Geospatial Techniques for Mapping Madapur micro-watershed using GIS and Remote Sensing Techniques

Abstract

Geographic Information Systems (GIS)-based land resource inventory (LRI) with high-resolution imagery is the most reliable tool for soil resource mapping. However, soil series-based mapping remains crucial for detailed soil studies in Madapur micro-watershed. A thorough geospatial analysis of land resources was conducted to support integrated land use planning efforts. This involves assessing various factors such as land cover, land use patterns, terrain features and soil characteristics. By adapting GIS and remote sensing data, soil maps were prepared for decision-making in land use planning initiatives, considering environmental sustainability, socio-economic factors and land resource availability. The research findings revealed the extent of soil erosion, gravel content, salinity levels, soil depth, soil pH and nutrient availability. In the moderately soil erosion category, the area covered 316 ha (65.67 %) followed by slightly erosion category covered 99 ha (20.56 %). Gravel content was prevalent, with 276 ha (57.39 %) falling into the gravelly category, while the remaining was non-gravelly. Salinity levels were low across the entire area with non saline. Soil depth in 278 ha (57.81%) area was very deep soil (>150 cm), while a significant portion 126 ha (26.16%) has moderately shallow depth (50-75 cm). The soil reaction is moderately alkaline, with 97.27 percent of the area showing this trait. Nitrogen deficiency is common, affecting 97.27 percent of the area with levels below 280 kg/ha. Phosphorus availability is moderate, ranging from 23 to 56 kg/ha. Potassium content is also moderate in 65.22% of the area, with levels between 140 and 330 kg/ha. Adequate levels of micronutrients like iron, copper and manganese were present, but zinc content was deficient. Despite soil limitations, a substantial portion (57.12%, 275 ha) is classified as good cultivable land with some soil limitations, suggesting potential for agricultural productivity with appropriate management practices.

Key words: Land resource inventory, Soil resource mapping, Micro-watershed, Remote sensing and GIS

Introduction

The growing pressure on land resources driven by population growth demands an integrated approach to resource management. Thus, comprehending soil and land resources and their suitability for diverse applications is crucial for achieving sustainable productivity improvements. Obtaining timely and accurate land resource data is fundamental for efficient planning and this can be achieved through systematic inventory using remote sensing and Geographic Information Systems (GIS). Site-specific Land Resource Inventory (LRI) for watershed-level planning has gained importance due to improper resource utilization and conservation. Watershed degradation, attributed to factors like deforestation and improper land use, poses challenges to sustainable development. Land degradation poses a significant challenge, with approximately 38.0 lakh hectares of cultivated land in Karnataka suffering its effects. Soil erosion, accounting for 35.0 lakh hectares of degradation, stands out as a primary contributor (Dey and Mandal, 2023). This phenomenon is pervasive across both rainfed and irrigated areas, leading to nutrient depletion and a decline in productivity (Geeta *et al*., 2017). Addressing these issues requires rational, site-specific land use options tailored to each landholding. For sustainable natural resource utilization, a detailed examination of land resources is imperative. Understanding their potential and limitations is essential for informed planning. Tailoring land use according to capabilities is crucial for conserving natural resources and ensuring sustainable agriculture. Knowledge of soil and land resources, including their spatial distribution, characteristics, potentials, and limitations, aids in devising strategies for sustainable productivity to meet the food demands of a growing population but also conserve natural resources in the state. Soil resource inventory provides insights into soil productivity potentials and limitations, laying the groundwork for successful watershed development. Land use and management practices significantly influence nutrient availability. Rapid inventory of natural resources using modern tools like remote sensing and geographic information systems (GIS) expedites the process (Hegde *et al*., 2018). These technologies revolutionize the mapping of spatial and non-spatial natural resource information, facilitating sustainable agricultural development. Hence, this study was aimed at generating land resource and mapping the watershed area for specific crop recommendations, design location-specific soil and water conservation strategies, and furnish the necessary datasets and inputs for planning, implementing, and monitoring all land-based development initiatives. This endeavour aimed to produce technical tools, packages and thematic outputs conducive for effective resource management and sustainable development.

