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Assessing Soil Fertility in Huliginahal Micro-watershed, Karnataka, India: A Basis for Site-specific Recommendations

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Authors' contributions

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

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Abstract

The measurement of soil accessible nutrient levels/contents of a region using the global positioning system (GPS) can assist in creating site-specific balanced fertilizer recommendations and understanding the condition of soil fertility spatially and temporally. Soil samples were collected at

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320m grid intervals from the Huliginahal Micro-Watershed in the northern dry zone of Karnataka, India, and tested for fertility characteristics. The analytical data were analysed, and statistical parameters such as maximum, minimum, mean, and standard deviation were calculated. Soil fertility maps for each parameter were generated in a GIS context using ArcGISv10.4. The soil was neutral to very strongly alkaline, while the EC ranged from non-saline to slightly saline. For the available soil organic carbon (OC) content 43.82 % of the study area was low, while 41.4 % was medium. Most of the study area (93.47%) recorded low available nitrogen. Available phosphorus (P) was low to medium in large parts of the study area (93.99%), with available potassium (K) being medium in a high percentage of the area (77.49%). Available sulphur (S) was medium to high in 41.56% and 52.44% of the area, respectively. Regarding available micronutrients, zinc (Zn), iron (Fe), copper (Cu) and manganese (Mn) were sufficient in more than half of the micro-watershed area. The mapping of nutrients by the GIS technique has thrown light on the soil fertility status of the Huliginahal Micro-Watershed area.

Keywords: Soil fertility map; GIS; watersheds; soil fertility constraints.

1. Introduction

"Intensively cultivated soils are being depleted of available nutrients, especially micronutrients. Therefore, assessment of the nutrient status of soils being intensively cultivated with high-yielding crops needs to be carried out. Soil testing is usually undertaken by collecting composite soil samples in the fields without geographic reference. The results of such soil testing are not useful for site-specific recommendations and subsequent monitoring" (Patil *et. al,* 2006). "The assessment of soil available nutrient levels/contents of an area using the global positioning system (GPS) will help in formulating site-specific balanced fertiliser recommendations and to understand the status of soil fertility spatially and temporally" (Kumar et al., 2022; Patil et al., 2016). "A geographic information system (GIS) is a powerful tool which helps to integrate many types of spatial information, such as agro-climatic zone, land use and soil management to derive useful information" (Patil *et. al,* 2006; Patil et al., 2016). "It has been well documented that dryland soils are not only thirsty but also hungry; therefore, in addition to soil and water conservation measures, addressing nutrient management constraints is essential to further enhance watershed productivity". Hence, planning soil fertility management at the micro-watershed level is crucial. The proposed study was planned with the objective of identifying available nutrient levels in the soils of Huliginahal Micro-Watershed in the northern dry zone of Karnataka, India.

2. Materials and Methods

The Huliginahal Micro-Watershed is located in Hunagunda taluka of Bagalkot district, Karnataka, India, covering an area of 894.89 ha (Fig. 1), falling under the Northern Dry Agro-climatic Zone of Karnataka in India.

The dharawad schist parent rock covers the micro-watershed area. Surface composite soil samples were collected using a handheld GPS at grid points of 320 m intervals in the study area. A total of 85 samples were collected from the micro-watershed. Chemical and fertility characteristics were analyzed after the soil samples were air-dried and ground (less than 2 mm). Standard methods were used to measure the pH (1:2.5) and electrical conductivity (EC) (1:2.5) of the soil–water ratio. The Walkley-Black method was used to calculate organic carbon (OC) (Nelson and Sommers 1996). Using the modified alkaline permanganate method, available nitrogen (N) was calculated. Sodium bicarbonate ($NaHCO_3$) was used as an extractant to determine the amount of available phosphorus (Olsen P) (Olsen and Sommers 1982). Using the ammonium acetate technique, available potassium (K) was calculated (Helmke and Sparks 1996). 0.15% calcium chloride ($CaCl_2$) was used as an extractant to determine the amount of available sulfur (S) (Tabatabai 1996). The process described by Lindsay and Norvell (1978) was used by DTPA to extract the micronutrients (Fe, Zn, Cu, and Mn). The mean, standard deviation, and coefficient of variation were used to evaluate the data's variability. The availability of macronutrients (N, P, K and S) was classified into low, medium and high categories based on standard soil fertility rating limits. The availability of micronutrients (Zn, Fe, Cu and Mn) was interpreted as deficient, sufficient or high using established critical limits recommended for Indian soils.

