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Spatial Assessment and Variation of Soil Physicochemical Properties and Water Quality in the Tungi Watershed of Maharashtra, India

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Authors' contributions

This work was carried out in collaboration among all authors. Author AS collected, analyzed soil samples, performed the statistical analysis, generated soil fertility maps, wrote the first draft of the manuscript and Author VPH designed the study, supervised during study. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To thoroughly evaluate the spatial variability of soil physicochemical properties and groundwater quality of the study area by systematic collection and analysis of geo-referenced soil and groundwater samples to quantify the physical, chemical and biological attributes of the soil. The objective is to gain a comprehensive understanding of soil and water quality in the Tungi watershed, providing valuable insights to guide sustainable land and water management practices in the region.

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Place and Duration of Study: Department of Soil Science and Agricultural Chemistry, College of Agriculture, Latur between 2020 and 2021.

Methodology: A total of one hundred geo-referenced surface soil samples (0-30 cm) and ten groundwater samples were methodically collected from the surrounding area of soil profiles in the Tungi watershed, situated in Latur, Maharashtra. Physical, chemical and biological properties of soil evaluated using recommended standard methods.

Results: Bulk density varied from 1.13 to 1.93 Mg m-3, particle density from 2.48 to 2.94 Mg m-3 and porosity from 22 to 58 percent. Soil pH ranged from 7.05 to 8.96 and electrical conductivity was within the permissible range. Organic carbon content of soils ranged from 0.15 to 1.05 percent, with some soils having a calcareous character (0.6 to 22.2 percent). The analysis of nutrient content revealed variable quantities with available nitrogen ranging from 53.31 to 250.88 kg ha-1, available phosphorus from 12.51 to 27.49 kg ha-1, available potassium from 106.9 to 851.5 kg ha-1 and available sulphur from 4.37 to 66.65 mg kg-1. Exchangeable calcium and magnesium quantities revealed ranges of 14.60 to 42.40 cmol(p+) kg-1 and 5.40 to 21.60 cmol(p+) kg-1, respectively. Furthermore, DTPA extractable iron varied from 4.24 to 16.38 mg kg-1, manganese from 4.76 to 25.84 mg kg-1, zinc and copper from 0.5 to 6.56 mg kg-1 and 0.72 to 15.56 mg kg-1, respectively and boron from 0.1 to 3.56 mg kg-1. Microbial population estimates revealed the dominance of bacteria over fungi and actinomycetes in the studied area. Groundwater carbonate and bicarbonate ranged from 0.01 to 0.62 m mol-1 and 6.35 to 10.24 mmol-1 respectively. The dug well, bore well and tube well water RSC ranged from 0.70 to 1.25 mmol-1.

Conclusion: This extensive study provides helpful insights into the regional variability of physical and chemical properties in both soil and water with help of soil fertility maps, providing better understanding of soil fertilizer input and environmental conditions in the Tungi watershed.

Keywords: Watershed; macronutrient; micronutrient nutrient status; soil fertility maps.

1. INTRODUCTION

Any country's natural resource is the national treasure and proper planning is important to make the best possible use of it. Sustainable management practices are crucially necessary around the world to preserve the agricultural lands' productive capacity. Efficient soil and water quality management and maintenance is crucial to guaranteeing continued high productivity, food security and environmental safety. India sustains 17 percent of the world's population, with water resources of 4.2% and global lands of 2.3 %. This may reduce further owing to growing population pressure and resulting land conversion for non-agricultural purposes. To supply the need for a blooming population, we are obligated to utilize the land beyond its capacity. It leads to soil resource deterioration such as erosion, extraction of nutrients, depletion of soil organic carbon, salinization, loss of soil structure and industrial pollution. Since land is a finite natural resource we cannot enlarge the area under cultivation, the only option is to sustainably boost yield per unit area from current soil resource.

Soil physicochemical properties and water quality are important indicators of the environmental status and agricultural potential of a region [1]. However, these factors may vary spatially due to natural and anthropogenic influences, such as climate, topography, land use, and management practices. Therefore, it is necessary to assess and characterize the spatial variability of soil and water attributes for better planning and management of natural resources [2]. Tungi watershed, located in the Latur district of Maharashtra, India, is a semi-arid region that faces challenges such as soil salinity, water scarcity and low crop productivity.

