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Geospatial modeling in assessment of biophysical resources for sustainable land resource management

G. P. OBI REDDY[1*], DIPAK SARKAR[1], JAGDISH PRASAD[1] & V. RAMAMURTHY[2]

[1]National Bureau of Soil Survey & Land Use Planning, Amravati Road, Nagpur 440 033, India

[2]National Bureau of Soil Survey & Land Use Planning, Regional Centre, Bangalore 560 024, India

Abstract: In this study an attempt has been made to delineate distinct biophysical resource units, assess human carrying capacity and prioritize the areas through geospatial modeling in Geographic Information System (GIS) for sustainable management of land resource in Tirora tehsil of Gondia district, eastern Maharashtra, India. Distinct biophysical resource units have been delineated based on the geospatial modeling of biophysical parameters with appropriate weights in GIS. The analysis of human carrying capacity at village level shows that about 47 villages were under deficit and 75 villages under surplus in the availability of calories in the year 2001. The biophysical resource units and human carrying capacity units were integrated in GIS through geospatial modeling to prioritize the distinct areas. The results indicate that very high priority unit occupies 19.15 per cent area of the tehsil, where proper resource management measures need be taken up on priority basis. The study demonstrates the potential of geospatial modeling in prioritization of areas for sustainable management of land resources.

Resumen: En este estudio se intentó delinear unidades distintas de recursos biofísicos, evaluar la capacidad de carga humana y priorizar las áreas, usando modelación geoespacial en un Sistema de Información Geográfica (SIG) para el manejo sostenible de los recursos de la tierra en el tehsil Tirora del distrito Gondia, Maharashtra oriental, India. Se delinearon distintas unidades de recursos biofísicos con base en la modelación geoespacial de parámetros biofísicos con los pesos apropiados en un SIG. El análisis de la capacidad de carga humana a nivel de las aldeas mostró que alrededor de 47 de ellas estuvieron en condiciones de déficit, mientras que 75 tuvieron un superávit en la disponibilidad de calorías en el año 2001. Las unidades de recursos biofísicos y la capacidad de carga humana fueron integradas en un SIG por medio de modelación geoespacial para priorizar las distintas áreas. Los resultados indican que las unidades de alta prioridad ocupan 19.15% del área del tehsil, en el que es necesario tomar medidas adecuadas de manejo de recursos sobre una base de prioridades. El estudio demuestra el potencial de la modelación geoespacial para la priorización de áreas para el manejo sostenible de los recursos de la tierra.

Resumo: Neste estudo foi feita uma tentativa para delimitar distintas unidades de recursos biofísicos, avaliar a capacidade de suporte humano e priorizar as áreas por meio da modelação geoespacial usando um Sistema de Informação Geográfica (GIS) para a gestão sustentável dos recursos do solo em Tirora tehsil, no distrito de Gondia, a leste de Maharashtra, Índia. Com base na modelação geoespacial dos parâmetros biofísicos, com pesos adequados em GIS, foram delimitadas unidades de recursos biofísicos distintas. A análise da capacidade de suporte humano ao nível da aldeia mostra que cerca de 47 aldeias se apresentam deficitárias e

Corresponding Author; e-mail: obireddygp@gmail.com

75 aldeias com excedente na disponibilidade de calorias no ano de 2001. As unidades de recursos biofísicos e a capacidade de carga humana foram integrados no SIG através de modelação geoespacial para priorizar as áreas distintas. Os resultados indicam que as unidades de muito elevada prioridade ocupam 19,15 por cento da área de tehsil, onde as medidas de gestão de recursos próprios são necessárias numa base prioritária. O estudo demonstra o potencial da modelação geoespacial na priorização de áreas para a gestão sustentável dos recursos terrestres.

Key words: Biophysical resource units, human carrying capacity, GIS, geospatial modeling and land resources.

Introduction

Many researchers have attempted to link the human activities with environment (Gray & Moseley 2005; Turner & Ali 1996) and sustainability (Musacchio 2009; Wu 2006). Sustainability is a necessary and sufficient condition for a population to be at or below any carrying capacity. Assessment of sustainability at lower administrative unit is important and has practical application, however, the literature indicates that small regions like villages have been given less priority in assessing the sustainability (Graymore 2005). To become sustainable, the villages must live equitably within the stock of land resources and sustainable carrying capacity of the region's ecosystems. To assess the sustainability in pragmatic way at village level, there is a need to develop geo-spatial database on land resources to evaluate biophysical resources and identify the priority areas for management of land resources.