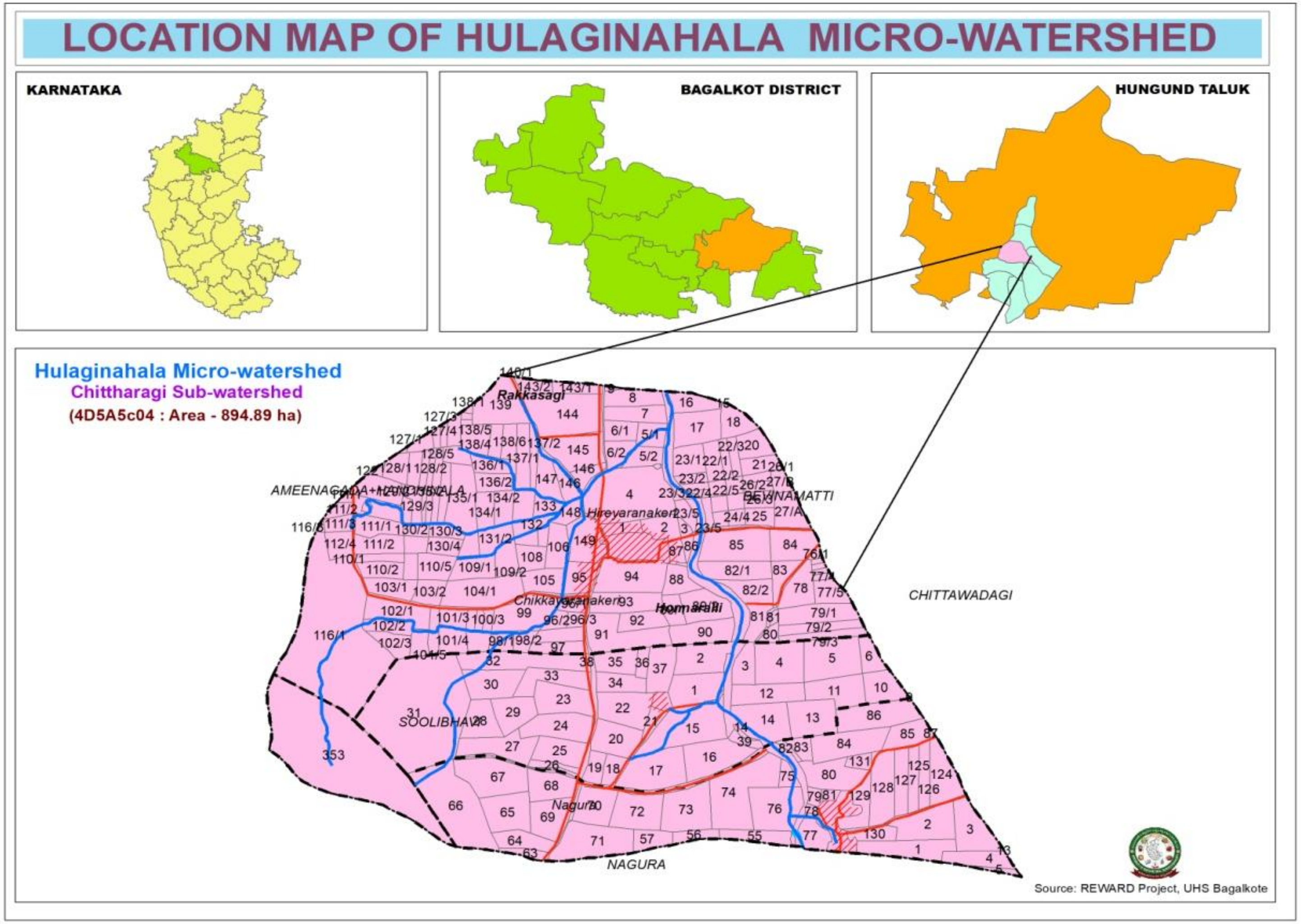

Fig. 1. Location map of Huliginahal micro-watershed

3. Results and Discussion

3.1 Soil Reaction and Electrical Conductivity (EC)

Soil pH in the Huliginahal Micro-Watershed varied from neutral to alkaline conditions. Values spanned 6.71–8.75, averaging 6.98 (SD = 1.01; Table 1). Elevated pH likely stems from the soils' calcareous and sodic properties, compounded by limited leaching and base buildup (Walkley and Black 1934). GIS mapping identified four distinct pH categories (Fig. 2).

These categories included neutral (pH 6.5–7.3; 52.02% of the area), slightly alkaline (pH 7.3–7.8; 23.96%), moderately alkaline (pH 7.8–8.4; 1.21%), slightly acidic (12.69%), and moderately acidic (4.09%). Neutral soils predominated across the micro-watershed.

Electrical conductivity (EC) values across the Huliginahal Micro-Watershed soils fell between 0.11 and 0.94 dS m^{-1}, with an average of 0.46 dS m^{-1} and a standard deviation of 0.21 (Table 1; Fig. 3). The modestly elevated soluble salt levels observed here reflect the area's semi-arid climate, which limits rainfall-driven flushing of ions from the soil profile. Overall, these concentrations classify the micro-watershed as non-saline, posing no salinity constraints for crop growth.

3.2 Organic Carbon

Soil organic carbon (OC) levels in the Huliginahal Micro-Watershed fluctuated between 0.32 and 0.82 g kg^{-1}, averaging 0.46 g kg^{-1} with a standard deviation of 0.22 (Table 1). GIS-based mapping showed that 43.82% of the area had low OC status, while 41.4% fell into the medium category (Fig. 4). These subdued levels likely arise from the dominant semi-arid environment, which accelerates organic matter breakdown due to high temperatures and low moisture, further exacerbated by minimal organic manure inputs, sparse field vegetation, and relentless intensive farming practices. Such patterns echo findings from (Walkley and Black 1934) in Karnataka's northern dry zone soils.

3.3 Available Macronutrients

Available nitrogen (N) concentrations in the Huliginahal Micro-Watershed soils varied from 100.35 to 238.69 kg ha^{-1}, with an average of 206.16 kg ha^{-1} and a standard deviation of 56.81 (Table 1; Fig. 5). Across the entire area, N levels consistently registered as low, highlighting a widespread deficiency. This scarcity can be traced to inconsistent soil management practices, including uneven applications of farmyard manure (FYM) and fertilizers across prior crops. In black soils like these, N often emerges as the primary growth limiter because much of it becomes unavailable through fixation into soil clays or losses via volatilization. Compounding this, the region's scant rainfall and elevated temperatures speed up organic matter decomposition, further depleting N reserves and intensifying shortages. Comparable deficiencies have been documented in non-saline clays, ranging to sandy loams and calcareous profiles.

Table 1. Chemical properties and available major nutrients status in Huliginahal micro-watershed

	Descriptive Statistics			
Parameters	**Mean**	**Minimum**	**Maximum**	**Std. Dev**
pH (1:2.5)	6.98	6.71	8.75	1.01
EC(ds m^{-1})	0.32	0.10	0.94	0.21
OC (%)	0.46	0.30	0.82	0.22
N (Kg ha^{-1})	206.16	100.35	338.69	56.81
P (Kg ha^{-1})	17.13	10.52	25.14	4.14
K (Kg ha^{-1})	265.07	109.92	620.20	118.47
S (ppm)	20.64	12.95	33.96	10.51
Fe (ppm)	6.33	2.08	15.32	2.63
Zn (ppm)	0.48	0.26	1.52	2.22
Cu (ppm)	0.16	0.86	6.20	1.15
Mn (ppm)	21.01	8.40	29.96	6.03

