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Advance tools and techniques in land resources inventory and characterization in tropical ecosystem: A review

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Abstract

Sustainable management of land resources is the major challenge in the 21st Century for the agricultural scientists, planners, administrators and farmers to meet the ever increasing food grain requirements for the present and future generations. An intimate knowledge on location, extent, spatial distribution, their characteristics, classification, potentials and problems of land resources is a prerequisite for developing rational land use planning. Soil is of the important component of land resources and its inventory and characterization provides an insight into the potentialities and limitation of soil for it's effectively utilization. Modern tools such as satellite remote sensing, Geographic Information System (GIS) and Global Positioning System (GPS) providing a new dimension in inventory, characterization, monitor and management of land resources for their effective use. Remote sensing techniques have reduced field work to a considerable extent and soil boundaries are more precisely delineated than in conventional methods. The review reveals that advance tools like remote sensing and GIS have immense potential in effective for mapping and characterizing of land resources.

Keywords: GIS, terrain characterization, land resource inventory, land degradation, land evaluation, remote sensing

1. Introduction

The sustainable productivity of land resources considered being the basis of all living beings; therefore, management, conservation and development of these resources are the most important aspects. After green revolution In India, food production increased from about 51 MT in1950 to about 272 MT in 2015-16 (Dhillon *et al.*, 2020) [27]. In order to sustain developmental processes in the long-term, it is necessary to have a judicious allocation of land for various activities according to its sustainability and capability (Bajpai, 2013) [5]. The continuous use, misuse and exploitation of land resources have resulted in its degradation and destruction. Soil resource information plays a critical role in the management of land resources. For optimum utilization available land resource on a sustainable basis, maintain the present level of soil productivity and to meet the demand of future, management of soil resources on scientific principal is very important. So the reliable and timely available of information on soils regarding their nature, extent and spatial distribution along with their potential and limitation assumes greater significance. Characterization and mapping of soils, developing rational and scientific criteria for land evaluation and interpretation of soils for multifarious land uses assumes greater importance (Rossiter, 1996) [83]. It is the need of hour to increase food supplies faster than the growth of the population (Davidson *et al.*, 1992) [23]. To steer these agricultural achievements towards the path of evergreen revolution, there is a need to blend the traditional knowledge with frontier technologies like remote sensing, GIS and GPS. These advance geospatial tools and techniques found to be more efficient and economical than conventional survey in inventory, mapping and characterization of land resources (Strahler and Jupp, 1990; Thilagam and Sivasmy, 2013) [107, 110]. India is blessed with a wide range of soils, geology, topography, physiography, and climate of tropical to subtropical.

India is considered as a museum of soil resources as 9 out of 12 soil orders, which describe the soils of the planet earth occur in India. In view of these endowments India possess a unique environment supporting a wide range of crops. Soil resource inventory provides an insight into the potentialities and limitation of soil for its effective use and management. Though conventional soil surveys were providing information on soils they are subjective, time consuming and laborious. Remote sensing techniques have significantly contributed for speeding up conventional soil survey programmes. In conventional approach approximately 80% of total work requires extensive field traverses in identification of soil types and mapping their boundaries and 20% in studying soil profiles, topographical features etc. Study of potential and problems of soils through the systemic soil resource inventory and objective specific interpretation of soil properties and their parameters are essential to develop suitable land use plans (Sehgal, 1989, Cronin *et al.*, 2009) [91, 20]. In recent years, the advancement in the field of geospatial technologies has become an important tool in land resource inventory so considerable field work with respect to locate soil types and boundaries is reduced owing to its synoptic view. The rapid advancing geospatial technologies have revolutionized the land resources mapping and generation of spatial databases on a regular basis for better mapping, management and implementation of various plans more efficiently at different levels (Maji *et al.*, 2001, Reddy *et al.*, 2017, 2017a) [46, 78, 80]. The analysis of the land resources data in GIS environment is essential and it became a powerful tool and it has a strong visual impact (Meyer and turner, 1992; Beek, 2000; Jayanti, 2013) [53, 7, 37].

