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SPATIAL DISTRIBUTION AND NUTRIENT DYNAMICS OF SOILS IN THE CHIKKATHANGALI MICRO-WATERSHED USING GEOSTATISTICAL TECHNIQUES

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ABSTRACT

The present investigation focused on evaluating the soil fertility dynamics of the Chikkathangali micro-watershed, a crucial agricultural and ecological zone within the Lower Tungabhadra catchment. Surface soil samples (0–20 cm depth) were systematically collected and subjected to detailed physicochemical analysis following standardized laboratory protocols. To assess spatial variability, geostatistical tools such as ArcGIS and kriging interpolation were employed to create detailed soil fertility maps. The soils of the study area exhibited a slightly acidic to slightly alkaline reaction (pH 6.40–7.39) and were non-saline, reflecting favorable chemical conditions for crop growth. However, the soils showed low organic carbon levels (0.32–0.65 g kg^{-1}), indicating a potential decline in soil quality and productivity. Available nitrogen ranged from low (204.60–223.40 kg ha^{-1}). Similarly, available phosphorus (20.16–63.78 kg ha^{-1}), potassium (100.93–349.84 kg ha^{-1}) and sulphur (3.15–18.45 mg kg^{-1}) contents varied considerably across the micro-watershed. Exchangeable calcium and magnesium levels were found to be adequate for plant nutrition. Micronutrient analysis indicated a low to high status of boron (0.30–11.60 mg kg^{-1}), whereas iron, copper, zinc and manganese were generally sufficient for crop requirements. The study emphasizes the need for a geospatially informed understanding of soil nutrient patterns to support efficient fertilizer management, improve agricultural output and ensure sustainable ecosystem functioning within micro-watershed landscapes.
Keywords **:** Micro-Watershed, Soil fertility, Mapping, GIS and Remote sensing, Nutrient Index.

Introduction

Understanding and mapping soil fertility form the cornerstone of sustainable land use and watershed management. As the primary medium for plant growth and a key component of ecosystem functioning, soil sustains agricultural productivity, regulates water and nutrient cycles, and supports biodiversity. With rising global population pressures and increasing food demand, the need to adopt sustainable agricultural strategies has become more pressing than ever. A thorough assessment of soil fertility and its spatial variability is essential for optimizing land utilization, maintaining productivity, and safeguarding environmental health.

Soil fertility represents the soil's inherent ability to supply essential nutrients in adequate quantities and balanced proportions to support plant growth. This property results from the complex interactions among soil's physical, chemical and biological components-such as texture, organic carbon, nutrient availability, pH, microbial activity, and water-holding capacity. Productive soils are fundamental to resilient agricultural systems that underpin food security and economic stability. However, modern challenges including deforestation, soil erosion, over-cultivation, excessive chemical use and rapid urban expansion are accelerating soil degradation, leading to nutrient depletion and declining fertility worldwide.

Sustainable land management emphasizes a balance between environmental conservation, social well-being and economic growth. It involves adopting practices that enhance soil health, protect biodiversity and ensure efficient use of natural resources. Within this context, watershed management provides an integrated framework for managing land, water and biological resources within a hydrological boundary. Watersheds play a crucial role in regulating water flow, sediment transport, and nutrient cycling, making their effective management indispensable for sustainable agriculture and ecosystem stability.

Soil fertility mapping serves as a vital scientific tool in this process. By spatially analyzing soil properties and nutrient distribution, it enables precise, site-specific interventions that enhance crop productivity, improve resource use efficiency and minimize environmental degradation. Since soil characteristics vary widely with topography, climate, vegetation and land use, spatial analysis using advanced technologies-such as Geographic Information Systems (GIS), remote sensing and geostatistical modeling-helps capture this heterogeneity. The resulting maps offer valuable insights for precision nutrient management and sustainable land-use planning.

In the framework of watershed management, understanding soil fertility patterns is crucial for maintaining ecosystem functionality and water resource quality. Fertile soils with balanced structure and high organic matter promote infiltration, reduce erosion and sustain hydrological balance. Conversely, nutrient-poor or degraded soils contribute to runoff, sedimentation and water pollution, ultimately impairing downstream environments. Integrating soil fertility evaluation into watershed development strategies is therefore essential for achieving long-term agricultural productivity, ecological stability and environmental resilience.

Materials and Methods

Hydrologically, the Chikkathangali micro-watershed forms part of the Vitalapura Sub-watershed, which lies within the Vedavathy watershed of the Lower Tungabhadra catchment in the Krishna basin. Administratively, this Sub-watershed is situated in Kadur taluk of Chikkamagaluru district, Karnataka.

To assess the fertility status of surface soils (0–20 cm depth), a grid sampling technique was employed with grids placed at 320 m intervals across the micro-watershed. In total, 81 surface soil samples were collected from predetermined grid points using a handheld GPS (Fig. 1). The collected samples were air-dried in shade, ground, and sieved through a 2 mm Indian Standard Sieve to obtain the fine earth fraction, separating out coarse fragments (>2 mm).

Method of analysis

Soil reaction

Soil pH was determined by taking 10 g soil in 1:2.5, soil: water suspension by dipping the combined electrode (glass electrode plus calomel electrode) using a digital pH meter (Jackson, 1973). The soil pH values were interpreted based on the interpretation criteria given by Natrajan *et al.*, 2016.

Electrical conductivity

The electrical conductivity of soils was measured in 1: 2, soil: water extract using an electrical conductivity bridge (Jackson, 1973). The results were expressed as dS m^{-1} at 25 °C.

Soil organic carbon

The organic carbon content in the soil sample was determined by treating a known weight of finely powdered soil (0.5 g) with the known excess quantity of chromic acid (sulfuric acid and potassium dichromate) to oxidize the organic carbon present in the soil to carbon dioxide. After oxidation, the untreated potassium dichromate left in the contents was back titrated against standard ferrous ammonium sulphate using the diphenylamine indicator (Walkely and Black, 1934). The soil organic carbon content was expressed in g kg^{-1}.

Available nitrogen

The available nitrogen content of the soil was determined by the modified alkaline $KMnO_4$ method, where the organic matter in soil was oxidized with alkaline $KMnO_4$ solution. The ammonia (NH_3) evolved during oxidation was distilled and trapped in boric acid mixed indicator solution. The total amount of NH_3 was estimated by titrating with standard acid (Subbiah and Asija, 1956).

Available phosphorus

Available phosphorus in soil samples was extracted by Olsen's method (0.5 $NaHCO_3$) for soils with pH $\geq$ 6.5 and Brays and Kurtz method (0.03 N NH_4F + 0.025 N HCl) for soils with pH < 6.5 as described by Jackson (1973). Phosphorus in the extractant was complexed by molybdenum and reduced by ascorbic acid in the presence of H_2SO_4 and estimated by using spectrophotometry at 660 nm.

Available potassium

Available potassium was extracted with neutral normal ammonium acetate (pH 7.0) and the content of potassium in the soil solution was estimated by a flame photometer (Jackson, 1973).

Exchangeable calcium and magnesium

The Exchangeable calcium and magnesium were determined by Versnate titration method (Black, 1965).

Available Sulphur

Available sulphur was extracted with 0.15 per cent calcium chloride solution and sulphur in the extract was estimated by the turbidometric method using $BaCl_2$ as a stabilizing agent. The turbidity was measured by using a spectrophotometer at 420 nm (Black, 1965).

DTPA extractable zinc, iron, manganese and copper

Available zinc, iron, manganese and copper were extracted by using DTPA extractant (0.005 M Diethylene Triamine Penta Acetic acid and 0.01 M $CaCl_2$ + 0.1 N Triethanol Amine at pH 7.3) and concentrations of Zn, Fe, Mn and Cu were measured by using Atomic Absorption Spectrophotometer (Perkin Elmer Model: PinAAcle 900F) (Lindsay and Norvell, 1978).

Available Boron

The available boron was extracted with hot water and estimated with azomethine-H reagent with absorbance of spectrophotometer at a wavelength of 420 nm as per the procedure outlined by John *et al.* (1975).