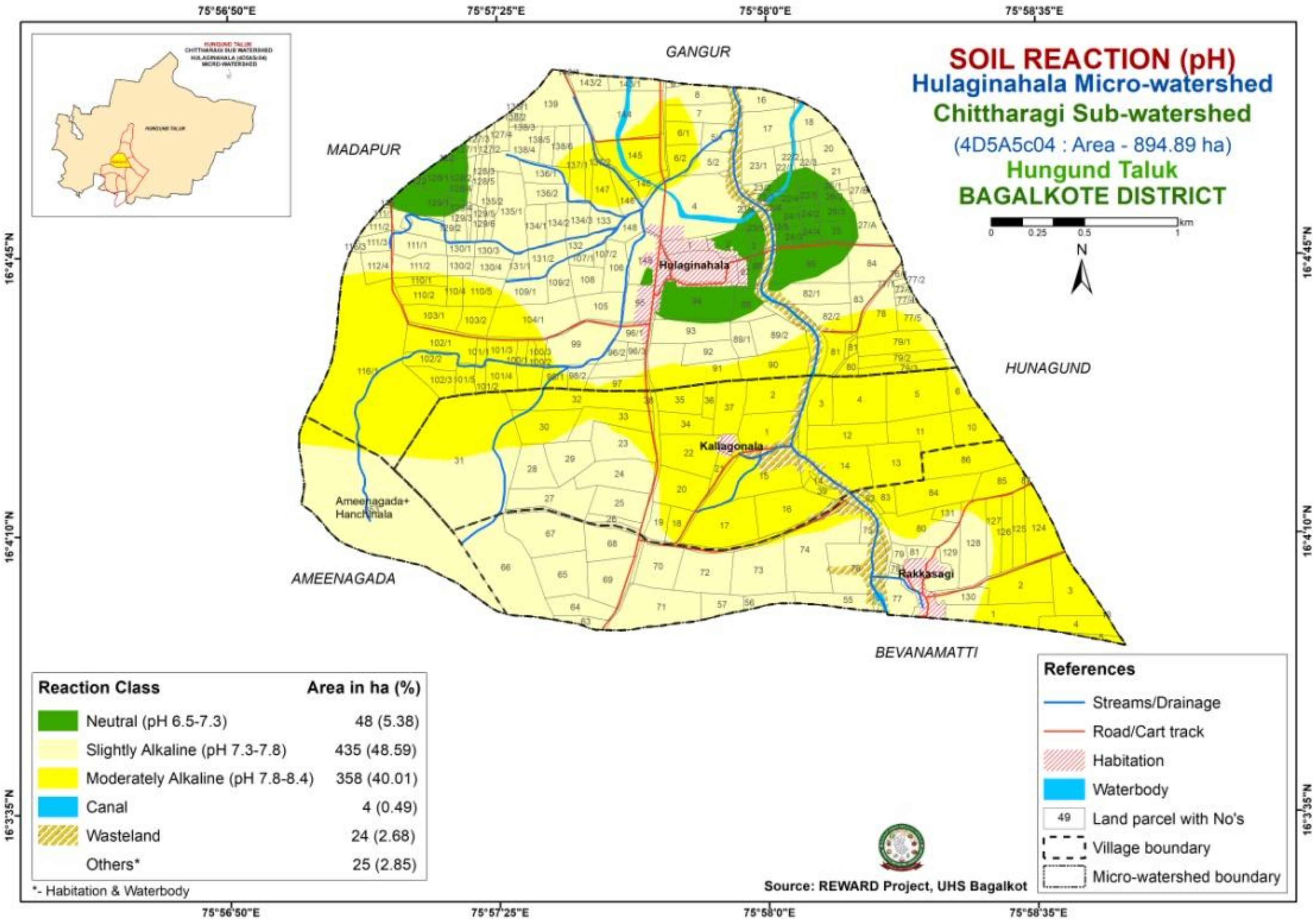

Fig. 2. Soil reaction status of Hulaginahal micro-watershed

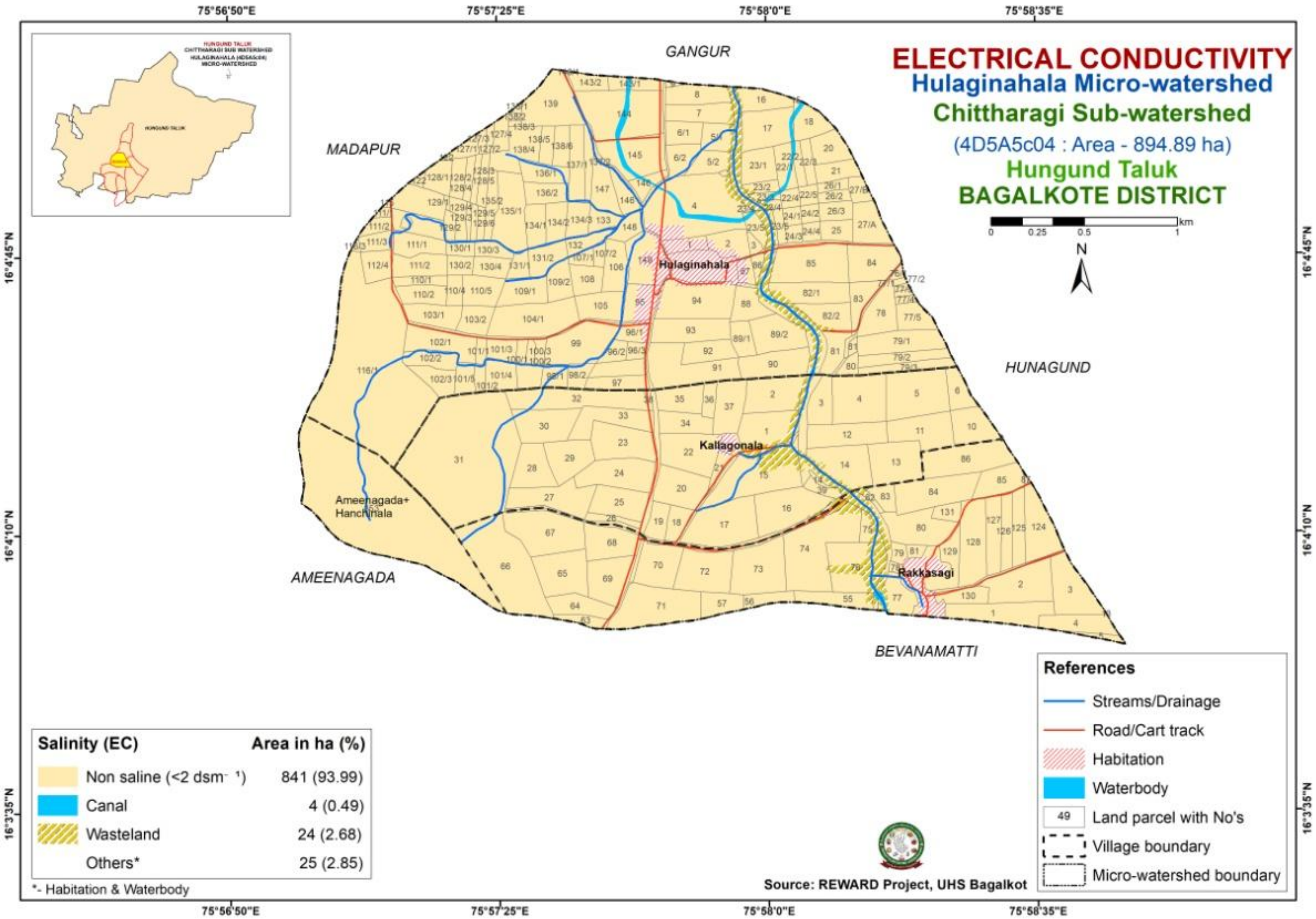

Fig. 3. Electrical Conductivity status of Hulaginahal micro-watershed

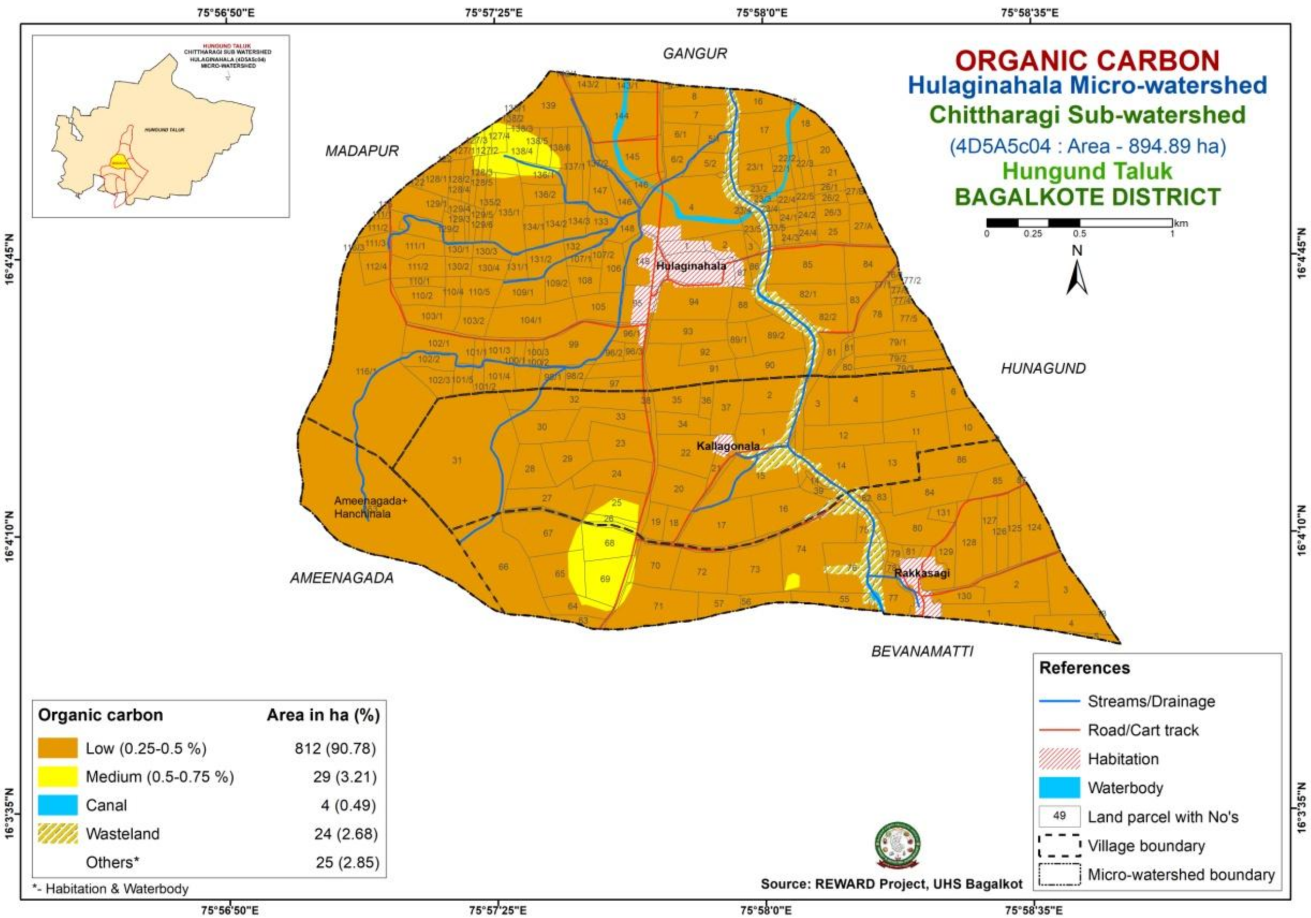

Fig. 4. Soil organic carbon status of Huliginahal micro-watershed

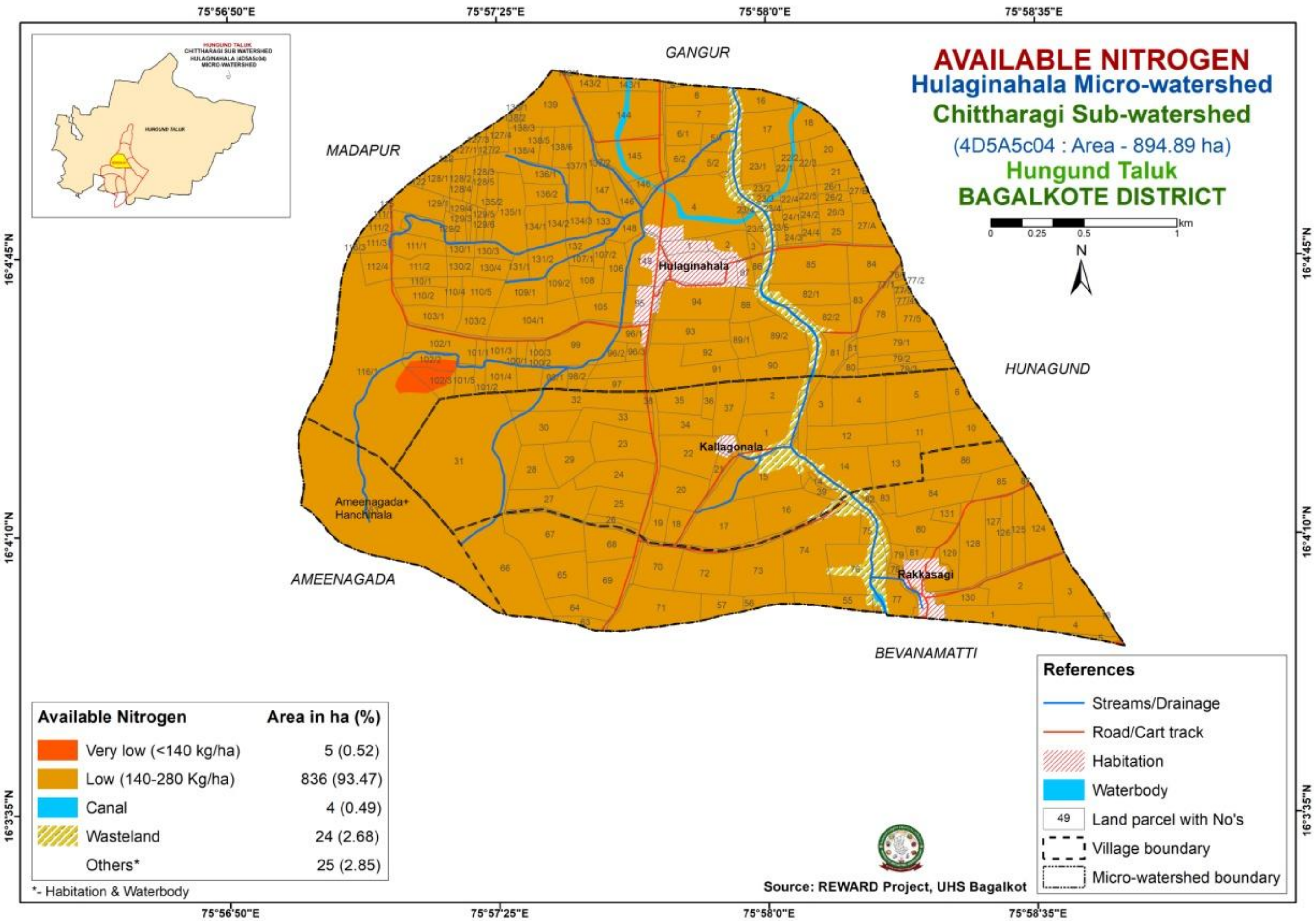

Fig. 5. Available Nitrogen status of Hulaginahal micro-watershed

Available phosphorus (P, as P_2O_5) in Huliginahal Micro-Watershed soils spanned 10.52–45.14 kg ha^{-1}, averaging 17.13 kg ha^{-1} with a standard deviation of 4.14 (Table 1; Fig. 6). GIS analysis indicated low P across 58.34% of the area and medium levels in 35.66%. Poor P accessibility ties directly to the soils' elevated pH, calcareous buildup, and scant organic matter, which together bind phosphorus into less soluble forms. This mirrors, who linked low P in Karnataka's Malaprabha command black soils to high calcium carbonate. Our results align with previous studies, including Shiva Prasad et al. (1998), both noting medium P dominance across Karnataka soils.

Available potassium (K, as K_2O) levels in the Huliginahal Micro-Watershed soils extended from 109.92 to 620.20 kg ha^{-1}, averaging 118.47 kg ha^{-1} with a standard deviation of the same value (Table 1; Fig. 7). GIS mapping classified 77.49% of the area as medium in K and 16.5% as high. Surface soils in Karnataka consistently show elevated