



Study on the Soil Fertility and Mapping in Ramasamudram-1 Microwatershed of Yadgir Taluk and District of Karnataka, India

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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Abstract

An investigation was under taken to study the soil fertility status of major nutrients, micronutrients and mapping in Ramasamudram-1 microwatershed of Yadgir taluk and district of Karnataka, India during the year 2019. Total seventy-four grid wise surface soil samples were collected at 320 m grid interval at 0-15 cm depth to assess the soil parameters (texture, pH, EC, OC, available P, K, S, Zn, Cu, Fe, Mn and B) and prepare the soil fertility maps through GIS using Kriging method. The results of the study indicated that, the texture of the soil varied from loamy sand to sand clay loam in surface. Soil reaction varied from acidic to neutral with non-saline in nature. The distribution of soil organic carbon (32%), available phosphorous (56%) and potassium (47%) status was found to be medium in most of the area of microwatershed. The available sulphur status was found to be low (57%) in maximum area of the microwatershed. The available zinc status was found to be sufficient (46%) in majority area of the microwatershed. The available copper, iron and manganese status of the soils were sufficient (58%) in entire area. Whereas available boron status was found to be low (57%) in maximum area of the microwatershed. Therefore, the study showed that, the soils of the microwatershed were medium in fertility status. There is need of proper fertilizer recommendation and soil management practices can be made productive thereby, increasing the crop yield.

Keywords: Fertility, grid, GIS, microwatershed, mapping, maximum, nutrients, samples

1. Introduction

The major constraints for poor productivity in rainfed agriculture are poor soil fertility, erratic and low rainfall (Ncube et al., 2009). To achieve potential yields in rainfed soils, require appropriate nutrient management strategies for multi nutrient deficient soil (Sahrawat et al., 2008). The attention has to be paid to diagnose and take corrective measures for deficiencies of major and micro nutrients in various crop production systems (Rego et al., 2005; Sahrawat et al., 2007; Manna et al., 2012). In India several studies have assessed the soil fertility status in a watershed for recommending optimum soil management practices, crops and cropping systems to ensure sustainable yields in the rainfed regions (Prabhavathi et al. (2013). Hence, it is necessary to know the fertility (macro and micro nutrients) status of the soils of the watersheds for assessing the kind and amount of fertilizers required for each of the

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crop intended to be grown (Mahendra Kumar et al., 2015). Balanced use of organics, fertilizers and biofertilizers plays an important role to maintain soil fertility in long run (Singh et al., 2014). Soil testing is usually followed by collecting composite soil samples in the fields without geographic reference (Hegde et al., 2020). The results of such soil testing are not useful for site specific recommendations and subsequent monitoring (Pujari et al., 2016). Soil available nutrients constraint of an area using Global Positioning System (GPS) will help in formulating site specific balanced fertilizer recommendation and to understand the status of soil fertility spatially and temporally (Hegde et al., 2020).

The information regarding the status of nutrients and nutrient mapping of soils is needed to implement the concept of watershed approach successfully (Vasundhara et al., 2020). Imbalanced and inadequate use of chemical fertilizers, improper irrigation and various cultural practices also deplete the soil quality rapidly (Medhe et al., 2012). In India, low fertility of soils is the major constraint to achieving high productivity goals. Therefore, it is important to investigate the soil fertility status and it may provide valuable information relating crop research. Considering these facts, the study was initiated with the objective to assess the soil fertility status of Ramasamudram-1 microwatershed of Yadgir taluk and district of Karnataka, India.

2. Materials and Methods

The Ramasamudram-1 microwatershed is located in the northern part of Karnataka in Yadgir Taluk and District, Karnataka (Figure 1). It lies between 16°45" and 16°37" north latitudes and 77°14" and 77°15" east longitudes and covers an area of 766 ha. It surrounded and comprised of Ramasamudra village on the north, west and central side and Arakera village on the eastern side. Major rock formations observed in the microwatershed are granite gneiss. The elevation ranges from 413 to 448 m above MSL. The climate

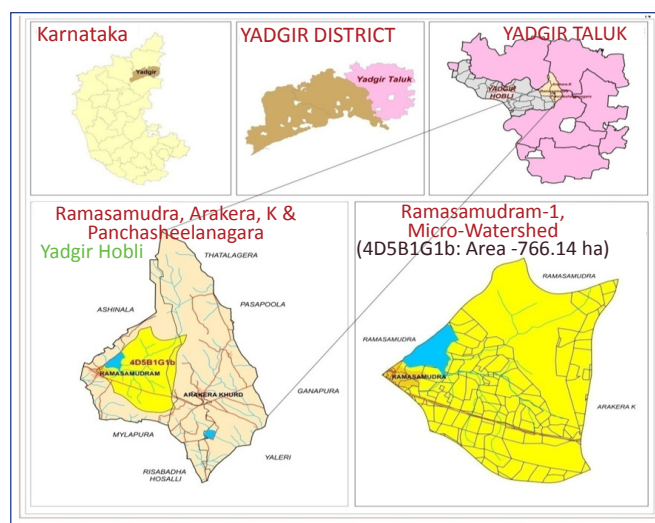


Figure 1: Location map of Ramasamudram-1 microwatershed

is semiarid and categorized as drought-prone with an average annual rainfall of 866 mm and mean maximum temperature of 30°C to 45°C. Length of growing period (LGP) ranges from 120 to 150 days. The detailed survey of the land resources occurring in the microwatershed was done in 2019 and carried out by using digitized cadastral map and satellite imagery as base supplied by the KRSAC. The cadastral map shows field boundaries with their survey numbers, location of tanks, streams and other permanent features of the area (Figure 2). Apart from the cadastral map, remote sensing data products from Cartosat-1 and LISS-IV merged at the scale of 1:7920 were used in conjunction with the cadastral map to identify the rock types, the landscapes, landforms and other surface features. The cadastral map was overlaid on the satellite imagery (Figure 3) that helps to identify the parcel boundaries and other permanent features. Apart from cadastral maps and images, toposheets of the area (1:50,000 scale) were used for initial traversing, identification of geology and landforms, drainage features, present land use and also for selection of transects in the microwatershed. Surface soil samples collected from farmer's fields (74 samples) for fertility status at 320 m grid interval were analyzed in the laboratory. By linking the soil fertility data to the survey numbers through GIS using Kriging method, soil fertility maps were generated for the microwatershed.

The collected soil samples were analyzed by adopting standard procedure. Particle size distribution was determined by international pipette method (Piper, 1966). Soil pH and electrical conductivity was determined at 1:2.5 soil water suspensions by potentiometric and conductometry method (Jackson, 1973). Organic carbon was measured by wet digestion method (Walkley and Black, 1934). Available phosphorus was extracted by using Olsen's extractant (0.5 M NaHCO₃) for neutral and alkaline soils and Bray's extractant for acid soils was determined by spectrophotometer (Jackson, 1973). The available potassium was estimated by extracting the soil with 1 N NH₄OAC (pH 7.0) by using flame photometer. Available sulphur was extracted from soil using 0.15% CaCl₂ solution and determined by turbidometrically (Black, 1965). The micronutrients like Zn, Cu, Fe and Mn in the soil were extracted with DTPA extractant by using Atomic Absorption Spectrophotometer (Lindsay and Norvell, 1978). Available boron in soil was extracted with hot water (HWS-B) and determined calorimetrically using Azomethine-H reagent (Gupta, 1979).

2.1. Nutrient status of soil maps

An excel format file consisting of data for X and Y co-ordinates in respect of sampling site location was created. A shape file (vector data) showing the outline of Ramasamudram-1 microwatershed was created. The excel format file was linked to the shape file (vector data) and exported as grid link shape file. Each point in the grid link layer represents a location where the samples have been measured. By interpolating,