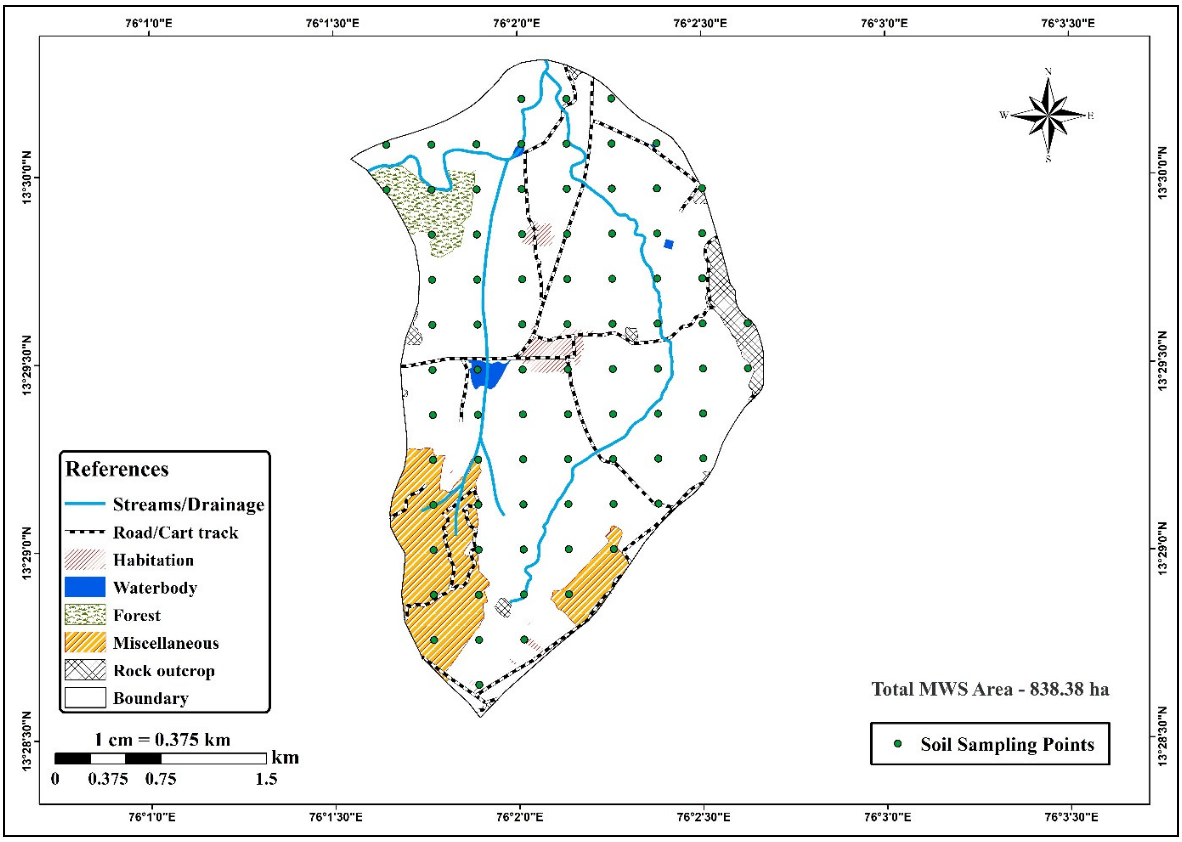

Fig. 1 : Location of the grid points for surface soil sampling in Chikkathangali micro watershed

Result and Discussion

Soil reaction (pH)

In Chikkathangali micro-watershed, surface soils exhibited a range of pH levels, from neutral to slightly alkaline pH. The pH varied between 6.40 and 7.39 with an average of 7.15 and a standard deviation of 0.71 (Table 1). Geospatial analysis revealed that, 47.63 per cent of the area (399 ha) had a neutral pH. Slightly alkaline conditions were observed in 33.14 per cent (278 ha) of the area (Table 2). The spatial distribution of soil pH across Chikkathangali micro-watershed is illustrated in Fig. 2.

The higher mean pH observed in the micro-watershed can be attributed to its lower topographic position, where basic cations from upper regions accumulate. The parent material, predominantly peninsular gneiss, also contributes to the soil's alkalinity. In contrast, the slightly lower pH in red soils may result from the presence of iron hydroxides (Dasog and Patil, 2011). Elevated pH values may further indicate higher base saturation (Meena *et al.*, 2006), aligning with similar observations by Seema (2022) in the Duglapura mini-watershed.

Electrical conductivity (EC)

The electrical conductivity (EC) of the soil samples from Chikkathangali micro-watershed ranged from 0.07 and 0.49 dS m^{-1} with an average of 0.18 dS m^{-1} and a standard deviation of 0.08 dS m^{-1} (Table 1). Geospatial analysis indicated that the entire micro-watershed had very low EC, indicating that the soils were non-saline (Table 2) (Fig. 3).

The variation in total soluble salts may be due to the area's slope and good drainage, which promote salt leaching. Similar results were reported by Swarnam *et al.* (2004) and Jhanvi (2020).

Organic carbon (OC)

The average organic carbon content of the soil samples from Chikkathangali micro-watershed was 0.48 g kg^{-1} with a range of 0.32 to 0.65 g kg^{-1}. The standard deviation was observed to be 0.09 g kg^{-1} (Table 1). The majority of the micro-watershed area *viz.,* 78.64 per cent (659 ha) of the total area had a low organic carbon content and 2.13 per cent (18 ha) had a medium organic carbon content (Table 2). The regional distribution of the soil organic carbon content in Chikkathangali micro-watershed is shown in Fig. 4.

Topography and the micro-watershed's position within the sub-watershed greatly influenced soil organic carbon levels. Low organic carbon may result from rapid oxidation under high temperatures (Balpande *et al.*, 2007), while medium levels reflect deposition of organic matter from upper slopes (Zhang *et al.*, 2013) and incorporation of crop residues (Nayak *et al.*, 2002). Similar trends were noted by Seema (2022) in comparable micro-watersheds.

Available nitrogen

The surface soils of Chikkathangali micro-watershed were found to have low available nitrogen. The average available nitrogen content was found to be 232.05 kg ha^{-1} and the content varied from 204.60 to 223.40 kg ha^{-1} with a standard deviation of 26.90 kg ha^{-1} (Table 1). The spatial analysis revealed that 80.77 per cent (677 ha) area had low available nitrogen content (Table 2) The spatial distribution of available nitrogen in Chikkathangali micro-watershed is illustrated in Fig. 5.

The low nitrogen content may result from continuous cultivation without sufficient nitrogen replenishment and limited use of nitrogen fertilizers (Pramod and Patil, 2015). Similar findings were reported by Jhanvi (2020).

Available phosphorus

The soil analysis results indicate that available phosphorus content in Chikkathangali micro-watershed ranged from 20.16 to 63.78 kg ha^{-1}. The average available phosphorus content was 31.26 kg ha^{-1} with a standard deviation of 5.32 kg ha^{-1} (Table 1). The geospatial analysis data revealed that majority of the micro-watershed area *i.e.,* 80.77 per cent area (677 ha) had medium available phosphorus content (Table 2). The spatial distribution of available phosphorus in Chikkathangali micro-watershed is illustrated in Fig. 6.

Medium phosphorus availability may be due to the clayey soils' high CEC and strong phosphorus-fixing capacity, which affect its retention and release (Rajashekar, 2018).

Available potassium

The findings of the study showed that the available potassium concentration in the surface soils of Chikkathangali micro-watershed ranged from 100.93 to 329.84 kg ha^{-1}. The average available potassium concentration of the whole micro-watershed was 191.68 kg ha^{-1} with a standard deviation of 56.76 kg ha^{-1} (Table 1). According to the geospatial study, 80.77 per cent (677 ha) of the area had medium available potassium content (Table 2). The spatial distribution of available potassium in Chikkathangali micro-watershed is shown in Fig. 7.

The medium potassium status may result from potassium-rich parent material and periodic application of potassic fertilizers, as also reported by Pulakeshi *et al.* (2014) and Seema (2022).

Exchangeable calcium and Magnesium

The soil analysis data showed that the average exchangeable calcium concentration in surface soils of Chikkathangali micro-watershed was 7.35 cmol (p^+) kg^{-1} and the concentration ranged from 2.60 to 11.60 cmol (p^+) kg^{-1} with a standard deviation of 2.12 cmol (p^+) kg^{-1} (Table 1). The geospatial analysis showed that the whole micro-watershed area had sufficient amount of exchangeable calcium (Table 2) (Fig. 8).

The soil analysis data showed that the average exchangeable magnesium concentration in surface soils of Chikkathangali micro-watershed was 4.69 cmol (p^+) kg^{-1} and the concentration ranged from 0.90 to 8.70 cmol (p^+) kg^{-1} with a standard deviation of 1.94 cmol (p^+) kg^{-1} (Table 1). The geospatial analysis showed that the whole micro-watershed area had sufficient amount of exchangeable magnesium (Table 2) (Fig. 9).

