E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; SP-8(12): 232-347
Received: 23-10-2025
Accepted: 25-11-2025

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Assessment and mapping of soil nutrient status in the bettadapura micro-watershed: A geospatial analysis

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DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i12Sc.4389

Abstract
This research endeavours to evaluate the fertility status of the Bettadapura micro-watershed, situated within the Lower Tungabhadra catchment area, a critical region for agricultural productivity and environmental sustainability. Through systematic soil sampling at 0-20 cm depths and utilizing prescribed standard methods, soil attributes were meticulously determined. Employing advanced geospatial techniques, including ArcGIS software and kriging interpolation, comprehensive soil nutrient status and fertility maps were generated. The findings revealed a spectrum of soil reactions ranging from moderately acidic to moderately alkaline (6.00-8.15), indicative of diverse soil conditions and soils are non-saline. Notably, the soil organic carbon content exhibited variations from low to high levels (2.10-12.50 g kg^{-1}), influencing soil health and productivity. Similarly, available nitrogen levels ranged from low to medium (106.50-291.20 kg ha^{-1}), posing challenges for optimal crop growth. Crucially, the study highlighted varying levels of available phosphorus (16.14 - 78.48 kg ha^{-1}), potassium (48.38 - 457.22 kg ha^{-1}), and sulphur (13.18 - 53.81 mg kg^{-1}), essential for plant nutrient uptake and growth. Exchangeable calcium (0.7 and 10.1 cmol (p^+) kg^{-1}) and magnesium (0.7 and 11.4 mol (p^+) kg^{-1}) were found to be sufficient. Micronutrient analysis uncovered fluctuations in boron levels (0.13 - 1.20 mg kg^{-1}), while available copper and manganese exhibited sufficient levels across the study area. Moreover, the majority of the study area displayed adequate levels of available zinc and iron, vital micronutrients for crop development. These insights underscore the significance of assessing soil nutrient status for informed land management decisions, facilitating sustainable agricultural practices, optimizing crop yields, and safeguarding environmental health in micro watershed ecosystems.

Keywords: Soil nutrient status, micro-watershed, geospatial analysis, GIS mapping, soil fertility

Introduction

Soil serves as the fundamental resource supporting the quality of human life and the advancement of agriculture. Throughout history, civilizations have relied on the productivity of soil to sustain themselves, providing essential sustenance and resources (Hillel, 2009) [7]. Effectively managing this vital resource poses a significant challenge for scientists, planners, administrators, and farmers, essential for guaranteeing food security for current and future generations (Kanwar, 2000) [11]. Soil fertility, reflecting the inherent capacity of soil to supply necessary nutrients to plants in appropriate amounts and ratios under favourable conditions, underscores its critical role in fostering agricultural development (Das *et al*, 2009) [5]. The assessment of soil nutrient status and mapping of soil resources at the micro watershed scale represent critical endeavours in contemporary agricultural and environmental sciences. Micro watersheds, being small-scale hydrological units, play a pivotal role in shaping local soil characteristics, nutrient distribution, and overall ecosystem health (Khadka *et al*, 2018) [13]. Understanding the intricate dynamics of soil nutrients within these micro watersheds is essential for devising sustainable land management strategies, enhancing agricultural productivity, and conserving natural resources (Panda, 2010) [19]. At the micro watershed scale, soil variability is influenced by a myriad of factors including topography, geology, land use practices, and climate. These factors interact to create diverse soil conditions, resulting in spatial heterogeneity of soil nutrient status within microwatersheds (Abate *et al*, 2016) [1]. Therefore, assessing soil nutrient status at a fine spatial resolution is imperative for capturing the nuances of soil fertility and guiding targeted management interventions. Moreover, mapping soil resources in micro watersheds provides valuable insights into the spatial distribution of key soil attributes such as nutrient content, organic matter content and pH levels. Geospatial mapping techniques offer a powerful tool for visualizing and analyzing soil variability across landscapes, facilitating informed decision-making for land use planning, agricultural management, and environmental conservation (Singh *et al*, 2023) [32].

The micro watershed scale is particularly relevant for soil nutrient assessment and mapping due to its close association with hydrological processes. Microwatersheds serve as the primary units for water collection, storage, and flow, making them integral components of larger watershed systems (Rout *et al*, 2016) [29]. Soil nutrient dynamics within microwatersheds not only influence agricultural productivity but also impact water quality, ecosystems, and overall watershed health. Therefore, understanding soil nutrient status at this scale is essential for effectively managing both land and water resources. Furthermore, the assessment and mapping of soil resources in micro watersheds hold significant implications for sustainable development and climate resilience. With increasing pressures on land and water resources due to population growth, urbanization, and climate change, there is a growing need to optimize land use practices and enhance agricultural sustainability (Chartres and Noble, 2015) [4]. By integrating soil nutrient data with geospatial information on land use, climate, and hydrology, stakeholders can develop tailored strategies to improve soil health, mitigate environmental risks, and promote resilient agricultural systems.

In this context, advances in remote sensing technologies, geographic information systems (GIS), and spatial modelling techniques have revolutionized the way soil resources are assessed and managed. These tools enable the integration of multi-source data, including satellite imagery, aerial photography, and ground-based measurements, to generate detailed maps of soil properties and nutrient distributions. Such spatially explicit information enhances our understanding of soil-landscape relationships and supports evidence-based decision-making for sustainable land management (Akanbi *et al*, 2024) [2]. The assessment of soil nutrient status and mapping of soil resources at the micro watershed scale are essential components of modern land management and environmental stewardship. By elucidating the spatial variability of soil nutrients within micro watersheds, stakeholders can devise targeted interventions to optimize agricultural productivity, conserve natural resources, and safeguard ecosystem health. As we confront global challenges such as food security, climate change, and environmental degradation, the importance of understanding and managing soil resources at the micro watershed scale becomes increasingly paramount.

2. Materials and Methods

2.1 Study area: The Bettadapura micro-watershed is situated within the Harisamudra subwatershed, which is a part of the Lower Tungabhadra catchment, nestled in the Kadur taluk of Chikkamagaluru district, Karnataka, India. Geographically, it spans between 13° 36' 3.816" N and 13° 34' 17.832" N latitude and 76° 11' 28.824" E and 13° 34' 17.832" N longitude (Fig. 1). Covering a total area of 690.69 hectares, this micro-watershed holds significance within the broader hydrological framework of the region.

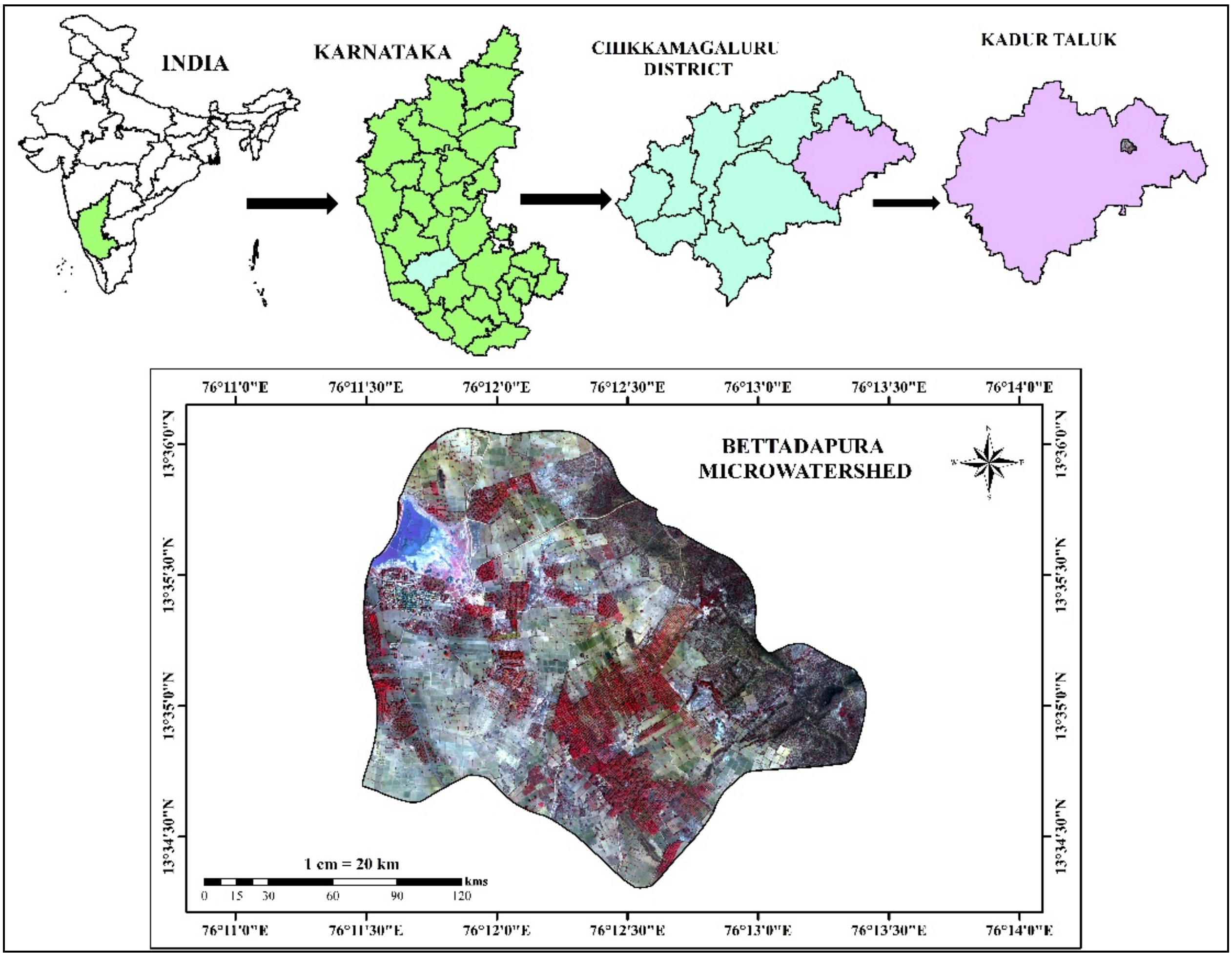

Fig 1: Location of the study area

2.2 Climate: The study area exhibits a consistently warm climate year-round, with March, April, and May classified as summer months. Temperature fluctuations range from 18 to 32 °C. December marks the lowest recorded minimum temperature at 18 °C. The area has an average annual rainfall of 787.65 mm. The rainfall distribution over the ten years is shown in fig. 2. Rainfall predominantly occurs during the southwest monsoon, supplemented by contributions from the Northeast monsoon, occurring over a seasonal period lasting approximately 4 to 5 months annually.