water-soluble and exchangeable K forms. These soils sustain adequate to abundant exchangeable K over extended periods, reliably supporting plant uptake (Lindsay *et al.,* 1978). The prevalent medium-to-high K status here stems from abundant K-bearing minerals like mica and feldspar in the underlying parent rock. Matching observations appear in Lindsay *et al.* (1978).

Available sulfur (S) concentrations in the Huliginahal Micro-Watershed soils ranged from 12.95 to 33.96 mg kg^{-1}, with an average of 20.64 mg kg^{-1} (Table 1; Fig. 8). GIS mapping classified 41.56% of the study area as medium in available S and 52.44% as high, creating a near-even split between these two categories. Lower S pockets trace back to the gypsum-like forms prevalent in black soils, which resist plant uptake, while broader medium-to-low trends reflect insufficient sulfur fertilizers amid ongoing crop harvests that deplete reserves. Standard ratings for soil tests appear in Table 2.

3.4 Available Micronutrients

3.4.1 Iron (Fe)

Levels ranged from 2.08 to 15.32 mg kg^{-1}, averaging 6.33 mg kg^{-1} (SD = 2.63; Table 1). GIS mapping pinpointed deficiencies in just 4.87% of the area, while 89.12% proved sufficient (Fig. 9). Spotty low Fe traces to calcium carbonate precipitation locking it away from roots, a pattern echoed in Patil *et al*. (2006). Surface Fe distribution lacks uniformity, varying with farmer-specific management and cropping choices.