Previous definitions of human carrying capacity have varied in context in the past few decades. Several researchers have attempted to illustrate human carrying capacity in order to provide a more robust model to estimate the size of the human population that the earth can support (Cohen 1995; Meyer & Ausubel 1999). In simple terms, Kirchner *et al.* (1985) defined human carrying capacity as maximum population can be sustained if there is not "degradation of the natural resource base". Carrying capacity is also often used as a management tool to identify thresholds beyond which irreversible and detrimental changes in the biophysical environment could occur. Komatsu *et al.* (2005) evaluated agricultural sustainability based on human carrying capacity in rural villages of Mongolia and China. The biophysical component relates primarily to the land resources, and recognizes that no biophysical system can withstand unlimited utilization of resources. However, in any sustainability studies, it is imperative to establish relevant temporal and spatial scales. The time scale that considered in the present study is human population, the availability of food production and demand, whereas, the spatial scale is obviously spatial pattern of biophysical land resources. Human carrying capacity depends on location, time, supply and consumption patterns and level of management of land resources.

The biophysical processes are interactions of climate, relief, landforms, water, soils and land use/land cover characteristics of the earth surface (Baban & Yusof 2002). Biophysical information, especially on productivity of an area, is one of the most crucial factors for activities ranging from monitoring ecosystems to decision making (Reeves *et al.* 2001). Remotely sensed data have been proven to be successful in mapping biophysical land units for vegetation and land cover types (Carrol 1996; Joshi *et al.* 2002; Kushwaha *et al.* 2010; Roy *et al.* 2002). The groundwater water regime is also viewed as an influencing parameter in biophysical characteristics of any region and depends on various terrain elements (Saraf & Choudhary 1998). Variability in crop production and meteorological parameters are critical factors affecting carrying capacity (Fearnside 1983, 1984). Characterization of land resources and generation of geospatial information on land resources and crop production at village administrative unit enable to assess human carrying capacity. However, in many cases it is difficult for the local administration to implement the resource management plans at a time in the entire tehsil. Hence, prioritization plays a key role in identification of critical areas based on the assessment of human carrying capacity in management of land resources on sustainable basis. Geospatial modeling in GIS enables to integrate the biophysical resources, crop production and consumption scenarios. In the study,