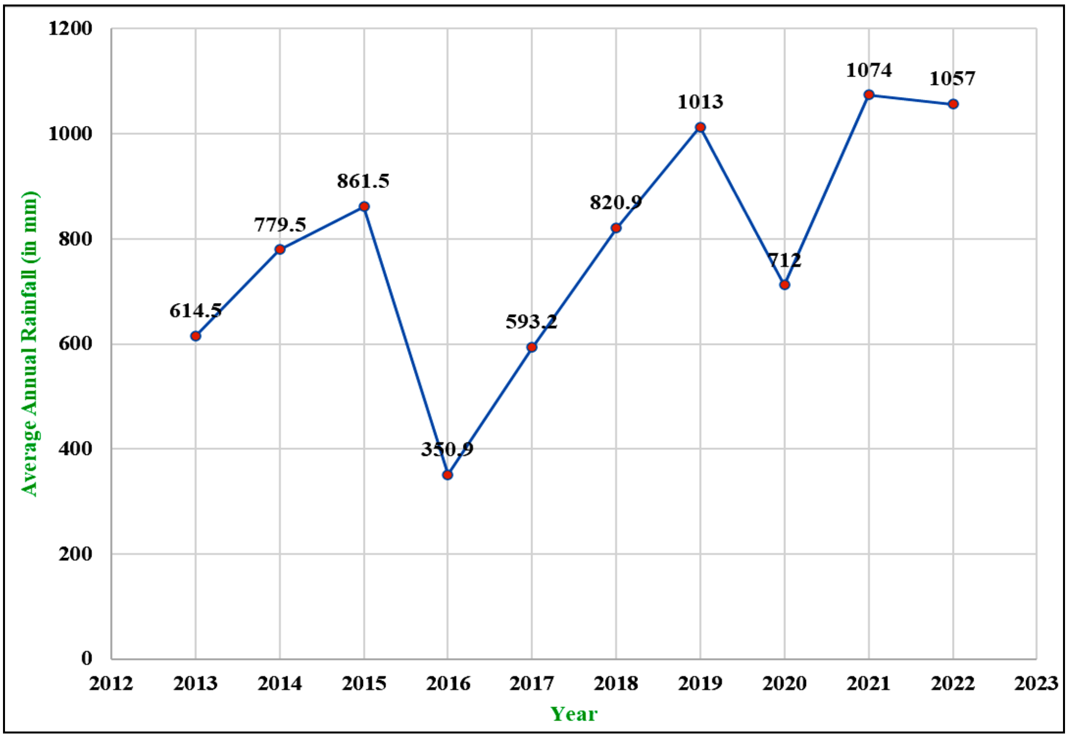

Fig 2: Graph representing the distribution of rainfall during 2013-2022 period

2.3 Soil Sampling

In the study area, grid sampling (0-20 cm) was performed by establishing grids at 320 m intervals within the micro-watershed. Using handheld GPS devices, a total of 66 surface samples were collected from predetermined grid points (Fig. 3) to assess soil fertility status. The location of these grid points was determined using the fishnet tool within the ArcGIS geospatial platform.

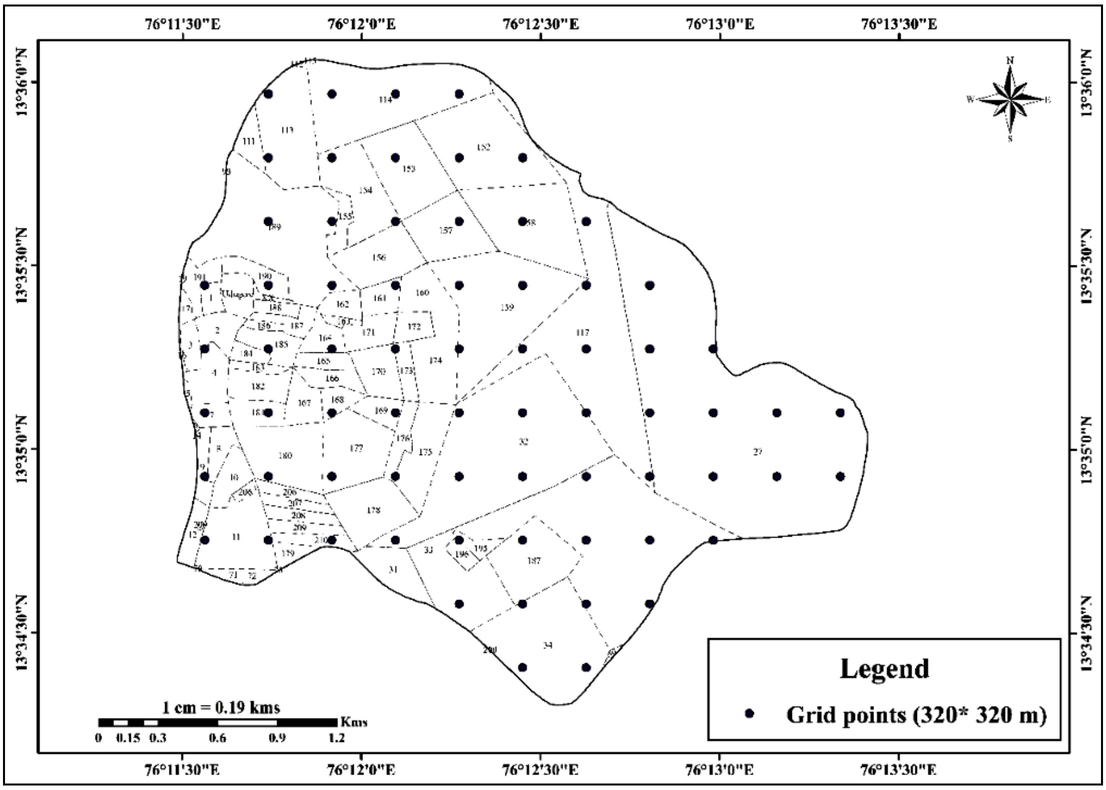

Fig 3: Grid points identified in Bettadapura micro-watershed

2.4 Preparation and laboratory analysis of soil samples
The grid soil samples were dried in the shade. The air-dried samples were ground and passed through a 2 mm Indian standard sieve. The coarse fragments (>2 mm) were separated from fine earth samples. The fine earth samples were stored in separate containers and used for various physicochemical laboratory analysis. The different soil parameters tested as well as methods adopted to analyze are mentioned below

2.4.1 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) [8]. The soil pH values were interpreted based on the interpretation criteria given by Natrajan *et al*. 2016 [17].

2.4.2 Electrical conductivity
The electrical conductivity of soils was measured in 1: 2, soil: water extract using an electrical conductivity bridge (Jackson, 1973) [8]. The results were expressed as dS m-1 at 25 ˚C.

2.4.3 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) [37]. The soil organic carbon content was expressed in g kg^{-1}.

2.4.4 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 KMnO4 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) [33].

2.4.5 Available phosphorus
Available phosphorus in soil samples was extracted by Olsen's method (0.5 $NaHCO_3$) for soils with pH ≥ 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) [8]. 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.

2.4.6 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) [8].

2.4.7 Exchangeable calcium and magnesium
The Exchangeable calcium and magnesium were determined by Versnate titration method (Black, 1965) [3].

2.4.8 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) [3].

2.4.9 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) [16].

2.4.10 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) [10].

2.5 Soil fertility maps
Soil fertility maps were prepared using ArcGIS 10.8 software. Initially, a database file (dbf) was created containing X and Y coordinates representing sampling locations at 320m grid intervals. Concurrently, a shapefile outlining the boundaries of the Bettadapura micro-watershed was generated within the ArcGIS environment. The dbf file was imported into the project window, with the X-field assigned to X-coordinates and the Y-field to Y-coordinates. The Z-field contained data for various soil nutrients. Simultaneously, the shapefile representing the Bettadapura micro-watershed was loaded into the project.
Utilizing the ArcGIS Spatial Analyst tool, the "Interpolate grid" option was selected from the surface menu. In the subsequent "grid specification dialogue," the output grid extent was aligned with the boundaries of the Bettadapura micro-watershed shapefile, and kriging was chosen as the interpolation method. Following the completion of the interpolation process, a digital map illustrating soil fertility levels was generated. This map was further refined by reclassifying it based on predetermined ratings for each soil nutrient.

2.6 Nutrient Index
Nutrient index (NI) value is a measure of nutrient supplying capacity of soil to plants (Singh *et al.*, 2016) [31]. The nutrient index approach introduced by Parker *et al.* (1951) [20] has been adopted and modified by several researchers such as Ravikumar and Govindaraju (2019) [26], Shetty *et al.* (2008) [30]. National and International organizations such as ICAR-NBSS and LUP, Ministry of Agriculture (Govt. of India), FAO, *etc.* This index is used to evaluate the fertility status of soils based on the samples in each of the three classes, *i.e.*, low, medium and high (Table 1). The nutrient index was evaluated for the soil samples analyzed using the following formula;

$$\text{Nutrient Index (NI)} = \frac{(N_L \times 1 + N_M \times 2 + N_H \times 3)}{N_T}$$

Where,
- **N_L:** Indicates number of samples falling in low class of nutrient status
- **N_M:** Indicates number of samples falling in medium class of nutrient status
- **N_H:** Indicates number of samples falling in high class of nutrient status
- **N_T:** Indicates total number of samples analyzed for a given area

Table 1: Ratings of Nutrient index

Sl. No.	Nutrient index	Value	Interpretation
1	Low	<1.67	Low fertility status of the area
2	Medium	1.67-2.33	Medium fertility status of the area
3	High	>2.33	High fertility status of the area

3. Results and Discussion

A total of 66 soil samples were collected from the study area using the grid sampling technique and were analyzed for their fertility status. This section briefs the details of the analysis results for the fertility status of the surface soils.

3.1 Soil reaction (pH)

Soil pH levels play a crucial role in determining the overall health and productivity of soil. Understanding and managing soil pH levels is essential for optimizing agricultural productivity and maintaining soil ecological balance within the watershed. Within the Bettadapura micro-watershed, soil pH ranged from 6.00 to 8.15, indicating a spectrum from slightly acidic to moderately alkaline conditions. The mean pH value was calculated at 6.49, with a standard deviation of 0.81. Notably, approximately 51.26% (354.08 ha) of the area exhibited a neutral pH, while 23.61% (163.06 ha) displayed slightly alkaline characteristics. Additionally, 15.01% (103.69 ha) of the region had slightly acidic soils, and 2.08% (14.41 ha) featured moderately alkaline pH levels (Table 3). The spatial distribution analysis revealed a prevalence of moderately alkaline pH across the study area, as illustrated in Fig. 4

Overall, the micro-watershed exhibited a predominantly slightly alkaline pH, largely influenced by the parent material. The presence of iron hydroxide species in red soil contributed to the lower pH values. The high pH levels observed may be attributed to a high degree of base saturation, as noted by Meena *et al.* (2006) [].

