Deciding Alternative Land Use Options in a Watershed Using GIS

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Abstract: The present approach adopted for suggesting alternative sustainable land use comprises taking into consideration present land use/land cover, soils, slope, and geomorphology. However, this paper deals with watershed management from a different perspective, by stressing the development of the watershed for agriculture activities; first, by implementing soil and water conservation works. The next step is to suggest alternative sustainable land uses based on soil and water conservation measures, groundwater prospects, land capability, and present land use/land cover in the area. The new approach is found to be very useful, as it takes into consideration basic factors necessary for the overall development and management of the watershed, and ensures stoppage of further degradation of the resources through appropriate soil conservation measures and land uses.

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Introduction

Rainfed agriculture is mostly practiced in areas which do not fall under any irrigation project, and where surface water resources are limited and groundwater is the main source of supplemental irrigation. In these areas, agriculture is a gamble due to nonuniform, erratic, and scanty rainfall. Natural resources like soil and groundwater are degraded in the process of depletion due to overexploitation. Under such circumstances, sustainable watershed management where resources are optimally utilized for the benefit of the people and development of a region, as a whole, is the desirable solution.

As the rainfed areas in India constitute about 66% of the net cultivated area, and the typical case study area in Andhra Pradesh represents the status of the entire Deccan trap (Alfisol region having receding groundwater potential) of the semiarid India, the outcome of the land use planning study, for large-scale applications, is definitely applicable. Therefore, in the present study, one such microwatershed near Hyderabad was used for proposing alternate land use options. Prevention of the soil erosion, conserving moisture and bringing fallow and scrublands under cultivation, and proposing alternate sustainable land use options were the objectives of the study, as shown in Fig. 1. Implementation of soil and water conservation measures is a prerequisite to revive the watershed, before beginning any agricultural activity, and hence, soil and water conservation mapping is taken as a basis for conserving resources on which land use options can be implemented.

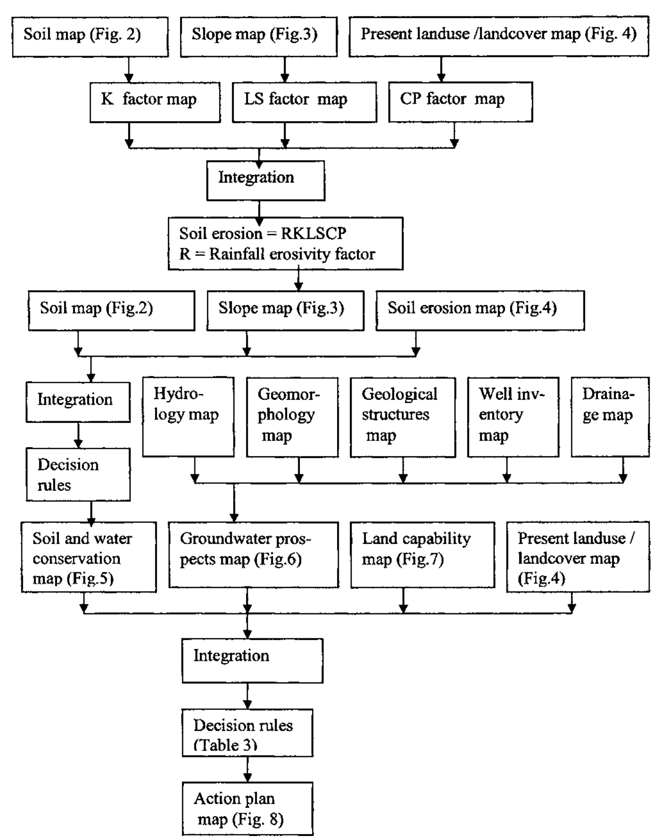

Fig. 1. Flow chart for methodology deciding alternate sustainable land use/land cover