3.4.2 Manganese (Mn)

Concentrations spanned 8.4–29.96 mg kg^{-1}, averaging 11.14 mg kg^{-1} (SD = 6.03; Table 1; Fig. 10) marking the area as uniformly sufficient. Spatial variability appeared evident, aligning with adequate Mn in chlorite schist-derived Vertisols from Karnataka's northern transition zone.

3.4.3 Copper (Cu)

The full watershed registered sufficient Cu, from 0.25 to 10.62 mg kg^{-1} (mean = 1.89 mg kg^{-1}, SD = 1.57; Table 1; Fig. 11). This matches observations in north Karnataka soils.

Table 2. Soil fertility ratings for available nutrients

Fertility rating major and micro nutrients			
	Low	**Medium**	**High**
Organic carbon (g kg^{-1})	<5	5-7.5	>7.5
Macro nutrients (kg ha^{-1})			
Nitrogen (N)	<280	280-560	>560
Phosphorus (P_2O_5)	<22.5	22.5-55	>55
Potassium	<140	140-330	>330
Sulphur (mg kg^{-1})	<10	10-20	>20
Micro nutrients (mg kg^{-1})	**Deficient**	**Sufficient**	**Excess**
Zinc (Zn)	<0.6	0.6-1.5	>1.5
Iron (Fe)	<2.5	2.5-4.5	>4.5
Copper (Cu)	<0.2	0.2-5.0	>5.0
Manganese (Mn)	<2.0	2-4	>4.0