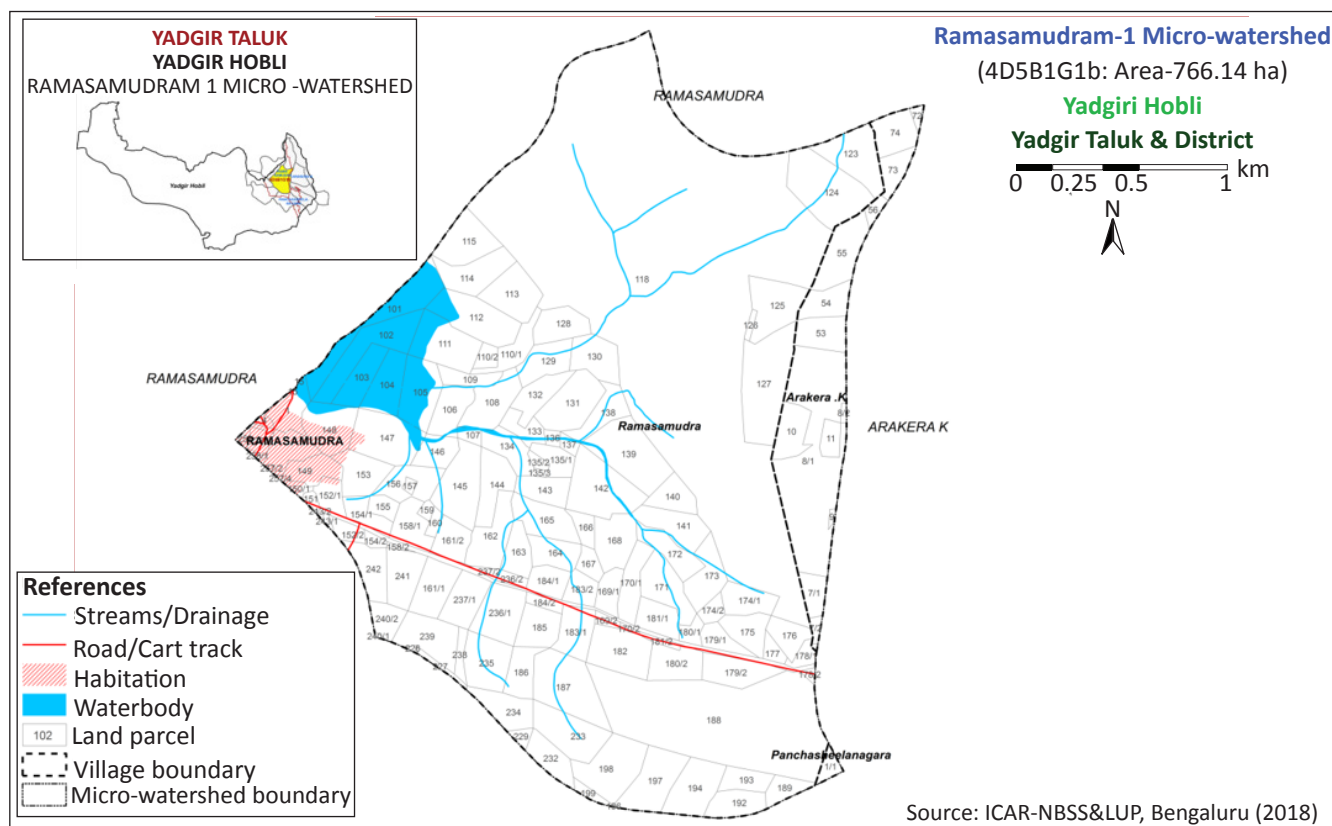


Figure 2: Scanned and digitized Cadastral map of Ramasamudram-1 microwatershed

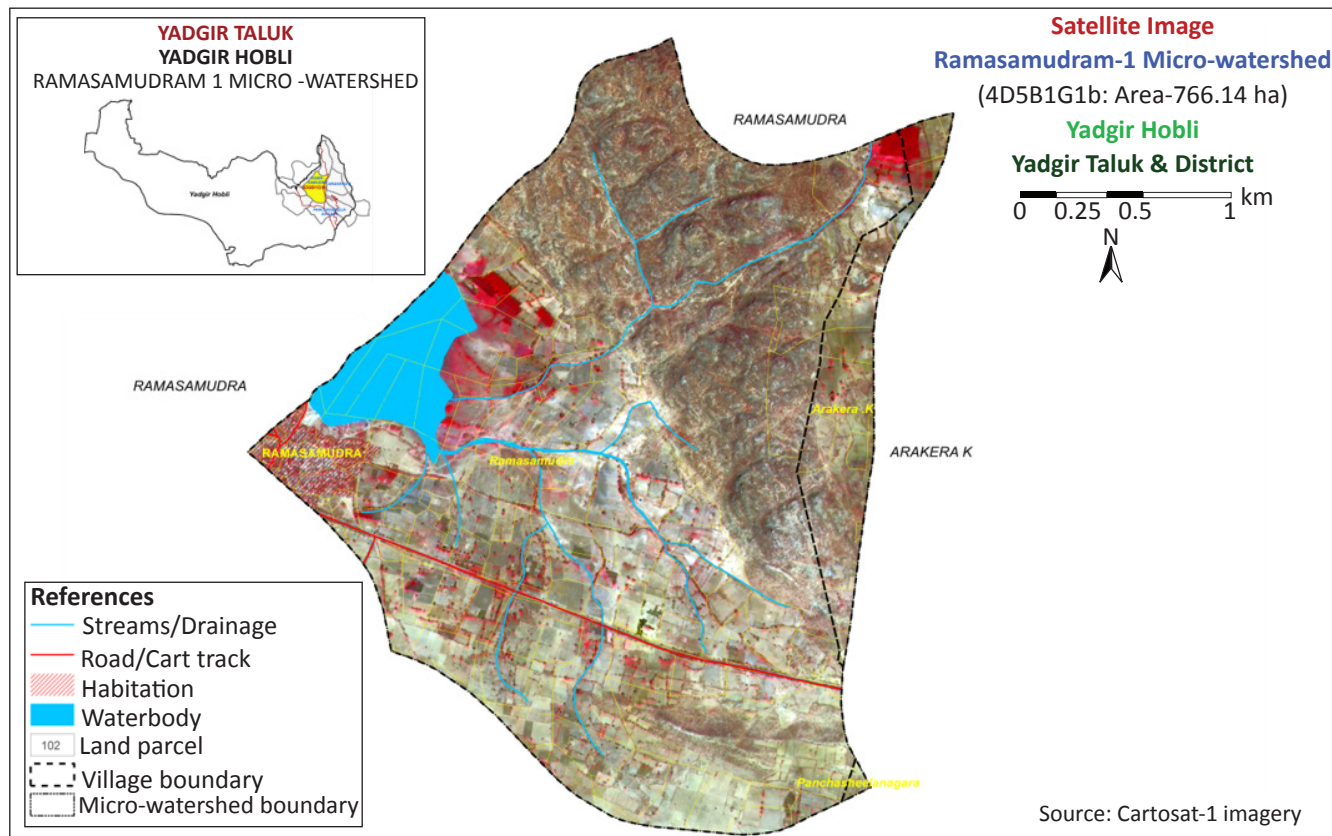


Figure 3: Cadastral map overlaid on IRS PAN+LISS IV merged imagery of Ramasamudram-1 microwatershed

the values between these input points will be predicted using Geo-wizard Kriging method, select geo statistical wizard in geo statistical Analyst tool, select Kriging option in theme selection field and in the data set field select your point data which is having all your data and in the data field column select the theme, to which one you want interpolate (example: boron, zinc, soil reaction, etc.) and click on next option. In the newly opened page select "ordinary" in Kriging type and select "prediction" in surface output type after that click on "next". In the place model selection select "exponential" or "spherical". In the next step select "smooth" option in neighbourhood type tool and below that you can select 'smoothing factor' how much you want. Once you got the result go to properties of the interpolated layer. One new window will open, that window select symbology option in that select classify inside of that window select method as manual and below that select classes according to your classifications.

After the classification, the values we need to take data layer as vector file. Right click on the classified layer go to Data-Export to vector. One new window will open in that window select "Filled contour" in contour type option than mention your output location and give ok. To the final output vector layer you need clip your common features (water body, habitation, railway, forest, mining/industrial, rock out crop, gullied region

and eroded area) from soil shape file of microwatershed. Copied polygon features paste on to interpolated layer. After you pasted the feature you need to clip that using clip option which is in Editor Tool as shown in adjacent image. Extract the required study area by using "clip" option which is there in the Geo processing option. In the option of input feature provide your Interpolated vector file and in the next step provide your boundary of microwatershed in "clipping feature" and show the output source before giving Ok. So that it will clip the required extent of microwatershed. Attributes has to be edit according to your classification. After editing all the required fertility maps can be prepared.

3. Results and Discussion

In the study area its soil fertility status with respect to texture, pH, EC, organic carbon, available phosphorous, potassium, sulphur, zinc, iron, manganese, copper and boron was assessed. The results obtained are presented and discussed below.

3.1. Texture of surface soils

The surface soil texture of the Ramasamudram-1 microwatershed was loamy sand to sand clay loam (Figure 4). An area of about 158 ha (21%) has soils that are sandy