Available Sulphur

The surface soils of Chikkathangali micro-watershed were found to have medium to high available sulphur content. The average available sulphur content was found to be 11.58 mg kg^{-1} and the content varied from 3.15 to 18.45 mg kg^{-1} with a standard deviation of 4.82 mg kg^{-1} (Table 1). The spatial analysis revealed that 17.92 per cent (150 ha) area had low available sulphur content and 62.85 per cent (527 ha) area had medium level of available sulphur (Table 2) The spatial distribution of available sulphur in Chikkathangali micro-watershed is illustrated in Fig. 10.

Soil sulphur content may be influenced by organic carbon levels and the fine texture that enhances sulphur retention. Similar findings were reported by Vikas (2016) and Manoj (2022).

Available zinc

The findings of the study showed that the available zinc concentration in the surface soils of Chikkathangali micro-watershed ranged from 0.72 to 2.83 mg kg^{-1}. The average available zinc concentration of the whole micro-watershed was 0.76 mg kg^{-1} with a standard deviation of 0.55 mg kg^{-1} (Table 1). According to the geospatial study, 80.76 per cent (677 ha) of the area was sufficient in available zinc content (Table 2). The spatial distribution of available zinc in Chikkathangali micro-watershed is shown in Fig. 11.

Zinc deficiency in some areas may result from alkaline soils, limited zinc application, and intensive cultivation (Thangasamy *et al*., 2005). Conversely, adequate zinc levels are linked to slightly acidic soils and organic matter addition, which improve availability (Swathi, 2023).

Available iron

The surface soils of Chikkathangali micro-watershed were found to have sufficient and deficient available iron content. The average available iron content was found to be 7.17 mg kg^{-1} and the content varied from 2.37 to 18.62 mg kg^{-1} with a standard deviation of 4.21 mg kg^{-1} (Table 1). The spatial analysis revealed that the micro-watershed had sufficient available iron content (Table 2) (Fig. 12).

Adequate iron content may be due to the ferruginous parent material and acidic soil conditions in parts of the micro-watershed. Similar results were reported by Ravikumar D and Govindaraju (2019), Jhanvi (2020), and Shwetha (2021).

Available manganese

The surface soils of Chikkathangali micro-watershed were found to have sufficient available manganese content. The average available manganese content was found to be 7.98 mg kg^{-1} and the content varied from 1.43 to 21.88 mg kg^{-1} with a standard deviation of 4.62 mg kg^{-1} (Table 1). The spatial analysis revealed that the micro-watershed had sufficient available manganese content (Table 2) (Fig. 13).

Adequate manganese content may result from high organic matter, which enhances its availability, and from the influence of parent material. Similar findings were reported by Yeresheemi (1996), Vikas (2016), and Krishna *et al*. (2017).

Available Copper

The surface soils of Chikkathangali micro-watershed were found to have sufficient available copper content. The average available copper content was found to be 0.75 mg kg^{-1} and the content varied from 0.26 to 1.79 mg kg^{-1} with a standard deviation of 0.32 mg kg^{-1} (Table 1). The spatial analysis revealed that the micro-watershed had sufficient available copper content (Table 2) (Fig. 14).

The adequate copper content in the area is likely linked to the parent material, specifically granite gneiss, which is naturally rich in copper (Rajkumar, 1994). Similar observations were reported by Ravikumar (2006) and Seema (2022).

Available Boron

The surface soils of Chikkathangali micro-watershed were found to have low to medium available boron. The average available boron content was found to be 0.25 mg kg^{-1} and the content varied from 0.30 to 11.60 mg kg^{-1} with a standard deviation of 0.14 mg kg^{-1} (Table 1). The spatial analysis revealed that 80.76 per cent (677 ha) area had low available boron content and 0.01 ha area had medium levels of available boron (Table 2) The spatial distribution of available boron in Chikkathangali micro-watershed is illustrated in Fig. 15.

Low boron content in much of the micro-watershed may result from a lack of boron-bearing minerals, low organic carbon, and acidic soil pH. Fine-textured soils with slightly higher pH showed higher boron levels. Similar results were reported by Seema (2022) and Manoj (2022).

Table 1: Fertility status of surface soils of Chikkathangali micro-watershed

Soil properties	Range	Mean	SD
Soil reaction (pH)	6.40 – 7.39	7.15	0.71
Electrical Conductivity (EC) (dS m^{-1})	0.07 – 0.49	0.18	0.08
Organic Carbon (g kg^{-1})	0.32 – 0.65	0.48	0.09
Available nitrogen (kg ha^{-1})	204.60 – 223.40	232.05	26.90
Available P_2O_5 (kg ha^{-1})	20.16 – 63.78	31.26	5.32
Available K_2O (kg ha^{-1})	100.93 – 349.84	191.68	56.76
Exchangeable Ca [cmol (p^+) kg^{-1}]	2.60 -11.60	7.35	2.12
Exchangeable Mg [cmol (p^+) kg^{-1}]	0.90 – 8.70	4.69	1.94
Available S (mg kg^{-1})	3.15 – 18.45	11.58	4.82
Available Zn (mg kg^{-1})	0.72 – 2.83	0.76	0.55
Available Fe (mg kg^{-1})	2.37 – 18.62	7.17	4.21
Available Mn (mg kg^{-1})	1.43 – 21.88	7.98	4.62
Available Cu (mg kg^{-1})	0.26 – 1.79	0.75	0.32
Available B (mg kg^{-1})	0.30 – 11.60	0.25	0.14

Table 2: Area under different chemical and fertility classes of Chikkathangali micro-watershed

<table>
<tr><th>Parameters</th><th colspan="6">Classes</th><th rowspan="2">Others</th></tr>
<tr><td rowspan="2">Soil Reaction (pH)</td><th>Strongly Acid</th><th>Moderately Acid</th><th>Slightly Acid</th><th>Neutral</th><th>Slightly Alkaline</th><th>Moderately Alkaline</th></tr>
<tr><td>-</td><td>-</td><td>-</td><td>399 (47.63)</td><td>278 (33.14)</td><td>-</td><td rowspan="17">23 (2.76)</td></tr>
<tr><td rowspan="2">Electrical Conductivity</td><th colspan="6">Non- Saline</th></tr>
<tr><td colspan="6">677 (80.77)</td></tr>
<tr><td></td><th colspan="2">Low</th><th colspan="2">Medium</th><th colspan="2">High</th></tr>
<tr><td>Organic Carbon (OC)</td><td colspan="2">659 (78.64)</td><td colspan="2">18 (2.13)</td><td colspan="2">-</td></tr>
<tr><td>Available Nitrogen</td><td colspan="2">677 (80.77)</td><td colspan="2">-</td><td colspan="2">-</td></tr>
<tr><td>Available Phosphorus</td><td colspan="2">-</td><td colspan="2">677 (80.77)</td><td colspan="2">-</td></tr>
<tr><td>Available Potassium</td><td colspan="2">-</td><td colspan="2">677 (80.77)</td><td colspan="2">-</td></tr>
<tr><td>Available Sulphur</td><td colspan="2">150 (17.92)</td><td colspan="2">527 (62.85)</td><td colspan="2">-</td></tr>
<tr><td>Available Boron</td><td colspan="2">677 (80.76)</td><td colspan="2">0 (0.01)</td><td colspan="2">-</td></tr>
<tr><td></td><th colspan="3">Sufficient</th><th colspan="3">Deficient</th></tr>
<tr><td>Exchangeable Calcium</td><td colspan="3"></td><td colspan="3">-</td></tr>
<tr><td>Exchangeable Magnesium</td><td colspan="3"></td><td colspan="3">-</td></tr>
<tr><td>Available Zinc</td><td colspan="3">677 (80.77)</td><td colspan="3"></td></tr>
<tr><td>Available Iron</td><td colspan="3">621 (74.02)</td><td colspan="3">57 (6.75)</td></tr>
<tr><td>Available Manganese</td><td colspan="3">677 (80.77)</td><td colspan="3">-</td></tr>
<tr><td>Available Copper</td><td colspan="3">769 (82.67)</td><td colspan="3">-</td></tr>
<tr><td colspan="8">*Note: Others include streams/drainage, road, habitation, forest and waterbodies
Figures in parenthesis indicate the percentage of total micro-watershed area</td></tr>
</table>

