LAND RESOURCE ASSESSMENT OF NAGENAHALLI WATERSHED DODDABALLAPUR TALUK BANGALORE RURAL DISTRICT USING REMOTE SENSING AND GIS TECHNIQUES.

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DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
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BANGALORE- 560 065
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DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
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CERTIFICATE

This is to certify that the thesis entitled **"Land Resource Assessment of Nagenahalli Watershed, Doddaballapur Taluk, Bangalore Rural District Using Remote Sensing and GIS Techniques."** *submitted by* **Ms. Nalina, C. N., ID No. PAK 8251** *for the degree of Master* **of Science** *in* **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** *to the University of Agricultural Sciences, Bangalore, is a record of research work carried out by her during the period of her study in this university, under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.*

BANGALORE
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Affectionately Dedicated to

My beloved Parents,

Narayanappa & Rathnamma

my sweet sister Usha

Loving brothers Raju & Kutty

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ABSTRACT

Land resources assessment of Nagenahalli watershed, Doddaballapur taluk, Bangalore Rural District using remote sensing and GIS techniques.

Comprehensive land resources information is important for efficient land use planning and fertilizer being the costliest input, the use of plant nutrients has to be need based.

Hence a detailed characterization of land resources were undertaken in Nagenahalli watershed, located between 13º 22′ 20.2″ to 13º 22′ 58″ N latitude and 77º 32′ 52.4″ to 77º 33′ 27.7″ E longitude and an elevation between 911 to 930 m above MSL covering 225.2 ha in Doddaballapur taluk, Bangalore Rural District. Climate of the area is semiarid tropical with a mean annual rainfall of 826.1 mm and temperature of 23.8 $^{\circ}$C. Cadestral map, satellite imagery and Google Earth images were used in conjunction with SOI toposheets to map the land use, study physiography-soil relationships and to prepare the soil map. The information gathered has been processed under GIS environment to generate thematic maps on crop suitability and fertility capability.

Soils are developed from granite and its colluvium. Horizon-wise soil morphological, physical and chemical properties of major soils were studied. Composite plot-wise surface soil samples were analysed for fertility. Five soil series have been identified and mapped into 15 soil mapping units. All the soil series identified are Nagenahalli- a (Na-Typic Kandiustalf), Nagenahalli-b (Nb-Typic Kandiustalf), Nagenahalli-c (Nc- Kanhaplic Haplustalfs), Nagenahalli-d (Nd-Ultic Paleustalfs) and Nagenahalli-e (Ne- Kandic Paleustalfs) are very deep except Nc, which is moderately shallow. The soils of Na and Nb are red with low CEC and low base saturation and having kandic horizon and soils of Na- series have gravel layer below 50 cm. Nc series covers largest area of 87.8 ha followed by Nd series, covering an area of 50.8 ha. The soils of Nc series are fine-loamy and are non-gravelly with very less clay content, while the soils of Nd and Ne series are fine, red and very gravelly. Gravel layer starts below 40 cm and have medium CEC. Major surface soils of the study area are non-gravelly and sandy clay loam (99 ha) textured and are poor in organic carbon (0.3 to 0.4 %) moderately or strongly acidic (176 ha) and low in available N (174 ha) and K (157 ha) but rich in P (170 ha) and sufficient (176 ha) in Zn. Major soils are suited to maize, ragi, and vegetables. Eucalyptus plantations on sloppy eroded lands (62.8 ha) can be retained but not on prime lands.

Signature of the Major Advisor

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INTRODUCTION

I INTRODUCTION

Soil and water resources are most important for fulfilling the requirement of food, fodder, fuel, fiber and timber needs of country's burgeoning population. Since India is already facing the food insufficiency due to climate change which has reported to be having adverse impact on food production in tropical countries like India. It has been assessed by FAO (2007) that there may be shortage of food grains in Asia and paddy cultivation may be adversely affected due to 1 to 3 ºC rise in global average temperature.

Therefore it is imperative to enhance the land productivity in a sustainable manner. Generation of information on land qualities, through survey of land resources like climate, water, geology, landforms, soils, land use etc. and use of this data in agricultural development planning could augment judicious application of inputs such as chemical fertilizers and better land use options will lead to optimal utilization of land resources and maintenance of soil health.

Soil surveys help in generating the required information on land resources. It is carried out in two stages: a reconnaissance survey, which provides a preliminary database followed by detailed survey to provide site specific information required for undertaking developmental work of an area (Anthony Young, 1998).

The land resources of the state are under severe strain due to the pressure of the growing population and competing demands of the various land uses. The state is basically an agrarian one with about 70 percent of the people still depending on agriculture for their livelihood. Out of the total geographical area of 19.17 million.ha, the net area sown is only about 54 per cent. There is not much scope for increasing the area under cultivation in future. Further, most of the arable lands are located in the arid regions of the state, characterized by their frequent drought and crop failures.

With the present rate of population increase, the per capita availability of land which at present is less than 0.20 ha will be further reduced to around 0.10 ha in 2025. In addition to this there is a significant diversion of farmlands to non-agricultural purposes, exerting further pressure on the already shrinking land and fast depleting water resources of the state. Another disturbing factor is the rate of depletion and degradation of the land resources, which affects not only the crop productivity but also the sustainability of the land resources in the state.

Apart from the above, wrong choice of crops, faulty agricultural practices, decrease in the soil fertility and imbalance in use of fertilizers, lack of appropriate cropping pattern and wrong choice of land use to exploit the full potentials of the resources by the farmers have greatly affected the productivity of the land resources in the state. Therefore the situation needs immediate attention of all the stakeholders, from policy makers to farmers involved in the management of the limited land resources of the state. It is a known fact that the root cause for the degradation is the neglect and irrational use of land resources. Hence the challenges like prevention of degradation of land resources, use of plant nutrients according to actual needs of the soil-crop situations. There by increasing the productivity per unit area can be achieved effectively only by addressing the issues at the farm level only, those will help in evaluating rational, site-specific and viable land use and soil management options suitable for each land holding in the villages. For this, detailed site specific database on land resources for all the villages in the state is a prerequisite.

The data required for farm planning can be obtained by carrying out detailed characterization and mapping of all the existing land resources like soils, climate, minerals and rocks, ground water, vegetation, crops, land use pattern etc. From the data collected, the problems and potentials of the area for agriculture development, suitable land use options and soils management aspects for each and every parcel of land holding can be identified easily. Few pilot studies carried out in various parts of the country have proved conclusively the importance of site specific database for farm planning and the desirability of establishing such a data base at village level for undertaking any farm development work in future in all the states (Natarajan *et al.,* 2002).

The key to meet the present day challenges lies in the integrated management of the natural resources. Therefore the knowledge of soil and land resources with respect to their spatial distribution, characteristics, potentials, limitations and their suitability for alternate land uses helps in formulating strategies to obtain higher productivity on sustained basis. This calls for systematic and reliable inventory of natural resources at a quicker phase through scientific and modern tools like remote sensing and geographic information system (GIS). These remote sensing techniques have proved to be rapid, reliable, and cost effective and provide quick information. The repetitively of the satellites used in remote sensing range from daily to 24 days in multi spectral, multi temporal and multi spatial format from the space platform for the given area of interest has revolutionized in providing vital inputs in inventorying, mapping, management and monitoring of natural resources like soil, vegetation and water resources.

Satellite remote sensing provides date for identification of watershed characteristics such as drainage, stream network, landforms etc., which could be used for proper management of watershed (Gawande, 1990).

In this context, the detailed soil survey of Nagenahalli watershed, Doddaballapur taluk, Bangalore Rural District representing Eastern Dry Zone in Karnataka State was undertaken to provide site-specific database in planning for optimum use of the land resources at village level. This study is undertaken with the following objectives.

1. To characterize and classify the soils of Nagenahalli watershed, Doddaballapur taluk, Bangalore Rural district using remote sensing and GIS.

2. To study and map the land resources of the watershed.

3. To identify the problems and potentials for agricultural development.

4. To prepare soil fertility and micronutrient status maps of the watershed.

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

Land resource information is vital as all types of lands are used for agriculture indiscriminately. Identification of good and poor lands is crucial for land use planning conventional survey is time consuming and expensive. If remote sensing data products used along with soil survey for collecting such information, the efficiency and accuracy of data gets improved. The highlights of some of the important related research works carried out both within and outside India have been reviewed and presented here under the following sub divisions.

1. Land resources inventory through detail soil survey coupled with remote sensing techniques
2. Characterization and classification of soils
3. Problems and potentials of soils
4. Soil fertility and suitability studies

2.1 Land resources inventory through detail soil survey coupled with remote sensing techniques

A multistage approach involving visual interpretation of Landsat imagery in conjunction with geological and topographical information supported by limited field check was followed to prepare physiographic soil map in Tamil Nadu by Kanda Kumar *et al.* (1983). They have identified different physiographic units and soils were classified up to soil series association level.

In a study based on visual interpretation, six main landforms and further sub divisions were made in Punjab by Sehgal *et al.* (1985). After detailed field study soils were classified up to association of sub- groups or great groups of soil taxonomy. The study concluded that based on the problems of soil, suitable management practices could be suggested to increase productivity and help in macro level land use planning.

Visual and digital remote sensing techniques were followed for generating soil and land use maps in Chitradurga district by Karale *et al.* (1985). They reported that digital data analysis helped better discrimination of soil and land cover classes. Soils were classified upto subgroup level.

It was concluded in the study conducted by Ravishankar *et al.* (1988) using IRS 1A data in parts of Bijapur and Belgaum that subgroup level association map could be prepared using LISS 1 data at 1:250,000 scale, where as mapping could be carried up to the family or their associations using LISS 2 data at 1:50,000 scale.

Remote sensing technique was employed by Sen *et al*. (1992) to identify and delineate soils of Dibrugarh district, Assam. They reported that by efficient ground truth collection the dominant soils in the area could be identified and mapped in collation with remote sensing technique.

Soil and land use mapping of Balachur watershed in Hoshiarpur districts, Punjab was carried out by Chandragit Singh *et al.* (1994) using aerial photographs, IRS-1A data, cadastral maps and SOI Toposheet. Six soil series were tentatively identified which were mapped as phases of soil series in plain area and as association of soil series in the hills. Village wise soil maps were prepared on 1:5,000 scales and the combined watershed Soil Map on 1:10,000 scales. Based on the inherent soil characteristics and external land features, land capability maps for the individual villages and for the entire watershed were also prepared.

Prasad *et al.* (2001) used IRS 1C PAN and LISS 3 data along with field observations and lab analysis, and identified nine soil series. The salt affected soils of parts of Krishna western delta in Prakasam district of Andhra Pradesh were classified into saline, sodic and saline- sodic soils developed on old tidal flats, swale plains and beach ridges/sands. The soils were classified into Typic Ustochrepts, Fluventic Ustochrepts and Typic Ustipsamments.

Soil resource mapping of Madhya Pradesh was carried out with the help of land sat imagery and soil profile studies by Tamgadge *et al.* (2001). The thematic maps on particle size distribution, soil depth, available water holding capacity, soil erosion and soil reaction was prepared, which will be helpful for policy makers to formulate project for overall developmental plan for implementation in the area. They reported that at higher elevation, very shallow to shallow loamy soils, at intermediate elevation shallow to moderately deep loamy to clay soils and at near low lands deep to very deep clayey soils were noticed.

The IRS-IB-LISS-2 FCC corresponding to the survey of India toposheets 58 J/12, 58 J/16 and 58 K/9 were interpreted for soil resource studies in lower Palar- Manimuthar watershed, Tamil Nadu. Based on morphological, physical and chemical properties, ten soil series were identified and classified according to US soil taxonomy (Arun Kumar, 2002).

Elvis *et al.* (2007) carried out soil survey and characterization of Dhamni watershed in Chandrapur district of Maharashtra using IRS-ID LISS-III data in conjuction with field survey and ancillary data and indicated that nearly 84.2 per cent of the total geographical area of the watershed was under cultivation while forest occupied only 4.5 per cent area whereas scrubland with patchy cultivation covered 9.4 percent of the watershed. Nine soil series were identified and mapped as soil series association into five mapping units .The soils belong to the order Inceptisol, Vertisol, and Mollisol.

2.2 Characterization and classification of soils

Sahu *et al.* (1990) while characterizing the red and lateritic soils of northern plateau zone of Orissa which were formed on highly weathered gneissic parent material observed that the content of clay increased with depth in all the profiles with a simultaneous decrease in sand content indicating traslocation of clay under well drained conditions. There was an evidence agrillic horizon because of illuvation of clay.

Reddy *et al.* (1993) studied morphological and physicochemical properties of red soils (Alfisols) of Nagarjuna sagar project area of Andhra Pradesh under irrigated and unirrgated conditions and observed that texture of soils ranged from sandy loam on the surface to sandy clay loam in the sub soils color of the Bt horizon in all irrigated soils was reddish brown whereas in unirrigated soils it was dark reddish brown.

Bhaskar and Subbaiah (1995) showed the presence of hard and compact laterite or ferrogenous layer by studying six representative profiles of Sumasila and Telugu Ganga project area in Nellore district located on the gently rolling plains. The soils were light in texture with low water holding capacity, slightly acidic to neutral reaction, low organic matter and CEC, and soils are relatively infertile. The soils were classified in the order of Alfisols, Inceptisols, and Entisols and also classified as Typic Ustorthent, Udic Rhodustalfs and Udic Ustochrepts.

Sharma *et al.* (1996) while characterzing soils in a toposequece over basaltic terrain of southern Rajasthan observed that the soils at elevated topography were shallow to moderately shallow, clayey to loamy- skeletal in texture and yellowish brown while at lower topography soils were deep to very deep, fine to fine loamy texture and grayish color.

Twelve soils in northern Telangana of Andhra Pradesh were studied by Vijay Kumar, *et.al*. (1996) for their genesis and classification. The soils were very low to low in organic carbon; low in available N and P_2O_5; medium to high in available K_2O, and neutral to slightly alkaline in reaction. Five soils were found with ochric epipedon and qualify for Inceptisols, three with argillic horizons and qualify for Alfisols, three with deep and wide cracks and qualify for Vertisols and one pedon with no profile development classified as Entisols.

Challa *et al.* (2000) while doing the characterization and classification of the problematic Vertisols in Maharastra reported that Khondwad and Kadambhe soils of peidmont plain were dark grayish brown while Amalner and Valpi soils of flood plain were dark yellowish brown in colour.

While studying morphological, physical and physicochemical characteristics of soils in Sivagiri micro watershed of AP, Thangswamy *et al. (*2005) revealed that the soils are deep to very deep, light yellowish brown to dark red, excessively to poorly drained, slightly acidic to moderately alkaline, low to medium in organic Carbon and low to medium in CEC with wide textural variations. Soils are low to medium in N, P and K and high in S where as deficient to sufficient in available Zn, deficient in Fe and sufficient in available Ca and Mn Gently sloping topography exhibit the development of argillic horizon (Bt) while the soils on nearly leveled lands have cambic horizons (Bw). The Entisol pedons did not show presence of any diagnostic horizons and soils have been classified as Aquic Ustorthents, Typic Ustipsamments, Typic Ustifluvents, Typic Haplustepts, Vertic Haplustopts, Typic Haplustalfs and Typic Rhodustalfs.

Gabhane *et al.* (2006) studied morphological and physicochemical characteristics of the soils of the soils of Akola district in Maharastra and revealed that most of the soils were clay in texture with clay content ranging from 34.4 per cent to 73.4 per cent and increased with depth, silt content ranges from 12.8 to 40 per cent and sand content in general was <10 per cent, pH was neutral to alkaline and showed increasing trend with depth, organic carbon varied from 0.32 to 0.72 per cent and decreased with depth , and the CEC of the soils varied from 51.16 to 62.98 cmol (p+) kg-1.

Sitanggang *et al.* (2006) studied the soils of watershed area of Shikohpur, Gurgaon for its characterization and classification. It was observed that the depth of soil in the study area varied from 35 to more than 150 cm due to variation in topography and slope gradients. The soils of hill top and hill side slopes experienced erosion and had the depth of 35 and 75 cm respectively, where as the soils on the ravenous area; piedmont plain and alluvial plain had a depth of 130 to more than 150 cm.

Rajendra Hegde *et al.* (2007) characterized and classified soils in Linganahalli microwatershed under Amani Shivpurkere watershed, Doddaballapur Taluk, Bangalore Rural District, Karnataka and observed surface soil texture ranged from sand, loamy sand, sandy loam and sandy clay loam. Bulk density of upper horizon ranged from 1.2 to 1.75 *M*g m^{-3}, pH of surface soil ranged from 5.0 to 7.3 (strongly acidic to neutral), EC from 0.20 to 1.23 dS m^{-1}. Soils are very low to medium in organic carbon (1.2 to 6 g kg^{-1}) and CEC from 1 to 11.8 cmol (p+) kg^{-1} at surface layer and the soils in the study area were free from major constraints and suitable for major adopted crops of the region.

2.3 Soil fertility and suitability studies

Badrinath *et al.* (1986) while studying the fertility status of some typical soils of coastal Karnataka reported that the available potassium varied from 30 to 220 kg ha^{-1}. The Puttur soils have low potassium content. Coarse textured and gravelly soils with deeper solum were particularly low in available potassium, possibly due to faster and deeper leaching.

Prasad and Sahu (1989) found that the available manganese content in some typical soil profiles of Bihar varied from 3.5 to 78.4 ppm, which decreased down the depth. Relatively higher amount of DTPA extractable manganese in the surface layer might be due to low pH, nature of the parent material and advanced stage of weathering.

A study of fertility status of some Alfisols from three districts of Meghalaya and reported that the organic carbon content was quite high and higher the altitude higher was the organic carbon. The soils were generally low in available P. only a small portion (8 %) from East Khasi hills may be considered deficient in available K. Among the micronutrient cations, deficiency of Zn, Cu, and Mn is expected in quite a few soils. None of the soil samples is found deficient in available Fe. Joplin *et al*. (1993).

Kannan and Mathan (1994) reported that the available zinc and available copper in some soils of selected watershed of Tamil Nadu showed decreasing trend through the depth of pedons might be due to its close association with organic carbon.

A strong relationship among available manganese on pH and organic carbon content in some red and black soils of Karnataka suggesting the role of these two factors in controlling manganese availability and also observed a decreasing trend of available zinc with depth. Rajkumar (1994).

Vijay kumar *et al.* (1994) studied the depthwise distribution of Zn, Cu, Fe and Mn in soils of northen Telangana in A.P and revealed that the soils were sandy loam to clay, neutral to alkaline in reaction, low in organic carbon and low to high in CEC. Appreciable variations in available micronutrient contents were observed between the profiles and also within the profile. In general the highest amounts of DTPA extractable Zn, Cu, Fe and Mn were found in the surface layers in almost all the profiles which was due to their regular addition through plant residues followed by suitable soil water regimes that increased the reduction process.

Dhane and Shukla (1995) in soils of Maharastra and Maji *et al.* (1993) in coastal soils of Sundarbans, West Bengal recorded decreasing trends of available iron down the depth. Iron and copper were found negatively correlated with pH and positively correlated with electrical conductivity and organic carbon.

Prasad *et al*. (1998) while characterizing the soils of Karnataka observed that soils derived from granite-gnesis parent material were found to be slightly acidic to near neutral in soil reaction and the available potassium was medium to high in most of the soils of the state except in lateritic soils of coastal plain and Western Ghats and in shallow red and black soils.

Fifteen soils from dominant coffee growing regions representing the red and laterite soils of Karnataka were studied for their site suitability by Kharche *et al. (*1999). They noticed that the well drained clay loam textured soils with high base saturation and adequate organic carbon receiving annual rainfall of 1800 to 2547 mm, cooler atmospheric temperature, 270 to 300 days growing period, 2 to 3 months dry spell with moderate to high humidity (70 to 85 %) and moderate light intensity are congenial for coffee growing. However poor root development and poor growth was noticed in valley land areas with shallow ground water table indicating that very deep soils are ideal for coffee.

Reddy and Shivaprasad (1999) while characterizing eleven soil series of six potato growing districts of Karnataka, noticed that there was a greater potential for increasing the area under potato cultivation from the present 35085 ha to 137350 ha in Karnataka, especially in the districts of Kolar, Bangalore, Hassan and Chickmagalur and the soils that have high potential for expansion of area under potato were Hosakote, Malur, Timmasandra, Vijayapura and Chickaballapura in Bangalore and Kolar districts and Bagolu and Idenahalli in Hassan district.

Venkatesh and Satyanarayana, (1999) studied the status and distribution of different forms of sulphur in soil profile samples collected from different Agricultural Research Stations of UAS Dharwad and adjacent farmers' fields under intensive oil seed crops. The range in contents of various forms of 'S' were 2.5 to 55.0ppm of available 'S' 26.0 to 277.5 ppm of NaH_2PO_4 extractable organic 'S' 1108 to 4591 ppm of total organic "S" respectively taking 10 ppm as critical limit. Surface samples of 11 soil profiles were found to be deficient in available 'S', besides soil properties, management factors like addition of 'S' through fertilizers and crop uptake also influenced the 'S' status in cultivated soils. The mean C:N, N:S and C:N:S ratios in the soil profile samples were 11.57: 1, 2.94:1 and 100:8.70:30 respectively.

Chinchmalatpure *et al*. (2001) studied the land and soil for the suitability of cotton, pearl millet and wheat with four watersheds of salt affected soils of Gujarat. Four pedons were dug in each watershed and their depth varied from 50 to 180 cm. Pedon in Bhadar watershed was of shallow depth which was developed on alluvial parent material.

Gangopadhyay *et al.* (2001) studied for representative soils formed on flat topped hillocks and undulating uplands. Study was aimed to develop a model for understanding a set of precise soil parameters requirement of rubber. Soil samples were collected from rubber- growing orchards of South and West Tripura. The soils were deep to very deep, well drained, dark brown to yellowish red, light textured, low to medium in organic matter and acidic in reaction. The CEC of the soils ranged from 4.4 to 18.9 c mol (p+) kg^{-1} the exchangeable acidity ranges from 0.2 to 6.5 c mol (p+) kg^{-1}. The increase in clay content with depth and the development of soil structure indicates the development of cambic horizon (Bw). Soils were classified taxonomically as Typic Dystrudept, Oxic Dystrudept and Dystic Eutrudept.

While studying seven profile samples from red soils of different agro climatic zones of Karnataka for the depth wise distribution of DTPA extractable Fe, Mn, Cu and

Zn and for their relationship with some soil properties, Dayananda *et al.* (2002) reported that DTPA extractable micronutrients decreased with depth and were found to be adequate in all the soil profiles. Organic carbon was the dominant factor controlling the availability of micronutrients in soils.

Bhaskar *et al.* (2004) recorded the micronutrient distribution in soils on hill slopes of Narang- Kongripara watershed of Meghalaya. The iron content in surface horizon ranged from 6.1 to 46 mg kg-1 and in sub-surface it ranged from 4.2 to 131.8 mg kg-1.

In a study on land capability evaluation of Sahaspur block in Uttaranchal, Esther *et al.* (2004) noted that the soil series belonged to four major soil orders viz. Entisols, Inceptisols, Alfisols and Mollisols and the area was classified into 6 major land capability classes (II, III, IV, VI, VII, VIII) nearly 85 per cent of the area was found suitable for cultivation and the rest non- arable, forest covered 45per cent of the area. Erosion hazards, Steep of topography and adverse soil factors were found to be the limiting factors. The land use for physiographic soil units was also suggested for sustainable development based on land capability classess.

While studying eighty surface soil samples from black and red soil regions representing different agro climatic zones of Karnataka for the distribution of DTPA extractable form of Fe, Mn, Zn, Cu and hot water soluble Boron and their relationship with some soil properties, Krishna murthy and Srinivasmurthy (2005) noticed that the Zn deficiency in large number of soils studied compared to Cu and Boron deficiency. While Fe and Mn were found to be adequate in all the soil series in black soil region, available Mn and Zn correlated positively but non significantly with clay and significantly and positively with organic carbon. Available Cu and B showed significant and positive correlation with clay but was non-significant with organic carbon. In red soil region available Fe, B and Zn showed significant and positive relationship with clay. Available Fe, Mn, Cu and B showed positive relationship with organic carbon except available Zn.

Depthwise distribution of CEC followed the pattern of clay distribution or otherwise more the clay content showed more CEC in soils in watershed area of Shikohpur, Hariyana. CEC ranged from 6 to 12.57 cmol (p+) kg-1 of soil and revealed considerable variations among and within profiles. Low CEC of these soils was due to low clay and organic carbon and also type of clay minerals present in these soils (Sitanggang *et al.* 2006).

2.4 Problems and potentials of soils

Sandy and eroded rocky catchments in association with torrential rainfall were the main causes of heavy sediment deposition and recharging capacityof reservoirs. The nature, volume and characters of the sediments depended upon environmental conditions and can be controlled through revegetation in catchments and construction of silt traps at the entrance of the reservoirs. Sharma and Joshi (1982).

Soni *et al.* (1983) while analyzing the effect of different vegetation cover on water movement noticed that the infiltration rate was highest under Eucalyptus spp. And also noticed that the infiltration was negatively correlated with the bulk density and positively correlated with pore space.

Goyal and Singh (1987) observed that soils mostly low in clay content and low to very low organic carbon showed a decreasing trend of available N with depth. Lower clay content in these soils with pH 7.8 to 8.5 was responsible for low CEC and thus low retension of ammonium ions on exchange complex leading to lower N availability.

Prasad *et al.* (1993) studied the erodibility of soils developed on different parent materials and explained that the quantity of micro-aggregates (0.1-0.25 mm) varied from 5.5 to 50.1 per cent in soils developed under different parent materials. The average value of 7.8, 46.0, 20.6 and 12.1 per cent of micro aggregates was recorded with soils under granite-gneiss, shale, micaceous schist and calcareous alluvium respectively.

Dhir (1994) reported that the recent spurt in human and livestock population with exploitative management have resulted in degradation. Deterioration of pasture land, depleting ground water resources and wind erosion were the major manifestations. Major expansion of development programmes with people's participation, rehabilitation of degraded pasture lands, restructuring of land use with increased emphasis on animal husbandry and adaptation of simple wind erosion control measures are some of the ingredients of a control strategy.

Naidu *et al.* (1994) studied the soil related constraints for production of mango in Kolar district of South Karnataka and observed that the soil depth in the study area was ranging from 46 to 189 cm having varied amounts of gravel content from 5 to 80 per cent in subsoils. Soils in Koppali, Guttapalli and Doddadasarahalli series were shallow in depth (<60 cm) and soils of Arkunte, Doddadasarahalli, Rayalapadu, Koppali and Guttapalli series had higher gravel (>40 %) content in subsoils. The authors were of the opinion that soil depth and coarse fragments were the serious limitations to cause dieback or decline of mango during adverse weather conditions.

Ghosh *et al.* (1996) studied different indicators of degradation process in the semi arid lands of Karnataka State by using temporal satellite information along with the surface and statistical data with the aid of a geographical information system. The results showed that degradation was a natural process but was aggravated by human activity.

Chand and Bhan (2000) studied the effect of different vegetative barriers in sorghum based intercropping system on runoff, soil loss and physico-chemical properties of soil during kharif 1995 and 1996. Results revealed that all the vegetative barriers were found effective in reducing soil loss however the performance of *Vetiveria* was best. Significant reduction in soil loss due to *Vetiveria zizahioides* and *Sesbania serban* barriers may be attributed to reduction in erosive velocity of runoff which helped to settle down and entrap soil particles behind the barriers.

Verma *et al.* (2005) reported that conventional tillage with straw mulch (SM) and manual weeding (MW) treatments reduced the run off in pea and tomato crop. Conservative tillage was found most effective in reducing soil sediments loss under pea and tomato crop.

Chandrappa *et al.* (2006) reported that application of 50 per cent N through chemical fertilizers along with 50 per cent N through paddy straw and 50 per cent N through Glyricidia recorded significantly higher organic carbon content (0.74 and 0.75 %, respectively) compared to other treatments. This may be due to higher nitrogen content in Glyricidia biomass which increased the available nitrogen content.

Yadav and Chippa (2007) studied the effect of FYM, gypsum and iron pyrites on fertility status in sodic soil irrigated with high RSC water. Application of FYM at 20 t per ha increased the available P and K in the soil and improvement in available N, S and Fe content of soil, grain and straw yields was recorded up to 30 t per ha. Application of gypsum, 50 percent of GR increased the available N, P, K, S and Fe content in soil, grain and straw yield over control. Whereas pyrites at the rate of 50 percent of its gypsum requirement brought about significant increase in the available P, S and Fe content of soil, grain and straw yield over control.

Huggins and Smith (2008) reported that practicing of 11 year no tillage and 3 year conventional tillage recorded significantly higher soil organic carbon (58.4 Mg/ha) compared to other management practice system. This may be due to higher carbon mineralization (5.22 Mg/ha) which led to increase in accumulation of organic carbon in the soil

METHODOLOGY

III MATERIALS AND METHODS

The details of the study area, database used for the land resource assessment, location of the pedons, site characterization, soil sample collection from pedons and soil analysis in the laboratory for different soil characters are described in this chapter.

3.1 Study area

The village Nagenahalli forms part of Doddaballapur taluk, Bangalore Rural District, representing eastern dry zone in Karnataka. The village is located besides the Ghati-Subhramanya High way which runs from Doddaballapur town, at the elevation range of 911 to 930 m above MSL.

Nagenahalli is located between $13^{\circ}22'20.66''$ N to $13^{\circ}22'20.2''$ N latitude and $77^{\circ}32'55.30''$ E to $77^{\circ}33'27.7''$ E longitude covering an area of 225.2 ha. It is bounded by Tubagere on east, Dhurgenahalli and Gadlapalya on North and Hadonahalli on South. Location map of the study area is shown in Fig 3.1.

3.2 Geology

The dominant geology of the area is Archaean granites and gniesses on upland and colluvium on convex lower sectors. Small patches are there with basic rocks in granitic landscape itself.

3.3 Landform

In order to understand the landform –soil relationships of the watershed, a measured cross section was studied using Suunto clinometers. Slope angles were measured at 10 to 20 meter intervals between the elevation of 950 and 920 m above MSL. The measured slopes were grouped together and based on the angular discontinuity, landforms were identified.

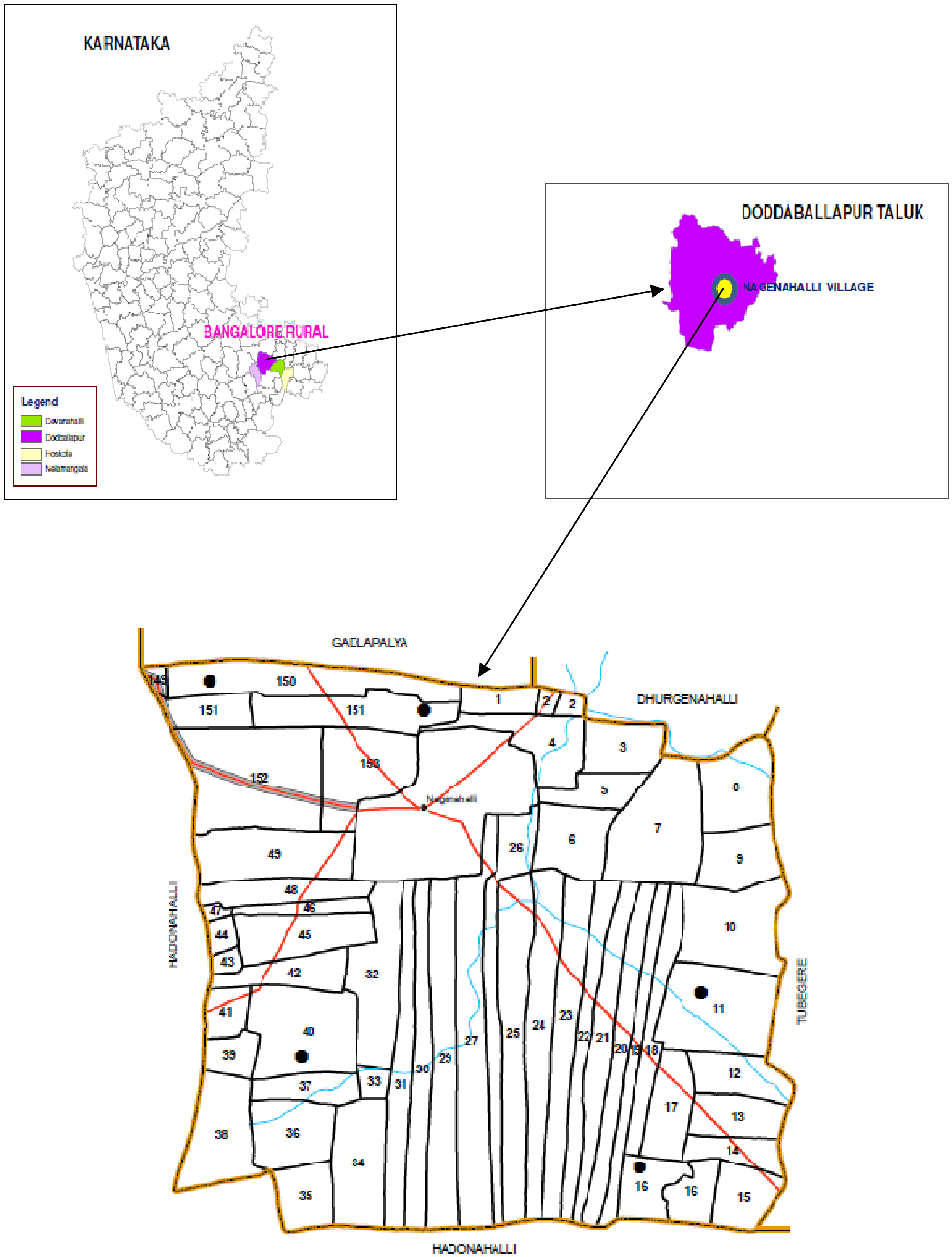


Fig. 3.1 location of the study area in, Doddaballapur taluk, Bangalore Rural District for land resource assessment

3.4 Climate

Climatic data of the study area is obtained from Indian meteorological department (IMD, 2001). Yearly and monthly distribution of normal rainfall, maximum, minimum and mean monthly temperatures were used in the study. Total duration of dry season that is taken as the number of months in which the precipitation falls below 50 mm was also calculated. Water balance diagram was prepared using climatic and soil data of the study area by following the method suggested by Thornthwaite and Mather (1955). The climatic data are given in table 3.1.

3.5 Land use/Land cover

Land use/Land cover mapping of the study area was carried out by visual interpretation techniques as per the land use land cover classification system developed by Department of Space (Anonymous, 1994). Satellite imagery was used along with Google Earth Image. Ancillary data like toposheet and other thematic maps were also refered. The interpreted details were then ground checked to validate and verify the present land use. The corrected details were then transferred on to a base map prepared from the toposheets, to get a final land use map. Fig 3.2. shows methodology followed in the preparation of land use/land cover map of the area.

3.6 Natural vegetation

Parthenium, *Mimosa pudica*, Pandanus, Pongamia, *Lantana camera*, *Eupatorium odaratum* and grasses are the major natural vegetation apart from forest species.

3.7 Data base

Detailed soil survey was carried out by using 1:12,500 (Scale) cadastral map as a basemap, Google Earth image and satellite imagery of the watershed were used in conjunction with SOI toposheet to map the existing land use/land cover. Physiography soil relationship was established using ground truth data. Plate 3.1. Shows the satellite imagery of the Nagenahalli watershed.

Table3.1: Climatic data of Doddaballapur

	J	F	M	A	M	J	J	A	S	O	N	D	Total
P	5.1	10.4	9.4	34.0	77.7	64.8	98.7	108.7	148.7	135.1	53.0	8.4	826.2
PE	118.4	129.7	164.7	158.0	156.0	127.9	116.4	114.0	108.9	104.7	98.4	99.8	1496.9
P-PE	-113.3	-119.6	-156.6	-124.0	-79.3	-62.2	-27.3	-5.3	39.7	28.1	94.9	-94.6	-757.9
APWL	-251.4	-371.0	-527.6	-651.6	-730.9	-793.1	-820.4	-825.7	0.0	0.0	-44.9	-139.5	-5156.1
Stor	1.7	0.28	0.03	0.00	0.00	0.00	0.00	0.00	39.70	67.80	34.96	8.66	153.10
AE	12.1	11.8	9.7	34.0	77.7	64.8	88.7	108.7	109.0	105.0	85.9	34.7	742.1
WD	104.9	118.2	156.4	124.0	79.3	62.2	27.3	5.3	0.0	0.0	12.1	68.3	757.9
WS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean temp (·C)	21.0	23.0	26.0	27.0	24.0	28.0	23.0	23.0	23.0	23.0	23.0	21.0	23.3

Source: soil climatic database for crop planning in India. NBSS and LUP. 1999

Semi arid (moist). Small or no seasonal water surplus. Megathermal.
P-precipation (mm)
PE-Potential evapotranspiration
AE-Actual evapotranspiration
AWC-Available water holding capacity
APWL-accumulated potential water loss
WD-water deficitStor-actual storage of soil moisture ,
WS-water surplus

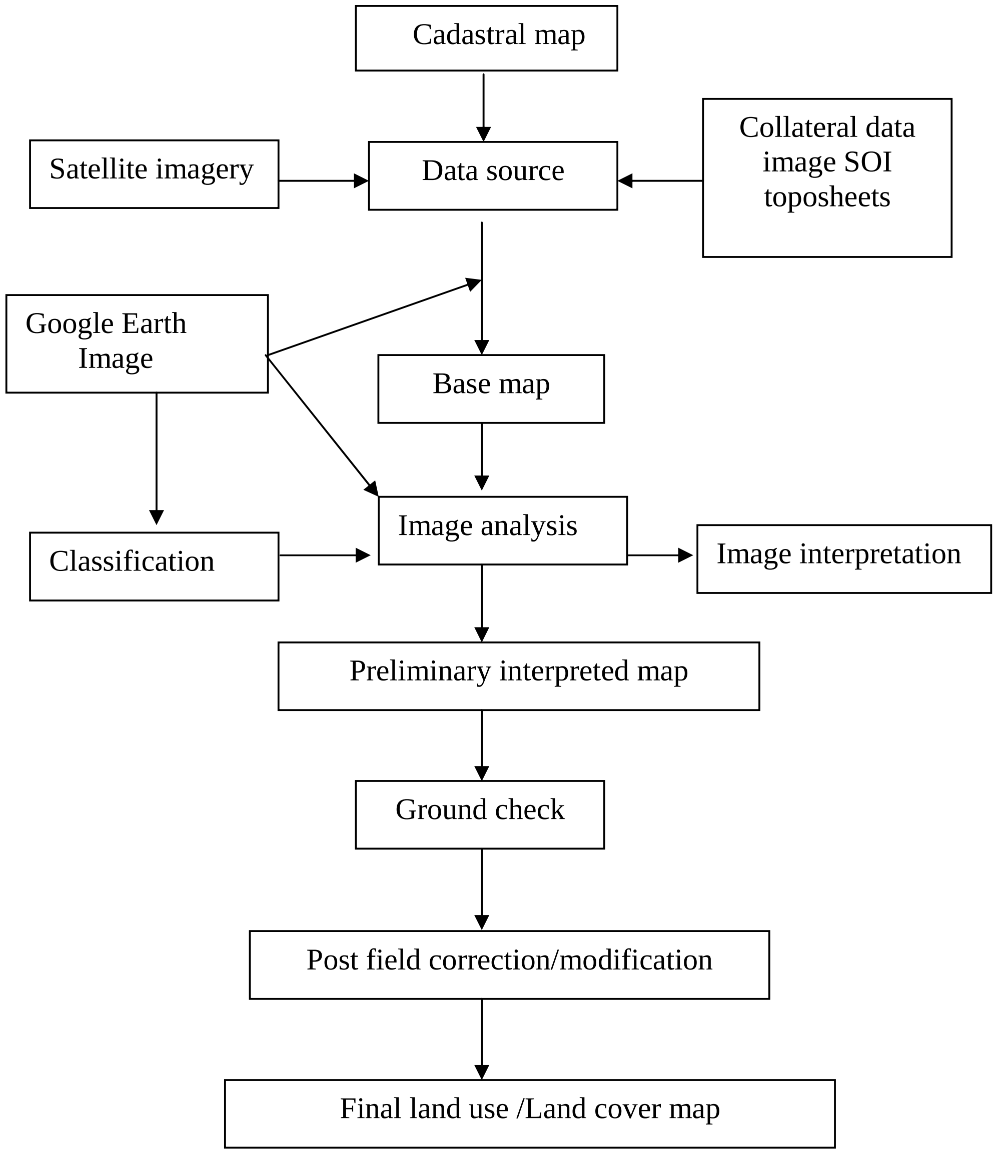
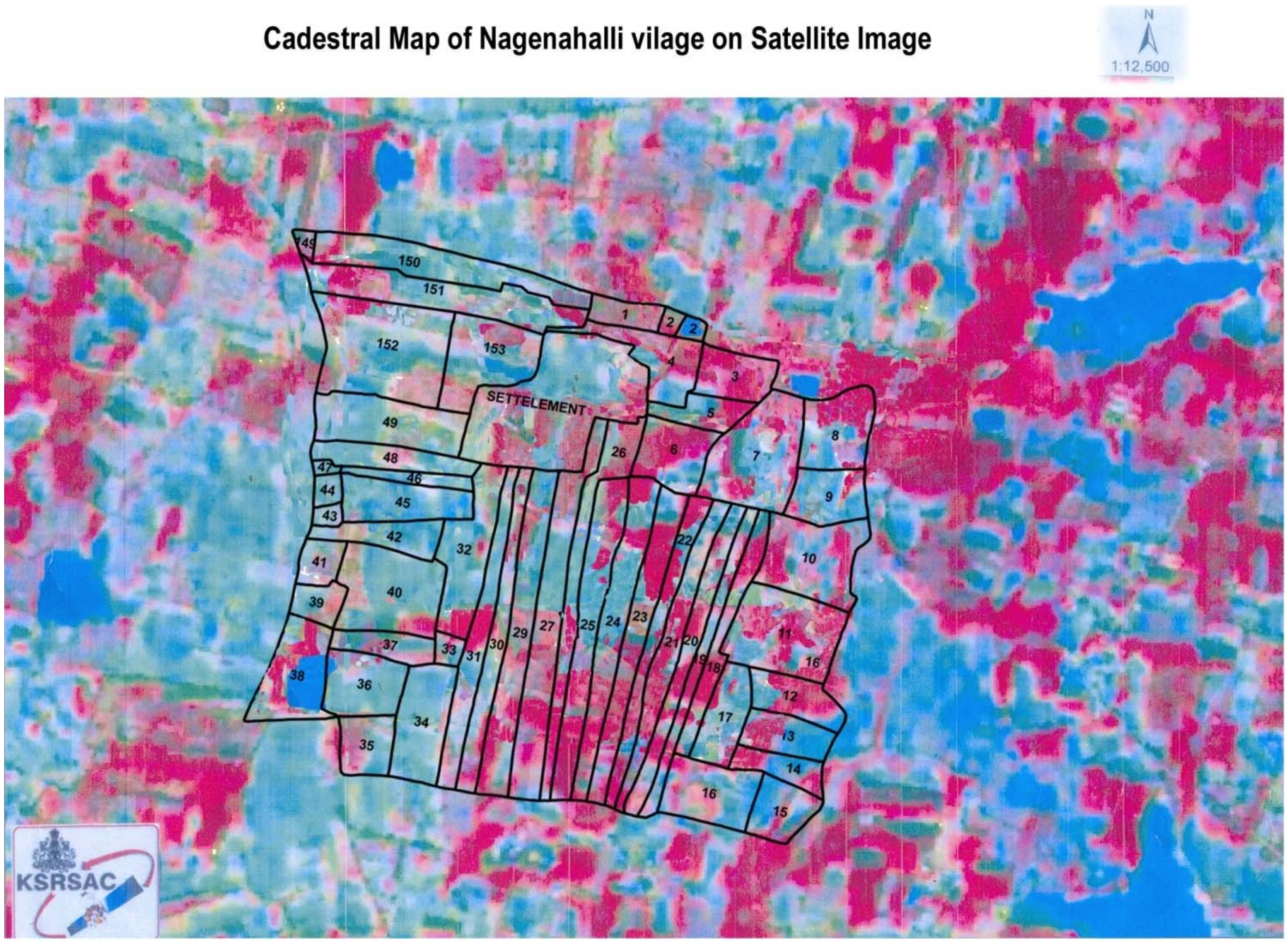


Fig 3.2 Methodology for preparation of land use/land cover map

Modified from Sathish,(2002)



(Imagery 1:12,500 scale, Source: KSRSAC)

Plate 3.1 cadastral map of Nagenahalli village, Doddaballapur taluk, Bangalore Rural District, on satellite image

3.8 Interpretation of satellite imagery

Imagery of Nagenahalli watershed of 1:12,500 scale was collected from Karnataka State Remote Sensing Application Centre, Bangalore. The imaginary was interpreted in conjunction with the toposheet based on the tonal variations, texture and pattern. Permanent structures like roads, settlements, and lakes were marked on the trace sheet mounted on the imagery.