2. Advance tools and techniques in characterization of land resources

Land resource information plays a key role in the management of natural resources. Management of soil resources on scientific principles is essential to maintain the present level of soil productivity as well as soil fertility and to prevent soil/land degradation. Use of remote sensing data in soil survey and mapping received appreciation during early 1980's in India (Velayutham, 1999) [115]. Advancement in space and information technology especially in the field of remote sensing has become an important tool in land resource inventory. The remote sensing technology is found to be more efficient and economical than conventional survey (Somasundaram *et al.*, 2000) [102]. Landsat-MSS/TM, SPOT and IRS - LISS-I / II /III etc., are being employed to map soils at different scales ranging from 1:250,000 to 1:50,000. The SPOT and IRS-PAN data offered stereo capability, which has improved the soil mapping efforts (Manchanda *et al.*, 2002) [48]. The soil information so generated is interpreted for various purposes like land capability classification, land irrigability assessment, crop suitability studies, management of watersheds, prioritization of watersheds etc. (Ali and Kotb, 2010) [2]. GIS is a powerful and sophisticated tool for displaying and analysing spatial relationships between geographic phenomena in the form of vectors and images. In recent years, thematic mapping has undergone a revolution as the result of advances in GIS. Integration of remote sensing within a GIS database can decrease the cost, reduce the time and increase the detailed information gathered for soil survey (Burrough *et al.*, 1986; Lillesand & Kiefer, 1987; Strahler *et al.*, 1990; Wilkie & Finn, 1996; Chilar *et al.*, 2000; Dewitte *et al.*, 2012) [15, 43, 107, 120, 26]. Characterization and evaluation of land resources in Khapri village of Nagpur district of Maharashtra has been carried out using IRS-P6 LISS-IV and IRS-ID PAN sharpened LISS-III data and GIS coupled with field survey (Nagaraju *et al.*, 2010) [56]. Reddy *et al.*, (2004) [74, 81] characterized the land resources around Mohgaon and Degma villages in Hingna tehsil, Nagpur district, India and reported extremely shallow and well drained soils (Lithic Ustorthents) on plateau summits and isolated mounds and deep soils (Vertic Haplustepts) in the main valley-floor. The soil-physiographic relationship has been developed to understand the landform processes and soil properties. In soil surveys, from the typifying pedons, horizon-wise soil samples were collected, processed and analysed for different physical and chemical properties following standard procedures (Black *et al.*, 1965; Sehgal *et al.*, 1989b; Soil Survey Staff 2000, 2010) [11, 91, 99]. Many workers used advance tools and techniques like remote sensing satellite data and GIS in Inventory and characterization of land resources in tropical ecosystem and they are summarised in Table 1.

With the technological advancements in remote sensing in terms of spatial, spectral, radiometric and temporal resolutions of different sensors and the availability of data in digital format, several studies have been demonstrated use of remote sensing data in characterization and mapping of soils at large scale (Srivastava and Saxena 2004; Solanke *et al.*, 2005; Shukla *et al.*, 2009) [105, 101, 96]. Utility of satellite data in inventory and characterization of land resources at different scales are summarised in Table 2.

3. Role of remote sensing inventory of land resources

Before launch of Landsat-1 in 1972 aerial photographs were being used as a remote sensing tool for soil mapping. Subsequently satellite data in both digital and analogue forms have been utilized for preparing small scale soil resource maps. During mid-eighties Landsat thematic maps and IRS-LISS II data were used by the scientists to map soils at 1:50,000 scale. At this scale soil could be delineated at association of soil series or family level. Indian remote sensing satellites (IRS IA, IB, IC and ID) provide state-of-the art database for natural resource inventories. Many researchers have been conducted to explore the potential of LISS I and LISS II data for soil resource mapping both at 1:250,000 and 1:50,000 scale (Manchanda *et al.*, 2002) [48]. Dhinwa *et al.*, 1992) [28] made an attempt to study the changes in the land use pattern of Bharatpur district with multi date remote sensing data of Landsat TM 1986 and IRS LISS-II data of 1989, and land use maps on 1:50,000 scale were prepared by employing ARC/INFO GIS package. Maharana and Singh (2001) [45] characterized degraded landforms of Arid Western Rajasthan using IRS-IB imagery of February 1995.