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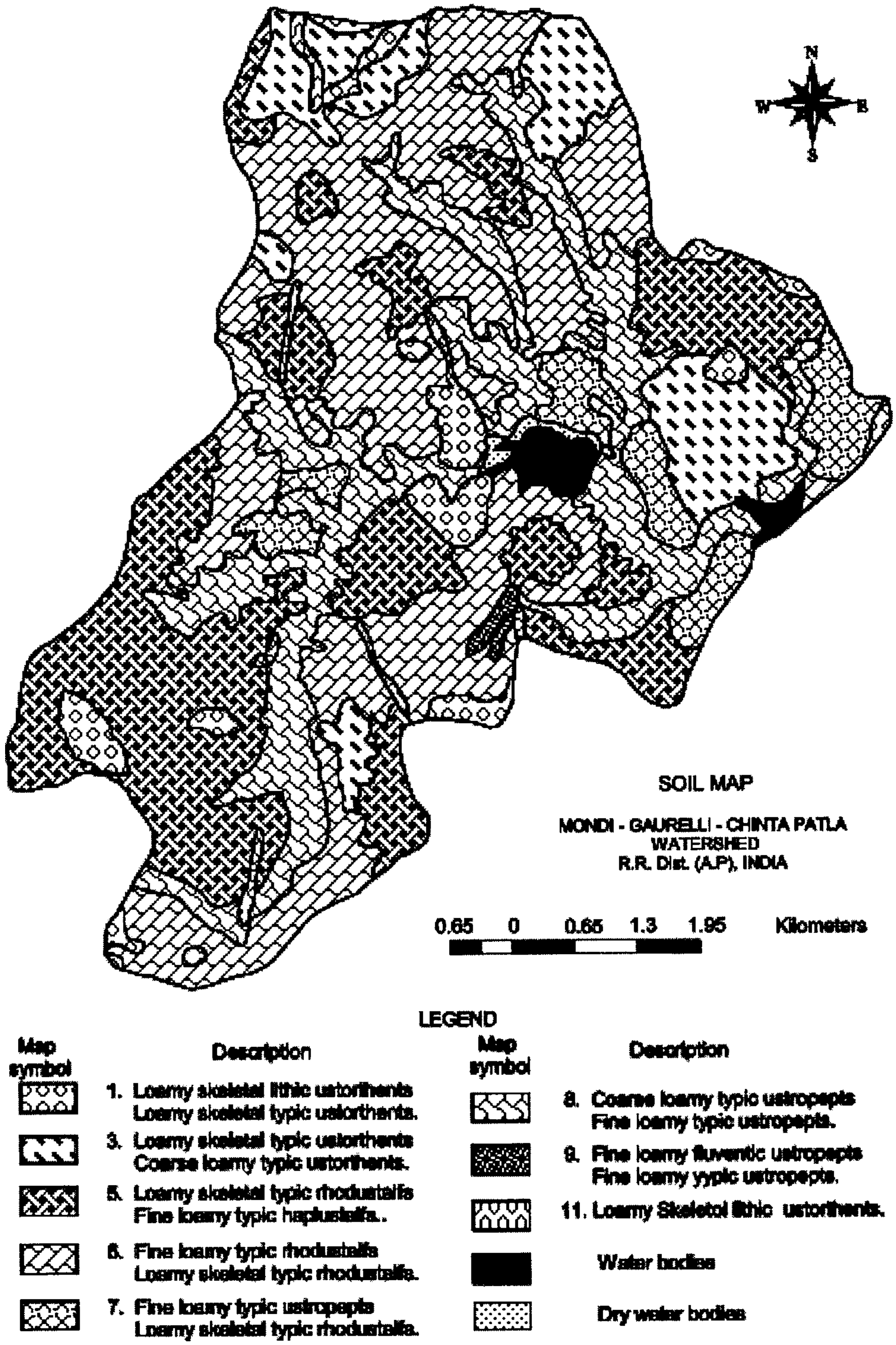


Fig. 2. Soil map (Courtesy National Remote Sensing Agency, Dept. of Space, Government of India)