“A wide range of agricultural soils represents diversely managed arable lands with the main goal of improving soil quality, crop yield and reducing the ecological footprint. Soil quality is defined as the soil’s capacity to function within natural or managed ecosystem boundaries and to sustain plant productivity while reducing soil degradation” [3]. “Many recent investigations have measured soil quality with a minimum data set that includes soil biological, chemical and physical characteristics to examine related properties with potential effects on biological productivity and environmental quality” [4,5]. “Soil survey provides an accurate and scientific inventory of different soils, their kind and nature, and extent of distribution to predict their characteristics and potentialities” [6].

"Geostatistical methods can provide reliable estimates for unsampled locations provided that the sampling interval resolves the variation at the level of interest' [7]. "Systematic soil collection from the field by using a GPS tool is very important for preparing GPS and GIS-based thematic soil fertility maps" [8]. "Tungi watershed was selected for study as it has a wide array of soils. The crop yield potential and soil site suitability differ from soil to soil" [9]. "Soil quality can be informed by a soil health card which determines the crops that can be cultivated on the particular soil and measures to develop the productivity of the crops" [10].

Given that agriculture is a fundamental pillar of the local economy, understanding the geographical distribution in soil properties becomes imperative for enhancing farming operations and resource management. Concurrently, assessing water quality is essential for maintaining sustainable water resources, integral to both agricultural and community well-being. The findings of this research will provide valuable information for identifying suitable areas for better crop production, implementing soil and water conservation measures and addressing land degradation in the Tungi watershed.

2. MATERIAL AND METHODS

2.1 Location, Climate and Rainfall of Study Area

Geographically, the Tungi watershed is located between 76°24'28'' to 76°37'02'' E longitudes and 18°14'31'' to 18°01'57'' N latitudes in Ausa tehsil of Latur district, Maharashtra [9]. The total area of Tungi watershed in Latur district is 24777.91 ha. The general elevation of the area ranges from 620 to 660 m above mean sea level (MSL). The climate of the area is hot, dry and sub-humid with annual rainfall of 794 mm at which nearly 85 per cent is received during June to September. The drainage of the watershed area is dendritic in pattern.

2.2 Remote Sensing and Collateral Data

Digital data of IRS-LISS-III with bands 2, 3 and 4 was used in the present study. The standard false colour composite (FCC) was generated with a combination of green, red and infrared bands (Fig 1). Georeferenced of imagery with reference to SOI toposheet using QGIS software. Screen digitization was done to prepare various fertility maps. Survey of India toposheet no. 56 B/8 and 56B/12 (1:50,000 scale) was used to collect topographic and location information. The toposheet was used to prepare base map for different landforms, generation of slope and drainage for planning the traverse route for ground truth collection.

2.3 Soil and Water Analysis

A total of one hundred (100) geo-referenced surface soil samples (0-30 cm) were methodically collected from the surrounding area of soil profiles in the Tungi watershed, situated in Latur, Maharashtra. The soil samples were sieved through a 2 mm sieve after being air-dried and crushed with a wooden roller. The processed soil samples were subjected to various chemical analyses. Soil texture, pH, electrical conductivity (EC), organic carbon (OC), and extractable N, P, K, Ca, Mg, S, Zn, Fe, Cu, Mn, and B were all measured in soil samples. Soil electrical conductivity and pH were determined in 1:2 soil-water suspensions [11,12]. The organic carbon

Flow chart showing detail survey of Tungi watershed of Latur

A comprehensive detail survey of Tungi watershed was carried out

↓

The thematic maps of the served area were to prepared

↓

The representative soil samples were collected by adopting free survey

↓

The representative profile sample (nine soil profile) was excavated for detail study of pedons [9]

↓

The survey of natural resources was carried out by using cadastral maps and toposheets

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Physiographic characterization of the watershed was carried out by using satellite images and toposheets