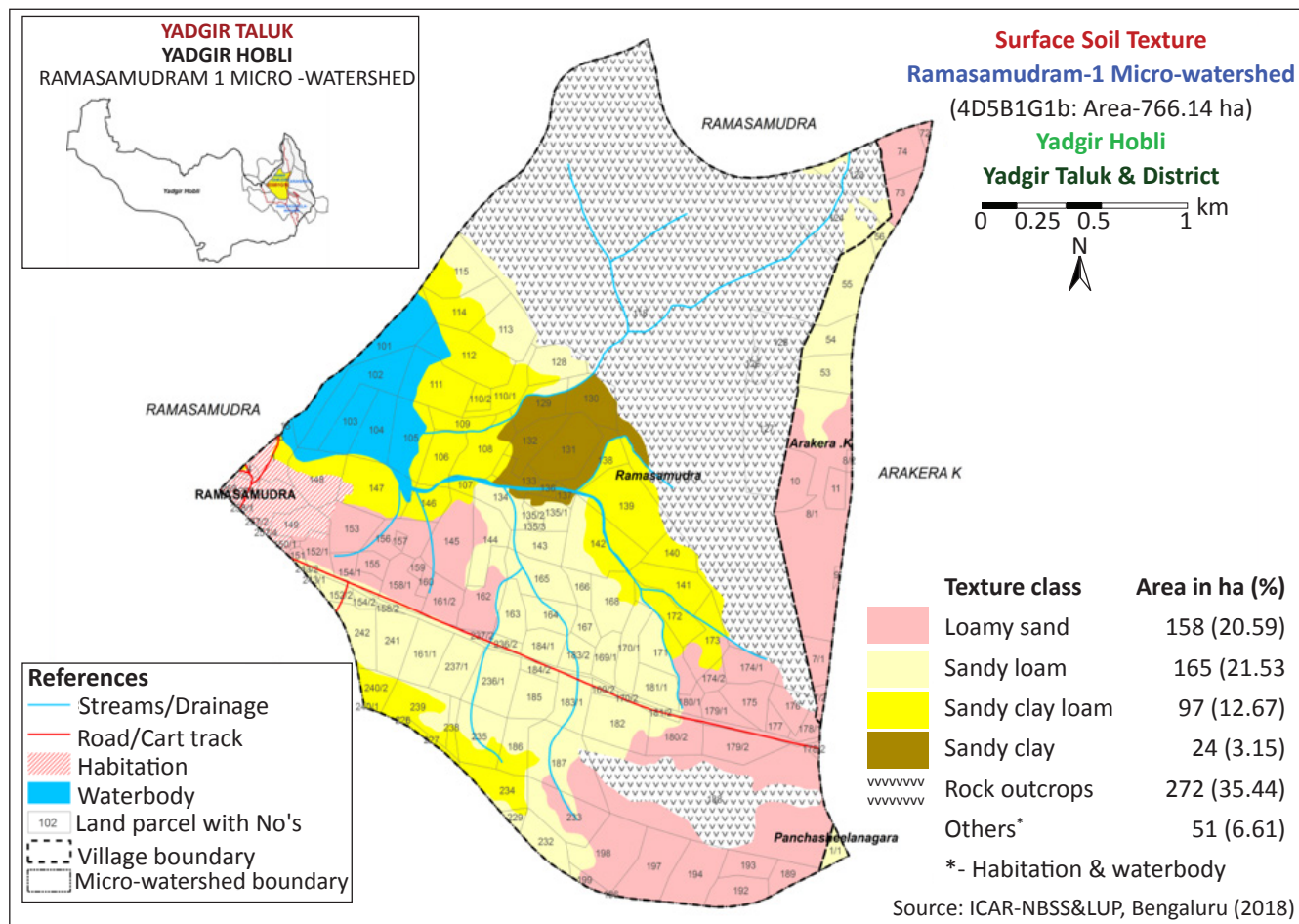


Figure 4: Surface soil texture map of Ramasamudram-1 microwatershed

(loamy sand) at the surface. Loamy (sandy loam and sandy clay loam) at the surface occur in a maximum area of 262 ha (34%). An area of about 24 ha (3%) has soils that are clayey (sandy clay) at the surface. The most productive lands with respect to surface soil texture are clayey and loamy soils (37%) that have high potential for soil-water retention and availability, and nutrient retention and availability, but clayey soils have more problems of drainage, infiltration, workability and other physical problems. The problem soils cover about 21% which have problems of moisture and nutrients. Gupta (2004) reported that, the variation in surface soil texture may be due to variations in parent materials, topography, weathering and translocation of clay. It affects absorption of nutrients, microbial activities, infiltration and retention of water, soil aeration, tillage and irrigation practices.

3.2. Soil reaction (pH), electric conductivity (EC) and organic carbon (OC)

The soil reaction status (Figure 5) of Ramasamudram-1 microwatershed was acidic to neutral in reaction. An area of about 15 ha (2%) was strongly acid (pH 5.0–5.5), 79 ha (10%) moderately acid (pH 5.5–6.0), 85 ha (11%) slightly acid (pH 6.0–6.5), 206 ha (27%) neutral (pH 6.5–7.3) and

59 ha (8%) was slightly alkaline (pH 7.3–7.8) in nature. The variations in soil pH were due to the parent material, rainfall and topography (Thangasamy et al., 2005). The soils were acidic due to the acidic parent material (Granite and gneiss). Therefore, periodically agricultural lime incorporation is imperative for improvement of soil pH. The high pH of the soil was due the presence of high degree of base saturation (Meena et al., 2006). Relatively high pH value in soil was due the accumulation of exchangeable bases in the solum. Thus, major soils in the microwatershed are neutral and acid in reaction.

The electrical conductivity of the soils was <2 dS m⁻¹ in the entire microwatershed and as such the soils are non-saline (Figure 6) in nature and could be attributed to excessive drainage of soils and consequently leaching of salts to downward layers resulting in low salt concentration. Similar results were reported by Poonia and Bhumbra (1973) and Singh and Mishra (2012).

The soil organic carbon content (an index of available nitrogen) in the soils of the microwatershed was medium (0.5–0.75%) in a maximum area of about 243 ha (32%). An area of about 201 ha (26%) are high (>0.75%) in organic carbon status (Figure 7).