4 Different Stages in Land resource inventory and characterization

4.1. Base map generation

Base map generation is the important stage in land resource inventory and characterization. Recent advances in remote sensing, GIS technologies and availability of high resolution Digital Elevation Models (DEM) have made paradigm shift in generation of base maps. Soil mapping of parts of Karnataka, Maharashtra and Andhra Pradesh on 1:1 million scale by Mirajkar and Srinivasan (1975) [54] was perhaps the first published Indian work based on Landsat image interpretation. Based on visual interpretation techniques soil association maps have been prepared in India (Martin and Saha, 2007; Dewitte *et al.*, 2012; Mandal *et al.*, 2010; Das *et al.*, 2014) [50, 26, 49, 22]. Sehgal and Sharma (1988) [92] generated soil map of Punjab using remote sensing technique and they opined that it was eight times more efficient than conventional method. Chatterjee *et al.*,

(1990) [16] used Landsat imagery to prepare soil map showing good soil physiography relationship for a part of Mahanadi Delta area. Landsat - IV MSS data was used to identify and delineate soils in a part of Dibrugarh district of Assam. The study revealed that the remote sensing techniques could be employed successfully to prepare small scale physiographic soil resource map depicting association of soil families (Sen *et al*., 1992) [93]. With the availability of PAN data with 5.8m spatial resolution from IRS- IC/ID, soil resource maps at 1:25,000 or larger scale has been attempted using PAN merged LISS-III data. The high resolution IKONOS data has the potential for farm level soil mapping with the scale of > 1:10,000 (Manchanda *et al*., 2002) [48]. Sarkar *et al.*, (2006) [88] used IRS-1D LISS-III fused with PAN data on 1:12,500 scales in Patloinala micro-watershed of Purulia district, West Bengal to prepare the physiographic map of the area.

4.2 Satellite data interpretation

Satellite data of various resolutions could be used in terrain characterization, land use/land cover analysis, delineation of landforms and land resource inventory and mapping. Satellite data interpretation is the processes of detection, identification, description and assessment of significant of an object and pattern available in the image. The method of interpretation may be either visual or digital or combination of both. Both the interpretation techniques have merits and demerits, however, in landform delineation for inventory and mapping of land resources, many authored adopted visual interpretation techniques (Reddy *et al*., 2002, 2003; Nagaraju *et al*., 2011; Reddy *et al*., 2012, Nasre *et al*., 2013) [76, 73, 59, 77, 60].

4.3 Terrain characterization

Traditionally, landform mapping was done by visual interpreting aerial photographs (Dent & Young, 1981) [25]. The advent of remote sensing technology has paved the way to gather information about the earth’s resources more accurately (Strahler *et al* 1964; Karale *et al*., 1988; Mc Bratney *et al*., 2000; Reddy *et al*., 2004; Velmurugan and Carlos, 2009) [106, 38, 74, 81, 116]. Satellite data with toposheets are used for characterizing physiographic variation in terms of slope, aspects and land cover for delineating the soil boundary (Speight *et al*., 1990; Mukerjee 1982) [103, 55]. The detailed analysis of landforms is an important aspect of any environmental or resource analysis and planning (Bell *et al*., 1994;, Blarzcsynski, 1997; Reddy *et al*., 1999; Wilson and Gallant 2000; Reddy *et al*., 2001; Reddy and Maji, 2003; Hengl and Reuter, 2008) [8, 12, 79, 121, 75, 73, 34]. Terrain attributes derived from digital elevation models and satellite imagery has been used to aid the delineation of soil boundaries. The utility of high resolution satellite data and GIS technologies supplemented with ground truth is found to be the most efficient and effective way in terrain characterization and soil resource inventory in a topo sequence and established soil-landform relationship to characterize the landform and soil properties. (Nagaraju *et al*., 2011; Reddy *et al*., 2012; Nasre *et al*., 2013) [59, 77, 60]. Knowledge of terrain morphology also is essential for any land-management endeavours that affect or disturb the surface of the land (Chorley *et al*., 1985; Blarzcsynski *et al*., 1997) [19, 12].