3.9 Traversing and selection of transects

Using base maps, google earth images, satellite imagery and toposheets, physiographic delineations were marked in the study area. Traversing was done to confirm the delineations and to select locations for the study of transects for the pedons.

3.10 Site characteristics

After the traversing, main physiographic units of the study area were identified. Soil profiles were excavated representing each identified physiographic unit in a transects. The site characteristics includes latitude, physiographic-unit, geology, parent material, rainfall, temperature, topography, elevation, erosion characteristics, runoff, drainage, stoniness, rock outcrops, natural vegetation and present land use and crop productivity of the study area were recorded in detail in the prescribed proforma.

3.10.1 Selection and description of sampling sites

Extensive traverse of the village was carried out as the first step to identify field boundaries and to study external land features. Survey numbers given in the cadastral map were identified in the field. Pedon locations were selected along the direction of slope by considering changes observed in external land features like break in slope, erosion, gravel, stoniness etc.

Pedon-1 (13° 22′ 53.3″N; 77° 33′ 07.2″ E)

The site is located at approximately 10 m from Nagenahalli village. The profile was located in the convex lower sector of the very gently sloping upland. The land was ploughed and kept under fallow at present. Maize was grown in the last season. Moderate slope was observed few meters away from the site in the southern side. Site characteristics of pedon 1 are given in table 4.3.

Pedon-2 (13° 22′ 54 ″N; 77° 32′ 55.3″E)

The site is located at approximately 50 m from the village drainage. The profile was positioned on the lower concave sector of the gently sloping upland. The land was presently under rattoon crop of eucalyptus plantation.

Pedon-3 (13° 22′ 34.9″ N; 77° 32′ 59″E)

The site is located near the KVK farm at approximately 500 m from the Nagenahalli village. The profile was positioned on the convex middle sector of the very gently sloping upland. The land was kept fallow at present after field crop of last year. Ground nut and eucalyptus plantations were there in the nearby fields.

Pedon-4 (13° 22′ 33.4″N; 77° 32′ 21.5″ E):

The site is located at approximately 1 km from the Tubagere village. The profile was positioned on the convex middle sector of the nearly level upland. The land was ploughed at present, for cultivating maize and red gram.

Pedon-5 (13° 22′ 20.6″N; 77° 33′ 22.3″ E):

The site is located at approximately 50 m from the Tubagere village. The profile was situated on the level middle sector of the upland. The land was fallow at present, being cultivated by ragi in the nearby field. Fig 3.5 shows Google Earth image depicting the pedon locations.

3.11 Soil morphological studies

At the selected site pedons were opened up to the parent material or up to 150 cm Morphological characteristics were studied horizon-wise for each pedon. The characteristics studied were depth of soil, boundary characteristics, colour, texture, coarse fragments, structure, consistency, size and type of pores and roots, type and quantity of cutans, size and quantity of nodules and any other features. The site and soil characteristics were recorded on a standard proforma as per the guidelines given in the USDA Soil Survey Manual (Soil Survey staff, 1970).

Based on the recorded observations, the soils were grouped into different soil series (Soil series: a group of soils having soil horizons similar or in differentiating characteristics and arrangement with the series control section, except for feature of surface soil and have developed on similar parent material and under comparable climatic and geomarphic environments, AIS and LUS, 1970). Soil depth, amount and nature of gravel, depth of occurrence of gravel layer, nature of substratum present below soil, base saturation, CEC, percent clay, mineralogy, moisture regimes and temperature are the major parameters, which were used to group the pedons studied in the area into different soil series. Using the above characteristics five soil series were established.

3.12 Field investigation

After identification of the soil series, field investigation was done and observations were recorded to map the soil. Variations in surface soils texture, slope, erosion, gravelliness, stoniness and rockiness were used to identify phases of the soil series (phase is subdivision of soil series based on surface features that affect its use and management). Soil samples were collected horizon-wise from pedons of the soils series for laboratory analysis. For the purpose of fertility assessment grid samples were collected from each plot from three points, pooled and halved to make a composite sample per plot.

3.13 Soil sampling

Core samples were collected from each horizon for bulk density estimation. Horizon-wise soil samples were collected from each pedon, for laboratory analysis based on the number of analysis the quantity of soil sample was collected from each horizon. The samples were placed in polythene bags with appropriate labels. Each polythene bag was kept inside the cloth bag and transported to the laboratory.

3.14 Laboratory characterization of soils

The soil samples upon arrival in the laboratory were air dried, ground and sieved through 2-mm sieve. The samples were analyzed for their particle size classes, soil reaction, electrical conductivity, organic carbon, cation exchange capacity, exchangeable hydrogen and aluminium, exchangeable bases etc. following standard procedures outlined in laboratory manual (Sarma *et al.* 1987) composite samples from each plot were also collected and analyzed for soil reaction, available N, P_2O_5, K_2O and micronutrients viz. Fe, Mn, Zn, and Cu. The data obtained were used for preparing various thematic maps.

3.15 Analytical methods

The standard procedures followed for analysis were outlined below.

3.15.1 Soil depth

Depth of solum from the surface to the parent material was measured in the profile by using measuring tape. In case of very deep soils, profiles were opened upto 150cm.

3.15.2 Bulk density

Core samples were collected from each horizon. Soil samples from the core were oven dried at 105°C for 24 hours and cooled in desicator. Weight of the dried sample was recorded. Volume of the core was measured. Bulk density was calculated with weight and volume of the soil (Jackson, 1973).

3.15.3 Soil texture

Particle size distribution of soil samples was determined by the International pipette method, which is based on stokes law after removal of organic matter by hydrogen peroxide and subsequent treatment with dispersing agents. The size fractions determined were sand (2-0.05 mm), silt (0.05-0.002 mm) and clay (<0.002 mm). Sand was separated by sieving method and silt and clay were by pipetting method. The sand was further separated into various size fractions by vibratory dry sieving through a set of six nested sieves. The sieves were separated and the different sand fractions transferred to weighed dishes and dried. The weight of each fraction was taken and presented as percentage of the < 2 mm soil (Richards, 1954).

3.15.4 Soil reaction

Soil reaction was determined in 1:2.5 ratio soils: water suspension by potentiometeric method using glass electrode (Jackson, 1973).

3.15.5 Electrical conductivity

Electric conductivity was measured in the soil: water (1:2.5) extract using conductivity bridge (Jackson, 1973).

3.15.6 Cation exchange capacity and exchangeable bases

Cation exchange capacity of soil samples was determined by NH_4OAc method (Jackson, 1958; Sarma *et al*., 1987). The ammonium acetate extract obtained from CEC estimation was used to determine the exchangeable bases (Ca, Mg, K and Na) using atomic absorption spectrophotometer. The residue was washed to free excess ammonia by leaching with alcohol and distilled to estimate the absorbed ammonia.

3.15.7 Available N

Available nitrogen was estimated with alkali-permanganate method (Subbaiah and Asija, 1956). To 20 g of soil, 100ml of 0.32 per cent $KMnO_4$ and 100 ml of 2.5 per cent NaOH were added and distilled. Ammonia liberated was collected in 4 per cent boric acid and titrated against standard acid (H_2SO_4).

3.15.8 Available P

The soil samples in acidic range were estimated with Bray's method and the soils in neutral and alkaline range were estimated with Olsen's method. Phosphorus estimation was done by colorimetric estimation by ascorbic acid reductant method using both the extracts. (Bray and Kurtz, 1945; Watanabe and Olsen, 1965).

3.15.9 Available K

Available potassium was extracted with neutral normal ammonium acetate solution and subsequent measurement with atomic absorption spectrophotometer (Jackson, 1973).

3.15.10 Micronutrient-Copper, Iron, Manganese, Zinc

Cationic micronutrients such as Iron, Copper, Manganese and Zinc were extracted by DTPA extract (0.005 *M*) (Diethylene Triamine Penta Acetic acid) and 0.01*M* $CaCl_2$ + 0.1 N Triethanalamine at pH 7.3) and the concentration was measured in atomic absorption spectrophotometer as outlined by Jackson (1973).

3.15.11 Organic carbon

Organic carbon was estimated with Walkely and Black method as described by Jackson (1973). In this method, soil was digested with concentrated sulphuric acid in 10 ml of 1 N potassium dichromate making use of heat of dilution of sulphuric acid. Excess of potassium dichromate not reduced by organic matter of the soil was determined by titration with standard ferrous ammonium sulphate in presence of diphenylamine indicator.

3.16 Preparation of base maps

A tracing film was overlaid on the toposheet covering the study area. Boundary of the watershed and important land features like rivers, tanks, roads etc. were extracted. Thus a map having the above common land features was used as a base, it was overlaid with cadastral map, interpreted image and Google Earth image to form the base for mapping.

3.17 Preparation of thematic maps

The soil maps finalized in the field were traced, scanned and digitized using geographical information system (GIS) to get the soil ma. It shows individual field boundaries, the survey numbers, soil series and its phases and other miscellaneous areas. Fig. 3.3 shows methodology for preparation of soil map. From the soil map, thematic

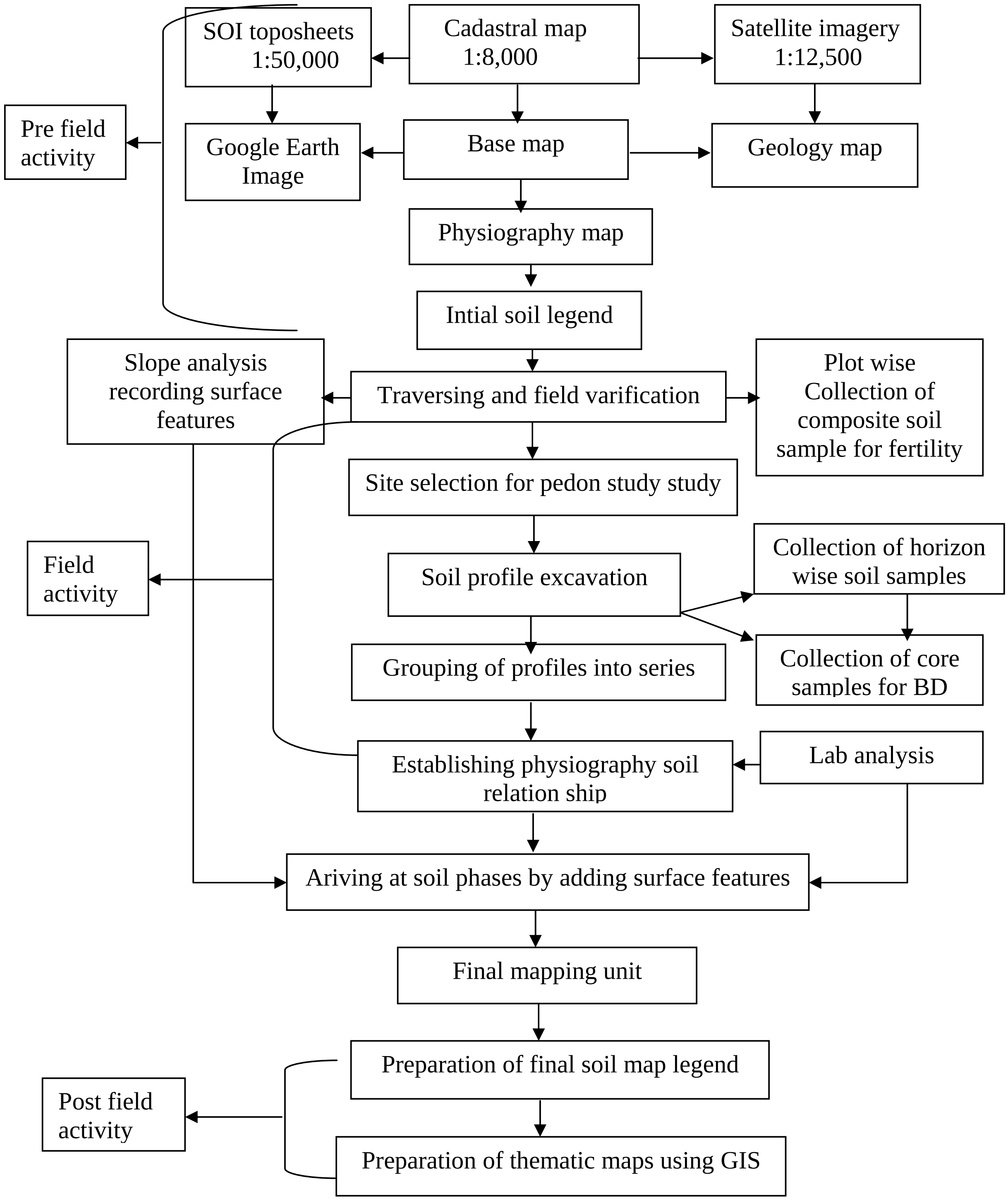


Fig 3.3 Methodology for soil map preparation.

Modified from Sathish, (2002).

maps on soil depth, drainage, slope, soil erosion, surface texture, surface gravelliness, rackiness, available water capacity, surface soil reaction and organic carbon status in the study area were mapped.

3.18 Finalization of soil map using GIS

GIS processing involved georeferencing of various thematic maps and vectorisation of the features using Arc GIS software. Simultaneously the attribute coding and the description for all feature classes were organized in master database tables. The topography was created and the master database was linked to respective themes. All the features were referenced with the standard codes. The soil, land use and watershed themes were built as polygon features, whereas streams and roads were built as line features. The water resources include line features as well as point features and these were included as shape files.

3.19 Land evaluation

Soil fertility and fertility capability and soil suitability classification for major crops were derived as per the standard procedures (AISLUS, 1970 and Naidu et al. 2006).The types of land evaluation methods followed in the present study are given below.

3.19.1 Soil fertility

Plot wise surface samples were collected and analyzed using standard procedures for the status of available nitrogen, available phosphorus, available potassium and available micronutrients. Soil fertility maps showing plot wise status of available major and micronutrients were prepared to know the fertility status of the soils of study area.

3.19.2 Fertility capability classification (FCC)

Fertility capability was prepared for the watershed according to the kinds of problems present for agronomic management of their chemical and physical properties**.** The soil phases of the Nagenahalli watershed are grouped into FCC units based on method proposed by Sanchez *et al.* 1982.

3.19.3 Land suitability classification

The land suitability classification for the major crops like ragi, maize, and vegetables like tomato, carrot and radish of Nagenahalli watershed was attempted based on the parametric approach of FAO (1976). The evaluation was done using several parameters, wherein every soil mapping unit was rated as per limitation technique using given criteria. Land suitability classification is a specific type of land evaluation method, proposed by FAO (FAO 1976 and 1983) to assess the resources of an area for specific crop rather than for a general use. Using the soil site suitability criteria land resources of the watershed were assessed for their suitability for the crops like ragi, maize, vegetables like tomato, carrot and radish and. Table 3.2, 3.3, 3.4, and 3.5 shows criteria used in assessing soil suitability for ragi, maize, tomato, carrot and radish.

Table 3.2 Soil- site suitability criteria for ragi

Soil site characteristics			Rating			
		unit	Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
climatic regime	Mean temperature in growing season	°C	28-34	25-27, 35-38	39-40, 20-24	>40, <20
	Total rainfall	mm	750-900	600-750	450-600	<450
Land quality	Land characteristics					
Moisture availability	Length of growing period	days	>110	90-110	9-60	<60
Oxygen availability to roots	Soil drainage	class	Well to moderate	imperfect	Poorly /excessive	-
Nutrient availability	Texture	class	l, sil, sp, cl,sicl,scl	sic,c,sc	ls,s,c>60 %	-
	pH	1:2.5	5.5-7.5	7.6-8.5 4.5-5.4	8.6-9.5 4.6-4.4	<4.0
Rooting conditions	Effective soil depth	cm	>75	51-75	25-50	<25
	Stoniness	%	5-15	15-40	40-75	>50
	Coarse fragments	Vol %	<15	15-35	35-50	>50
Soil toxicity	Salinity(EC)	ds/m	<1	1-2	2.0-4.0	-
Erosion hazard	Slope	%	<3	3-5	5-10	>10

Source: Naidu *et al.*, 2006

Table 3.3 Soil- site suitability criteria for Maize

Land use requirement		Rating				
		Unit	**Highly suitable (S1)**	**Moderately suitable (S2)**	**Marginally suitable (S3)**	**Non suitable (N)**
Climatic regime	Mean temperature in growing season	°C	30-34	35-38, 26-30	38-40, 26-20	-
Land quality	Soil-site characteristics					
Moisture availability	LGP	Days	>100	100-80	60-80	-
Oxygen availability to roots	Soil drainage	class	Well drained	Mod.To imperfectly	Poorly/excessively	V. poor
Nutrient availability	Texture	class	l,cl,scl, sil	sl,sicl,sic,c (n-s)	c (s-s)	
	pH	1:2.5	5.5-7.5	7.5-8.5 and 5.0-5.5	8.5-9.0 and <5.0	
	CEC	cmol (p+)/kg	>20	15-20	10-15	
	OC	%	High	Medium	Low	
Rooting conditions	Effective soil depth	cm	>100	100-75	75-50	<50
	Coarse fragments	Vol %	Non gravelly	15-35	35-50	>50
Soil toxicity	Salinity (EC saturation extract)	dSm^{-1}	Non saline	1.0-2.0	2.0-4.0	
	Sodicity (ESP)	%	Non sodic	10-15	>15	
Erosion hazard	Slope	%	<3	3-5	5-8	

Source: Naidu *et al.*, 2006

Table 3.4 Land suitability criteria for tomato

Land use requirement		Unit	Rating			
			Highly suitable S_1	**Moderately suitable S_2**	**Marginally suitable S_3**	**Not suitable N**
Climate regime	Mean temperature in growing season	^0C	25-28	29-32 and 20-24	15-20 ,33-36	<15 , >36
	Total rainfall	mm	600-750	500-600 and 750-1000	400-500, >1000	
Moisture availability	Length of growing period	Days	>150	120-150	90-120	
Land quality	Soil-site characteristic					
Oxygen availability to roots	Soils drainage	Class	Well drained	Moderate	Imperfect	Poor
Nutrient availability	Texture	Class	l, sl, cl, scl	sic, sicl, scc(m/k)	c(ss)	ls, s
	pH	1:2.5	6-7	7.1-8.5 and 5-6	<5 and >8.5	
	CEC	C mol (p^+)/kg	>15	10-15	>10	
Rooting conditions	Effective soil depth	cm	75>	50-75	25-50	<25
	Coarse fragments	Vol %	<15	15-35	>35	
Soil toxicity	Salinity (EC saturation extract)	ds/m	Non-saline	Slight	Strongly	
Erosion hazard	Slope	%	1-3	3-5	5-10	>10

Source: Naidu *et al.*, 2006

Table 3.5 Land suitability criteria for carrot and radish

Soil site characteristics	Suitable			Not suitable
Temperature (^oC)	Highly	Moderately	Marginally	
Depth (cm)	15-28 and 18-26	28-32 and 12-18	>32 and <12	-
Drainage	>50	25-50	<25	-
Gravel (%)	Well drained	Moderately to imperfectly drained	Poorly drained	Very poorly drained
Texture	Non gravelly	15-35	35-50	>50
pH	6.0-7.0	7.1-8.5 and 5.0-5.9	>8.0 and<5.0	-
Slope (%)	<3	3-5	5-10	-

Source: Naidu *et al.*, 2006

RESULTS

IV EXPERIMENTAL RESULTS

Results of the investigation carried out on the land resource assessment of Nagenahalli watershed, Doddaballapur taluk, Bangalore Rural District using remote sensing and GIS techniques are presented in this chapter. Remote sensing data products and GIS techniques were used to characterize and classify the soils of Nagenahalli watershed. Study was aimed to map the land resources of the watershed, to identify the problems and potentials for agricultural development and to prepare soils fertility and micronutrient status maps of the watershed.

4.1 Climatic data analysis of the study area

Climate of the study area is semi arid tropical monsoonic type. Mean annual rainfall is about 826.3 mm (IMD, 2001). Rainfall received mainly from South West Monsoon and North East also contributes to some extent. The rainy days extend from July to mid October and maximum rainfall is normally received in the month of mid September followed by October during 35 to 45 standard meteorological weeks (Fig 4.1). The five driest months are November to middle of April.

Water balance study (Fig 4.2) indicated that most of the weeks receive rainfall lesser than the potential evapo-transpiration only in about 8 weeks on an average. 20 weeks on an average receive rainfall more than the half of the potential evaporation requirement. In majority of the weeks, near dry condition prevails in the area.

As per the water balance diagram, the normal length of growing period is around 130-140 days and 180-210 days, during good monsoon years.

Mean annual temperature of area is 23.8 °C, mean maximum temperature is 28.0 °C, mean minimum temperature of the coldest month is 21.0 °C, Mean annual soil temperature is 24.8 °C, mean annual summer soil temperature is 26.1 °C and mean annual summer area temperature is 23 °C. Potential evapotranspiration ranged from 98.4-164.7 mm per month.

Fig Location of the study area in Karnataka-Bangalore rural district, Doddaballapur taluk for land resource assessment.

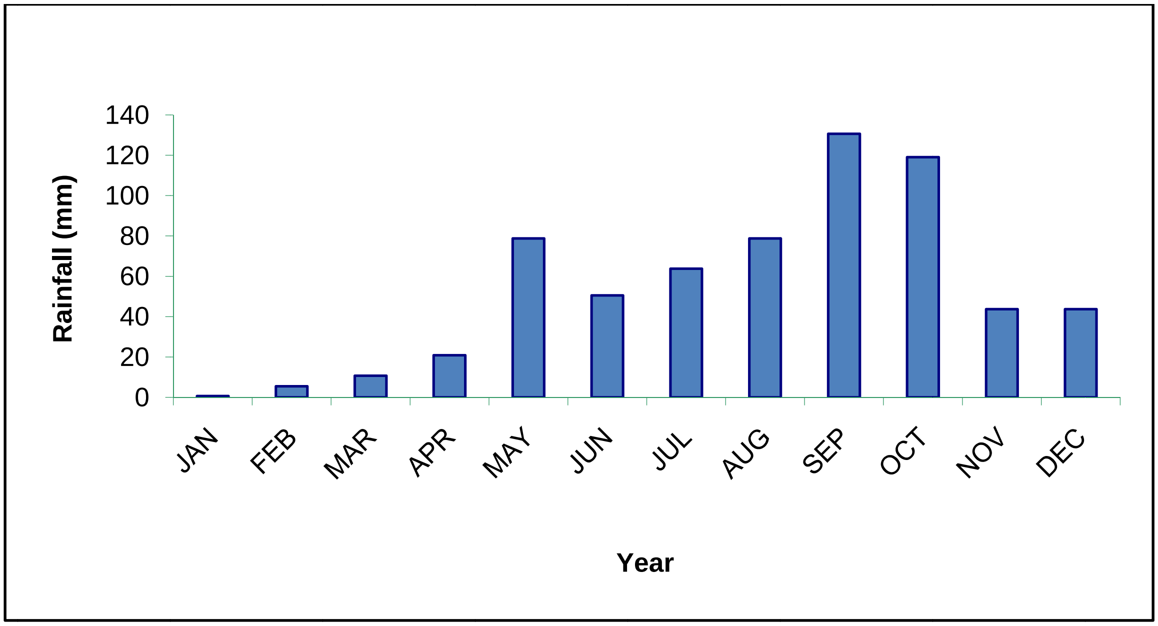


Fig 4.1 Average monthly distribution of rainfall in Doddaballapur taluk for the period from 1969-2001

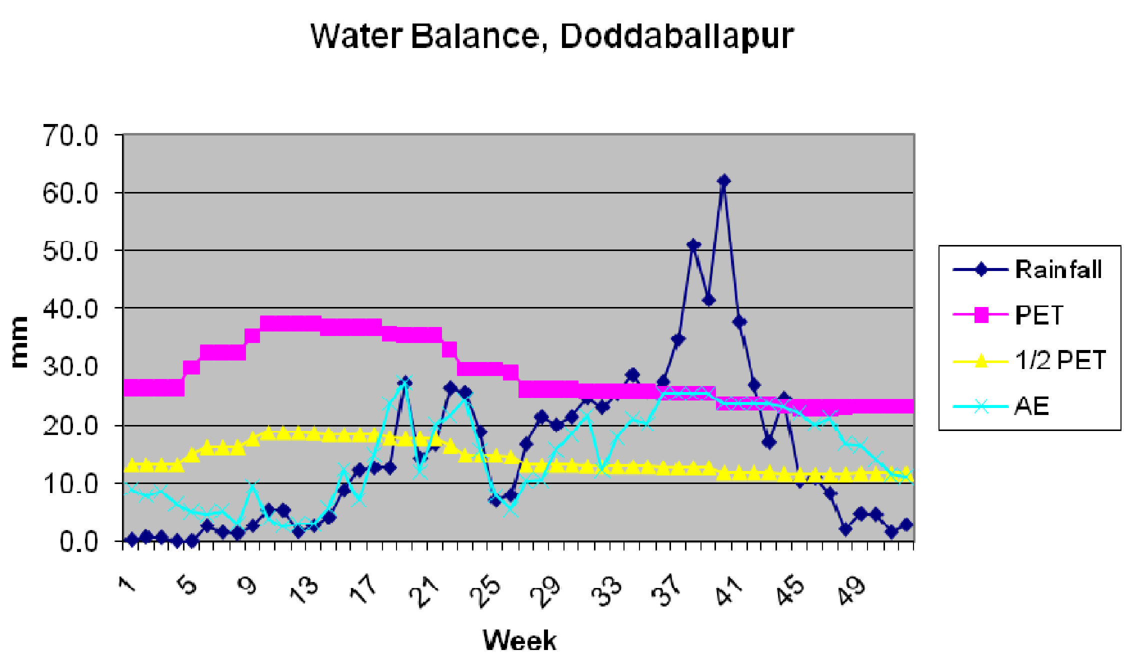


Fig 4.2 Water balance diagram of Doddaballapur taluk.

4.2 Land use

Ragi and maize are the major crops in rainy season and vegetables like tomato, carrot, radish, khol-khol, cucumber chilly were also cultivated in irrigated areas (plate 4.1, 4.2., 4.3). The gently sloping uplands and some lands which are not having irrigation facilities were under eucalyptus plantation which is the prevailing practice in the study area. The land use map of Nagenahalli is shown in map 4.1.

Entire land use of the area is dependent on the onset of monsoon showers. The cropped land occupies 47.9 per cent of the total geographical, followed by cultivable waste which accounts for 19.5 per cent, lands with gentle slops and erosion problems are under Eucalyptus plantation accounts for 16.2 of the total geographical area. The details on land use pattern for Nagenahalli is presented in table 4.1 and fig 4.3.

Table 4.1 Land use pattern in Nagenahalli watershed

Land use particulars	Area	% to TGA
Gross cropped area	107.80	47.9
Current fallow	16.58	7.4
Cultivable waste	43.96	19.5
Eucalyptus plantation	36.60	16.2
Rock outcrops	0.73	0.3
Tank	5.62	2.5
Habitation	13.91	6.2
Total	225.20	100.0

Ragi and red gram based cropping system is the major practice in the study area accounts for 41.5 per cent of the total croped area followed by ragi based cropping system (30.2 %), maize based cropping system accounts for 6.8 per cent and Vegetable based cropping system accounts for 5.2 per cent of the total cropped area. The details on cropping pattern for Nagenahalli are presented in table 4.2 and fig 4.4.

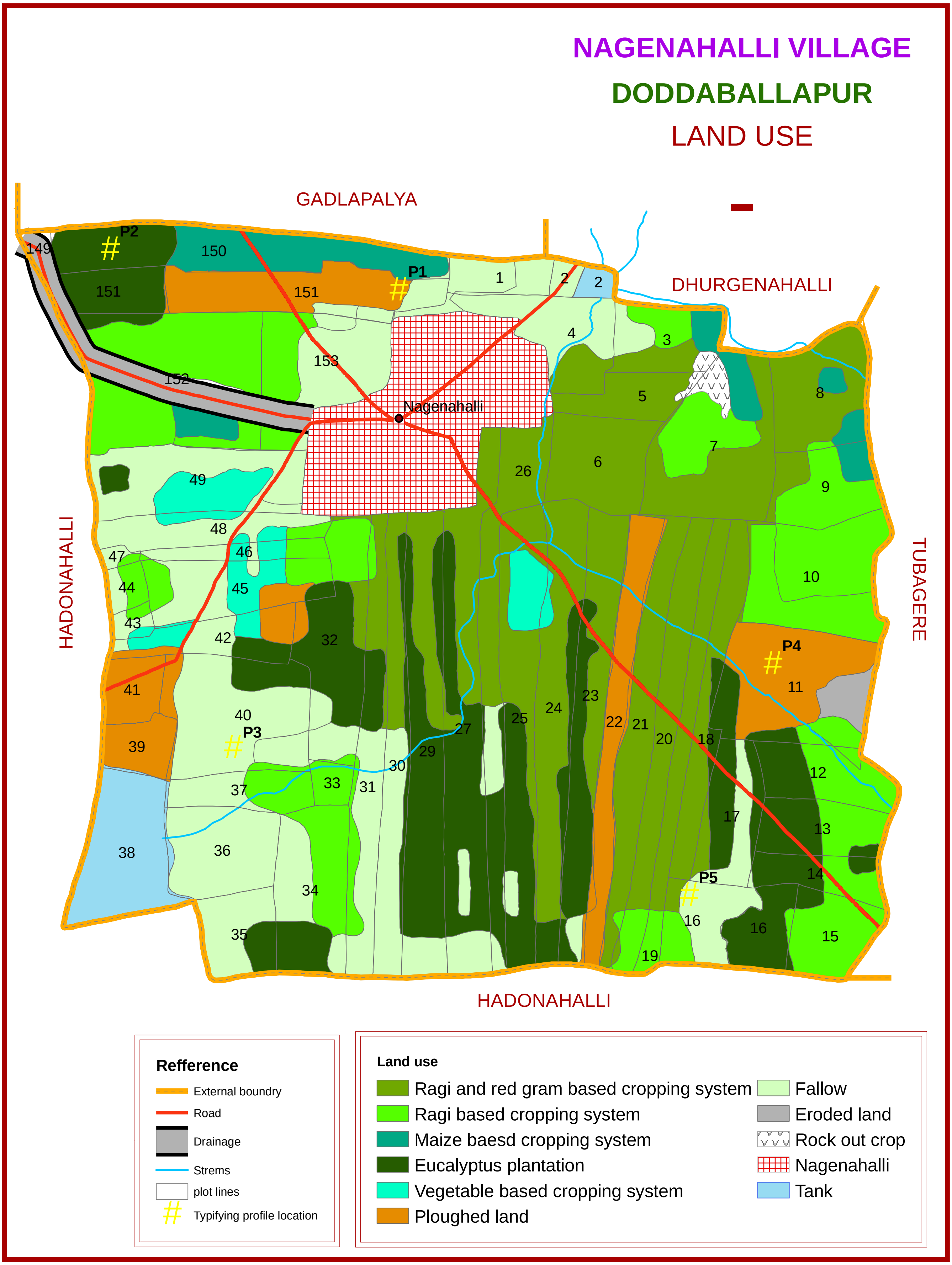


Fig 4.1 Land use map of Nagenahalli villge

Table 4.2 Cropping pattern in Nagenahalli watershed

particulars	Area	% to total cropped area
Ragi based cropping system	37.80	30.2
Ragi and red gram based cropping system	51.95	41.5
Maize based cropping system	8.49	6.8
Vegetable based cropping system	6.56	5.2
Miscellaneous	20.40	16.3
Total cropped area	125.20	100.0

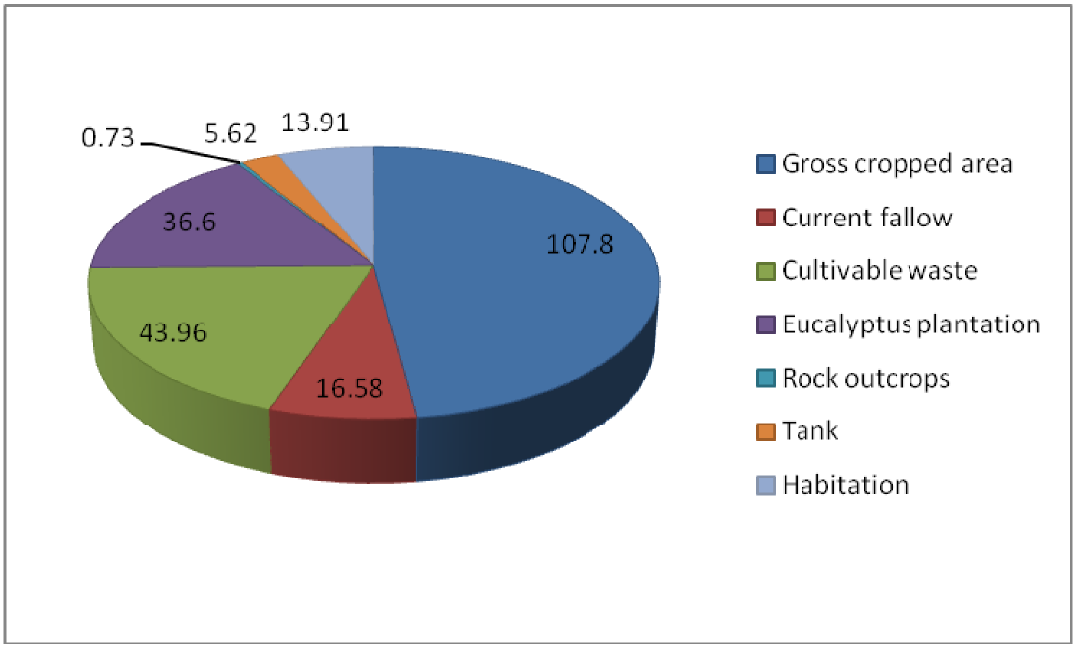


Fig 4.3 Land use pattern in Nagenahalli watershed, Doddaballapur taluk, Bangalore Rural District

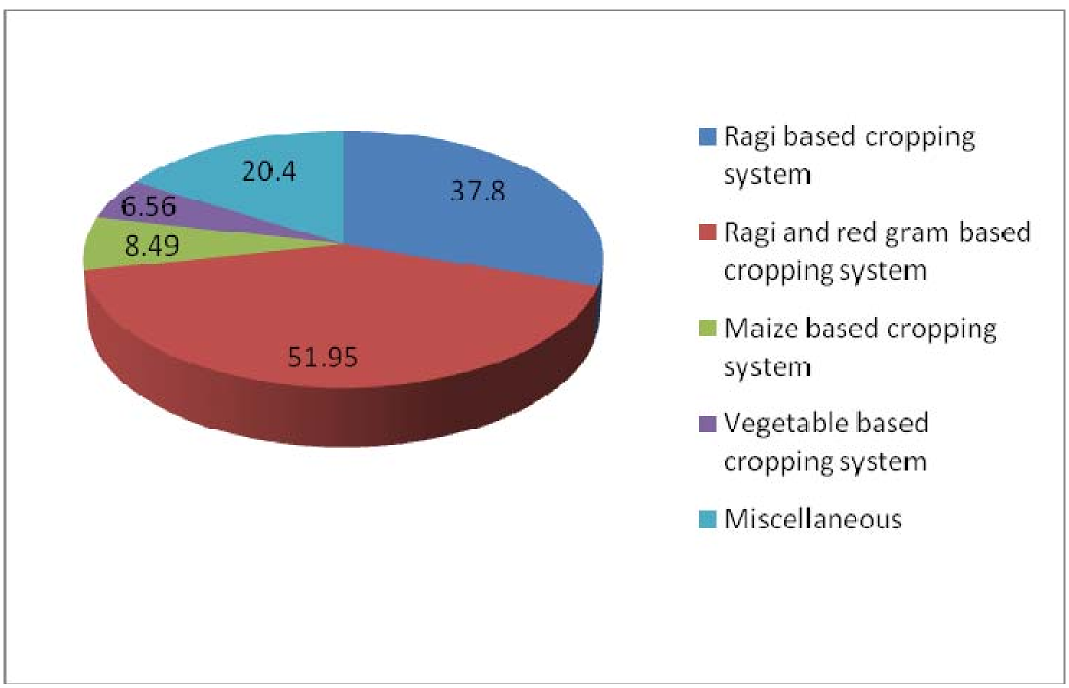


Fig 4.4 Cropping pattern in Nagenahalli watershed, Doddaballapur taluk, Bangalore Rural District

Plate 4.1 Ragi based cropping system in survey No.13

Plate 4.2 Tomato crop in survey No.45

Plate 4.3 Maize crop in survey No.150

4.3 Land resource inventory

The soils of Nagenahalli village occur on granite and granite gneiss land form and were characterized by the upland physiographic units such as level to nearly level linear uplands, level to nearly level uplands on convex upper sector, very gently sloping uplands on convex middle sector, on convex or concave lower sector and on concave lower sector. In Nagenahalli village 5 soil series were identified and classified upto the family level. Soils were classified under Alfisols as per soil taxonomy. The 5 soil series were mapped into 15 mapping units. A map showing soil phases and series association was prepared and shown in map 4.2

4.4 Landform

The watershed is located on uplands. Level to nearly level uplands, very gently sloping uplands and gently sloping uplands are the physiographic delineations observed in the Nagenahalli watershed. The uplands are level to nearly level on convex lower sector, convex middle sector and also on upland summits. Whereas very gently sloping uplands were noticed on convex middle sector and gently sloping uplands were noticed on convex lower sector. Five profile locations were selected for the study (Plate 4.4).