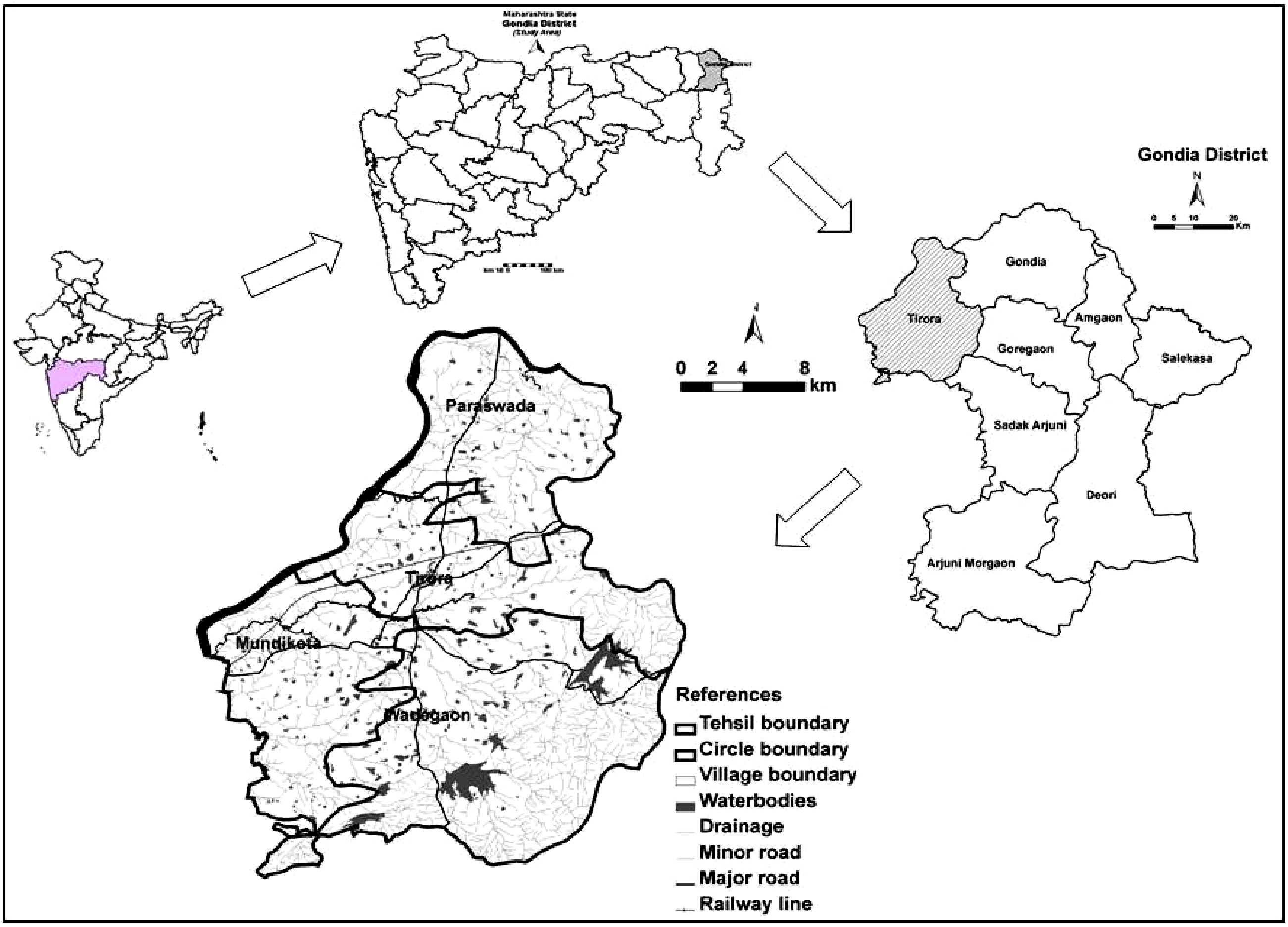

Fig.1. Location map of the study area.

an attempt has been made to delineate distinct biophysical resource units, assessment of human carrying capacity and to prioritize the areas through geospatial modeling in GIS for sustainable management of land resource in Tirora tehsil of Gondia district, eastern Maharashtra, India.

Materials and methods

Study area

The study area of Tirora tehsil is located in north-western part of Gondia district, Eastern Maharashtra, Central India and lies in between 21° 22' 03" to 21° 38' 09" N latitudes and 80° 00' 00" to 80° 21' 24" E longitudes with an area of about 626.0 km^2 (Fig. 1). The elevation of the tehsil ranges from 280 m to 620 m above mean sea level (MSL). Geologically, Gondia tehsil is having complex geological formations encompassing from Alluvium, Sakoli Group, Amgaon Gneissic complex and Tirodi Gneissic complex. The climate is hot sub-humid type with annual mean minimum and maximum temperature of 7.4 °C and 47.5 °C, respectively. The average annual rainfall of the tehsil is about 1557.8 mm.

Biophysical resources

The detailed methodology followed in the study has been shown in Fig. 2. Potential evapo-transpiration (PET) was estimated using Penman's method (Rao *et al.* 1971). The length of climatic moist period (CMP) was calculated using a climatic water balance program (Mandal *et al.* 1999; Thornthwaite & Mather 1955). Length of Growing Period (LGP) is defined as the period (in days) during the year, when precipitation exceeds half of the evapo-transpiration, plus a period required for evapo-transpiration up to 100 mm of water from excess precipitation stored in the soil profile (FAO 1996). LGP was estimated by combining CMP and soil available water capacity (AWC) raster maps in GIS. The slope map of the tehsil was generated

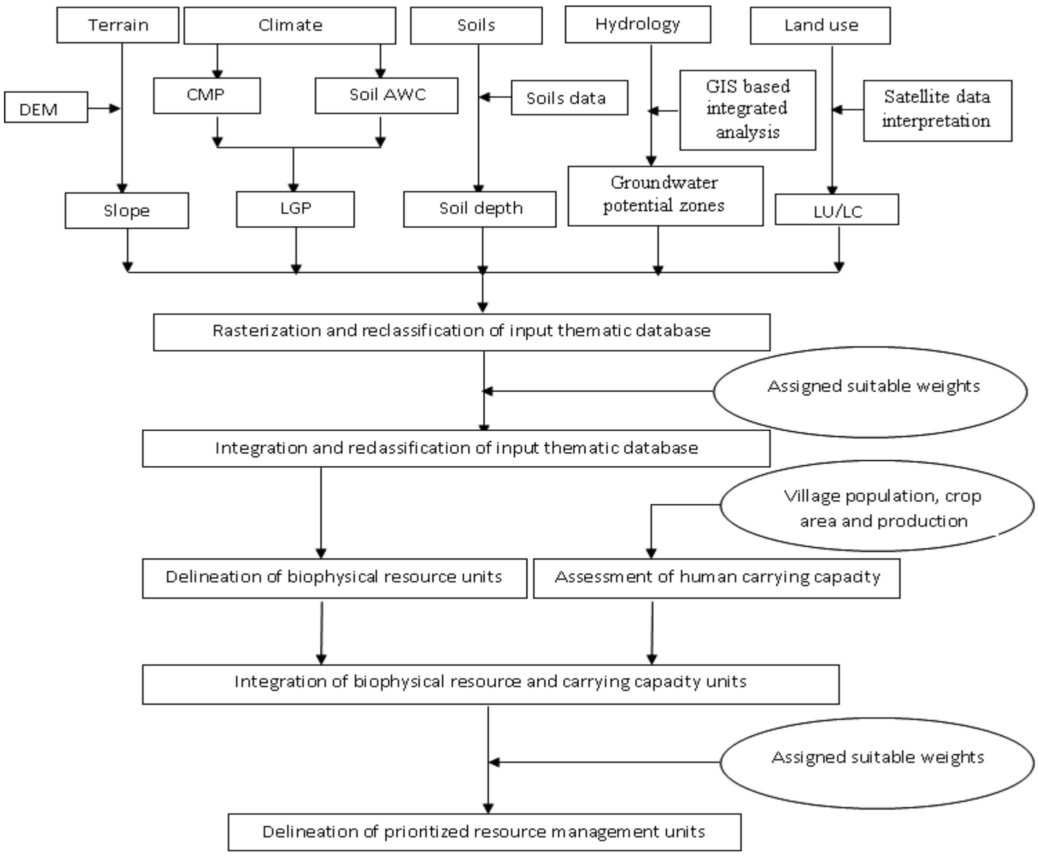

Fig. 2. Methodology flow chart in delineation of priority units.