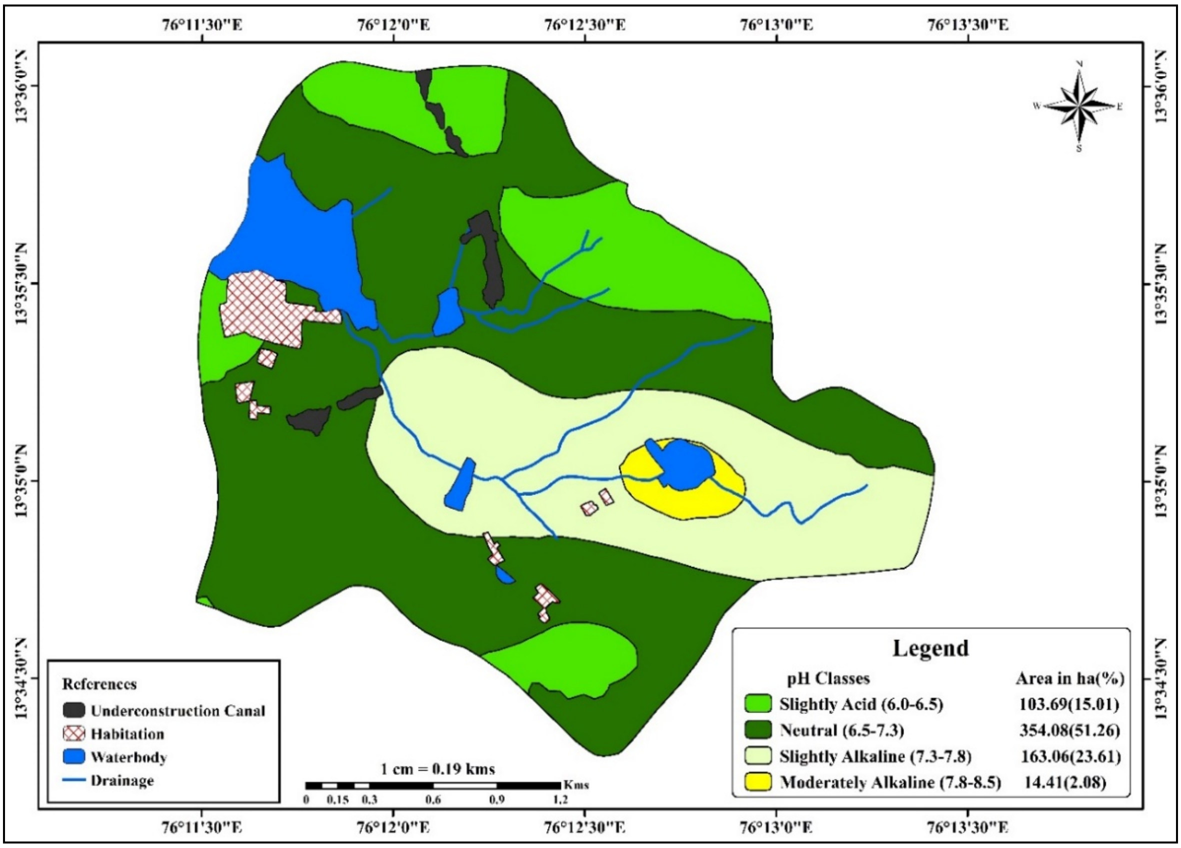

Fig 4: Soil reaction (pH) map of Bettadapura micro-watershed

3.2 Electrical conductivity (EC)

Soil electrical conductivity (EC) serves as a critical indicator of soil health and fertility. In the context of the micro-watershed, soil samples exhibited EC values ranging from 0.38 to 1.99 dS m^{-1}, with a mean value of 0.92 dS m^{-1} and a standard deviation of 0.39 dS m^{-1} (Table 2) (Table 3). Notably, the total soluble salt content was found to be very low, indicating a non-saline nature of the soils within the micro-watershed (Fig. 5) (Table 2). This observation can be attributed to factors such as slope and effective drainage conditions, which facilitate the removal of bases from the soil. These findings align with previous studies by Swarnam *et al.* (2004) [34] and Jhanavi (2020) [9]. Understanding soil electrical conductivity is vital for assessing soil fertility, nutrient availability, and overall land management strategies within the micro-watershed.

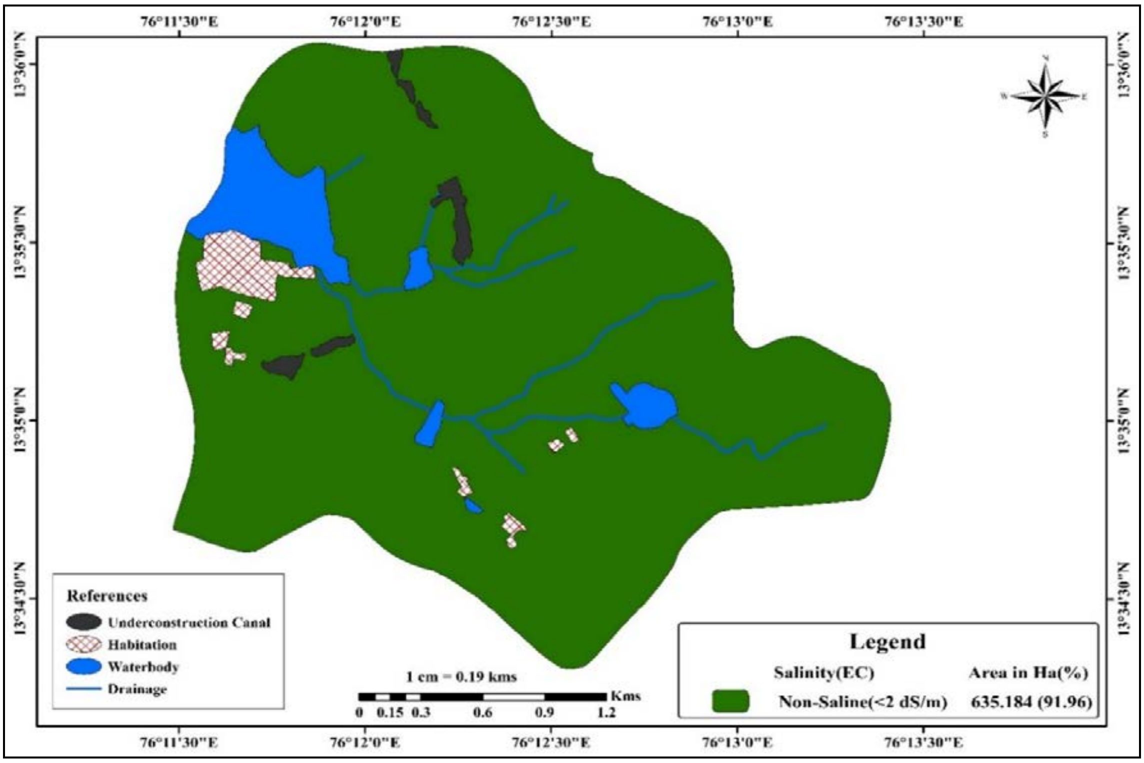

Fig 5: Spatial distribution of electrical conductivity (EC) in Bettadapura micro-watershed

3.3 Soil organic carbon (SOC)

Soil organic carbon (SOC) is a fundamental component influencing soil fertility, structure, and overall soil health. In this study, the analysis of soil samples revealed SOC levels ranging from 2.1 to 12.5 g kg^{-1}, with an average value of 5.94 kg^{-1} (Table 2). The standard deviation was calculated at 2.38 g kg^{-1}. Notably, a significant portion of the study area, accounting for 44.06 percent (304.35 ha) of the total area, exhibited high organic carbon content, while 37.84 percent (261.35 ha) and 10.07 percent (69.53 ha) of the region displayed medium and low levels of organic carbon, respectively (Table 3). The spatial distribution map (Fig. 6) provides insights into the variability of soil organic carbon within the micro-watershed. The observed medium to high organic carbon content can be attributed to practices such as the incorporation of crop residues and other organic matter sources into the soil. These findings are consistent with prior studies conducted by Nayak *et al*. (2002) [18] and Vikas (2018) [36], highlighting the importance of maintaining adequate soil organic carbon levels for sustaining soil fertility and agricultural productivity.

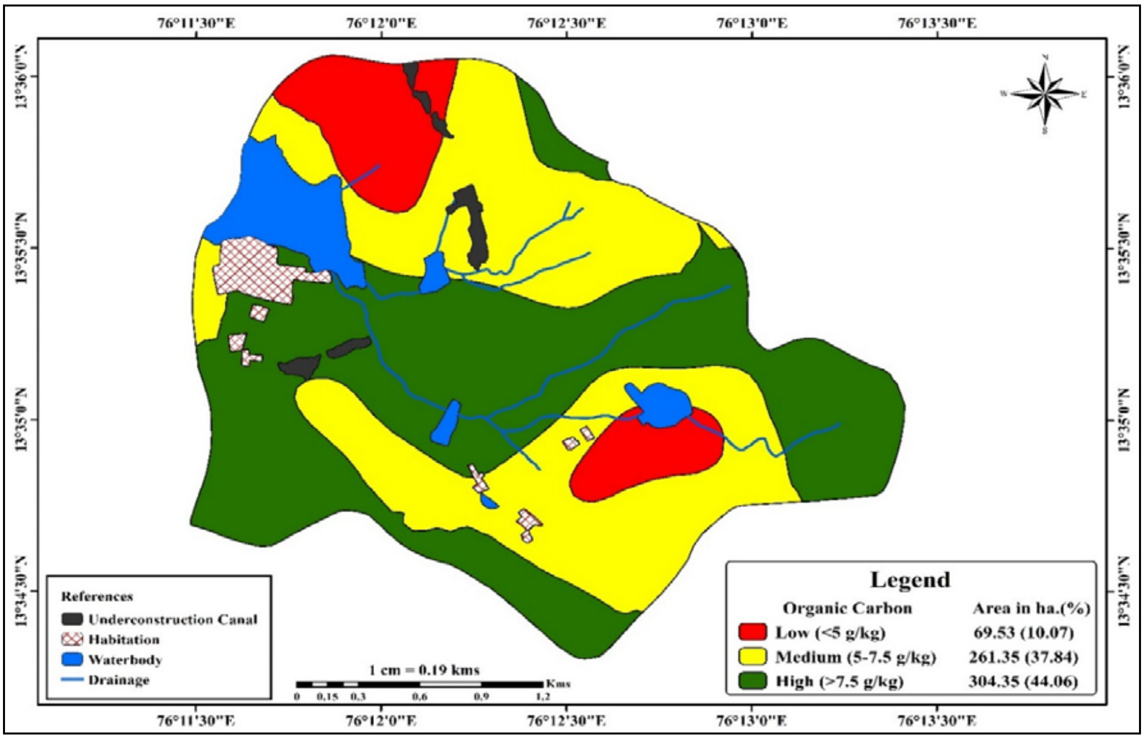

Fig 6: Soil organic carbon status of surface soils of Bettadapura micro-watershed

3.4 Available nitrogen

Nitrogen stands out as the primary element essential for plants, needed in significant quantities, constituting approximately 1.5-2.0% of plant dry matter. Additionally, it contributes to around 16% of the total protein content in plants. The micro-watershed area overall displayed a range of nitrogen content from low to medium levels, with available nitrogen varying between 106.5 to 291.2 kg ha^{-1}. The average nitrogen content was calculated at 198.72 kg ha^{-1}, with a standard deviation of 41.33 kg ha^{-1} (Table 2). Notably, 77.48% of the area, covering 535.32 ha, exhibited low available nitrogen, while 22.50%, equivalent to 155.37 ha, showed medium nitrogen content, as depicted in Fig.7 (Table 3). The medium nitrogen content observed within the micro-watershed could be attributed to the significant presence of soil organic carbon in the area. However, it may also result from intensive and continuous cultivation practices without adequate supplementation from external sources. Limited usage of nitrogenous fertilizers might contribute to nitrogen deficiency issues (Pramod and Patil, 2015) [22]. These findings corroborate with previous research by Jhanavi (2020) [9]. It's noteworthy that nitrogen remains the most limiting nutrient in black soils, with its availability decreasing due to fixation and volatilization losses (Karajanagi *et al*., 2016) [12]. Understanding and addressing nitrogen availability are critical for effective land management and sustainable agricultural practices within the micro-watershed.