Materials and Methods

Study Area

LRI for the Madapura micro-watershed, Haralhalli sub-watershed in Ranibennuru taluk, Haveri district is located in between 14^0 45' – 14^0 47' North latitudes and 75^0 37' – 75^0 40' East longitudes (Fig. 1). It was selected for data base generation under WDPD project. Madapura micro-watershed (4D4C2M1c) is a part of Haralhalli sub-watershed (1148 ha) covering an area of 481 ha and spread across Chowdadhanapura, Gudivanti, Nookapura and Ramapur villages. The major geology of Haveri district is schist and Gneiss-granite in small part.

Climate

The study area comes under Northern Transitional Zone (Agro-climatic Zone 8) with annual rainfall 685 mm. The region experiences a semi-arid climate and is prone to drought, receiving an annual rainfall of 866 mm.

Data used

In the survey, False Color Composites (FCC) of combined Cartosat-1 and LISS-IV satellite data (as depicted in Fig. 2) were utilized alongside digitalized cadastral maps (Natarajan and Dipak, 2010). Each physiographic unit within the micro-watershed underwent thorough exploration, with transects selected to cover the full spectrum of soil variability observed on the surface. These transects were strategically positioned along the slope to encompass changes in land features such as slope breaks, erosion, gravel, stones, and saline/sodic conditions. Soil profiles were meticulously located at closely spaced intervals along these transects to ensure comprehensive coverage. Subsequently, these profiles were meticulously examined and described in detail, encompassing their morphological and physical attributes.

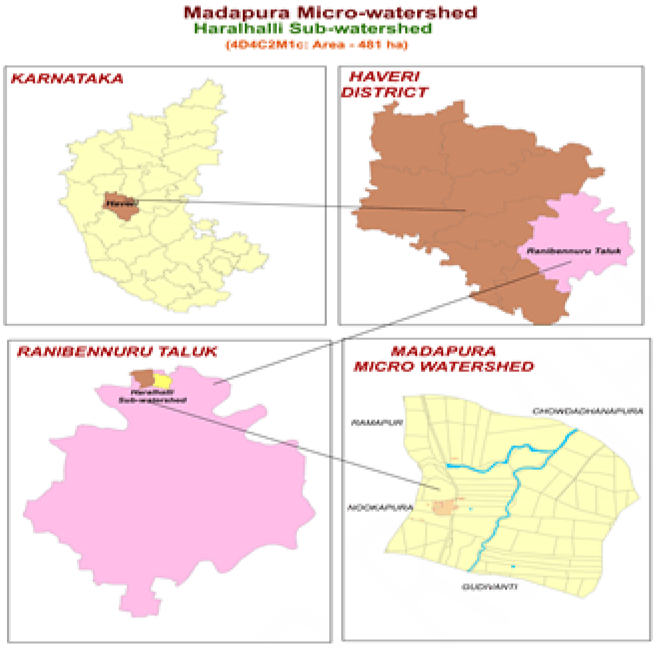

Fig.1 Location map of Madapura micro-watershed

Fig. 2 Satellite image of Madapura micro-watershed

Methods

A three-tier approach comprising image interpretation, field surveys, and laboratory analysis followed by cartography and GIS was employed. The watershed boundary was delineated using published SOI maps at a 1:50,000 scale by drawing lines perpendicular to the elevation contour lines for land draining to a common outlet (Proff *et al*. 2005). Additionally, information on drainage, road networks, settlements, village locations, water bodies, and slope was extracted from the SOI maps. The soils were analysed, categorized and grouped into different soil series based on their characteristics. The soil series, being uniform in behaviour across different management levels and sharing similar horizons and properties, emerged as the most consistent unit (Hegde *et al*., 2021). These soil series were further depicted on the map as different phases of soil series (as shown in Fig. 3). Essentially, a soil map illustrates the geographical extent and distribution of different soil mapping units, or phases, classified within each soil series.

To characterize each soil series, representative master profiles were employed to collect soil samples for laboratory analysis, focusing on their physical and chemical attributes (Sarma *et al*., 1987). The fertility status of surface soil samples (0–20 cm depth) was scrutinized in the laboratory at 320 m grid intervals. In delineating soil series phases, the study identified five distinct soil series in the area, which were further mapped into eight unique mapping units (Fig. 3). Each property's weighted mean was calculated, facilitating the extraction of various soil units with specific soil-site characteristics, as detailed in Table 1. These weighted average data were utilized to assess land capability classification and soil-site suitability, following the criteria outlined by FAO in 1983. To visually represent these findings, maps depicting land capability and soil-site suitability were generated using ArcGIS 10.4.