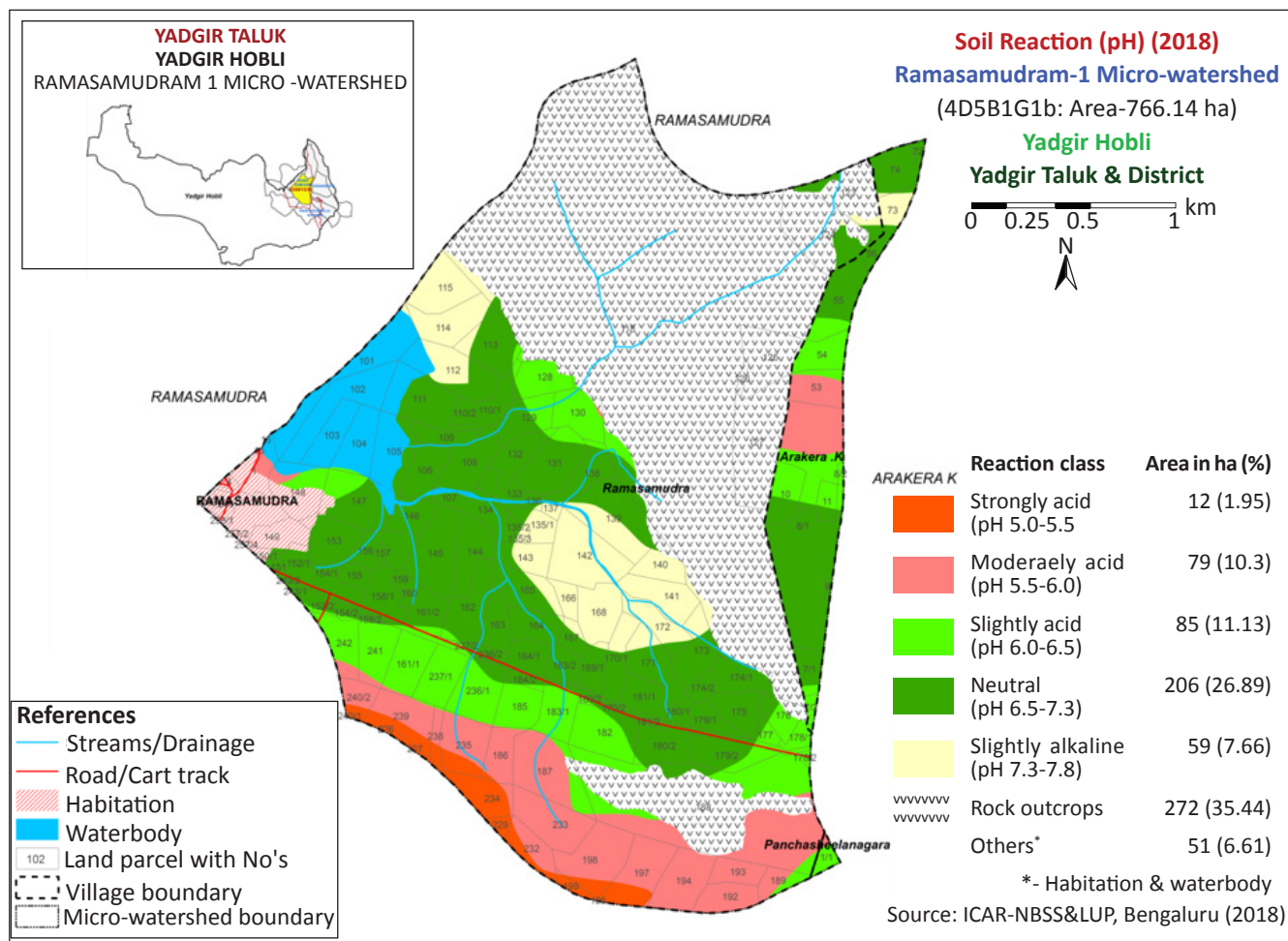


Figure 5: Soil reaction (pH) map of Ramasamudram-1 microwatershed

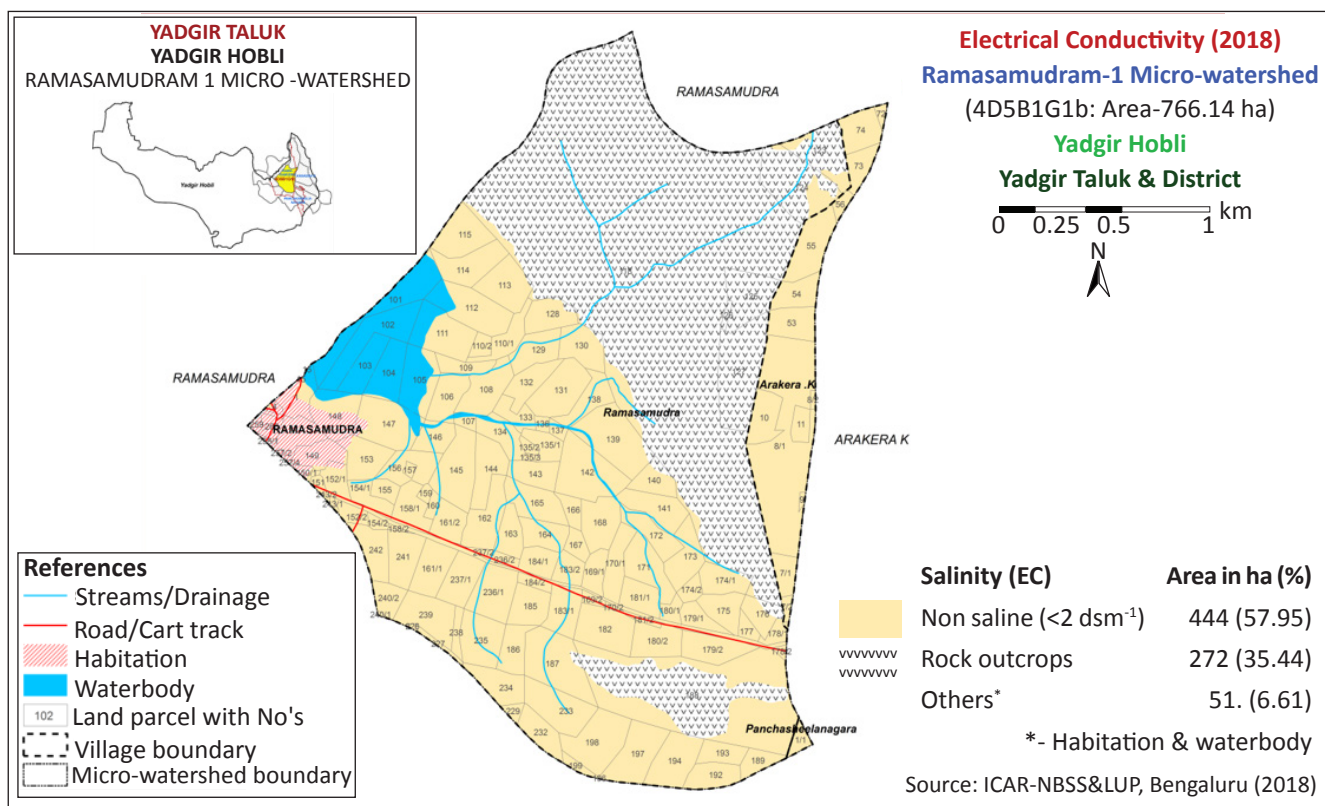


Figure 6: Electrical conductivity (EC) map of Ramasamudram-1 microwatershed

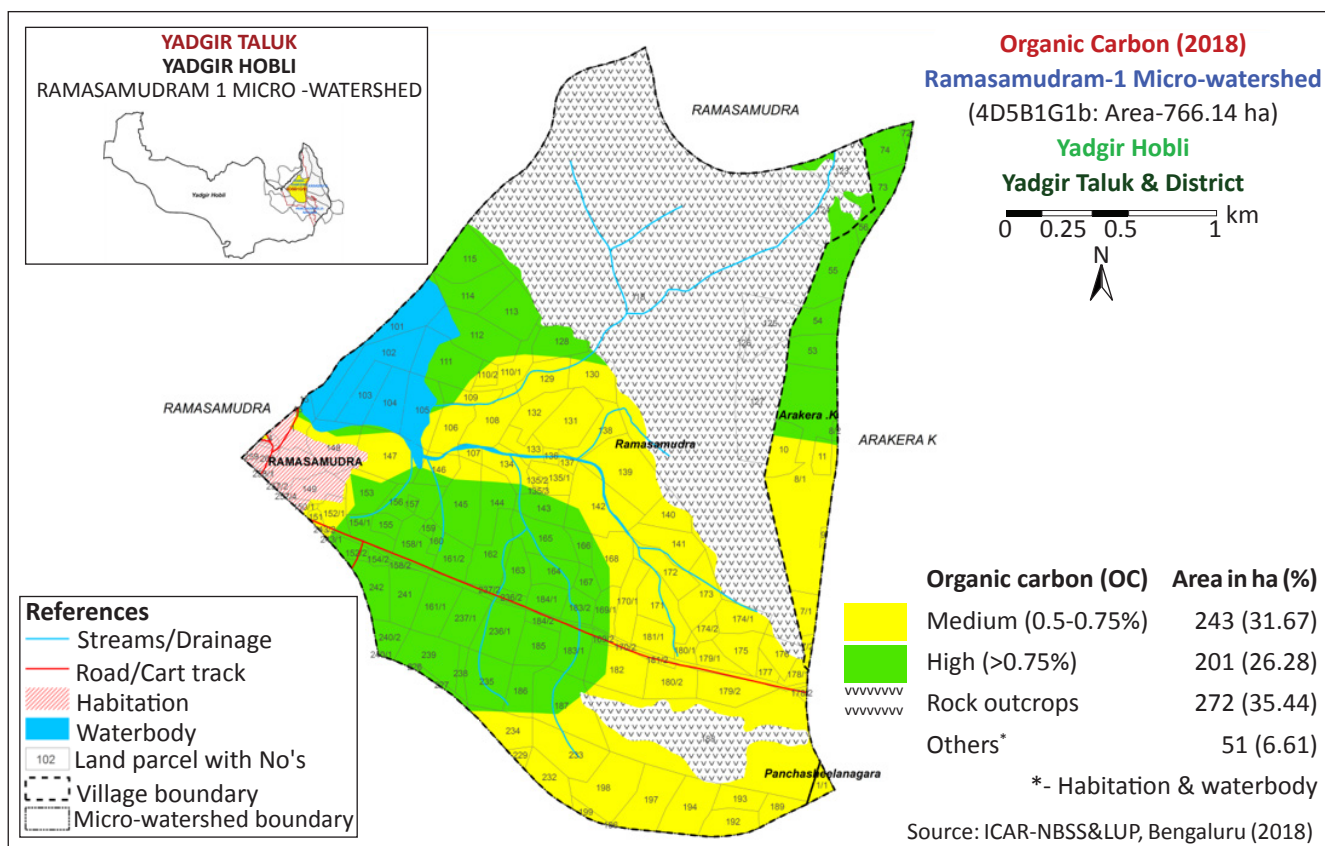


Figure 7: Soil organic carbon (OC) map of Ramasamudram-1 microwatershed

The medium to high organic carbon status of soils could be attributed to regular addition of organics in the form of FYM and compost. According to Rao et al. (2008) higher clay content in soil was responsible for maximum organic carbon

content in soils.

3.3. Available phosphorus, potassium and sulphur

Available phosphorus (Figure 8) status in soils of

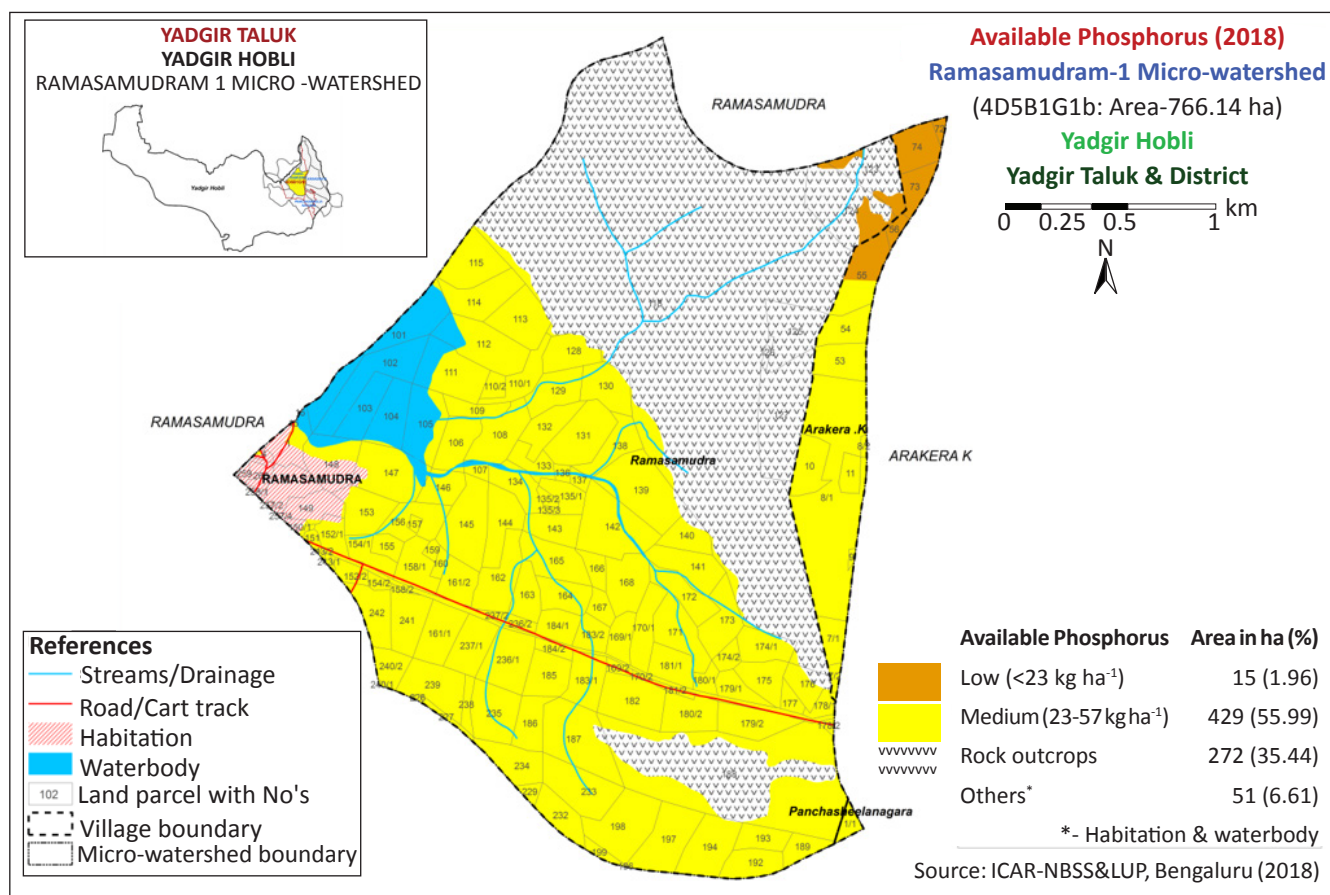


Figure 8: Soil available phosphorus map of Ramasamudram-1 microwatershed

Ramasamudram-1 microwatershed was medium (23-57 kg ha⁻¹) in a maximum area of about 429 ha (56%) and low (<23 kg ha⁻¹) in an area of 15 ha (2%). Medium status of soils may be attributed to the semi arid environment with low rainfall and the continuous use of high analysis phosphatic fertilizers especially SSP (Nalina et al., 2016). The clay content along with CEC and phosphorus fixing capacity of the soils might be the reason behind the medium range of available phosphorus status in soils.

of organic manures. Tawande et al. (1976) reported that sulphur content depends on the combined action of factors namely nature of parental material, rainfall, clay and organic matter content. The findings are in corroboration with the finding of Mahendra Kumar et al. (2015), Das et al. (2012) and Sakal et al. (2000).