from the Digital Elevation Model (DEM) using the standard in built algorithm in GIS based on contour values at 20 m interval obtained from Survey of India (SOI) toposheets. The IRS-ID LISS-III satellite data of November 8, 1999 and March 7, 2000 of the study area were geometrically corrected with the help of Survey of India (SOI) toposheets (1:50,000 scale) in Geomatica (*ver* 10.0) image analysis software. Visual interpretation techniques were followed in delineation of distinct landform units based on the tone, texture, shape, drainage pattern and differential erosion characteristics of the satellite data in conjunction with geological formations and land use/land cover parameters (Lillesand & Kiefer 2002). Adequate field checks were conducted for deriving information on landform units to establish the relationship between the image elements and landform unit characteristics.

The available information on the soils of the study area on 1:50,000 scale at series association level was used (Anonymous 1990). Using the reclassification technique in GIS soil depth and texture thematic maps were generated. Land capability was assessed by comparing the characteristics of a land mapping units with criteria set for each capability class (AIS & LUS 1971; Klingebiel & Montomery 1961). The factors considered in deciding irrigability classes were effective soil depth, texture, moisture holding capacity, soil salinity and alkalinity hazards, drainage, soil erosion, groundwater table and associated landform. The soil irrigability classes were worked out according to their limitation for sustained use under irrigation regardless of their location or the size of the individual areas (AIS & LUS 1971). The IRS-ID LISS-III satellite data for *kharif* (November 1999) and *rabi* (March 2000) seasons were digitally classified by adopting supervised classification algorithm in Geomatica software (PCI 2003) to generate various land use/land cover classes in *kharif* and *rabi* seasons, respectively. The two season land use/land cover maps were integrated using the 'union' option in GIS to generate the final land use/land cover map.

The remote sensing data in conjunction with ground truth information provides information on the geology, geomorphology, structural pattern and recharge conditions, which ultimately define the groundwater regime (Krishnamurthy *et al.*

1996). The lineament patterns in the study area have been mapped based on the analysis of satellite data and subsurface lithology, anomaly of drainage patterns and vegetation. Multi-criteria overlay analysis has been performed in GIS considering the slope, geological and landform units, drainage density, soil depth, lineament density and land use/land cover layers to delineate distinct groundwater potential zones (Krishnamurthy & Srinivas 1995). The input thematic layers have been assigned weightages based on the influence of each parameter in the integrated analysis. The collected field data on groundwater levels from six observatory wells in and around the tehsil from Central Ground Water Board (CGWB) for the period from the year 1990 to 2000 was used to validate the delineation of groundwater potential zones.

Biophysical resource units

The length of growing period, slope, soil depth, groundwater potentials zones and land use/land cover, land capability, land irrigability layers were converted into raster format and suitable weightages were assigned to each class in input layers in the scale 1 to 10 and integrated through geospatial modeling in GIS to delineate distinct biophysical resource units (Reddy & Maji 2004). Lower values in the generated biophysical resource map shows higher biophysical status and vice versa.

Human carrying capacity

The village-wise area under different crops for the year 2000 - 2001 and population for the year 2001 were collected, compiled and then linked to the villages of the tehsil in GIS to assess the human carrying capacity at village level using standard methodology (Singh & Dhillon 1984). Major crops (paddy, wheat, total pulses, total oilseeds and total fruits and vegetables), cultivated at village level were considered for analysis of human carrying capacity. Based on the area and productivity of the crop, the crop-wise total production was estimated and converted in terms of calories to find out the average calories available at village level in the tehsil. Human carrying capacity has been assessed based on the available and demand of food grains for human consumption in terms of calories (NSSO 2005) for the population of year 2001 and 2011 at village level in the tehsil. Based on the population growth rate of 2011 (Census 2011), population was projected for the year 2021 and village-wise human carrying capacity has been estimated by assuming the yields and areas of considered crops as constant.

Prioritization of land resource management

The village-wise calories availability and requirement were analyzed and mapped in GIS for the selected years. Based on the gap analysis, the surplus and deficit zones have been identified to prioritize the critical areas (group of villages) in availability of calories for human consumption. Later, the human carrying capacity units were integrated with biophysical resource units through geospatial modeling in GIS to identify the distinct priority areas and analyze their constraints and potentials. The input layers were assigned weights (scale 1-10) and integrated in GIS to delineate distinct priority areas based on their potentials and limitations. In the integrtaed map, higher values indicates higher priotiy, whereas lower values as lower priority areas for land resource management. Based on the potentials and limitations of delineated priority areas, action plan has been formulated to enhance the overall unit productivity of land resources in the tehsil.