From the literature review and the present practice adopted by the Integrated Mission for Sustainable Development (IMSD) of National Remote Sensing Agency (NRSA, technical guidelines, Department of Space, NRSA 1995) Hyderabad, India, the themes incorporated for framing decisions rules for alternative land uses are land use/land cover, geomorphology, soil, and slope. There is no rule of thumb to scientifically decide the land use options, except on the basis of land capability classification. But, the constraint of groundwater is felt everywhere and its availability is being reduced from year to year. Also, the farmers are not in a position to completely diversify their cropping system, as per land capability classes, since they are comfortable with current practices most of the time. Hence, due respect needs to be given to the present land uses in deciding land use options. Presently, more emphasis is given to land use diversification in the watershed programs, where the technique of scientifically deciding land use options considering present practices of the farmers is taken into account. A large amount of money is being earmarked for watershed projects. About 60% of the allocated funds are for resource development, including soil and water conservation measures. Therefore, the present paper deals with watershed management from a different angle, by deciding land use options after imple-

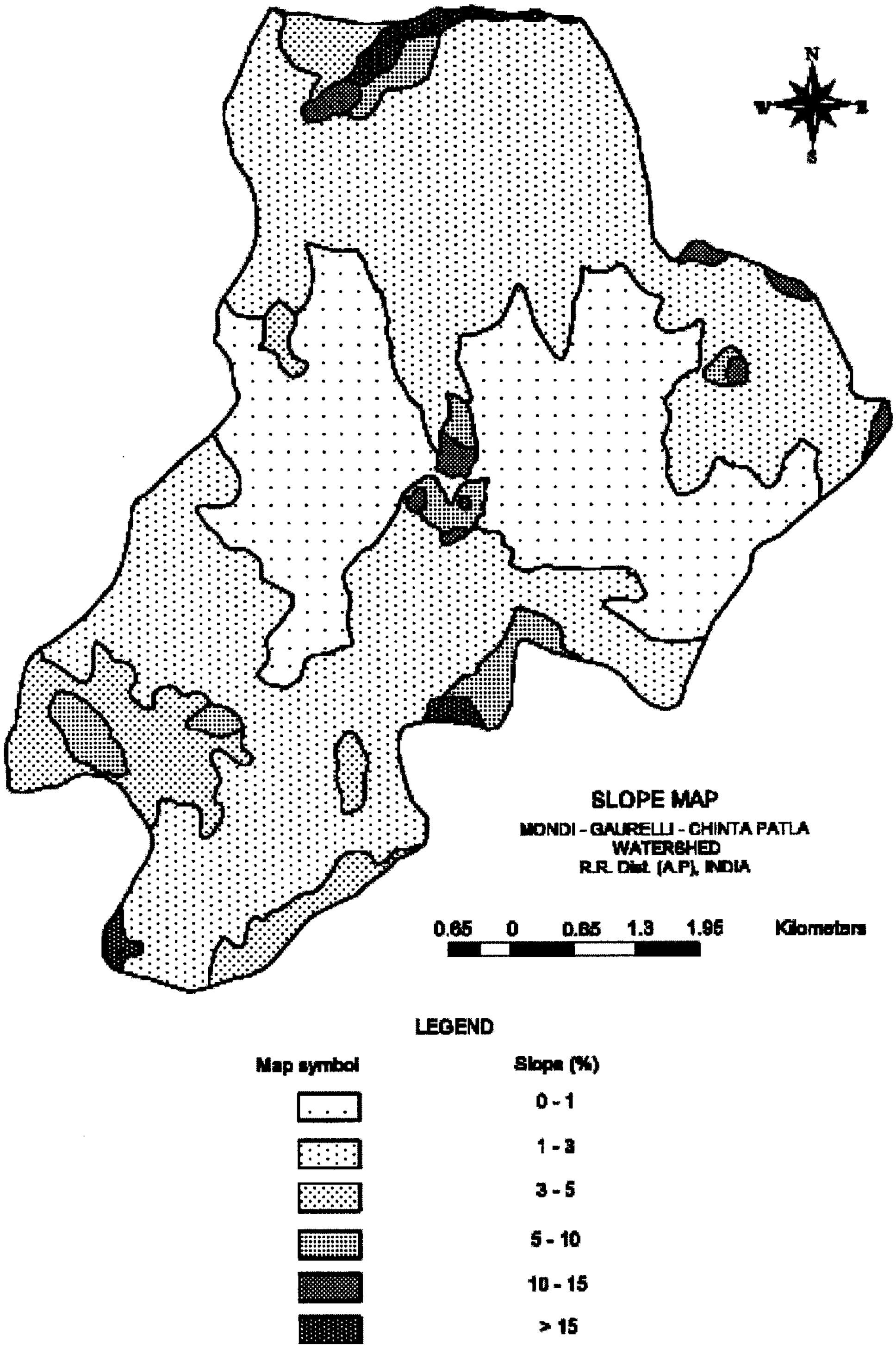


Fig. 3. Slope map

menting soil and water conservation practices. Rainfed areas are affected with severe soil erosion problems. Soil erosion and water loss have serious social and economic consequences. Hence, it has become necessary to conserve soil and water. The problem of soil erosion is related to soil type, soil depth, allowable soil erosion rate, actual soil erosion rate, slope, and rainfall in the watershed. Therefore, in the present work, all these factors have been considered for deciding the soil and water conservation practices. The next step is, suggesting alternative sustainable land uses based on soil and water conservation measures, groundwater prospects, land capability, and present land use/land cover in the area. A soil and water conservation measures map is adopted as implementation of conservation measures ensures the preparedness of the field for cultivation. Also, it reflects the combined effect of soil, slope, and soil erosion characteristics instead of characteristics of soil and slope separately. Land capability classification is an interpretative grouping of soils mainly based on: Inherent soil characteristics, external land features, and environmental factors that limit the use of land. The land capability class is the highest level of generalization and indicates the intensity of limitations. The governing criterion for land capability classifications is influence of soil depth, slope, effect of erosion conditions,