3.4. Micronutrients (Available zinc, copper, iron, manganese and boron)

Available potassium content in soil was low (<145 kg ha⁻¹) in an area of 85 ha (11%) and medium in maximum area of about 359 ha (47%) in the microwatershed (Figure 9). The presence of kaolinite types of clay mineralogy led to medium and low ratings (Pramod and Patil, 2015) of available potassium in soils.

Available zinc content was deficient (<0.6 ppm) in an area of about 87 ha (11%) and sufficient (>0.6 ppm) in maximum area of 357 ha (47%) in the microwatershed (Figure 11). This may be due to the high organic carbon content as it was noticed in the present study. Sharma and Lal (1992) opined that the higher amount at the surface layer was related to higher organic carbon content of the soil. Higher zinc content in surface layer may be due to regular addition of plant residues. Similar results were observed by Mahendra Kumar et al. (2015), Tiwari and Mishra (1990), Krishnamurthy and Srinivasamurthy (2005) and Chidanandappa et al. (2008).

Maximum area of about 439 ha (57%) was low (<10 ppm) in available sulphur content. An area of about 5 ha (1%) is medium (10–20 ppm) in available sulphur content (Figure 10) in the soils of Ramasamudram-1 microwatershed. The low sulphur in soils might be attributed to continuous use of high analysis sulphur free fertilizers, inclusion of high yielding varieties in the intensive cropping system and restricted use

