapping revealed that 62.53 per cent of the area had medium available S levels, while 13.17 per cent exhibited higher levels (Table 2 and Fig. 8). The higher sulphur content could be attributed to graphitic sulphide rich minerals in schistose parent material of the soil. These sources, though initially non-available, may release sulphur over time. Past studies by Srikanth *et al*. (2008), Pulakeshi *et al*. (2012), Patil *et al*. (2016) and Patil *et al*. (2019) have corroborated these findings, documenting significant influence of parent material and soil properties (especially organic carbon) on sulphur levels.

Available micronutrients

The available Fe in the micro-watershed ranged from 3.30 to 32.48 mg kg^{-1} with mean and SD value of 13.13

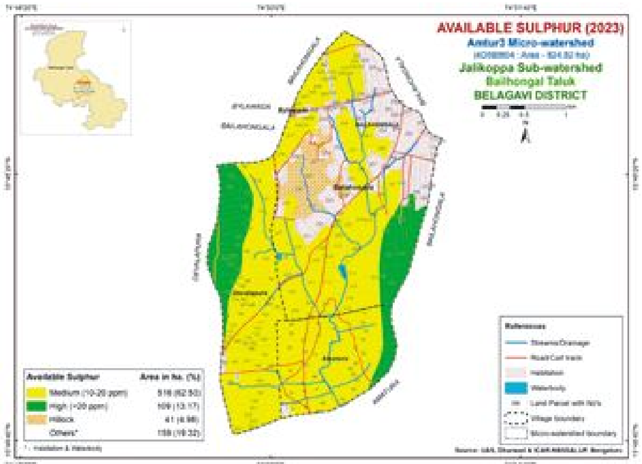

Fig. 8 : Available sulphur status of Amtur-3 micro-watershed.

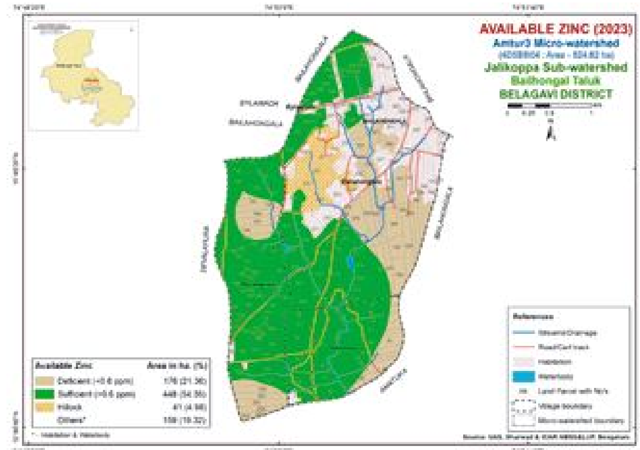

Fig. 10 : Available zinc status of Amtur-3 micro-watershed.

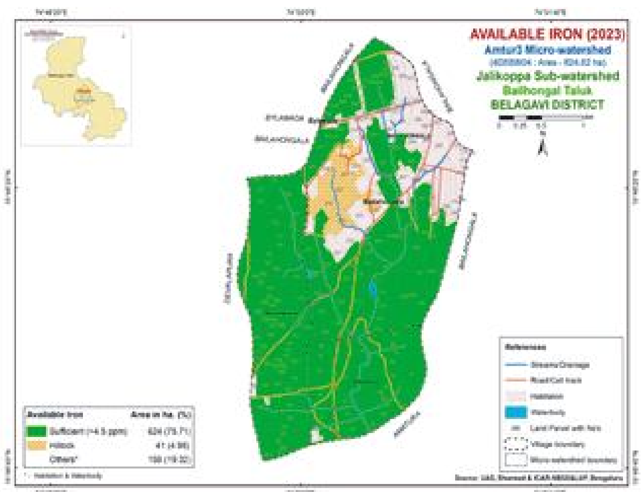

Fig. 9 : Available iron status of Amtur-3 micro-watershed.

Table 3 : Available micronutrients status in Amtur-3 micro-watershed.

Particulars	Fe	Mn	Cu	Zn	B
	(mg kg^{-1})				
Range	3.30-32.48	11.09-37.82	0.34-4.96	0.27-3.08	0.50-2.13
Average	13.13	27.66	2.69	0.77	1.17
SD	7.23	5.20	0.93	0.52	0.46
CV (%)	55.10	18.78	34.52	66.50	39.23

and 7.23 mg kg^{-1}, respectively (Table 3). The CV of 55.10 per cent for available Fe content indicated its larger spatial variability in the micro-watershed. The GIS Map of available Fe status revealed its sufficiency in 75.71 per cent of the area (Fig. 9). The higher spatial variability of available iron in surface soils was also reported by Nayak *et al*. (2002). This type of variation may be due to the soil management practices and cropping pattern adopted by different farmers. The high Fe content in soils may be due to presence of minerals like magnetite, hematite and limonite which together constitute bulk of trap rock in these soils (Vijaya Kumar *et al*., 2013). Similar results were also observed by Sathish *et al*. (2018).