4.5 Imagery interpretation and soil land form relationship

Most of the area under watershed is cultivated and were observed to have dark red colour with uniform texture due to the presence of eucalyptus plantations. Slight decreased red colour indicates ragi and maize based cropping systems and light pinkish red colour indicates the cultivable waste lands which are left as fallow where naturally grown grasses were observed, light green tones indicates the ploughed areas which are presently under fallow, and blue colour indicates the water body, rarely at one or two places dark brown patches were observed in the imagery and they were identified as boulders or rock lands from the toposheet. Very gently sloping uplands and gently sloping uplands were observed with whitish tones due to dominance of sand in surface, since whitish tones were higher along the dried natural water courses like streams. The interpretation of False colour colour composites of satellite image are given in table 4.3.

Table 4.3 Satellite image interpretation

Sl.no	FCC colour codes	FCC texture code	Interpretation
1	Dark red	Uniform coarse texture	Eucalyptus plantation
2	Dark red	Fined texture with lined uniformity	Maize based cropping system
3	Faint red	Coarse texture with lined uniformity	Ragi and ground nut based cropping system
4	Pinkish red	Uniform fine texture	Cultivable waste lands with grassy cover
5	Light green with yellowish tinge	Corse texture	Ploughed land showing red soils
6	Light brown	Fine texture	Sheet wash eroded with crusted red soils.
7	Dark brown	Fine texture	Granite rocky area
8	Dark blue fine texture	Fine texture	Water body
9	White	Coarse texture	Sandy surface

* FCC: False Colour Composite

The physiography of the area comes under nearly level upland to very gently sloping upland. In each physiographic unit, profiles were studied depending upon slope in order to establish relationship between physiography and soil erosion is observed in all these uplands. In general sheet wash/slope wash are the dominant geomorphic processes of erosion observed on these erosional upland. The profiles examined showed increasing soil development with increasing depth. The weathering front is observed to be more than 150 cm from the surface. The soil profiles examined have showed well developed illuvial horizon with their clay cutons. The pedon in the level to nearly level uplands on the convex middle sector and pedon in the gently sloping uplands on the convex lower sector are characterized by gravel layer on subsurface at above 45 cm with mostly of quartz and feldspars. Accordingly the area was selected to assess the land resources and to study and map the fertility status of soils to have better land management options. Fig 4.5 shows land form-soil relationships in the Nagenahalli watershed.

4.6 Characterization and classification of soils

4.6.1 Characterization of soils

The identified soil series were characterized for its morphological, physical and chemical properties. Soil samples collected from representative profiles of each series were analyzed for their physico-chemical properties and presented in tables.

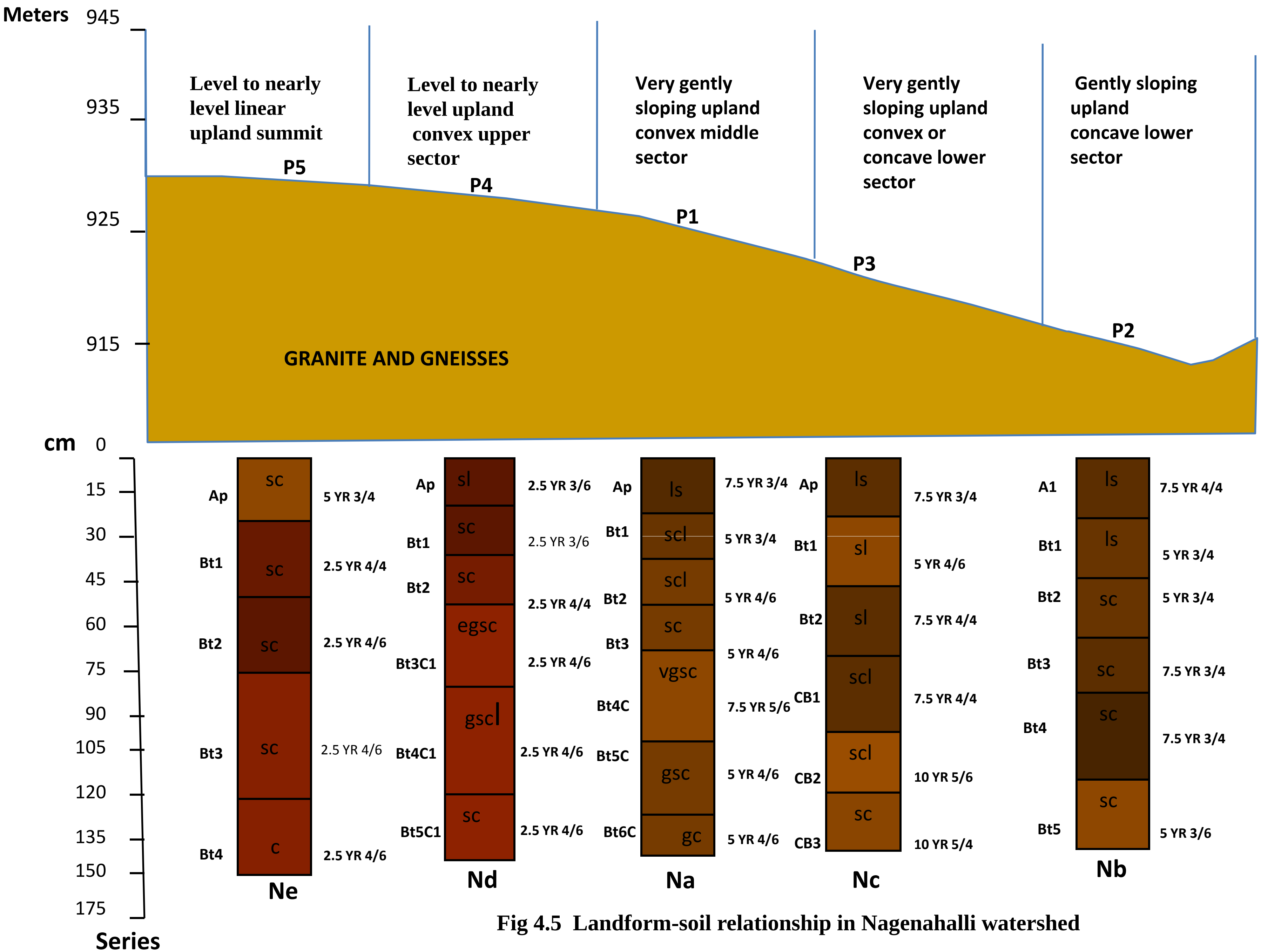


Fig 4.5 Landform-soil relationship in Nagenahalli watershed

Table 4.4 Details of pedons identified for assessment of land resources of the watershed

Study area	Pedon no.	Land forms	Land use
Nagenahalli	1	Very gently slopping upland	Ploughed land (Maize in nearby plots)
	2	Gently slopping upland	Eucalyptus plantation (Rattoon crop)
	3	Very gently slopping upland	Fallow land (Ground nut and eucalyptus in nearby plots)
	4	Nearly level upland	Ploughed land (Red gram and ragi in nearby plots)
	5	Nearly level upland	Fallow land (Ragi and eucalyptus in nearby plots)

4.6.1.1 Pedon-1

4.6.1.1.1 Site characteristics

The site is located at approximately 100 m from Nagenahalli village. The profile is located in the convex lower sector of the very gently sloping upland with a slope lenth of 300 to 600 m and slope gradient of 0-1 per cent, at an elevation of 918 m from MSL (plate 4.5). Maize was grown in the last season. Site characteristics of pedon 1 are given in table 4.5 and plate 4.6

4.6.1.1.2 Morphology

Solum depth was more than 150 cm (Plate 4.7). Soil colour of the horizon varied from dark brown in the surface (7.5 YR 3/4) to yellowish red (5YR 4/6) in the sub

(Source: Google earth)

Plate 4.4 Land scape and pedon locations in Nagenahalli watershrd, Doddaballapur taluk, Bangalore Rural District

(Source: Google earth)

Plate 4.5 Land scape and location of pedon 1 in Nagenahalli watershed

Plate 4.6 Site characteristics of pedon 1 in Nagenahalli watershed

Table 4.5 Site characteristics of pedon 1

Location: 100 m from Nagenahalli village , Doddaballapur taluk, Bangalore Rural District, Karnataka; 13º 22' 20.6″ N latitude and 77º 33' 22.3″ E longitude.

Climate: Semiarid tropical

Elevation: 918 m above MSL

Rain fall: 889.0 mm

Mean annual temperature: 23.8 ºC

Slope: 0-1 %; Surrounding country: Undulating

Erosion: Slight

Drainage: Well drained

Soil parent material: Granite-Colluvium

Land use: Ploughed, maize, ragi and beans in near by plots

Average yield: Maize: 1200 kg/ha

Soil classification: Fine, kaolinitic, isohyperthermic, Typic Kandiustalfs

Plate 4.7 Profile view of Pedon 1 in Nagenahalli village-Survey No 151

surface horizon. The structure was moderate fine subangular blocky in the surface and moderate, medium to coarse subangular blocky in sub surface with many coarse pores in the surface layer and common fine pores in the second and third layer and few very fine pores in remaining layers. Abrupt smooth boundary between first and second and between fourth and fifth horizon was observed and in the remaining horizons the boundary was clear and smooth. Many very fine to few very fine roots were observed in the surface and Bt1 horizon. There were seven horizons observed in the profile (Ap, Bt1, Bt2, Bt3, Bt4C, Bt5C, Bt6C). Patchy thin clay skins in the second and fifth horizon and continuous to thick patchy clay skins were observed in the remaining horizons. Few fine faint red to brown mortals (2.5 YR to 10 YR hue) were present throughout the subsurface horizon. Rock fragments were found in fifth, sixth and seventh horizon ranging from 25 to 40 percent. The consistency was slightly hard, friable to very hard, firm towards depth and stickiness and plasticity also increased with depth which varies from non sticky non plastic to very sticky plastic (Fig 4.6 and table 4.6).

4.6.1.1.3 Physical properties

The texture of the pedon varied from loamy sand in surface to sandy clay in subsurface horizon. Clay content was increasing from 10 percent to 48.5 percent with depth. The soils of Bt4C, Bt5C and Bt6C were very gravelly to gravelly in nature having coarse fragments to the extent of 25 to 40 percent. Bulk density ranged from 1.27 to 1.65 Mg m^{-3} which was decreased with depth and had low organic carbon content ranging from 0.07 to 0.39 per cent. The soils have low to medium water holding capacity ranging from 50 to 150 mm m^{-1} and water holding capacity decreased with depth (Table 4.7).

4.6.1.1.4 Chemical properties

The soil pH was slightly acidic to neutral with electrical conductivity range of 0.03 to 0.09 dSm^{-1} from surface to sub surface horizons. Highest EC was recorded in the Bt5 horizon and lowest in the surface horizon. Cation exchange capacity ranged from 3.2 to 6.1 cmol (p+) kg^{-1} and the highest CEC was recorded in the surface horizon and Bt1 horizon recorded the lowest CEC. The dominant cation was Ca in the soil ranged from 1.18 to 2.6 cmol (p+) kg^{-1} followed by Mg, Na, and k. Mg ranged from 0.41 to 0.70 cmol

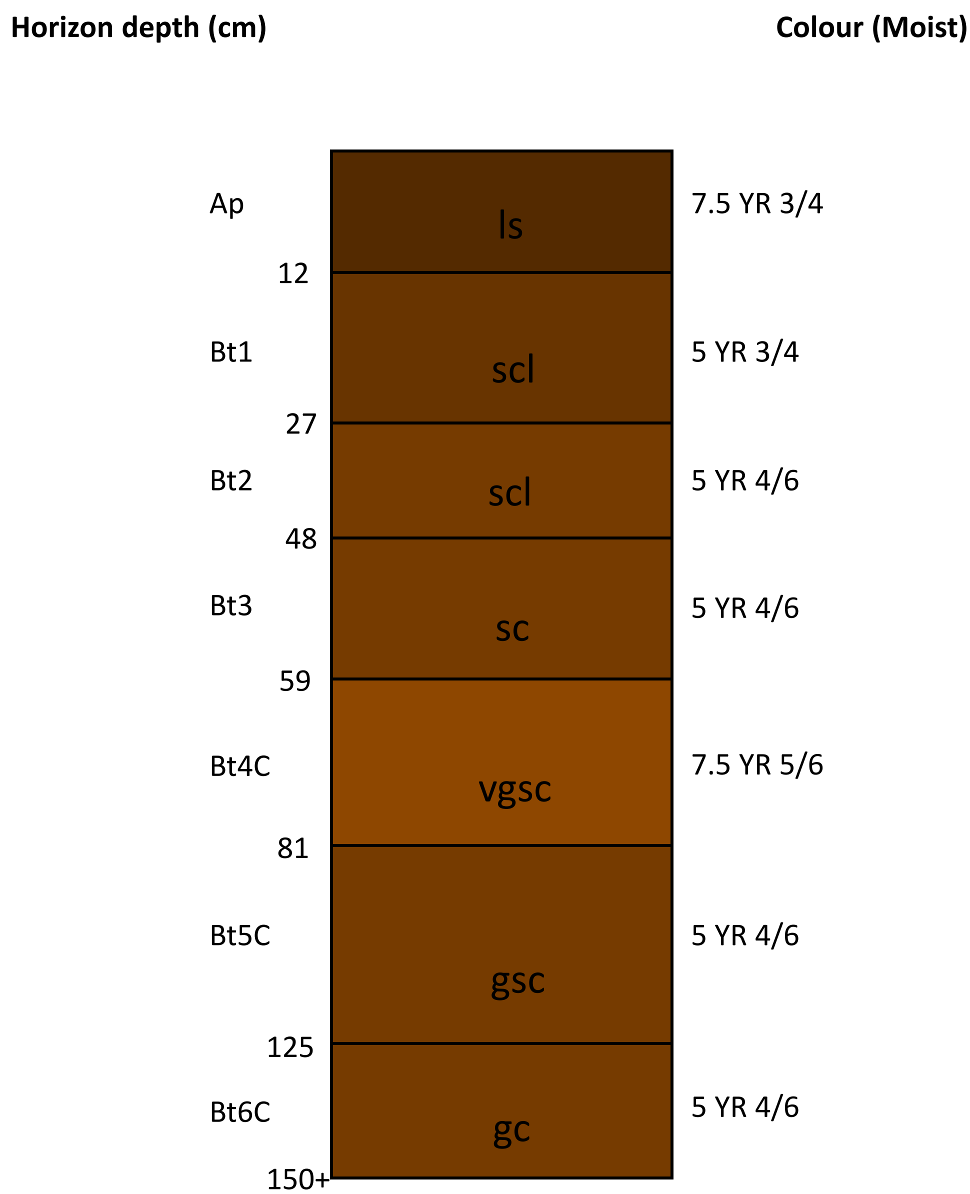


Fig 4.6 Profile diagram of pedon 1, Nagenahalli watershed, Doddaballapur taluk, Bangalore rural district

Table 4.6 Soil morphology of pedon 1

Ap	0-12	Dark brown (7.5 YR 5/4 M), brown (7.5 YR 4/4 D) loamy sand; moderate fine sub angular blocky structure; slightly hard, friable, non sticky and non plastic consistency; many very fine roots and many medium pores; moderately acid (5.9) and abrupt smooth boundary.
Bt1	12-27	Dark reddish brown (5YR 3/4 M), reddish brown (5YR 4/4 D) sandy clay loam; moderate medium sub angular blocky structure; very hard, friable sticky and plastic consistency; few very fine roots and common fine pores; patchy thin clay skins; strongly acid(5.3) and clear smooth boundary
Bt2	27-48	Yellowish red (5YR 4/6), sandy clay loam; moderate medium sub angular blocky structure; friable, sticky and plastic consistency; common fine pores; patchy thick clay skins; moderately acid (5.8) and clear smooth boundary.
Bt3	48-59	Yellowish red (5YR 4/6), sandy clay; moderate medium sub angular blocky structure; firm, very sticky and plastic consistency; common very pores; continuous thick clay skins; few fine faint red (2.5 YR 4/6) few fine faint mottles; slightly acid (6.2) and abrupt smooth boundary.
Bt4C	59-81	Strong brown (7.5 YR 5/6) sandy clay; dark brown (7.5YR 3/4M) clay; moderate coarse sub angular blocky structure; firm, very sticky and plastic consistency; few very fine pores; continuous thick clay skins; few fine faint brown (10YR 4/8) mottles; neutral (6.9) and clear smooth boundary.
Bt5C	81-125	Yellowish red (5 YR 4/6) sandy clay; moderate coarse sub angular blocky structure; firm, very sticky and plastic consistency; few fine pores; patchy thick clay skins; few fine faint red (2.5YR 4/6) morttles; neutral (7.0) and clear smooth boundary.
Bt6C	125- 150+	Yellowish red (5 YR 4/6)clay; moderate coarse sub angular blocky structure; firm, very sticky and plastic consistency; few very fine pores; patchy thin clay skins; few fine faint yellowish brown(10YR 6/4) morttles; neutral (6.8) and clear smooth boundary.

(p^+) kg^{-1} .Na ranged from 0.11 to 0.34 c mol (p+) kg^{-1} and k was in the range of 0.06 to 0.16 cmol (p+) kg^{-1}(Table 4.8).

4.6.1.1.5 Fertility properties

Major available nutrients like N, P (P_2O_5), K (K_2O) ranged from 94.1 to 627.2, 15.6 to 62.5, 73.2 to 170.0 kg/ha respectively. Highest amount of available nitrogen was recorded in the surface horizon of the profile. Decreasing trend was observed in N concentration with increasing depth. Highest amount of P and K were recorded in Bt3 and Bt5 horizons respectively among micronutrients Fe recorded the highest amount in the whole profile which ranged from 1 to 23 mg/kg, followed by Mn, Cu and Zn. Highest amount of Cu was found in Bt2 horizon, Fe and Mn were found highest in Bt1 and Zn was found highest in surface horizon (Table 4.9).

4.6.1.2 Pedon -2

4.6.1.2.1 Site characteristics

The site is located at approximately 50 m from the village drainage. The profile is positioned on the lower concave sector of the gently sloping upland with a slope length of 300 to 600 m and slope gradient of 3-5 per cent, at an elevation of 914 m from MSL (Plate 4.8). The land was presently under eucalyptus plantation. Site characteristics of pedon 2 are given in table 4.10 and plate 4.9.

4.6.1.2.2 Morphology

The solum depth was more than 150 cm (Plate 4.10), soil colour of the surface horizon was brown (7.5 YR 4/4) and the color of the subsurface horizon varied from dark reddish brown (5 YR 3/4) to yellowish red (5 YR 4/6). The structure of the surface horizon was weak fine sub angular blocky and in sub surface horizon the structure varied from moderate medium to coarse and strong medium sub angular blocky with many medium pores at the surface and few fine to very fine pores in the sub surface. Six horizons were observed in this profile (A1, A2, Bt1, Bt2, Bt3, and Bt4). Abrupt smooth boundary was observed between first and second horizon and clear to gradual smooth boundary was observed between the subsequent horizons. Many very fine to few fine

Table 4.7 Physical properties of pedon 1

Ngh **P1:** Fine, kaolinitic, isohyperthermic, Typic Kandustalfs

Pedon location: 100 m from Nagenahalli village, Doddaballapur taluk, Bangalore Rural District (13 25 53.30 N; 77 33 7.20 E)

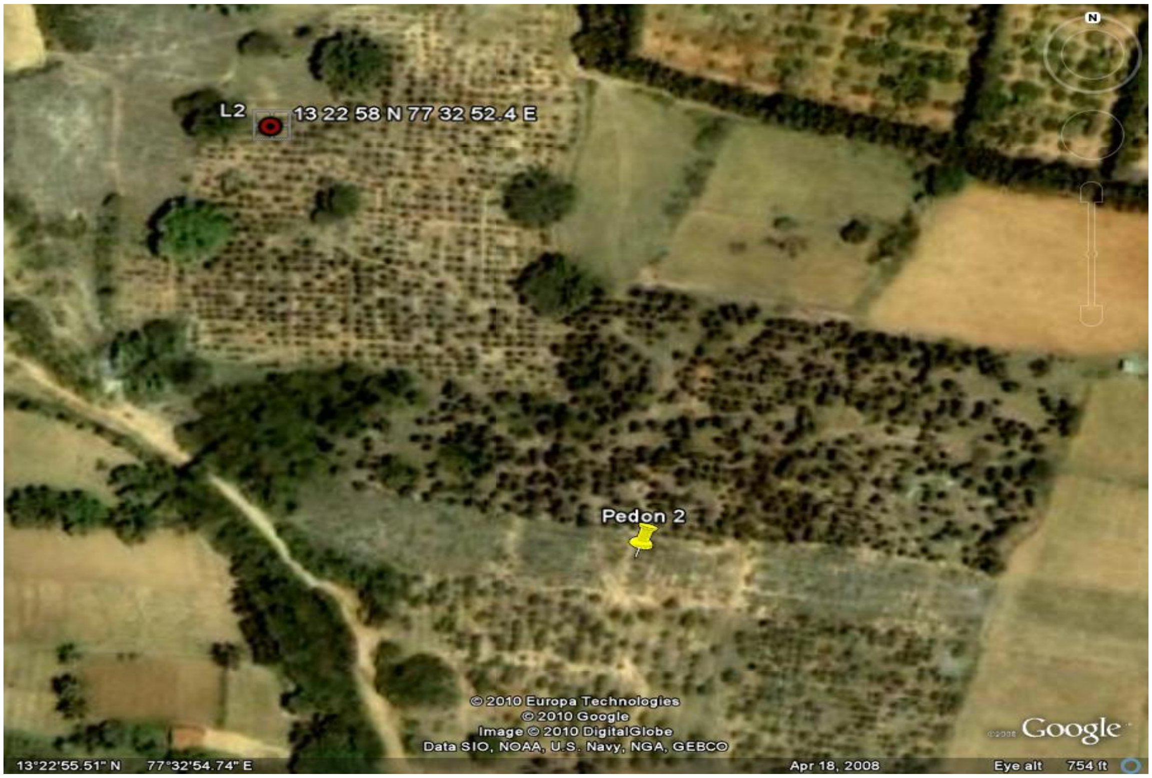
Depth (cm)	Horizon	BD Mg m^{-3}	Particle-size distribution (%)								Coarse fragments whole soil vol.%	Texture class (USDA)	Org.C (%)	AWC (mm m^{-3})
			Sand(mm)						Silt (mm)	Clay (mm)				
			V.coarse 2-1	Coarse 1-0.5	Medium 0.5-0.25	Fine 0.25-0.1	V.fine 0.1-0.05	Total	0.05-0.002	<0.002				
0-12	Ap	1.50	3.04	13.17	27.94	7.08	35.23	86.50	3.50	10.00	-	ls	0.39	120
12-27	Bt1	1.46	4.80	11.10	18.11	30.09	8.40	72.50	1.50	26.00	-	scl	0.36	150
27-48	Bt2	1.65	3.01	9.26	23.53	24.75	11.41	72.00	2.00	26.00	-	scl	0.29	150
48-59	Bt3	1.40	9.41	9.43	17.28	14.48	8.3	54.05	5.50	44.40	-	sc	0.25	110
59-81	Bt4C	1.50	12.13	12.5	12.9	23.9	18.9	48.00	3.50	48.50	35-40	vgsc	0.14	50
81-125	Bt5C	1.34	11.84	13	4	16.4	4	49.00	2.50	48.50	25-30	gsc	0.07	70
125-150+	Bt6C	1.27	7.4	6.99	5.29	16.03	9.79	45.50	7.00	47.50	25-30	gc	0.07	90

Table 4.8 Chemical properties of pedon 1

Depth (cm)	Exchangeable bases					Extractable acidity			Cation exchange capacity			Base saturation		Ratio to clay
	Ca	Mg	Na	K	Total	$BaCl_2$-TEA	1N KCl H^+	1N KCl Al^{3+}	NH_4OAc	Sum of cations	ECEC	NH_4OAc	Sum of cations	CEC NH_4OAc
	< -- cmol (P+) kg ^{1} -------------- >											< ------- % ----->		
0-12	1.50	0.50	0.27	0.12	2.39	12	0.06	_	3.20	15.24	3.24	75	21	0.61
12-27	2.60	0.42	0.11	0.11	3.24	14	0.06	_	6.10	16.39	2.39	53	14	0.12
27-48	1.18	0.56	0.19	0.06	1.99	6	0.01	_	3.70	7.99	1.99	54	24	0.14
48-59	1.25	0.60	0.34	0.09	2.28	14	0.01	_	5.00	16.28	2.25	46	14	0.11
59-81	1.40	0.70	0.24	0.14	2.48	_	_	_	5.10	2.48	2.48	49	100	0.10
81-125	1.81	0.69	0.26	0.16	2.92	_	_	_	4.70	2.92	2.92	62	100	0.09
125-150+	1.92	0.41	0.17	0.12	2.62	_	_	_	4.30	2.62	2.62	61	100	0.09

Table 4.9 **Fertility properties of pedon 1**

Depth (cm)	Horizon	pH (1:2.5)		EC dSm^{-1}	Major available nutrients ($kg\ ha^{-1}$)			Micronutrients ($mg\ kg^{-1}$)			
		H_2O	1*M* KCl		N	P_20_5	K_2O	Cu	Fe	Mn	Zn
0-12	Ap	5.96	6.16	0.07	627.20	65.64	133.72	1.22	18.80	10.20	2.60
12-27	Bt1	5.35	4.10	0.09	595.84	28.72	170.01	1.60	23.00	30.80	0.56
27-48	Bt2	5.86	4.50	0.09	125.44	18.50	144.48	2.80	22.20	10.20	0.62
48-59	Bt3	6.27	4.42	0.09	156.80	22.50	104.16	0.92	12.40	4.96	0.44
59-81	Bt4C	6.51	4.70	0.03	268.80	30.80	73.24	0.50	5.40	4.86	0.14
81-125	Bt5C	6.51	5.39	0.04	188.16	38.50	122.97	0.40	1.00	3.38	0.12
125-150+	Bt6C	6.89	5.45	0.03	94.08	23.08	127.68	0.16	1.80	2.56	0.80



(Source: Google earth)

Plate 4.8 Land scape and location of pedon 2 in Nagenahalli watershed

Plate 4.9 Site characteristics of pedon 2 in Nagenahalli watershed

Table 4.10 Site characteristics of pedon 2

Location: 50 m from village drainage, Nagenahalli, Doddaballapur taluk, Bangalore rural district, Karnataka; 13 º 22' 20.6″ N latitude and 77º 33' 22.3″ E longitude.

Climate: Semiarid tropical

Elevation: 914 m above MSL

Rain fall: 889.0 mm

Mean annual temperature: 23.8 ºC

Slope: 3-5 %; Surrounding country: Undulating

Erosion: Moderate

Drainage: Moderately well drained

Soil parent material: Granite

Land use: Eucalyptus

Average income: Rs. 10,000-15, 000/- per acre once in 5 years.

Soil classification: Fine, kiolinitic, isohyperthermic, Typic Kandiustalfs.

Plate 4.10 Profile view of pedon 2 in Nagenahalli village- Survey No 150

roots were observed up to Bt2 horizon. Few firm faint yellow (10 YR 6/4) mottles were observed in fifth horizon and continuous thick to patchy thick clay skins were observed in the subsequent horizons. The consistency of the surface soil was slightly hard, friable, non sticky and non plastic and it was very hard to extremely hard, firm to very firm and very sticky plastic from A2 to Bt2 horizon and hard, firm and very sticky plastic in Bt3 and Bt4 horizons (Fig 4.7 and table 4.11).

4.6.1.2.3 Physical properties

The texture varied from loamy sand to sandy clay from surface to sub surface horizon. Clay content was increased from surface to subsurface horizon by 11-42 per cent, the BD was 1.66 mg m^{-3} in the surface horizon and 1.67 in the subsurface Bt_5 horizon and low organic carbon content was noticed in the profile ranging from 0.03 to 0.43 per cent and it decreased with depth. The soils recorded the medium water holding capacity ranged from 110-120 mm m^{-1} (Table 4.12).

4.6.1.2.4 Chemical properties

The soil pH of the pedon ranged from strongly acidic to neutral, strong acidity was noticed in the surface horizon, and in the Bt2, Bt3, B4 & Bt_5 horizons the pH was ranging from 4.7 to 6.77. The electrical conductivity of the profile ranged from 0.01to 0.03 dsm^{-1}. Cation exchange capacity ranged from 2.80 to 6.60 cmol (p^+) kg^{-1}. Highest CEC was recorded in the Bt4 horizon and the surface A horizon. A2 & Bt1 horizons had recorded more CEC compared to the Bt2 & Bt3 horizons. Among exchangeable bases Ca was the dominant cation in the soil and it ranged from 1.25 to 2.82 cmol (p^+) kg^{-1} followed by Mg, Na and K. Mg ranged from 0.21 to 0.82, cmol(p^+) kg^{-1}, Na ranged from 0.13 to 0.18 and K was in the range of 0.09 to 0.15 cmol(p^+) kg^{-1}(Table 4.13).

4.6.1.2.5 Fertility properties

Major available nutrients like available N, P(P_2O_5) and potassium (K_2O) ranged from 25.1 to 186.8, 3.6 to 22 and 102.1 to 162.6 kg/ha respectively. High amount of N is recorded in surface and Bt1 horizon and the N content suddenly decreased to 25.08 kg/ha in Bt2 and Bt3 horizons and again the N content rises to highest in Bt4 and Bt5 horizons.

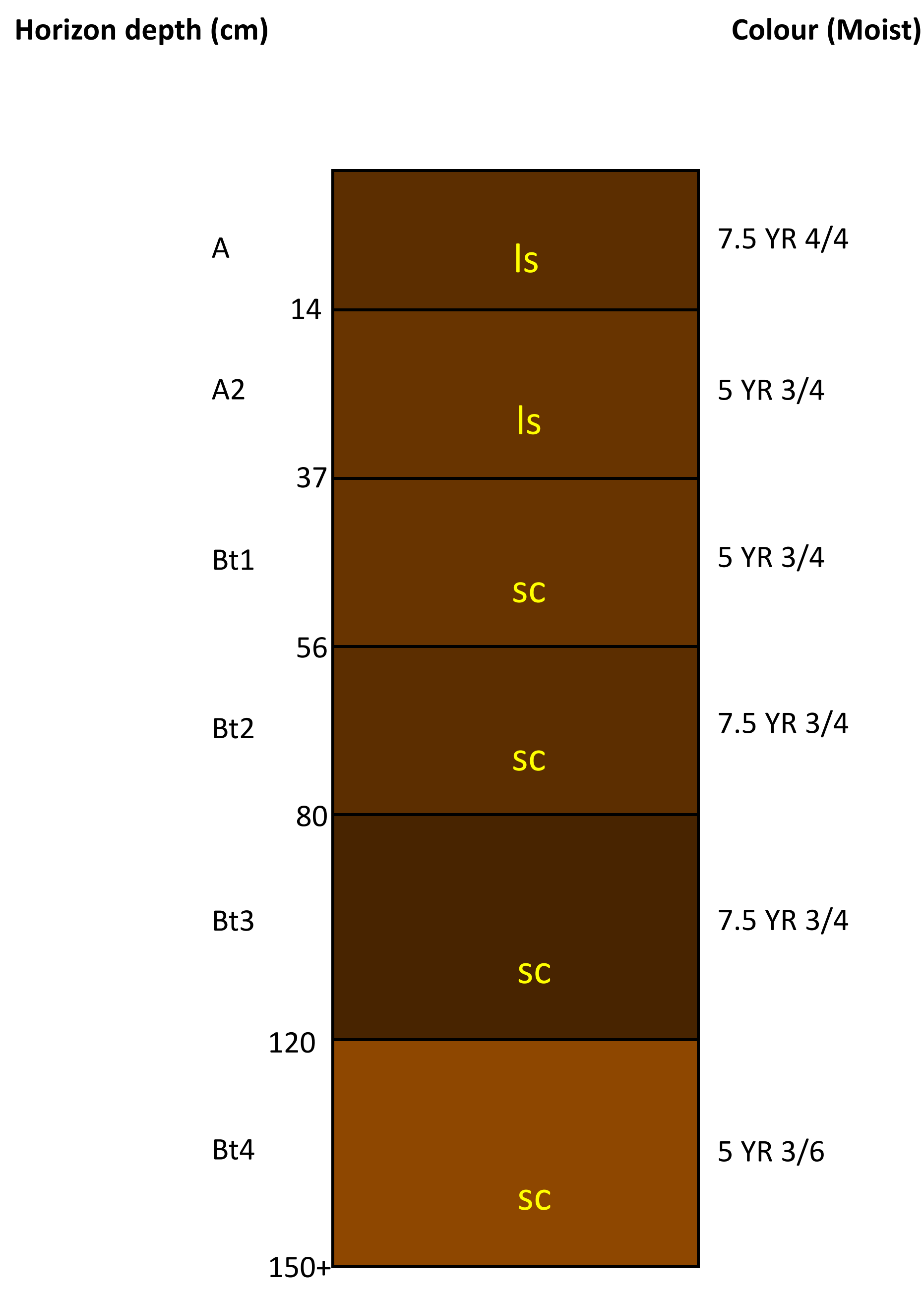


Fig 4.7 Profile diagram of pedon 2, Nagenahalli watershed, Doddaballapur taluk, Bangalore rural district

Table 4.11 Soil morphology of pedon 2

Horizon	Depth (cm)	Characteristics
A1	0-14 cm	Brown (7.5 YR 5/4 D), brown (7.5 YR 4/4 M) loamy sand; weak fine sub angular blocky structure; slightly hard, friable, non sticky and non plastic consistency; many very fine roots and many medium pores; very strongly acid (5.0) and abrupt smooth boundary
Bt1	14-37 cm	Reddish brown (5YR 4/4 D),dark reddish brown (5YR 3/4 D) loamy sand; moderate medium sub angular blocky structure; very hard, firm, very sticky and plastic consistency; many fine roots and few fine pores; continuous thick clay skins; moderately acid (5.6) and clear smooth boundary
Bt2	37-56 cm	Reddish brown (5YR 4/4 D), dark reddish brown (5YR 3/4 M) sandy clay; strong medium sub angular blocky structure; extremely hard, very firm, very sticky and plastic consistency; few fine roots and few very fine pores; patchy thick clay skins; neutral (6.5) and gradual smooth boundary
Bt3	56-80 cm	Brown(7.5 YR 4/4 D), dark brown (7.5 YR 3/4 M) sandy clay; moderate coarse sub angular blocky structure; very hard, very firm, very sticky and plastic consistency; few fine roots and few very fine pores; patchy thick clay skins; neutral (6.9) and gradual smooth boundary
Bt4	80-120 cm	Brown (7.5 YR 4/4 D), dark brown (7.5 YR 3/4M)sandy clay; moderate coarse sub angular blocky structure; hard, firm, very sticky and plastic consistency; few very fine pores; few coarse concretions; few fine faint light yellowish brown (10YR 6/4) mottles; neutral (6.9) and clear smooth boundary.
Bt5	120-150 cm	Yellowish red (5YR 4/6D), yellowish red (5YR 4/6M) sandy clay; strong medium sub angular blocky; heavy, firm, very sticky and plastic consistency; few fine pores; continuous thick clay skins; neutral (6.9) and clear smooth boundary.

Table 4.12 physical properties of Pedon 2

Ngh **P2 :** Fine, kiolinitic, isohyperthermic, Typic Kandustalf

Pedon location: 50 m from main drainage line, Nagenahalli village, Doddaballapur taluk, Bangalore Rural District (13   22 54   N; 77   32 55.30   E)

Depth (cm)	Horizon	BD Mg m^{-3}	Particle-size distribution (%)											
			Sand (mm)						Silt (mm)	Clay (mm)	Coarse fragments whole soil vol.%	Texture class (USDA)	Org. C (%)	AWC (mm m^{-3})
			V. coarse 2-1	Coarse 1-0.5	Medium 0.5-0.25	Fine 0.25-0.1	V. fine 0.1-0.05	Total	0.05-0.002	<0.002				
0-14	A1	1.66	2.90	10.61	34.50	26.30	10.65	85.00	3.00	11.00	-	ls	0.43	120
14-37	Bt1	1.69	7.65	17.70	20.26	28.02	11.37	85.00	4.00	7.00	-	ls	0.36	120
37-56	Bt2	1.66	3.83	13.17	13.67	18.53	7.28	56.50	2.00	41.50	-	sc	0.32	110
56-80	Bt3	1.66	6.34	14.43	15.59	12.60	8.52	57.50	2.50	40.00	-	sc	0.25	110
80-120	Bt4	1.67	3.67	11.65	23.38	18.4	7.26	54.5	5.00	40.50	-	sc	0.29	110
120-150+	Bt5	1.67	5.20	10.87	9.90	26.10	5.90	54.5	3.50	42.00	-	sc	0.03	110

Table 4.13 Chemical properties of pedon 2

Depth (cm)	Exchangeable bases					Extractable acidity			Cation exchange capacity			Base saturation		Ratio to clay
	Ca	Mg	Na	K	Total	$BaCl_2$ TEA	1N KCl		NH_4 OAc	Sum of cations	ECEC	NH_4OAc	Sum of cations	CEC
							H^+	Al^{3+}						
	<- -- cmol (P+) kg^{1} --------------------------- >											< ----- % ------>		
0-14	2.50	0.42	0.13	0.09	2.69	14	0.46	0.10	4.1	16.69	2.79	66	16	0.37
14-37	2.48	0.69	0.15	0.11	3.43	10	0.16	_	5.60	13.43	3.43	61	18	0.80
37-56	1.91	0.63	0.18	0.13	2.85	14	0.01	_	4.80	16.85	2.85	59	16	0.11
56-80	1.25	0.21	0.18	0.15	1.79	_	_	_	4.80	1.79	1.79	64	100	0.07
80-120	1.25	0.17	0.16	0.14	1.72	_	_	_	4.80	1.72	1.72	61	100	0.06
120-150+	2.82	0.82	0.14	0.10	3.38	_	_	_	4.60	3.38	3.38	59	100	0.16

Table 4.14 Fertility properties of pedon 2

Depth (cm)	Horizon	pH 1:2.5	EC (dSm^{-1})	Major available nutrients (kg ha^{-1})				Micronutrients (mg kg^{-1})		
		H_2O	1*M* KCl	N	P_2O_5	K_2O	Cu	Fe	Mn	Zn
0-14	A1	4.70	0.02	125.44	22.05	102.14	0.82	22.66	18.20	0.30
14-37	Bt1	5.60	0.02	125.44	4.62	123.64	0.80	18.04	11.20	0.38
37-56	Bt2	5.80	0.02	25.08	3.60	142.50	0.70	16.80	10.80	0.12
56-80	Bt3	6.51	0.01	25.08	15.39	162.62	0.40	8.20	8.20	0.16
80-120	Bt4	6.77	0.03	186.86	15.39	151.90	0.54	7.80	7.00	0.34
120-150+	Bt5	6.73	0.02	125.44	20.52	108.19	0.50	7.60	2.20	0.30

P and K contents were found highest in surface and Bt_3 horizons respectively. Among micronutrients Fe recorded the highest amount which ranged from 7.360 to 22.66 mg/kg followed by Mn, Cu & Zn. Highest amount of Fe & Mn were found highest in all horizons. Except Zn which is low in its content, all other micronutrients were found twice in their amounts (Table 4.14).