Available copper content was sufficient (>0.2 ppm) in the

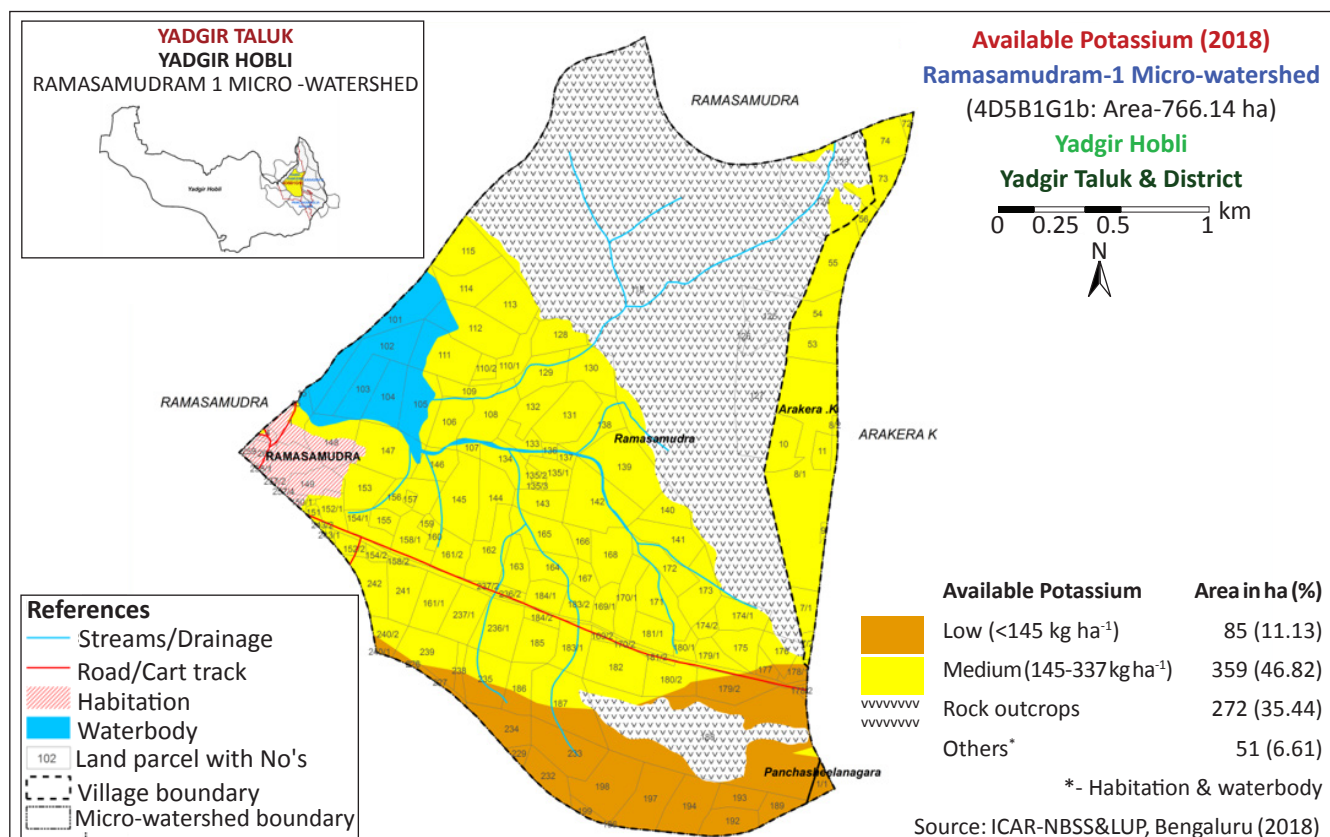


Figure 9: Soil available potassium map of Ramasamudram-1 microwatershed

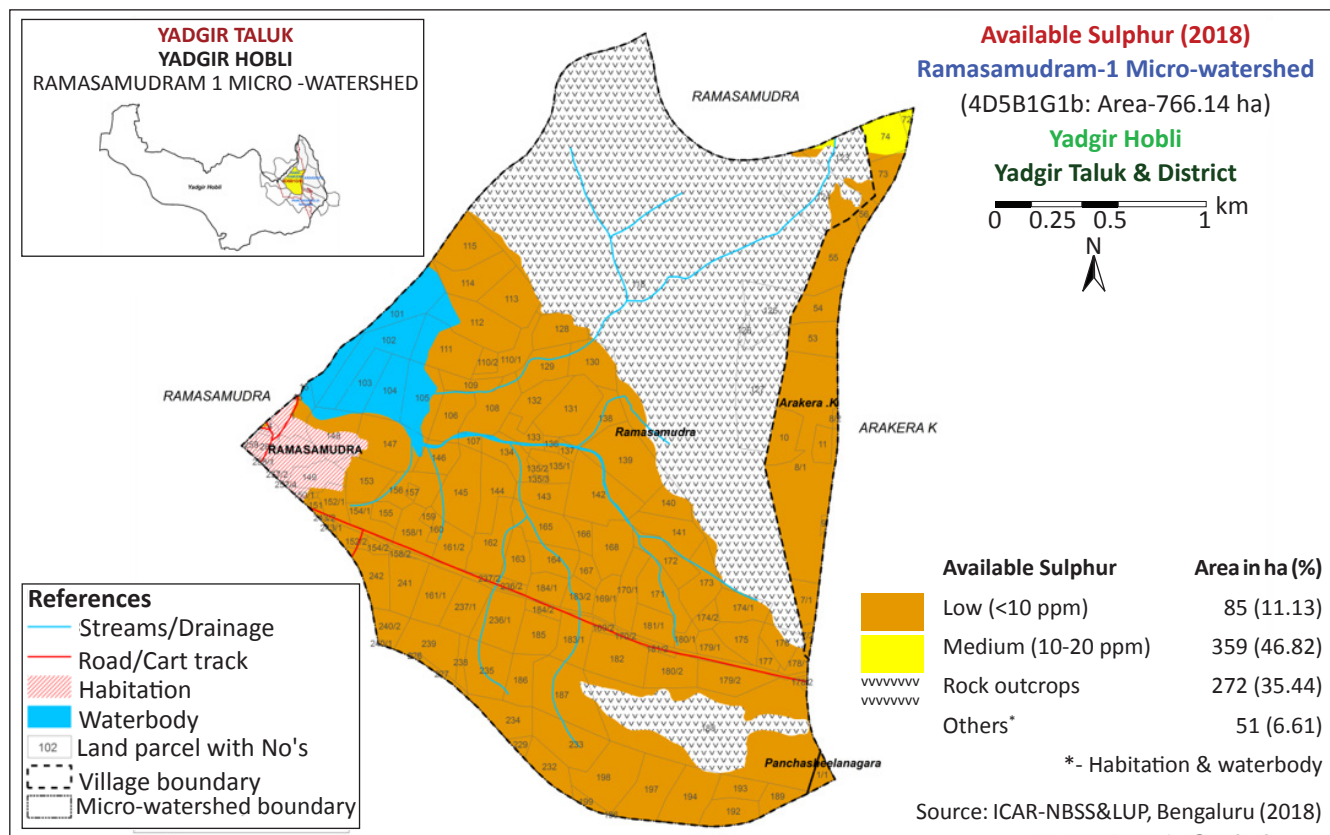


Figure 10: Soil available sulphur map of Ramasamudram-1 microwatershed

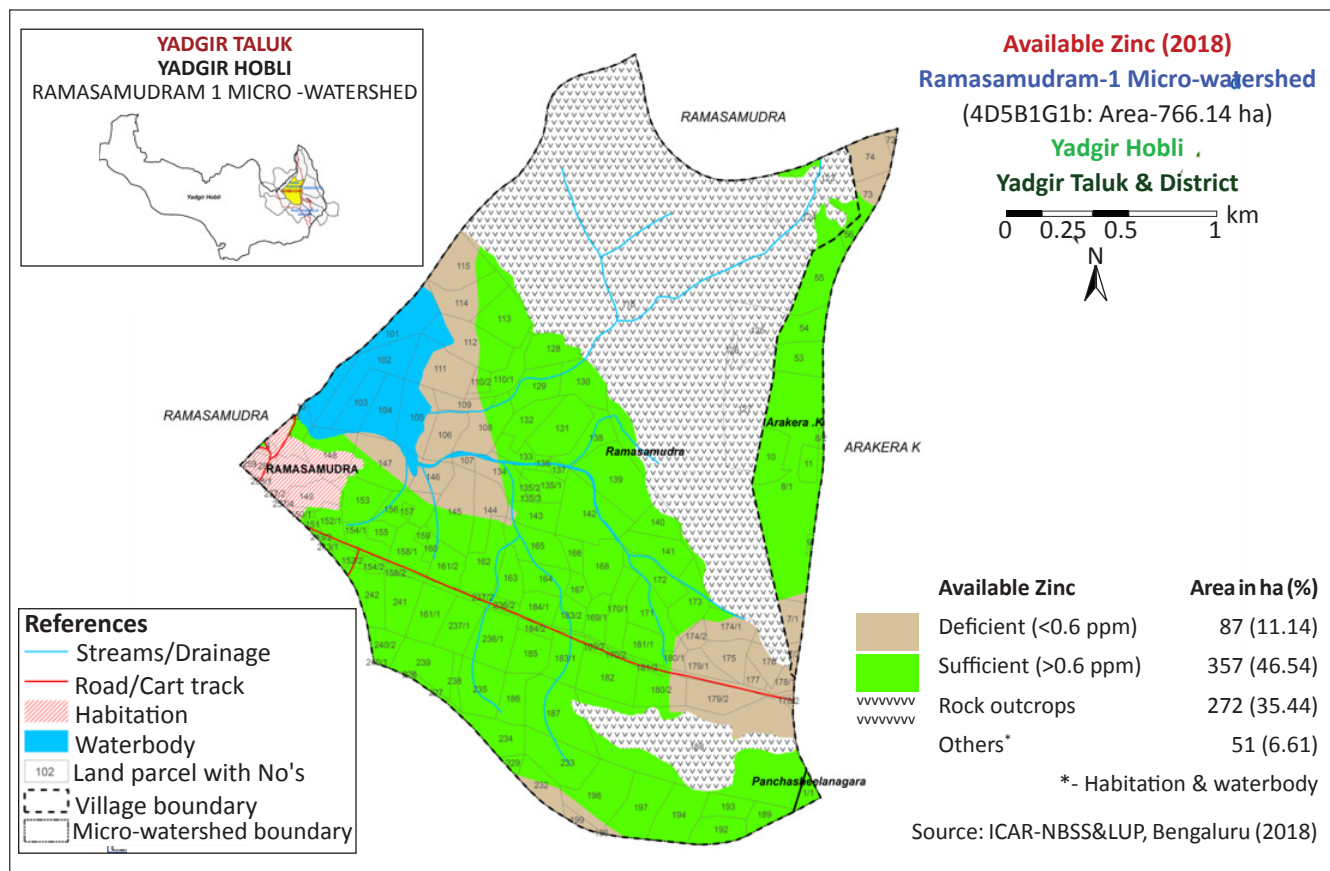


Figure 11: Soil available zinc map of Ramasamudram-1 microwatershed

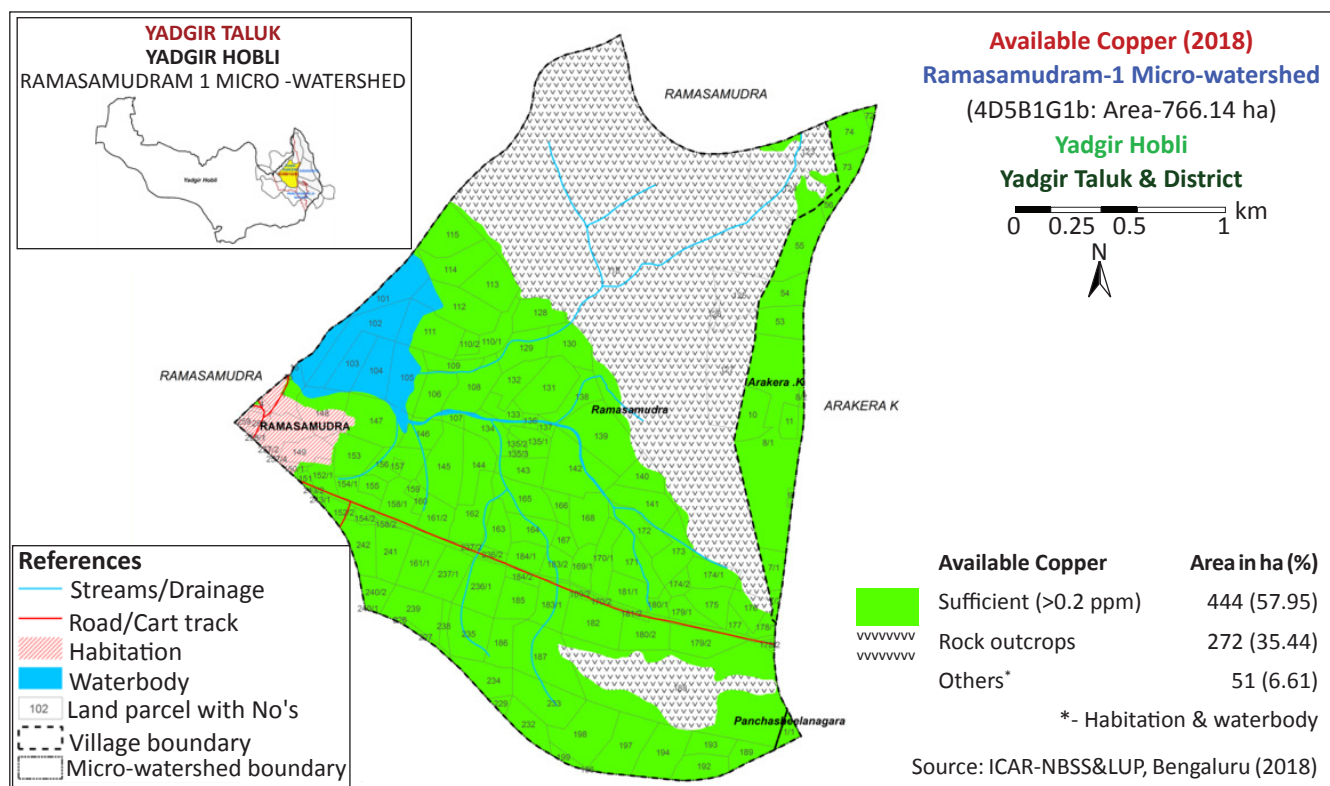


Figure 12: Soil available Copper map of Ramasamudram-1 microwatershed

entire microwatershed area (Figure 12). Higher copper availability may be attributed to organic matter content, clay and CEC of soils which enhanced its availability to crops. The results are in line with the studies reported by Sharma et al. (2003) and Kumar and Babel (2011).

Available iron content was sufficient (>4.5 ppm) in the entire microwatershed area (Figure 13). Prasad and Sakal (1991) were of the opinion that the sufficient amount of available iron might be due to the presence of organic matter indicating that organic matter influenced the solubility and availability of iron in the soil. Therefore the distribution of DTPA-iron followed the pattern of distribution of organic carbon which might be attributed to their regular addition through crop residues on

the surface (Tiwari and Mishra, 1990).

Available manganese content was sufficient (>1.0 ppm) in the entire microwatershed area (Figure 14). The sufficient amount of available manganese might be due to the presence of organic matter influenced the solubility and availability of manganese in the soil. Similar results were reported by Mahendra Kumar et al. (2015).

Maximum area of about 440 ha (57%) was low (<0.5 ppm) in available boron content and medium (0.5–1.0 ppm) in an area of 4 ha (1%) in the microwatershed (Figure 15). The available boron status is also closely followed the organic carbon in these soils.

