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Assessment of soil fertility through GIS techniques and thematic mapping in micro-watershed of Hassan, Karnataka

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Abstract
The study was conducted to assess the soil fertility status and to prepare the fertility mapping at Honnvalli micro-watershed of Hassan district during 2019 by using GIS and GPS techniques. The 105 grid soil samples were drawn from an area of 420 ha each at 400 m intervals and analysed for surface soil physicochemical and biological properties. The results revealed that overall Honnavalli micro-watershed found acidic pH area (93%), low organic carbon (55% area) and normal EC (100% area), further the watershed area was low in available N (51% area), P_2O_5 (77% area) and medium in K_2O (48% area). The exchangeable Ca and Mg were sufficient in 95 and 72 per cent of the watershed area, respectively. The 95 per cent of the watershed area has sufficient available Sulphur. The surface soil fertility maps of pH, EC, OC, available nitrogen, phosphorus and potassium, exchangeable calcium and magnesium and available Sulphur were prepared through ArcGIS and thematic maps.

Keywords: Geographic information system (GIS), global positioning system (GPS), micro-watershed, arcgis, soil fertility status and thematic map

Introduction
Soil is the most wondrous gift of nature to all the earthlings. It is a vital natural resource base performing fundamental functions for the benefit of humankind and the environment. On count of this benevolence, Indians treat soil as 'mother' and cherish fondly that they were brought into being by it (soil). Share of India in the global degraded soil area is about 10% it was largely impelled by anthropogenic misuse of soil via non-scientific, indiscriminate and non-sustainable intensive agricultural practices. It has become more imperative now than holders-farmers, builders and common folks. They have to be part of protection and conservation ever before to protect and preserve quality of soil resource to sustainably build productivity growth. Since onslaught on soil quality, more than nature, is the act of all stake programs also. In that pursuit, the present research work carried out on assessment of soil fertility status of Honnavalli micro-watershed of Hassan district by using remote sensing and geographical information system (GIS) techniques as a tool for precise and sustainable soil management. In the present day, the concept of watershed-based approach has emerged as potential means to achieve sustainable production in rainfed areas. Our aim of optimizing the utilization of land resources with intensification of agriculture resulted either in fast depletion of soil fertility status or occasionally in their accumulation. It is therefore important to monitor the fertility status of soil from time to time with a view to maintain the soil health. Hence, geo-referenced information on the location, extent, quality of land and display of spatial data is a must. Due to the land resources available for agriculture are shrinking in India, there is an overwhelming need to manage and conserve the natural resource base by adopting site specific and viable land management technologies.

Remote sensing technology has emerged as a powerful tool for studying soil resources as it helps in studying the soils in spatial domain in a time and cost-effective manner (Saxena, 2003) [1]. Remote Sensing is the most efficient tool in the bag of geoscientists for geological, geomorphological and soil resource mapping with respect to their nature, extent, spatial distribution, potential and limitations for optimal utilization of natural resources on a sustainable basis. Geographic information system (GIS) is defined as a powerful set of tools for collecting, storing, transforming and displaying spatial data from the real world (Zhang *et al.*, 2010) [3]. Precision agriculture (site-specific farming) involving remote sensing, global positioning system and geographical information system can be of great use for their assessment and management of soil fertility (Semay *et al.*, 1998) [2].

This helps the farmers to identify the right input at the right time in the right amount, which not only avoids wastage of inputs but also reduces the pollution due to excessive use of inputs.

Geographical Information System (GIS) analyses and displays multiple data layers derived from various sources and provides valuable support to handle voluminous data being generated through conventional and remote sensing technology both in spatial and non-spatial format. GIS can be used in producing a soil fertility map of an area, which will help in formulating balanced fertilizer recommendations and to understand the status of soil fertility spatially and temporally. Thus, GIS can be employed in various spheres of agriculture. Digital maps are very powerful tools to achieve this. Honnavalli micro-watershed lies in Hassan district of Karnataka state where important crops like Paddy, Maize, Coffee, Aracanut, Ragi, Banana, Chilli *etc*., are largely grown. Hence an attempt was made to delineate the soil fertility status and to prepare the thematic maps of pH, EC, OC, available nitrogen, phosphorus and potassium, exchangeable calcium and magnesium and available Sulphur by using geographic information system (GIS) techniques with aim of providing balance nutrition through soil test-based fertilizer recommendation, for sustainable crop production in the study area.

Material and Methods

The Honnavalli micro-watershed is located in Alur taluk of Hassan district, Karnataka state and having total area of 420 hectares lies between 12° 56' 4.176" - 12° 56' 58.234" North latitude and 75° 54' 1.635" - 75° 54' 55.337" East longitude and lies 953 meters above mean sea level.The zone covers 14 taluks of 5 districts. It has an area of 1.22 million ha. The zone consists of the Malnad, the Western Ghats and parts of the Plateau region (Fig. 1). Preliminary traverses of the entire Honnavalli micro-watershed was carried out with the help of cadastral map, satellite imagery and toposheets. The field boundaries and survey numbers given on the cadastral sheet were located on ground by following permanent features like roads, cart tracks, canals, streams, tanks *etc.,* and wherever changes noticed were incorporated on the cadastral map. The cadastral map of Honnavalli micro-watershed is given in Fig 2.The major crops grown were paddy, maize, ragi, and ginger in the kharif season, cauliflower in rabi and during summer, chilli, maize, ginger and fodder *etc.*

Database

Space borne multi spectral digital data

The satellite data used for the study was provided by Karnataka State Remote Sensing Application Centre, Bengaluru. The merged data of Cartosat-1 (PAN) and Resourcesat-2 (LISS IV) MX in the form of digital and geo-coded were analysed in the GIS environment along with cadastral maps. These inputs were used for soil sample collection for the study.

Topographic maps

The required topographic map at 1:4000 scale covering the study area of micro-watershed (4B4B3T2c) was collected from the Survey of India and utilized for the study.

Database creation and organization

For study purposes the digital cadastral map of micro-watershed procured from the Karnataka State Remote Sensing Application Centre (KSRSAC), Bengaluru was used. For database creation and union of various thematic maps the Geographic Information System (GIS) with ArcGIS software was used.

Field equipments

Field equipments used for work during studies and grid sampling are soil digging tools like spade, polythene cover, markers and Global positioning system (GPS) - (Model-Garmin 72H) instrument was utilized for correct location of the grids and also for collecting surface soil samples to study the spatial variability of soil fertility status. The GPS was conceived as a ranging system from known positions of satellites in space to unknown positions on land, sea and space. The antenna detects the electromagnetic waves arriving from the satellites, converts the wave energy into an electric current, amplifies the signal strength and sends the signals to the electronic receiver. The latitude and longitude were on the screen, which was utilized for fixing the grid point for collection of the soil samples. During the present investigation, GARMIN, GPS 72H receiver in stand-alone mode was used to collect the information regarding the geographical location of the ground truth sites and soil sampling sites.

Lab equipments

Equipment available at remote sensing laboratories in the Dept. of Soil Science and Agricultural Chemistry at University of Agricultural Sciences, Bengaluru was used. Soil samples were analysed using laboratory facilities of the Department of Agronomy, University of Agricultural Sciences, GKVK, Bengaluru.

Methodology

Preparation of digital database

The digital data was processed to transform it for improving the image contrast and to generate photo-products for subsequent interpretation. The imagery was georeferenced with a sub-pixel accuracy using first order polynomial transformation. The detail flow of preparation of vector map of study area given in (Fig. 3).