4.4 Land use/land cover analysis

Ghosh *et al*., (1996) [33] compared land-use/land cover change of Pranmati watershed between 1963 and 1993 using remote sensing data and GIS software. Land use land cover classes in Gaur Ganga Watershed in Uttaranchal state was analysed by Bisht and Kothyari (2001) [10] using toposheet and visual interpretation of Landsat 5 TM image bands 2, 3 and 4 using Simple Macro Language (SML) in ARC/ INFO software. Loss of vegetation cover was estimated to be 5.07 and 8.1 percent during 1963-1996 and 1986 -1996, respectively. Singh *et al*., (2004) [97] observed the changes in Mangrove forest cover from 1994-2001 by using IRSI B LISS II and IRS-ID LISS III data and found an increase of 44 percent Mangrove vegetation in coastline forest of Goa. Mahajan *et al*., (2001) [44] carried out the topographic analysis of Ashwani-Khad watershed, Himachal Pradesh using IRS-ID satellite data of 1999 and GIS. Potdar *et al*., (2003) [67] prepared the land use/land cover map of Nanda-Khairi watershed, Nagpur district, Maharashtra on 1:50000 scale using IRS-1C, LISS-III data of two seasons (March, 2000 and November, 2000). Nasre *et al*., (2013) [60] prepared land use/land cover map of Karanji watershed, Yavatmal district, Maharashtra using remote sensing data and assessed for their sustainable use. Nagaraju *et al*., (2014) [58] delineated distinct land use/land cover classes using Cartosat-1 merged IRS-P6 LISS-IV data in Savli village Wardha district. In Mohari watershed, the spatio-temporal changes and land transformation processes over a period of 25 years (1980-81 to 2005-06) shows that area under rain fed rice-fallow system has been reduced from 31.0 to 14.1 percent. At the same time area under irrigated rice-fallow system has been increased 12.3 to 32.4 percent (Reddy *et al*., 2003) [73]. Nagaraju *et al*., (2015) [57] prepared land use/land cover map in Saraswati watershed, Buldhana district, Maharashtra based on FCC of IRS-P6 LISS-III data and used in land resource inventory and mapping.

4.5 Delineation of Landforms

A detailed landform maps could be generated through analysis of topographical sheets, satellite data and DEMs, which can form as base map in soil resource inventory and mapping. Maji *et al*., (2005) [47] used IRS-1C LISS-III data and identified summit crest, escarpment, isolated mounds, denuded plateau, foot slopes, upper piedmont, lower piedmont and narrow valley floor as dominant landforms in basaltic terrain in subhumid tropics of Central India. Solanke *et al*., (2005) [101] prepared physiography map of Ganeshpur micro-watershed of Nagpur district, Maharashtra, based on interpretation of PAN+LISS III merged data of April 2002 and subsequent ground truth verification. Sarkar *et al*., (2006) [88] used IRS-1D LISS-III fused with PAN data on 1:12,500 scale in Patloinala microwatershed of Purulia district, West Bengal to prepare the physiography map of the area. Martin and Saha (2007) [50] used RS and GIS techniques for the preparation of physiography map of Ason river watershed using LANDSAT TM data in conjunction with SOI toposheet (1:50,000 scale) and delineated physiographic units as hills, piedmont, valley, side slope and alluvial plain. Kashiwar *et al*., (2009) [39] visually interpreted FCC of IRS-1D LISS-III and PAN sharpened LISS-III in conjunction with SOI toposheet in Salai watershed of Nagpur district, Maharashtra. Ardak *et al*., (2010) [3] used IRS-P6 LISS-lV and IRS-1D PAN sharpened LISS-lll (1:12500 scale) data and GIS coupled with field survey for characterization and evaluation of land resources in Khapri village of Nagpur district of Maharashtra. Nasre *et al*., (2013) [60] interpreted IRS-P6 LISS-IV and LISS-III (1:50000 scale) satellite data of two seasons to prepare physiography and soil map of Karanji watershed of Yavatmal district, Maharashtra for identification of major physiographic units. Bhandari *et al*., (2014) [9] characterized the physiography of Tons watershed, Dehradun. Nagaraju *et al*., (2014) [58] used a high-resolution DEM with a posting of 10 m generated from a Cartosat-1 stereo pair to derive terrain attributes. Sahu *et al.*, (2015) [86] interpreted IRS-P6 LISS-IV with Digital Elevation Model (DEM) derived from Cartosat-1 stereo data of two seasons in Miniwada Panchyat, Nagpur district on basaltic terrain of Central India for the identification of major landforms. Nagaraju *et al.*, (2015) [57] studied the soils of Saraswati watershed in Buldhana district of Maharashtra and identified instinct physiographic units. The detailed landform maps depicts spatial variations of terrain features, which in turn, immensely help in inventory and mapping the soils and finalize the soil mapping units in the region.