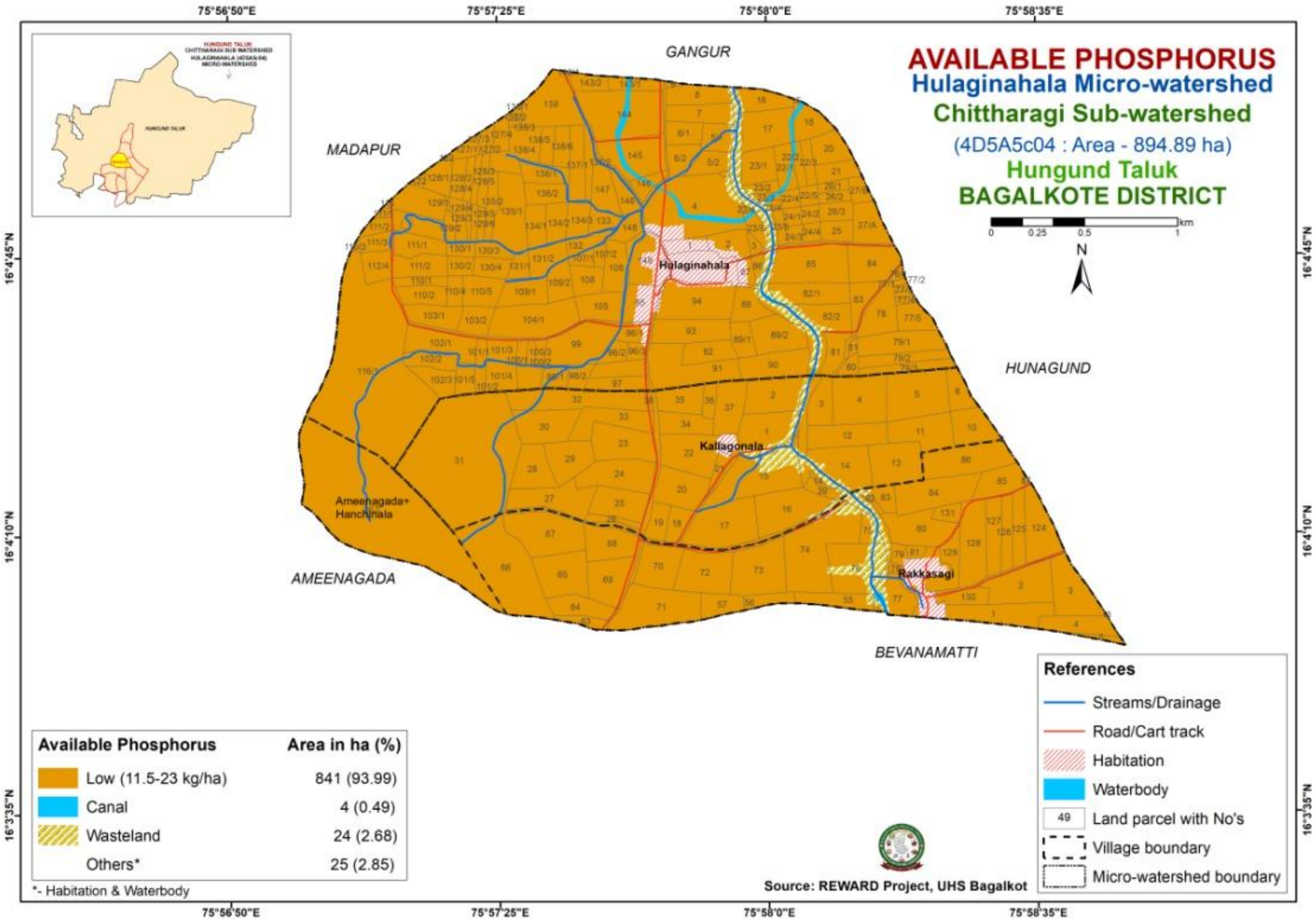

Fig. 6. Available Phosphorus status of Hulaginahal micro-watershed

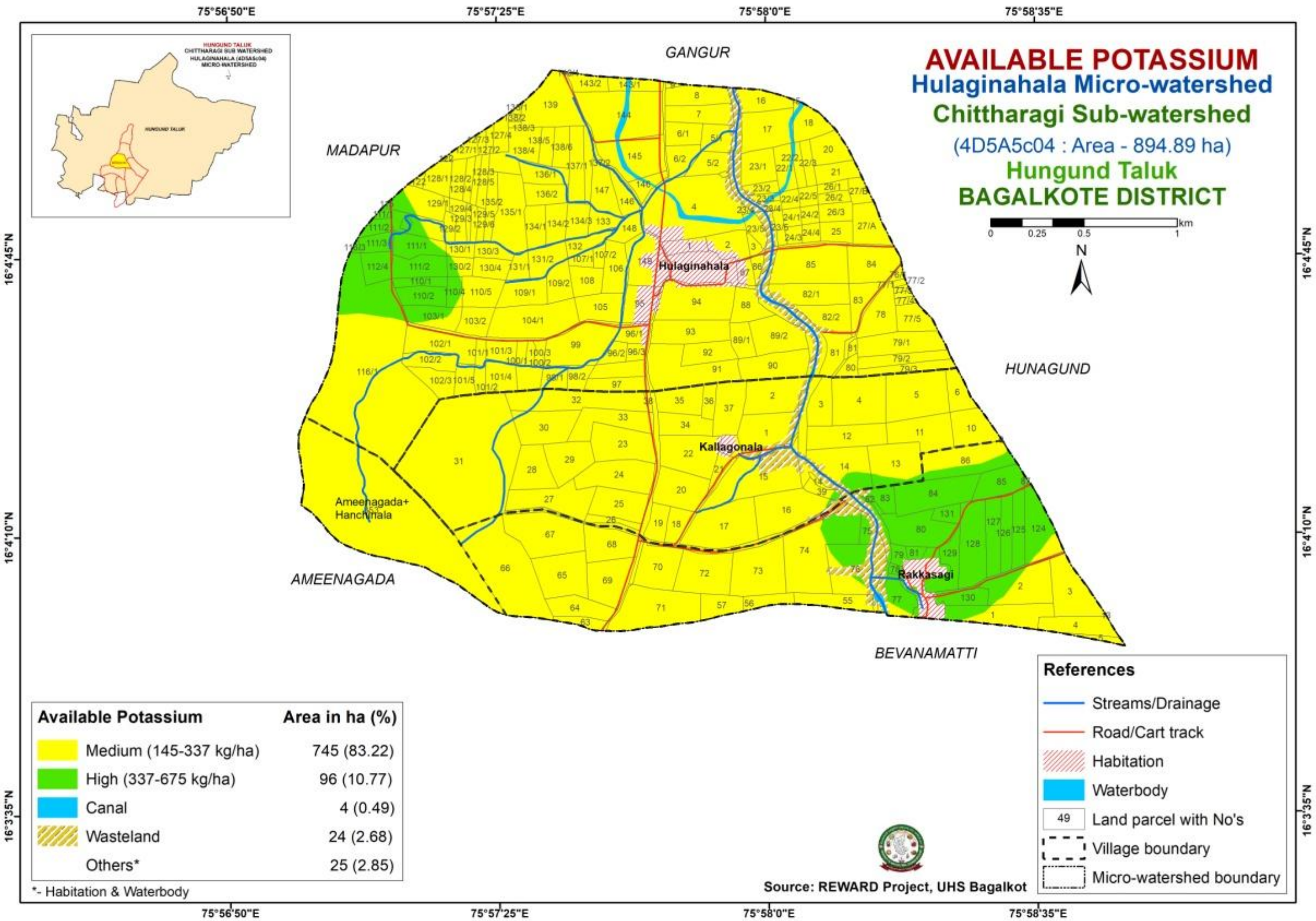

Fig. 7. Available potassium status of Hulaginahal micro-watershed

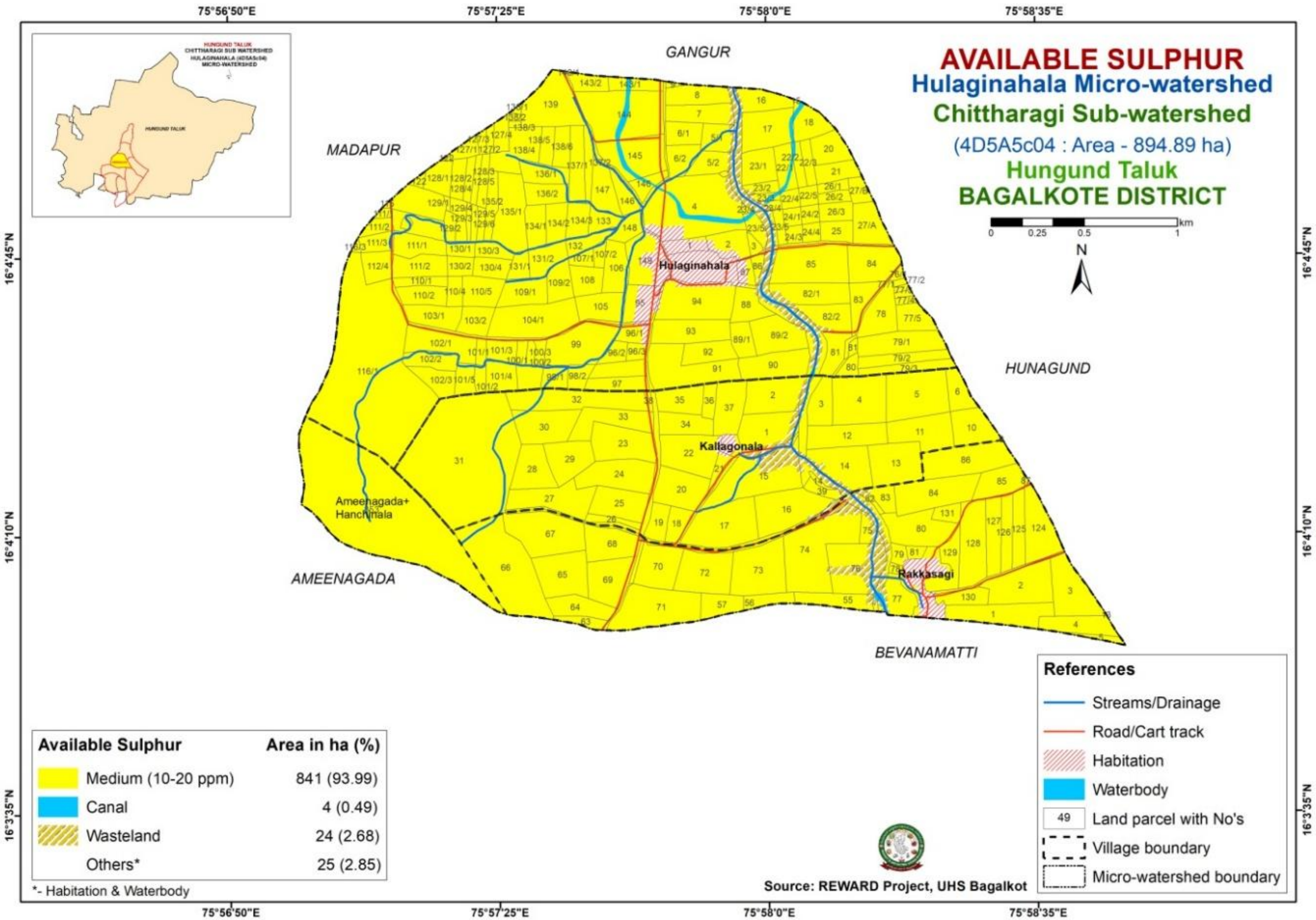

Fig. 8. Available sulphur status of Hulaginahal micro-watershed

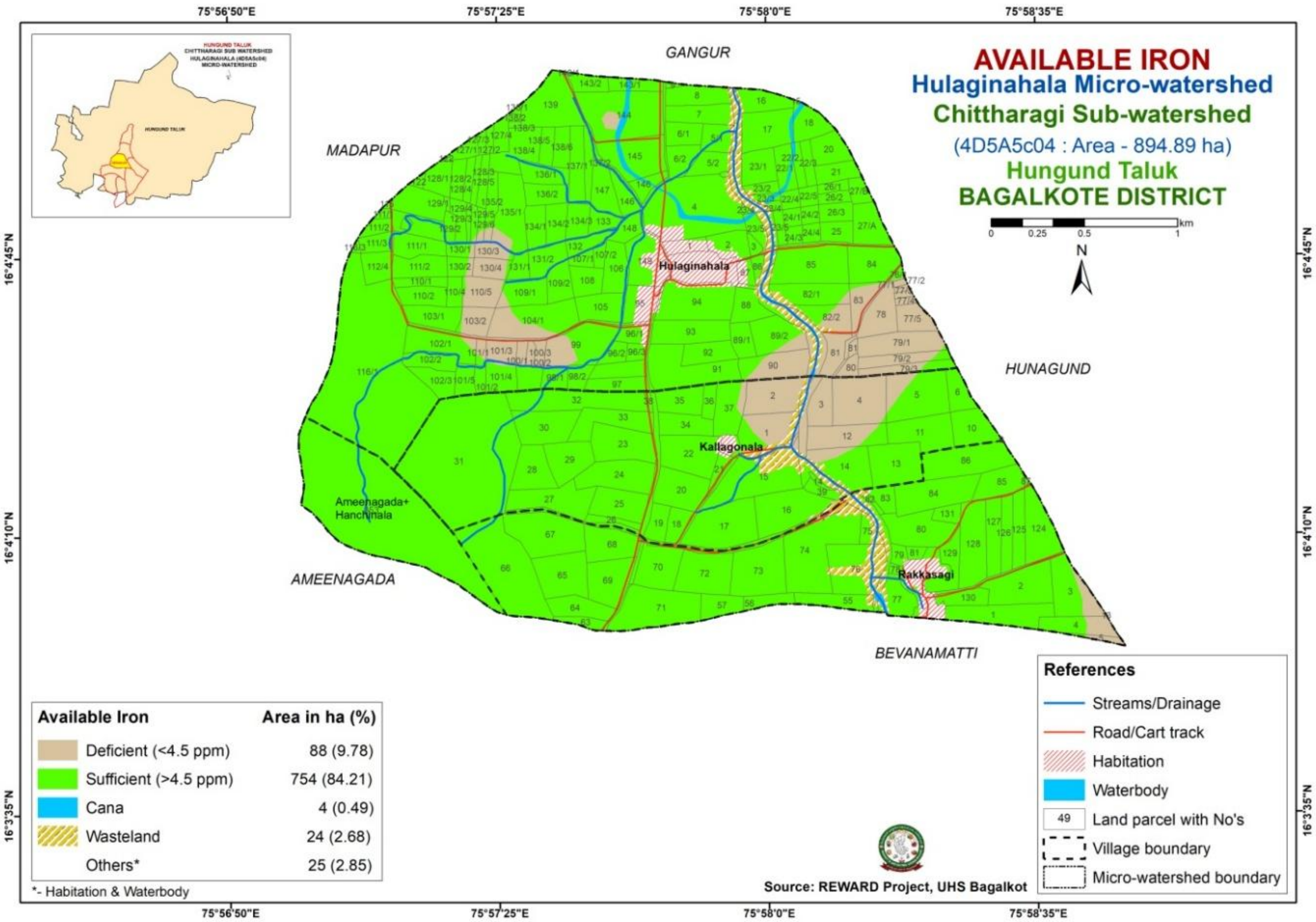

Fig. 9. Available Iron status of Hulaginahal micro-watershed

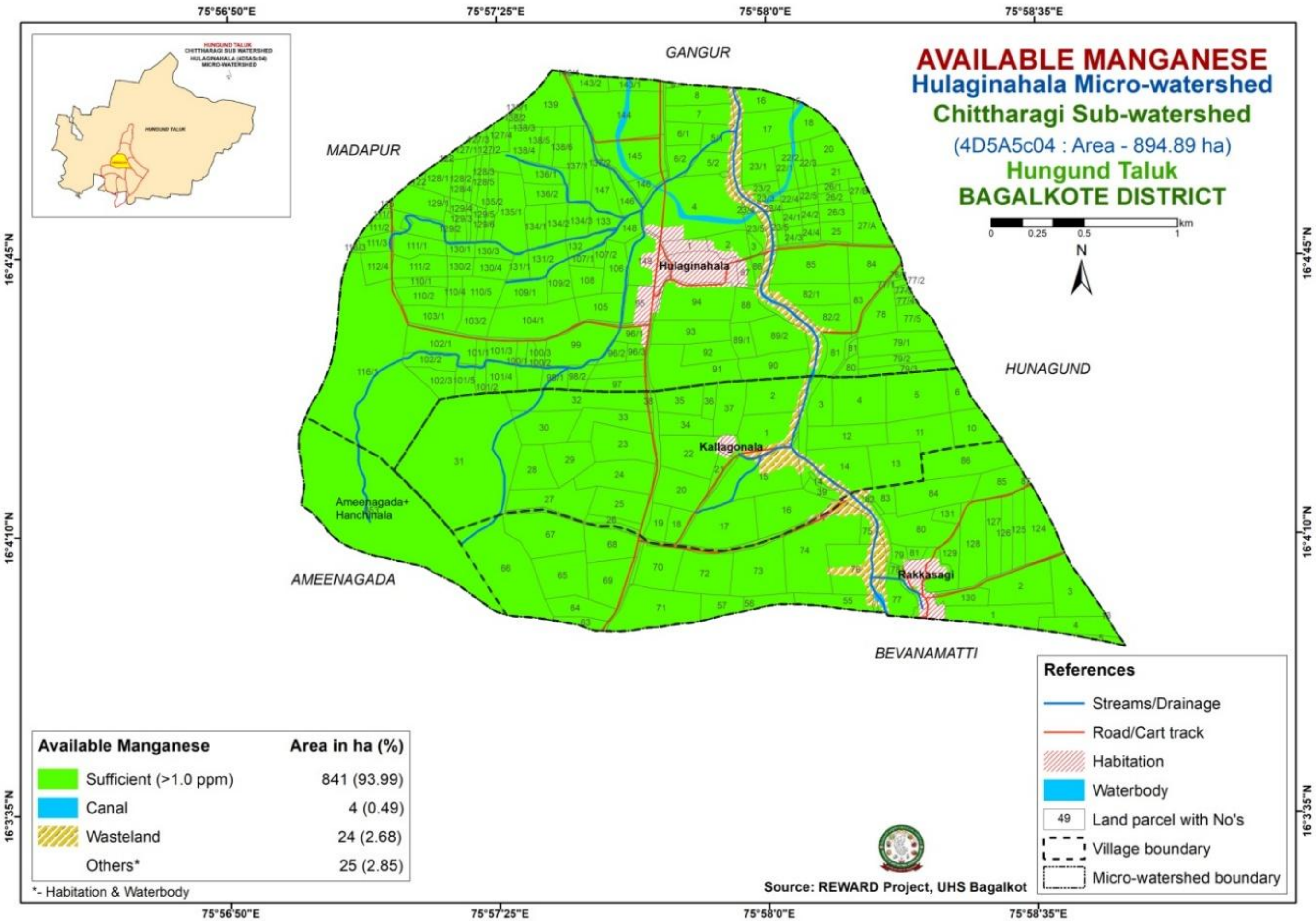

Fig. 10. Available manganese status of Hulaginahal micro-watershed

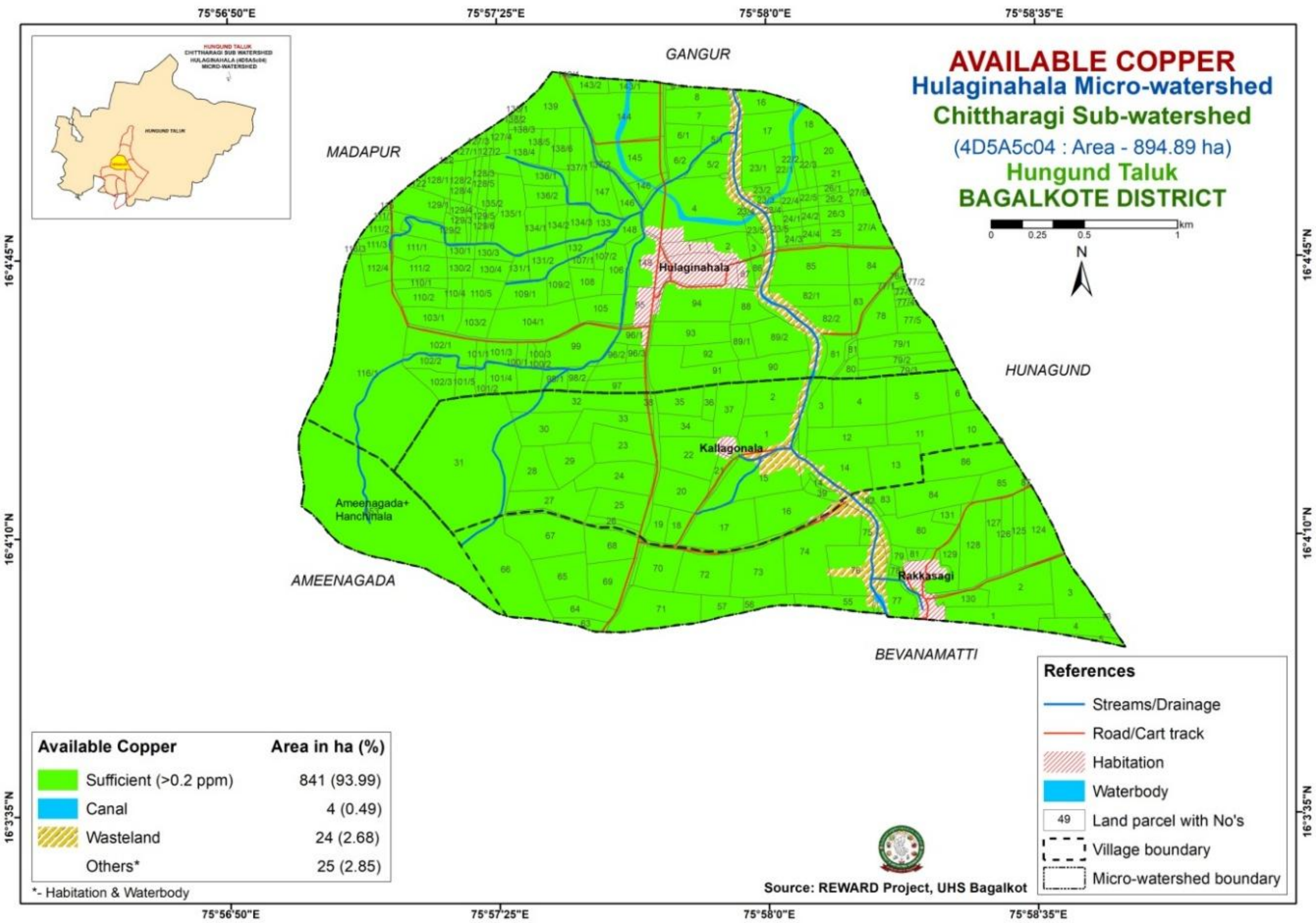

Fig. 11. Available copper status of Hulaginahal micro-watershed

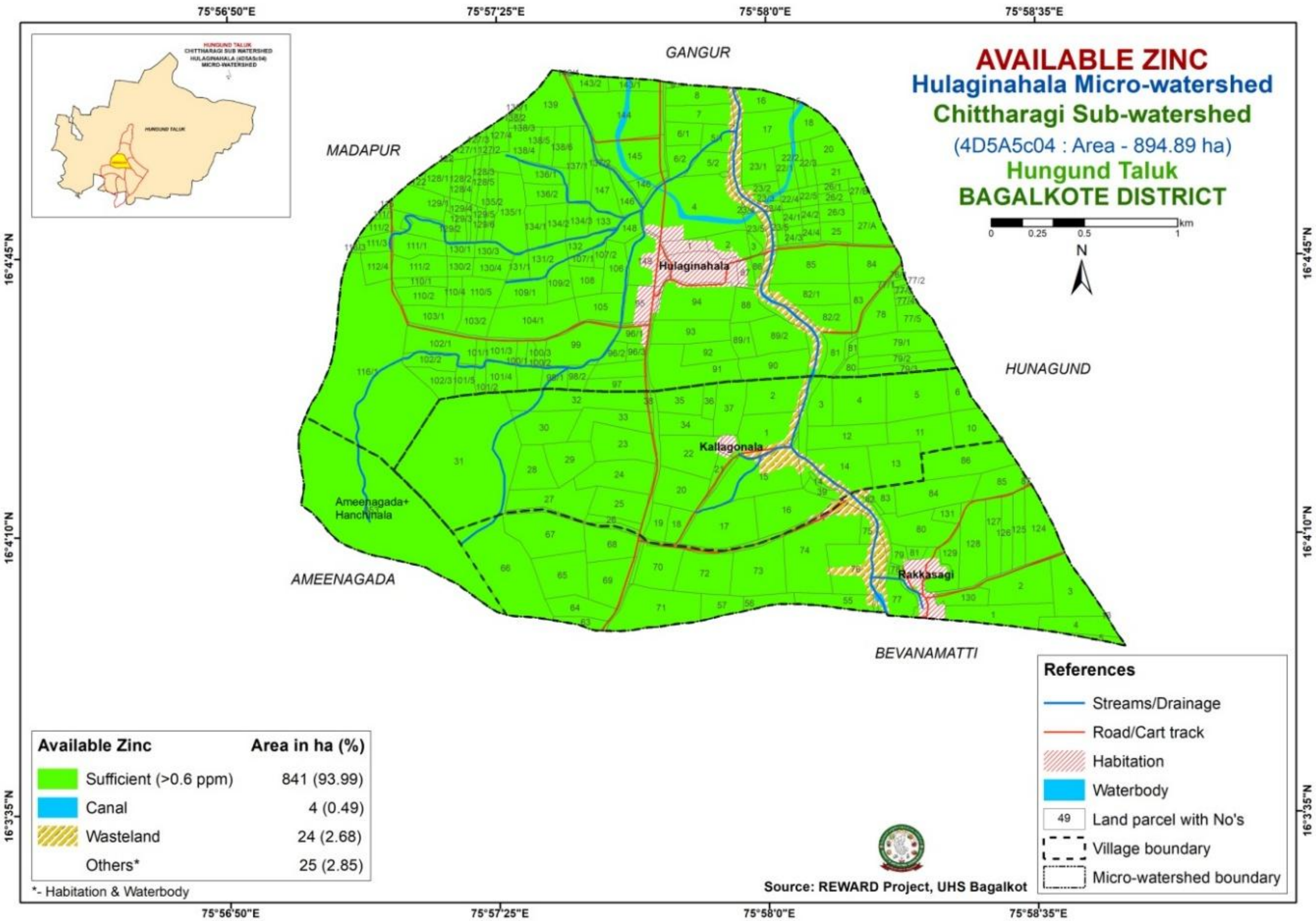

Fig. 12. Available zinc status of Hulaginahal micro-watershed

3.4.4 Zinc (Zn)

Zn varied from 0.04 to 3.66 mg kg^{-1} (mean = 0.6 mg kg^{-1}, SD = 0.43; Table 1; Fig. 12), with GIS confirming sufficiency across 93.99% of the terrain. Zn availability increased with organic carbon and decreased with pH, consistent with the relationship between higher pH and Zn decline.

4. Conclusion

In conclusion, soils in the Huliginahal Micro-Watershed (northern dry zone, Karnataka, India) range from neutral to strongly alkaline, with non-saline to mildly saline traits necessitating prompt management of alkaline patches to curb degradation. Macronutrients present challenges, organic carbon rates are low to medium, nitrogen stays deficient throughout, phosphorus spans low to medium, potassium holds steady as sufficient, and sulfur falls low to medium. Micronutrients zinc, iron, copper and manganese suffice across over half the terrain. GIS nutrient mapping highlights pressing fertility deficits, urging site-specific interventions for enduring crop productivity and soil vitality.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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Competing Interests

Authors have declared that no competing interests exist.

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