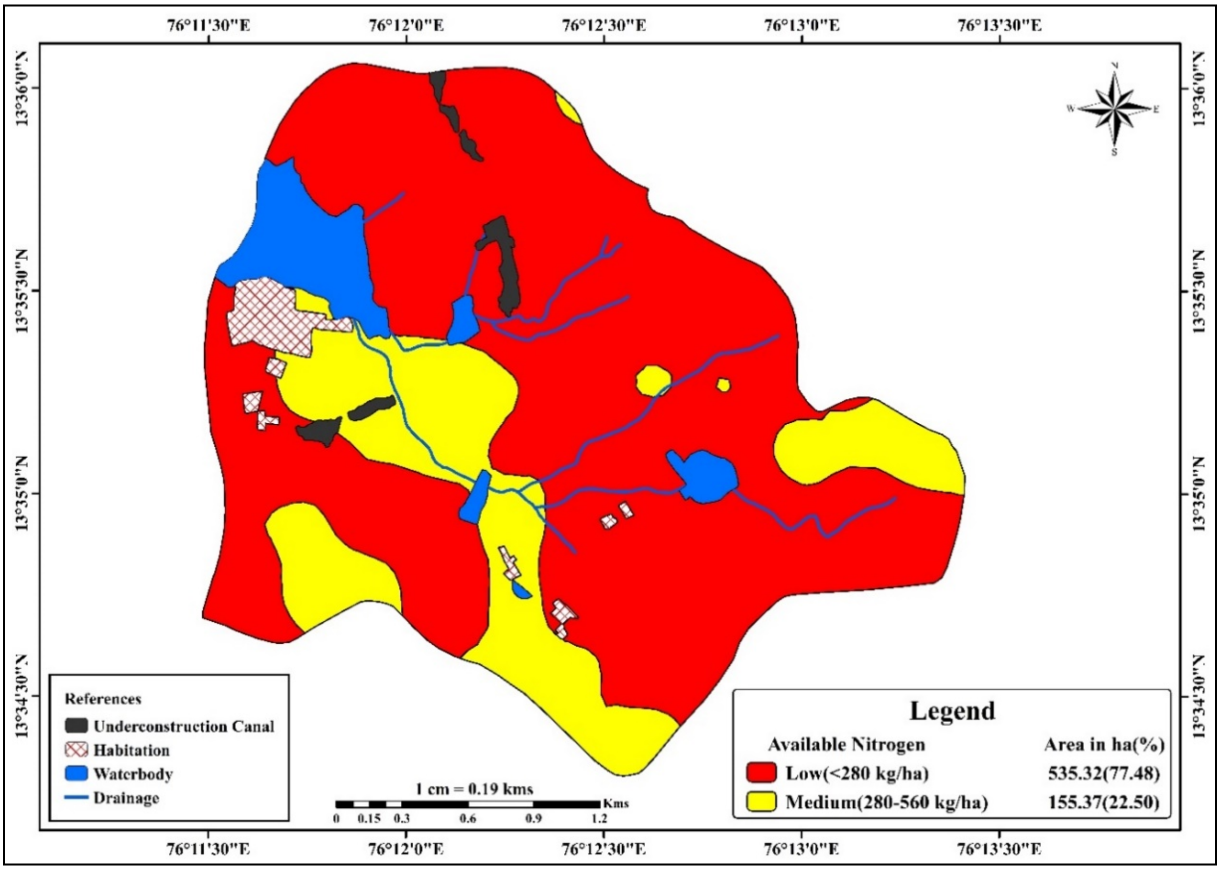

Fig 7: Available nitrogen status of surface soils of Bettadapura micro-watershed

3.5 Available phosphorus: Phosphorus has been called the "Master key to agriculture" because low crop production is attributed mainly to the deficiency of phosphorus, except nitrogen, than the deficiency of other elements. The analysis results depict that the available phosphorus content varied between 16.14 and 78.48 kg ha^{-1}. The mean value was 32.16 kg ha^{-1} with a standard deviation of 15.69 kg ha^{-1} as shown in Table 2. 79.04 per cent of the total area, *i.e.*, 545.94 ha, had medium phosphorus content, 7.48 per cent (51.67 ha) area had high available phosphorus content and 5.45 per cent (37.63 ha) of area had low available phosphorus as shown in Fig. 8 (Table 3).The micro-watershed area was low to high in available phosphorus status. The clay soil's CEC and phosphorus fixing capacity might be the reason behind the medium range of available phosphorus content (Rajashekar, 2018) [24]. High phosphorous content may be due to application of fertilizers that contain phosphorus. The spatial distribution of available phosphorus in the micro-watershed is depicted in Fig. 8.

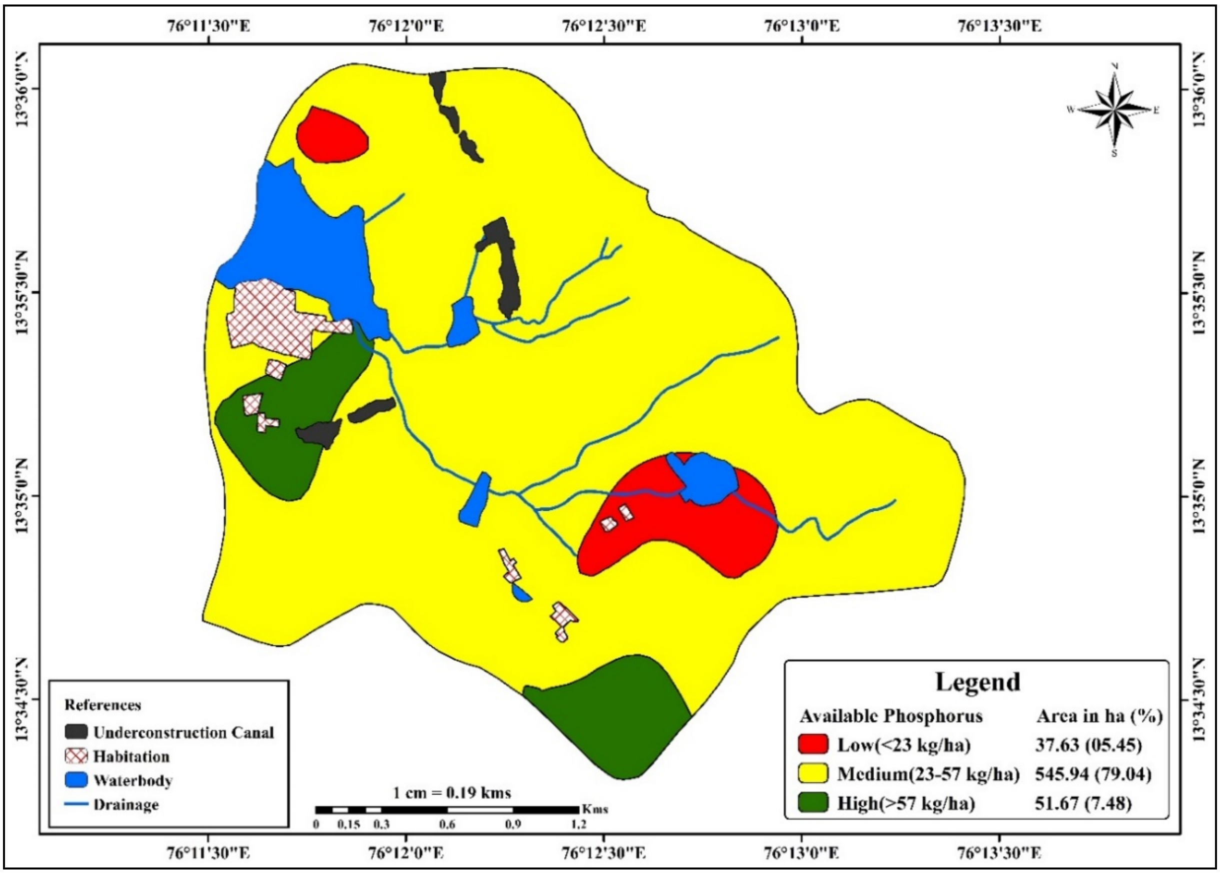

Fig 8: Available phosphorus status of surface soils of Bettadapura micro-watershed

Table 2: Fertility status of surface soils of Bettadapura micro-watershed

Soil properties	Range	Mean	SD	CV
Soil reaction (pH)	5.52 - 8.15	6.49	0.81	0.12
Electrical Conductivity (EC) (dS m^{-1})	0.38 - 1.99	0.92	0.39	0.43
Organic Carbon (g kg^{-1})	2.10 - 12.50	5.94	2.38	0.4
Available nitrogen (kg ha^{-1})	106.5 - 291.20	198.72	41.33	0.21
Available P_2O_5 (kg ha^{-1})	16.14 - 78.48	32.16	15.69	0.49
Available K_2O (kg ha^{-1})	48.38 - 457.22	213.19	120.30	0.56
Exchangeable Ca [cmol(p^+) kg^{-1}]	0.70 - 10.10	3.34	2.55	0.74
Exchangeable Mg [cmol(p^+) kg^{-1}]	0.70 - 11.40	4.31	2.45	0.55
Available S (mg kg^{-1})	07.18 - 53.81	29.07	9.25	0.32
Available Fe (mg kg^{-1})	1.03 - 25.04	10.68	6.98	0.65
Available Cu (mg kg^{-1})	0.41 - 1.96	1.11	0.40	0.36
Available Mn (mg kg^{-1})	1.85 - 18.53	12.21	5.40	0.44
Available Zn (mg kg^{-1})	0.22 - 2.02	0.65	0.34	0.52
Available B (mg kg^{-1})	0.13 - 1.20	0.40	0.24	0.61

Total number of samples (n)=66

3.6 Available potassium: Potassium serves as a crucial macronutrient for plants, facilitating essential physiological functions crucial for their growth and development. These include enzyme activation, osmoregulation, and maintaining cell turgor pressure, all of which contribute significantly to overall plant vigor and health. Within the micro-watershed, the available potassium content ranged from 48.38 to 457.22 kg ha^{-1}, with an average of 213.19 kg ha^{-1} and a standard deviation of 120.3 kg ha^{-1} (Table 2). The majority of the study area had medium available potassium content, *i.e.*, 54.19 per cent (374.33 ha) area and 27.66 per cent (191.03 ha) area had low potassium content (Table 3). The remaining area *i.e.*, 10.11 per cent (69.86 ha) had high available potassium content. Fig. 9 depicts the spatial distribution of available potassium in the study area. The higher potassium content can be attributed to the potassium-rich parent materials from which the soils have formed. It can also be due to application of potassic fertilizers. Similar results were reported by Jhanavi, 2020 [9] and Pulakeshi *et al.* (2014) [23]. The spatial distribution of available potassium in the micro-watershed is depicted in Fig. 9.