Preparation of base map

A tracing film was overlaid on the toposheet covering the study area. Boundaries of the micro-watershed and important land features like roads, streams, tanks *etc.* were extracted. Thus, a map having the above common land features was used as a base map for preparing different thematic maps. The cadastral map procured from KSRSAC was used in the study to identify survey numbers.

Delineation of the study area

Study area was delineated with the help of topographic maps and the watershed atlas prepared by KSRSAC. The data pertaining to the study area was extracted as a subset for further processing.

Assessment of soil fertility and mapping

Collection of soil samples for analysis

Collection of 105 composite soil samples from surface (0 -15 cm) were collected over the Honnavalli micro-watershed covering an area of 420 ha at 400 m grid intervals. The GPS data at each sample location was collected (Plate 2). The collected soil samples were analyzed for all physico-chemical properties (Soil pH, EC, OC, available N, P2O5, k2O and Sulphur. Exchangeable Ca and Mg).

Preparation of point map

The latitude and longitudes of sample sites of soil were collected in the study area by using a handheld GPS instrument GARMIN GPS72H receiver. The GPS technology proved to be very useful for enhancing the spatial accuracy of the data integrated in the GIS. The ArcGIS 10 software was used in this study. Based on the location data obtained, prepared point feature showing the position of samples in MS excel format and linked with the spatial data by join option in ArcMap. The spatial and the non-spatial database developed are integrated for the generation of spatial distribution maps.

Preparation of thematic maps for soil properties

The principle method of preparation of thematic maps is kriging. It is centred on the existence of a spatial structure where observations close to each other are more alike than those that are far apart (spatial autocorrelation). The average degree of dissimilarity between unsampled values and a nearby data value is measured by experimental variogram and thus can depict autocorrelation at various distances. A suitable model is derived by using weighted least squares and parameters from analysis of the experimental variogram.

The incorporation of variable interdependence and the available error surface output are some of its advantages. A disadvantage is that Kriging requires more input from the user and it requires substantially more computing and modelling time. The spine interpolation is a Radial Basis Function (RBF) in ArcGIS. The steps for kriging using ArcGIS 10 are presented as a flow diagram in (Fig. 4). After the map is prepared, it is clipped to the study area shape and final mapping was carried out as per the flow diagramand exported as. Jpeg or. Pdf format.

By interpolation of point data soil spatial variability maps were prepared. Initially, the geo-referenced soil test results for all properties such as pH, EC, available N, available P (P_2O_5) and available K (K_2O) were plotted using ARC/Info software. The interpolation technique used was ordinary kriging.

Preparation of soil fertility maps using GIS

A database file consisting of data for X and Y coordinate in respect of sampling site location was created. A shape file (vector data) showing the outline of the Honnavalli micro-watershed area was created in ArcView 3.1.

The database file was opened in the project window and in X-field X-coordinates was selected and in Y-field Y-coordinates was selected. The Z field was used for different nutrients. The Honnavalli micro-watershed shape file was also opened and from the "Surface menu" of ArcView spatial analyst "Interpolate grid option" was selected.

On the output "grid specification dialogue", the output grid extent chosen was the same as Honnavalli micro-watershed. Then map was reclassified based on ratings of respective nutrients.

Results and discussion

Spatial variability of surface soil properties in the study area

The spatial and temporal variability in soil properties has been known for many years (Burrough, 1993) [4]. In present study the spatial distribution of surface soil properties such as soil texture, soil reaction, electrical conductivity, organic carbon, available nitrogen, phosphorus potassium and sulphur, exchangeable calcium and magnesium area assessed for Honnavalli micro-watershed. Soil fertility testing is a practical application for research in crop production. Its diagnostic values are both specific and general-specific in the sense that it offers site specific fertilizer recommendation. The results of the soil testing are impressive, as soil test-based fertilizer recommendation should ensure high crop productivity and prove eco-friendly by preventing wastage of fertilizer. Geographical information system that facilitate landscape scale site-specific assessment of soil fertility and can better describe and address the spatial and temporal variability of soil fertility.

Computation of results using geostatistical procedures

To study the spatial variability of the soil properties, ground truth analysis was done by using GARMIN GPS instrument through geo referenced points locating longitude and latitude of the Honnavalli micro-watershed and data obtained from study area for various surface soil properties were analysed by using proper statistical procedures. By using interpolation methods, the Spatial variability maps were prepared *i.e.*, Kriging. The summary of the results on spatial variability of the soil properties at Honnavalli micro-watershed is given below.

Summary of the spatial variability of surface soil properties

Descriptive statistical analysis of spatial variability of soil properties of Honnavalli micro-watershed are presented in Table1.The soil reaction of Honnavalli micro-watershed varied from 4.06 to 7.42 and mean of 5.54. The CV of soil pH was 11.52 per cent, which is very low as compared to all other soil properties in the study area. The mean electrical conductivity value is < 0.06 and ranged from 0.01 to 0.26 dSm^{-1} and mean value of 0.06 dSm^{-1} with coefficient of variation as 59.85 per cent. The organic carbon status in the study area varied from 0.03 to 1.99 per cent and mean value 0.53 per cent and CV of 79.83 per cent. The nitrogen status ranged from 145.60 to 646.40 kg ha^{-1} and mean of 311.26 kg ha^{-1} with a CV of 39.16 per cent. The available phosphorus status varied from 2.02 to 154.70 kg ha^{-1} and mean of 18.57 kg ha^{-1} with CV of 127.04 per cent. The potassium content varied from 12.00 to 489.84 kg ha-1, and mean value of 173.71 kg $ha^{-1}$and coefficient of variation being 64.79 percent. The exchangeable calcium ranges from 0.5 to 10.5 meq/100g and mean value of 3.79 meq/100g and CV of 45.11 per cent and exchangeable magnesium content observed from 0.25 to 7.50 meq/100g and mean value of 1.97 meq/100g and the CV of (69.26%). The soil available sulphur varied from 6.50 to 140.50 ppm and mean of 50.35 ppm with a CV of 40.87 per cent.

The results pertaining to Honnavalli micro-watershed reveal that highest CV was observed for phosphorus (127.04%), followed by OC (79.83%).

Soils vary across fields and within the fields of micro-watershed areas, hence to prove this fact studies were done. The data revealed that CV was highest for Phosphorus (127.04), followed by OC (59.78%) and the lowest CV was observed in pH (11.52%) Similarly, Jagadish *et al.* (2009) [5] observed more variability for soil EC (83.32%), followed by Phosphorus (59.78%) and least CV for soil pH (4.43%). It is also confirmed with the results of Gupta *et al.* (2001) [6] and Raj Setia *et al.* (2012) [7] that among the soil chemical properties, soil pH is the least variable parameter and nutrients are more variable parameter across the study area and made spatial variability of nutrients.

GIS based spatial variability mapping

The fundamental purpose of soil fertility evaluation is to quantify the ability of soil to supply for plant growth. So that proper understanding of spatial variability in soil properties at field level is essential. GIS techniques can be used to generate fertility maps of a given area which helps to assess the variation of soil fertility, spatially and temporally and compute complex spatial relationships between soil fertility factors. By using GIS techniques maps were prepared for spatial variability of all soil properties through spatial interpolation of point-based measurements of soil properties. Interpolation techniques include, inverse distance weighting and kriging commonly used in agriculture (Franzen and Peck, 1995) [8].

Soil fertility maps were generated for the available pH, EC, OC, nitrogen, phosphorus, potassium, zinc, copper, iron and manganese using a kriging method at 1:4000 scale. The study area is divided into different fertility zones where each zone is representing a specific range of fertility status of nutrients.