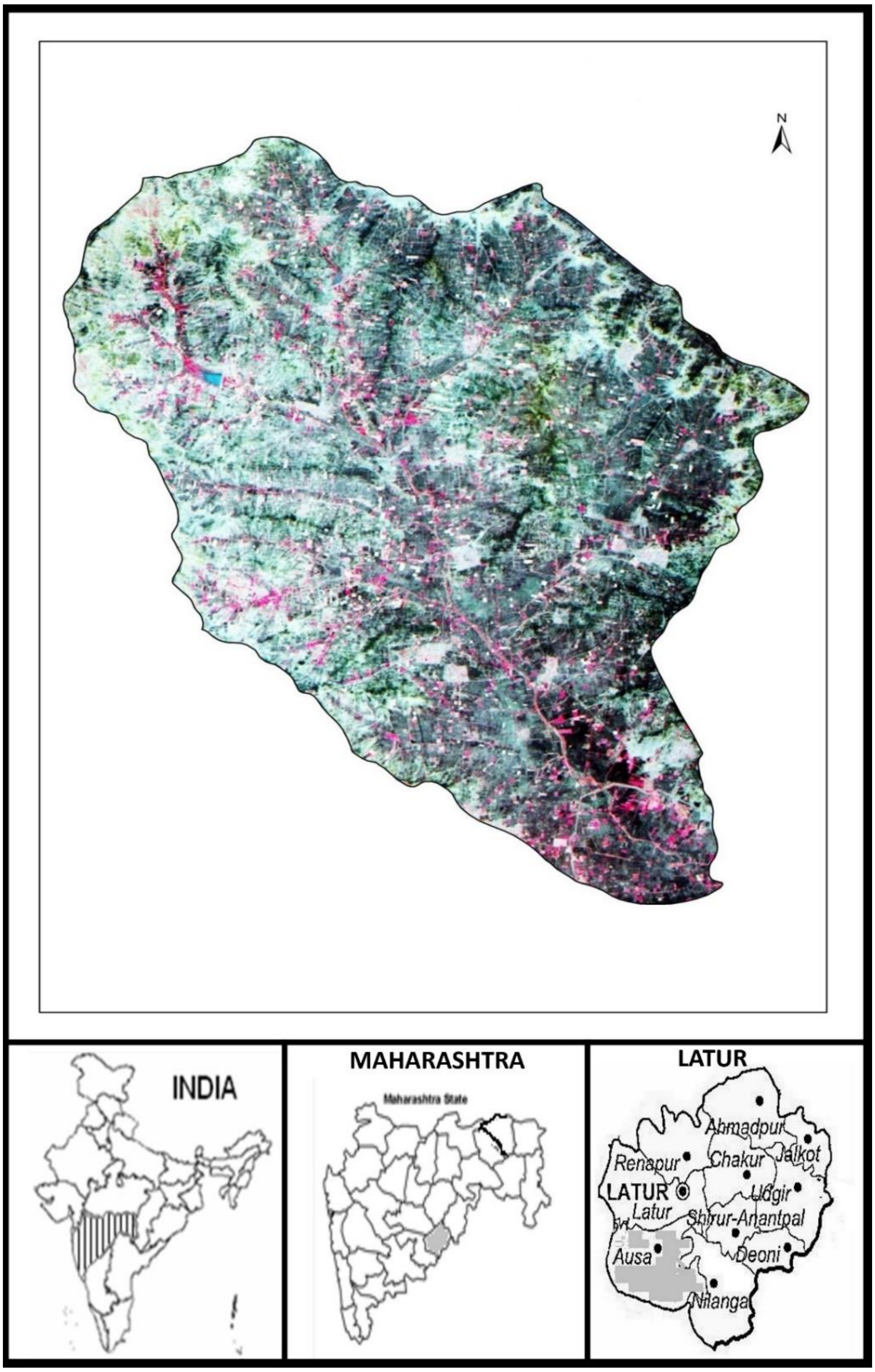

Fig. 1. Satellite data of Tungi watershed of Latur district of Maharashtra, India

content of soil samples was determined using a modified Walkley and Black method [11]. The alkaline potassium permanganate method was used to determine the amount of nitrogen extracted from soil samples [13]. Phosphorus was extracted from neutral to alkaline soils using 0.5 M $NaHCO_3$ (pH 8.5) [14]. Estimation of extractable K, Ca and Mg was carried out using 1N ammonium acetate (pH 7.0) [15]. The soil samples were analyzed for Ca and Mg in 1N neutral ammonium acetate extracts by titrating them with EDTA solution [16]. Sulphur content in soil samples was estimated using 0.15% $CaCl_2$ solution and measured using a colorimeter by the turbidimetric method [17]. DTPA extractant (pH 7.3) was used to measure the amounts of Zn, Cu, Fe, and Mn in soil [18]. Boron in soil samples was determined using hot $CaCl_2$ extractable method [19]. Soil microbial count was estimated using serial dilution methods [20].