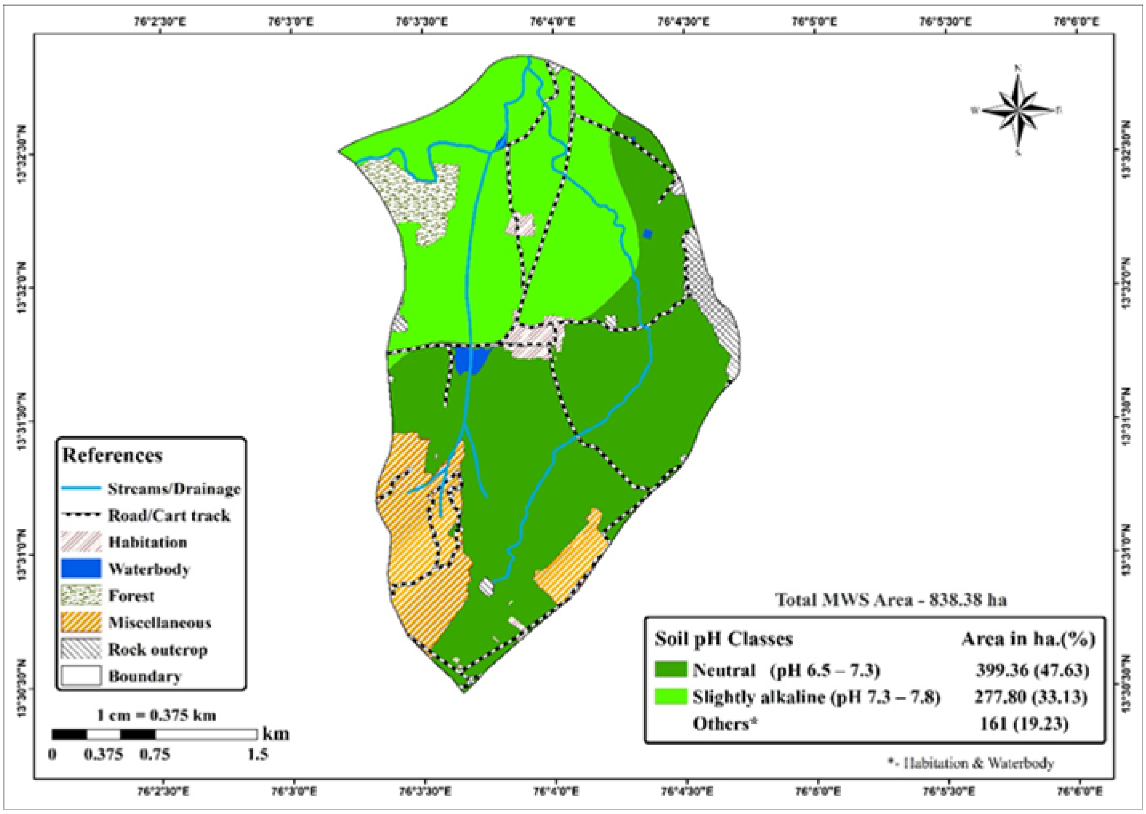

Fig. 2: Soil reaction (pH) map of Chikkathangali micro-watershed

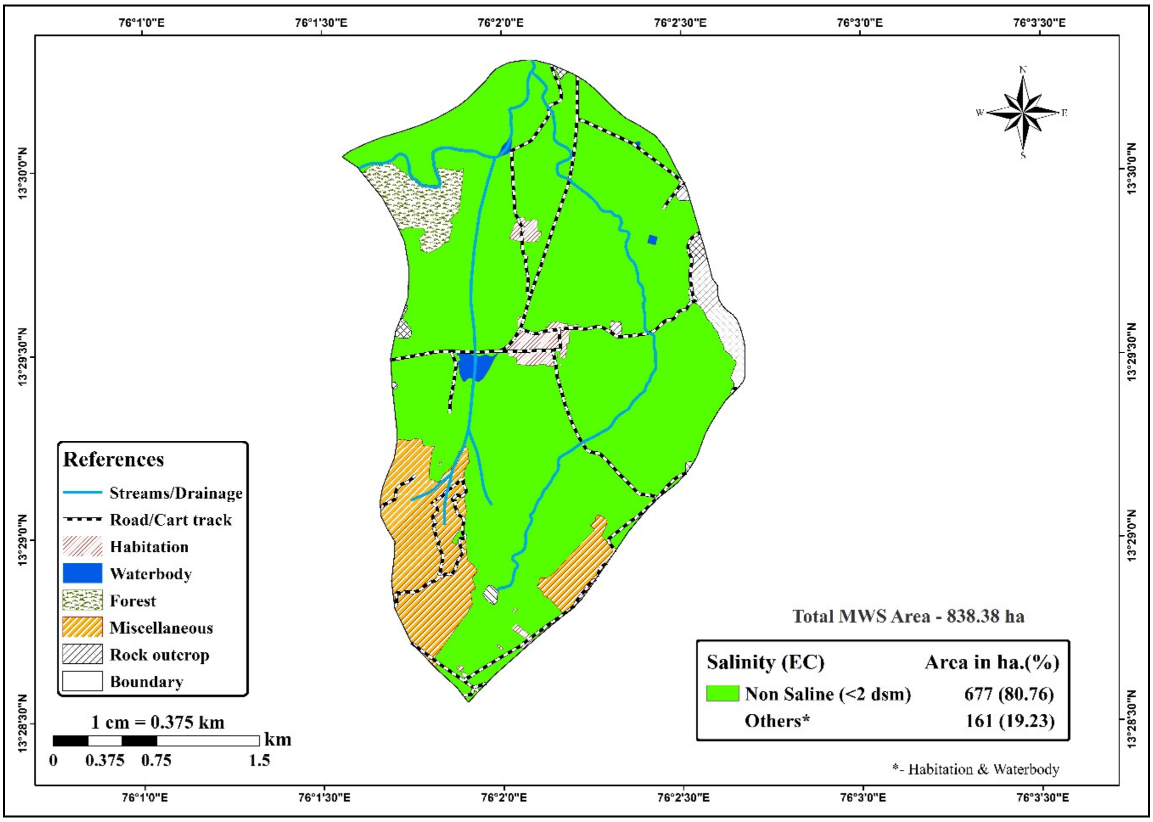

Fig. 3: Soil salinity (EC) map of Chikkathanagali micro-watershed

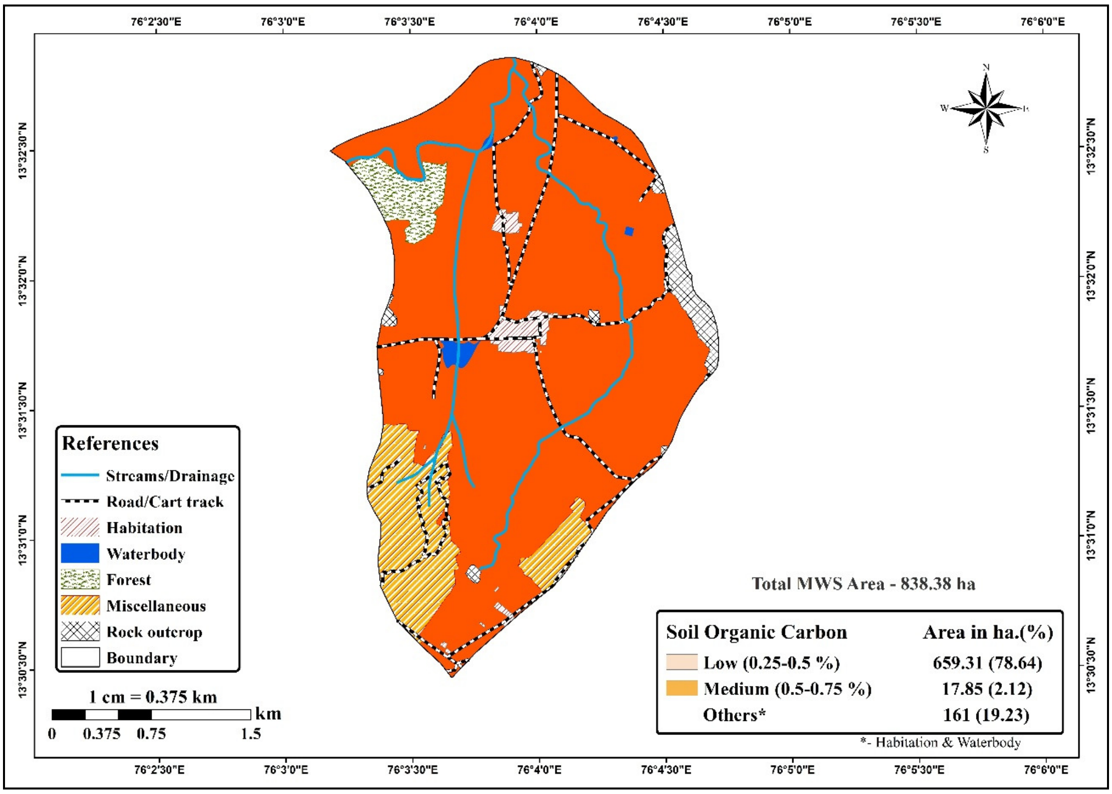

Fig. 4: Spatial distribution of Soil organic carbon of Chikkathanagali micro-watershed