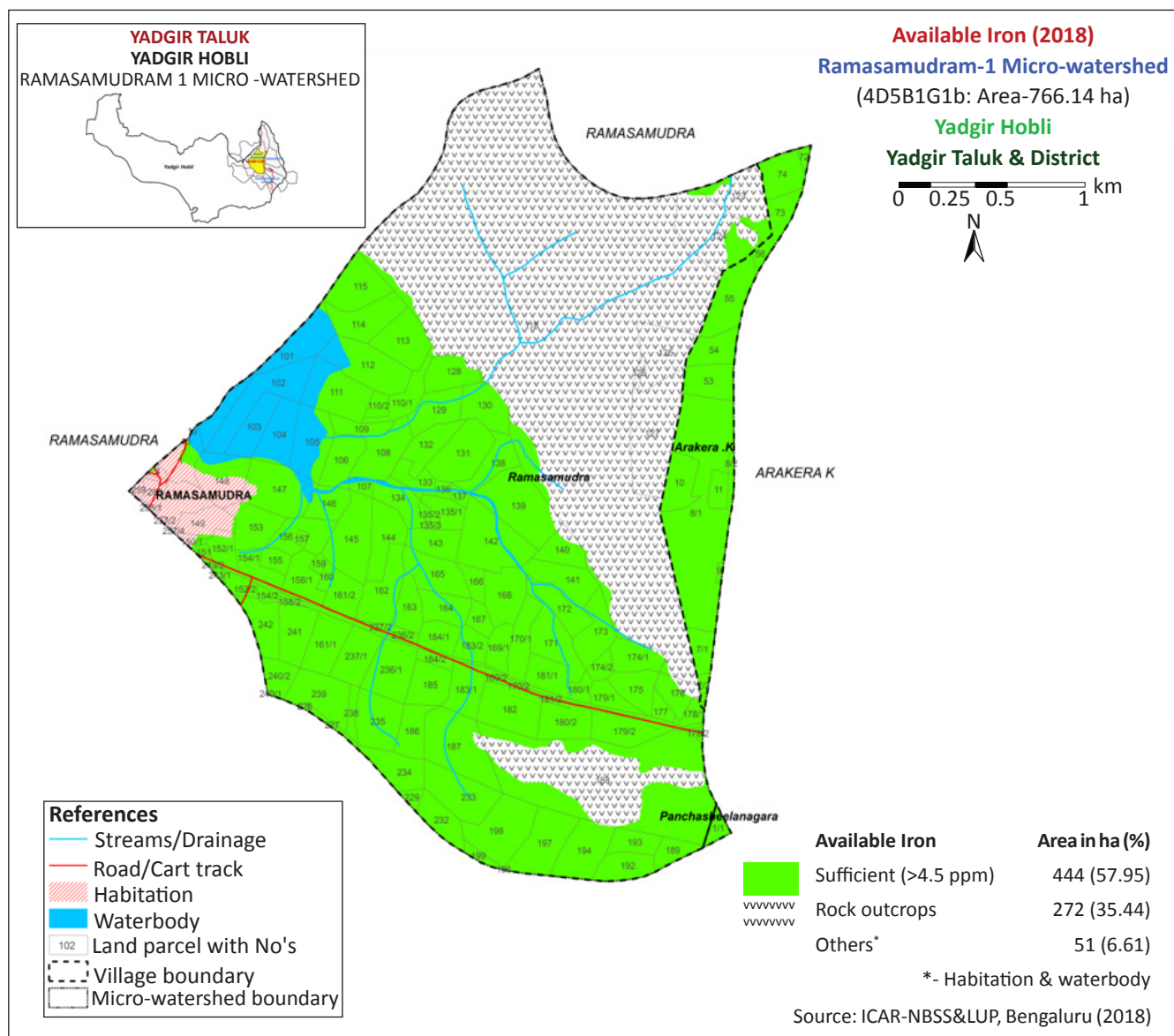


Figure 13: Soil available iron map of Ramasamudram-1 microwatershed

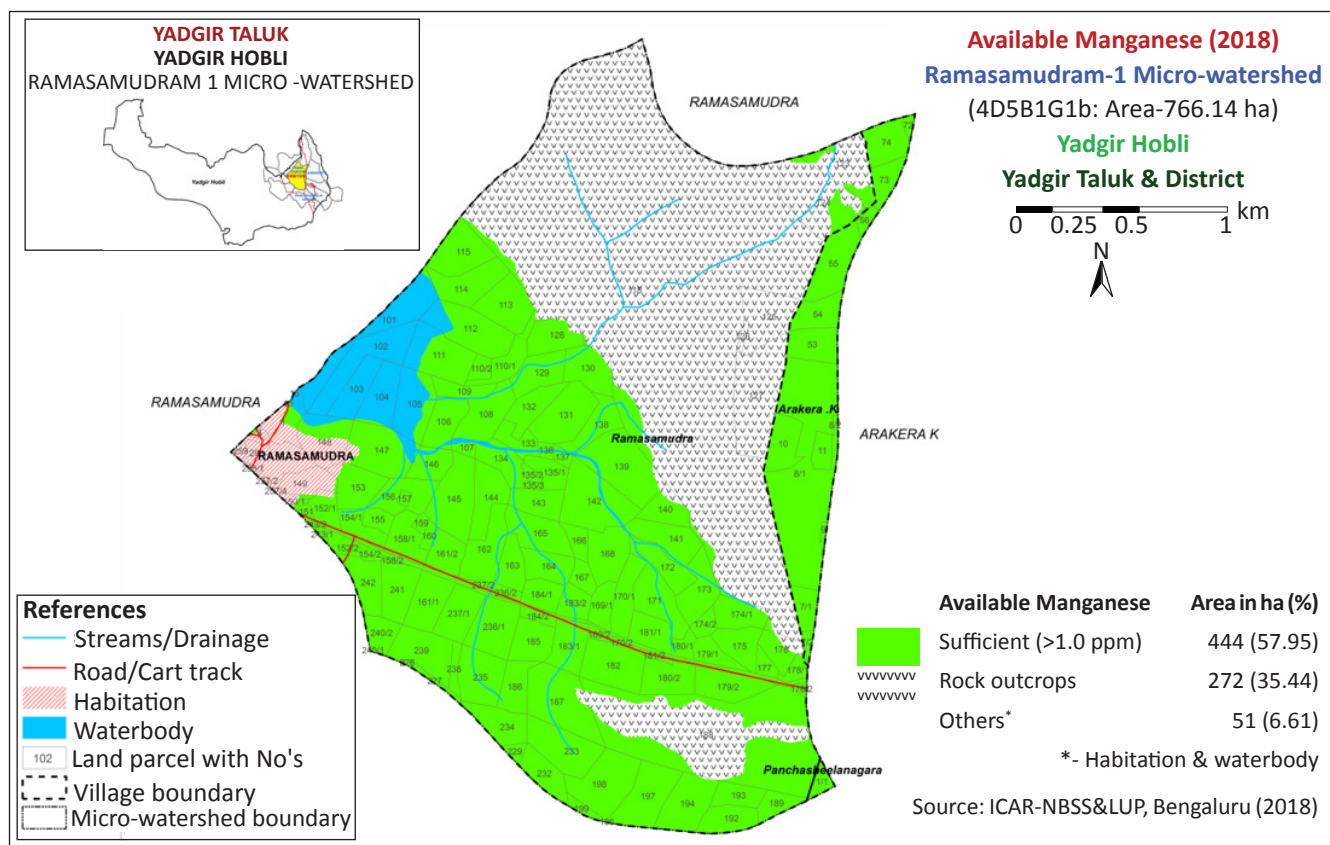


Figure 14: Soil available manganese map of Ramasamudram-1 microwatershed

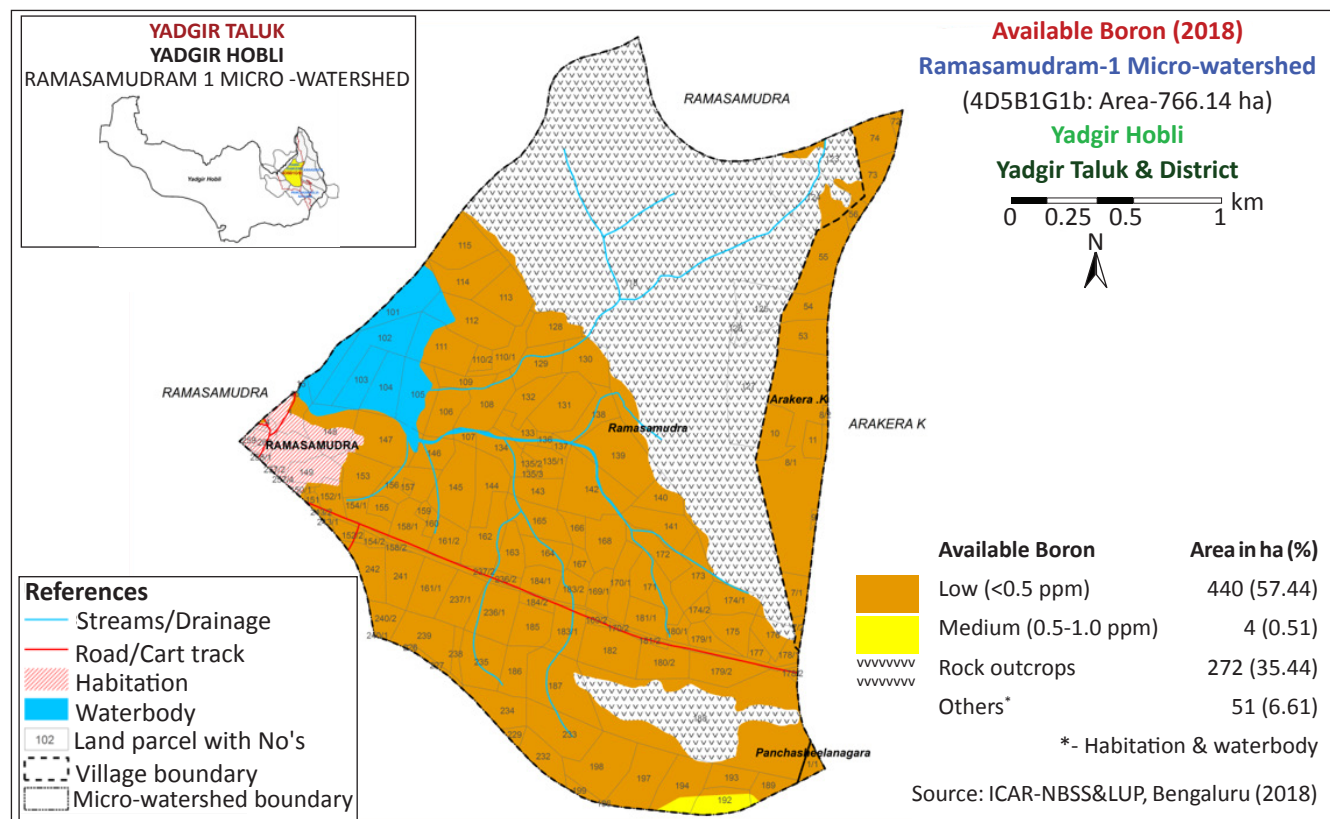


Figure 15: Soil available boron map of Ramasamudram-1 microwatershed

4. Conclusion

The soils are acidic to neutral with non-saline in nature. Organic carbon was medium to high. Available phosphorous, potassium and sulphur was low to medium in distribution. Micronutrient (zinc, copper, iron and manganese) was sufficient in entire area of the microwatershed but boron was found to be low. The study showed that, soils are medium in fertility status. The proper fertilizer recommendation and soil management practices can be made productive thereby, increasing the crop yield.