Soil test values were grouped into different categories such as low, medium and high based on the variability in the soil in case of major nutrients and sufficient and deficient in case of micronutrients. The final maps thus generated gave the extent of spatial variability in soil properties. The results of the spatial variation maps generated are presented below.

Table 1: Descriptive statistical analysis of spatial variability of soil properties of Honnavalli micro-watershed

S. No.	Soil property	Range	Mean	SD	CV (%)
1.	pH	4.06 - 7.42	5.54	0.63	11.52
2.	EC (dS m^{-1})	0.01- 0.26	0.06	0.03	59.85
3.	OC (g kg^{-1})	0.03 - 1.99	0.53	0.42	79.83
4.	N (kg ha^{-1})	145.60 - 646.40	311.26	121.89	39.16
5.	P (kg ha^{-1})	2.02 - 154.70	18.57	23.59	127.04
6.	K (kg ha^{-1})	12.00 - 489.84	173.71	112.55	64.79
7.	Ca (meq. /100 gm)	0.50 - 10.50	3.79	1.71	45.11
8.	Mg (meq. /100 gm)	0.25 - 7.50	1.97	1.37	69.26
9.	S (ppm)	6.50 - 140.50	50.35	20.58	40.87

Soil reaction (pH) map

The spatial distribution of pH in soils of Honnavalli micro-watershed represented by five soil reaction classes *viz*., very strongly acidic (4-5.0), strongly acidic (5.1-5.5), moderately acidic (5.6-6.0), slightly acidic (6.1-6.5) and neutral (6.6-7.4) area showed in (Fig. 5). The soils of moderately acidic pH (5.6-6.0) occupies maximum area of 140 ha (33%), followed by strongly acidic pH (5.1-5.5) with area of 120 ha (29%), soils of very strongly acidic with area of 72 ha (17%), slightly acidic pH (6.1-6.5) with area of 60 ha (14%) whereas neutral pH (6.6-7.4) occupied with minimum area of 28 ha (7%).

Electrical conductivity (EC) map

The extent of spatial distribution of EC in the study area is depicted in (Fig. 6). The entire study area was represented by only one EC class (< 0.8 dSm^{-1}) and ranged from 0.01 to 0.26 dSm^{-1}, the total area of micro-watershed covering 420 ha has normal salinity, hence land suitable for all crops to grow.

Organic carbon map

The Organic carbon (%) content in Honnavalli micro-watershed area was divided into three classes *viz.,* low (<0.5%) occupies maximum area of 232 ha (55%), followed by high (>0.75%) occupies with area of 112 ha (27%) and medium (0.5-0.75%) covering with area of 96 ha (18%). In the entire area it varied from 0.03 to 1.99 per cent. The map showing the organic carbon status given in (Fig.7).

Available nitrogen map

The spatial variability of available nitrogen content in the study area categorized into three fertility classes *viz.,* Low (<280 kg ha^{-1}), medium (280-560 kg ha^{-1}) and High (>560 kg ha^{-1}). It ranged from 145.60 to 646.40 kg ha^{-1}. The maximum area of 216 ha (51%) is in low range, followed by 45 per cent (188 ha) area under medium available nitrogen content. Whereas the minimum area of 16 ha (4%) covers high available nitrogen content. The extent of spatial variability of available nitrogen maps is depicted in (Fig. 8).

Available phosphorus map

The spatial distribution of available phosphorus content of Honnavalli micro-watershed was categorized into three fertility classes. The soils of low phosphorus content (<23 kg ha^{-1}) occupied with area of 324 ha (77%), whereas 15 per cent (64 ha) falls under medium (23-56 kg ha^{-1}) range and remaining 8 per cent (32 ha) with high available phosphorus content (>56 kg ha^{-1}). The extent of available phosphorus mapped and depicted in the (Fig. 9).

Available potassium map

The extent spatial variability of available Potassium content of Honnavalli micro-watershed is presented in Fig. 10. The available potassium categorized into three classes *viz.* low (<140 kg ha^{-1}), medium (140-330 kg ha^{-1}) and high (>330 kg ha^{-1}). The maximum area of 200 ha (48%) falls under medium available potassium class, followed by 44 per cent (184 ha) with low available potassium content, whereas high potassium content with minimum area of 36 ha (8%).

Exchangeable calcium map

The exchangeable calcium content of Honnavalli micro-watershed was categorized into sufficient (> 1.5 meq/100g) and deficient (< 1.5 meq/100g). About 95 per cent (400 ha) is of the study area under sufficient exchangeable calcium content whereas the remaining 5 per cent (20 ha) area falls under deficient condition. The extent of spatial variability of exchangeable calcium is shown in the (Fig. 11).

Exchangeable magnesium map

The exchangeable magnesium content of the study area was categorized into sufficient (> 1 meq/100g) and deficient (< 1 meq/100g). About 72 per cent (304 ha) of the study area is under sufficient exchangeable magnesium content whereas the remaining 28 per cent (116 ha) area falls under deficient condition. The extent of spatial variability of exchangeable magnesium is presented in the (Fig. 12).

Available sulphur map

The available sulphur in Honnavalli micro-watershed was categorized into three classes viz., low (<10 ppm), medium (10-20 ppm) and high (>20 ppm). The soils of high available sulphur content occupied with highest area of 400 ha (95%), whereas 4 per cent (16 ha) area falls under low sulphur content and remaining only 1 per cent (4 ha) covers medium available sulphur content. The extent of different available sulphur content classes presented in (Fig. 13).

Conclusion: Geo-referenced soil samples and co-ordinates of the sampling sites (Honnavalli micro-watershed) were collected and analysed. The assessed soil fertility status was linked to the grid points. The thematic maps for spatial variable soil properties are prepared using geo-statistics. We used ArcGIS software for thematic mapping using interpolation technique and kriging method. The surface soil fertility maps of pH, EC, OC, available nitrogen, phosphorus, potassium, exchangeable calcium and magnesium, available sulphur are prepared on the basis of soil fertility ratings. This will help the farmers to identify and overcome the nutrient related constraints in the crop production.