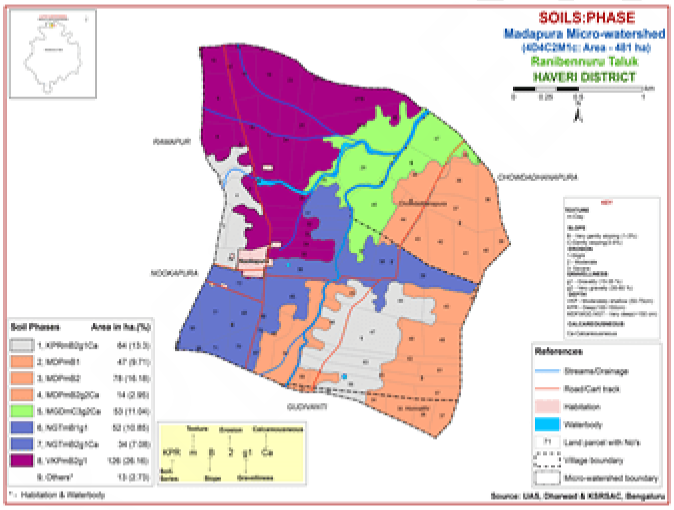

Fig. 3 Soil phase map of Madapura micro-watershed

Table 1: Characteristics of soil units

Sl. No.	Soil phase	Depth (cm)	Texture	Slope (%)	Erosion	Gravels (%)	calcareousness
1	KPRmB2g1Ca	100-150	Clay	1-3	Moderately eroded	15-35	Calcareous
2	MDPmB1	>50	Clay	1-3	Slightly eroded	-	-
3	MDPmB2	>50	Clay	1-3	Moderately eroded	-	-
4	MDPmB2g2Ca	>50	Clay	1-3	Moderately eroded	35-60	Calcareous

5	MGDmC3g2Ca	>50	Clay	3-5	Severely eroded	35-60	Calcareous
6	NGTmB1g1	>50	Clay	1-3	Slight eroded	15-35	-
7	NGTmB2g1Ca	>50	Clay	1-3	Moderately eroded	15-35	Calcareous
8	VKPmB2g1	50-75	clay	1-3	Moderately eroded	15-35	-

Result and discussion

Soil Depth

Soil depth is mainly influencing the root space and the volume of soil from where the plants fulfil their water and nutrient demands. Soil depth class of study area was categorised into 3 classes, covers 126 ha (26.16 %) moderately shallow (50-75 cm), 64 ha (13.3 %) area with deep depth (100-150 cm) and the majority of the watershed area, specifically 278 hectares (57.81%), consists of very deep soil (>150 cm) (Fig. 4). Soil depth is a critical factor in determining farm suitability, as evidenced by the findings of this study. The variation in the depth of the solum could be due to landscape configuration important in influencing the rate at which water flows (Gebrehanna *et al*., 2022). A similar finding was also noted by Walia *et al*. (2013) moderately shallow to very deep soils occupying about 72 per cent area could be preferred for agriculture.

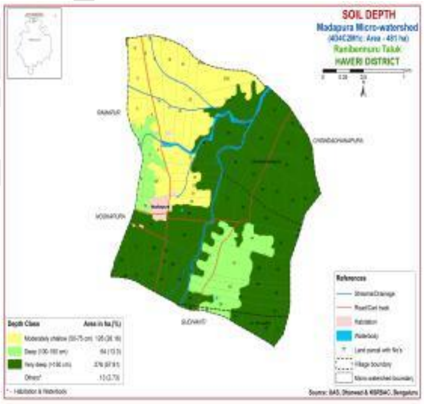

Fig. 4 Soil depth map of Madapura micro-watershed

Soil texture

Total 468 ha i.e., 97.27 per cent area of the micro-watershed covers clay textural soil (Fig. 5). The heavier textures of the soils are due to less erosion, less slope and good managements by the farmers (Vedadri and Naidu, 2018; Basavaraj *et al*., 2023).