5. Acknowledgement

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6. References

- Black, C.A., 1965. Methods of soil analysis, part I and II. American society of Agronomy, Inc., Publishers, Medison, Wisconsin, USA.
- Chidanandappa, H.M., Yogesh, G.S., Gurumurthy, K.T., Shivaprakash, B.L., 2008. Status of DTPA extractable zinc in soils under paddy land use cover in Cauvery command of Mandya district, Karnataka. *Mysore Journal of Agricultural Sciences* 42(2), 247–250.
- Das, K.N., Basumatari, A., Borkotoki, B., 2012. Forms of sulphur in some rapeseed growing soil of Assam. *Journal of the Indian Society of Soil Science* 60(1), 13–19.
- Gupta, U.C., 1979. Some factors affecting the determination of hot-water-soluble boron from podzol soils using azomethine-H. *Canadian Journal of Soil Science* 59, 241–247.
- Gupta, P.K., 2004. Soil, plant, water and fertilizer analysis. Shyam Printing Press, Agrobios, India, p 38.
- Hegde, R., Somashekar, T.N., Chaitra, S.P., Arpitha, G.M., Bardhan, G., Mahendra Kumar, M.B., Dhanorkar, B.A., Niranjana, K.V., Chandran, P., 2020. Soil organic carbon status under different land use systems and soil fertility status of Rachanahalli subwatershed, Yadgir district in Karnataka, India. *International Journal of Chemical Studies* 8(1), 680–686.
- Jackson, M.L., 1973. Soil Chemical analysis. Second edition. Printice Hall of India, New Delhi, 498.
- Krishnamurthy, R., Srinivasamurthy, C.A., 2005. Distribution of some available micronutrients in black and red soils of Karnataka. *Mysore Journal of Agricultural Sciences* 39(1), 57–63.
- Kumar, M., Babel, A.L., 2011. Available micronutrient status and their relationship with soil properties of Jhunjhunu tehsil, district Jhunjhunu, Rajasthan, India. *Journal of Agricultural Sciences* 3(2), 97–106.
- Lindsay, W.L., Norvell, W.A., 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of American Journal* 42, 421–428.
- Mahendra Kumar, M.B., Subbarayappa, C.T., Ramamurthy, V., Shreenivas, B.V., Vijay Kumar, C., 2015. Characterization of surface soils in irrigated land management unit-1 (Command area) of Mysore District, Karnataka. *Ecology, Environment and Conservation* 21(1), 471–476.
- Manna, M.C., Sahu, A., Rao, S., 2012. Impact of long-term fertilizers and manure application on C-sequestration efficiency under different cropping systems. *Indian Journal of Soil Conservation* 40(1), 70–77.
- Meena, H.B., Sharma, R.S., Rawat, R.S., 2006. Status of macro and micronutrients in some soils of tonk district of Rajasthan. *Journal of the Indian Society of Soil Science* 54(4), 508–512.
- Nalina, C.N., Anil Kumar, K.S., Chandrakala, M., Sheela Rani, S., Sujata, K., Shilpa Shree, K.G., Hegde, R., Sing, S.K., 2016. Soil nutrient status mapping of Nagenahalli micro-watershed under Eastern dry zone of Karnataka by remote sensing, detailed soil survey and GIS techniques. *Indian Journal of Agricultural Research* 50(5), 389–397.
- Ncube, B., Twomlow, S.J., Dimes, J.P., Vanwijk, M.T., Giller, K.E., 2009. *Soil Use and Management* 25(1), 78–90.
- Piper, C.S., 1966. Soil and plant analysis. Hans Publishers. Bombay.
- Poonia, S.R., Bhumbra, D.R., 1973. Some physico-chemical characteristics of salt affected adjacent normal soils of Rathak district. *Journal of the Indian Society of Soil Science* 21, 335–341.
- Prabhavathi, M., Patil, S.L., Raizada, A., 2013. Assessment of soil fertility status for sustainable crop production in a watershed of semi-arid tropics in Southern India 41(2), 151–157.
- Pramod, T., Patil, P.L., 2015. Characterization and classification of soil resources of Balapur micro-watershed. *Karnataka Journal of Agricultural Sciences* 28(4), 510–517.
- Prasad, R., Sakal, B.P., 1991. Availability of iron in calcareous soils in relation to soil properties. *Journal of the Indian Society of Soil Science* 39, 658–661.
- Pujari, K.L., Patil, P.L., Dasog, G.S., Hebsur, N.S., Manjunath, M.V., Alagundagi, S.C., 2016. Identification of soil fertility constraints by geographic information system technique in Kotur microwatershed. *Journal of Farm Science* 29(1), 32–36.
- Rao, A.P., Naidu, M., Ramavatharam, N., Rao, G.R., 2008. Characterization, classification and evaluation of soils on different landforms in Ramachandrapuram mandal and Chittoor district in Andhra Pradesh and sustainable land use planning. *Journal of the Indian Society of Soil Science* 56(1), 23–33.
- Rego, T.J., Wani, S.P., Sahrawat, K.L., Pardhasaradhi, G., 2005. Macrobenefts from boron, zinc and sulfur application in Indian SAT: A step for grey to green revolution in agriculture. global theme on agro-ecosystems report no. 16. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi- Arid Tropics (ICRISAT).



- Sahrawat, K.L., Wani, S.P., Rego, T.J., Pardhasaradhi, G., Murthy, K.V.S., 2007. Widespread deficiencies of sulphur, boron and zinc in dryland soils of the Indian semi-arid tropics. *Current Science* 93, 1428–1432.
- Sahrawat, K.L., Rego, T.J., Wani, S.P., Pardhasaradhi, G., 2008. Stretching soil sampling to watershed: evaluation of soil-test parameters in a semi-arid tropical watershed. *Communications in Soil Science and Plant Analysis* 39(19), 2950–2960. DOI: 10.1080/00103620802432857.
- Sakal, R., Sinha, R.B., Singh, A.P., Bhogal, N.S., Ismail, M.D., 2000. Influence of sulphur on yield and mineral nutrition of crops in maize-wheat sequence. *Journal of the Indian Society of Soil Science* 48(2), 325–338.
- Sharma, S.K., Lal, F., 1992. Status of DTPA extractable zinc in soils of Humid southern zone of Rajasthan. *Journal of the Indian Society of Soil Science* 40(2), 393–394.
- Sharma, R.P., Singh, M., Sharma, J.P., 2003. Correlation studies on micronutrients *vis-a-vis* soil properties in some soils of Nagaur district in semi-arid region of Rajasthan. *Journal of the Indian Society of Soil Science* 51(4), 522–527.
- Singh, R.P., Mishra, S.K., 2012. Available macro nutrients (N, P, K and S) in the soils of Chiraigaon block of district Varanasi (U.P) in relation to soil characteristics. *Indian Journal of Scientific Research* 3(1), 11–21.
- Singh, Y.P., Raghubanshi, B.P.S., Rajbeer, S.T., Verma, S.K., Dubey, S.K., 2014. Soil fertility status and correlation of available macro and micronutrients in Chambal region of Madhya Pradesh. *Journal of the Indian Society of Soil Science* 62(4), 369–375.
- Thangasamy, A., Naidu, M.V.S., Ramavatharam, N., Reddy, R.C., 2005. Characterization, classification and evaluation of soil resources in Sivagiri microwatershed of Chittoor district in Andhra Pradesh for sustainable land use planning. *Journal of the Indian Society of Soil Science* 53, 11–21.
- Tawande, S.K., Patil, J.D., Zende, G.K., 1976. The forms and contents of sulphur in soils of Maharashtra state. *Journal of Maharashtra Agricultural Universities* 1(1), 1–6.
- Tiwari, J.R., Mishra, B.B., 1990. Distribution of micronutrients in Tal land soils (Udic Chromusterts) of Bihar. *Journal of the Indian Society of Soil Science* 38, 319–321.
- Vasundhara, R., Hedge, R., Dharumarajan, S., Niranjana, K.V., 2020. Spatial assessment of soil fertility status in Shiratti subwatershed of semi-arid tropics in Southern India. *International Journal of Bio-resource and Stress Management* 11(2), 163–170.
- Walkley, A.J., Black, I.A., 1934. Estimation of soil organic carbon by the chromic acid titration method. *Soil Science* 37, 29–38.