Results and discussion

Assessment of biophysical resources

Slope

Slope analysis shows that level to nearly level slopes (0 - 1 %) occupies nearly 65.15 per cent, very gentle slopes (1 - 3 %) with 7.05 per cent, gentle (3 - 8 %) with 7.10 per cent, moderate slopes (8 - 15 %) with 5.00 per cent, moderately steep slopes (15 - 30 %) with 5.12 percent, steep slopes (30 - 50 %) with 3.17 per cent and very steep slopes (> 50 %) with 0.90 per cent of total geographical area (TGA). Water bodies and settlements occupy 6.60 per cent of TGA.

Length of growing period

Analysis of LGP indicates that the LGP in the tehsil ranges from less than 160 to more than 220 days. The spatial analysis of LGP shows that the area under LGP less than 160 and 160 - 170 days is mainly associated with hilly and plateau areas in eastern parts of the tehsil. However, the majority of the area is under LGP ranges from 170 - 180 days and cover mainly in central part of the tehsil. The area under LGP ranges from 180 - 190 and 190 - 200 days is noticed along the deep soils in valleys and plain areas. The area under higher LGP ranges from 200 - 210, 210 - 220 and above

220 days is mainly noticed along the aggraded valley fills of Wainganga river.

Landforms

Dissected hilltops, dissected hills, subdued hills and residual hills are characterized by various fluvial erosional activities and associated with granite gneisses formations mainly in eastern and south eastern parts of the study area. Isolated mounds and linear ridges are sinuous, narrow, highly disintegrated by mechanical weathering processes and are remnants of land reduction process. Shallow, moderate and deeply weathered pediments are low in relief and are associated with granite gneisses formations in central part of the study area with stratified to semi-stratified fluvial sediments. Narrow valleys and broad valley floors are mainly associated with shallow, moderate and deeply weathered pediments with deposited sediments of clay and sandy clay loam soils. Colluvial foot slopes and aggraded valley fills have unequal width with moderate slopes and consist of fluvial deposits mixed with sandy loam and sandy clay loam and noticed along the Wainganga river course.

Soils

Soils on the moderately weathered pediments are predominantly shallow. Moderately deep soils are mainly associated with moderately weathered pediments. Very deep soils are associated with moderate and deeply weathered pediments, colluvial foot slopes and aggraded valley fills. The AWC is critical factor in deciding the LGP, majority of the area in the tehsil is under very high soil AWC (> 200 mm) zone and is associated with moderate and deeply weathered pediments and aggraded valley fills. The analysis shows that majority of the area is under land capability sub-class IIs followed by IIes, IIIes and VIes covering an areas of 38.60, 30.25, 24.15 and 0.40 per cent of the TGA, respectively. Land irrigability classes shows that majority of the soils are rated as sub-class 2s having moderate limitation of soil for irrigation followed by 2sd, 3st, 3s, and 5st and cover 34.41, 25.34, 24.9, 8.25 and 0.5 per cent of the TGA, respectively.

Land use/land cover analysis

The analysis of land use/land cover indicates that area under double crops was mainly confined to narrow zone along the Wainganga river and occupies nearly 6.15 per cent area of the tehsil. The majority area (48.10 per cent) is under single crop. Permanent fallows occupy 7.85 per cent of the area. Under forest category, dense forest, scrub forest and open forest occupy nearly 17.75, 1.15 and 1.30 per cent area of the tehsil, respectively. Under wastelands category, land with scrubs and land without scrubs occupy nearly 2.00 and 9.10 per cent area of the tehsil, respectively. The water bodies and settlements occupy an area of about 6.05 and 0.55 per cent of TGA, respectively.

Groundwater potential zones

The analysis shows that the groundwater potential zones vary from excellent to very poor. The excellent potential zone was mainly associated with main valley floor of Wainganga river. The majority area is under very good groundwater potential zone and associated with moderate to deeply weathered pediments, aggraded valley fills with deep to very deep soils. The good ground water potential zone was identified with shallow to moderately weathered pediments with moderate deep soils. The moderate groundwater potential was found in shallow weathered pediments, dissected and subdued plateau. The poor and very poor groundwater potential zones were associated with dissected hills, subdued hills, isolated mounds particularly in southwestern parts of the tehsil.