Soil gravelliness

The kind of coarse-grained soil that has relatively good physical properties were categorised under soil gravelliness. 276 ha (57.39 %) of the study area covers gravelly class (15-35%), 125 ha (25.9 %) area non gravelly (<15%) and some portion of area 67 ha (13.99 %) comes under very gravelly (35-60%). This is mainly due to differential weathering of rocks (Basavaraj *et al*., 2023).

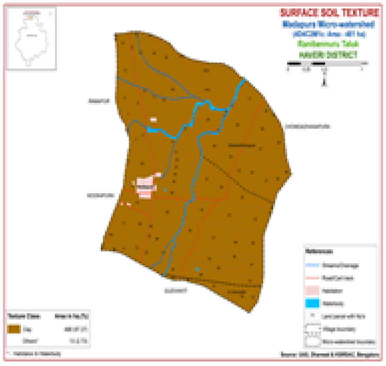

Fig. 5 Surface soil texture map of Madapura micro-watershed

Slope

Slope gradient influences the rate at which runoff flows on the soil surface and erodes the soil and alters the overall use of the land. Two slope classes were found in the Madapura micro-watershed. Maximum area of about 415 ha (86.23 %) falls under very gently sloping (1-3%) lands and 53 ha (11.04 %) falls under gently sloping (3-5%) (Fig. 7). This primarily stems from the land's physiography, including factors such as landform, texture, relief *etc*., as determined by Hegde *et al*. (2018). Similar kind of finding was observed in Amara *et al*. (2021) the slope was varied form very gently sloping to gently sloping.

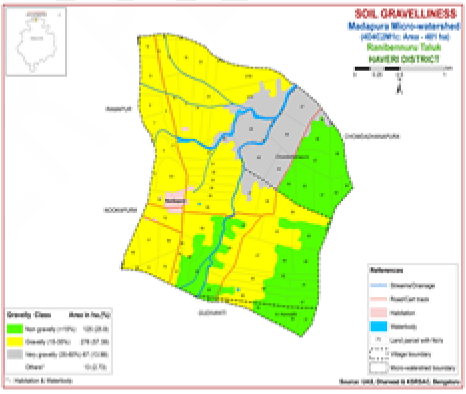

Fig. 6 Soil gravelliness map of Madapura micro-watershed

Soil erosion

Soil erosion is a gradual process that occurs when the impact of water or wind detaches and removes soil particles, causing the soil to deteriorate. Soils that are severe eroded (e3 class) cover in an area of about 53 ha (11.04 %) whereas moderate eroded (e2 class) soils cover a major area of about 316 ha (65.67 %) and 90 ha (20.56 %) area covers slight erosion (e1 class) (Fig. 8). The abundance of mild inclines in the highlands facilitates the effortless separation and displacement of soil particles from the terrain.