4.6 Land Resource Inventory and Mapping

Soil is the base for every production system and mapping of their properties, extent and spatial distribution at watershed level is extremely important for developing land use (Sarkar *et al.*, 2006) [88]. Many authors have reported that the potential of satellite remote sensing and GIS as promising tools in soil resource inventory and mapping (Srivastava and Saxena 2004; Reddy *et al.*, 2008) [105]. Remote sensing data in conjunction with ancillary data provide the best alternative in delineation of distinct soil mapping units (Hora, 2010) [35]. The use of multi-temporal remote sensing databases complemented with terrain information was found to be very essential for deriving reliable soil categorization (Dobos *et al.*, 2000, McBratney *et al.*, 2000) [29, 51]. GPS with high resolution data during the soil survey provides a wide array of uses as locating position for accurate and detailed soil mapping, recording the location of profile description sites and locating boundaries of recently altered areas (Longley *et al.*, 1999) [122].

4.7 Laboratory analysis

Sankar *et al.*, (2010) [87] carried out detailed soil survey (1:5000 scale) of Kutturavupatti village (573 ha) in Sivagangai district of Tamil Nadu during 2005-06 to delineate the area for agricultural suitability. Aher & Sharma, (2014) [1] studied morphometric characterization of Gagar watershed in Kumaon region of Uttarakhand and observed that there was a decrease in stream frequency with increase in stream order. Patil *et al.*, (2014) [66] studied changes in soil organic carbon stock as an effect of land use system in Gondia district of Maharashtra and observed that soil carbon stock at 0-30 cm. The Soil pH varied from 7.1 to 8.6with an average of 7.8 and the relatively high pH of the soils might be due to the presence of high degree of base saturation in soils of Tonk district of Rajasthan (Meena *et al.*, 2006; Thangasamy *et al.*, 2005) [52, 109]. Walia and Rao (1996) [119] noticed that the EC of soils in Bundelkhand watershed of Uttar Pradesh was low (less than 0.1 dSm-1) suggesting very low amount of soluble salts. The EC of Vertisols and Inceptisols developed from different parent materials were normal with very low (<1 dSm-1) salt content (Chinchmalatpure *et al.*, 1998) [118]. The soils are based saturated and high in CEC: clay ratio (0.65 to 0.75) and classified as Typic/Chromic Haplusterts. (Sahu *et al.*, 2001) [85].

5. Interpretation of land resource data

The land resources data generated through systematic surveys could be effectively used and analysed using advance tools like GIS in assessment of soil fertility, land degradation, land evaluation and land use planning.

5.1 Soil fertility assessment

Prabhavathi *et al.*, (2013) [68] carried out assessment of the soil fertility status in a watershed of Semi-Arid Tropics in Southern India for efficient soil management and cropping systems for sustainable yields. Ram *et al.*, (2014) [72] carried out a rapid reconnaissance soil survey of Markapurmandal of Prakasam district of Andhra Pradesh and found that the soils of hill side slope and undulating pediments developed over quartzite, sandstone and shale complex was shallow to moderately deep, brown (7.5 YR 4/4) to dark brown (7.5 YR 3/4) in colour, well drained with poor fertility.