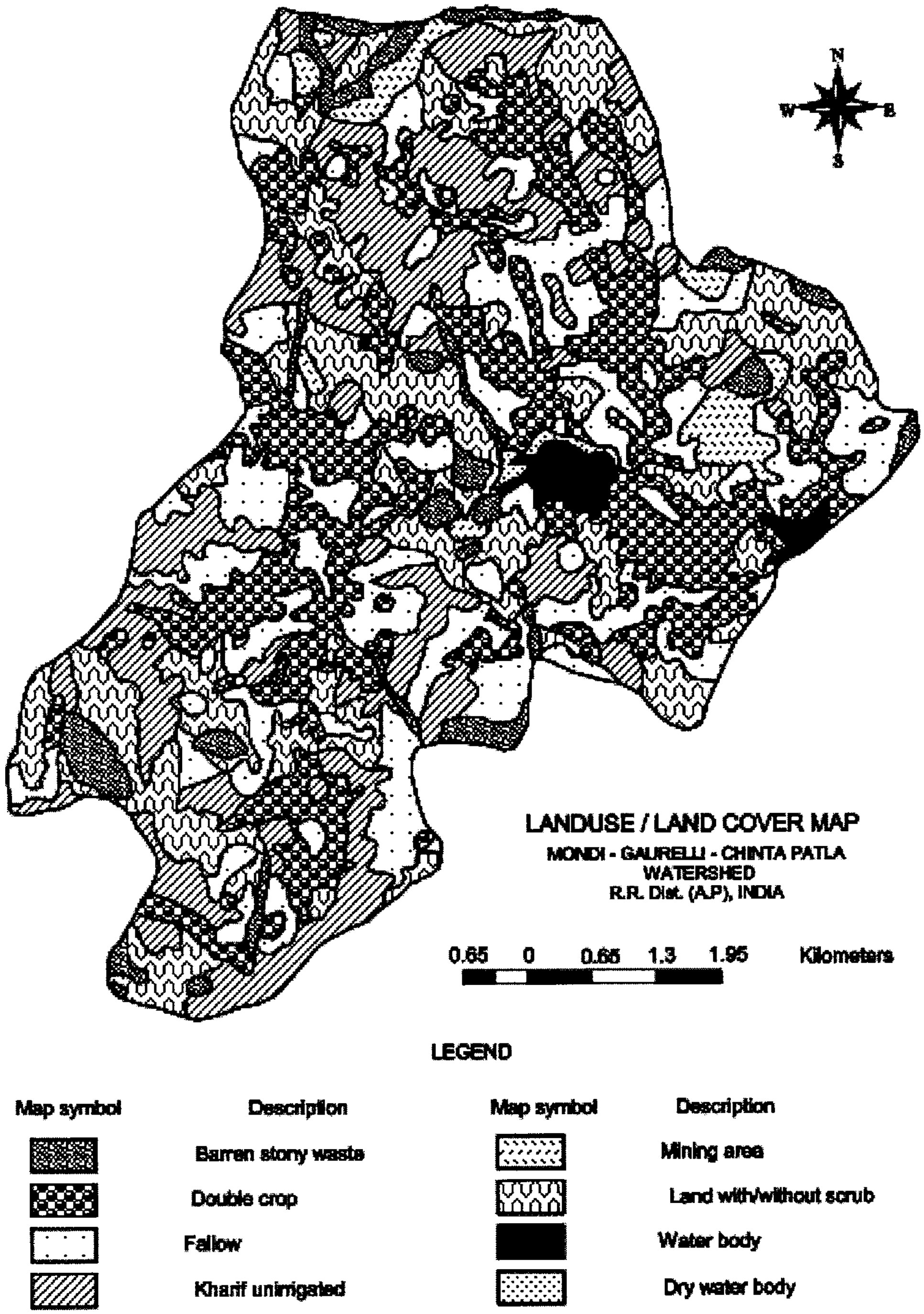


Fig. 4. Land use/land cover map

and influence of climate. In land capability classification, each of the factors like soil, land features, and climate are considered separately and independently of each other. The final land capability class is decided after considering morphology and physicochemical properties of soil profile, land features, and effect of climate. Therefore, instead of using only a soil map for suggesting alternate land use options, the land capability map has also been used.

It is necessary to assess the groundwater potential in the rainfed areas having erratic, nonuniform rainfall with groundwater as the main source of supplemental irrigation. This helps in deciding alternate land use strategies. This plays a key role in deciding whether an irrigated crop, crop/plant requiring supplemental irrigation, horticulture, crop, etc., can be introduced in the area and if so, where? The groundwater prospects map takes into consideration the combined effect of geology, hydrology, geological structures, and yield of wells to assess the groundwater prospects of the area. The current land use/land cover map has been considered, as it shows the present practices followed in the watershed, and hence, serves as a guide to include the local preferences and easy acceptance of the plan. GIS is used as a tool for carrying out the analysis, as it has both quantitative and qualitative abilities.