Ten (10) groundwater samples were collected from the well and tube well in plastic bottles for laboratory analysis. pH and EC of water sample using glass electrode pH meter [11,12]. Soluble cation (K^+, Na^+, Ca^{++},Mg^{++}), soluble anion (CO_3^-, HCO_3^-, Cl^-, SO_4^-), SAR (Sodium Adsorption Ratio) [21] and RSC (Residual Sodium Carbonate) [22] determined.

Georeference-based soil fertility maps were prepared by using QGIS software.

3. RESULTS AND DISCUSSION

3.1 Physical Properties of Soil

Physical property of the soil has a great impact on its usage and behavior towards plant production. The physical condition of the soil influences the support of the growing plant, its root penetration and microbial activity in the rhizosphere. The bulk density of soil ranged from 1.13 to 1.93 mg m^{-3} with an average value of 1.60 mg m^{-3}. This means most of the area is facing soil compaction which might be problem for emergence of young plants. Similar result reported in physical properties of Purna valley [23]. The particle density of soil ranged from 2.48 to 2.94 mg m^{-3} with an average value of 2.66 mg m^{-3}. The particle density of soils is considered to depend on the mineralogical composition of soils. Since the soil types of study area differ, hence the particle density differs up to extent. The porosity of soil ranged from 22 to 58 percent with average 39.41 percent. The variation in porosity may be due to variation in bulk density and organic carbon content in the soil. In general, black soils have high bulk density. It may be due to high clay and well-shrink type over burden leading to compaction, there by reduction in porosity [24].

3.2 Chemical Properties of Soil

3.2.1 Soil pH, electrical conductivity and calcium carbonate of tungi watershed

The chemical properties of soil play an important role in determining the retention of plant nutrients and its availability. The pH ranges from 7.05 to 8.96 with average value 7.98. These values of soil pH indicate that all the soils under study area were slightly alkaline to alkaline in reaction. "The soil pH variability could be due to the nature of the parent material, geomorphic location, fertilizer application, and management practices. The alkaline reaction of soil is probably due to the presence of sufficient lime content and basaltic aluminum parent material rich in aluminosilicates and alkaline earth form which these soils are derived" [25]. Soil EC of Tungi watershed in safe limit or normal. The low EC of soil might be due to free drainage condition which favored the removal of released based by percolation and drainage and reflect high leaching due to rainfall [26]. Calcium carbonate content of soil ranged from 0.6 to 22.2 percent with the mean 7.91 percent. Soils of Tungi watershed of Latur district were low calcareous to high calcareous in nature.

3.2.2 Soil organic carbon and available macronutrient of tungi watershed

Organic carbon of soils of Tungi watershed varied from 0.15 to 1.05 percent with an average value 0.65. The low organic carbon content may be attributed to the poor vegetation and high rate of organic matter decomposition under hyperthermic temperature regime which leads to extremely high oxidizing condition beside this, course texture soils are generally low in organic carbon. The available nitrogen content of these soils ranged from 53.31 to 250.88 kg ha^{-1} with a mean value of 153.70 kg ha^{-1}. Low nitrogen content in soils was primarily due to its low addition, higher mobility and loss through volatilization of ammonia, leaching and runoff, denitrification, microbial and chemical fixation [27]. The available phosphorus ranged from 12.51 to 27.49 kg ha^{-1} with a mean value 20.02 kg ha^{-1}. The poor availability of P in these soils may be due to their low P (inherent), sesquioxide fixation (Fe and Al oxides and hydroxides), and calcium phosphate formation in calcareous soils [28]. The increase in available phosphorus status is due to use of FYM, being direct source of phosphorus and it might have also solublized the native phosphorus in the soil through release of various organic acids which had chelating effect, that reduced phosphorus fixation [29]. The available potassium content in soils ranged from 142.3 to 958.8 kg ha^{-1} with an average value of 516.20 kg ha^{-1}. This high level of K is possibly due presence potassium-rich parent material and clay minerals biotite and smectite and dissolution of K-bearing minerals under alkaline conditions [30]. The exchangeable calcium content of the soils ranged from 14.60 to 42.40 cmol(p^+) kg^{-1}