5.2 Land degradation

Soil erosion has been the hindrance of ecological development in the locality, which has instigated extra care of the India Government and researchers (Sharma, 2010; Nagaraju *et al.*, 2011; Nasre *et al.*, 2013; Shit *et al.*, 2015) [94, 59, 60, 95]. Awkwardly, consistent or economically feasible means of measuring soil erosion is missing in these areas. There is a growing demand for envisaging yearly soil loss from erosion and portraying the geographical distribution of soil erosion to make available a technical basis for soil management planning (Prasannakumar *et al.*, 2012) [70]. Remote Sensing imagery provides information about various land utilization types in spatial format which is vital for erosion assessment (Saha and Singh 1991; Pandey *et al.*, 1992) [84, 62]. The potential utility of remote sensing data has been well recognized in mapping and assessing land attributes such as physiography, soils, land use/land cover (Solanke *et al.*, 2005; Sarkar *et al.*, 2006) [101, 88] and integration of these attributes to compute soil erosion (Potdar *et al.*, 2003) [67]. The rapid evolution in satellite remote sensing in terms of spatial, spectral, radiometric and temporal resolutions of different sensors, the availability of data in digital format and spatial analysis in GIS using an integrated approach has made possible the quantitative assessment of soil erosion and mapping (Skidmore *et al.*, 1997) [98]. Satellite remote sensing provides scientific input for faster and precise mapping of natural resources (Saxena *et al.*, 2000; Bodhankar *et al.*, 2002) [89, 13] and degraded/ eroded lands (Skidmore *et al.*, 1997) [98]. Tiwari (2004) [111] suggested bio-engineering measures in high to very high risk of soil erosion area to conserve surface runoff and thus reducing soil loss for enhancing vegetation cover and improving soil productivity.

5.3 Land Evaluation

Land evaluation is systematic assessment of soil and land for determining their capability and suitability under a set of climate, management practices with socioeconomic status of land holders for developing/formulating optimum land use plan. The main objective of the land evaluation prediction of the inherent capacity of a land unit to support a specific land use for a long period of time without deterioration, in order to minimize the socioeconomic and environmental costs (De la Rosa, 2000; Das *et al.*, 2014) [22]. Gabhane *et al.*, (2006) [32] evaluated the land for land use planning of micro-watershed in Vidarbha region of Maharashtra. Panhalkar Sachin, (2011) [63] evaluated the soils of Dudhganga basin of Southern Maharashtra and grouped the soils in to class II, III, IV and VI using RS and GIS tools. Van Vliet *et al.*, (1979) [114] stated that land capability classes can provide a reasonable prediction of potential yield. Gabhane *et al.*, (2006) [32] evaluated the land for land use planning of micro-watershed in Vidarbha region of Maharashtra. The study area was classified into land capability classes II, III, IV and VI. Tripathi *et al.*, (2006) [113] worked in Kiar-Nagali microwatershed in North-West Himalaya and grouped the soils into VIIIe, VIIes, IIIes and IIe land capability sub-classes. Panhalkar and Sachin, (2011) [63] evaluated the soils of

Dudhganga basin of Southern Maharashtra and grouped the soils in to class II, III, IV and VI using RS and GIS tools. Ram *et al.*, (2014) [72] carried out a rapid reconnaissance soil survey of Markapur mandal of Prakasam district of Andhra Pradesh and found that the soils of undulating pediments and hill side slope were grouped under land capability class IV and VII, whereas, soils of pediplains and stream bank were placed under land capability class II and III, respectively. Bhandari *et al.*, (2014) [9] classified the area in the watershed of Tons river in Dehradun into land capability classes II, III, IV and VI using RS and GIS.