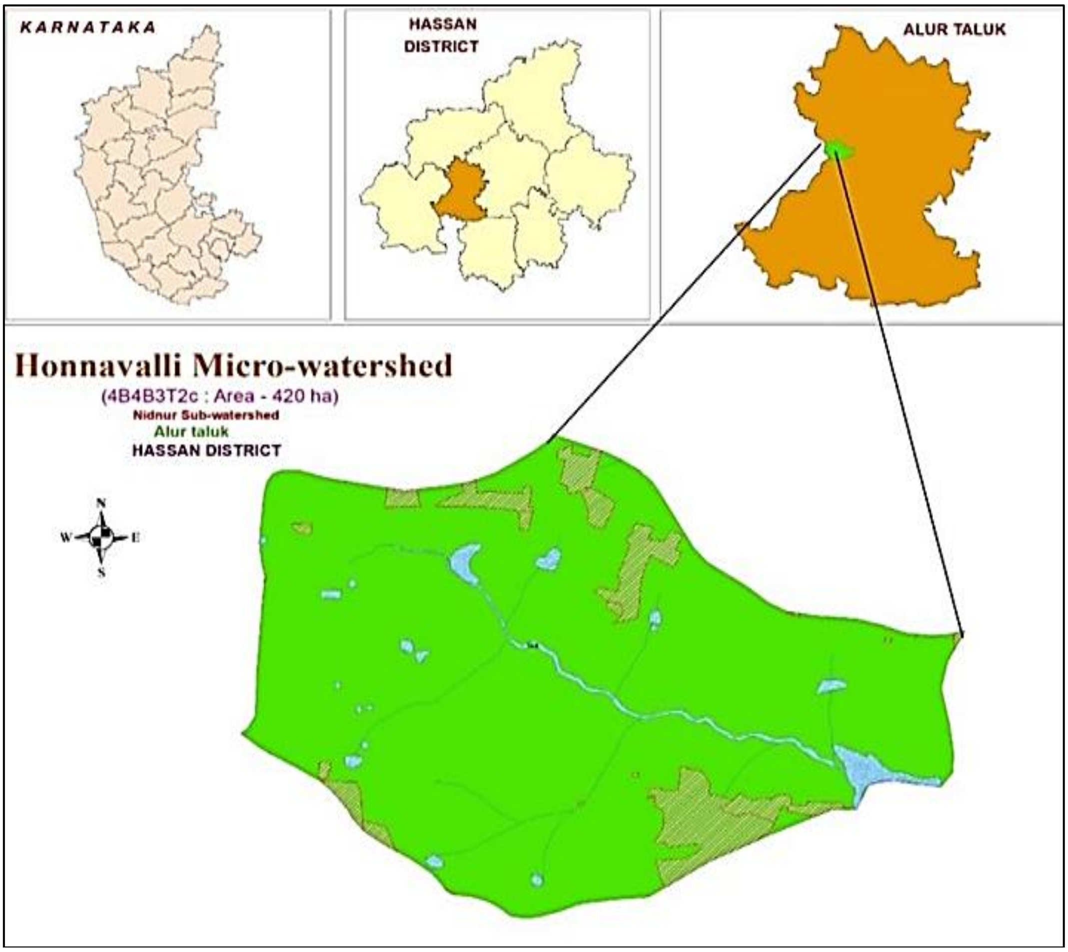

Fig 1: Location map of Honnavalli micro-watershed

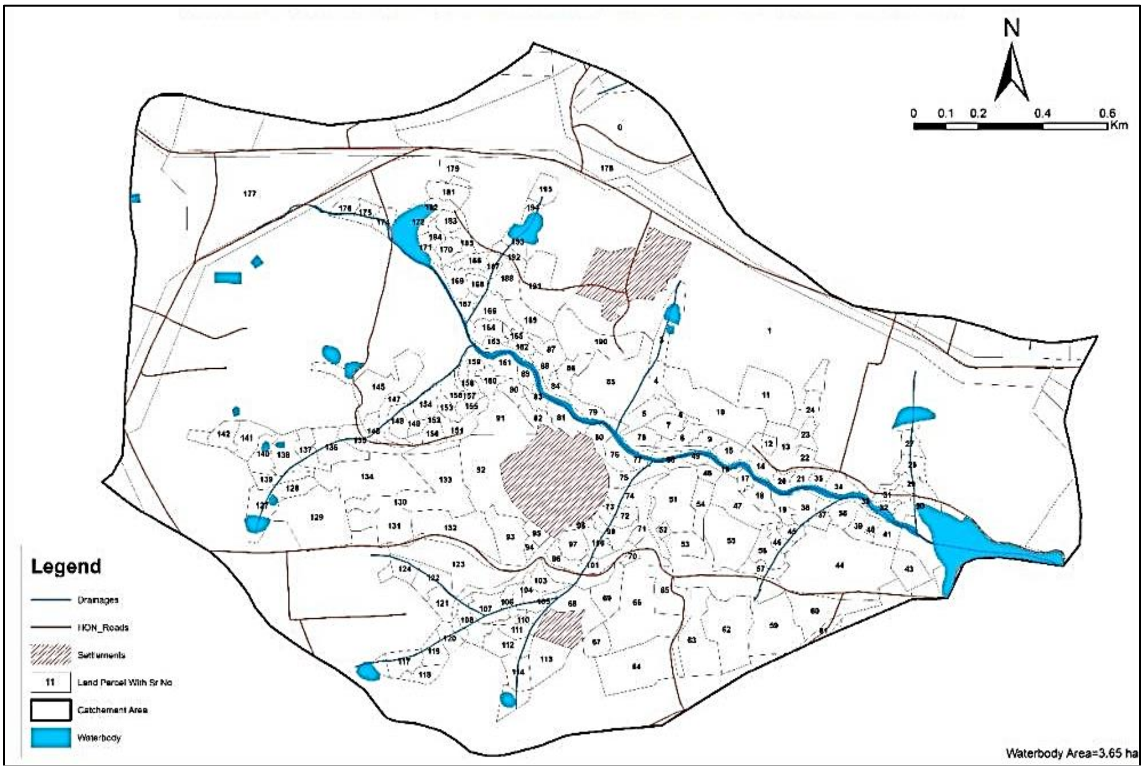

Fig 2: Cadastral map of Honnavalli micro-watershed

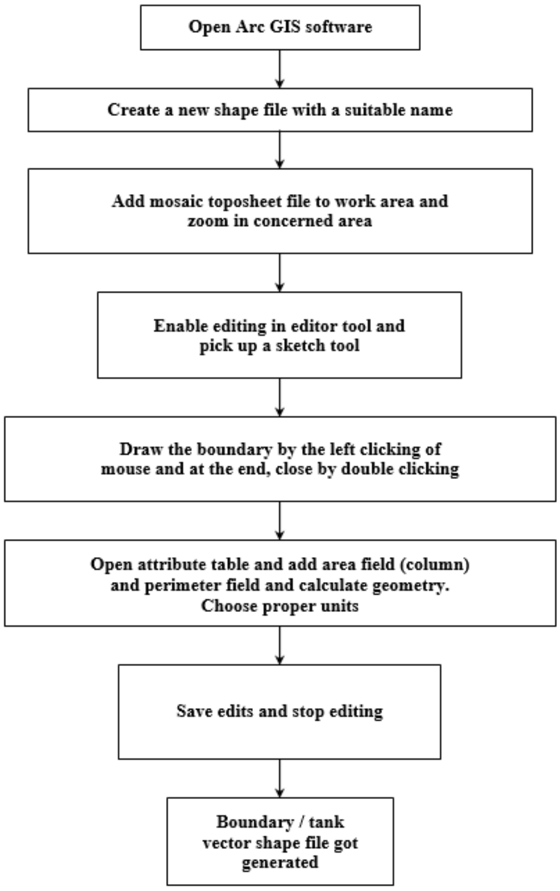

Fig 3: Preparation of vector layer (shape file) of study area boundary using ArcGIS