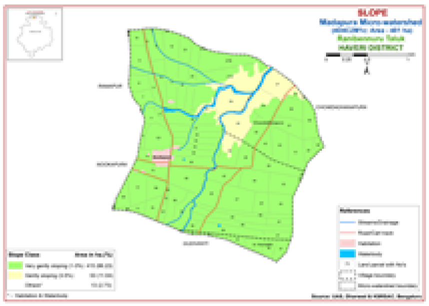

Fig. 7 Soil slope map of Madapura micro-watershed

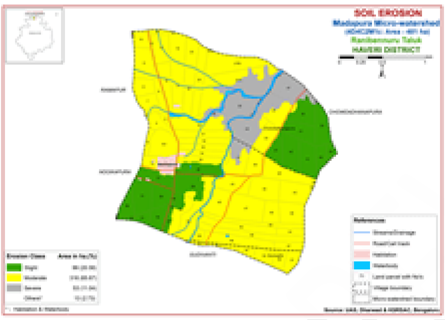

Fig. 8 Soil erosion map of Madapura micro-watershed

Soil nutrient status

The data on soil fertility has been analysed and distinct maps for each nutrient in the micro-watershed created using the Kriging method within GIS. Soil analysis of the Madapura micro-watershed for soil reaction (pH) showed that entire micro-watershed area i. e., 468 ha (97.27 %) has moderately alkaline (7.8-8.4) (Fig. 9) and non-saline (<0.5 dSm^{-1}) (Fig. 10). The soil alkalinity is due to presence of calcium carbonate and increase in exchangeable bases brought by runoff water in these soils. These findings are consistent with the results reported by Hegde *et al.* (2018) and Ram *et al.* (2010). A substantial portion of the micro-watershed, approximately 295 hectares (61.31%), has medium soil organic carbon content (0.5-0.75%) (Fig. 11). Additionally, 173 hectares (35.96%) of the area exhibit high soil organic carbon content (>0.75%) similar results reported by Kumar *et al.* (2021) and entire area 468 ha (97.27 %) area follows the low available nitrogen content (Fig. 12). This is due to continuous removal by crops and Indian soils are already low in available nitrogen content (Rao *et al.*, 2008). Entire area of the soils was medium (23-56 kg ha^{-1}) in available phosphorus content (Fig. 13) whereas 314 ha (65.22 %) area was medium in potassium (150-330 kg ha^{-1}) and 154 ha (32.06) high in potassium (>330 kg ha^{-1}) (Fig. 14) due to the precipitation of added phosphorous as iron and aluminium phosphate of low solubility (Gupta, 1965) and presence of potassium bearing minerals and rocks in study area. Total study area is medium in sulphur content (10-20 ppm) (Fig. 15), sufficient in micronutrients (Fe, Cu, Mn) (Fig. 15, 16, 17 respectively) (Dhailwal *et al.*, 2022) except Zn which is deficit (Fig. 18). The zinc deficient was attributed to the alkaline soil condition which occur due to high precipitation of hydroxides and carbonates (Thangasamy *et al.*, 2005).