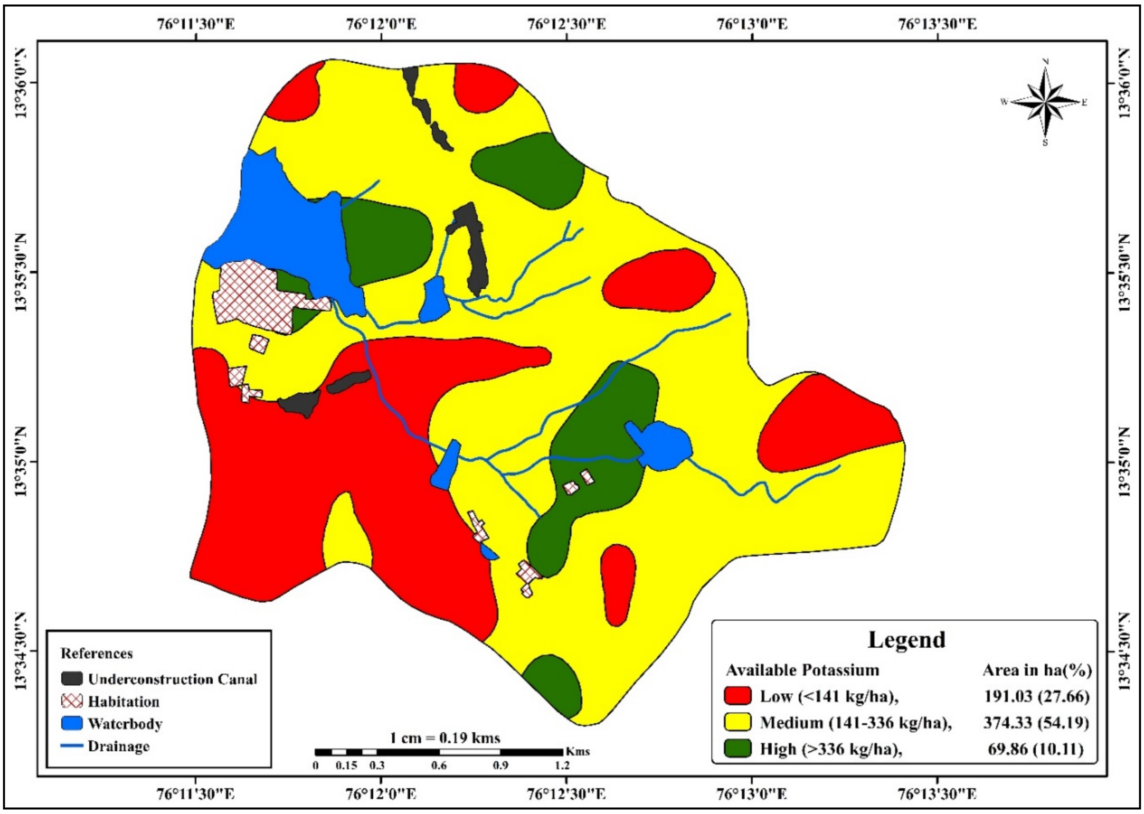

Fig 9: Available potassium status of surface soils of Bettadapura micro-watershed

Table 3: Area under different chemical and fertility classes of Bettadapura micro-watershed

<table>
<tr><th>Parameters</th><th colspan="5">Classes</th><th rowspan="2">Others</th></tr>
<tr><td rowspan="2">Soil Reaction (pH)</td><th>Slightly Acidic</th><th>Neutral</th><th colspan="2">Slightly Alkaline</th><th>Moderately Alkaline</th></tr>
<tr><td>103.69 (15.01)</td><td>354.08 (51.26)</td><td colspan="2">163.06 (23.61)</td><td>14.41 (2.08)</td><td rowspan="17">55.42 (8.04)</td></tr>
<tr><td rowspan="2">Electrical Conductivity</td><th colspan="5">Non- Saline</th></tr>
<tr><td colspan="5">635.23 (91.96)</td></tr>
<tr><td rowspan="2">Organic Carbon (OC)</td><th>Low</th><th colspan="3">Medium</th><th>High</th></tr>
<tr><td>69.53 (10.07)</td><td colspan="3">261.35 (37.84)</td><td>304.35 (44.06)</td></tr>
<tr><td>Available Nitrogen</td><td>535.32 (77.48)</td><td colspan="3">155.37 (22.50)</td><td>-</td></tr>
<tr><td>Available Phosphorus</td><td>37.63 (05.45)</td><td colspan="3">545.94(79.04)</td><td>51.67 (07.48)</td></tr>
<tr><td>Available Potassium</td><td>191.03(27.66)</td><td colspan="3">374.33(54.19)</td><td>69.86 (10.11)</td></tr>
<tr><td>Available Sulphur</td><td>55.76 (08.06)</td><td colspan="3">348.24 (50.41)</td><td>231.24 (33.48)</td></tr>
<tr><td>Available Boron</td><td>181.33 (26.25)</td><td colspan="3">444.27 (64.32)</td><td>09.64 (1.39)</td></tr>
<tr><td></td><th colspan="3">Sufficient</th><th colspan="2">Deficient</th></tr>
<tr><td>Exchangeable Calcium</td><td colspan="3">635.23 (91.96)</td><td colspan="2">-</td></tr>
<tr><td>Exchangeable Magnesium</td><td colspan="3">635.23 (91.96)</td><td colspan="2">-</td></tr>
<tr><td>Available Zinc</td><td colspan="3">392.50 (56.83)</td><td colspan="2">242.73 (35.14)</td></tr>
<tr><td>Available Iron</td><td colspan="3">625.76 (90.60)</td><td colspan="2">09.48 (1.37)</td></tr>
<tr><td>Available Manganese</td><td colspan="3">635.23 (91.96)</td><td colspan="2">-</td></tr>
<tr><td>Available Copper</td><td colspan="3">635.23 (91.96)</td><td colspan="2">-</td></tr>
</table>

Note: Others include habitation, water bodies, and underconstruction canal.
* Figures in parenthesis indicate the percentage of total micro-watershed area

3.7 Exchangeable calcium and magnesium

Calcium serves as a crucial secondary nutrient essential for promoting cell growth, division, elongation, and various other vital biological functions. The study area had sufficient exchangeable calcium (Table 2). The values ranged between 0.7 and 10.1 cmol (p^+) kg^{-1}. The average value was 3.34 cmol (p+) kg^{-1} with a standard deviation of 2.55 cmol (p^+) kg^{-1} (Fig. 10). The study area had sufficient amount of exchangeable calcium (Table 3).

Magnesium plays a central role as the primary atom in chlorophyll, with its concentration typically ranging from 0.2% to 0.4% of the dry matter in plants. The study area had sufficient exchangeable magnesium (Table 2). The values ranged between 0.7 and 11.4 cmol (p^+) kg^{-1}. The average value was 4.31 cmol (p+) kg^{-1} with a standard deviation of 2.45 cmol (p^+) kg^{-1} (Fig. 11). The study area had sufficient amount of exchangeable magnesium (Table 3).

Ananthanarayana *et al.* (1986) reported higher exchangeable Ca and Mg contents in black soils than red soils. The high amount of clay and type of clay might have led to high concentrations of both cations. These results were in consonance with the findings of Harshitha (2018) [6] and Jhanavi (2020) [9]. The spatial distribution of exchangeable calcium and magnesium in the micro-watershed is depicted in Fig. 10 and Fig. 11, respectively.

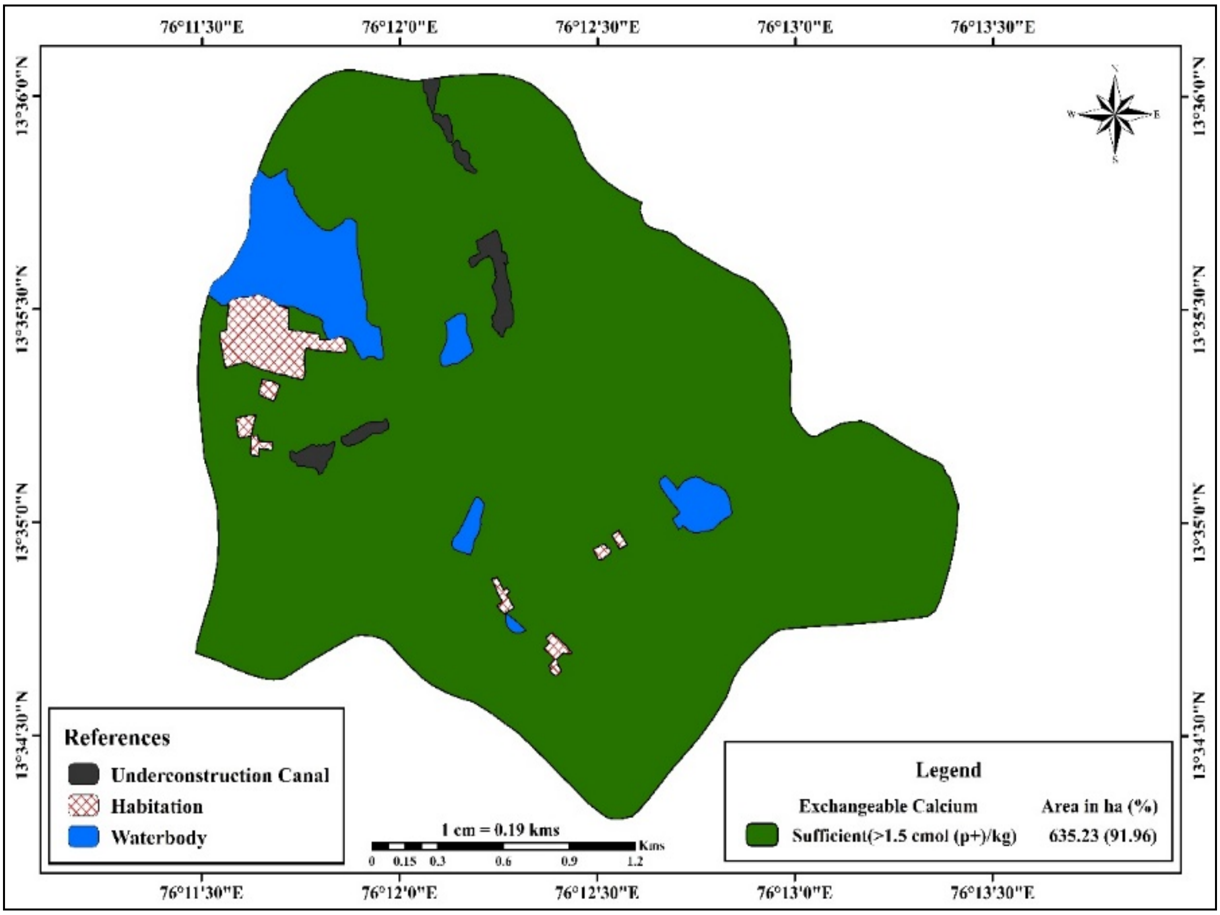

Fig 10: Exchangeable calcium status of surface soils of Bettadapura micro-watershed