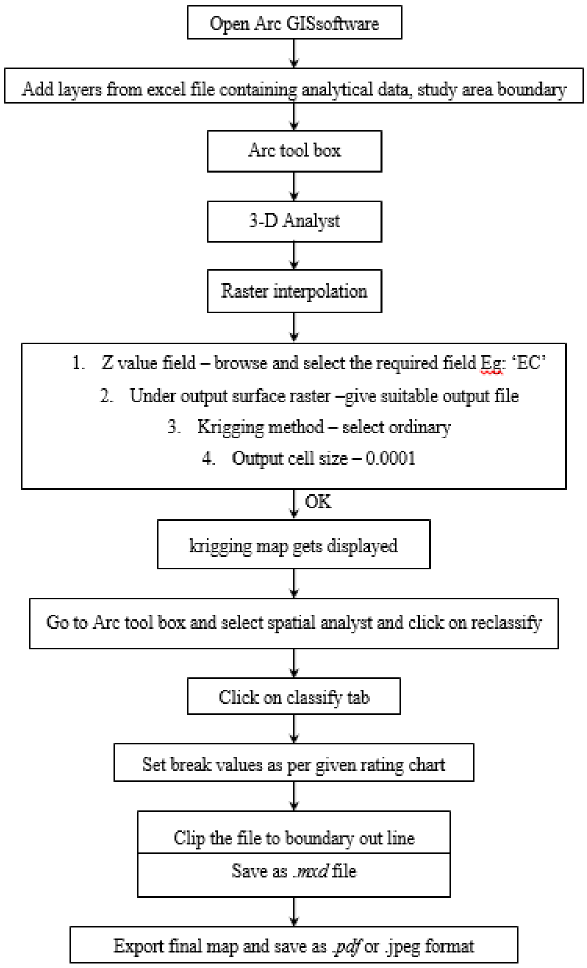

Fig 4: Soil fertility map using kriging function in Arc GIS

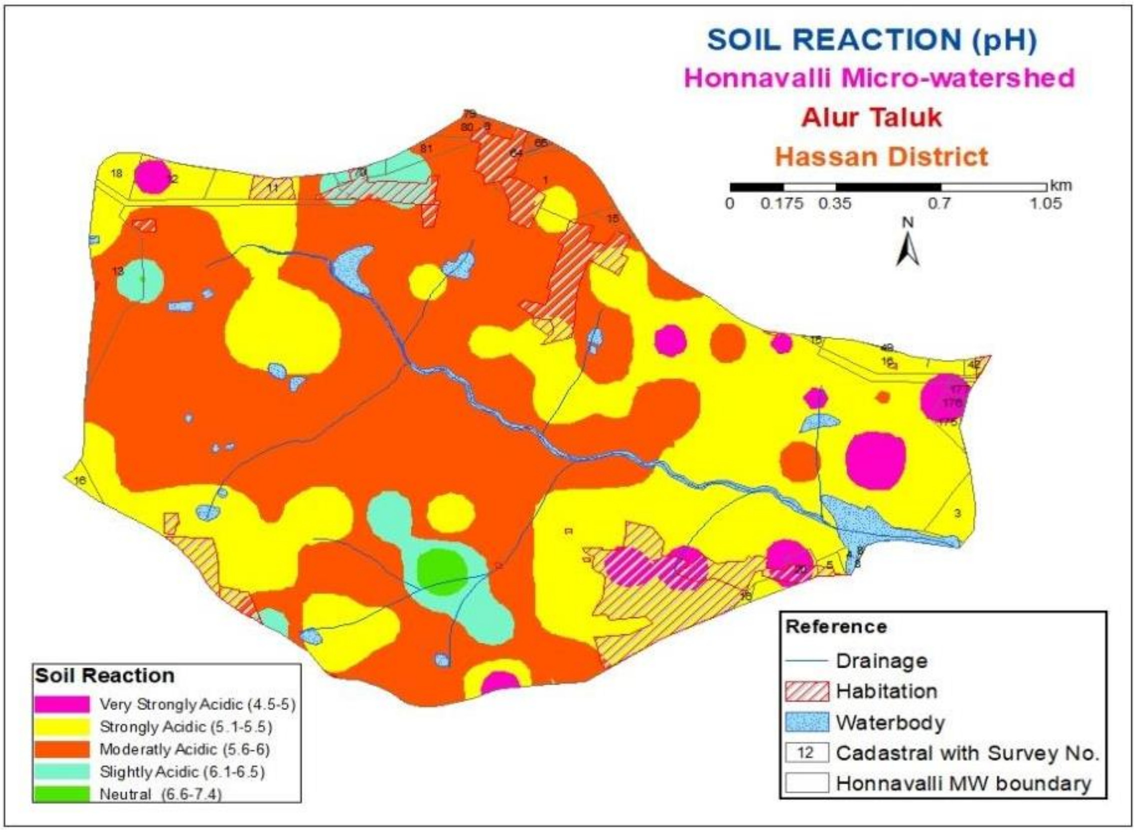

Fig 5: Spatial distribution of soil reaction (pH) in Honnavalli micro-watershed

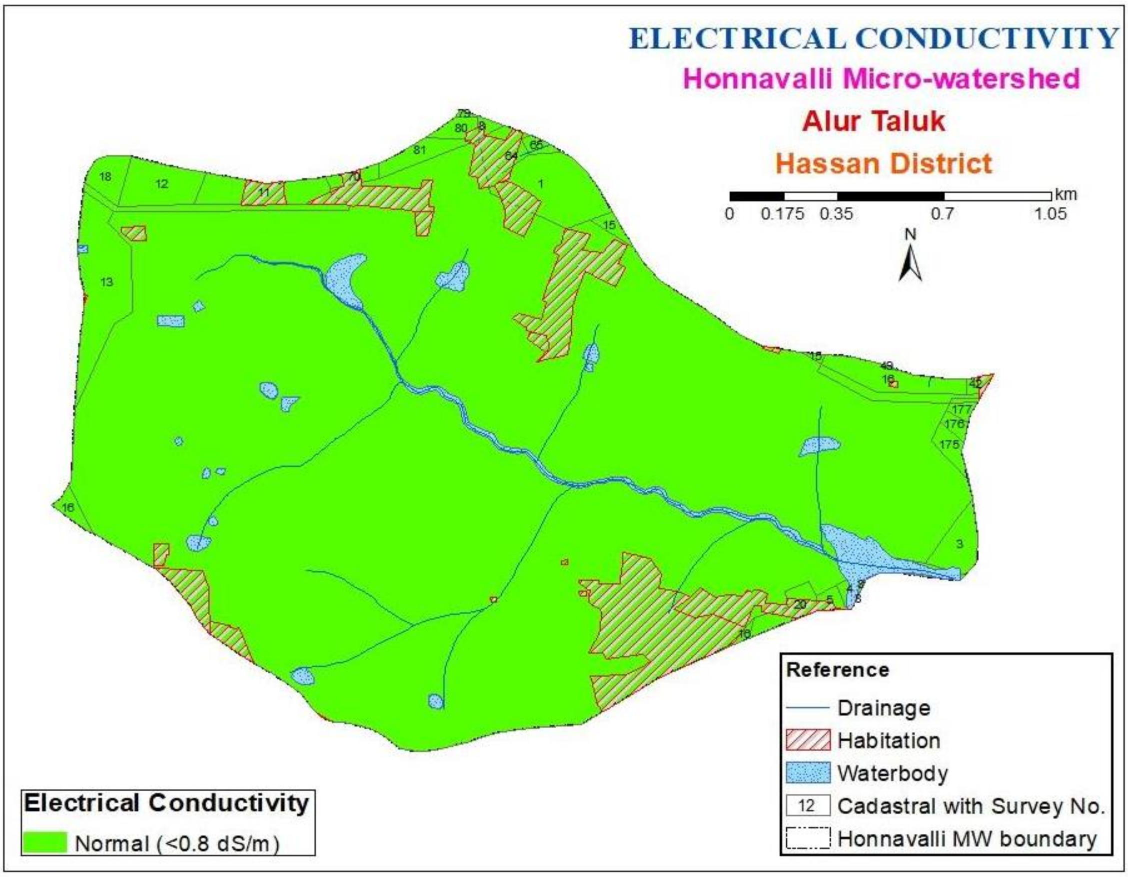

Fig. 6: Spatial distribution of electrical conductivity (EC) in Honnavalli micro-watershed