5.4 Land Use Planning

Land use planning (LUP) as the systematic assessment of the potential of land resources, land use alternatives and socio-economic conditions in order to adopt the best land use options (FAO, 1993) [30]. Land use planning is important policy oriented activity to mitigate the negative effect of land use and to enhance the efficient use of resource with minimum impact of future generation (FAO, 1993, Patil *et al.*, 2015) [30, 65]. Land use decisions are made at the farm level, influenced by policy decisions at the national level, and to a lesser extent at the regional and sub-regional levels (Schipper, 1996) [90]. Land evaluation has always been considered a core importance of LUP. LUP can be applied at three broad levels, namely, national, district and local (FAO, 1993; Roetter *et al.*, 2005; Baja *et al.*, 2007) [30, 82, 4]. Tagore and Shah (2013) [108] studied land use planning using remote sensing and GIS of Bhoj wetland. Pradeep *et al.*, (2014) [69] studied land use planning in the area of Usilampatti Block in Madurai district and observed that major part of the study area is agricultural land. The tool can be use as stand-alone program to develop a land use plan to different land use types, based on set of production of scenarios and preferences (Klingebiel and Montgomery, 1961; Van Vliet *et al.*, 1979; Branch *et al.*, 1998; Yeh *et al.*, 1999; Tripathi *et al.*, 2006; Ram *et al.*, 2014; Bhandari *et al.*, 2014; Koyel, 2014; Nguyen, *et al.*, 2015) [40, 114, 14, 122, 113, 72, 41, 9].

6. Discussion

Inventory and characterization of land resources is prerequisite not only to understand their nature, extent, potential and constraints, but also plan towards sustained agricultural production to meet the challenges of increasing population and sustained agricultural production. The review shows that modern tools such as satellite remote sensing, GPS and GIS have immense potential to map and characterize land resources more efficiently and in a cost-effective manner and manage for their effective utilization. Especially remote sensing techniques have reduced the field work to a considerable extent and soil boundaries are more precisely delineated than in conventional methods. The review also shows that the advance tools of remote sensing and GIS are highly proven technologies, which are effective for mapping and characterizing land resources. The availability of high resolution satellite data like IRS-LISS IV, Sentinal 1, 2, IKONOS data in conjunction with digital elevation models derived from Cartosat-I, II, have immense potential for large scale and farm level land resource mapping at a scale 1:10,000 or even larger for implementation of various agricultural plans and land resource conservation plans at micro-level.

7. Conclusion

The review strongly reveals that inventory of the land resource base is a prerequisite not only to understand their potential and constraints, but also plan towards sustained agricultural production. The soil resource maps serve as a base for monitoring changes in soil quality. Remote sensing and GIS techniques greatly enhance our ability to map and characterize land resources more efficiently and in a cost-effective manner. The remote sensing technology is found to be more efficient and economical than conventional survey in the present day situation. The use of multi-temporal remote sensing databases complemented with terrain information was found to be very essential for deriving reliable soil categorization. The land resource data could be effectively used for land evaluation and prediction of the inherent capacity of a land unit to support a specific land use for a long period of time without deterioration. Digital land resource information in GIS environment along with ancillary data is a powerful tool to assess soil fertility, land degradation, land evaluation and land use planning.