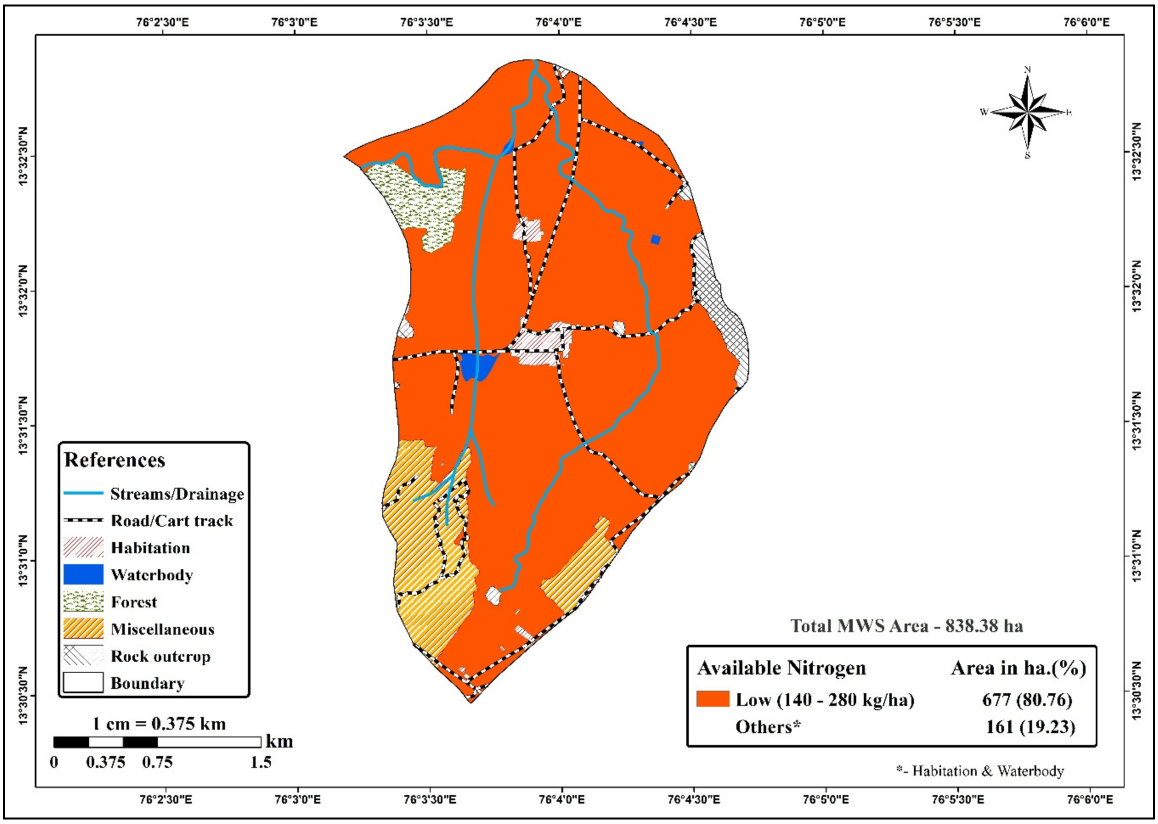

Fig. 5: Spatial distribution of available nitrogen of Chikkathanagali micro-watershed

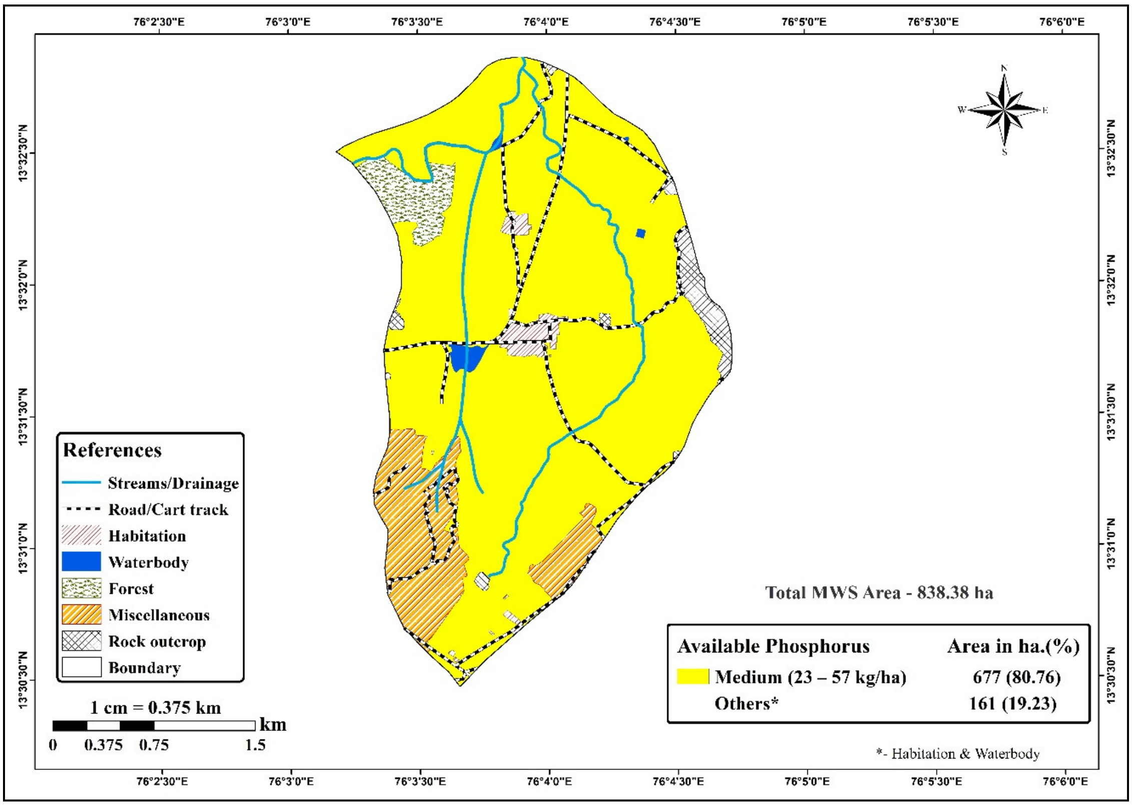

Fig. 6: Spatial distribution of available phosphorus of Chikkathanagali micro-watershed

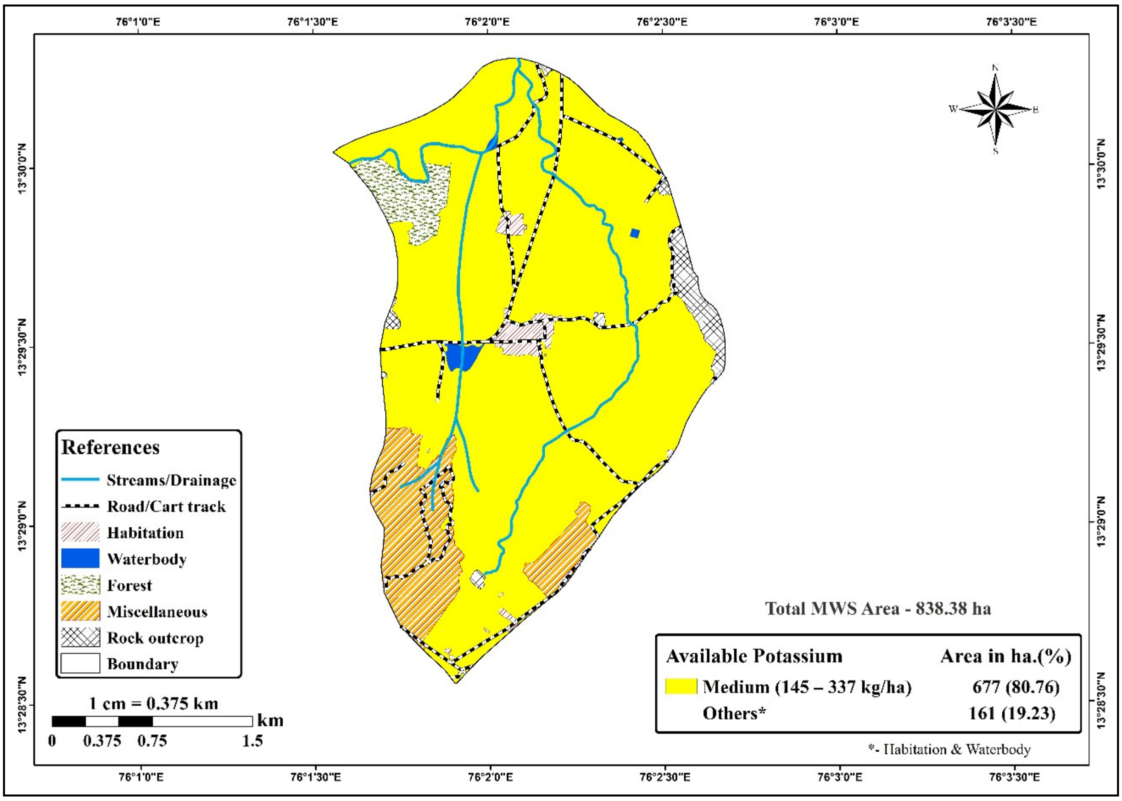

Fig. 7: Spatial distribution of available potassium of Chikkathanagali micro-watershed