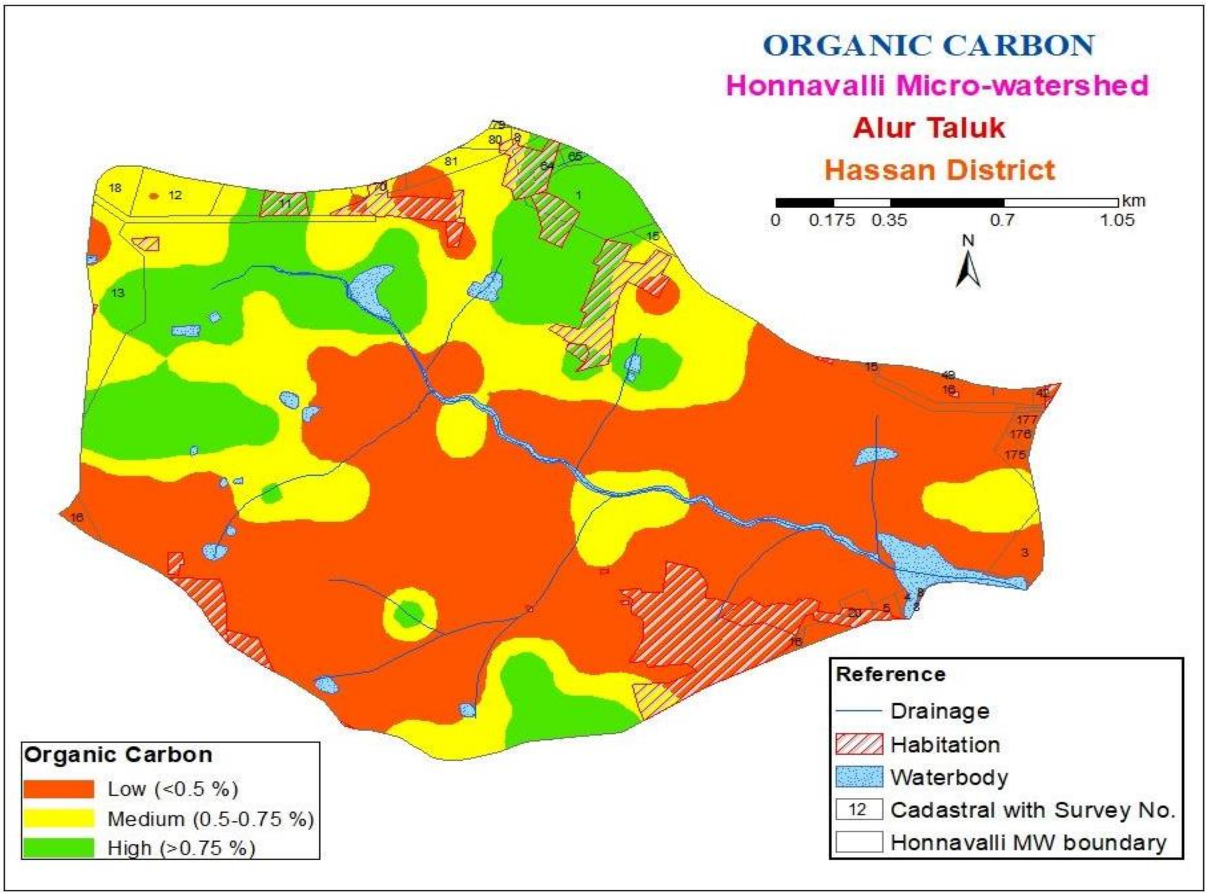

Fig. 7: Spatial distribution of organic carbon in Honnavalli micro-watershed

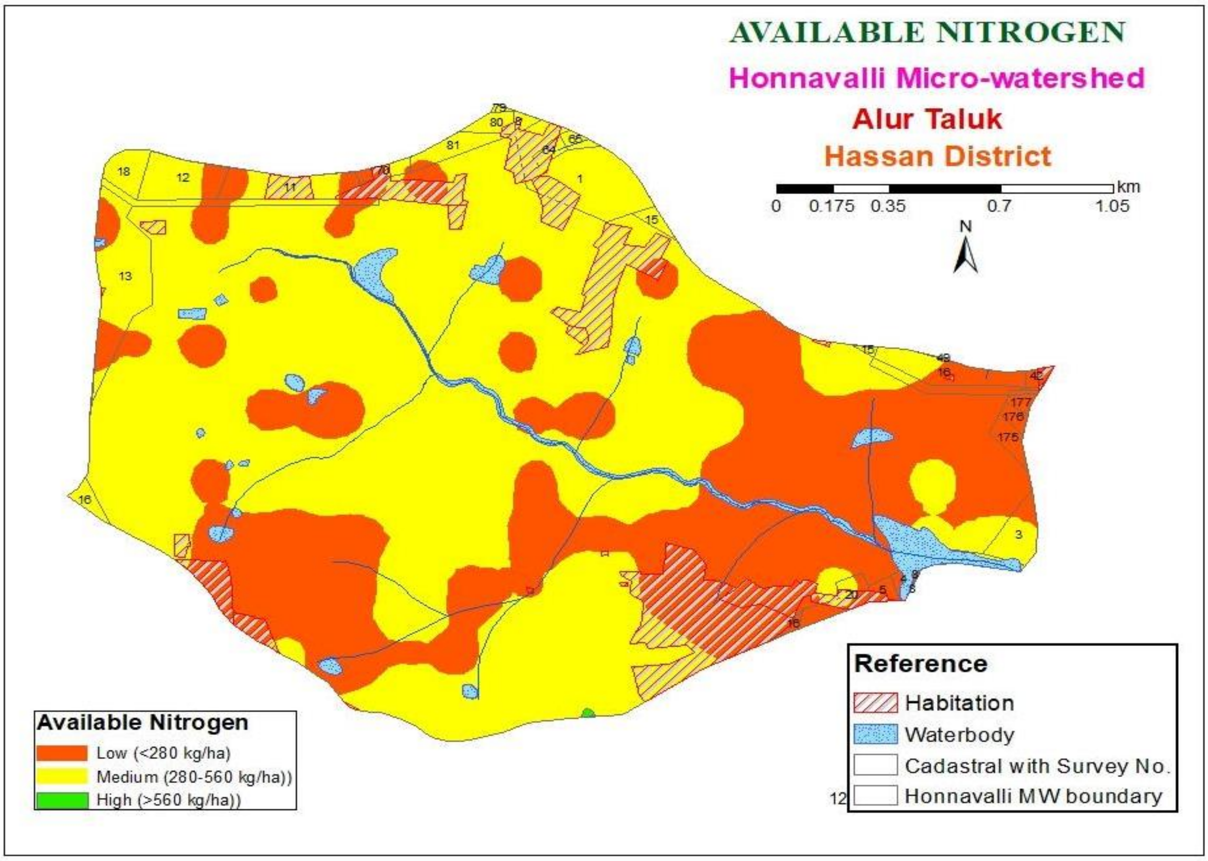

Fig. 8: Spatial distribution of available nitrogen in Honnavalli micro-watershed