4.6.1.3 Pedon -3

4.6.1.3.1 Site characteristics

The site is located near the KVK farm at approximately 500 m from the Nagenahalli village. The profile is positioned on the convex middle sector of the very gently sloping upland wth a slope length of 300 to 600 m and slope gradient of 3-5 per cent, at an elevation of 916 m from MSL (Plate 4.11). The land was kept fallow. Site characteristics of pedon 3 are given in table 4.15 and Plate 4.12.

4.6.1.3.2 Morphology

Solum depth was more than 150 cm (Plate 4.13). there were six horizons observed in this profile (Ap, A2, Bt1, BC1, BC2, BC3). Solum colour ranged from dark brown (7.5 YR 3/4) in surface horizon, brown (7.5 YR 4/4) and yellowish brown (10 YR 5/4) in subsurface horizons. The structure was weak fine sub angular blocky at the surface and moderate medium sub angular blocky in the A2 and Bt1 horizons and moderately coarse sub angular blocky in the remaining horizons. Abrupt smooth boundary was observed between all the horizons except in the second horizon where clear and smooth boundary was found. The surface had slightly hard, friable, non sticky and non plastic consistency which increased towards depth to very hard, firm, sticky plastic to very firm, very sticky plastic. Many very fine roots were at the surface to common very fine to few very fine roots noticed up to the BC1 horizon. Thin patchy clay skins in second and third horizon with few fine faint brown to red mottles from third horizon were present. Few coarse to common medium concretions were present throughout the subsurface horizon. The quantity of concretions increased towards depth up to BC1 horizon (more iron nodules were observed in BC1 horizon) (Fig 4.8 and table 4.16)

(Source: Google earth)

Plate 4.11 Land scape and location of pedon 3 in Nagenahalli watershed

Plate 4.12 Site characteristics of pedon 3 in Nagenahalli watershed

Table 4. 15   Site characteristics of pedon 3

Location: Near KVK farm 500 m from village Nagenahalli, Doddaballapur taluk, Bangalore Rural District, Karnataka; 13º 22' 34.9″ N; latitude, 77 º 32' 59″ E;longitude.

Climate: Semiarid tropical

Elevation: 916 m above MSL

Rain fall: 889.0 mm

Mean annual temperature: 23.8 ºC

Slope: 1-3 %

Erosion: moderate

Drainage: well drained

Soil parent material: granite

Land use: fallow land, eucalyptus and ragi in near by plots

Average yield: Ragi: 600 kg/ha

Soil classification: Fine loamy, mixed, isohyperthermic, Kanhaplic Haplustalfs

Plate 4.13 Profile view of pedon 3 in Nagenahalli village - Survey No 40

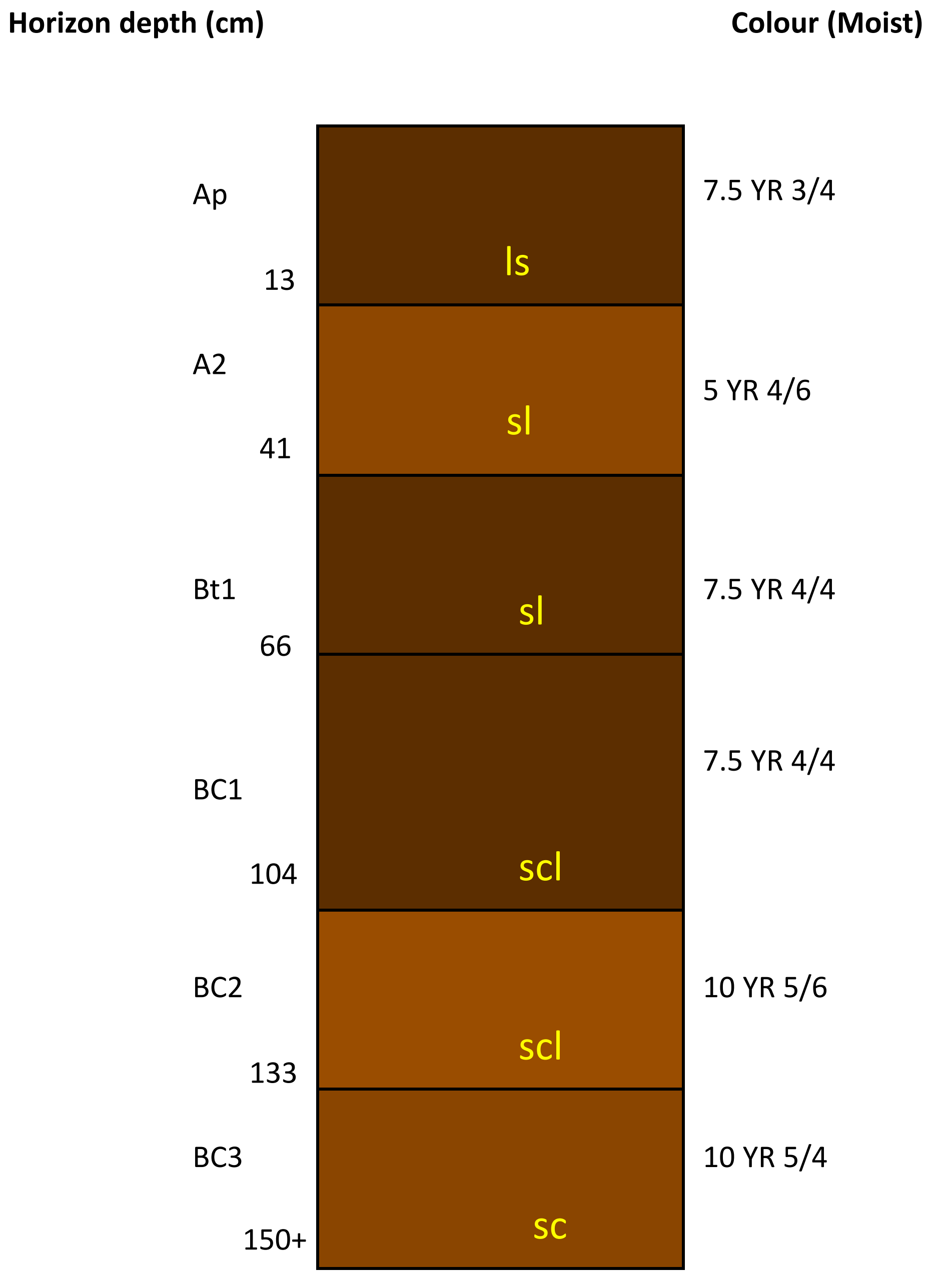


Fig 4.8 Profile diagram of pedon 3, Nagenahalli watershed, Doddaballapur taluk, Bangalore rural district

4.6.1.3.3 Physical properties

The texture varied from loamy sand in AP, A2 and Bt1 horizons to Sandy clay loam in BC1 and BC2 horizons BC3 horizon showed sandy clay texture. The clay content ranged from 13 to 40.5 percent which increased from surface to subsurface horizon. The BD values ranged from 1.45 to 1.71 Mg m^{-3} where Bt1 horizon recorded the highest bulk density. Organic carbon content was found low ranging from 0.01 to 0.36 per cent which showed a decreasing trend with depth and the soil had medium water holding capacity of 110 to 150 mm m^{-1}(table 4.17).

4.6.1.3.4 Chemical properties

The soils are moderately acidic to slightly acidic with a pH range of 5.4 to 6.9 and the electrical conductivity was ranged from 0.03 to 0.07 $dSm^{-1}$with highest in Bt2 horizon and lowest EC in the surface horizon. Cation exchange capacity ranged from 0.90 to 8.30 cmol (p^+) kg^{-1}which is increased with depth. Highest was recorded in the BC3 horizon. AP horizon recorded the lowest CEC of 0.90 cmol (p_+) kg^{-1}. Ca was abundant in the soil followed by Mg, K and Na. Ca ranged from 0.36 to 4.25 c mol (p+) kg^{-1}. Magnesium ranged from 0.18 to 1.27, Potassium ranged from 0.07 to 0.40, Na ranged from 0.09 to 0.20 cmol (p+) kg^{-1}. There is no variation in case of Na content among first 3 horizons. All the exchangeable bases were increased with depth (Table 4.18).

4.6.1.3.5 Fertility properties

Among available nutrients, Nitrogen, Phosphorus (P_2O_5) and potassium (K_2O) ranged from 62.7 to 188.1, 5.4 to 29.5 and 78.0 to 427.4 kg/ha respectively. Highest amount of Nitrogen was found in BC2 horizon of the profile; where as the highest amount of phosphorus and potassium were found in surface horizon and BC3 horizon respectively. Among the micronutrients, manganese was high in the whole profile, which ranged from 12.42 to 34.20 mg/kg^{-1} followed by iron, copper and zinc. Highest amount of manganese was found in BC1 horizon, where as highest amounts of Cu, Fe & zinc were found in surface horizon, Bt2 horizon and BC1 horizon respectively (Table 4.19).

Table 4.16 Soil morphology of pedon 3

Horizon	Depth(cm)	Characteristics
Ap	0- 13 cm	Brown (7.5 YR 4/4 D) dark brown (7.5 YR 3/4 M) loamy sand; weak, fine, sub angular blocky structure; slightly hard, friable, non sticky and non plastic consistency; many very fine roots; strongly acid (5.4) and abrupt smooth boundary
Bt1	13-41 cm	Yellowish red (5 YR 4/6 M) sandy loam; moderate medium sub angular blocky structure; very hard, friable, slightly sticky and slightly plastic consistency; common very fine roots; strongly acid (5.4) and clear smooth boundary
Bt2	41-66 cm	Brown (7.5 YR 4/4 M) sandy loam; moderate medium sub angular blocky structure; very hard, firm, sticky and plastic consistency ; common very fine roots; few common concretions; few fine faint (7.5 YR 4/2 M) brown mottles; strongly acid (5.3) and abrupt smooth boundary
CB1	66-104 cm	Brown (7.5 YR 4/4 M) sandy clay loam; moderate coarse sub angular blocky structure; sticky and plastic consistency; few very fine roots; common medium concretions; few fine faint (10 YR 6/6 M) brown yellow mottles; moderately acid (5.6) and and abrupt smooth boundary
CB2	104-133 cm	Yellowish brown (10 YR 5/6) sandy clay loam; moderate coarse sub angular blocky structure; very sticky and plastic consistency; common medium concretions; few faint(2.5YR 4/6 M) red mottles.; moderately acid (5.9) and abrupt smooth boundary
CB3	133-150^{+}	Yellowish brown (10YR 5/4) sandy clay; medium coarse sub angular blocky structure; very sticky and plastic consistency; few medium concretions; few fine faint (2.5 YR 4/8 M)red mottles; moderately acid (5.9) and abrupt smooth boundary.

Table 4.17 Physical properties of pedon 3

Ngh **P3**: Fine loamy, mixed, isohyperthermic, kanheplic haplustalfs

Pedon location: 500 m from Nagenahalli village (near KVK form),Doddaballapur taluk,Bangalore Rural District (13 22 34.90 N;77 32 59 E)

Depth (cm)	Horizon	BD Mg m^{-3}	Particle-size distribution (%)								Coarse fragments whole soil vol.%	Texture class (USDA)	Org. C %	AWC (mm m^{-3})
			Sand (mm)						Silt (mm)	Clay (mm)				
			V. coarse 2-1	Coarse 1-0.5	Medium 0.5-0.25	Fine 0.25-0.1	v. fine 0.1-0.05	Total	0.05-0.002	<0.002				
0-13	Ap	1.62	4.22	41.61	6.28	26.2	6.81	85.50	1.50	13.00	-	ls	0.36	120
13-41	Bt1	1.63	2.95	21	24.96	15.54	19.05	83.50	16.00	13.50	-	sl	0.32	120
41-66	Bt2	1.71	3.61	7.60	35.16	20.83	9.30	76.50	4.50	19.00	-	sl	0.25	120
66-104	CB1	1.52	3.84	20.37	20.30	19.41	5.08	69.00	7.00	24.00	-	scl	0.07	150
104-133	CB2	1.45	1.65	13.66	11.76	25.78	5.15	58.00	13.50	28.50	-	scl	0.04	150
133-150+	CB3	1.65	3.12	8.16	10.43	8.76	24.55	55.00	4.50	40.50	-	sc	0.01	110

Table 4.18 Chemical properties of pedon 3

Depth (cm)	Exchangeable bases					Extractable acidity			Cation exchange capacity			Base saturation		Ratio to clay
	Ca	Mg	Na	K	Total	$BaCl_2$-TEA	1N KCl H^+	1N KCl Al^{3+}	NH_4OAc	Sum of cations	ECEC	NH_4OAc	Sum of cations	CEC NH_4OAc
	< ---------- cmol (P+) kg 1 ---------- >											< ------ % ------>		
0-13	0.52	0.18	0.09	0.07	0.86	10.00	0.11	0.1	0.90	10.86	0.96	96	7	0.07
13-41	0.36	0.21	0.09	0.08	0.74	6.00	0.09	0.1	1.40	16.74	0.84	53	4	0.10
41-66	2.25	1.27	0.09	0.11	2.72	10.00	0.81	0.1	4.20	12.72	2.82	65	21	0.22
66-104	1.86	0.31	0.10	0.13	2.40	16.00	0.16	0.1	3.00	18.40	2.50	80	13	0.12
104-133	3.21	1.01	0.13	0.22	4.57	16.00	0.06	_	6.80	20.57	4.57	67	22	0.24
133-150+	4.25	0.97	0.20	0.40	5.82	14.00	0.06	_	8.30	19.82	5.82	70	29	0.20

Table 4.19 Fertility properties of pedon 3

Depth (cm)	Horizon	pH (1:2.5)		EC dSm^{-1}	Major available nutrients ($kg\ ha^{-1}$)			Micronutrients ($mg\ kg^{-1}$)			
		H_2O	1*M* KCl		N	P_2O_5	K_2O	Cu	Fe	Mn	Zn
0-13	Ap	5.42	3.94	0.03	156.80	29.50	129.70	0.56	12.20	12.42	0.26
13-41	A2	5.42	3.97	0.02	62.72	17.44	86.01	0.42	15.00	18.50	0.22
41-66	Bt1	6.32	3.82	0.09	125.44	25.90	77.95	0.52	20.20	32.00	0.18
66-104	BC1	6.64	3.92	0.06	94.08	12.05	144.50	0.40	19.8	34,20	0.32
104-133	BC2	6.64	4.27	0.05	188.16	5.40	238.56	0.28	12.20	16.60	0.10
133-150+	BC3	6.92	4.41	0.07	156.80	5.40	427.39	0.24	9.40	13.40	0.18

4.6.1.4 Pedon -4

4.6.1.4.1 Site characteristics

The site is located at approximately 1 km from the Tubagere village. The profile was positioned on the convex middle sector of the nearly level upland with a slope length more than 600 m and slope gradient of 0-1 per cent, at an elevation of 927 m from MSL (Plate 4.14). The land was ploughed, for cultivating maize and red gram. Site characteristics of pedon 4 are given in table 4.20 and Plate 4.15.

4.6.1.4.2 Morphology

Depth of the solum was more than 150 cm (Plate 4.16). Soil colour was ranged from dark red (2.5 YR 3.6) to red (2.5 YR 4/6) in surface and subsurface horizons respectively. The structure was weak fine subangular blocky in the surface and varied to moderate to strong medium subangular blocky in the sub surface horizons with many coarse to common very fine pores throughout the profile. There were six horizons observed in this profile (Ap, Bt1, Bt2, Bt3C, Bt4C, Bt5C). Abrupt smooth boundary between Ap and Bt horizon, Bt2 and Bt3C horizon, Bt3C and Bt4C and clear smooth boundary between Bt1 and Bt2, Bt4C and Bt5C horizon with many coarse roots at the surface to few very fine roots in the Bt1 horizon and common very fine roots are present throughout the profile with thin patchy clay skins in the sub surface. Consistency was slightly hard, friable, non sticky, to non plastic in the surface soil to slightly hard, friable, very sticky plastic in the sub surface horizon. Rock fragments are present in the Bt3C and Bt4C horizons which ranged from 35 to 60 percent (Fig 4.9 and table 4.21)

4.6.1.4.3 Physical parameters

The texture varied from sandy loam to sandy clay and also sandy clay loam in Bt4C1. The soil of Bt3C1 and Bt4C1 were extremely gravelly to gravelly in nature having coarse fragments to the extent of 35 to 60 percent. Clay content was increasing from surface to subsurface horizon (15 to 42.5 per cent), bulk density ranged from 1.50 to 1.60 Mg m^{-3} and the value decreased with increasing depth. Organic carbon content was

(Source: Google earth)

Plate 4.14 Land scape and location of pedon 4 in Nagenahalli watershed

Plate 4.15 Site characteristics of pedon 4 in Nagenahalli watershed

Table 4.20 Site characteristics of pedon 4

Location: 1 km from Tubgere village, Nagenahalli, Doddaballapur taluk, Bangalore Rural District, Karnataka; 13º 22' 33.4″ N latitude and 77º 33' 21.5″ E longitude.

Climate: Semiarid tropical

Elevation: 927 m above MSL

Rain fall: 889.0 mm

Mean annual temperature: 23.8 ºC

Slope: 0-1 %

Erosion: Moderate

Drainage: Well drained

Soil parent material: Granite

Land use: Ploughed, maize and ragi in near by plots

Average yield: Maize: 1200 kg/ha, Ragi 700 kg/ha

Soil classification: Clayey-skeletal, mixed, isohyperthermic,Ultic Paleustalfs

Plate 4.16 Profile view of pedon 4 in Nagenahalli village - Survey No 11

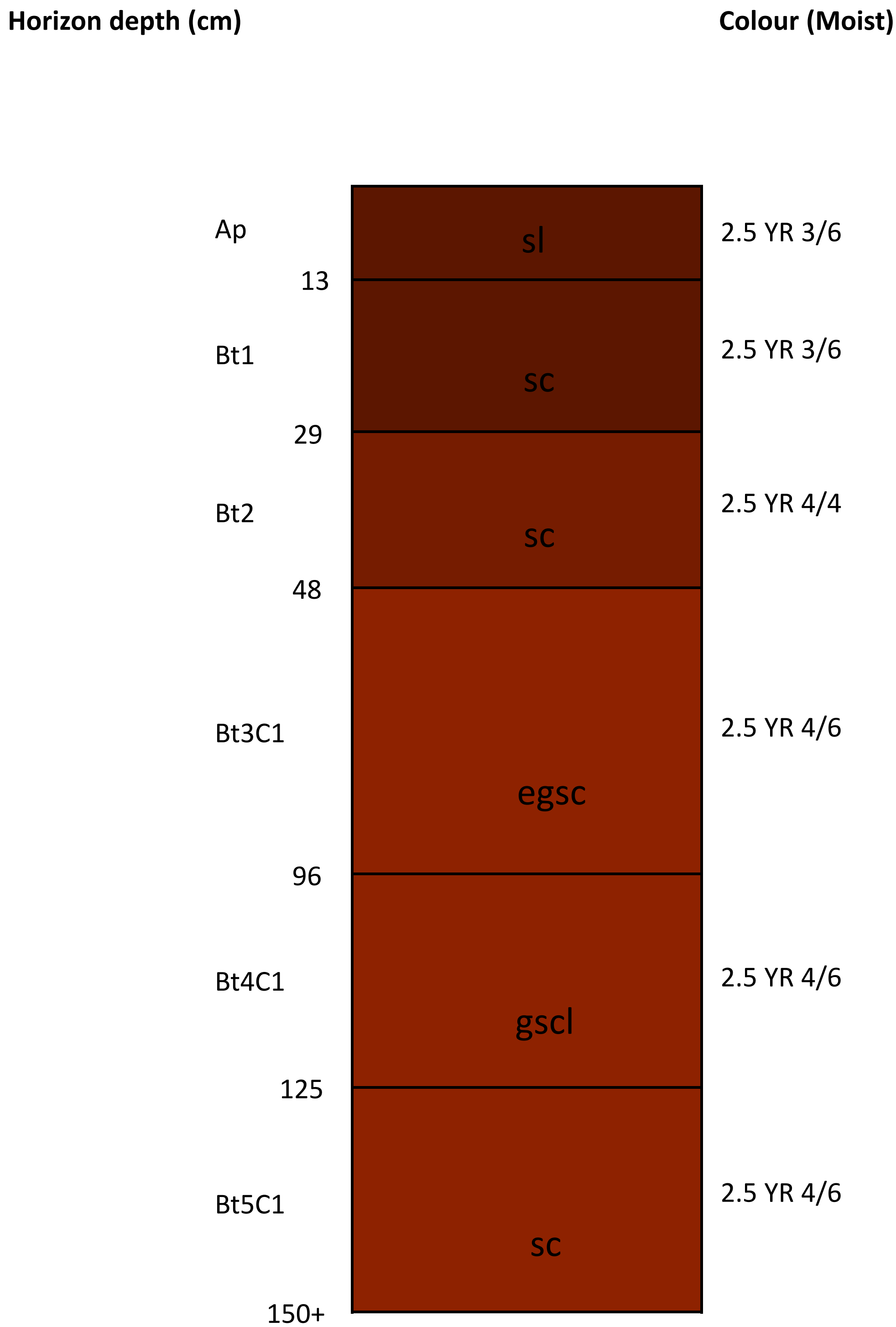


Fig 4.9 Profile diagram of pedon 4, Nagenahalli watershed, Doddaballapur taluk, Bangalore rural district

Table 4.21 Soil morphology of pedon 4

Horizon	Depth(cm)	Characteristics
Ap	0-13 cm	Red (2.5 YR 4/6 D), dark red (2.5YR 3/6 M) sandy loam; weak fine subangular blocky structure; slightly hard, friable, non sticky and non plastic consistency; medium very fine roots and medium coarse pores; patchy thin clay skins; very strongly acid (4.7) and abrupt smooth boundary
Bt1	13 29 cm	Red (2.5 YR 4/6 D), dark red (2.5 YR 3/6 M) sandy clay; moderate medium sub angular blocky structure; slightly hard, friable, sticky and plastic consistency; few very fine roots and medium fine pores; patchy thin clay skins; strongly acid (5.1) and clear smooth boundary
Bt2	29-48 cm	Reddish brown (2.5 YR 4/4), sandy clay; strong medium subangular blocky structure; hard, friable, sticky and plastic consistency; common fine pores; patchy thin clay skins; moderately acid (5.9) and abrupt wavy boundary
Bt3C	48-96 cm	Red (2.5 YR4/6 D), red (2.5 YR 4/6M) clay; moderate medium subangular blocky structure; hard, friable, very sticky and plastic consistency; common very fine pores; patchy thin clay skins; neutral (6.5) and abrupt wavy boundary
Bt4C	96-125 cm	Red (2.5 YR 4/6), clay; moderate medium subangular blocky structure; slightly hard, friable and plastic consistency; common very fine pores; patchy thin clay skins; neutral (6.8) and clear smooth boundary
Bt5C	125-150^{+}	Red (2.5 YR 4/6), clay; strong medium subangular blocky structure; slightly hard, friable, and plastic consistency; common very fine pores; patchy thin clay skins; neutral (6.9) and clear smooth boundary

found low ranged from 0.01 to 0.27 percent and it decreased with depth. The soils had low to medium water holding capacity ranging from 50-150 mm m^{-1} (Table 4.22).

4.6.1.4.4 Chemical properties

The soils were moderately acidic to slightly acidic and neutral, with a pH range of 4.8 to 6.9. The electrical conductivity of the profile ranged from 0.01 to 0.06 dSm^{-1}. Highest EC was recorded in the surface horizon. Cation exchange capacity ranged from 4.60 to 13.10 cmol (p+) kg^{-1}. Highest CEC was recorded in Bt2C1 and low CEC was recorded in surface horizon. Ca was the dominant cation in the soil and it ranged from 2.08 to 6.12 cmol (p+) kg^{-1} followed by Mg, Na and K, where Mg ranged from 0.59 to 1.04 cmol (p+) kg^{-1} and there was no variation in Mg content among first three horizons. Sodium ranged from 0.14 to 0.20 cmol (p+) kg^{-1} and potassium ranged from 0.08 to 0.16 cmol (p+) kg^{-1}. Highest amount of K and Mg were found in surface horizon, calcium was found highest in Bt3C1 and Na was highest in Bt5C1 horizon (Table 4.23).

4.6.1.4.5 Fertility properties

Among the major available nutrients, the nitrogen ranged from 62.7 to 282.2 kg/ha which was found highest in Bt3C1 horizon. Phosphorus (P_2O_5) and potassium (K_2O) ranged from 4.6 to 76.7, and 86.7 to 165.9 kg/ha respectively. Highest amount of phosphorus (P_2O_5) and potassium (K_2O) were recorded in the surface horizon and they showed decreased concentration with depth. Manganese was found highest in the whole profile among the micronutrients followed by Fe, Cu and Zu and the amounts ranged from 6.1 to 29.0, 7.2 to 21.0, 0.28 to 0.90 and 0.04 to 0.54 mg kg^{-1} of Mn, Fe, and Cu & Zn respectively (Table 4.24).

4.6.1.5 Pedon 5

4.6.1.5.1 Site characteristics

The site is located at approximately 50 m from the Tubagere village. The profile is situated on the level middle sector of the upland with a slope length of more than 600 m and slope gradient of 0-1 per cent, at an elevation of 928 m from MSL (Plate 4.17).

Table 4.22 Physical properties of pedon 4

Ngh **P4:** Clayey-skeletal, mixed, isohyperthermic,Ultic Paleustalfs

Pedon location: 1 km from Tubegere village, Doddaballapur taluk, Bangalore Rural District (13 22 33.40 N; 77 33 21.50 E)

Depth (cm)	Horizon	BD Mg m^{-3}	Particle-size distribution (%)								Coarse fragments whole soil vol.%	Texture class (USDA)	Org. C %	AWC (mm m^{-3})
			Sand (mm)						Silt (mm)	Clay (mm)				
			V. coarse 2-1	Coarse 1-0.5	Medium 0.5-0.25	Fine 0.25-0.1	V. fine 0.1-0.05	Total	0.05-0.002	<0.002				
0-13	Ap	1.60	3.3	6.21	26.63	30.57	16.72	83.00	2.00	15.00	-	sl	0.27	150
13-29	Bt1	1.60	2.77	20.37	14.02	21.97	2.37	61.50	1.00	37.50	-	sc	0.24	110
29-48	Bt2	1.60	3.83	11.47	4.91	15.31	15.51	51.00	7.50	41.50	-	sc	0.26	110
48-96	Bt3C1	1.60	8.45	12.74	9.97	11.8	17.43	59.50	4.50	36.00	60	egsc	0.14	50
96-125	Bt4C2	1.58	12.68	11.49	11.08	14.62	6.63	56.50	9.50	34.00	35	gscl	0.03	100
$125\text{-}150^{+}$	Bt5C3	1.50	9.00	9.82	5.65	14.80	7.21	46.50	11.00	42.50	-	sc	0.01	110

Table 4.23 Chemical properties of pedon 4

Depth (cm)	Exchangeable bases					Extractable acidity			Cation exchange capacity			Basesaturation		Ratio to clay
	Ca	Mg	Na	K	Total	$BaCl_2$-TEA	1N KCl H^+	1N KCl Al^{3+}	NH_4OAc	Sum of cations	ECEC	NH_4OAc	Sum of cations	CEC NH_4OAc
	< -- cmol (+) kg 1										-- >	< ----- % ------>		
0-13	2.08	1.04	0.14	0.16	3.41	12.00	0.31	-	4.60	15.41	3.41	74	22	0.31
13-29	2.28	1.04	0.16	0.08	3.56	14.00	0.16	_	6.30	17.56	3.56	56	20	0.17
29-48	4.37	1.04	0.17	0.09	5.67	14.00	0.01	_	11.90	19.67	5.67	48	28	0.29
48-96	6.12	0.59	0.19	0.10	6.98	12.00	0.11	0.2	13.10	18.98	7.18	53	36	0.36
96-125	3.27	0.87	0.18	0.09	4.41	_	_	_	8.20	4.41	4.41	54	100	0.24
125-150+	2.45	0.76	0.20	0.08	3.49	_	_	_	8.10	3.49	3.49	57	100	0.14

Table 4.24 Fertility properties of pedon 4

Depth (cm)	Horizon	pH (1:2.5)		EC dSm^{-1}	Major available nutrients ($kg\ ha^{-1}$)			Micronutrients ($mg\ kg^{-1}$)			
		H_2O	1*M* KCl		N	P_2O_5	K_2O	Cu	Fe	Mn	Zn
0-13	Ap	4.77	3.69	0.06	156.80	76.94	165.90	0.60	21.00	29.00	0.54
13-29	Bt1	5.67	4.01	0.04	62.72	9.23	87.36	0.90	16.40	46.80	0.50
29-48	Bt2	5.97	4.73	0.04	94.08	5.40	90.72	0.72	9.00	16.70	0.28
48-96	Bc1	6.82	5.32	0.02	282.24	12.80	102.14	0.28	8.00	6.12	0.04
96-125	Bc2	6.94	5.50	0.01	219.52	4.61	98.11	0.36	7.20	12.30	0.30
$125\text{-}150^{+}$	Bc3	6.94	5.75	0.02	188.16	23.08	86.70	0.40	7.60	12.42	0.28

(Source: Google earth)

Plate 4.17 Land scape and location of pedon 5 in Nagenahalli watershed

Plate 4.18 Site characteristics of pedon 5 in Nagenahalli watershed

Table 4.25 Site characteristics pedon 5

Location: 50 m from Tubegere village, Nagenahalli, Doddaballapur taluk, Bangalore Rural District, Karnataka; 13º 22' 20.6″ N latitude and 77º 33' 22.3″ E longitude.

Climate: Semiarid tropical

Elevation: 928 m above MSL

Rain fall: 889.0 mm

Mean annual temperature: 23.8 ºC

Slope: 0-1 %

Erosion: Moderate

Drainage: Well drained

Soil parent material: Granite

Land use: Ploughed, ragi in near by plots

Average ragi yield: 600 kg/ha

Soil classification: Fine, mixed, isohyperthermic, Kandic Paleustalfs

The land was kept fallow. Site characteristics of pedon 5 are given in table 4.25 and Plate 4.18.

4.6.1.5.2 Morphology

Solum depth was 151 cm (Plate 4.19). There were five horizons observed in this profile (Ap, Bt1, Bt2, Bt3, Bt4).Soil colour ranged from yellowish red (5 YR 4/6) to dark red (2.5 YR 3/4) and red (2.5 YR 4/6) in surface to subsurface horizons. The structure was weak fine subangular blocky at the surface and moderate to strong medium sub angular blocky in the remaining horizons. Abrupt to clear smooth boundary was seen between horizons throughout the profile. Consistency increases with depth from slightly hard, friable, slightly sticky and slightly plastic in the surface horizon to hard, very friable, very sticky plastic in all the remaining horizons. Few very fine roots are observed in Ap, Bt1, Bt2 horizons with common medium to many and few fine concretions in Bt2, Bt3, Bt4 horizons. patchy thin to continuous thick clay skins were observed in the sub surface horizon with many medium to common very fine pores throughout the profile (Fig 4.10 and table 4.26)

4.6.1.5.3 Physical parameters

The texture varies from sandy loam to sandy clay and clay. Increased clay content was noticed with increasing depth from 18.5 to 47.5 per cent. The bulk density ranged from 1.20 to 1.60 Mg m^{-3} and BD decreased with depth. Organic carbon content was found low ranging from 0.01 to 0.29 percent which is decreasing with depth. The soils have medium water holding capacity ranging from 110 to 150 mm m^{-1} (Table 4.27).

4.6.1.5.4 Chemical properties

The surface soils were strongly acidic and the acidity decreased with depth to moderately acidic to slightly acidic. The electrical conductivity ranged from 0.02 to 0.07 dSm^{-1}. Cation exchange capacity ranged from 3.70 to 12.70 cmol (p+) kg^{-1}, where highest CEC was recorded in Bt1 horizon and the surface horizon recorded the lowest CEC in the profile. Among the exchangeable bases, calcium was the dominant cation ranged from 0.43 to 5.91 cmol (p+) kg^{-1} followed by Mg, Na & K. Mg ranged from 0.76 to 1.18 cmol

Plate 4.19 Profile view of pedon 5 in Nagenahalli village - Survey No 16

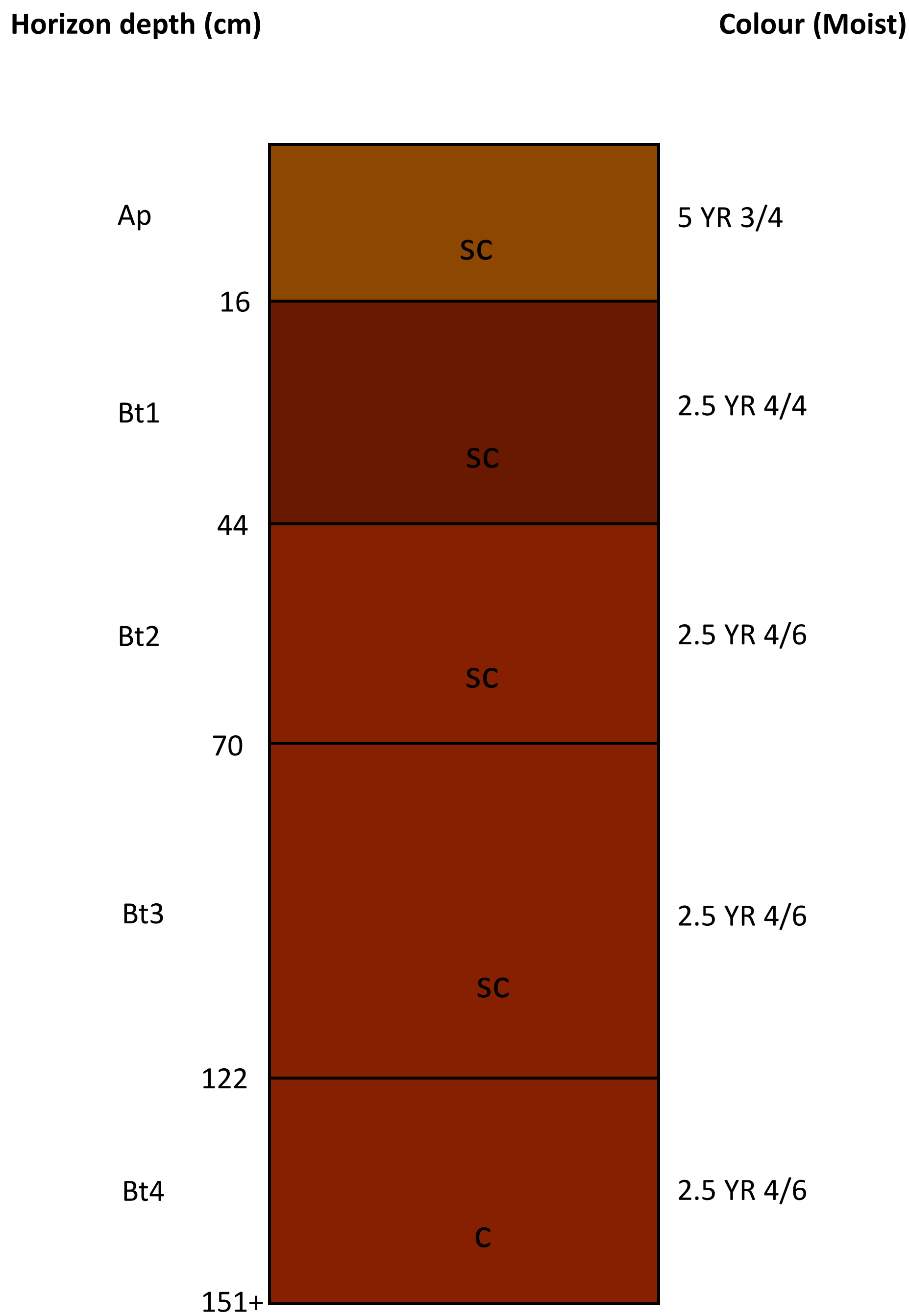


Fig 4.10 Profile diagram of pedon 5, Nagenahalli watershed, Doddaballapur taluk, Bangalore rural district

Table 4.26 Soil morphology of pedon 5

Horizon	Depth(cm)	Characteristics
AP	0-16 cm	Yellowish red (5YR 5/6 D), yellowish red (5YR 4/6M) sandy clay loam; weak fine sub angular blocky structure; slightly hard, slightly sticky and slightly plastic; few very fine roots; many medium pores.
Bt1	16-44 cm	Reddish brown (2.5 YR 4/4 D), dark reddish brown (2.5YR 3/4 M) clay; moderate medium subangular blocky structure; hard, very friable, very sticky and plastic consistency; few fine roots and common fine pores; patchy thin clay skins; strongly acid (5.3) and clear smooth boundary
Bt2	44-70 cm	Red (2.5 4/6 D), dark red (2.5 YR3/6 M) clay; strong medium subangular blocky structure; hard, very friable, very sticky and plastic consistency; few very fine roots and common fine pores; patchy thin clay skins; common medium concretions; slightly acid (6.1) and clear smooth boundary.
Bt3	70-122 cm	Red (2.5 YR 4/6), clay; strong medium subangular blocky structure; hard, very friable, very sticky and plastic consistency; common very fine pores; many fine concretions; patchy thick clay skins; slightly acid (6.4) and clear smooth boundary.
Bt4	122-150^{+}cm	Red (2.5 YR 4/6), clay; moderate medium subangular blocky structure; hard, very friable, very sticky and plastic consistency; common very fine pores; few fine concretions; continuous thick clay skins; slightly acid (6.5)and clear smooth boundary.

(p+) kg^{-1}, Na ranged from 0.16 to 0.30 cmol (p+) kg^{-1} and K was in the range of 0.11 to 0.20 cmol (p+) kg^{-1} (Table 4.28).

4.6.1.5.5 Fertility properties

Major available nutrients like nitrogen, phosphorus (P_2O_5), and potassium (K_2O) were ranged from 62.7 to 156.8, 2.60 to 192.3 and 98.1 to 118.3 kg/ha respectively. Nitrogen content was found highest in Bt2 and Bt4 horizons. Whereas phosphorus content was found highest in surface horizon and it decreased with depth and the potassium content was found highest in Bt4 horizon which increased with depth. Among micronutrients, manganese recorded the highest amount in the whole profile, which ranged from 15.6 to 34.4 mg kg^{-1} followed by Fe, Cu and Zn which ranged from 0.64 to 1.28, 6.00 to 18.60 and 0.24 to 0.34 mg kg^{-1} respectively (Table 4.29).

4.6.2 Soil classification

The soils of Nagenahalli village, were classified up to family level as per as USDA soil taxonomy (Soil survey staff, 1996) based on the morphological, physical and chemical properties of soils. The soils were grouped into order Alfisols.

4.6.2.1 Soil series and phases

Five soil series were identified and mapped into 15 phases in the study area viz. Nagenahalli- a series (**Na**), Nagenehalli-b series (**Nb**), Nagenahalli-C series (**Nc**), Nagenhalli-d Series (**Nd**) and Nagenahalli-e series (**Ne**). Dominant series were Nc (38.9 %) followed by series Nd (22.54 %), Na (15.24 %), Ne (9.7 %) and Nb (4.5 %). Map 4.2 depicts soil map of the study area showing distribution of soil series including soil phases.

4.6.2.1.1 Na-series

Based on the morphological and physical properties of pedon-1, Na-series was identified, which was classified under order Alfisols, suborder Ustalfs, great group Kandiustalfs, with fine Kaolinitic isohyperthermic family of Typic Kandiustalf.