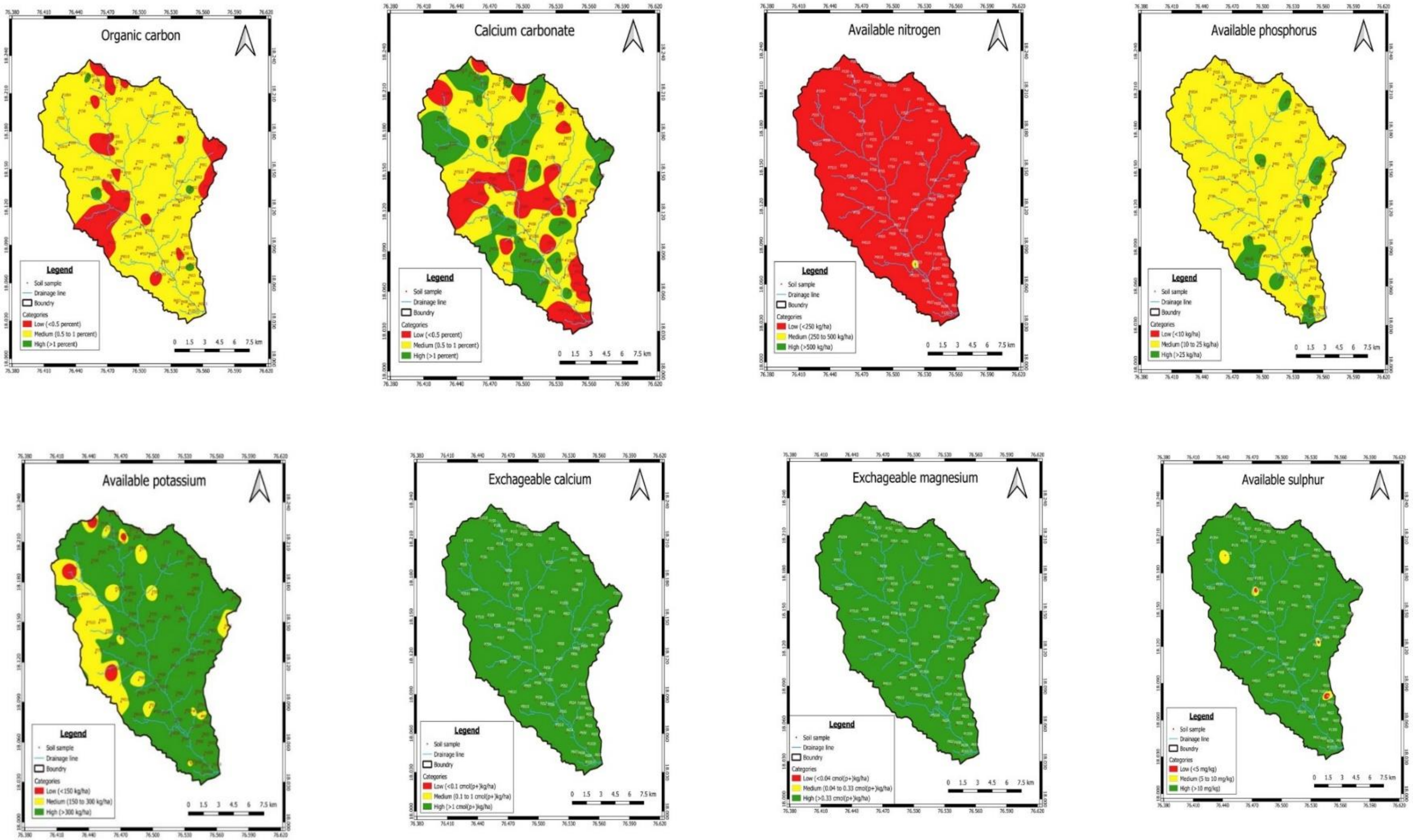

Fig. 2. Soil organic carbon and available macronutrient of Tungi watershed of Latur district of Maharashtra

with an average of 27.94 cmol (p^+) kg^{-1}.. The exchangeable magnesium content in soils varied from 5.40 to 21.60 cmol (p^+) kg^{-1} with a mean (G.M) value of 36.71 cmol (p^+) kg^{-1}. Continuous application of organics along with inorganic fertilizers significantly increased the cation exchange capacity (CEC), exchangeable calcium and magnesium while, decrease in Na [31]. the available sulphur content of in soils ranged from 4.37 to 66.65 mg kg-1 with an average value of 36.71 mg kg^{-1}. Furthermore, farmers mostly use NPK fertilizers, S is not replenished in the soils following plant uptake which causes its deficiency. The variation was found in the availability of secondary macronutrients with soil type.