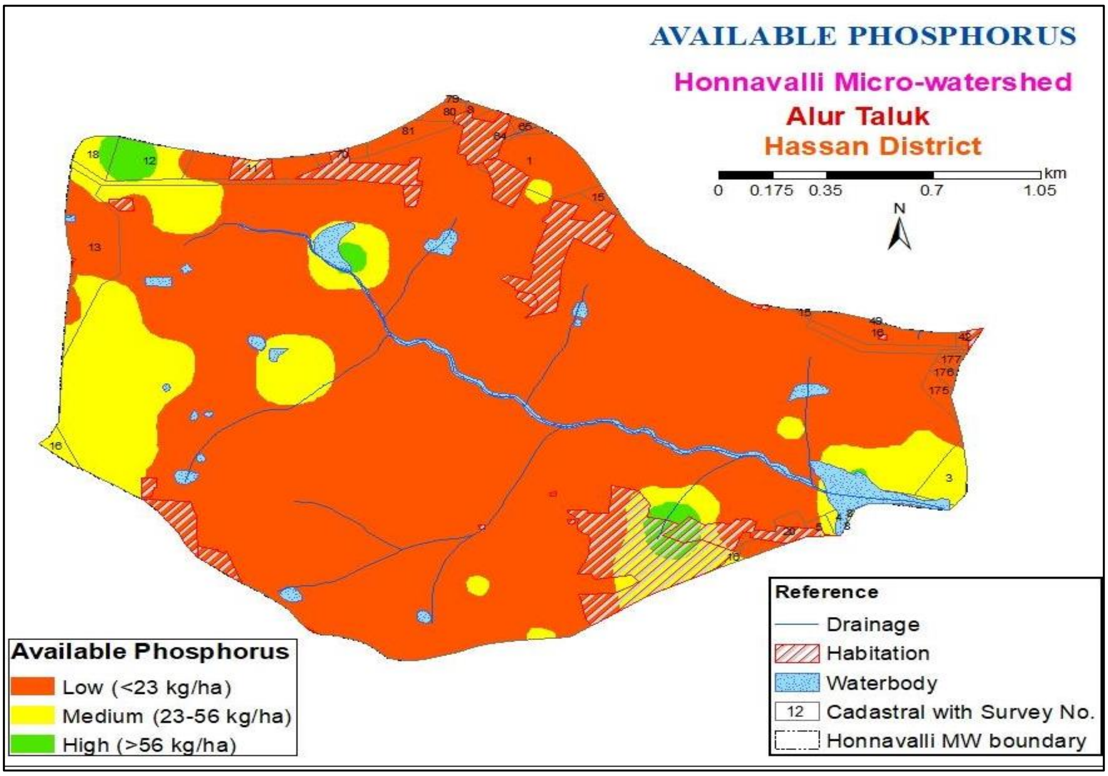

Fig. 9: Spatial distribution of available phosphorus in Honnavalli micro-watershed

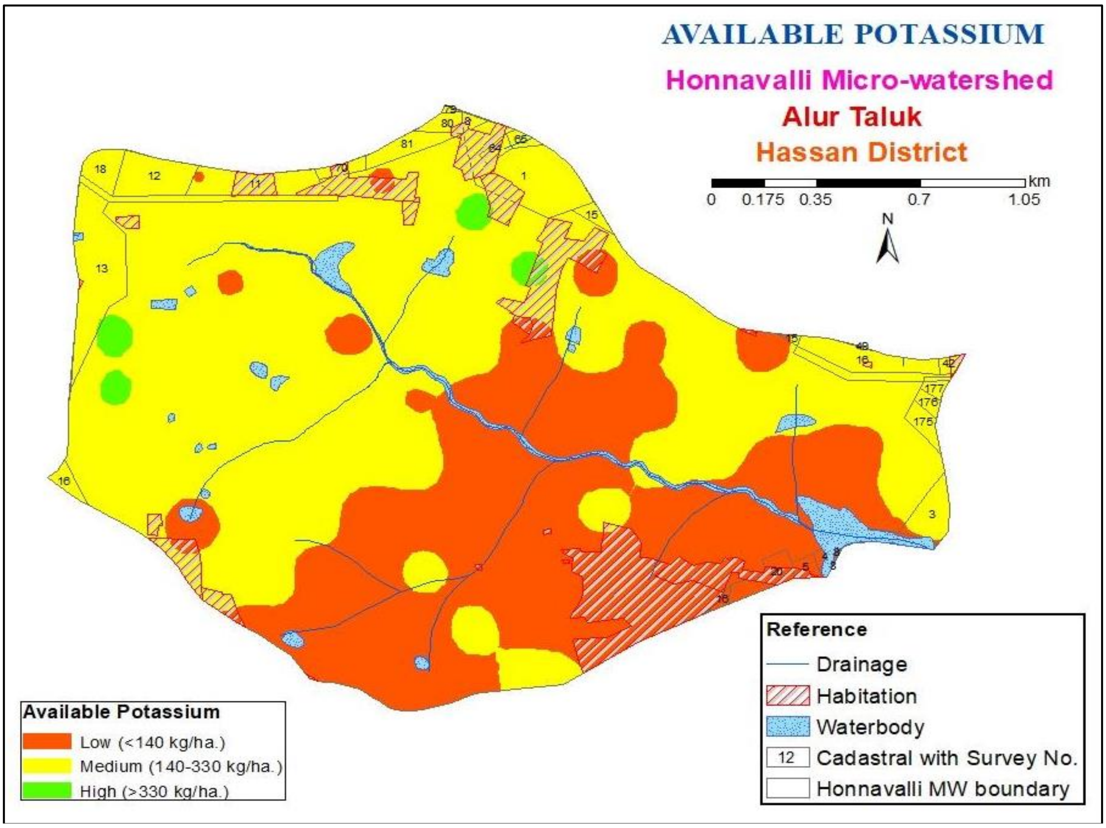

Fig. 10: Spatial distribution of available potassium in Honnavalli micro-watershed