Table 4.27 Physical properties of pedon 5

Ngh P5: Fine, mixed, isohyperthermic, Kandic Paleustalfs

Pedon location: 50m t from Tubgere village, Doddaballapur taluk, Bangalore Rural District (13   22 20.60   N; 77   33 22.30 E)

Depth (cm)	Horizon	BD Mg m^{-3}	Particle-size distribution (%)								Coarse fragments whole soil vol.%	Texture class (USDA)	Org. C %	AWC (mm m^{-3})
			Sand (mm)						Silt (mm)	Clay (mm)				
			V. coarse 2-1	Coarse 1-0.5	Medium 0.5-0.25	Fine 0.25-0.1	V. fine 0.1-0.05	Total	0.05-0.002	<0.002				
0-16	Ap	1.60	5.53	16.35	29.45	17.35	10.31	79.00	2.50	18.50	-	sl	0.29	150
16-44	Bt1	1.30	3.16	11.30	18.60	19.56	8.06	60.50	1.50	38.00	-	sc	0.25	110
44-70	Bt2	1.20	1.58	27.42	2.26	15.49	2.27	49.50	4.00	46.50	-	sc	0.12	110
70-122	Bt3	1.30	3.78	14.77	6.42	10.26	13.91	46.50	6.50	47.00	-	sc	0.04	110
122-150+	Bt4	1.30	5.35	7.56	9.85	13.03	7.98	43.50	9.00	47.50	-	c	0.01	140

Table 4.28 Chemical properties pedon 5

Depth (cm)	Exchangeable bases					Extractable acidity			Cation exchange capacity			Base saturation		Ratio to clay
	Ca	Mg	Na	K	Total	$BaCl_2$ TEA	1N KCl H^+	1N KCl Al^{3+}	NH_4OAc	Sum of cations	ECEC	NH_4OAc	Sum of cations	CEC NH_4OAc
	< --cmol (+) kg 1 ------------------------------ >											< ------ % ------>		
0-16	0.43	0.76	0.17	0.18	1.45	8.00	0.71	0.1	3.70	9.45	1.55	39	15.34	0.2
16-44	5.37	1.14	0.16	0.20	6.76	12.00	0.11	_	12.70	18.76	6.76	53	36.03	0.33
44-70	3.75	1.18	0.27	0.16	5.31	14.00	0.06	_	9.20	19.31	5.31	58	27.50	0.20
70-122	5.91	1.17	0.28	0.19	7.47	14.00	0.06	_	10.40	21.47	7.47	72	34.80	0.22
122-150+	4.57	1.00	0.30	0.11	5.98	12.00	0.06	_	9.00	17.98	5.98	66	33.26	0.19

Table 4.29 Fertility properties of pedon 5

Depth (cm)	Horizon	pH (1:2.5)		EC dSm^{-1}	Major available nutrients (kg ha^{-1})			Micronutrients (mg kg^{-1})			
		H_2O	1*M* KCl		N	P_2O_5	K_2O	Cu	Fe	Mn	Zn
0-16	Ap	4.57	4.49	0.02	94.08	192.36	98.11	1.02	18.60	25.20	0.34
16-44	Bt1	5.37	4.21	0.02	62.72	6.41	114.91	1.28	10.20	34.40	0.24
44-70	Bt2	6.59	4.96	0.02	156.80	6.41	114.24	1.04	7.00	15.60	0.24
70-122	Bt3	6.80	5.11	0.03	62.72	2.60	116.92	0.64	6.80	17.00	0.42
122-150+	Bt4	6.80	5.23	0.07	156.80	2.60	118.27	0.70	6.00	18.50	0.33

4.6.2.1.2 Nb-series

Soils of Nb-series were identified based on morphological and physical properties of pedon-2. The soils were classified under order Alfisols, suborder Ustalfs, great group Kandiustalfs, with fine kaolinitic isohyperthermic family of Typic Kandiustalfs. The pedon-1 and 2 have same morphology but the difference is that the soils of pedon-1 had a gravel layer at 59 cm depth which was not there in the pedon-2 classifying into Nb-series.

4.6.2.1.3 Nc-series

Based on the morphological and physical properties of pedon-3, Nc-series was identified. This series was classified under the order Alfisols, suborder Ustalfs, great group Haplustalfs, with fine loamy mixed isohyperfhermic family of Kanlaplic Haplustalfs.

4.6.2.1.4 Nd-Series

Soils of Nd-sereis were identified based on morphology and physical properties of pedon-4. These soils were classified under order Alfisols, suborder Ustalfs, great group Paleustalfs with clayey skeletal mixed isohylperfhermic family of Ultic Paleustalfs.

4.6.2.1.5 Ne-series

Based on the morphology and physical properties of pedon-5 Ne-series was identified which was classified under order Alfisols, suborder Ustalfs, great group Pleustalfs, with fine mixed isohyperfhermic family of Kandic Paleustalfs.

The five soil series identified were mapped into 15 phases viz. NabB, BahB, $NahC_2$, NbbC1, NbCB2, NcbB1, NciA, NchB, NchB2, NCmB, NdCA, NdbBr, NdhC2, NeCA1and NeCB1 based on texture erosion and sloppiness of the soils. Table 4.30 shows area and distribution of soil series and phases in the study area. Table 4.31 shows legend of soil map of Nagenahalli watershed.

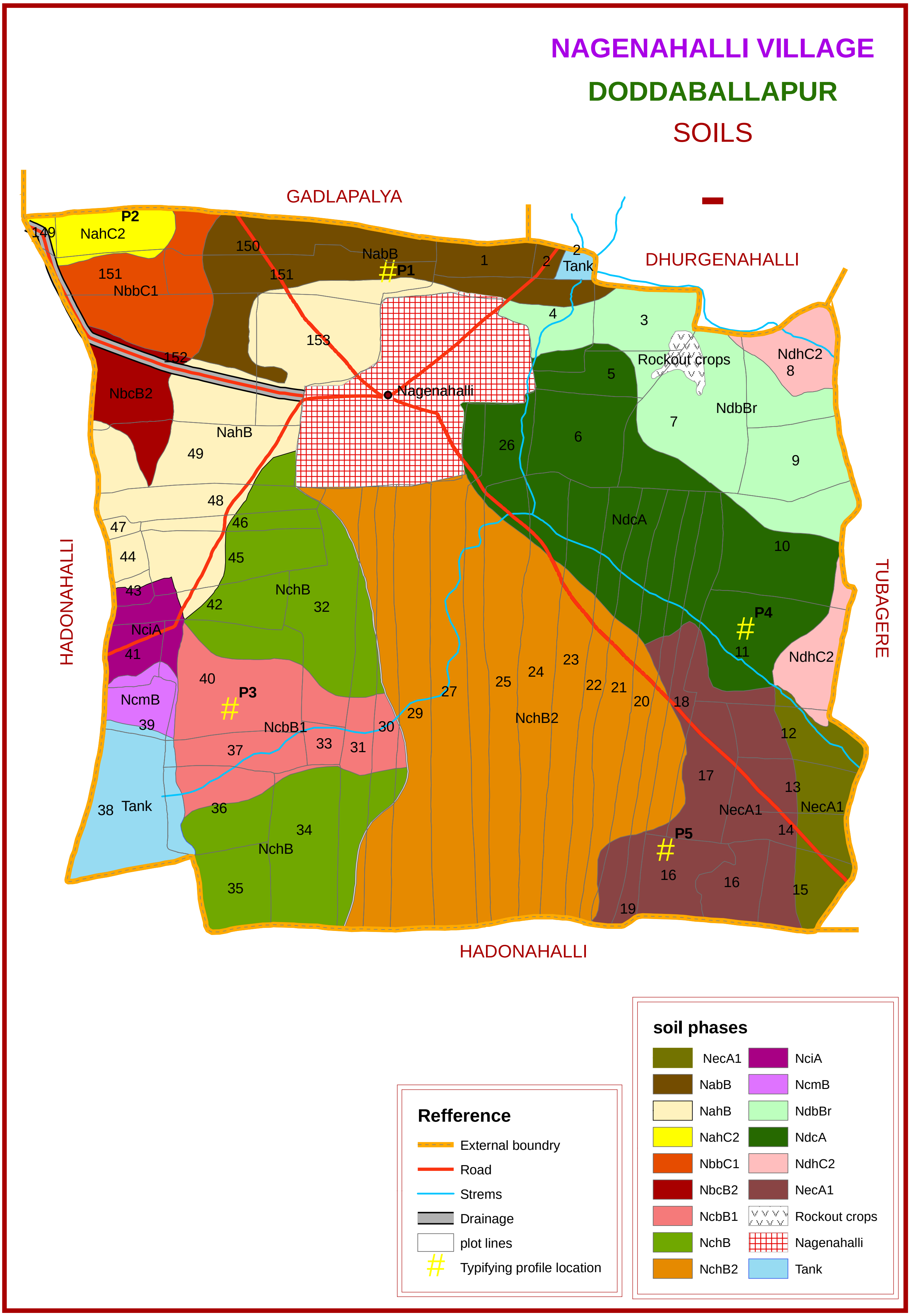


Fig 4.2 Soil phases of Nagenahalli village

Table 4.30 Area and distribution of soil series and phases in Nagenahalli watershed Doddaballapur taluk, Bangalore rural District

Soil Series	Soil Phases	Area(ha)	%
Na	NabB	12.05	15.2
	NahB	19.40	
	NahC2	2.90	
Nb	NbbC1	6.30	4.5
	NbCB2	3.82	
Nc	NCbB1	11.48	38.9
	NCiA	2.76	
	NchB	23.31	
	NchB2	48.34	
	NcmB	1.78	
Nd	NdCA	28.41	22.5
	NdbBr	17.32	
	NdhC2	5.04	
Ne	NeCA1	16.44	9.7
	NeCB1	5.41	

Table 4.31 Legend of soil map of Nagenahalli watershed Doddaballapur taluk, Bangalore rural District

Map unit	Mapping legend	Description
1	NabB	Nagenahalli a series, 1-3 per cent slope loamy sand surface texture.
2	NahB	Nahenahalli a series, 1-3 per cent slope sandy clay loam surface texture.
3	NahC2	Nagenahalli a series, 3-5 per cent slope sandy clay loam surface texture and moderately eroded.
4	NbbC1	Nagenahalli b series, loamy sand surface texture, 3-5 per cent slope and slightly eroded.
5	NbcB2	Nagenhalli b series, sandy loam surface texture, 1-3 per cent slope and moderately eroded.
6	NcbB1	Nagenahalli c series, loamy sand surface texture, 1-3 per cent slope and slightly eroded.
7	NciA	Nagenahalli c series, sandy clay surface texture, 0-1 per cent slope.
8	NchB	Nagenahalli c series, sandy clay loam surface texture with 1-3 per cent slope.
9	NchB2	Nagenahalli c series, sandy clay loam surface texture, 1-3 per cent slope and moderately eroded.
10	NcmB	Nagenahalli c series, clayey surface texture with 1-3 per cent slope.
11	NdcA	Nagenahalli d series, sandy loam surface texture with 0-1 per cent slope.
12	NdbBr	Nagenahalli d series, loamy sand surface texture with 1-3 percent slope and 1-2 per cent surface rock cover.
13	NdhC2	Nagenahalli d series, sandy clay loam surface texture, 3-5 per cent slope and moderately eroded.
14	NecA1	Nagenahalli e series, sandy loam surface texture, 0-1 percent slope and slightly eroded.
15	NecB1	Nagenahalli e series, sandy loam surface texture, 1-3 percent slope and slightly eroded.

4.7 Soil survey interpretation

The basic data collected from detailed soil survey of Nagenahalli watershed, gave the comprehensive information on the soil resources of the village. This can be used to assess the problems and potential of the area for Agriculture Development.

4.7.1 Soil depth

It determines the effective rooting depth of plants and the capacity of the soil to hold water and nutrients. The limits used to group the soils into various depth classes in the survey are very deep (> 150 cm) and moderately shallow (50-75 cm).

Very deep soils occurred extensively in convex lower sector and convex middle sector of the uplands (Table 4.32 and map 4.3).

Table 4.32 Soil depth in Naganahalli

Soil Depth classes	Area (ha.)	Per cent
Very deep	113.3	50.3
Moderately shallow	91.5	40.6
Miscellaneous	20.4	9.0
Total	225.2	100

4.7.2 Soil Drainage

The soil drainage classes given by the soil survey (AISLUS, 1970) were applied to the soil-site data to arrive at the drainage class for the mapping units. The various drainage classes identified and their extent of occurrence are given in the table 4.33 and their distribution is shown in the map 4.4.

In Nagenahalli, very gently sloping upland soils occurred in the eastern region. Nearly level uplands occurred in the south eastern parts were well drained. The soils belonging to very gently sloping and gently sloping uplands of northwest and south

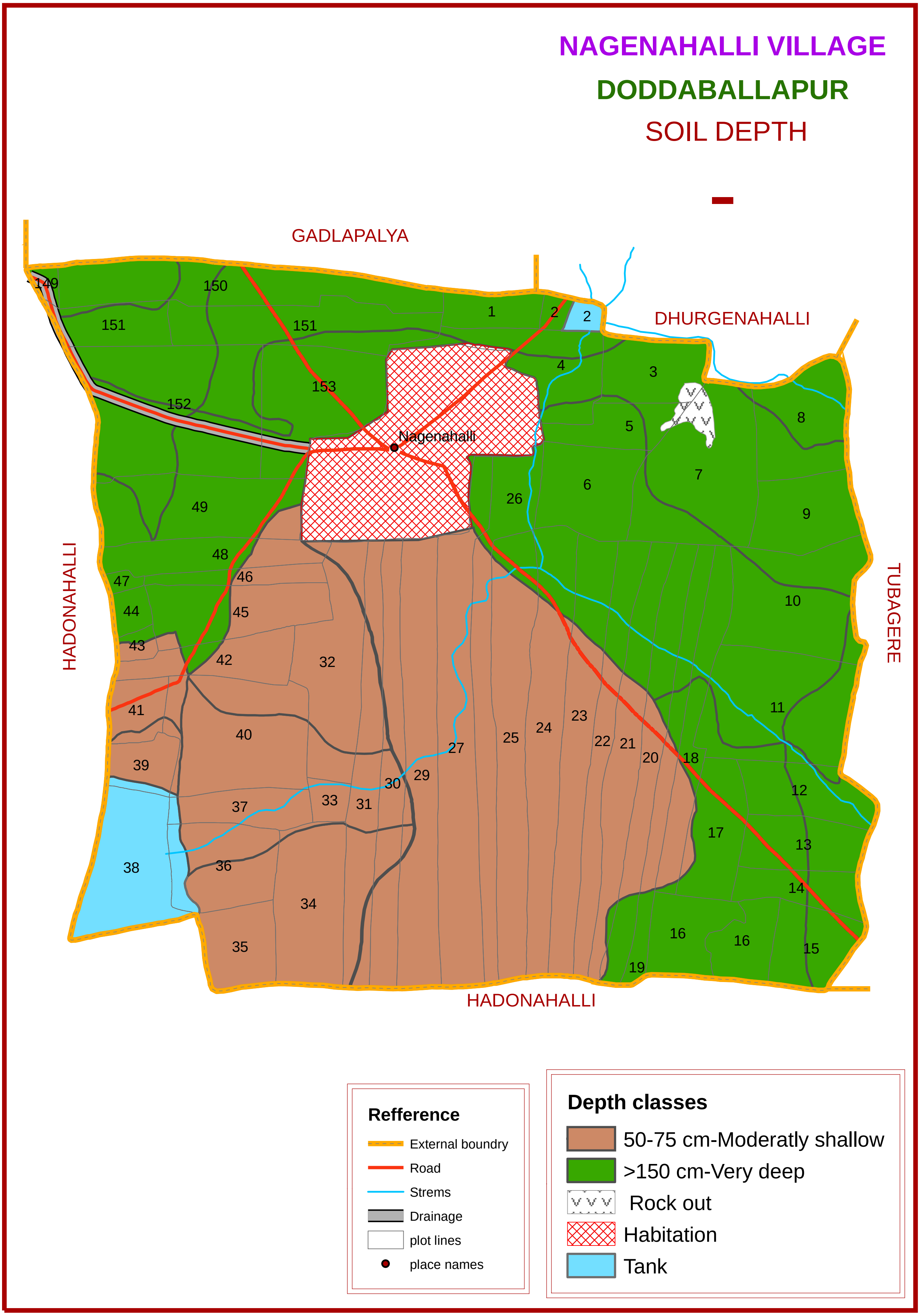


Fig 4.3 Soil depth map of Nagenahalli village

western parts were moderately well drained. Well drained soils occurred in large extent (50.5 %) than moderately well drained (40.4 %).

Table 4.33 Soil drainage in Naganahalli

Soil Drainage classes	Area (ha.)	Percent
Well drained	113.8	50.5
Moderately well drained	90.9	40.4
Miscellaneous	20.4	9.0
Total	225.2	100

4.7.3 Slope

Three slope classes were recorded in the village and mapped (Table.4.34 and Map 4.5).Study revealed that (86.6) percent of the land of the Nagenahalli had very gentle slope, (3.5 %) with gentle slope and only (0.79 %) had level to nearly level land.

Table 4.34 Soil slope classes in Nagenahalli

Soil slope classes	Nagenahalli	
	Area (ha)	%
A. level to Nearly level (0-1%)	1.78	0.79
B. Very gently sloping (1-3%)	195.0	86.6
C. Gently sloping (3-5%)	7.9	3.5
Miscellaneous	20.4	9.0
Total	225.2	100

4.7.4 Soil Erosion

Natural erosion was noticed in the study area which depending on factors like rainfall, slope, soil erodability etc. The water is the main agent responsible for soil erosion in the study area. Sheet erosion is the dominant type of soil erosion observed in

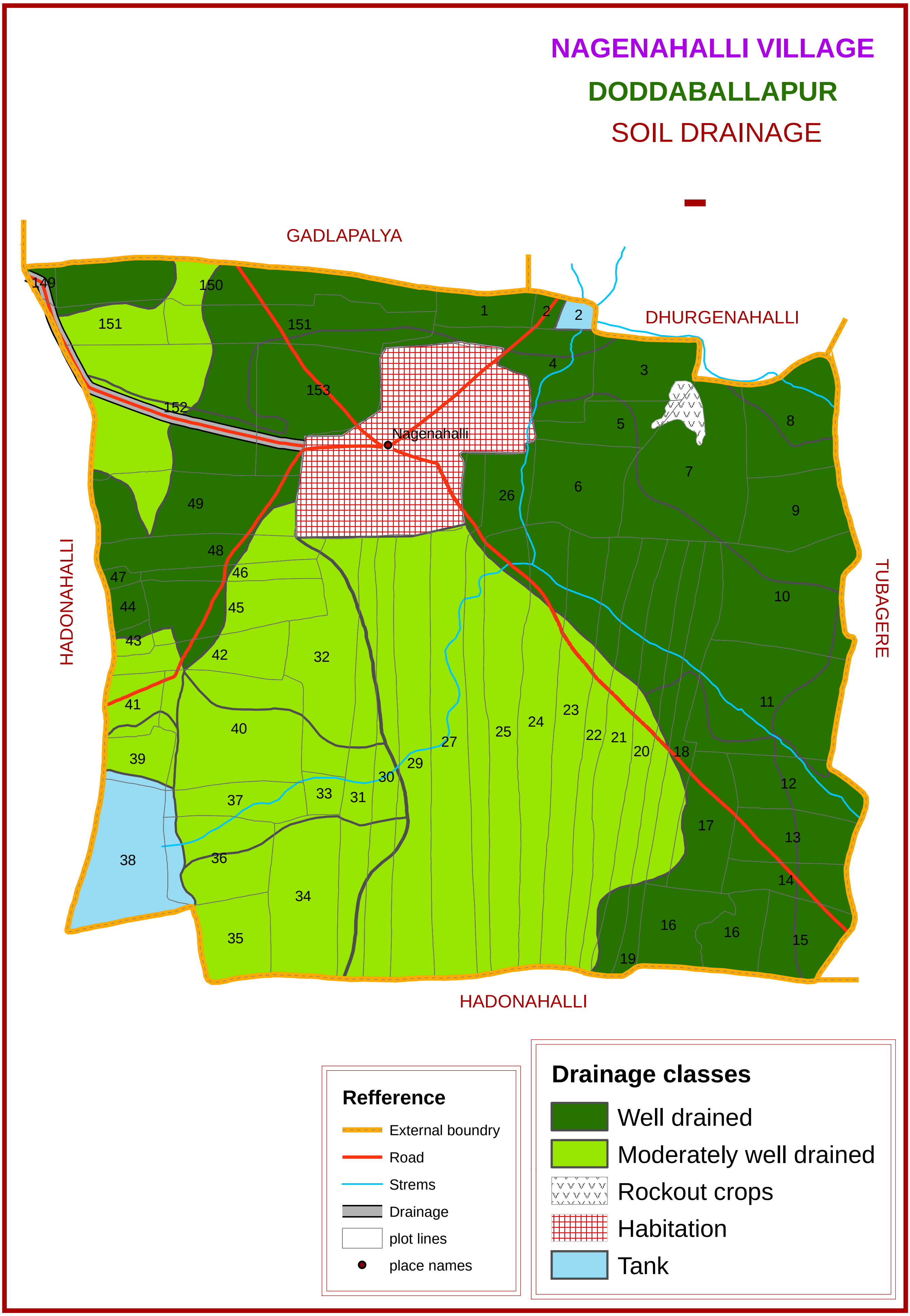


Fig 4.4 Soil drainage map of Nagenahalli village

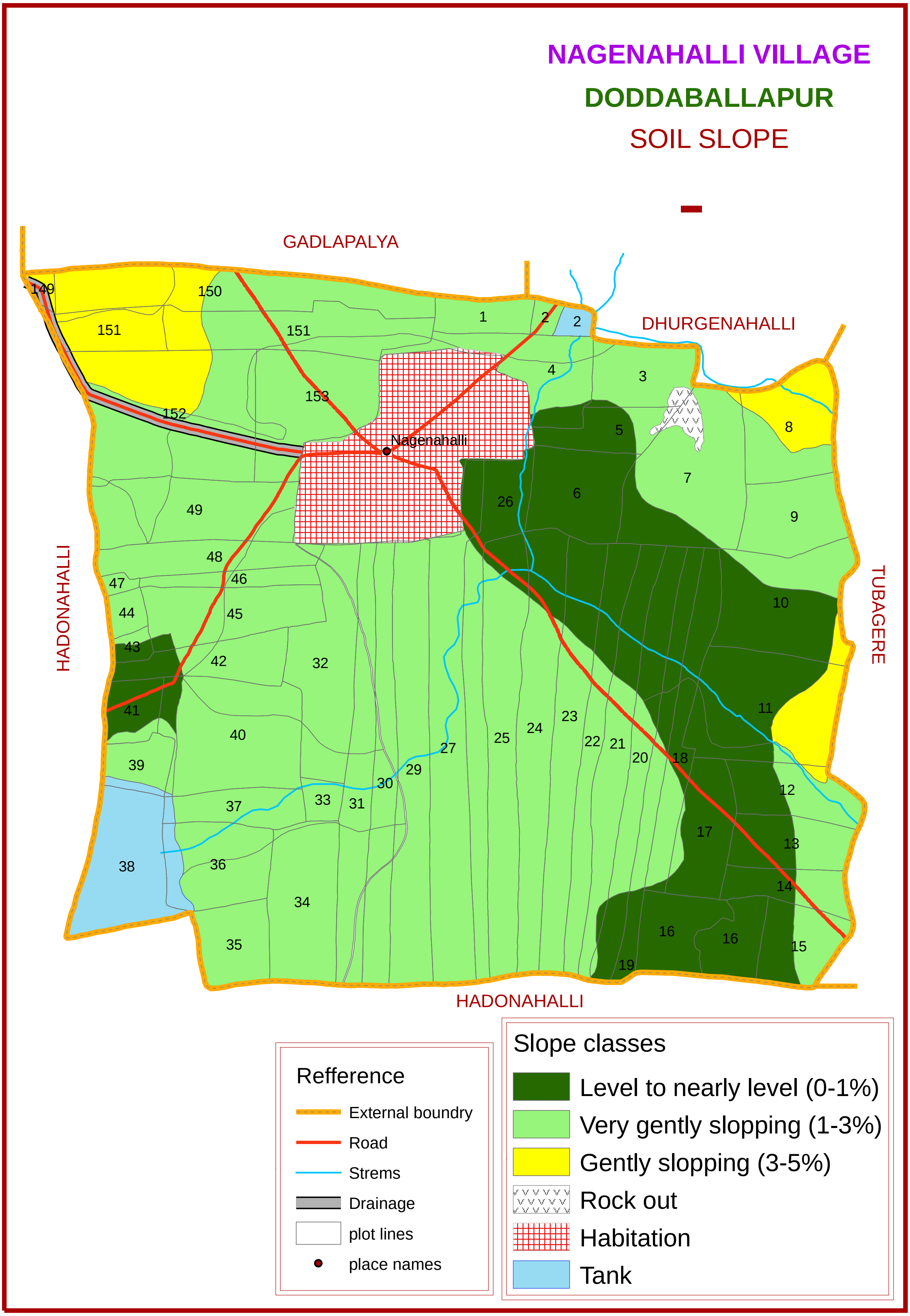


Fig 4.5 Soil Slope map of Nagenahalli village

very gently to gently sloping uplands. The occurrence of various soil erosion classes is shown on the erosion map (map 4.6) out of the total area 49 per cent of the land do not experienced erosion risk while 14 per cent experience slight erosion risk and only 27.9 per cent under moderate erosion risk (table 4.35).

Table 4.35 Erosion classes in Nagenahalli

Soil Erosion classes	Nagenahalli	
	Area (ha)	%
None	110.5	49.0
Slight erosion	31.5	14
Moderate erosion	62.8	27.9
Miscellaneous	20.4	9.0
Total	225.2	100

4.7.5 Surface soil texture

The soils of the study are grouped into various textural classes like loamy sand, sandy loam, sandy clay loam, sandy clay and clay. It is one of the important parameter used to identify phases of soil series established. Sandy clay loam and sandy loam were the dominant texture groups observed in surveyed area. The distribution is sandy clay loam (44 %) followed by sandy loam (24.0 %), loamy sand (20.9 %) and sandy clay (1.2 %) and clay (0.8 %) which occurs in a limited extent (Table 4.36 and map 4.7).

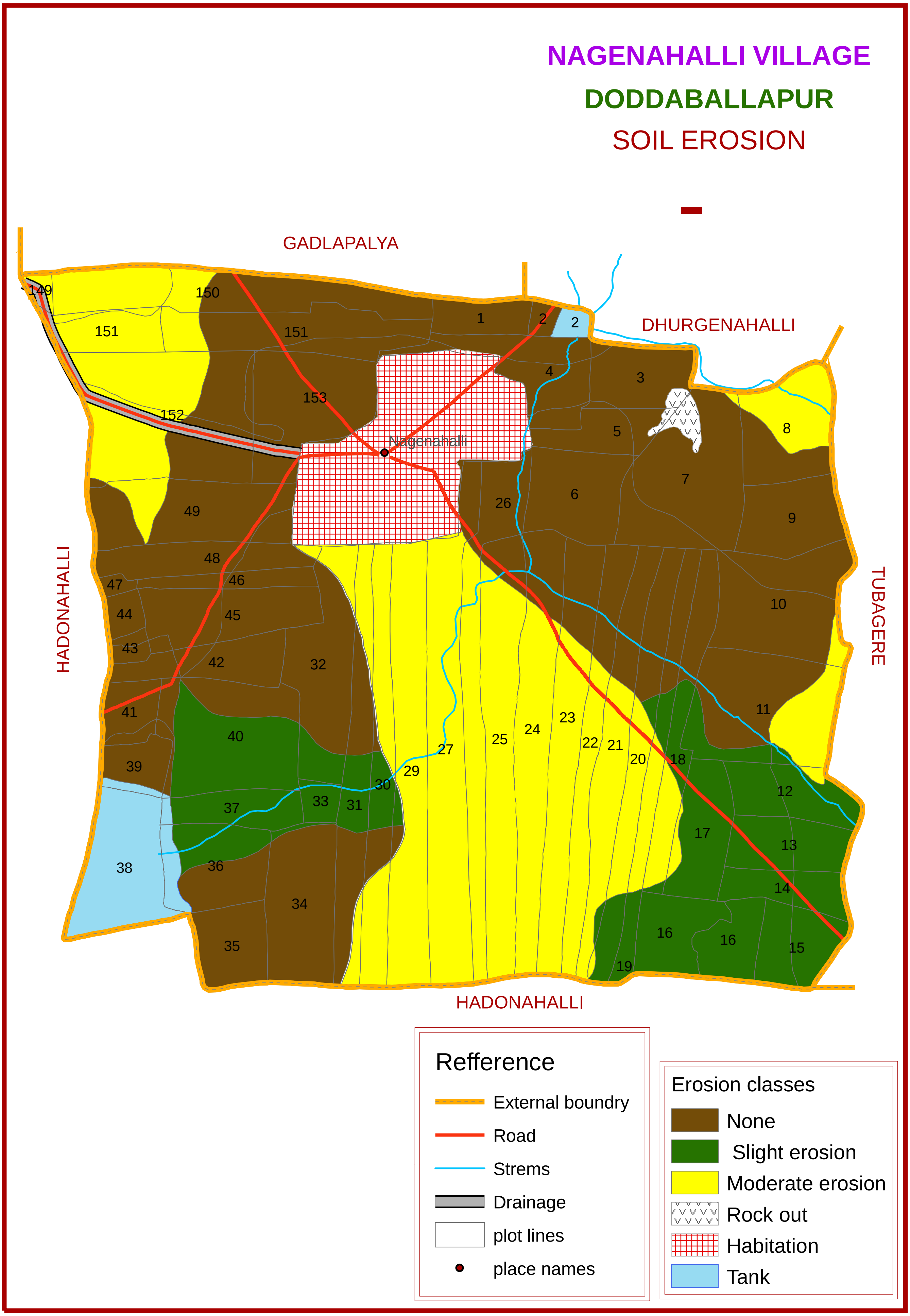


Fig 4.6 Soil Erosion map of Nagenahalli village

Table 4.36 Soil textural classes in Nagenahalli

Soil Texture	Nagenahalli	
	Area (ha)	%
Loamy sand	47.1	20.9
Sandy loam	54.1	24.0
Sandy clay loam	99.0	44
Sandy clay	2.7	1.2
Clay	1.8	0.8
Miscellaneous	20.4	9.0
Total	225.2	100

4.7.6 Surface stoniness

The soils of the whole study area comes under non-gravelly class (0-15 %) which are better for crop production as the gravelliness makes obstraction to free root development of crops and germination of seeds of small seeded crops.

4.7.7 Rockiness

Rockiness refers to coverage of the soil with exposed rocks, which hinders plant growth directly by impeding root development and through interference of mechanical manipulation and tillage of soil. Out of total study area only 1.1 % of the cultivated area experienced slight rockiness (Table 4.37 and map 4.8).

Table 4.37 Surface rockiness in Nagenahalli

Surface rockiness class	Nagenahalli	
	Area (ha)	%
Non-rocky (<0.1 % cover)	202.2	89.8
Slightly rocky (1-5 % cover)	2.6	1.1
Miscellaneous	20.4	9.0
Total	225.2	100

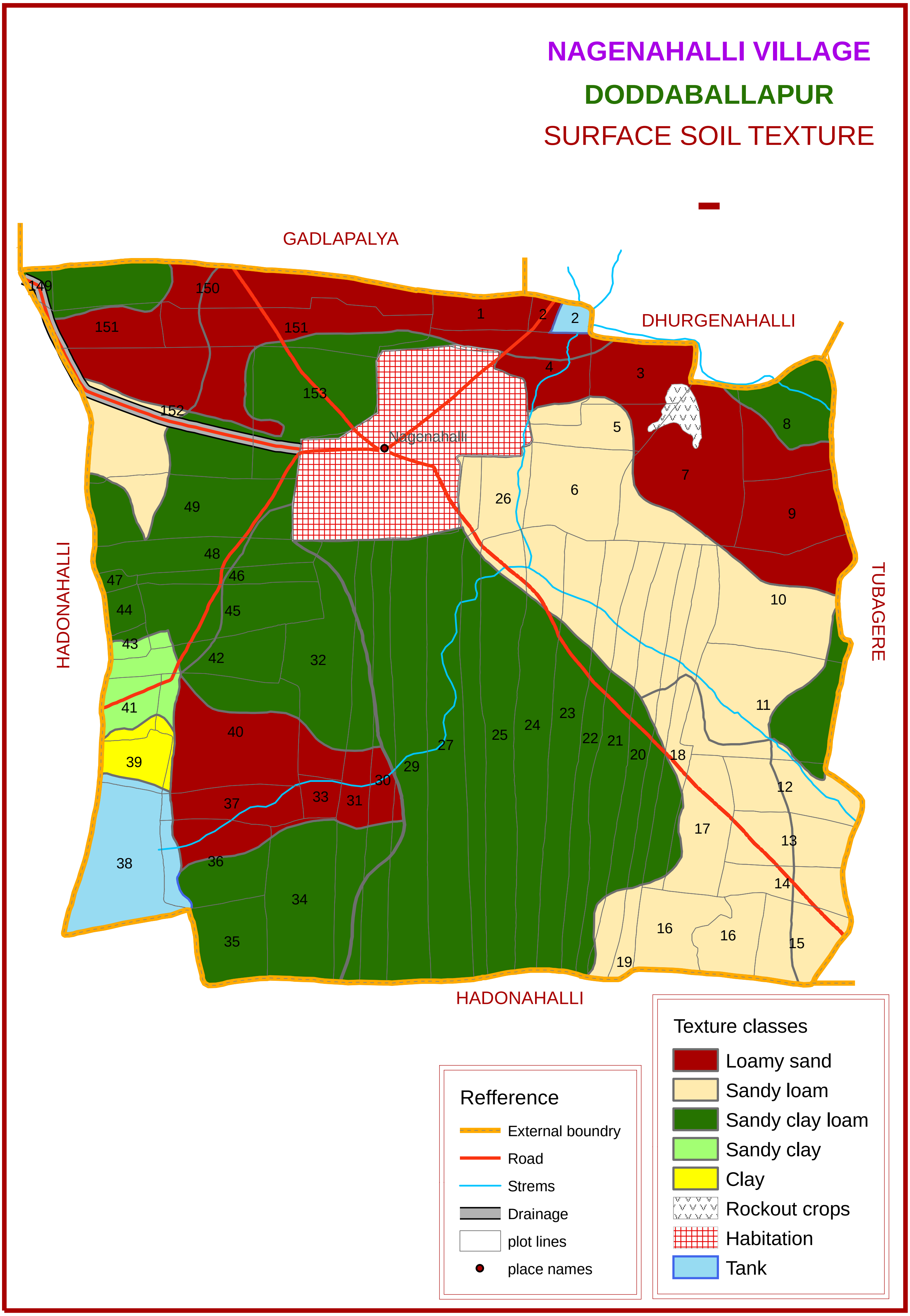


Fig 4.7 Surface soil texture map of Nagenahalli village

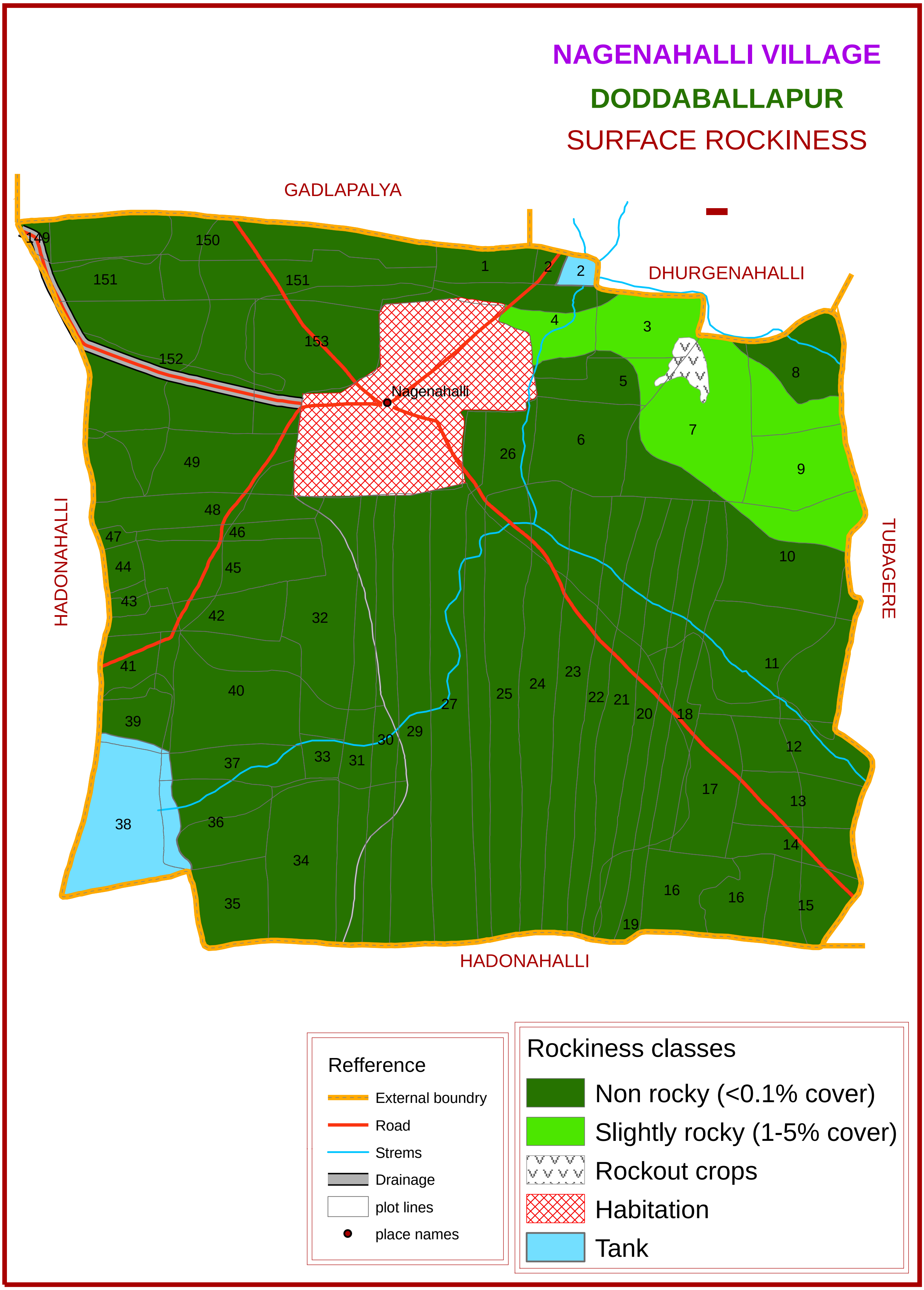


Fig 4.8 Surface rockyness map of Nagenahalli village

4.7.8 Organic carbon status

The status of organic carbon relates to the inherent fertility of soil. The study showed that the organic carbon content in surface and subsurface of all the pedons were low and it decreased with depth.

4.8 Problems and potentials for Agriculture

4.8.1 Climatic constraints

Climate is the major limitation in the study area with lesser rainfall than evapotranspiration. Water balance studies using Thornthwaite and Mather (1995), showed the length of dry season as around 6 months, where precipitation falls below 50 mm and it does not support growing of rainfed crops.

4.8.2 Soil Erosion

Nearly 60.12 ha of the study area was prone to moderate erosion. Sheet Erosion was common in nearly 8.0 ha area wherever gentle slope was observed particularly in uncultivated lands.

4.8.3 Soil fertility status

The soils were poor in available nitrogen. 173.0 ha of the study area were very low in nitrogen status. About 156.9 ha area was low in K content. Whole study area recorded the low organic carbon levels and such low levels are not ideal for higher crop productivity.

4.9 Land evaluation

Detailed survey of the area will gave a comprehensive information base on the nature, extent and distribution of various land resources and soil resources. This information helps in identification of perceived problems and potentials of the area for crop production and other developmental works in the watershed.

4.9.1 Soil fertility

The results obtained from the laboratory analysis of the surface samples which were collected plot wise for the status of available nitrogen, available phosphorus, available potassium and available micronutrients are presented in tables() and maps().

4.9.1.1 Soil reaction

The various soil reaction classes observed and descriptive terms in use for ranges in the study area are given below.

Surface soil reaction of plots of Nagenahalli (Table 4.38 Map 4.9) revealed that 33.2 per cent of area were moderately acidic in reaction, followed by 24.7 per cent strongly acidic, 12.2 per cent neutral, 9.9 per cent very strongly acidic, 24.7 per cent are slightly acidic and 1.9 per cent moderately alkaline.