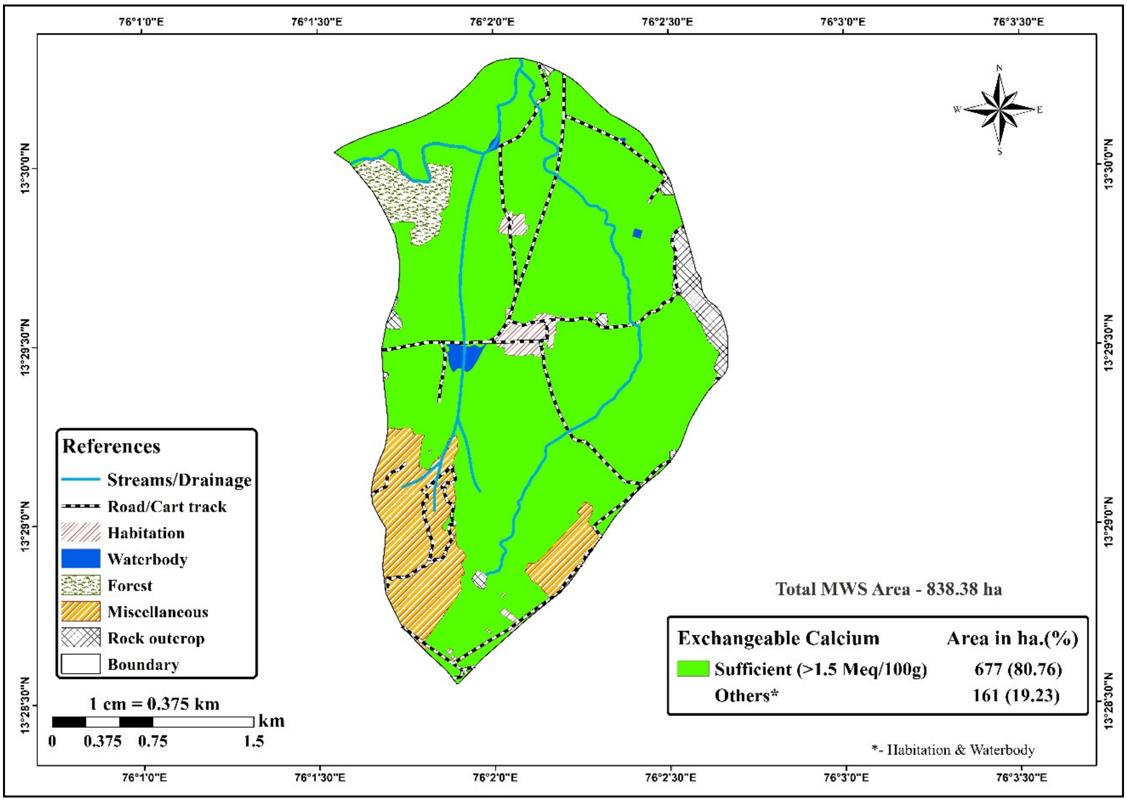

Fig. 8: Spatial distribution of exchangeable calcium of Chikkathanagali micro-watershed

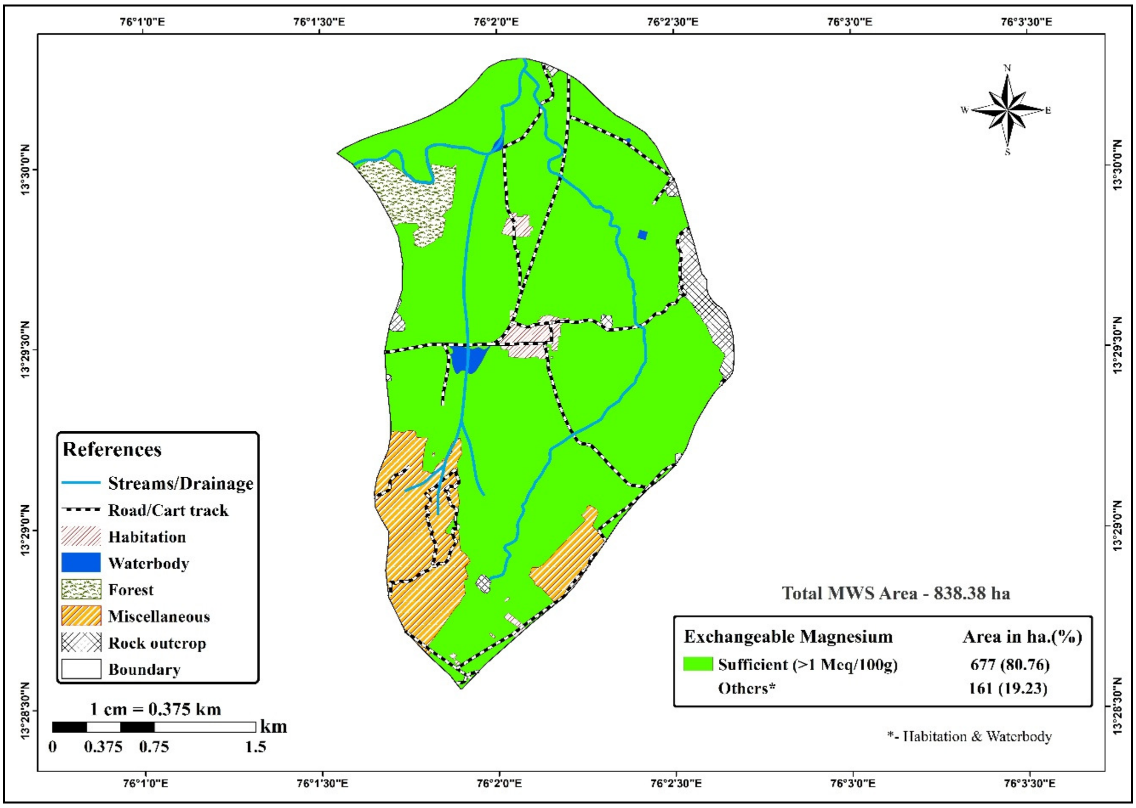

Fig. 9: Spatial distribution of exchangeable magnesium of Chikkathanagali micro-watershed