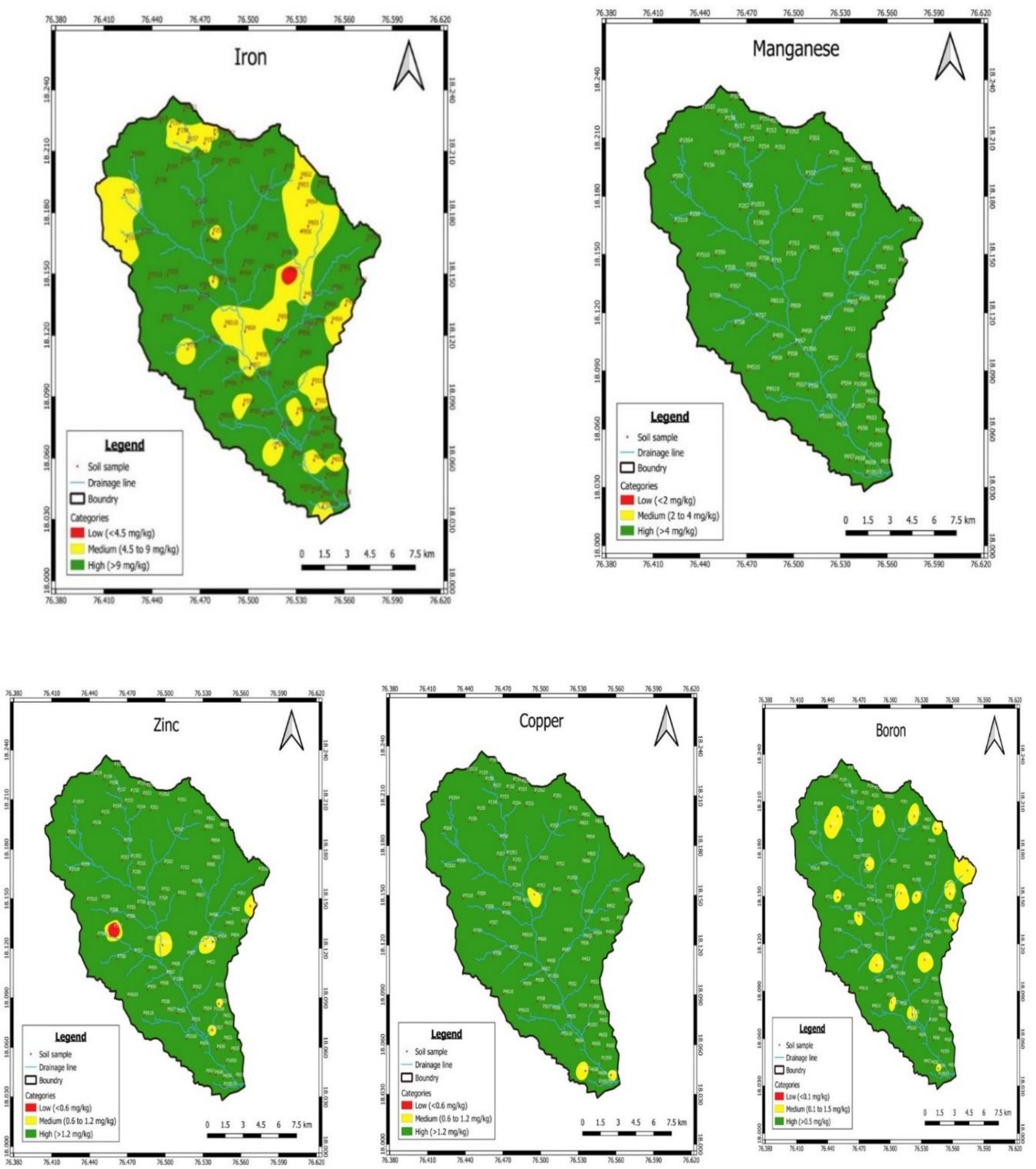

Fig. 3. Soil available micronutrient of Tungi watershed of Latur district of Maharashtra