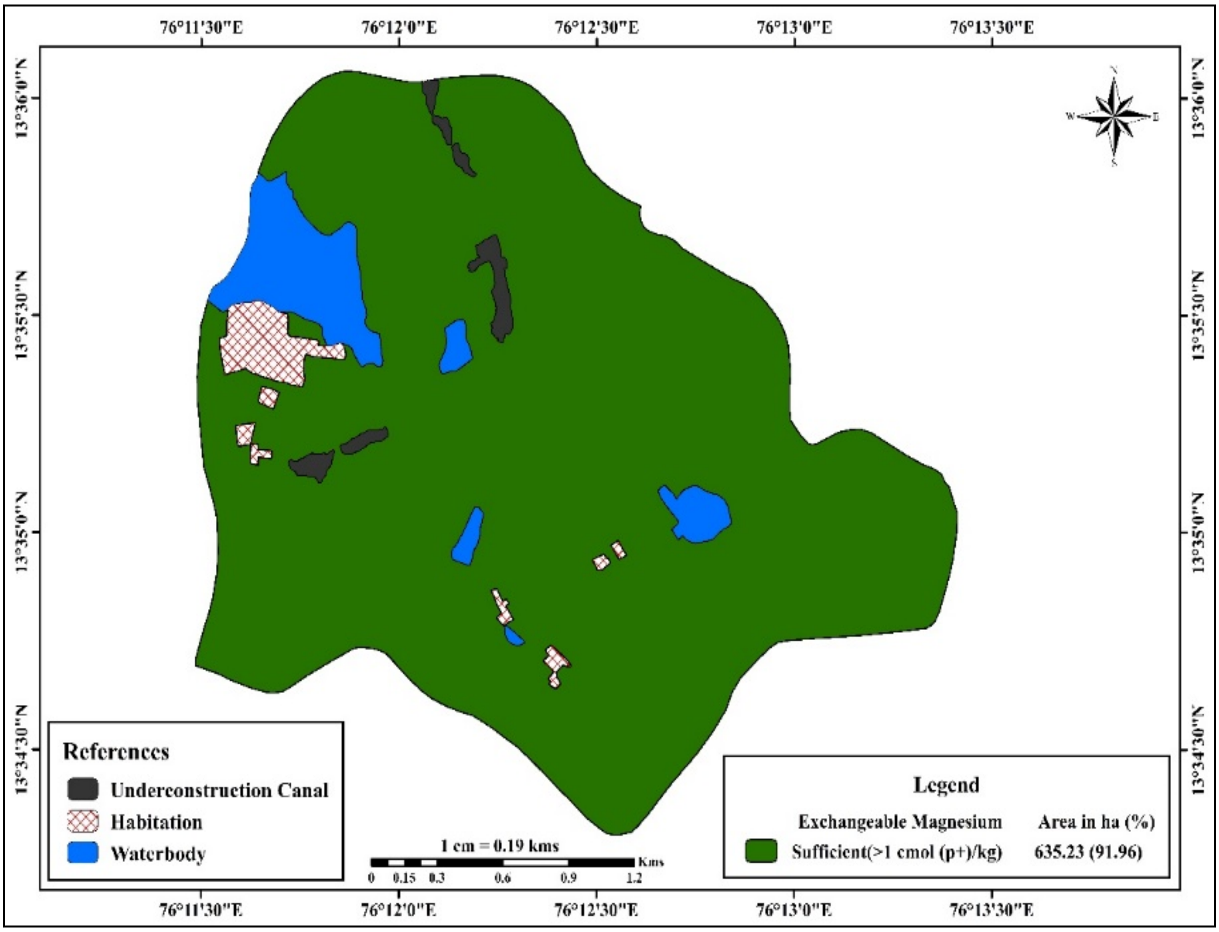

Fig 11: Exchangeable magnesium status of surface soils of Bettadapura micro-watershed

3.8 Available sulphur

Sulphur, ranked ninth in abundance among elements in the Earth's crust, plays a vital role in plants by facilitating the synthesis of chlorophyll, proteins, seed oil content, as well as amino acids methionine and cysteine. The available sulphur content of the micro-watershed area varied between 13.18 and 53.81 mg kg^{-1} with a mean value of 29.07 mg kg^{-1}. The standard deviation was 9.25 mg kg$^{-1,}$ as shown in Table 2. An area of 348.24 ha (50.41%) had medium available sulphur content, 231.24 ha (33.48%) had high available sulphur content and 55.76 ha (8.06%) had low available sulphur content (Table 3) as shown in Fig. 12. The absence of significant amount of sulphur bearing minerals can be the reason for low sulphur content in the study area. The organic carbon has also significantly contributed to sulphur content in the soils. The fine textured nature of most soils in the study area might also have contributed to the same. Similar remarks were made by Vikas (2018) [36] in the Gollarahatti-2 micro-watershed. The spatial distribution of available sulphur in the micro-watershed is depicted in Fig. 12.

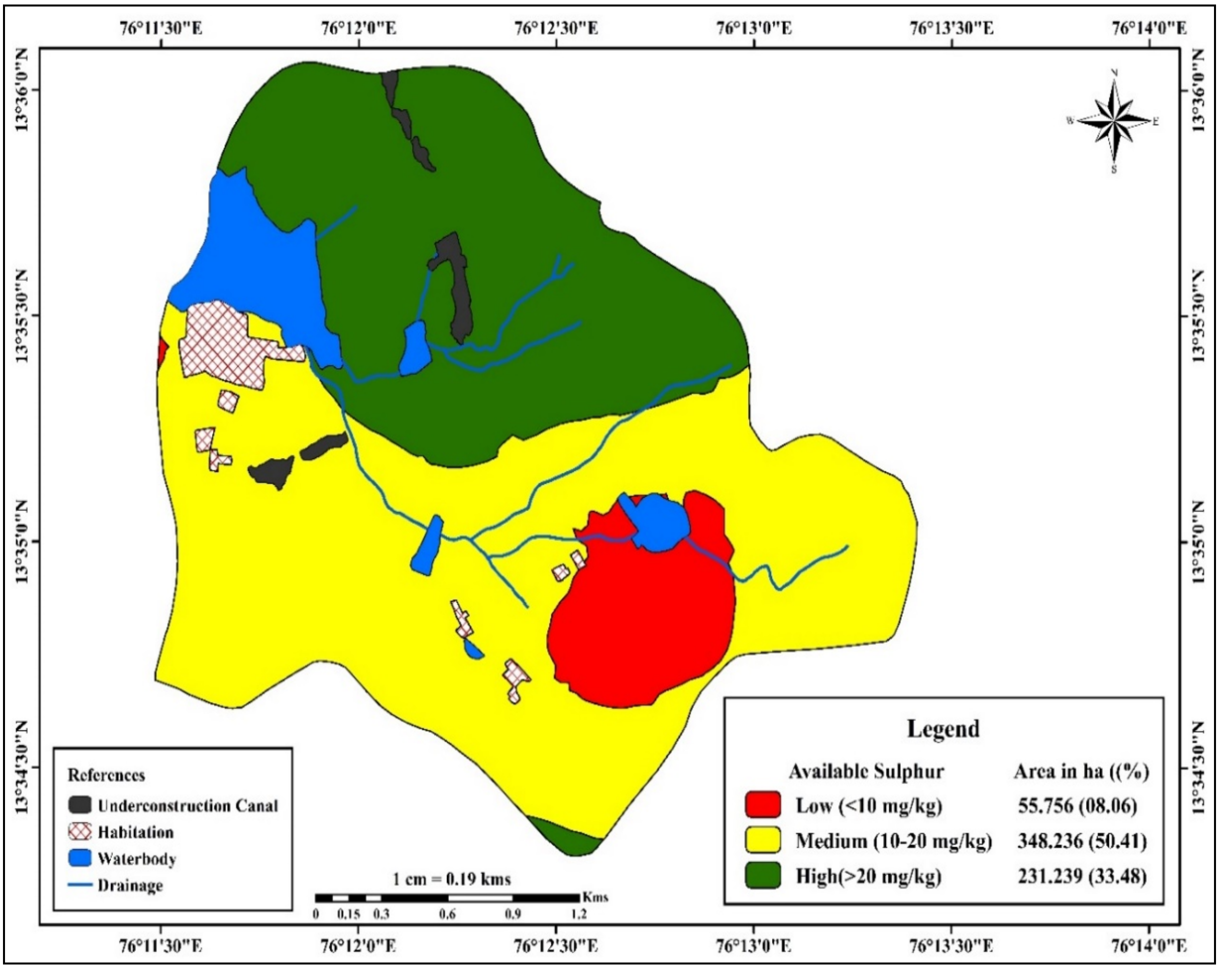

Fig 12: Available sulphur status of surface soils of Bettadapura micro-watershed

3.9 Available zinc: This element contributes to essential processes like cytochrome and nucleotide synthesis, auxin metabolism, chlorophyll production, enzyme activation, and the preservation of membrane integrity. Zinc deficiency is prevalent globally, affecting nearly all crops positively upon zinc application. The outcomes of the study revealed that the majority of the study area had a sufficient amount of available zinc. The values ranged between 0.22 and 2.02 mg kg^{-1}. The average value was 0.65 mg kg^{-1} with a standard deviation of 0.34 mg kg^{-1} (Table 2). 56.83 per cent (392.50 ha) area had sufficient available zinc, and 35.14 per cent (242.73 ha) of the area was deficient (Table 3) (Fig. 5.13). The alkaline condition of soil might be the reason behind the deficiency of zinc in few pockets in the study area (Thangasamy *et al.*, 2005) [35]. Soils being not subjected to intensive cultivation might be a reason for the sufficiency of available zinc in the surface samples (Rajashekar, 2018) [24]. The spatial distribution of available zinc in the micro-watershed is depicted in Fig. 13.