Table 4.38 Surface soil reaction classes

Soil reaction classes	Nagenahalli	
	Area (ha)	%
Very strongly acid (4.5-5.0)	22.3	9.9
Strongly acid(5.0-5.5)	55.6	24.7
Moderately acid (5.5-6.0)	74.8	33.2
Slightly acid (6.0-6.5)	20.3	9.0
Neutral (6.5-7.3)	27.5	12.2
Moderately alkaline (7.8-8.4)	4.2	1.9
Miscellaneous	20.4	9.0
Total	225.2	100

4.9.1.2 Available Nitrogen

Available nitrogen content of the soils in the Nagenhalli are grouped into three classes, viz., very low, low and medium. About 75.7 per cent of the study area was rated

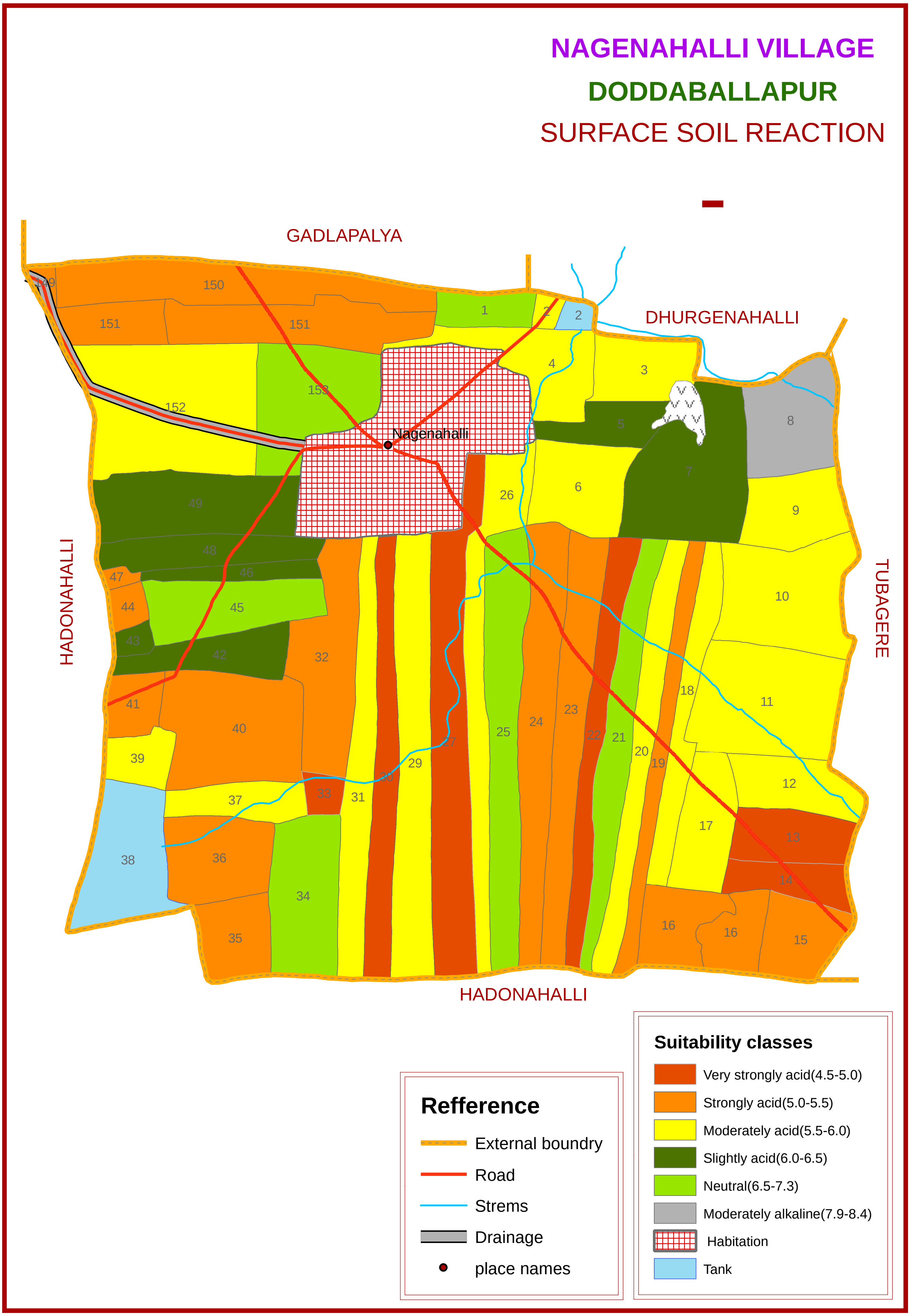


Fig 4.9 Surface soil reaction (plotwise) of Nagenahalii village

as very low (Table 4.39 and Map 4.10). 13.2 per cent showed low and only 2.1 per cent showed medium available nitrogen.

Table 4.39 Available nitrogen status of Nagenahalli

Available nitrogen classes	Nagenahalli	
	Area (ha)	%
Very low < 140 kg/ha	170.5	75.7
Low 140 to 280 kg/ha	29.6	13.2
Medium 280 to 560 kg/ha.	4.7	2.1
Miscellaneous	20.4	9.0
Total	225.2	100

4.9.1.3 Available phosphorus

Available phosphorus content of the soils in the Nagenahalli are grouped into three classes viz., Medium, high and very high. Available phosphorus status of the soil revealed that about 75.6 per cent of the soils studied were very high in phosphorus (Table4.40 and Map 4.11) while 12 per cent were high and 3.3 per cent were medium.

Table 4.40 Available phosphorus (P_2O_5) statues of Nagenahalli

Available phosphorus classes	Nagenahalli	
	Area (ha)	%
Medium 22.90 to 56.33 kg/ha	7.4	3.3
High 56.30 to 112.66 kg/ha.	27.1	12
Very high > 112.66 kg/ha.	170.3	75.6
Miscellaneous	20.4	9.0
Total	225.2	100

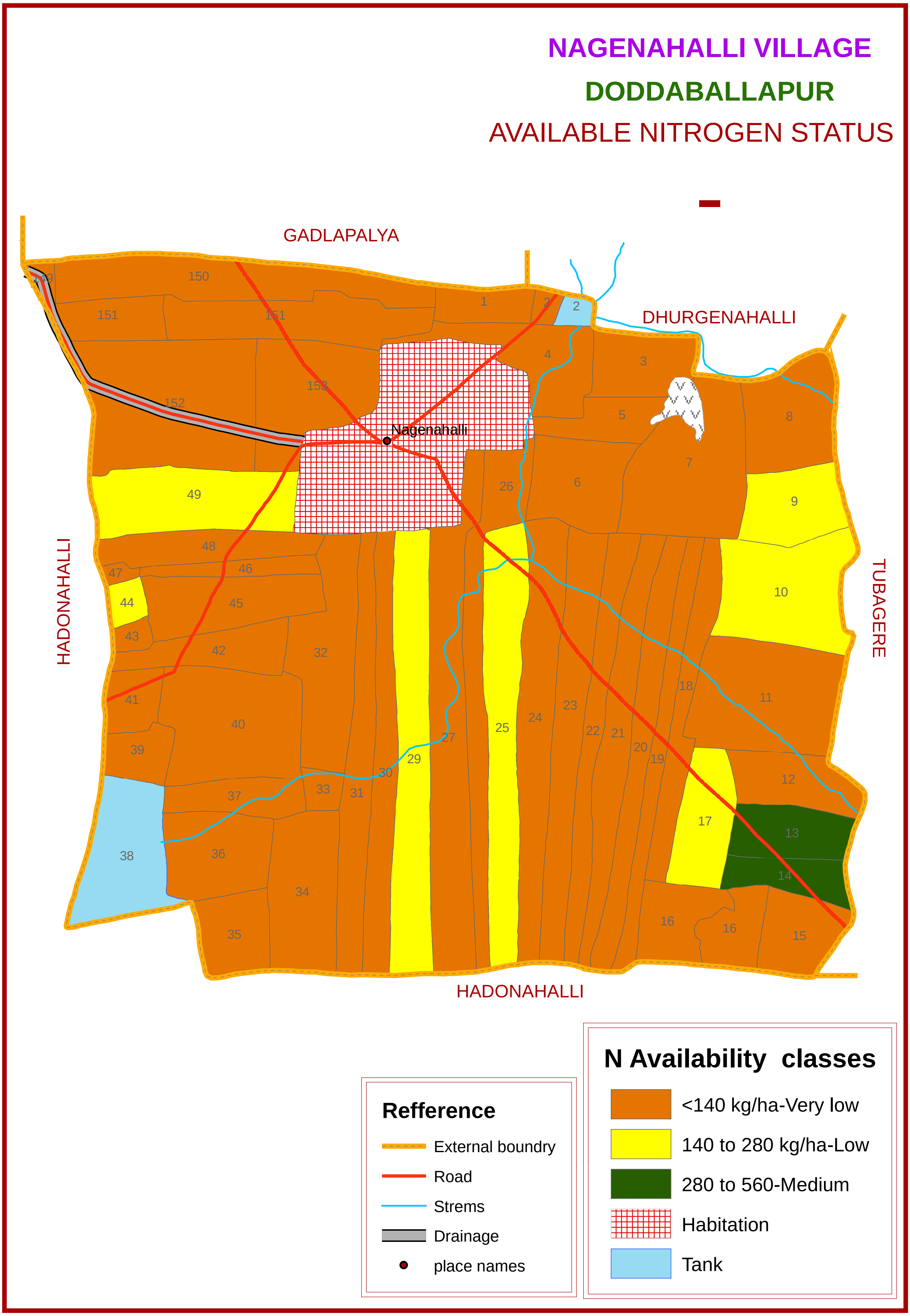


Fig 4.10 Available Nitrogen status (plotwise) of Nagenahalli village

* Very low class is included to dipict the seviority of fertility problem in the study area.

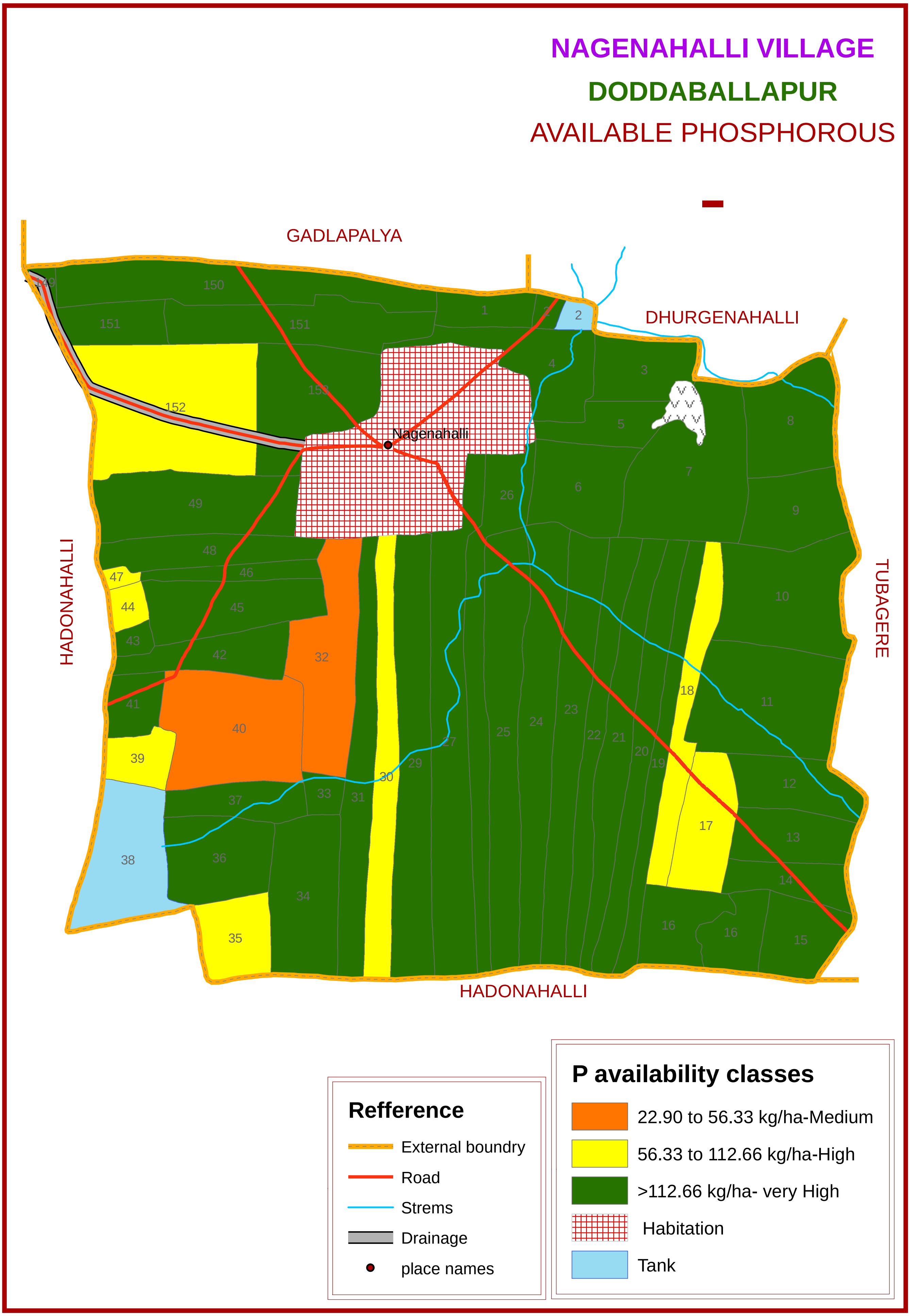


Fig 4.11 Available Phosphorous status (plotwise) of Nagenahalli village

* Very high class included to dipict the intensity of high availability.

4.9.1.4 Available Potassium

Available potassium content of the soils of Nagenahalli are grouped into four classes.viz., very low, low, medium and high.

Study revealed that about 69.9 percent area were low (Table 4.41 and Map 4.12) while 10.6 per cent were very low and 11.1 per cent were medium and 1.3 per cent were high in available potassium.

Table 4.41 Available potassium (K_2O) status of Nagenahalli

Available Potassium(K_2O) classes	Nagenahalli	
	Area (ha)	%
Very low < 70.5kg/ha	23.9	10.6
Low 70.50 to 141 kg/ha.	152.9	69.9
Medium 141 to 336 kg/ha	25.1	11.1
High > 336 kg/ha.	2.9	1.3
Miscellaneous	20.4	9.0
Total	225.2	100

4.9.1.5 Available Zinc

Soil available zinc status was grouped into 4 classes. Viz., low, marginal, adequate and high, for fertilizer recommendation. About 43.2 per cent of the study area was rated as adequate (table 4.42 and map 4.13) 25.4 per cent of the area as high, while 12.2 per cent of the area as marginal and 10.0 per cent of the area as low.

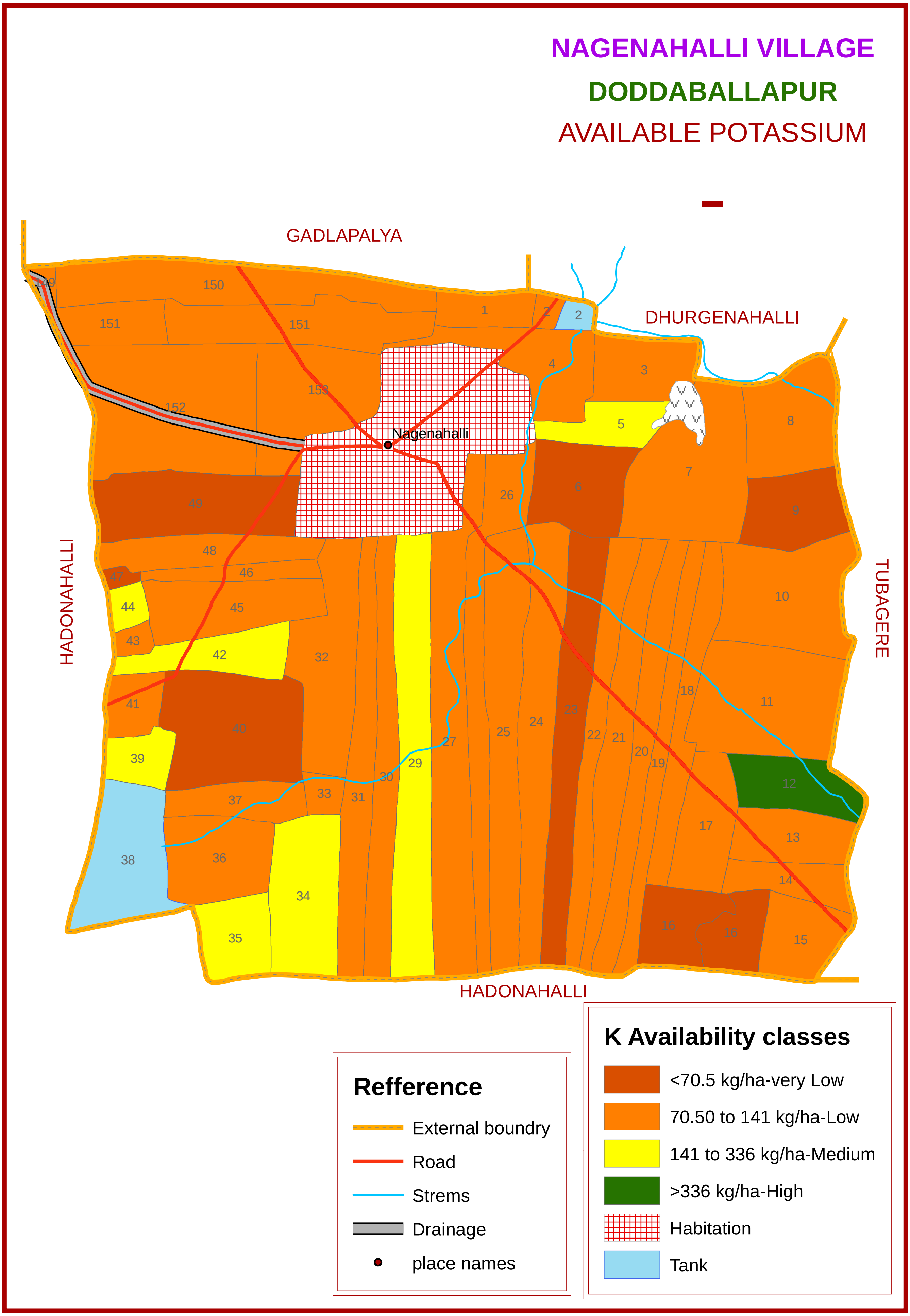


Fig 4.12 Available Potassium status (plotwise) of Nagenahalli village

* Very low class is included to dipict the seviority of fertility problem

Table 4.42 available zinc status of Nagenahalli

Available Zinc classes	Nagenahalli	
	Area (ha)	**%**
Low <0.5ppm	22.6	10.0
Marginal 0.5 to 0.75ppm	27.5	12.2
Adequate 0.75 to 1.5ppm	97.4	43.2
High > 1.5 ppm	57.2	25.4
Miscellaneous	20.4	9.0
Total	225.2	100

Other micronutrients like Iron, Copper and Manganese were found to be adequate in the soils of the study area. Table 4.43 shows the plot wise nutrient status of the study area.

4.9.2 Fertility capability classification

The soils first are classified based on the presence or absence of the soil constraints. FCC emphasizes quantifiable topsoil parameters as well as subsoil properties, which are directly related to plant growth.

Table 4.44 and map 4.14 represent the FCC classes of soils of Nagenhalli, Maximum area (21.4 %) was occupied by Lheko with moderately shallow loamy soils with low CEC, low K reserves, low organic carbon and acidic soil reaction with very gentle slopes. Next is by Lchieko (12.5 %) with very deep soils with loamy surface and clayey subsurface having low CEC, low K reserve, low organic carbon, high P fixation and acidic soil reaction with level to nearly level lands flowed by Lheko (10.3 %) with moderately shallow loamy soils with low CEC, low K reserves, low organic carbon and acidic soil reaction with very gentle slopes.

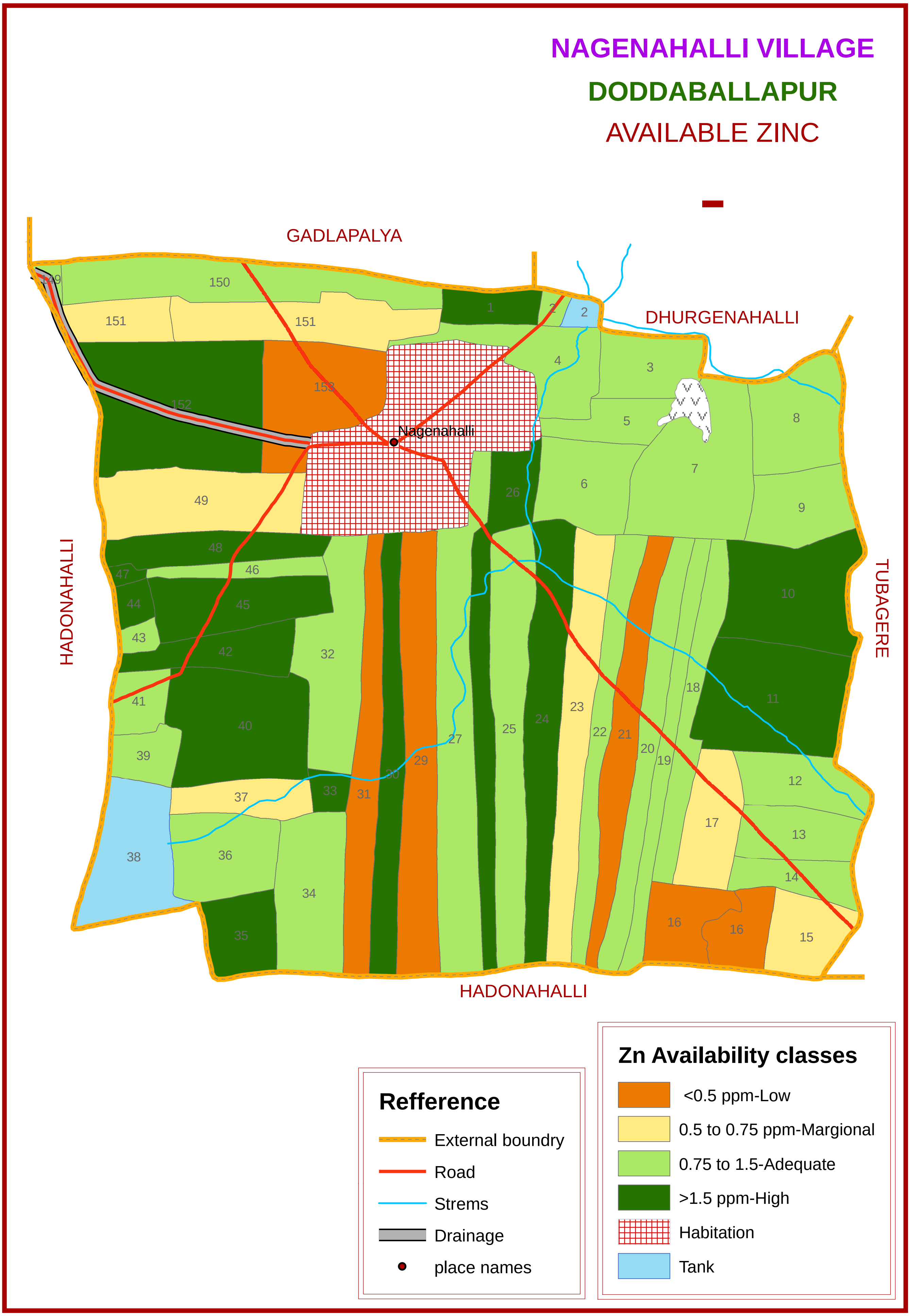


Fig 4.13 Available Zinc status (plotwise) of Nagenahalli village

Table 4.43 Fertility properties of surface (plot wise) samples

Sl. no	Survey number	pH	EC (dSm^{-1})	Available nutrients (kg ha^{-1})			Micronutrients (mg kg^{-1})			
				N	P_2O_5	K_2O	Cu	Fe	Mn	Zn
1	Ngh-1	6.96	-	94.08	333.45	135.74	1.70	22.00	19.04	2.28
2	Ngh-2	5.96	-	62.72	318.08	133.05	1.10	25.60	19.71	0.90
3	Ngh-4	5.90	-	94.08	342.45	84.67	0.64	26.00	9.12	0.80
4	Ngh-5	5.93	-	94.08	351.15	158.59	0.90	28.00	13.02	0.84
5	Ngh-6	6.23	-	94.08	245.70	67.20	0.64	16.80	17.02	0.80
6	Ngh-7	5.82	-	62.72	390.19	75.26	0.70	15.60	16.20	1.28
7	Ngh-8	6.41	-	62.72	247.76	133.05	0.52	15.00	14.20	1.46
8	Ngh-9	8.13	-	156.80	372.00	69.88	0.88	23.00	10.64	1.02
9	Ngh-10	5.53	-	188.16	368.12	71.23	0.98	3.60	18.64	2.34
10	Ngh-11	5.90	-	125.44	366.60	114.24	1.60	22.6	18.60	5.20
11	Ngh-12	5.51	-	62.72	289.06	521.47	1.00	18.80	18.20	0.76
12	Ngh-13	5.68	0.15	376.32	169.02	76.60	1.60	20.80	24.60	0.90
13	Ngh-14	4.72	0.12	313.60	205.44	83.32	1.70	15.20	27.40	0.96
14	Ngh-15	4.66	0.16	94.08	390.62	75.26	1.56	17.80	22.20	0.64
15	Ngh-16	5.21	0.36	62.72	233.40	61.82	1.06	13.40	18.20	0.50
16	Ngh-17	5.30	-	188.16	66.94	104.83	1.30	17.00	16.60	0.66
17	Ngh-18	5.54	-	125.44	81.82	87.20	1.10	36.20	18.20	0.98
18	Ngh-19	5.72	-	125.44	338.23	133.05	1.10	18.20	22.20	0.94
19	Ngh-20	5.11	-	94.08	252.37	94.08	1.00	21.40	20.40	0.96
20	Ngh-21	5.70	-	125.44	342.40	91.39	0.86	27.00	18.20	0.60
21	Ngh-22	6.52	-	94.08	303.96	124.99	1.00	31.00	15.00	0.98
22	Ngh-23	4.50	0.15	94.08	216.61	55.10	0.70	15.00	6.46	0.58
23	Ngh-24	5.04	-	125.44	206.72	103.48	0.90	14.00	17.20	2.16
24	Ngh-25	5.34	-	219.58	209.80	138.43	0.60	18.60	21.40	1.08
25	Ngh-26	6.72	-	94.08	135.42	100.80	0.80	23.60	12.60	1.62
26	Ngh-27	5.64	-	62.72	387.19	86.01	0.70	22.60	18.20	0.94

Sl. no	Survey number	pH	EC (dSm^{-1})	Available nutrients (kg ha^{-1})			Micronutrients (mg kg^{-1})			
				N	P_2O_5	K_2O	Cu	Fe	Mn	Zn
27	Ngh-29	5.84	-	156.80	112.24	146.49	1.22	34.60	16.40	0.52
28	Ngh-30	4.94	-	94.08	95.67	110.20	1.20	36.00	12.60	1.80
29	Ngh-31	5.83	-	62.72	248.28	100.80	0.68	17.80	12.20	0.48
30	Ngh-32	5.39	-	125.44	55.91	116.92	1.20	28.20	16.40	1.40
31	Ngh-33	4.68	-	62.94	336.76	138.43	1.70	30.60	10.80	2.40
32	Ngh-34	6.82	-	94.08	260.33	166.65	1.60	33.60	20.86	0.78
33	Ngh-35	5.46	0.20	62.72	95.41	252.67	1.80	67.00	16.24	1.96
34	Ngh-36	5.44	-	94.08	371.69	71.23	1.50	32.20	27.00	1.10
35	Ngh-37	5.66	-	125.44	333.45	129.02	2.60	89.00	18.40	0.70
36	Ngh-38	5.33	-	188.16	21.29	135.74	4.00	56.20	15.12	1.12
37	Ngh-39	5.99	-	94.08	141.06	166.65	2.20	148.20	30.60	0.78
38	Ngh-41	5.14	0.06	31.36	143.12	71.23	1.60	51.00	17.00	1.02
39	Ngh-42	6.10	0.18	62.72	311.62	151.87	2.80	113.60	18.20	1.92
40	Ngh-43	6.35	-	62.72	307.91	75.26	2.80	129.60	14.60	0.90
41	Ngh-44	5.48	-	156.80	139.26	147.84	1.02	19.20	13.06	2.46
42	Ngh-45	7.16	-	125.44	386.37	115.58	0.98	26.20	10.64	2.12
43	Ngh-46	6.47	-	94.08	336.84	116.92	2.16	202.02	7.66	1.00
44	Ngh-47	5.12	-	94.08	124.65	67.20	1.30	28.00	9.44	2.66
45	Ngh-48	6.15	-	94.08	325.92	90.04	1.40	52.20	17.00	1.76
46	Ngh-49	6.04	-	156.80	329.09	67.20	0.6	58.00	15.12	0.52
47	Ngh-149	5.30	-	62.72	387.03	90.04	0.66	24.40	18.80	1.32
48	Ngh-150	5.38	-	62.72	334.25	98.11	1.30	50.00	16.20	0.96
49	Ngh-151	5.31	-	94.08	201.08	96.76	1.10	11.50	18.40	0.72
50	Ngh-152	5.75	-	62.72	80.23	87.36	1.08	25.00	10.20	1.82
51	Ngh-153	6.70	-	94.08	364.74	72.57	0.98	24.00	18.20	0.56
52	Ngh-0	5.45	-	94.08	48.23	73.92	0.90	14.60	18.40	2.18

Table 4.44 Area and description of FCC units of Nagenahalli

Sl. No.	FCC Unit	Description	Area (ha)	Per cent
1.	SLeko (1-3 %)	Very deep red soils with sandy surface, loamy subsurface having low CEC, low K reserves low organic carbon and very gentle slopes.	12.03	5.34
2.	Leko (1-3 %)	Very deep red soils with loamy surface and loamy subsoil having low CEC, low K reserves, low organic carbon and very gentle slopes.	19.37	8.60
3.	Leko	Very deep red soils having loamy surface and subsurface with low CEC, low K reserves and low organic carbon	2.92	1.29
4.	SCheko (3-5 %)	Very deep red soils having sandy surface and clayey subsurface having acidic soil reaction, low CEC, low K reserves and low organic carbon and gentle slopes.	6.28	2.70
5.	LCheko (1-3 %)	Very deep red soil having loamy surface and clayey sub soil with acid soil reaction, low CEC, low K reserves and low organic carbon and very gentle slopes	3.81	1.69
6.	SLheko (1-3 %)	Moderately shallow soils with sandy surface and loamy sub soil, low CEC, low K reserves and low organic carbon with acidic soil reaction and very gentle slopes.	11.46	5.08
7.	CLheko (0-1 %)	Moderately shallow soils with clayey surface and loamy sub surface having low CEC, low K reserves, acidic soil reaction with level to nearly level land.	2.75	1.22

8.	L heko	Moderately shallow soils with loamy surface and subsurface with low CEC, low K reserves, low organic carbon and acidic soil reaction.	23.67	10.32
9.	Lheko (1-3 %)	Moderately shallow soils with loamy surface and subsurface, low CEC, low K reserves, low organic carbon and acidic soil reaction with very gentle slopes.	48.24	21.42
10.	CL heko (1-3 %)	Moderately shallow soils with clayey surface and loamy subsurface having low CEC, low K reserves, low organic carbon and acidic soil reaction with very gentle slopes.	1.78	0.79
11.	LChieko (1-3 %)	Very deep red soils with sandy loam surface and sandy clay subsurface having low CEC, low K reserves low organic carbon, high P fixation, acidic soil reaction and very gentle slopes.	16.41	7.28
12.	SChieko (1-3 %)	Very deep red soils with sandy surface and clayey subsurface having low CEC, low K reserves, low organic carbon, high P fixation, acidic soil reaction and very gentle slopes.	17.29	7.67
13.	LChieko (3-5 %)	Very deep red soils with loamy surface and clayey subsurface, having low CEC, low K reserves, low organic carbon, high P fixation, acidic soil reaction and with gentle slopes.	5.03	2.23

14.	LChieko (0-1 %)	Very deep red soils with loamy surface and clayey subsurface having low CEC, low K-reserves, low organic carbon, high P fixation and acidic soil reaction with nearly level lands.	28.35	12.58
15.	LChieko	Very deep red soils with loamy surface and clayey subsurface having low CEC, low K-reserves, low organic carbon, high P fixation and acidic soil reaction.	5.39	2.39
16	Miscellaneous		20.4	9.01
17	Total		225.2	100

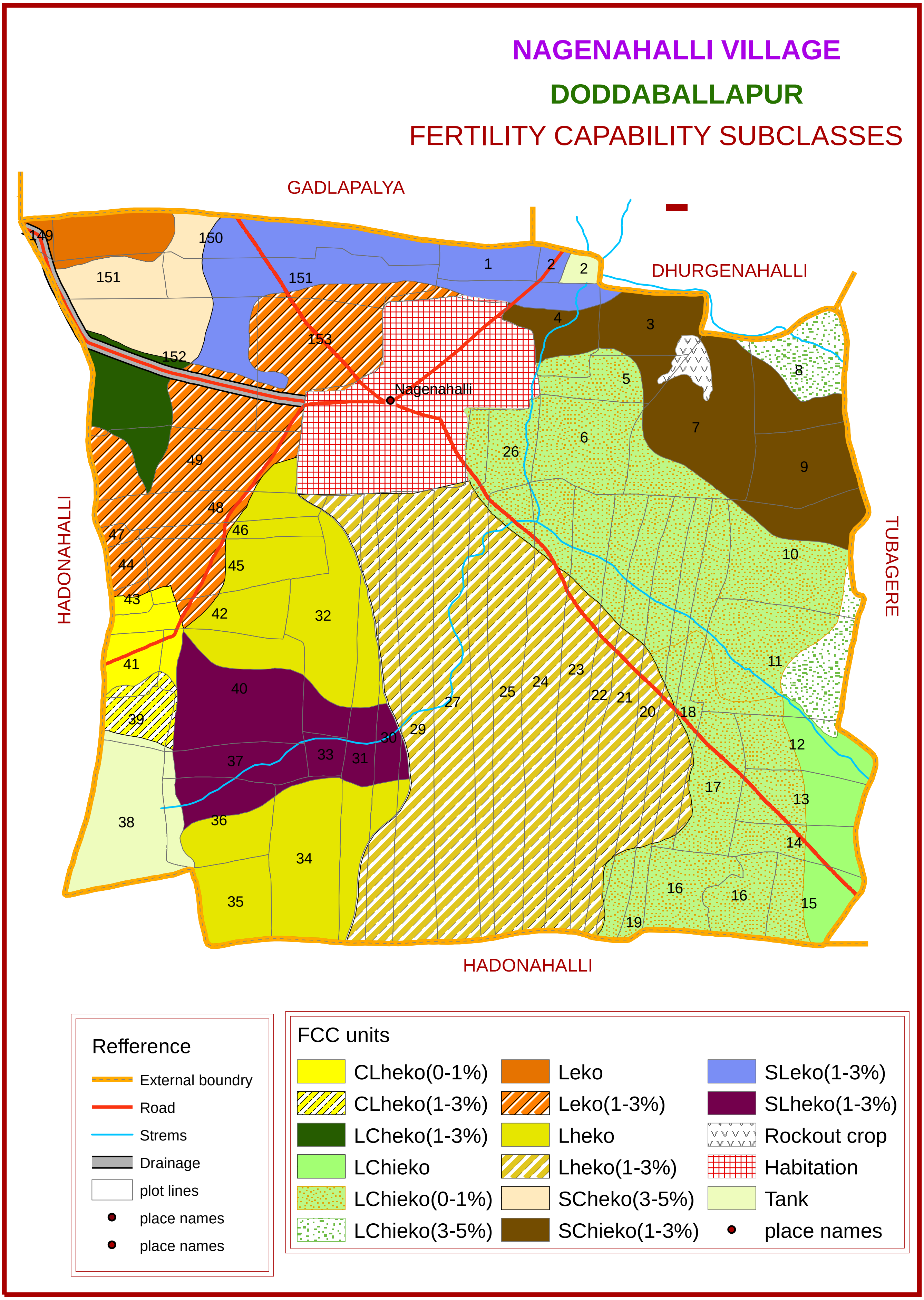


Fig 4.14 FCC sub classes map of Nagenahalli village

4.9.3 Land suitability for major crops

The overall suitability of the soils was determined based on the degree and number of limitations for a particular unit. The final soil suitability was based on the number and degree of limitations. In the present study the suitability class's viz., highly suitable (S1), moderately suitable (S2) and marginally suitable (S3) were adopted to categorize the soils.

4.9.3.1 Land suitability for Ragi

Land suitability for ragi an important staple food crop of the village grown in large area has been worked out and presented in a map 4.15. In the village 144.8 ha (64.3 %) of the land was classified under highly suitable followed by areas which were moderately suitable (9.94 ha, 4.6 %) and areas which are marginally suitable for Ragi cultivation constituting (47.0 ha, 20.9 %). Land suitability classes with extent are shown in table 4.45.

Table 4.45 Soil suitability for Ragi

Sl No.	Suitability classes	Description	Area (ha)	%
1.	S1	Highly suitable land with no limitations other than slight climatic limitation	144.8	64.3
2.	S2t	Moderately suitable land with slight soil texture limitations	4.9	2.2
3.	S2e	Moderately suitable land with slight limitations due to proneness to erosion	5.4	2.4
4.	S3t	Marginally suitable Land with moderate soil texture limitation.	47.0	20.9
5	Miscellaneous		20.4	9.0
6	Total		225.2	100

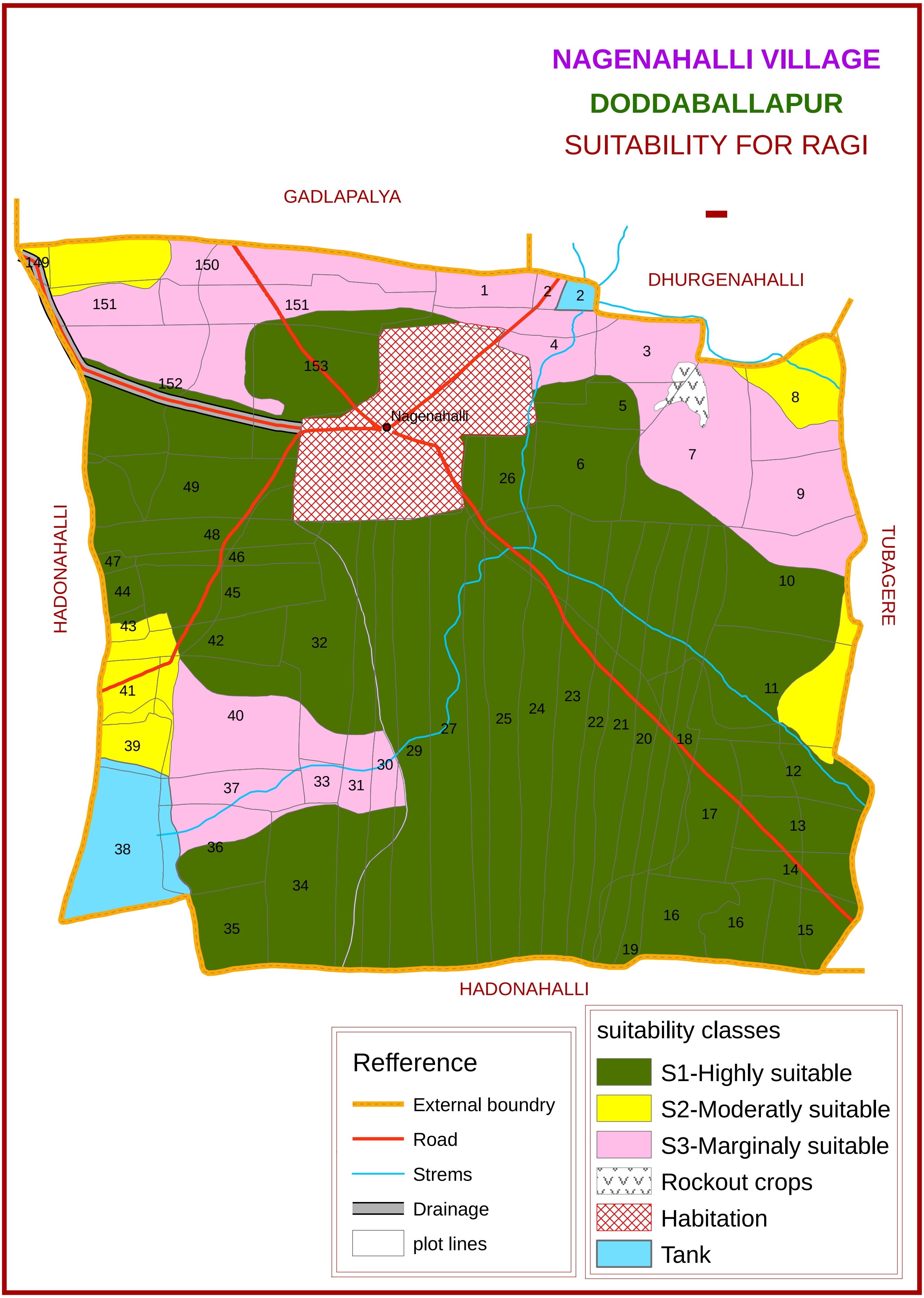


Fig 15 Land Suitability for Ragi

4.9.3.2 Land suitability for Maize

Maize is an important cereal crop grown as cash crop in the study area. A map showing the distribution of the suitability of soils for maize was prepared and depicted in the (Map 4.16). In the study area, 157.31 ha (69.85 %) of the land was classified under moderately suitable and 47.06 ha (20.90%) of the land was classified under marginally suitable for maize cultivation (Table 4.46).