Characterization of biophysical resource units

Evaluations of biophysical parameters play an important role in characterization and prioritization of areas for sustainable land resource planning and management (Reddy & Maji 2004). The knowledge based criteria has been followed in assigning the suitable weights for the input parameters (Table 1) and analysis of biophysical resource units shows that there are five distinct biophysical resource units in the tehsil (Fig. 3). The lower values in the map indicate higher the biomass and vice versa. Very good biophysical resource unit (7.3 %) was noticed in central and northwestern parts of tehsil and has highest biophysical production. The majority area (28.4 %) is under good biophysical resource mainly in central parts of tehsil and associated with moderate and deeply weathered pediments. The area under moderate biophysical resource (27.8 %) is noticed in central and southeastern parts of tehsil in association with moderate and deeply weathered pediments and deep soils. Poor biophysical resource unit (25.4 %) was noticed in southern and southeastern parts of the tehsil and characterized by moderately shallow soils. The area under very poor biophysical resource unit (4.8 %) is associated with dissected hills, subdued

Table 1. Weights assigned to input thematic layers in geospatial modeling for delineation of biophysical resource units.

Theme	Relative class	Assigned weight
Slope	Nearly level to level (0-1%)	1
	Very gentle (1-3%)	2
	Gentle (3-8%)	3
	Moderate (8-15%)	5
	Moderately steep (15-30%)	7
	Steep (30-50%)	8
	Very steep (>50%)	9
Landforms	Dissected hills/ subdued/ residual hills	10
	Isolated mounds, linear ridges	9
	Narrow scarp slopes	8
	Broad scarp slopes	6
	Subdued plateau	5
	Shallow weathered pediments	4
	Moderately weathered pediments	3
	Deeply weathered pediments	2
	Narrow valleys, broad valley floors, colluvial foot slopes, aggraded valley fills	1
Length of growing period	175-200	8
	200-225	7
	225-250	5
	250-275	3
	275-300	1
Soil depth	Shallow	8
	Moderately deep	5
	Very deep	1
Groundwater potential	Excellent	1
	Very good	3
	Good	5
	Moderate	7
	Poor, very poor	9
Land use/land cover	Double cropped area	1
	Single cropped area	3
	Permanent fallows	6
	Land with scrub	6
	Land without scrub	9
Land capability	IIs	2
	IIes	5
	IIIes	7
	VIes	8
Land irrigability	2s	2
	2sd	3
	3s, 3st	4
	5st	7

hills and moderately shallow soils. The very poor biophysical resource unit has very low agriculture productivity.

Assessment of human carrying capacity

In Tirora tehsil, village-wise calories availability, requirement and gaps have been analyzed and mapped using GIS to assess the spatio-temporal patterns of human carrying capacity (Reddy *et al.* 2006). Based on the gap analysis the surplus and deficit zones (group of villages) have been identified for further analysis in association

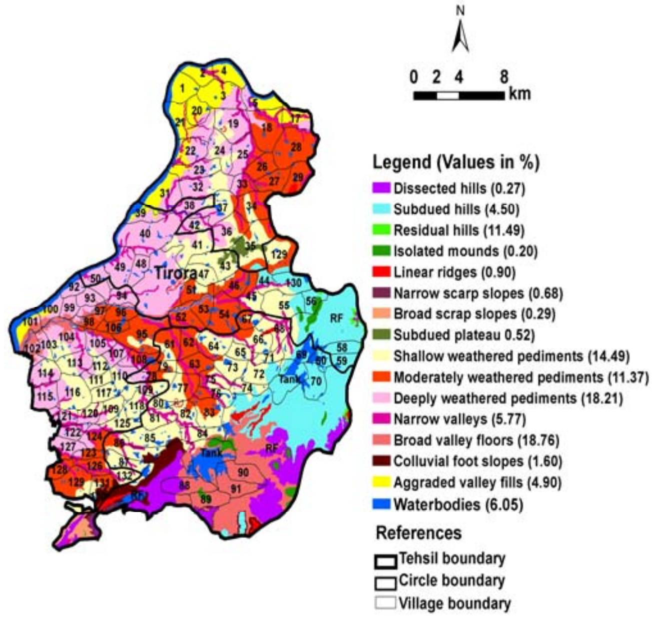

Fig. 3. Landforms of the study area.

with existing resources to find out critical areas. The analysis of human carrying capacity for the year 2001 shows high deficit (> 800 million calories) in five villages in different parts of the tehsil (Table 2 and Fig. 4). Moderate deficit (800 to 400 million calories) was noticed in eight villages mainly in southern and southeastern parts of tehsil. Low deficit (< 400 million calories) was noticed in thirty four villages in the tehsil and it indicates the deficiency of food grains availability in the tehsil. Low surplus (< 400 million calories) was noticed in forty six villages across the tehsil and it shows that these villages meet their requirement of food grains with little surplus. Moderately surplus (400 to 800 million calories) was noticed in twenty five villages locating different parts of the tehsil and these villages have surplus food grains. High surplus (> 800 million calories) was noticed in four villages located in isolated places in the tehsil and these villages have surplus of food grains even after meeting their requirement.