3.2.3 Soil available micronutrient of tungi watershed

Among the DTPA extractable micronutrient, DTPA-Fe varied from 4.24 to 16.38 mg kg^{-1} with an average value of 10.57 mg kg^{-1}. It had increased with an increase in clay content, organic carbon and CEC in soil whereas, the same decrease with increase in sand content, pH and EC of soil [32]. Surface layer of Vertisols had sufficient Fe content and it decrease with depth [33]. DTPA-Mn varied from 4.76 to 25.84 mg kg^{-1} with an average value of 13.55 mg kg^{-1}. The sufficiency of available Mn might be due to high organic matter content and optimum soil moisture content. DTPA-Zn varied from 0.5 to 6.56 mg kg^{-1} with an average value of 3.46 mg kg^{-1}. The content of Zn increases with low pH and high organic carbon content but decreases with increase in pH. Since, most of the soils are alkaline, low in OC and dominated by $CaCO_3$, zinc may be precipitated as hydroxides and carbonates as a result their solubility and mobility might have decreased and reduced the availability [34]. DTPA-Cu varied from 0.72 to 15.56 mg kg^{-1} with a mean value of 4.57 mg kg^{-1}. The higher amount of DTPA-Cu in there soils might be due to higher biological activities and chelating effect [35]. Also, high content of DTPA-Cu in these soils was might be due to presence of Cu minerals like Cuprites and chalcocite, etc. in the parent material [36]. The available boron content of in soils ranged from 0.1 to 3.56 mg kg^{-1} with an average value of 1.41 mg kg^{-1}. Total boron in Indian soils of Vertisol and Alfisol of the Deccan trap formed from granite, basalt, shale, slate and limestone had 28–57 mg kg^{-1} [37]. This high B status in soil may be due to the accumulation of B in highly soluble form of calcium and sodium borates and boron occurs mostly in organic matter in the surface soil.

3.3 Microbial Count of Tungi Watershed

The microbial population of fungi were observed in the range of 6.1 x 10^4 to 13.2 x 10^4 cfu g, with an average 9.10 x 10^4 cfu g of soil. The increased amount of fungal population might be due to the transformation of organic material into humus which has helped in the multiplication of microorganisms by improving the soil properties. The population of actinomycetes was observed in the range of 10.46 x 10^5 to 32.34 x 10^5 cfu g, with an average 20.68 x 10^5 cfu g of soil. The lower value of the actinomycetes population was found where routine ploughing was taken annually and the increased amount of actinomycetes could be observed due to the available moisture, good water holding capacity and well aggregation formation due to the continuous use of organic inputs along with minimal soil disturbance [38]. The population of bacteria were observed in the range of 31.68 x 10^7 to 60.39 x 10^7 cfu g with an average of 43.96 x 10^7 cfu g of soil. The bacterial population predominated over fungi and actinomycetes. A relatively high bacterial multiplication rate was associated with FYM, which may be attributed to the ready source of carbon from FYM, which acts as a substratum for stimulating bacterial growth.

3.4 Chemical Composition and Quality of Irrigation Water in Tungi Watershed

Evaluation of the quality of irrigation water tube well, dug well and bore well water resources in Tungi watershed is essential for better land use planning. The carbonate and bicarbonate ranged from 0.01 to 0.62 m mol^{-1} and 6.35 to 10.24 $mmol^{-1}$ respectively. The dug well, bore well and tube well water had residual sodium carbonate (RSC) ranged from 0.70 to 1.25 mmol-1. This suggests that all water sample is safe for irrigation purpose.

4. CONCLUSION

From the results of this study, it may be concluded that the soils of the Tungi watershed of the Latur district had a high value of bulk density may be attributed to the smectite clay and the severe compaction stress. Soils were slightly alkaline to alkaline in reaction, the salt concentration in the safe limit, low to high calcareous. Variations were seen in the organic carbon content and in fertility status. All soil samples were categorized low in available nitrogen, low to moderately high in available phosphorus and low to very high in available potassium. The soils were rich in exchangeable calcium, magnesium and available sulphur. Most of the soil samples (99%) were sufficient i.e. ranged above the critical limit in DTPA extractable micronutrients (Fe, Mn, Zn and Cu) and low to high in available boron. The population of bacteria predominated over the fungi and actinomycetes. All water sample is safe for irrigation purpose. Georeferenced-based soil fertility maps can be useful for managing soil fertilizer input for overall balanced nutrition and site-specific soil management for sustainable crop production. Overall, this research not only increases our understanding of the local ecosystem but also highlights the necessity of holistic approaches to land and water resource management for the wider objective of attaining agricultural sustainability and environmental resilience in the Tungi Watershed.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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