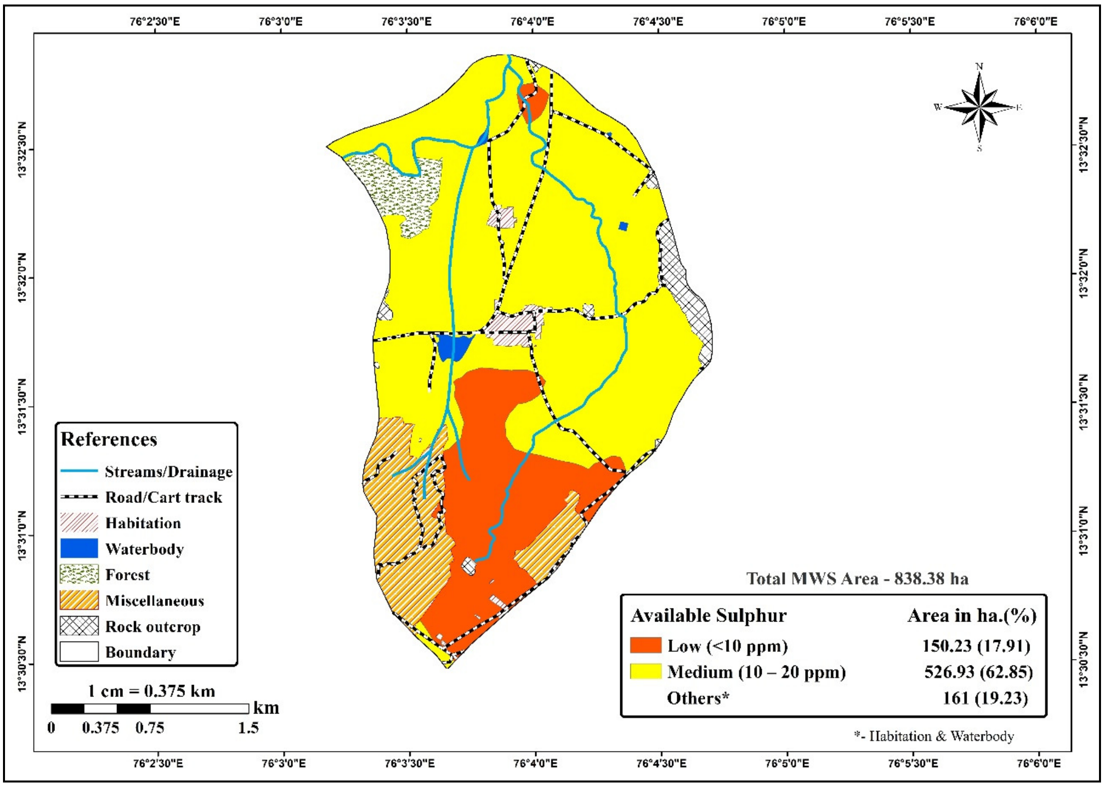

Fig. 10: Spatial distribution of available sulphur of Chikkathanagali micro-watershed

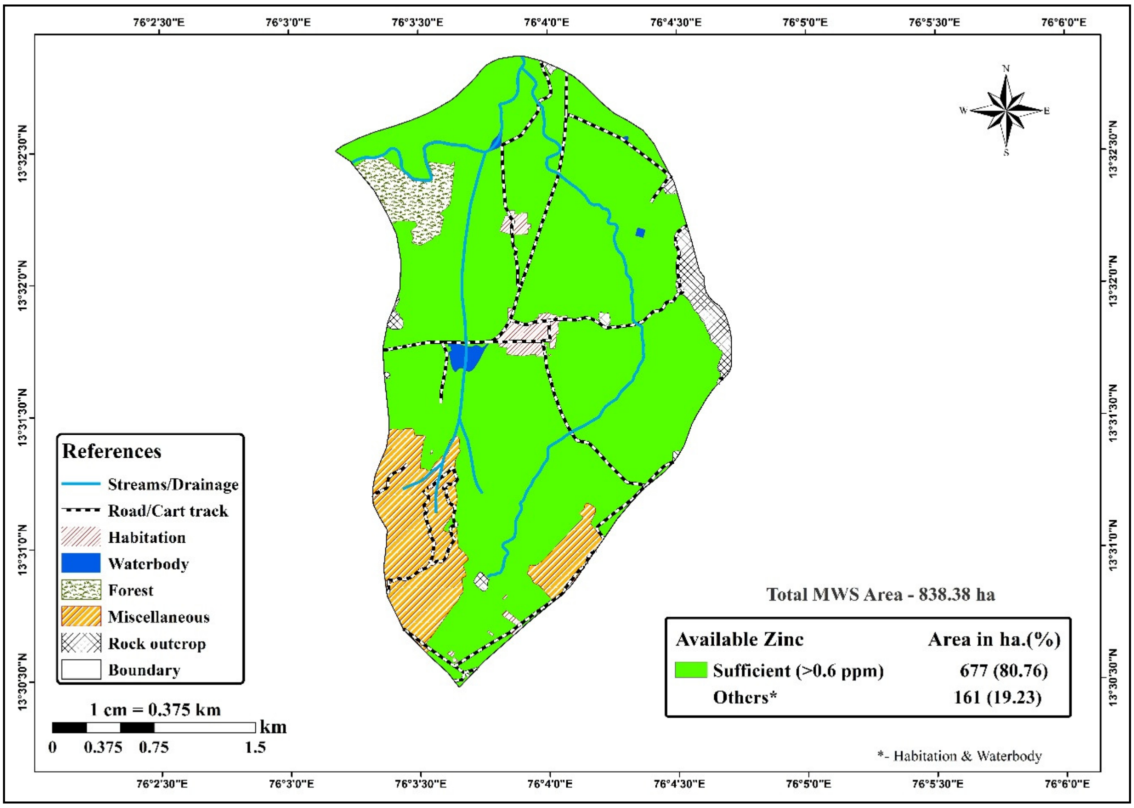

Fig. 11: Spatial distribution of available zinc of Chikkathanagali micro-watershed

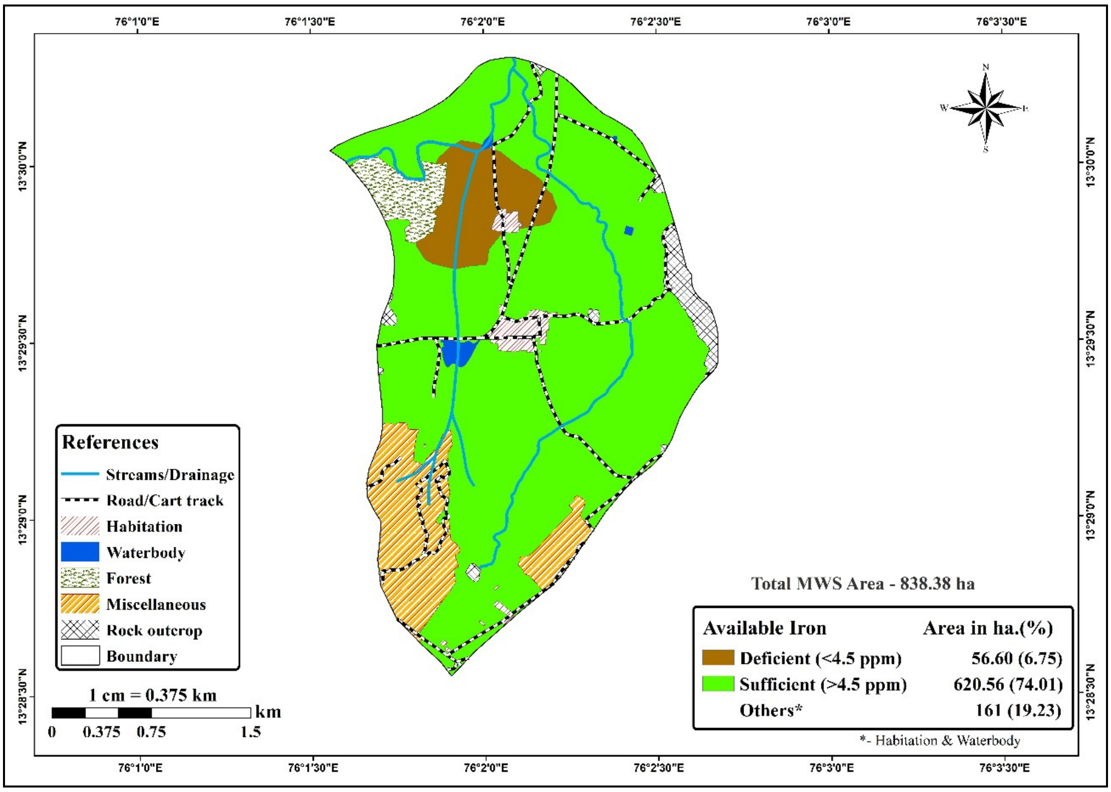

Fig. 12: Spatial distribution of available iron of Chikkathanagali micro-watershed