Human carrying capacity: the future scenario

Human carrying capacity for the projected population for the year 2021 shows high deficit (> 800 million calories) in six villages of the tehsil (Table 2 and Fig. 5). Moderate deficit (800 to 400 million calories) may occur in fifteen villages mainly in southern and eastern parts of tehsil. Low deficit (< 400 million calories) may occur in forty-one villages spreading across the tehsil and it indicates the deficiency of food grains availability in the tehsil. Low surplus (< 400 million calories) was noticed in thirty-seven villages across the tehsil, this shows that these villages are meeting their requirement of food grains with little surplus. Moderately surplus (400 to 800 million calories) was noticed in twenty villages and these villages have surplus of food grains. High surplus (> 800 million calories) was noticed in three villages located in isolated places in the tehsil, it indicates that these villages have surplus of food grains even after meeting their requirement.

Table 2. Number of villages under different carrying capacity classes.

Carrying capacity class (Calories in millions)	2001	2011	2021*
> -800	5	6	6
-800 - -400	8	9	15
-400 - 0	34	43	41
0 - 400	46	37	37
400 - 800	25	23	20
> 800	4	4	3
Total	122	122	122

Note: **Projected carrying capacity based on the population projections of the tehsil.*

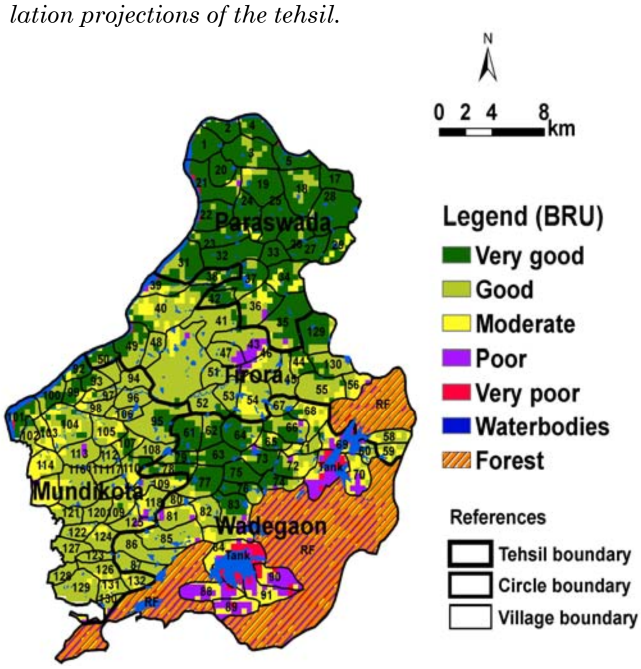

Fig. 4. Biophysical resource units of the study area.

Prioritization of areas for sustainable land resource management

Through geospatial modeling in GIS with suitable weights for the input parameters (Table 3),

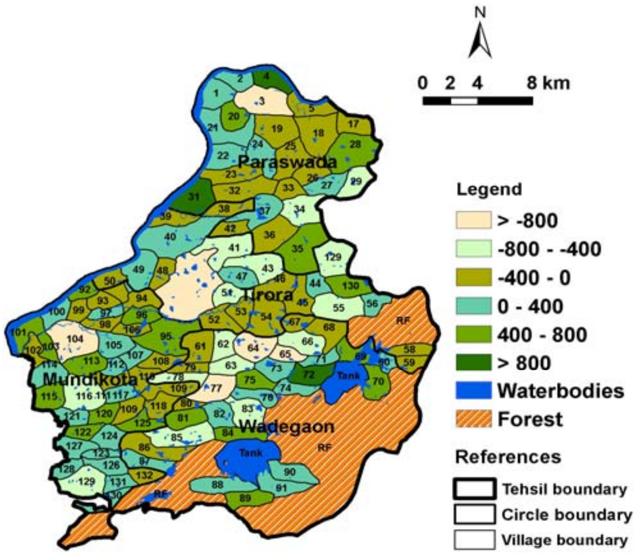

Fig. 5. Status of human carrying capacity in the year 2021 (projected).

Table 3. Weights assigned in identification of priority areas in geospatial modeling.

Thematic map	Relative class	Assigned weights
Biophysical resources units		
	Very good	1
	Good	4
	Moderate	5
	Poor	7
	Very poor	9
Carrying capacity units		
	Very high deficit	10
	High deficit	8
	Low deficit	6
	Low surplus	4
	High surplus	2
	Very high surplus	1

the human carrying capacity units of the year 2001 and the biophysical resource units were integrated to identify and characterize the priority areas for sustainable management of land resources in the tehsil (Fig. 6). The integrated analysis indicates that very low (< 6.0) and low (6.0 - 7.0) priority areas in northern, western and southern parts of the tehsil with an area of 7.10 and 17.20 per cent of TGA, respectively. These areas had low and very low priority due to high biophysical resource stock and high human carrying capacity. The medium (7.0 - 8.0) priority areas have been noticed in central and southern parts of the tehsil with an area of 22.30 per cent due to the moderate biophysical resource stock and human carrying capacity. The areas in north-eastern, central and southern parts of the tehsil are under high (8.0 - 9.0) and very high (> 9.0) priority with an area of 7.45 and 19.15 per cent, respectively, because of low biophysical resource stock and low human carrying capacity. The potentials and constraints at unit level were analyzed to formulate a need based sectorial action plan at tehsil level for optimum utilization of available resources for sustainable development. The analysis shows that significant area in tehsil is under very high and high priority area and in these units the focus should be on soil and water conservation and recharge of groundwater, double cropping i.e., cereal in *kharif* followed by pulses in *rabi*. Permanent fallows need to be brought under silvi-pasture and horti-pasture systems to improve the biophysical productivity (Table 4).