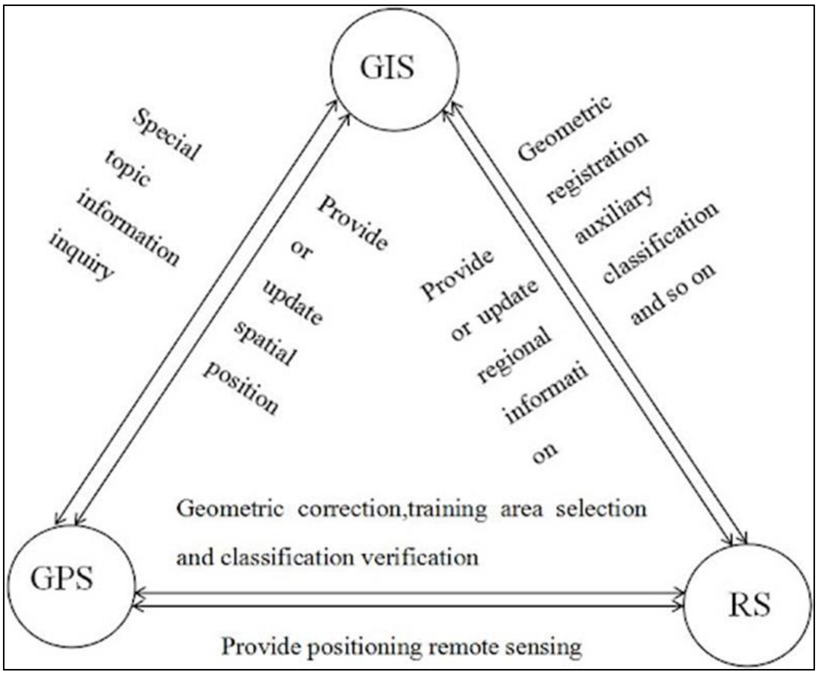

Fig 1: Interaction and Integration of Remote sensing, GPS & GIS

Table 1: Remote sensing and GIS applications in inventory and characterization of land resources in tropical ecosystem

S. No	Satellite	Resolution (meters)	Study Area	Purpose	Reference
1	LANDSAT- VIII	30	Dharva, Yavatmal, Maharashtra, India	Land Evaluation Land	Patangray *et al.*, (2017) [64]
2	LISS - 3 & 4	23.5 & 5.8	Bareli watershed, Shivni Madhya Pradesh, India	Evaluation, Land quality	Ingale *et al.*, (2017) [36]
3	DEM, ASTER	30	Subarnarekha river basin, West Bengal, India	Soil erosion	Kumar *et al.*, (2016)
4	IRS-P6 LISS III and LISS-IV	23.5 and 5.8	Meghalaya block	Characteriza- tion and evaluation of land resources	Das *et al.*, (2014) [22]
5	IRS-P6 LISS IV	5.8	Borgaon Manju watershed, Maharashtra, India	Soil Resource inventory	Reddy *et al.*, (2012) [77]
6	LANDSAT-7	30	Warora Tehsil of Chandrapur District of Maharashtra, India	Soil erosion	Nagaraju *et al.*, (2011) [59]
7	Resourcesat-1+ Cartosat-1	2.5	Mohammadabad village Andhra Pradesh, India	Soil fertility assessment	Wadodkar and Ravishakar (2011) [118]
8	WorldView-2	0.46(PAN) 1.84 (NIR)	Nawalparasi district (Nepal)	Precision Agriculture	Barala (2010) [6]
9	IKONOS	1 (PAN) 4 (NIR)	Bhopalpur village Uttar Pradesh, India	Village mapping	Praveen*et al.*, (2010) [71]
10	LISS-III	5.8	Khapri village of Nagpur district, Maharashtra, India	Land resources evaluation	Ardak *et al.*, (2010) [3]
11	Cartosat-1	2.5	Sheo tehsil, Rajasthan, India	Demarcation of watershed	Tomar and Singh (2012) [112]
12	IRS-P6, LISS III, LISS IV	5.8	Bandu watershed West Bengal, India	Watershed prioritization	Das *et al.*, (2012) [21]
13	PAN+LISS III	5.8	Pavagada tehsil, Karnataka, India	Resource management	Vittala*et al.*, (2010) [117]

Table 2: Utility of satellite data in inventory and characterization of land resources at different scales

Scale	Sensor	Soil classification	Useful for	Resolution (meter)
1:250000	LANDSAT-MSS IRS- LISS-I, WIFS	Subgroup, families and their association	Regional level	75.5
1:50000	IRS-LISS-II/III LANDSAT-TM SPOT	Soil series and their association	State level	36.25
1:25000	IRS-IC/ID (PAN + LISS-III MERGED DATA	Soil series and their association	Taluka level	23.5
1:8000 or larger	LISS-4/ CARTOSAT	Types and phase	Village level	5.8

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