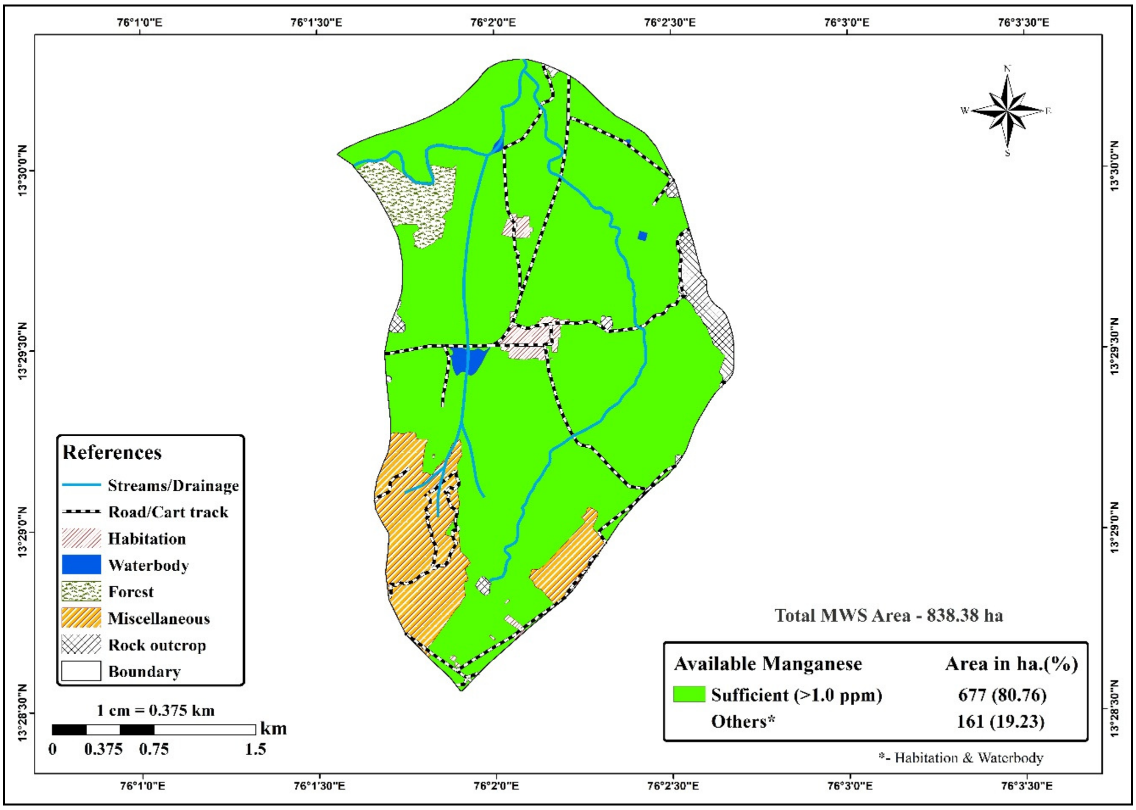

Fig. 13: Spatial distribution of available manganese of Chikkathanagali micro-watershed

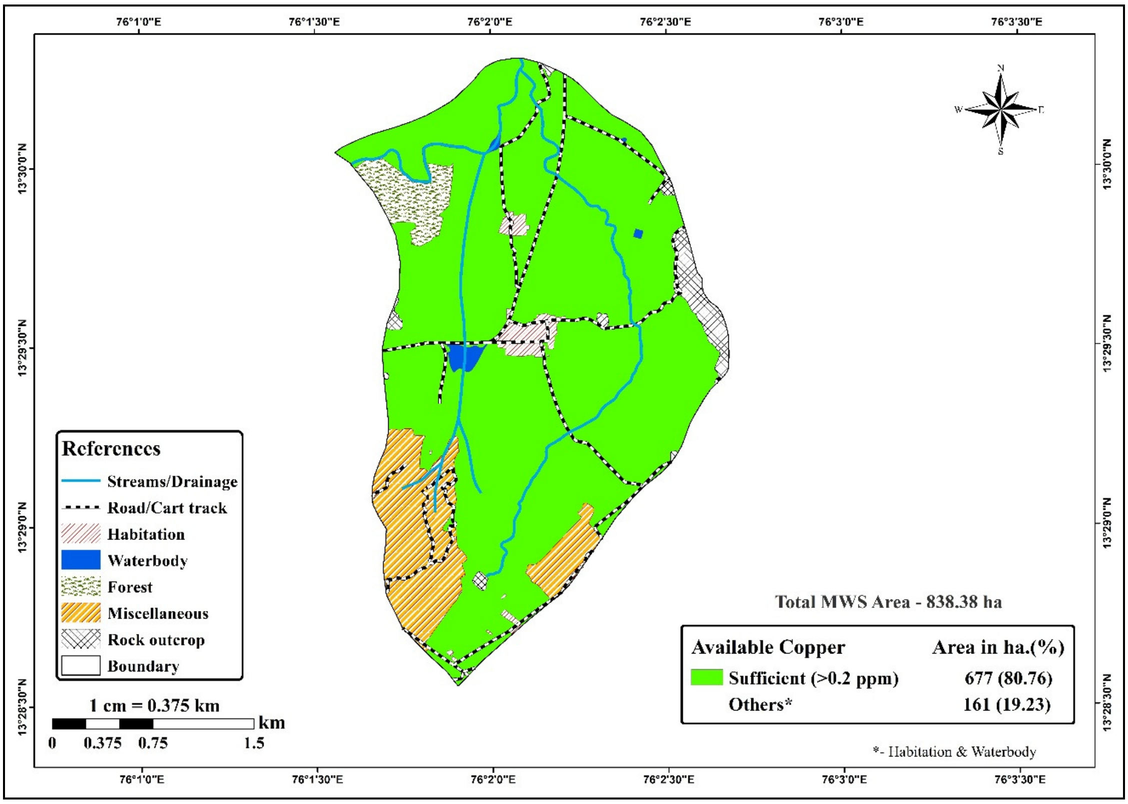

Fig. 14: Spatial distribution of available copper of Chikkathanagali micro-watershed

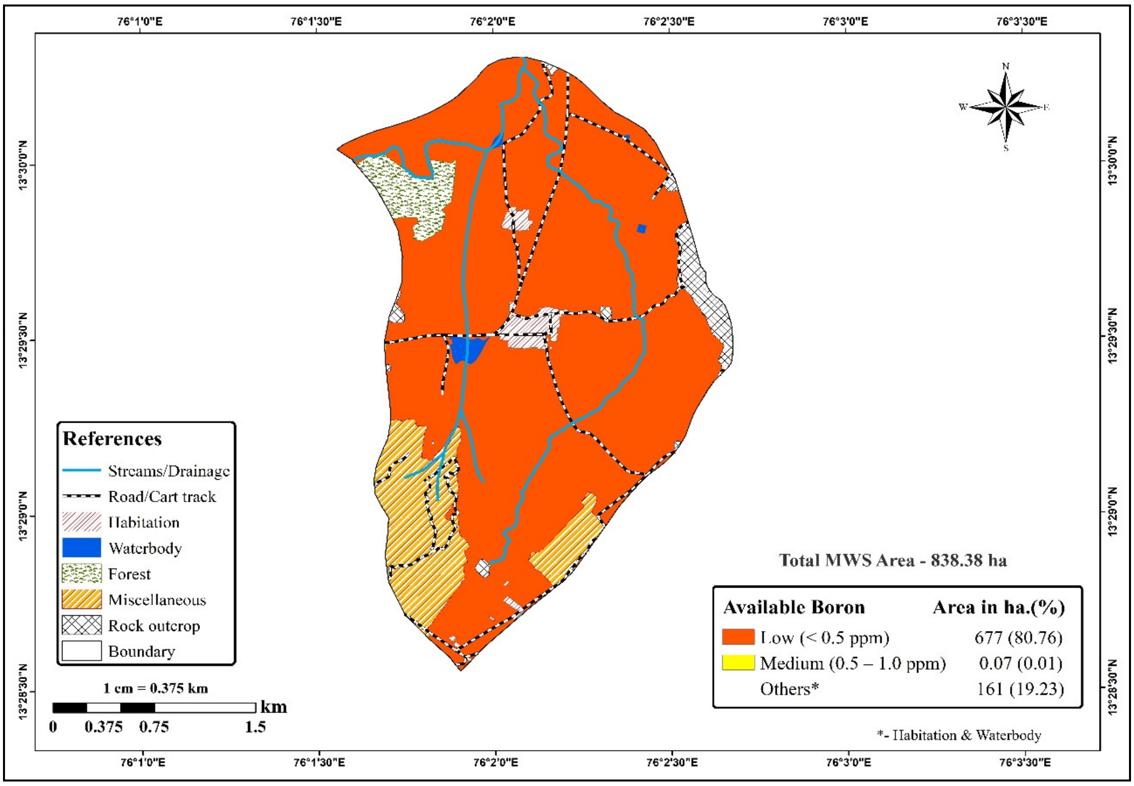

Fig. 15: Spatial distribution of available boron of Chikkathanagali micro-watershed

Conclusion

This study provides a comprehensive assessment of soil nutrient dynamics in the Chikkathangali micro-watershed, within the Lower Tungabhadra catchment of Karnataka. Through systematic sampling and geospatial analysis, the study evaluated soil fertility and its implications for agriculture and environmental sustainability. Geospatial mapping revealed spatial variations in nutrient distribution, offering valuable insights for site-specific land management and sustainable crop production. Overall, the findings emphasize the importance of nutrient mapping for improving productivity, conserving resources, and guiding policies that promote sustainable agriculture and ecosystem resilience.

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