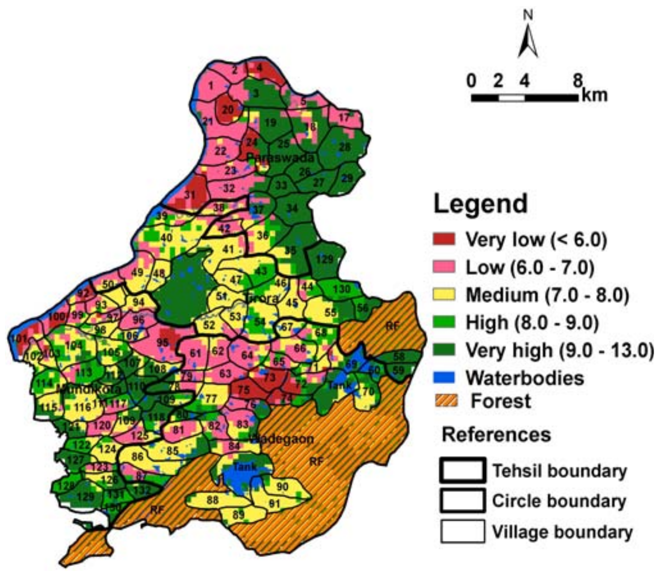

Fig. 6. Prioritized areas for land resources management in the study area.

Conclusions

The analysis of remote sensing satellite data with necessary field verifications show fifteen distinct landform units in the study area. The soil depth is ranging from shallow to very deep in the study area. The groundwater potential in the tehsil varies from excellent to very poor zones. The analysis showed that there are five distinct bio-physical resource units in the tehsil. The analysis

Table 4. Priority areas and their potentials, constrains and strategies for sustainable management of land resource in Tirora tehsil*.

Priority areas	Constraints	Potential	Strategies
Very low (7.10 %)	Mono cropping and lack of assured irrigation facilities	Excellent to very good groundwater resources, leveled lands with deep soils and very good biophysical resource stock	Double cropping and intensive crop production in irrigated areas with cereal-pulses/oil seeds. Augment irrigation facilities through tube wells and surface tanks.
Low (17.20 %)	Medium to shallow soils and mainly under mono cropping	Excellent to very good groundwater resources, leveled lands with deep soils and good biophysical resource stock	Double cropping and intensive crop production in irrigated areas with cereal-pulses/oil seeds. *In-situ* soil and water conservation in shallow to medium deep soils.
Medium (22.30 %)	Single crop, fallow lands, poor forest cover and high grazing pressure	Very good groundwater resources, deep soils, moderate biophysical resource stock	Bring fallow land under agro-horti-pasture system, double cropping of cereal-pulses/oil seeds, introduction of multi-purpose tress (MPT's) and improved pasture legumes in fallow and scrublands.
High (7.45 %)	Rolling sloppy lands, poor water source, single cropped area, permanent fallow and poor biophysical resource stock	Good groundwater resources, deep soils	Fallow lands on hill terrain need to be brought under silvi-pasture system and plateau lands under agri-horti-system. *In-situ* soil and water conservation in shallow soils and to check soil erosion check dams or gabbian structure need to be constructed on rolling sloppy lands
Very high (19.15 %)	Shallow to very shallow soils, poor water resources, single cropped area, poor to very poor biophysical resource stock	Moderate forest cover, moderate slopes, good groundwater resources.	Introduction of short duration pulses, soybean and other oil seed crops in plain areas. Introduction of pasture, grasses and legumes in very shallow soils. Contour terraces need to constructed on rolling lands. Horti-pasture or agro-forestry systems needs to be developed in marginal lands.

*Note: Area under forest, water bodies and settlements was excluded.

of human carrying capacity for the year 2001 indicates that the high deficit (> 800 million calories), moderate deficit (800 to 400 million calories) and low deficit (< 400 million calories) in five, eight and thirty four villages, respectively. GIS based geospatial modeling helped in integration of biophysical resource units and human carrying capacity for prioritization of the areas. Based on the analysis of resource potentials and constraints, strategies have been generated for optimum utilization of available land and water resources in the tehsil. The study demonstrated the utility of geospatial modeling using remote sensing data, ancillary data and field survey data to derive distinct biophysical units and human carrying capacity.

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