Table 4.46 Soil suitability for maize

Sl No.	Suitability classes	Description	Area (ha)	%
1.	S2s	Moderately suitable land with slight limitation due to soil fertility.	90.8	40.3
2.	S2ts	Moderately suitable land with slight soil texture and soil fertility limitation	58.5	26
3.	S2es	Moderately suitable land with slight limitation due to proneness to erosion and soil fertility.	7.9	3.5
4.	S3ts	Marginally suitable land with moderate soil texture limitation and slight soil fertility limitation.	47.0	20.9
5	Miscellaneous		20.4	9.0
6	Total		225.2	100

4.9.3.3 Land suitability for Tomato

Among vegetable crops, tomato is most commonly grown in the study area. A map showing the distribution of suitability of soils for tomato was prepared and depicted in the map 4.17. In the study area 64.13 ha (28.5 %) of the land was classified under highly suitable followed by areas which were moderately suitable (120.15 ha, 53.35 %) and areas which are marginally suitable (20.6 ha, 9.1 %). Land suitability classes for tomato with extent area shown in table 4.47.

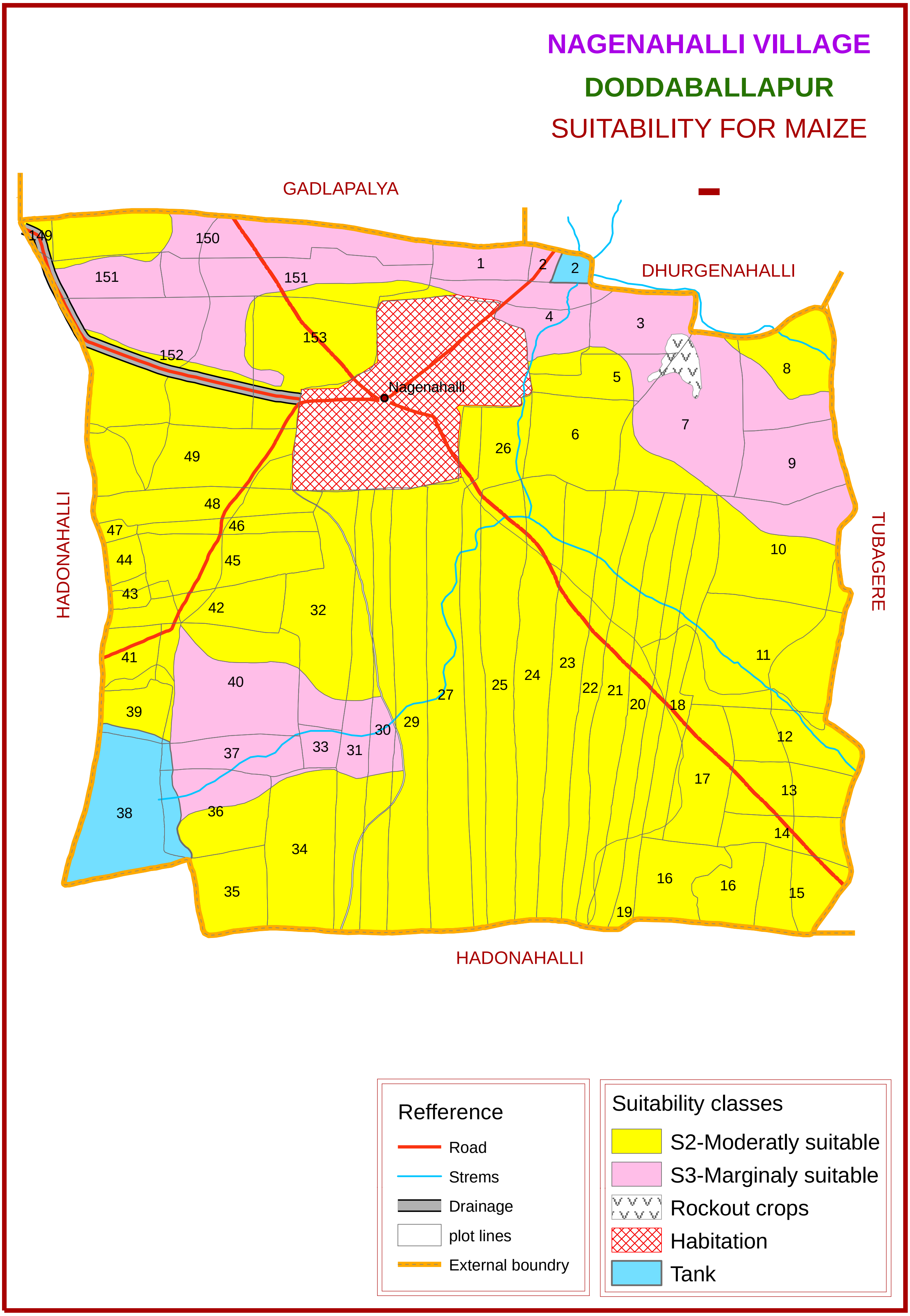


Fig 4.16 Suitability for Maize

Table 4.47 Soil suitability for Tomato

Sl No.	Suitability classes	Description	Area (ha)	%
1.	S1	Highly suitable land with no limitations other than slight climatic limitation	64.1	28.5
2.	S2s	Moderately suitable land with slight limitation due to soil fertility	28.6	12.7
3.	S2ts	Moderately suitable land with slight soil texture and soil fertility limitations.	31.5	14.0
4.	S2es	Marginally suitable land with slight limitation due to proneness to erosion and soil fertility.	60.0	26.6
5.	S3ts	Marginally suitable land with moderate limitation due to soil texture and slight soil fertility limitation	20.6	9.1
6	Miscellaneous		20.4	9.0
7	Total		225.2	100

4.9.3.4 Land suitability for carrot and radish

Carrot and radish are the two important root vegetables grown in the study area. A map showing the distribution of suitability of soils for carrot and radish was prepared and depicted (Map 4.18). In the village 144.8 ha (64.7 %) of the land was highly suitable followed by areas which were moderately suitable (52.9 ha, 23 %) and areas which are marginally suitable for cultivation of carrot and radish constituting 7.1 ha (3.1 %) land suitability classes with extent are given in table 4.48.

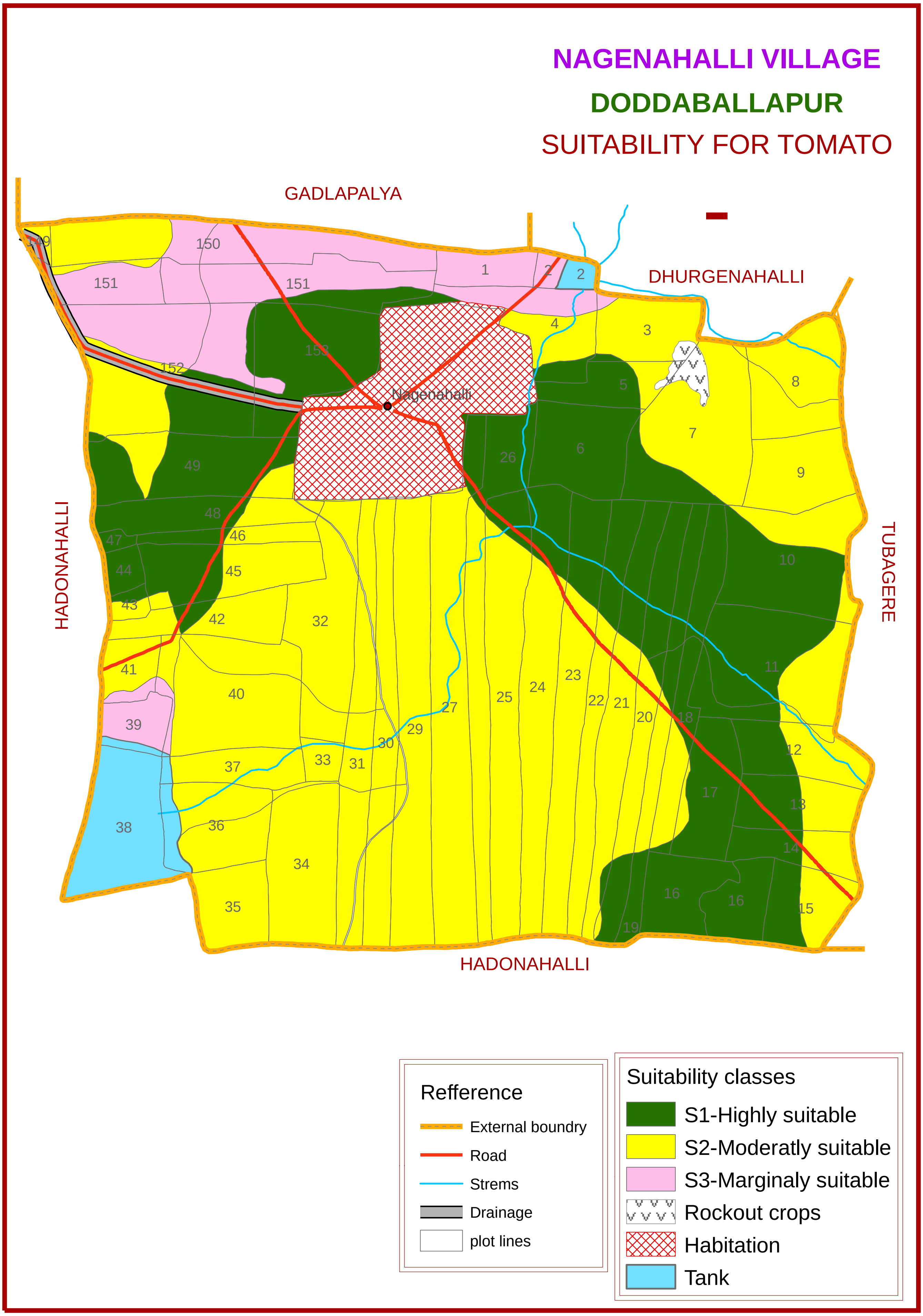


Fig 4.17 Land suitability for tomato

Table 4.48 Soil suitability for carrot and radish

Sl No.	Suitability classes	Description	Area (ha)	%
1.	S1	Highly suitable land with no limitations other than slight pH limitation.	145.8	64.7
2.	S2t	Moderately suitable land with slight limitation due to soil texture and soil acidity.	48.0	21.3
3.	S2e	Moderately suitable land with slight limitation due to proneness to erosion and soil acidity	3.9	1.7
4.	S3t	Marginally suitable land with moderate limitation due to soil texture and slight limitation due to soil acidity.	1.9	0.8
5.	S3e	Marginally suitable land with moderate limitation due to proneness to erosion and slight limitation due to soil acidity.	5.2	2.3
6	Miscellaneous		20.4	9.0
7	Total		225.2	100

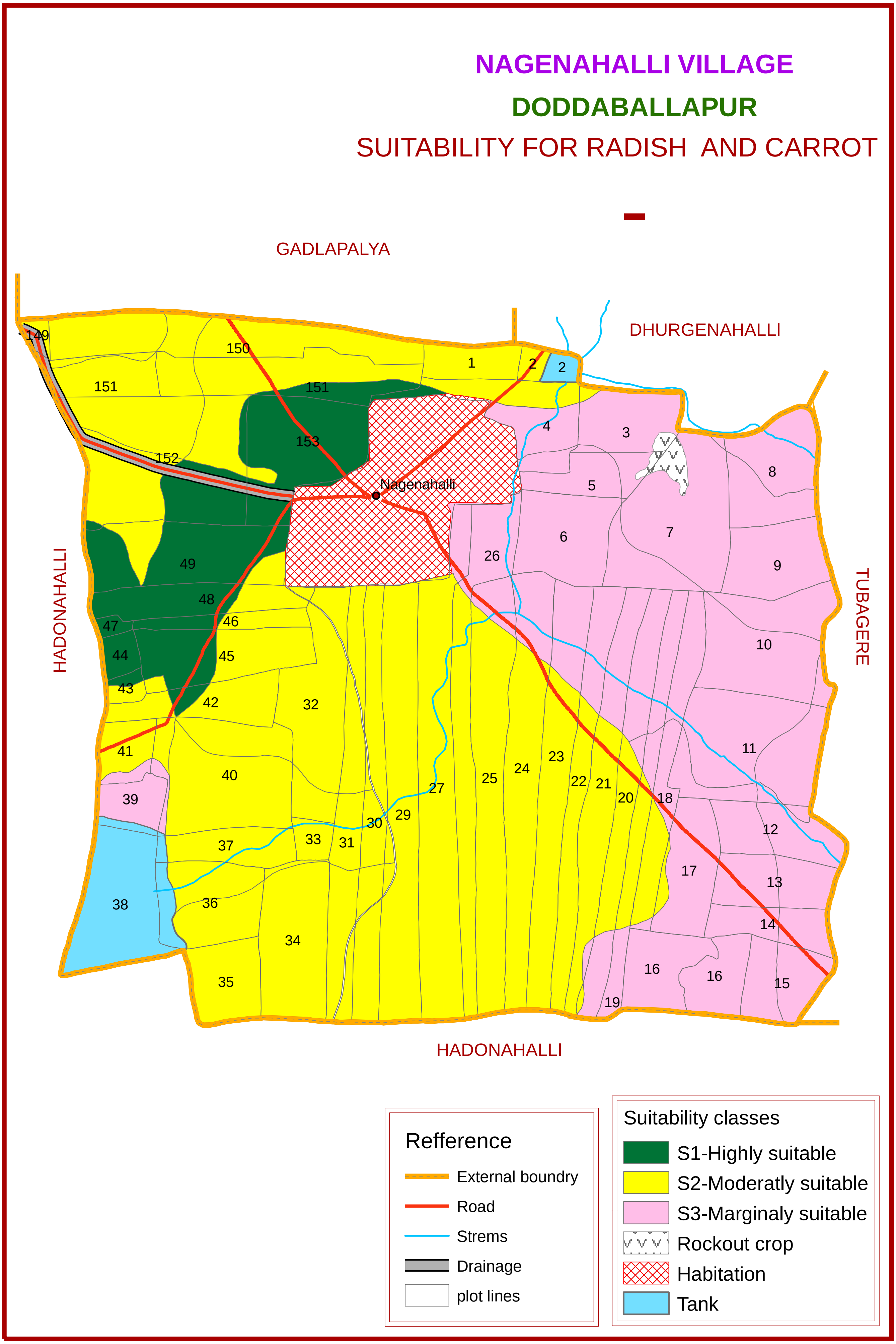


Fig 4.18 Land suitability for radish and carrote

DISCUSSION

V DISCUSSION

A field investigation carried out to assess the land resources of the Nagenahalli watershed using remote sensing and GIS techniques have brought out certain facts, which are discussed here. This chapter has been organized under different heads viz. climatic analysis, Land resource inventory, soil morphology, physical properties, chemical properties, soil fertility, soil classification, soil survey interpretation, Problems and potentials for Agriculture and land evaluation methods.

5.1 Climatic analysis

The uneven distribution of rainfall and lack of suitable conservation structures lead to wastage of water through the run-off. Hence it is necessary to harvest and store water during the rainy season so as to utilize the same during the dry season. Therefore the analysis of the rainfall for Nagenahalli village was carried out to know the rain fall distribution, storage and utilization pattern.

As per the water balance diagram, the normal length of growing period was around 130-140 days and 180-210 days, during good monsoon years. This gives an indication and the potential of the area for two crops by properly spacing the planting dates, the farmers can adjust and grow two crops, a short duration crop and a medium duration crop provided there is scope for a life saving irrigation for crops. Like any rainfed area, assured rainfall was an exception rather than a norm in this belt also. So most of the years, if careful crop planning is not done in time, farmers will have to face the uncertainty in crop prospects.

5.2 Land resource inventory through satellite remote sensing

Land resource inventory was conducted through visual interpretation of satellite data in conjunction with google earth images and SOI toposheets, supported by limited field study and laboratory analytical data. Based on the basic visual interpretation elements such as tone, texture, size, shape, association and pattern, coupled with contour information from toposheets, a physiography map was prepared. Based on physiography soil relationship, soil profiles were excavated, soil samples were analyzed and about 5 soil series were identified, similar to the studies conducted by Kanda Kumar *et al.* (1983). Thus the visual interpretation technique help in minimizing reconnaissance survey for locating and plotting soil boundaries thereby reducing about 60 to 70 per cent of field work (Karale ,1992) when compared to the conventional soil survey. In traditional system plotting of soil boundaries was directly related to the skill of soil surveyor and the traversing plan, whereas visual interpretation of satellite data provides accurate soil boundaries which reduces the time and cost involved in survey and mapping. The results show that satellite data in conjunction with limited field studies provide details of soil features that were not always recorded even in ground survey through reconnaissance and semi detailed intensities as reported by Karale *et al.* (1991).

The distribution of soil series association shows three mapping units under upland convex middle sector and under upland convex upper sector, two mapping units under upland concave lower sector and under linear upland summit and five mapping units under upland convex or concave lower sector. The morphological, physical and chemical properties of the soils were influenced by the physiographic conditions of the soils.

5.3 Soil Characterization and classification

5.3.1 Soil Characterization

The morphological physical and chemical properties of soils studied in Nagenahalli watershed were discussed based on the results from the representative soil profiles of each series which were named as Nagenahalli ‘a’ series (Na), Nagenahalli ‘b’ series (Nb), Nagenahalli ‘c’ series (Nc), Nagenahalli ‘d’ series (Nd), Nagenahalli ‘e’ series (Ne).

5.3.1.1 Soil morphology

Soil colour of pedon 1, 2, 3 varied from dark brown to yellowish red. Base saturation of these three pedons was more than other 2 pedons. This might be due to removal of bases and selective accumulation of sesquioxides rather slow here compared to pedon 4 and 5 pedon 4 and 5 the colour varied from red to dark red colour. This was due to leaching of bases, leaving sesquioxides and further oxidation might be the reason for development of red to dark red colour. Natarajan (1995) in his study concluded laterisation process in uplands of Bangalore plateau is due to moist soil horizons throughout the year.

The structure of all the pedons varied from weak, medium subangular blocky to strong medium sub angular blocky. The dominant structure recorded was moderate medium sub-angular blocky. Poor surface structure was observed in pedons 2, 3, 4 and 5 except in pedon 1 due to moderate erosion and removal of top soil. Consistency of soil varied from slightly hard, friable, non sticky in surface horizon to very hard, very friable to very sticky in subsurface horizons of all the pedons. Clay content of the soil might had played a major role in this kind of consistency. Soil pores were medium to coarse in surface and fine to very fine in subsurface horizons, as the silt and sand content were more in surface soils where as the concentration of fine particles like clay will increase with depth due to clay illuviation.

Iron nodules were recorded from 80cm depth awards in all the pedons except pedon 4 due to the laterization, prevailing in these areas. Whereas quartz pebbles were observed in pedon 4 unlike iron nodules observed in lateritic areas due to weathering of granites and assortment of quatz gravel by flowing water.

5.3.1.2 Soil physical properties

5.3.1.2.1 Bulk density

It was observed that the bulk density decreased with depth in all the pedons except in pedon-2. Pedon-1 and pedon-3 were located in very gently sloping uplands. Pedon-4 and pedon-5 were located in nearly level uplands, where as pedon -2 was located in the gently sloping upland with moderate slopes. Due to the severity of erosion, most of the soil material was removed leaving only the compact layer below. Among the five pedons studied podon 2 showed higher BD with depth. Lower bulk density observed in surface horizons of pedon-1, 4 and pedon-5 due to continuous cultivation. Pedon-4 recorded highest bulk density 1.72 Mg m^{-3} in the subsurface might be due to the presence

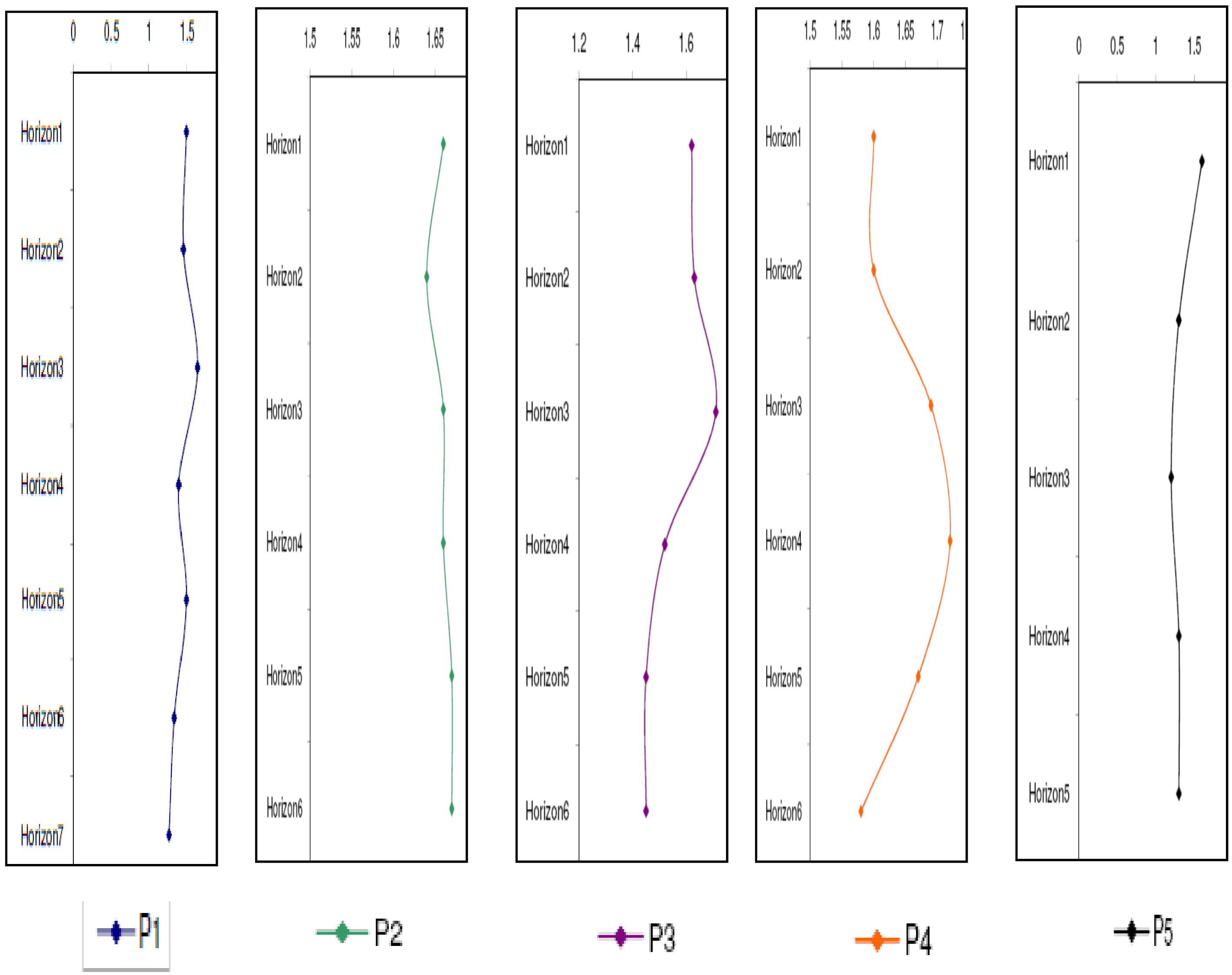


Fig 5.1 Depth wise bulk density of soils of Nagenahalli watershed

of gravel layer. Mehtha *et.al* (2005) observed similar results where they concluded that the cultivation reduced the bulk density compared to natural land, owing to improved aeration and better aggregation assisted by high organic carbon content.

5.3.1.2.2 Clay distribution

Clay distribution of soil profiles with increasing depth is given in fig (5.1). Clay illuviation was observed in all the profiles. The pedons had loamy sand to sandy loam surface soil texture with 10 to 18.5 percent. Clay content increased with depth, 36 to 48.50 per cent in the control section.

5.3.1.2.3 Soil organic carbon

Organic carbon content in soil ranged from 0.07 to 0.43 %. Its content was low in all the pedons. Surface horizons recorded the high values and its values decreased with depth in all the pedons similar findings were reported by (Pal. *et al*.1985).

5.3.1.2.4 Available Water Capacity

Available water capacity in different pedons varied from 50 mm to 150 mm. The difference was due to clay content, coarse fragments, bulk density and organic matter. AWC was less, wherever coarse fragments were present in the sub surfaces. AWC did not vary much between the horizons as all were uplands. Pedon-2 had less AWC due to the effect of erosion and also due to high bulk density. Similar results were observed by Rajendra Hegde *et al* (2007), in the neighboring watershed in the same agro ecological zone.

5.3.1.3 Soil chemical properties

5.3.1.3.1 Soil reaction

Soil pH varied from very strongly acidic to moderately alkaline (fig 2). The pH was increased with depth in all the pedons. Similar result was recorded by Walia and Rao (1997) in red soil. It can be attributed to intense leaching of bases throughout the profile. Lower pH in the surface was recorded in the pedon2 (4.7). Heavy leaching of bases in the gentle slope topography was responsible for the low pH in this pedon. Pedon-

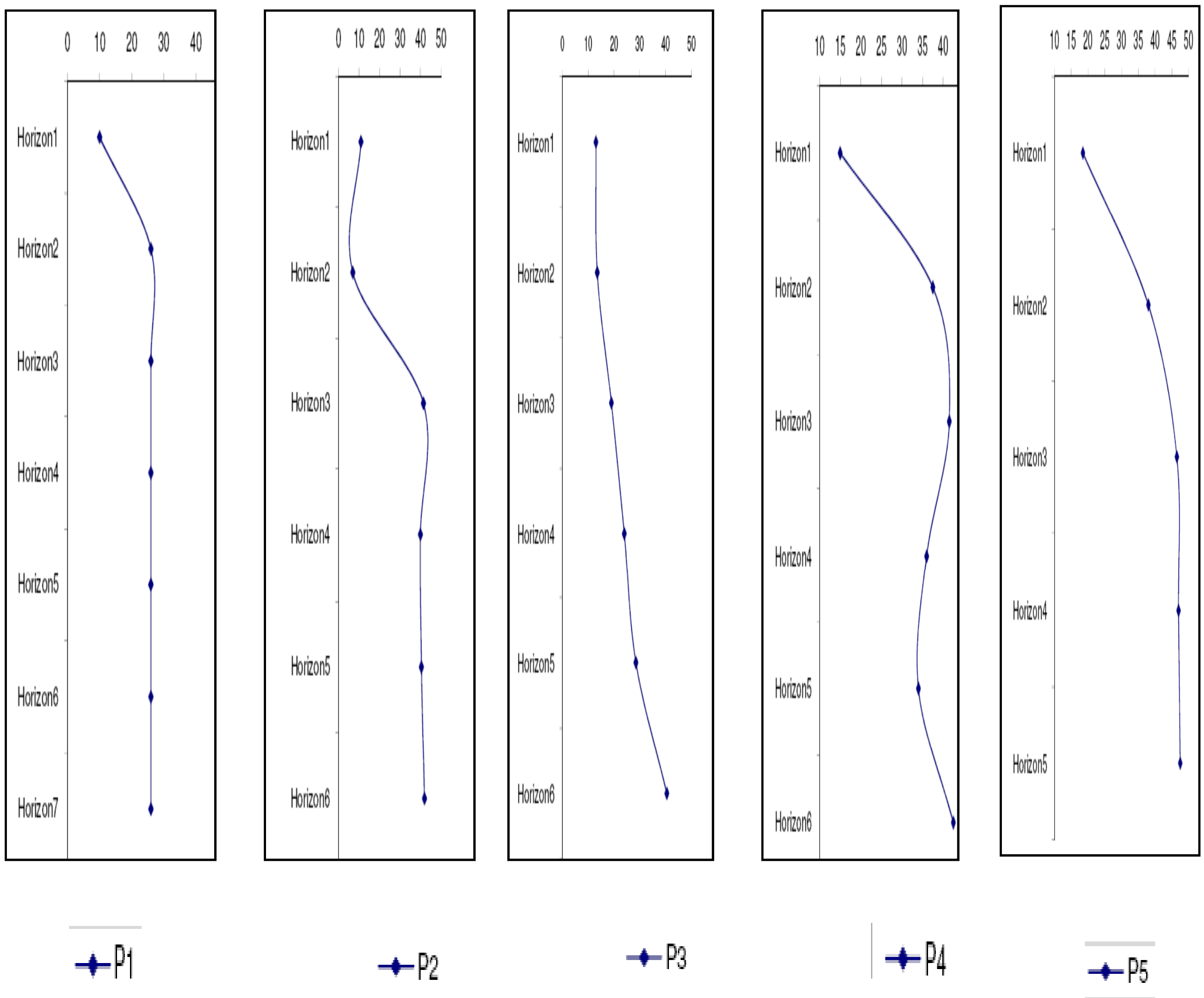


Fig 5.2 Depth wise clay distribution in soils of Nagenahalli watershed

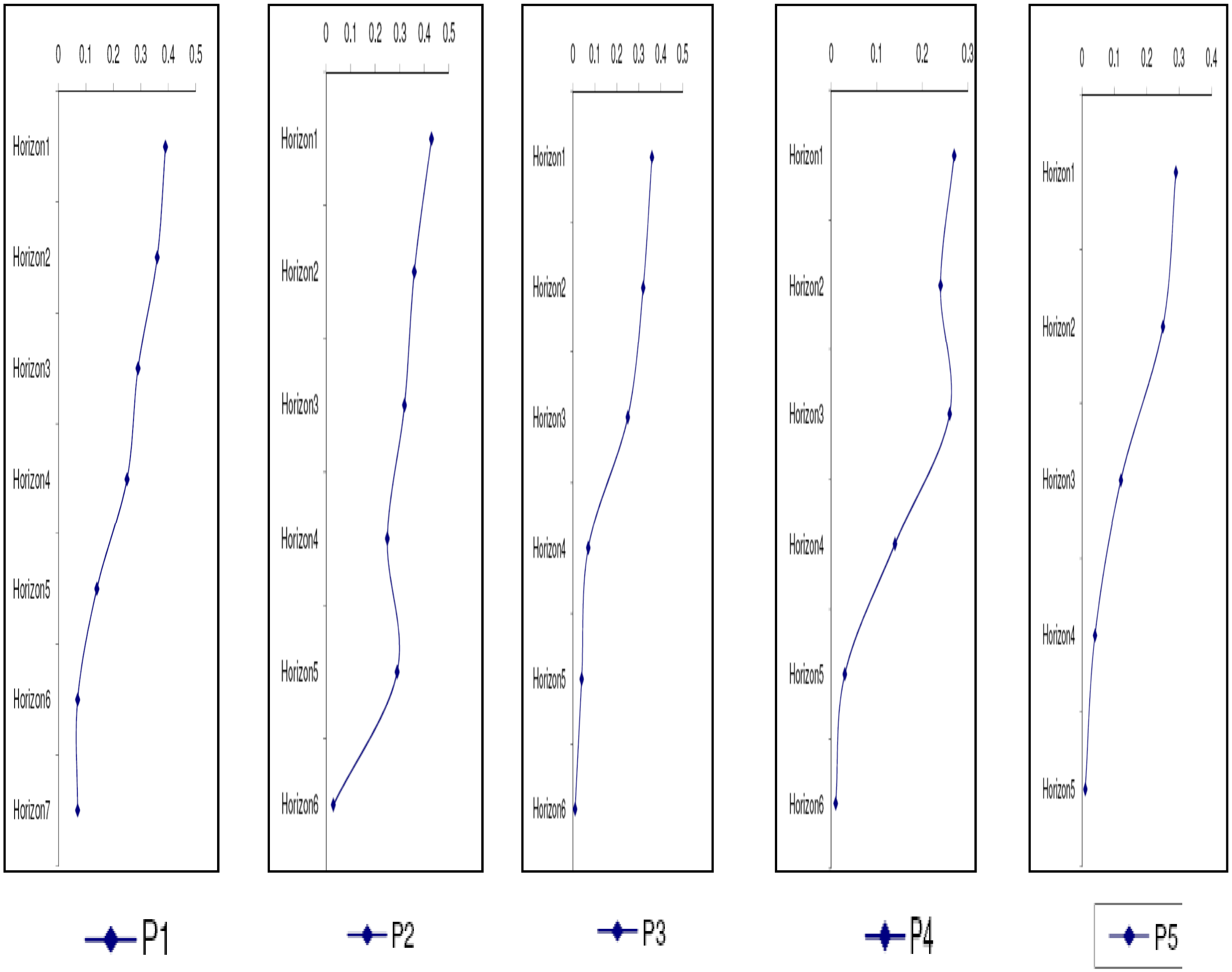


Fig 5.3 Depth wise distribution of organic carbon in soils of Nagenahallia watershed

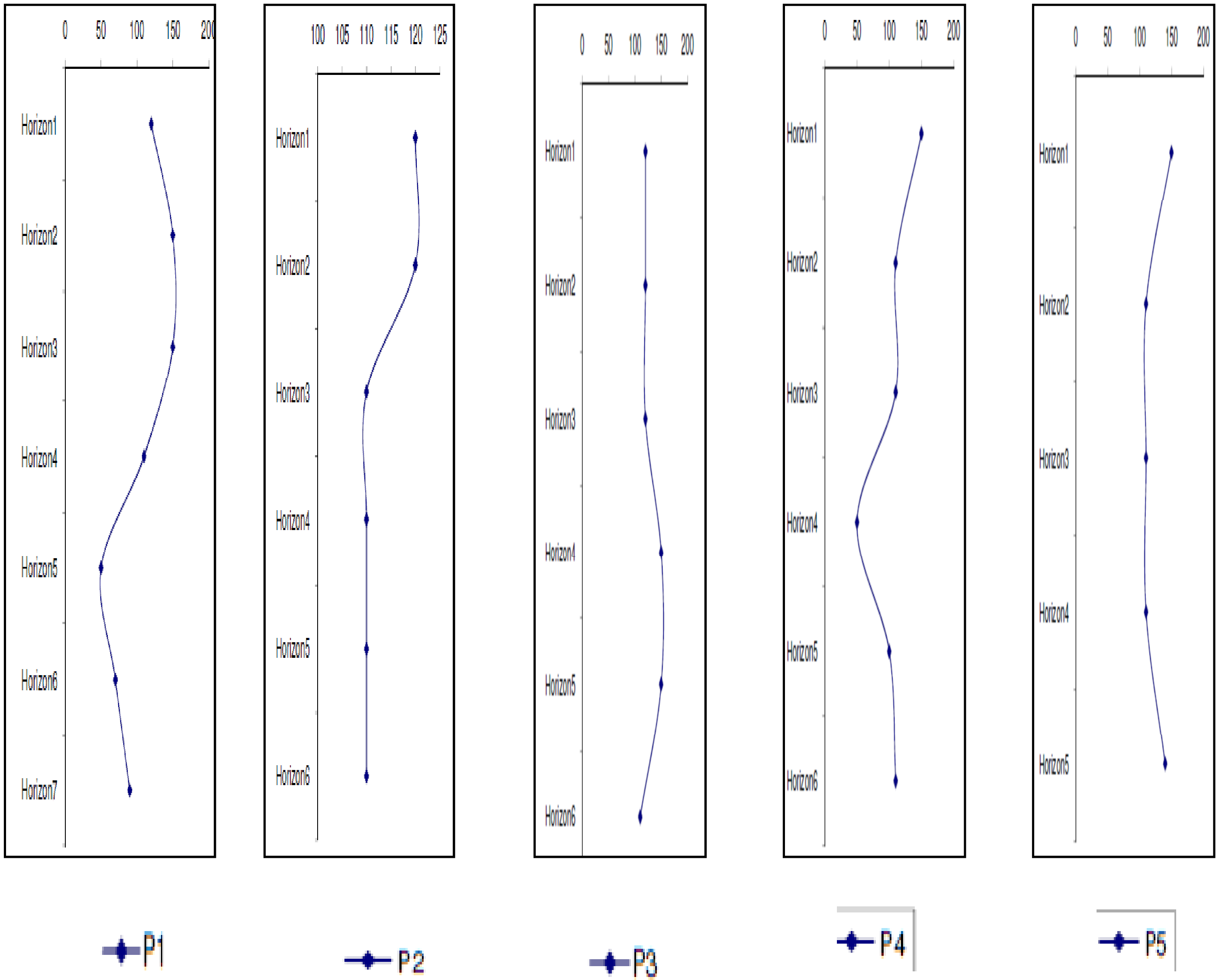


Fig 5.4 Available water holding capacity of soils of Nagenahalli watershed

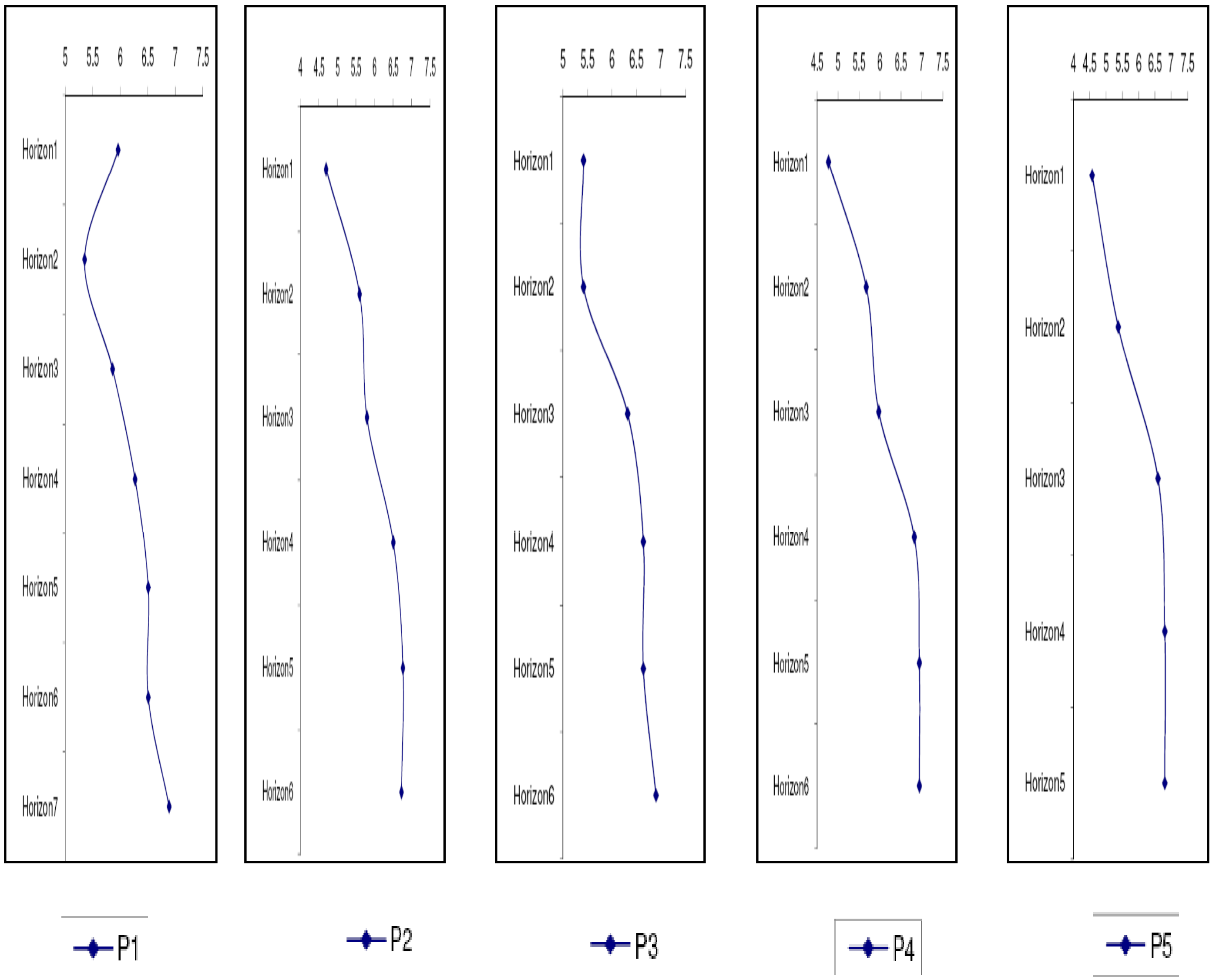


Fig 5.5 Surface and subsoil reaction of different pedons.