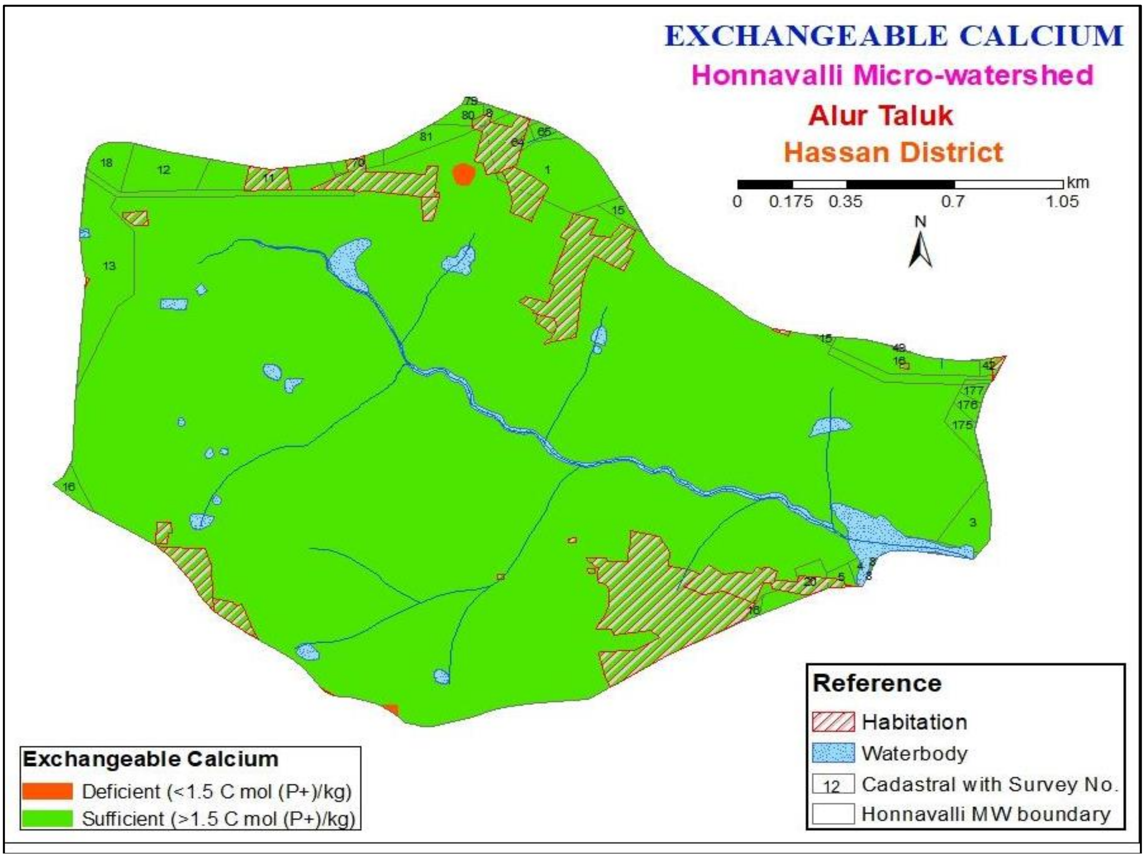

Fig. 11: Spatial distribution of Exchangeable calcium in Honnavalli micro-watershed

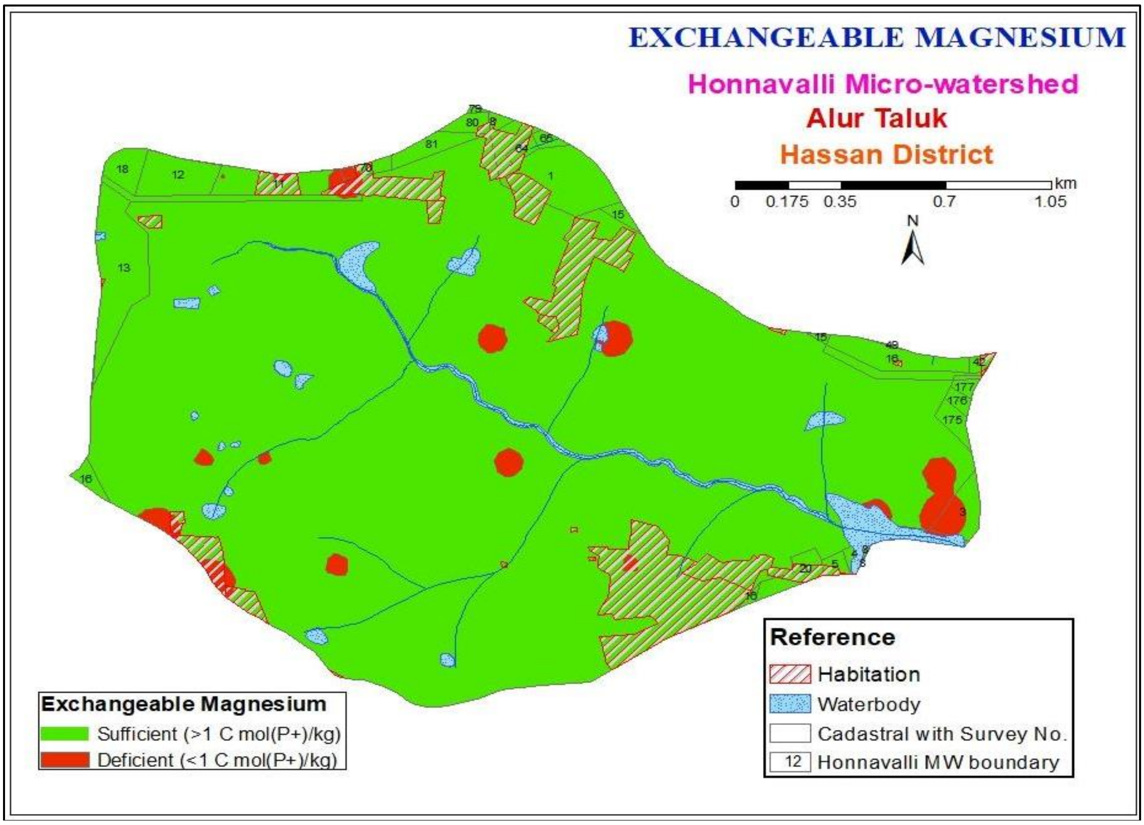

Fig. 12: Spatial distribution of Exchangeable Mg in Honnavalli micro-watershed

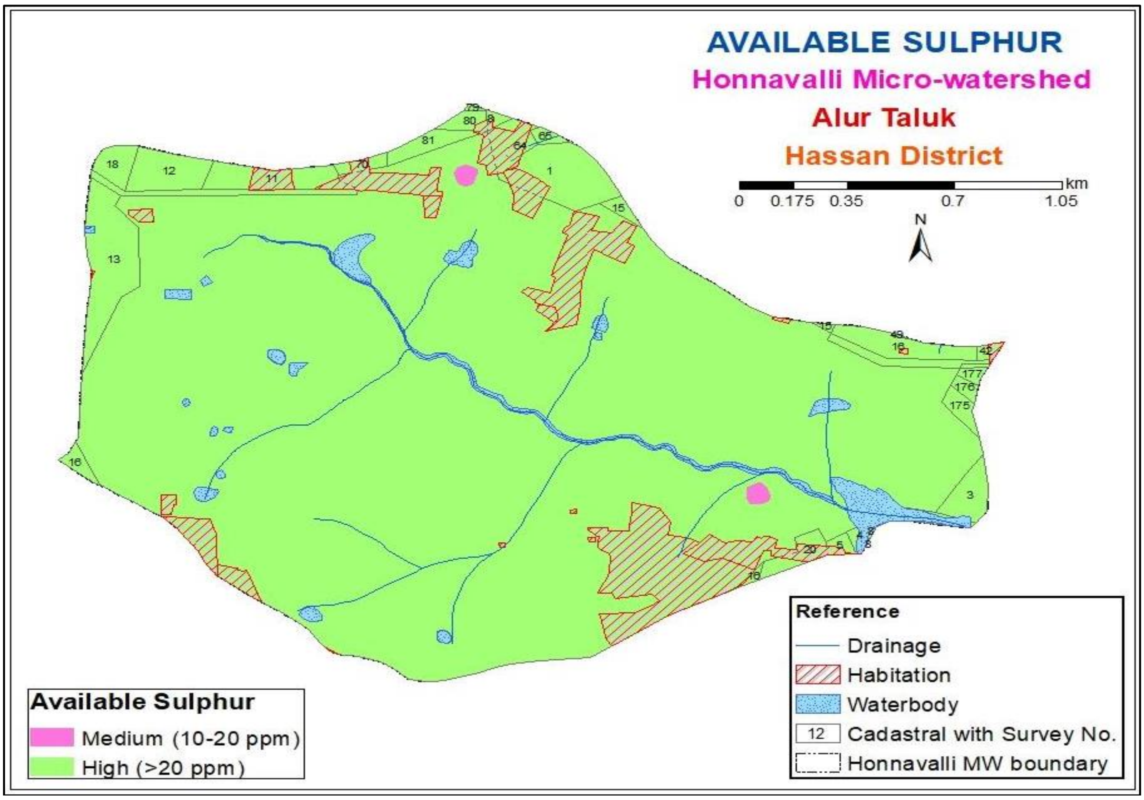

Fig 13: Spatial distribution of available Sulphur in Honnavalli micro-watershed

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