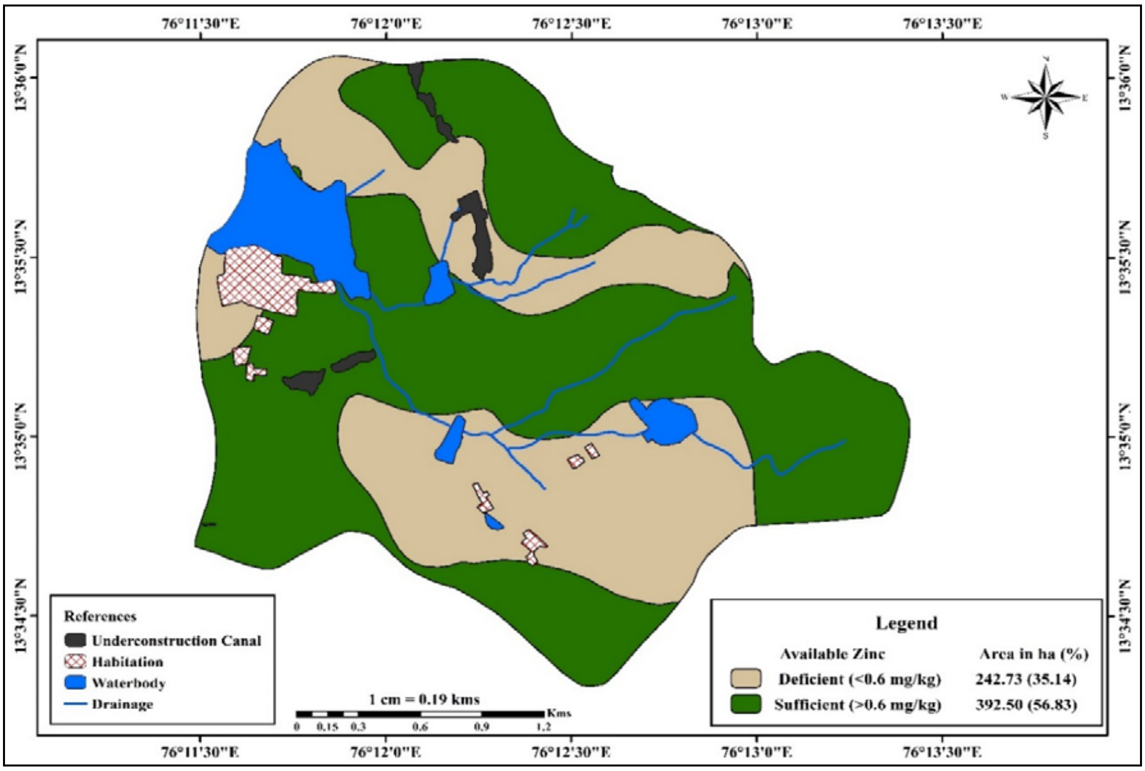

Fig 13: Available zinc status of surface soils of Bettadapura micro-watershed

3.10 Available iron

Iron stands as an indispensable micronutrient crucial for the functioning of nearly all living organisms, as it plays pivotal roles in metabolic processes including DNA synthesis, respiration, and photosynthesis. The study revealed that the available iron content ranged between 1.03 and 25.04 mg kg^{-1}. The average value was 10.68 mg kg^{-1} with a standard deviation of 6.98 mg kg^{-1} (Table 2). The study area had sufficient amount of available iron (Table 3) (Fig.14). Smaller area was found to be deficient (Table 2). This might be due to the ferruginous parent material, which is known to possess higher iron content. These results obeyed with the findings of Ravikumar *et al.* (2009) [28] and Jhanavi (2020) [9]. The results are in line with the findings of Pooja (2020) [21]. The spatial distribution of available iron in the micro-watershed is depicted in Fig. 14.

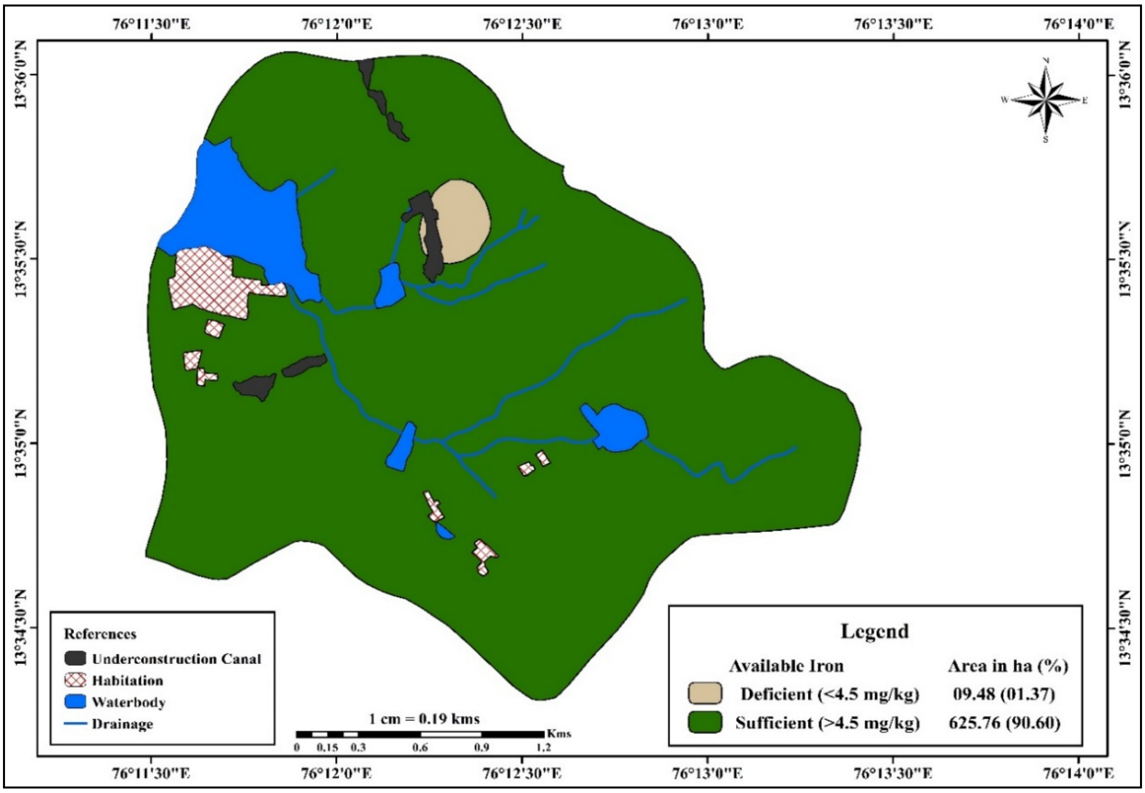

Fig 14: Available iron status of surface soils of Bettadapura micro-watershed

3.11 Available manganese

Manganese holds significance as an essential micronutrient, functioning as a cofactor that activates numerous enzymes crucial for catalyzing oxidation-reduction, decarboxylation, and hydrolytic reactions in plants. The outcomes of the study revealed that the available manganese content varied between 1.85 and 18.53 mg kg^{-1} with an average value of 12.21 g kg^{-1}. The standard deviation was 5.4 mg kg^{-1} (Table 2). The study area had sufficient quantity of available manganese content (Table 3) (Fig. 15). Sufficient content of manganese can be attributed to the high organic matter content in the study area. The higher content of DTPA extractable manganese content in the soils of the micro-watershed area can be attributed to its parent material. Yeresheemi (1996) [38] also attributed the sufficient content of manganese to high organic matter content in the Upper Krishna command area. Similar findings were reported by Vikas (2018) [36] and Krishna *et al*. (2017) [15]. The spatial distribution of available manganese in the micro-watershed is depicted in Fig. 15.

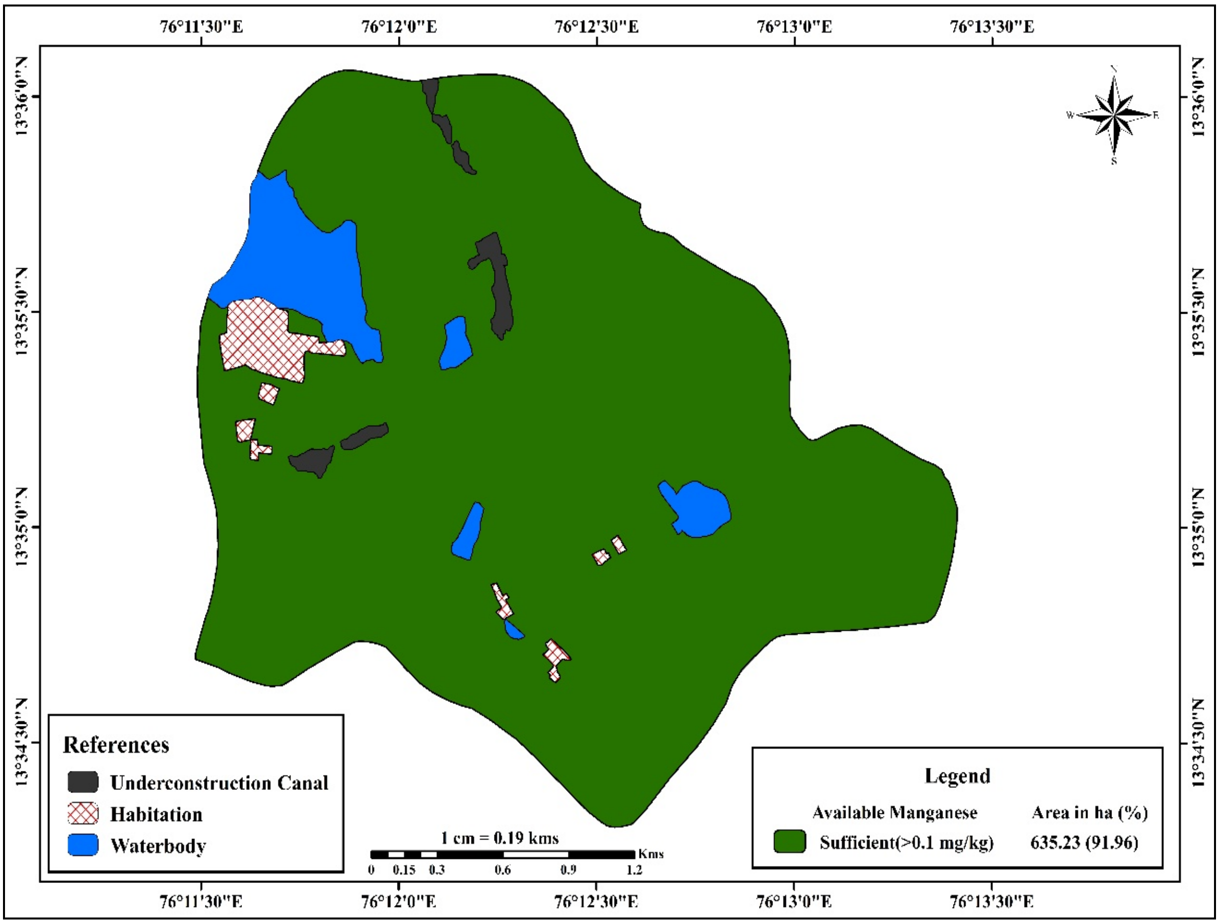

Fig 15: Available manganese status of surface soils of Bettadapura micro-watershed

3.12 Available Copper

Copper holds significance as a vital micronutrient essential for facilitating lignin synthesis, while also serving as a constituent of various crucial plant enzymes such as ascorbic acid, oxidase, phenolase, and plastocyanin. The available copper content of the soils of the study area varied between 0.41 and 1.96 mg kg^{-1} (Table 2). The average value was 1.11 mg kg^{-1} with a standard deviation of 0.4 mg kg^{-1}. The study area had sufficient available copper, as shown in Table 3 and Fig. 16. The sufficiency of copper in the study area was related to its parent material, *i.e.*, granite gneiss containing higher copper content (Rajkumar, 1994) [25]. Similar results were observed by Ravikumar (2006) [27] and Harshitha *et al*. (2018) [6]. The spatial distribution of available copper in the micro-watershed is depicted in Fig. 16.