4 and pedon-5 located in nearly level land recorded higher pH than the pedons located on slopes.

5.3.1.3.2 Electrical conductivity (EC)

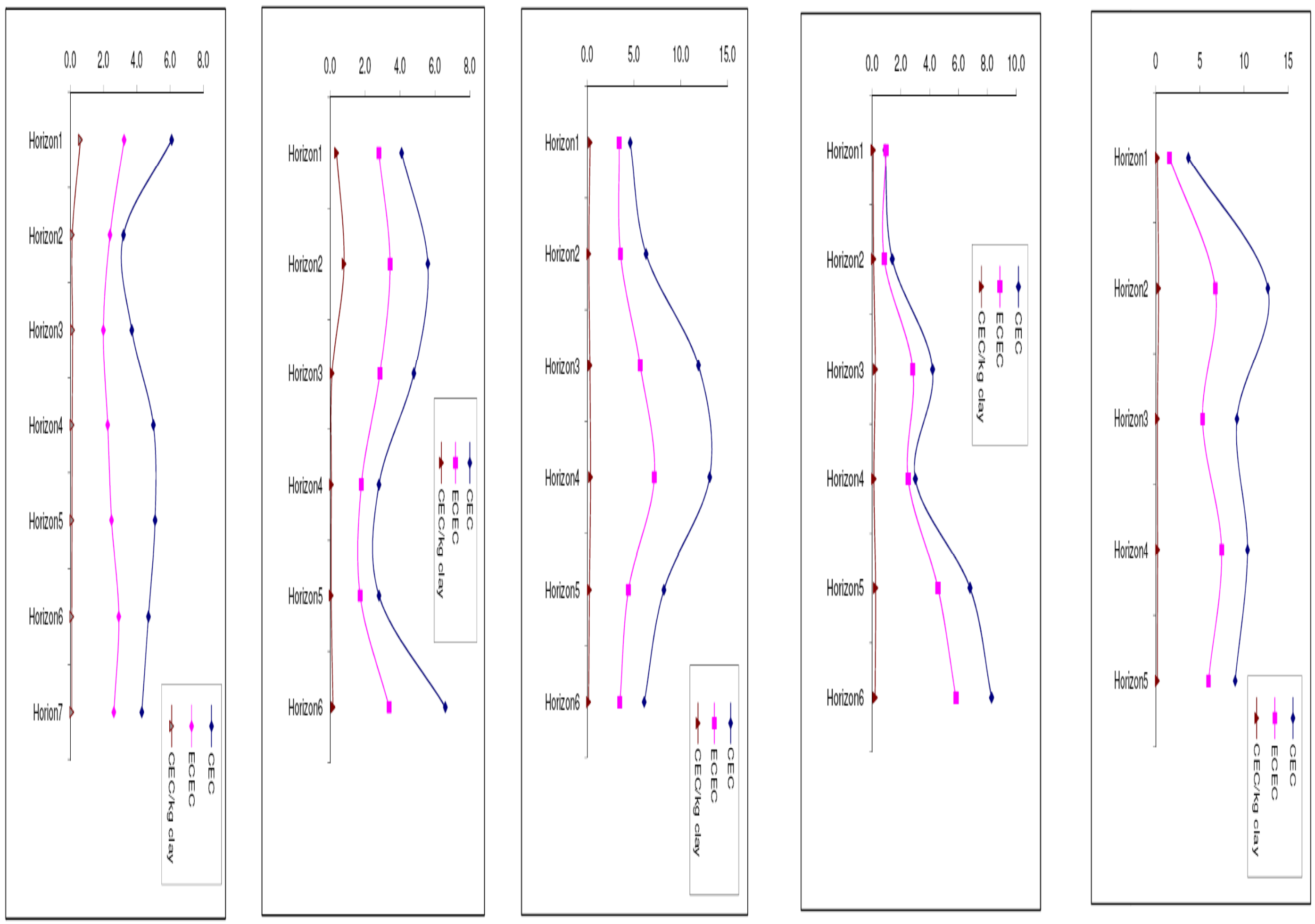
Electrical conductivity values of pedons ranged from 0.01 to 0.09 dSm^{-1}. EC of all the pedons were very less. Pedon-1 and pedon-4 recorded slightly higher EC at the surface. Both the pedons were under cultivation.Hence addition of fertilizers and manures might have added more electrolytes. Pedon-2 recorded lower EC which was on gently sloping land occupied with rattoon eucalyptus plantation. Pedon-3 which was on very gently sloping upland recorded slightly higher EC values than pedon-2. It was due to slope and land was kept fallow with natural vegetation like grasses. These factors resulted in decreased leaching of bases.

5.3.1.3.3 Cation exchange capacity(CEC)

Cation exchange capacity varied between the pedons and also between the horizons in each pedon. In pedon-1, CEC varied from 3.2 to 6.1 cmol (p+) kg ^{1}. Dominance of 1:1 type Kaolinitic clay was the reason for low CEC in these soils (Rajan, 2008). Pedon-2 recorded the lower most CEC. This was due to moderate erosion with rapid run off, which resulted in removal of clay, and silt and organic matter (Sitanggang *et al.* 2006). Pedon-3 which was under natural vegetation, showed maximum variation in the CEC value. Pedon-4 and Pedon- 5 recorded minimum variation in CEC between the subsurface horizons. The low CEC in the surface horizon was due to leaching of soil especially of bases, clay and silt to subsurface horizons and illuviation of kaolinite dominated clay to lower layers and accumulation of sesquioxides.

5.3.1.3.4 Available Nitrogen

The available nitrogen status was low in almost all the pedons. It ranged between from 62.7 to 627.2 kg/ha. Pedon-1 recorded highest Nitrogen range. Highest nitrogen content was recorded in the surface horizon as the land was under cultivation. Application of fertilizers and manures in these soils has increased the N-content. Pedon-2 recorded the minimum variation in its nitrogen content. It was 125. 4 kg/ha, in surface



P1 P2 P3 P4 P5

Fig 5.6 Cation exchange characteristics of soils of Nagenahalli watershed

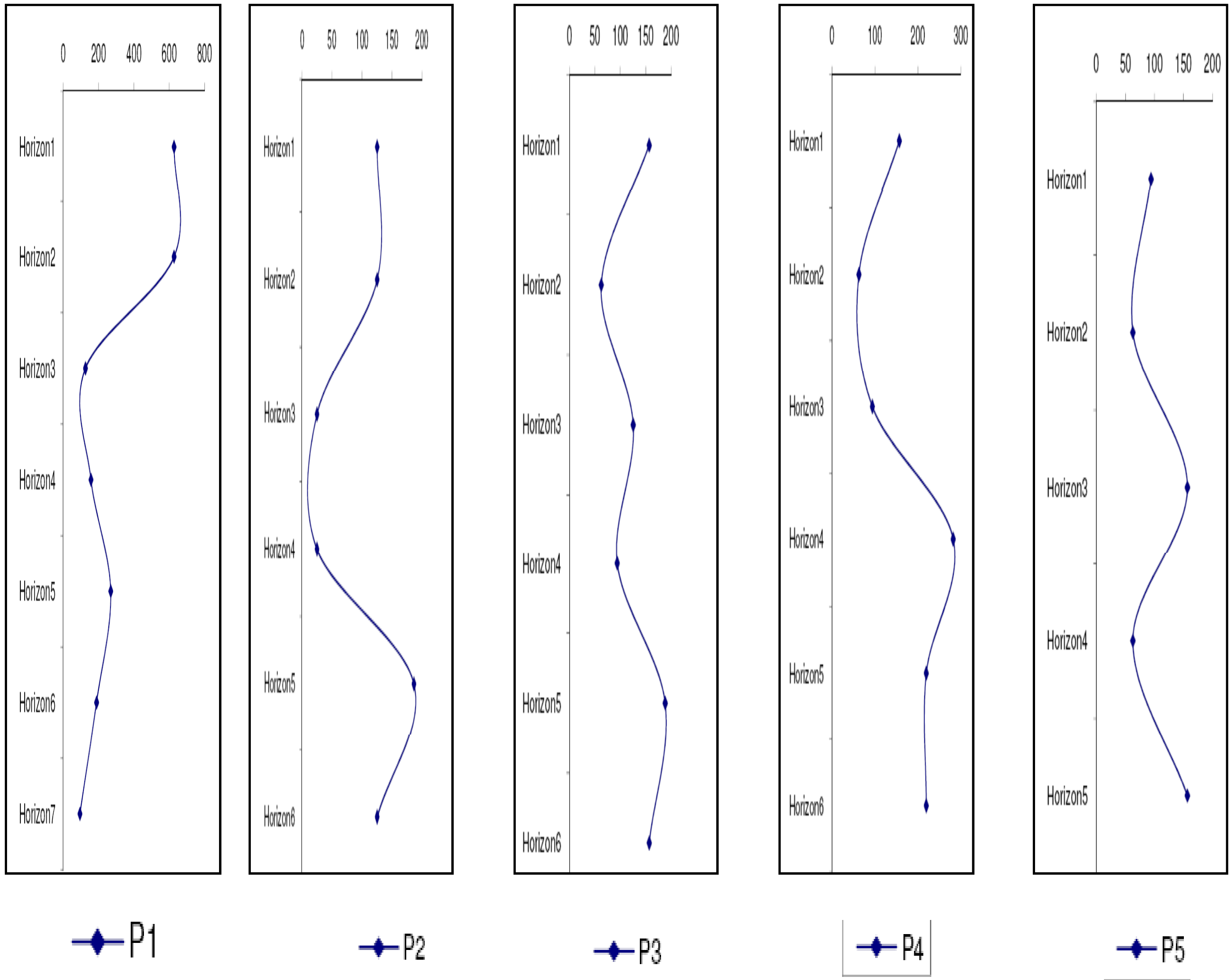


Fig 5.7 Available Nitrogen in surface and subsoil of different pedons.

horizons and increased to 186.86 kg/ha, in Bt4 horizon. Through this area was affected by erosion, adoption of conservation practices in the recent years was resulted in growth of grasses and other vegetation and increased the organic matter accumulation (Rajan, 2008). Pedon-3 recorded highest nitrogen in the surface due to the increased level of organic matter accumulation by natural vegetation and nitrogen follow same pattern. Pedon-4 located in the ploughed land recorded the Nitrogen content in the range of 62.7 to 282 kg/ha. Pedon-5 showed increasing nitrogen content with depth. The land was not under cultivation through it was cultivated earlier. Leaving the land fallow for many years led to the leaching of nitrogen from surface to the lower layers (Rajan, 2008).

5.3.1.3.5 Available phosphorus

Available phosphorus varied from 2.6 to 76.9 kg/ha in surface horizons. Pedon-1 recorded high available P and the value decreased with depth. The land is under intensive cultivation with maize and ragi crops. Further fertilizers and manures were added every year during cultivation. Diammonium phosphate (DAP) was extensively used in the region for all crops. This was be the reason for the accumulation of available phosphorus in the surface horizon. Similar trend was observed in Pedon-4, but the content of available phosphorus was less compared to pedon-1. Low amount of available phosphorus was observed in pedon-2, pedon-3 and pedon-5, which were not under cultivation during the current year.

5.3.1.3.6 Available potassium

The available potassium of pedons ranged from 73.2 to 427.4 kg/ha. The available potassium values were higher in surface horizons of pedon-1 and pedon -4. This was due the intensive root growth supplemented with potassic fertilizers.

Pedon-2, pedon-3 and pedon-5 showed increased potassium content with depth may be due to leaching and accumulation from surface to lower layers under uncultivated situation.

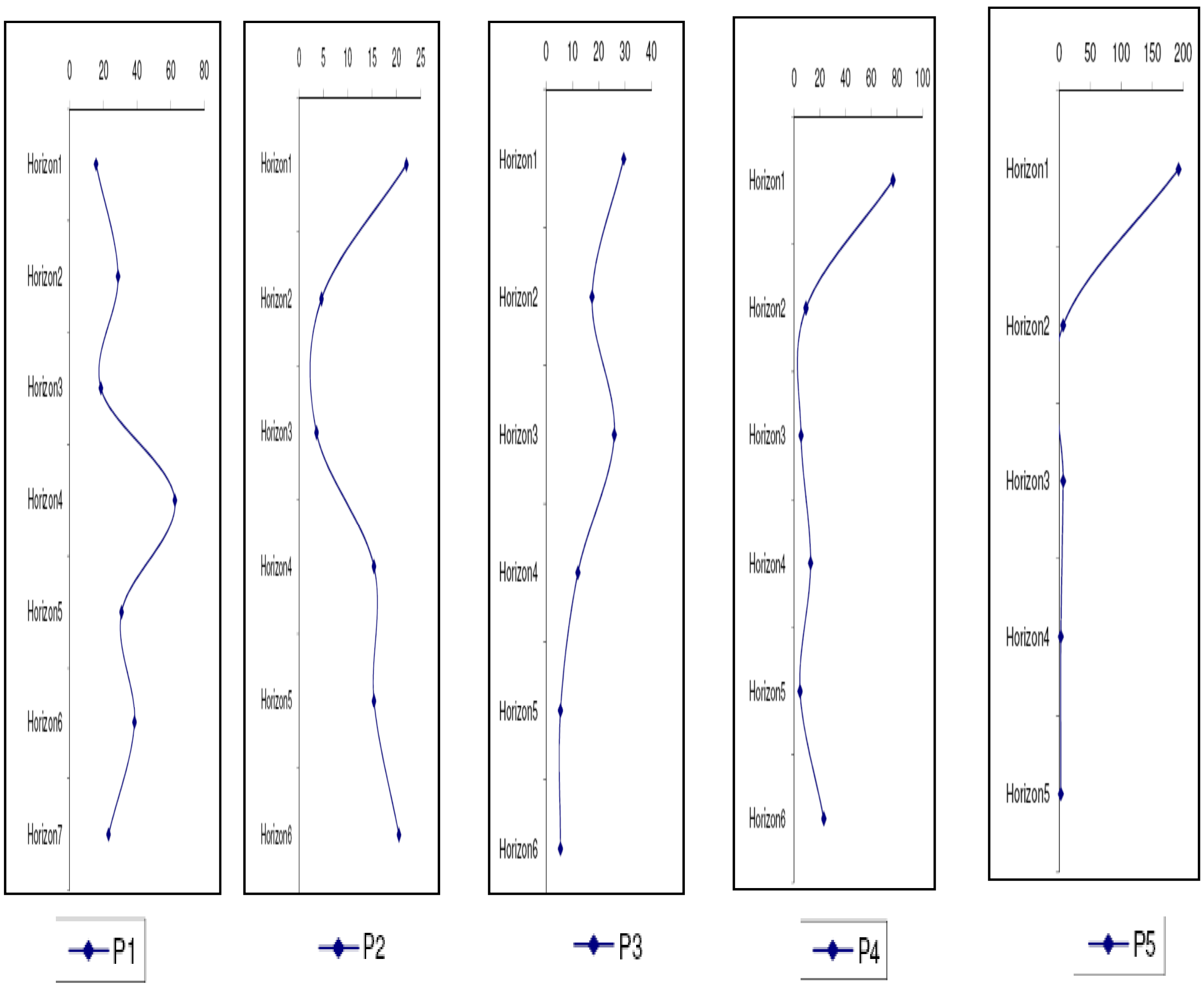


Fig 5.8 Available phosphorus in surface and subsoil of different pedons.

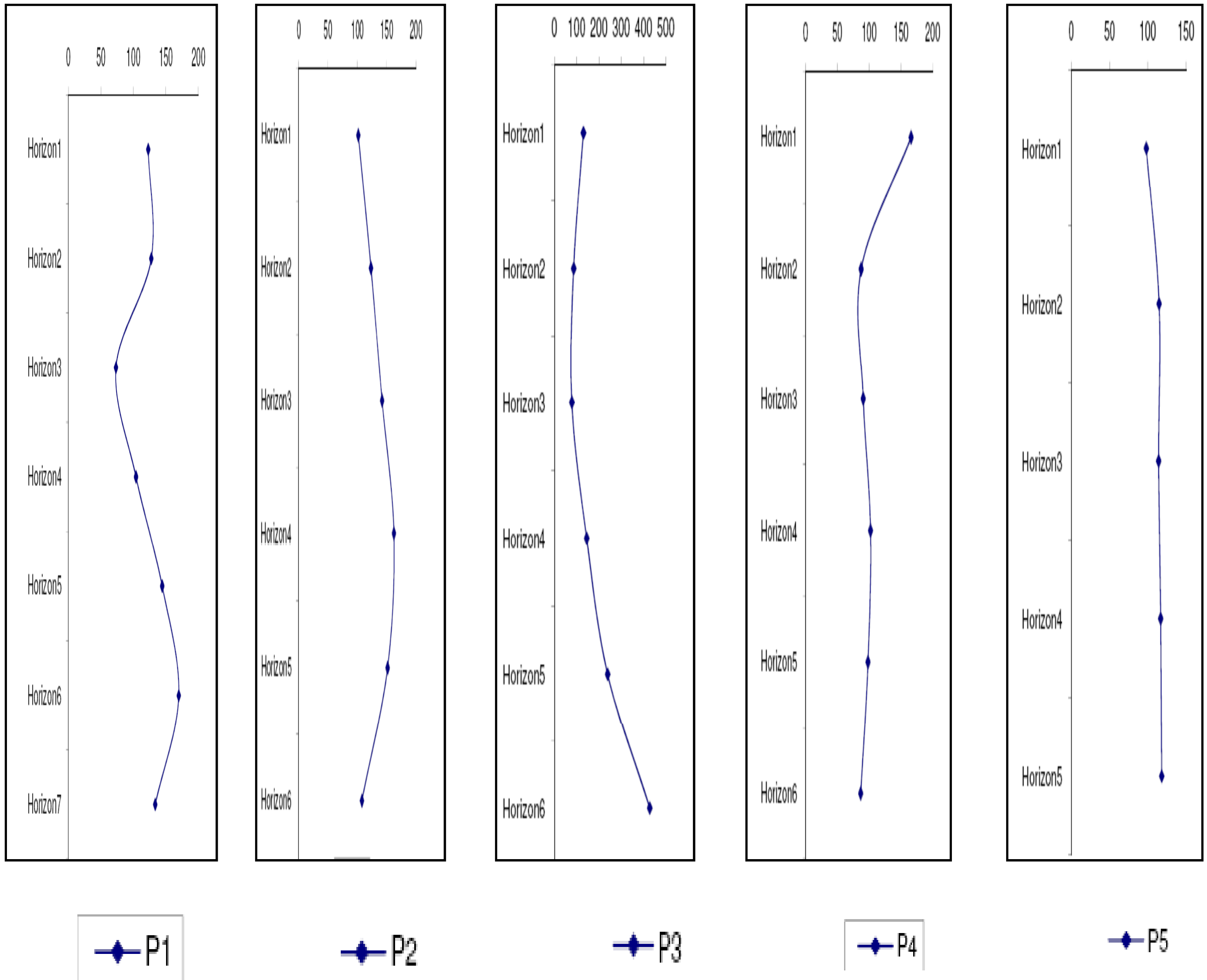


Fig 5.9 Available Potassium in surface and subsoil of different pedons.

5.3.1.3.7 Available micronutrients

The DTPA extractable copper, iron and manganese were found to be supplemented in higher range. Similar result was observed by Bhaskar *et. al.* (2004) in hill slopes of Narang-Kongripara watershed of Meghalaya. In Pedon-1 surface horizon recorded the highest zinc content of 2.6 ppm and it reached to low range of 0.1 ppm in subsurface horizons. Similarly pedon-4 recorded marginal levels of zinc in first two horizons and decreased to low with depths. All other pedons recorded the lower zinc content found below the critical limits. Concentration of micronutrients decreased with depth. Similar results were recorded by Kannan and Mathan (1994) in Tamil Nadu soils and Rajkumar (1994) in paddy soils of TBP conserved area.

5.3.2 Soil classification

The soils of Nagenahalli watershed were classified up to family level as per USDA Soil Taxonomy (Soil Survey Staff, 1996) similar studies were conducted by Goyal *et al.* (1999) based on the morphological, physical and chemical properties of soils.

All the pedons were classified under the order Alfisols as they possessed argillic horizon and base saturation percentage was more than 35 percent. Under order Alfisols, pedon-1 and pedon-2 were classified under suborder Ustalfs. Since moisture regime was Ustic and great group Kandiustalfs because of presence of Kandic horizon and pedons did not show clay decrease with increasing depth. The presence of illuvial clay and its significant increase from the surface horizon to the illuvial horizon qualifies the subsurface horizon to be designated as an argillic horizon. The cation exchange capacity of the major part of the argillic horizon was less than 16 cmol (p^+) kg^{-1} clay and clay distribution almost remained constant with depth in the argillic horizon. From these properties pedon-1 and pedon-2 were classified as a fine, Kaolinitic, Isohyperthermic, Typic Kandiustalf (Na-series) had gravel layer at 59 cm depth and there is no gravel layer in Nb-Series.

Pedon-3 was identified as Nc-series and is classified under order Alfisols, suborder Ustalfs. This pedon belonged to the great group Haplustalfs it had a hue of 7.5

YR and value of 3 or more. CEC per kg clay of the pedon is further <24 and grouped under the subgroup Kanhaplic Haplustalfs. The soils had fine loamy texture with less clay content and no coarse fragments. The clay distribution in the soil was such that the percentage of clay decreased by more than 20 per cent along with clay, small quantities of mica was also recorded in the mineralogy. Form these properties pedon-3 was classified as fine loamy, mixed isohyperthermic, Kanhaplic Haplustalfs.

Pedon-4 was identified as Nd-series and classified under order Alfisol and Suborder Ustalfs. The pedon had an argillic horizon of significantly higher percentage of clay showing the evidence of clay illuviation. A very gravel particle size class throughout one or more subsurface horizons and a clay increase of 20 percent or more within a vertical distance of 2.5 cm made the soil to great group Paleustalfs and subgroup Ultic Palaeustalfs as the agrillic horizon with a base saturation of less than 75 percent. The soils of Nd series were very deep, red, and very gravelly and fine textured. Gravelly layer starts after 40 cm depth in this series.

The soils of pedon-5 were very deep fine texture has mixed clay mineralogy. This was classified under order Alfisol, suborder Ustalfs. This series had higher percentage of clay and a clay increase of 20 percent or more within a vertical distance of 2.5cm renders the soil to group under great group Paleustalfs and subgroup Kandic Paleustalfs. Series had CEC of less than 24 cmol (P+) kg^{-1} clay. Based on the above properties the soils of Ne-series were classified as, fine, mixed, and Isohyperthermic Kandic Paleustalfs.

5.4 Soil survey interpretations

The dominantly occurring very deep soils on uplands with very gentle to gentle slopes, good for crop production and provided with sufficient soil and water conservation measures are in place. The soils of the whole study area were non-gravelly and non-rocky. These were better for crop production owing to good available water holding capacity and better soil-plant-root relationship. Sandy clay loam, sandy loam and loamy sand dominated surface textures prevailing were found best for production of field crops like ragi, maize, vegetables and horticultural plantation crops. The lands, which were moderately eroded had gentle slopes (3 to 5 %) and were useful for Eucalyptus plantations, which being the current practice here. The soils were poor in organic matter and medium in available water capacity in most of the areas. Low available water capacity was observed in soils belonging to Na-series. Low AWC was attributed to coarse texture of the sub soil (25 to 40 % coarse fragments). These soils were fairly suitable for crop production if provided with adequate soil and water conservation measures.

5.5 Problems and potentials for Agriculture

5.5.1 Climatic constraints

Low rainfall, received in a shorter spell, was the major constraint for crop production in the area. Since the streams were seasonal the water reservoirs also get dried up during summer. Majority of the farmers grow crops like ragi, maize, red gram in rainfed conditions as some farmers use bore wells for supplementing the water needs of the crops. Ground water exploitation without concurrent efforts to recharge the same through rainwater harvesting was making the situation very alarming.

5.5.2 Soil erosion

Slight to moderate soil erosion was the problem in the study area. Nearly 60.1 ha of the study area under moderate erosion. Therefore it necessitates soil and water conservation structures and drainage outlets for each field along with field bunding. This shall not only help in checking soil erosion but also help in protective irrigation to crops using stored water. The data base generated during the present study provides the scientific foundation for toning up these measures.

5.5.3 Soil fertility status

Soils of the watershed hav very low nitrogen (173.0 ha), low potassium (156.9 ha) and very low organic carbon (204.7 ha) indicated the soils are poor in plant available nutrients. Application of organic manures, nitrogen and potassic fertilizer in the required rates can improve the soil quality and nutrient status contributes to increased crop productivity. The soil fertility data base made during the study shall be of great utility for this purpose.

5.6 Land evaluation

Evaluating the lands for their potentials for wide range of land uses and for formulating land use plans, which are economically viable, socially acceptable and environmentally sound is most essential. The basic resource survey provides data which is useful when interpreted properly to obtain the required information. In this study soil fertility, fertility capability and land suitability for major crops were worked out for each plot in different soils mapping units of Nagenahalli watershed.

5.6.1 Soil fertility

Soil fertility is the inherent capacity of soil to support crop production by way of supplying all nutrients essential for plant growth.

5.6.1.1 Organic carbon status

Present study revealed that 204.7 ha of the soils were low in organic carbon status. Semiarid environment with low rainfall was contributing towards low organic carbon status of the soils studied.

5.6.1.2 Soil reaction

The study of surface soil reaction of the Nagenahalli watershed revealed that majority of the soils (32.3 %) was moderately acidic followed by strongly acidic (24.7 %) and neutral soils (12.2 %). Neutral soils are best suited for crop production, as most of the nutrients are available at neutral pH. Moderately alkaline soils can be reclaimed by treating with gypsum and leaching out (Anil kumar *et.al*, 2010).

5.6.1.3 Available nitrogen

Study revealed that 76.8 per cent of the surface soils was very low, while 13.6 per cent of the soils were medium in available nitrogen status. Semiarid environment with low rainfall and low organic carbon status of the soils contributed towards very low or low available nitrogen status of the soils, confirming the study of Anil kumar *et.al*. (2002).

5.6.1.4 Available phosphorus

Available phosphorus status of the surface soil studied revealed that 74.67 percent of the surface soil studied was very low. About 2.20 percent of the soils were low, 3.29 percent of the soils were medium and 11.57 percent of the soils were high in available phosphorus status. Skewed fertilizer application was responsible for the situation. Anil Kumar *et al. (*2002) also found similar observations.

5.6.1.5 Available potassium

Study revealed that 11.5 per cent of the surface soils were very low, while 69.7 percent of the soils were low, 12.03 percent of the soils were medium and only 1.30 percent of the soils were high in available potassium. Semiarid environment with low rainfall and low organic carbon status of the soils were contributing towards low or medium available potassium status of the soils. Anil Kumar *et.al*. (2002) also found similar results.

5.6.1.6 Available micronutrients

Soil available micronutrients showed sufficient presence in most of the soils studied except in case of available zinc confirming the study of Anil Kumar *et al.* (2010). Study revealed that about 42.8 per cent of the study area was adequate, 24.96 percent of the area had higher levels, 11.8 per cent of the area was found marginal and 9.62 percent of the study area was low in available zinc status.

5.6.2 Fertility capability classification

Natural soil classification system places more emphasis on subsurface than surface soil properties, because of their more permanent nature, whereas most soil management practices are largely limited to the plough layer. It has been reported that more than 70 soil per cent of yield variability are due to soil properties related to the plough layer. FCC emphasizes quantifiable topsoil parameters as well as subsoil properties which are directly to plant growth.

Fertility capability classification is designed specially to help the farmer to overcome the constraints affecting the fertility and productivity of soil and other resources. FCC is a technical system for grouping soils according to the kinds of problems they present for agronomic management of their chemical and physical properties. The kinds of problems for grouping soils in the study area were low CEC, gentle slopes, low K reserves, acidic reaction and semiarid climate with low rainfall and low organic carbon status of the soils. All these were contributing towards low fertility or productivity status of the soils of the study area.

5.6.3 Land suitability classification

The earlier system of land evaluation grades the land from suitable to unsuitable irrespective of type of land use and management. Such a system cannot provide the necessary information to the land user to make a choice between land use options. The FAO framework for land evaluation was used in the present study to know the consequences of applying the specified management to a particular parcel of land so that a choice could be made from the alternatives. This method assesses the suitability of land for major crops such as ragi, maize, tomato, carrot and radish on the basis of a matching exercise between the growth and production requirement of the crop. Based on the number and degree of limitations (Khadse *et al.*, 2001) in the present study the suitability classes viz., highly suitable (S1), moderately suitable (S2) and marginally suitable (S3) were adopted to categorize the soils.

5.6.3.1 Land suitability for ragi

The soil phases NahB, NbcB2, NChB, NchB2, NecB1, NecB2, NdcB, , were highly suitable whereas NbbB1, NahC2, NcmB, NciA, NcbB1 and NdhC2, were marginally suitable for cultivation of ragi. The major limitations included rainfall, topography, and texture and soil erosion. Khadse *et al.* (2001) also found similar results.

5.6.3.2 Land suitability for Maize

The soil phases NahB, NahC2, NbcB2, NchB2, NchB, NciB, NdCB, NdhC2, NemB, NecB2 and NeCB1, were moderately suitable, whereas NabB, NbbB1, NcbB1 and NdbBr were marginally suitable for cultivation of maize. None of the soil series could be grouped under highly suitable class because of moderate to severe soil limitations. The major limitations were soil erosion, texture and soil fertility confirming the earlier study by Rathore (1999).

5.6.3.3 Land suitability for tomato

The soil phases NecB, NdcB and NabB were highly suitable whereas NahC2, NbcB2, NcbB1, NchB, NchB2, NciA, NdbBr, NdhC2 and NecB2 were moderately suitable and NabB, NbbB1 and NcmB were marginally suitable for cultivation of tomato the major limitations include texture, erosion and soil fertility for the profitable cultivation of tomato.

5.6.3.4 Land suitability for carrot and radish

The soil phases NbcB2, NchB2, NchB, NdcB, NecB1 and NecB2 were highly suitable whereas NabB, Nahc2, NbbB1, NcbB1, NciA and NdbBr were moderately suitable and NcmB and NdhC2 were marginally suitable for cultivation of carrot and radish. Soil pH was the common limitation in the entire study area for cultivation of carrot and radish along with the limitations like texture and soil erosion. Anil Kumar *et al*. (2010) also made similar observations.

5.7 Soil formation

Various factors of soil formation (Jenny, 1941) decides the properties of soil. In the study area, climate was the most dominant factor, which had serious impact on soil properties followed by topography, time and biota. Parent material also influenced the soil formation process to a great extent.

The dominant soil forming processes were leaching of bases, and consequent development of acidic soil reaction, residual enrichment of Fe/Al oxides and clay illuvaiations. The variations in rainfall across the study area were reflected in soil properties and intensity of soil forming process.

5.7.1 Removal of the bases

Rainfall is the most important factor contributing to removal of bases. Base saturation in study area ranged from 63 to 79 per cent. The mean surface soil base saturation was 71.0 per cent. The mean sub surface soil base saturation was 69-67 percent. Intense rainfall and soil conditions favoring free drainage and leaching of bases were responsible for the lower base content of the soils.

5.7.2 Acidic soil reaction

Depletion of bases was reflected in pH values recorded for the soils, which were in acidic range with few exceptions. Soils in the study area ranged from very strongly acidic to neutral. The reaction in the surface ranged from 4.5 to 7.4. The lower pH indicated the predominance of electronegative colloids in the soil. It showed that weathering was not very advanced in these soils.

5.7.3 Residual enrichment of Fe/Al oxides

Iron oxides formed pseudo-aggregates during weathering process by precipitation of hydrous oxide of iron (Oades, 1963). The soils in the study area recorded considerable amount of ferruginous gravel in solum pointing out enrichment with iron oxides.

5.7.4 Clay illuviation

Clay illuviation is major process of soil formation in tropics. The clay content in surface horizon ranged from 27 to 38 percent. The mean clay content in subsurface ranged from 21.7 to 48.25 per cent. The clay content of the subsoil horizons gave a clear indication of illuviation of clay in all the pedons studied.

SUMMARY & CONCLUSION

VI SUMMARY

A field investigation was carried out on land resources assessment of Nagenahalli watershed, Doddaballapur taluk, Bangalore Rural District with the objectives of characterization and classification of the soils of the study area using remote sensing and GIS.

Remote sensing with synoptic view and repetitive coverage helps in assessing of natural resources and generating reliable and accurate database quickly when compared to the conventional system. The remote sensing information that was generated upon the integration with the attribute data in a geographic information system provides information on composite resource units. The resource units show information about soils, its potentials, constraints and topography which act as a guide in suggesting soil conservation measures and potential land use plans which are technically feasible, economically viable and socially acceptable.

GIS is a computer based tool helps in capturing, storing, integrating, analyzing and displaying the spatial and non spatial data. The thematic information of any particular area can be extracted and studied in detail for evolving detailed developmental planning. Thus GIS paves way for analyzing the natural resources information on larger areas.

Detailed soil survey was conducted to assess the land resources of the Nagenahalli village. Analysis of climatic parameters as well as land form features was performed during the study. Five representative sites were selected for profile study, i.e. two sites in level to nearly level upland on upland summit and on convex upper sector, two in very gently sloping upland, on convex middle sector and on convex or concave lower sector, and one site in gently sloping upland on concave lower sector for soil characterization and land evaluation studies. Horizon wise soil samples were analyzed for morphological, physical and chemical properties, classified and evaluated for fertility, fertility capability and suitability of land.

Soils of pedon 1 were very deep surface soil colour was dark brown (7.5YR 3/4). Subsurface soil colour varied from dark reddish brown (5YR 3/4) to yellowish red (5YR

4/6) with well drained, the texture of the profile varied from loamy sand on surface to sandy clay loam to sandy clay on subsurface. Bulk density was in the range of 1.27 to 1.65 Mg m^{-3} with low soil organic carbon. Soil pH ranged from moderately acidic (6.0) in the surface horizon to slightly acidic (6.27) in subsurface. Low CEC and high base saturation were noticed due to the presence of kandic horizon and no clay increase with depth, pedon-1 was classified under Kandiustalfs.

Soils of pedon 2 were very deep, surface soil colour was brown (7.5YR 4/4) and the sub surface soil colour varied from dark reddish brown (5YR 3/4) to yellowish red (5YR 4/6). Soils were moderately well drained, the texture varied from loamy sand on surface to sandy clay on subsurface. Bulk density was in the range of 1.62 to 1.67 Mg m^{-3} with low soil organic carbon. Soil pH ranged from very strongly acidic (4.7) in the surface horizon to neutral (6.8) in the subsurface. Low CEC, very high base saturation, presence of argillic horizon and significant increase of illuvial clay from the surface horizon to the illuvial horizon, the pedon was classified under Kandiustalfs.

Solum depth was moderately deep in pedon 3, surface soil colour was dark brown (7.5YR 3/4) and the subsurface soil colour varies from yellowish red (5YR 4/6) to yellowish brown (10YR 5/4). Soils were well drained, the texture of the profile varied from loamy sand on surface to sandy clay loam to sandy clay loam on subsurface. Bulk density ranged from 1.45 Mg m^{-3} to 1.75 Mg m^{-3} with low organic carbon. Soil pH ranged from strongly acidic (5.4) to moderately acidic (6.9). Low CEC and very high base saturation and pedon have a colour hue of 7.5 YR and value moist of 3 or more were observed. CEC/kg clay of the pedon was <24, because of these characteristics it was grouped under the subgroup Kanhaplic Haplustalfs.

Solum depth was very deep in pedon 4, surface soil colour was dark red (2.5YR 3/6) and the sub surface soil colour was red (2.5YR 4/6). Soils were well drained, the texture of the profile varied from sandy loam on surface to sandy clay on sub surface. Bulk density ranged from 1.50 Mg m^{-3} to 1.60 Mg m^{-3} with low organic carbon. Soil pH ranged from very strongly acidic (4.8) to neutral (6.9), low CEC and were very high base saturation. Because of the presence of argillic horizon of significantly higher percentage of clay that is, a clay increase of more than 20 percent within a vertical distance of 2.5 cm made the soil to be grouped under great group Paleustalfs.

Soils of pedon 5 were very deep, surface soil colour was yellowish red (5YR 4/6) to dark reddish brown (2.5YR 3/4) to red (2.5YR 4/6) in the subsurface. The texture of the profile varied from sandy loam on surface to sandy clay and clay in subsurface. Bulk density ranged from 1.20 Mg m^{-3} to 1.60 Mg m^{-3} with low organic carbon. Soil pH ranged from very strongly acidic (4.3) to neutral (6.8). CEC was low and base saturation was very high. The soil of pedon 5 is grouped under subgroup Kandic Paleustalfs as CEC was less than 24 c mol (P+)/ kg clay.

Based on the morphological, physical and chemical properties of soils and related information, problems and potentials of soils were identified and land evaluation studies such as estimating soil fertility status of the study area, assigning interpretative fertility capability classes and land suitability classification were carried out and maps were prepared.

Plot wise soil samples analyzed for the fertility indicated that 173.02 ha of the study area were very low in available nitrogen, 156.87 ha are low in available potassium and the soils of the entire study area were low in organic carbon which indicated that the soils are poor in plant available nutrients.

These soils were grouped under 15 fertility capability classes based on the presence or absence of the soil constraints. The soils of the study area are classified into different FCC units based on the limitations such as soil depth, soil reaction, soil erosion, topography, low CEC, low organic carbon and low potassium reserves. The information thus obtained was valuable to understand the productive potentials and this was used as an important input in soil fertility management and crop recommendations.

Land suitability analysis for major crops such as ragi, maize, tomato, radish and carrot was assigned on the basis of matching of soil site characteristics with growth and production requirements of these crops. Thus prepared map for suitability would help in assessing the suitability of these major crops so as to take up alternate cropping system to obtain better returns.

Land use / land cover map was prepared using satellite data and through the visual interpretation techniques. Ragi and red gram based cropping system was the major land use occupying about 23.07 percent of the total geographical area (TGA) of the village followed by fallow land which is about 19.96 percent of the TGA of the village.

The following are the conclusions of the land resources assessment, soil characteristics and the land evaluation studies.

1. Nagenahalli village receives 826.3 mm rainfall annually which was scanty and uneven, resulting in low soil moisture availability in the cropping season which could be conveniently avoided by enriching the organic carbon content in the soil and by adoption of soil and water conservation methods.

2. Inventory of soil resources was created to derive soil fertility, fertility capability, soil suitability to crops, which helps in making appropriate crop planning for optimum production.

3. Soils were moderately shallow to very deep, very strongly acidic to slightly alkaline.

4. The soils of the entire study area were low in organic carbon status mainly due to the semi arid tropical climate.

5. Slight to moderate erosion in the study area necessitated soil conservation structures and drainage outlets for each field along with field bunding.

6. Soils showed clay illuviation or increasing clay content with depth and are low to medium AWC.

7. Gravelliness in the subsoils in level to nearly uplands of the convex middle sector, convex lower sector and also linear upland summits of the study area was noticed.

8. Among the chemical properties pH, base saturation, CEC per kg clay decided the soil characteristics and management.

9. Soils studied were very low to low in available nitrogen, very high to high in available phosphorus and low to medium in available potassium.

10. Exchangeable calcium remained high in all the pedons followed by magnesium.

11. Among the micronutrients iron, manganese and copper showed contents higher than the optimum and near toxic levels in most soils, whereas zinc showed adequate to high in its availability.

12. Based on the inventory of the natural resources, a package was recommended for agriculture development which acts as a model for land resource in semiarid region.

Thus in the present study an attempt was made to create a comprehensive database of all the land resources, their limitations and potentials for the profitable farming. The database can be made use for the rural development programs by all the developmental agencies. The database is of great use for individual farmers also in conserving and utilizing the resources for sustainable production.

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