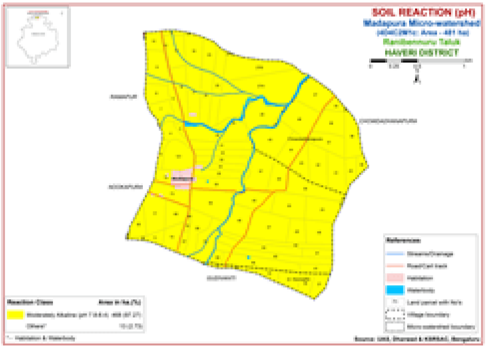

Fig. 9 Soil reaction map of Madapura micro-watershed

Fig. 10 Salinity map of Madapura micro-watershed

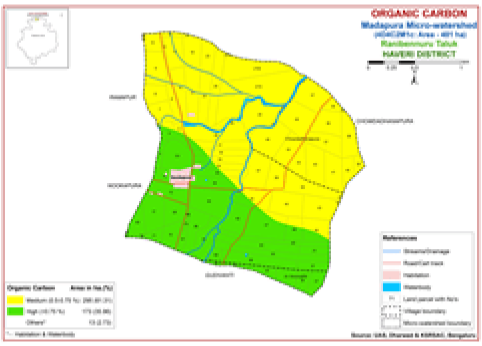

Fig. 11 Organic carbon map of Madapura micro-watershed

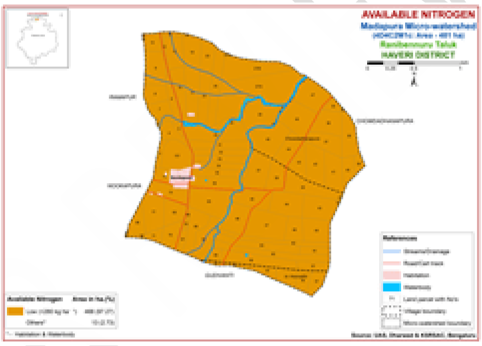

Fig. 12 Available nitrogen map of Madapura micro-watershed

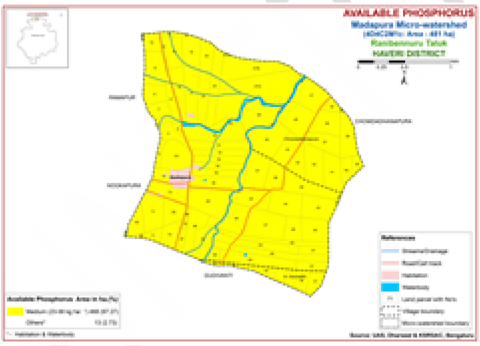

Fig. 13 Available phosphorous map of Madapura micro-watershed

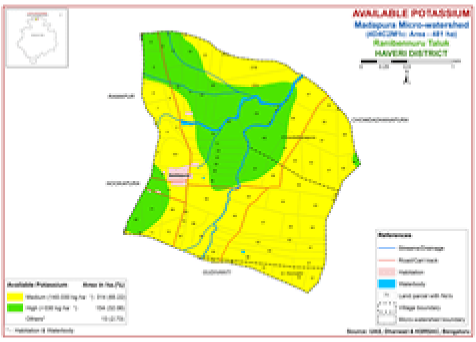

Fig. 14 Available potassium map of Madapura micro-watershed

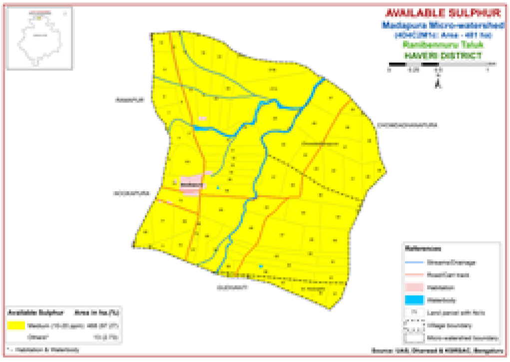

Fig. 15 Available sulphur map of Madapura micro-watershed

Fig. 16 Available iron map of Madapura micro-watershed

Fig. 17 Available copper map of Madapura micro-watershed

Fig. 18 Available manganese map of Madapura micro-watershed

Fig. 19 Available zinc map of Madapura micro-watershed

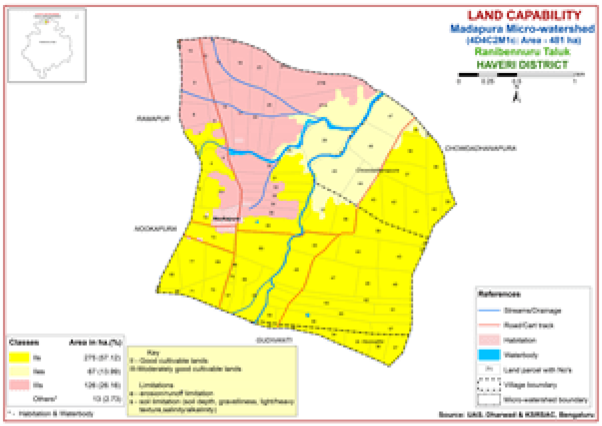

Fig. 20 Land capability classification in Madapura micr-waterhsed

Land capability classification

The classification of land capability is determined by matching the characteristics of soil units outlined in Table 1. The mapping units and their extent within the watershed, along with their assigned land capability classification presented in figure 20. Within the Madapura micro-watershed, the 8 soil mapping units are categorized into two subclasses based on the predominant limitations within each capability class. Additionally, two broader land capability classes have been identified based on a combination of soil characteristics, external land features and environmental factors. Within the micro-watershed, approximately 342 ha (71.11%) are classified as good cultivable land. This includes two sub-classes: 275 ha (57.12%) with erosion or runoff limitations and 67 ha (13.99%) with soil depth, gravelliness, light or heavy texture, salinity or alkalinity, in addition to erosion or runoff limitations. The remaining area 126 ha (26.16 %) categorised under III land capability class (moderately good cultivable lands) with erosion or runoff limitation. Similar findings were obtained by Hegde *et al*. (2021) in soils of Yaadhalli-1 micro-watershed of Yadagir district and Basavaraj *et al*. (2023) in soils of Dabarabad sub-watershed of Kalaburagi district.

Conclusion

The Land Resource Inventory (LRI) database presents a comprehensive overview of various soil types, their distribution, classifications, characteristics and potential uses. This information is visually represented through maps, atlases and tables. It highlights areas facing specific challenges, such as soil degradation or water conservation needs and identifies regions suitable for various types of crops, including both annual and perennial varieties. Additionally, it helps assess nutrient levels in different areas, facilitating the creation of soil health cards for individual plots of land. Moreover, the LRI database assists in crafting land use plans tailored to sub-watersheds, aiming for sustainable agricultural growth while preserving ecological balance. By providing real-time advice to farmers and aiding decision-making on land use, this database contributes to the protection and management of natural resources.

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