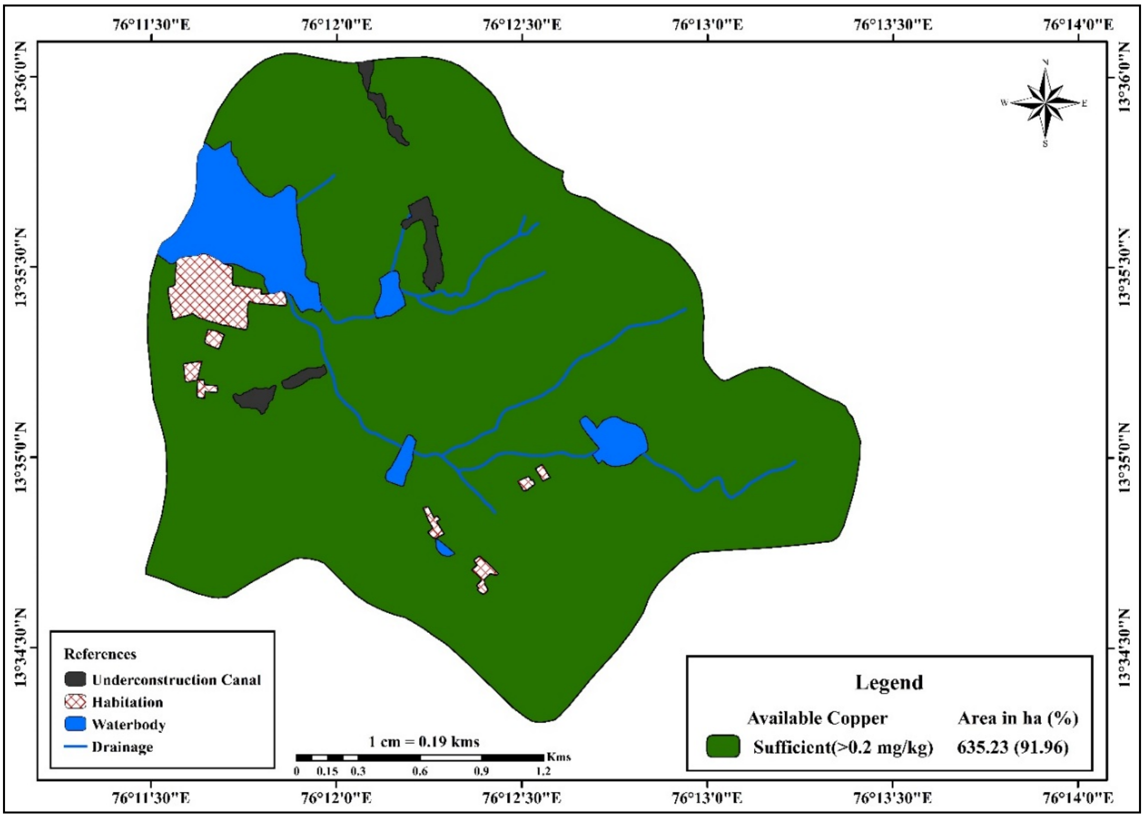

Fig 16: Available copper status of surface soils of Bettadapura micro-watershed

3.13 Available Boron: Boron stands out as a crucial micronutrient essential for facilitating the healthy growth and development of plants. The available boron content of the soils of the study area varied between 0.13 and 1.20 mg kg^{-1}. The average value was 0.4 mg kg^{-1} with a standard deviation of 0.24 mg kg^{-1} (Table 2). An area of 444.27 ha (64.32%) had medium available boron content, 181.33 ha (26.25%) had low available boron content and 9.64 ha (1.39%) had high available boron content (Table 3) as shown in Fig. 17. The medium content of boron can be attributed to the medium organic matter content and neutral to alkali soil reaction in the study area. Similar findings were reported by Vikas (2018) [36] and Jhanavi (2020) [9]. The spatial distribution of available manganese in the micro-watershed is depicted in Fig. 17.

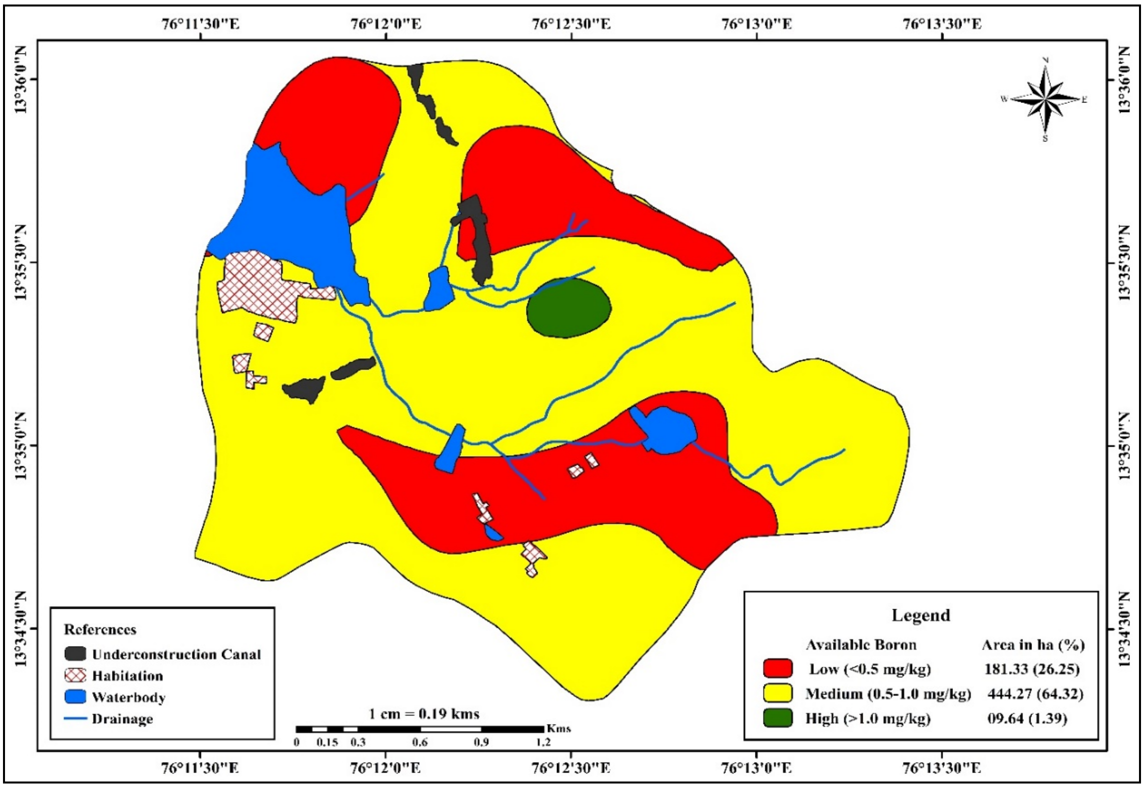

Fig 17: Available boron status of surface soils of Bettadapura micro-watershed

3.14 Soil fertility evaluation using nutrient index values

The nutrient index values gives us a vague insight into the fertility status of a particular region or area for a particular nutrient element. It was found that the micro-watershed had a nutrient index value of 1.76, 1.76 and 1.74 for soil organic carbon, available phosphorus and available potassium, respectively. A nutrient index value of 1.05 was obtained with respect to available nitrogen (Table 4).

Table 4: Nutrient index values of different nutrient elements in the study area

Parameter	Nutrient Index (NI)	Remarks
Organic carbon (OC)	1.76	Medium
Available Nitrogen	1.05	Low
Available Phosphorus	1.76	Medium
Available Potassium	1.74	Medium

The nutrient index values for soil organic carbon, available phosphorus, and available potassium were medium, indicating medium fertility status of the soils of the area with respect to these nutrient elements whereas, available nitrogen had low nutrient index value. Since the study area was found to have low available nitrogen in majority of the area because less presence of soil organic carbon in the area. However, it may also result from intensive and continuous cultivation practices without adequate supplementation from external sources. Limited usage of nitrogenous fertilizers might contribute to nitrogen deficiency issues (Pramod and Patil, 2015) [22]. These findings corroborate with previous research by Jhanavi (2020) [9]. the nutrient index value was also in the low category. The medium range of soil organic carbon content can be attributed to practices such as the incorporation of crop residues and other organic matter sources into the soil (Kirankumar and Hundekar, 2018) [14]. In case of phosphorus the clay soil's CEC and phosphorus fixing capacity might be the reason behind the medium range of available phosphorus content (Rajashekar, 2018) [24]. The medium range of potassium content can be attributed to the potassium-rich parent materials from which the soils have formed. It can also be due to application of potassic fertilizers. Similar results were reported by Jhanavi, 2020 [9] and Pulakeshi *et al.* (2014) [23] and Ravikumar and Govindaraju (2019) [26] also reported similar findings at Koranahalli sub-watershed.

4. Conclusion

In this comprehensive study, we conducted an in-depth assessment of soil nutrient dynamics in the Bettadapura micro-watershed, situated within the Lower Tungabhadra catchment area of Karnataka. Through meticulous soil sampling and advanced geospatial analysis, we gained valuable insights into the fertility status of the soil and its implications for agricultural productivity and environmental sustainability. Our findings revealed a diverse spectrum of soil reactions, ranging from moderately acidic to moderately alkaline, indicating varied soil conditions within the micro-watershed. Notably, soil organic carbon content exhibited significant variations, influencing soil health and productivity. We observed challenges in optimal crop growth due to varying levels of available nitrogen, phosphorus, potassium, and sulphur across the study area. Additionally, micronutrient analysis highlighted fluctuations in boron levels, while other micronutrients such as copper, manganese, zinc, and iron generally exhibited sufficient levels for crop development.

The integration of geospatial techniques allowed us to generate comprehensive soil nutrient status and fertility maps, providing valuable spatial information for informed land management decisions. Our research emphasizes the significance of evaluating soil nutrient status with precision in spatial resolution, offering guidance for specific actions aimed at sustainable land management practices and maximizing crop productivity.

Overall, this research emphasizes the significance of soil nutrient assessment and mapping for enhancing agricultural productivity, conserving natural resources, and safeguarding environmental health in micro watershed ecosystems. By understanding the intricate dynamics of soil nutrients, stakeholders can devise tailored strategies to address soil fertility challenges, promote sustainable agricultural practices, and ensure the resilience of ecosystems in the face of global challenges such as food security and climate change.

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