The available Mn in the micro-watershed was sufficient and ranged from 11.09 to 37.82 mg kg^{-1} with mean and SD value of 27.66 and 5.20 mg kg^{-1}, respectively (Table 3). The CV of 18.78 per cent for available Mn content indicated its relatively lesser spatial variability in the micro-watershed as compared to Fe. Sufficient content of Mn was also observed by Ravikumar *et al*. (2007b) in *Vertisols* of Malaprabha command area, Pulakeshi (2012) in the soils of northern transition zone of Karnataka derived from chlorite schist and Manojkumar (2011) in the soils of northern transition zone of Karnataka derived from basalt.

The available Cu in the entire micro-watershed showed sufficient levels ranging from 0.34 to 4.96 mg kg^{-1} with mean and SD value of 2.69 and 0.93 mg kg^{-1}, respectively (Table 3). The CV of 34.52 per cent for available Cu content highlighted spatial variations within the micro-watershed. Consistent findings of sufficient copper status in soils of northern Karnataka were also noted by Ravikumar *et al*. (2007b), Manojkumar (2011) and Pulakeshi (2012).

The available Zn in the micro-watershed ranged from 0.27 to 3.08 mg kg^{-1} with mean and SD values of 0.77 and 0.52 mg kg^{-1}, respectively (Table 3). The CV of 66.50 per cent for available Zn content indicated its higher spatial variability in the soils of the Amtu-3 micro-watershed. The GIS map showed that it was deficient in 21.36 per cent and sufficient in 54.35 per cent of the study area (Fig. 10). The availability of Zn in soils tends to be more under neutral pH conditions and tend to increase with increase in organic carbon (OC) content. Satyavathi and Suryanarayana Reddy (2004) reported lower Zn availability under elevated pH

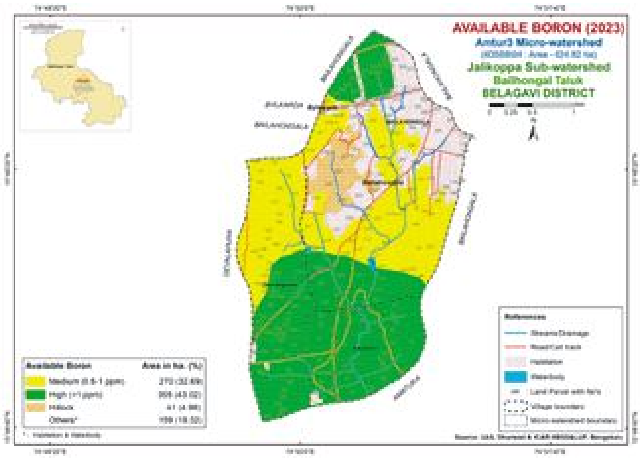

Fig. 11 : Available boron status of Amtur-3 micro-watershed.

conditions. In soils with higher alkalinity, low organic carbon and higher predominance of $CaCO_3$, zinc may have precipitated as hydroxides and carbonates, leading to reduced solubility and mobility, thereby decreasing its availability (Patil *et al*., 2006 and Katti *et al*., 2020).

The available B in the micro-watershed was sufficient and ranged from 0.50 to 2.13 mg kg^{-1} with mean and SD values of 1.17 and 0.46 mg kg^{-1}, respectively (Table 3). The CV of 39.23 per cent for available B content indicated that it varied spatially in the micro-watershed. The available boron content was high in 355 ha (43.02 %) and medium in 270 ha (32.69 %) (Fig. 11). Like available sulphur, available boron status also closely followed the organic carbon status in these soils (Harshita, 2018). A similar result was reported by Gurumurthy *et al*. (2019) and Katti *et al*. (2020).

Conclusion

The soils of Amtur-3 micro-watershed in the northern transition zone of Karnataka exhibited neutral to slightly alkaline reaction and low electrical conductance. They were low in available nitrogen, low to medium in available phosphorus, medium 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 to sufficient and available boron content varied from medium to high in the micro-watershed. Nutrient mapping using GIS techniques revealed considerable areas showing deficiencies in available nitrogen, phosphorus (P_2O_5) and zinc, which are critical soil fertility constraints, demanding immediate attention for sustained crop production. To address these constraints, it is essential to replenish the deficient nutrients through balanced fertilization, precision agriculture techniques and integrated nutrient management practices involving organic manures.

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Conflict of interest

The authors declare that they have no conflict of interest.

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