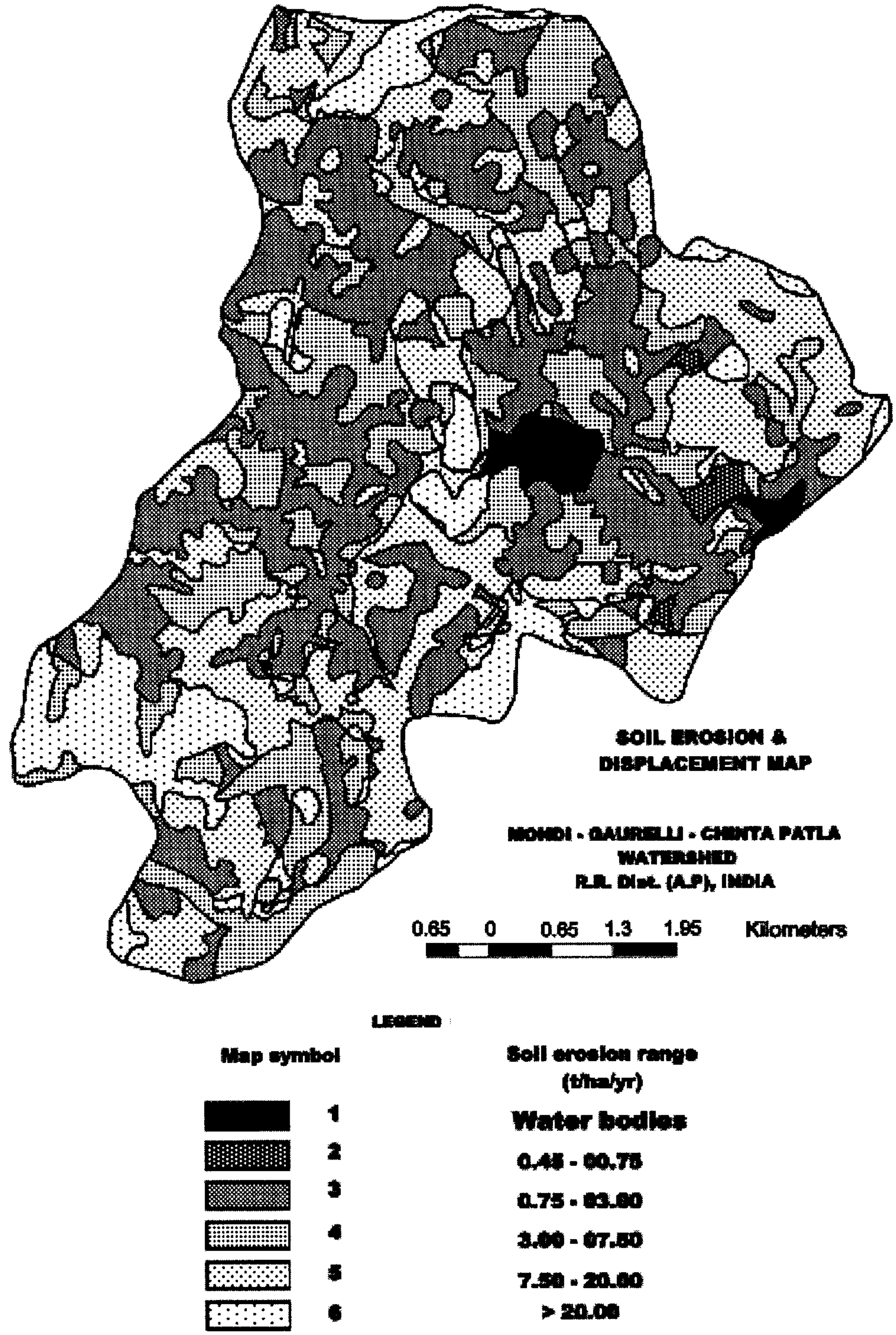


Fig. 5. Soil erosion and displacement map

Methodology

The Mondi Gaurelli-Chintapatla watershed having a geographical area of 48 km^2 located in Ranga Reddy District, Yacharam Mandal of Andhra Pradesh in semiarid India was selected for the study. It lies between 78°41′ to 78°44′ E longitudes and 17°0′ to 17°5′ N latitudes. It falls in a drought prone region of the Telangana region. The watershed lies in a rainfed region and is in a highly eroded state. Existing degradation of the watershed is depicted through the soil erosion and displacement map, as well as present land use/land cover map. Nearly 50% of the geographical area of the watershed is under fallow and scrub category. Agriculture is the main occupation of the inhabitants and for want of water, agriculture is suffering. In 41% of the watershed, the soil erosion rate is more than the allowable limit for the soil depth. Groundwater levels are also falling continuously.

The processes followed for preparing the alternate land use action plan are:

1. Studying the associated themes, such as soil, slope, land use/land cover, drainage,
2. Estimating the soil erosion,

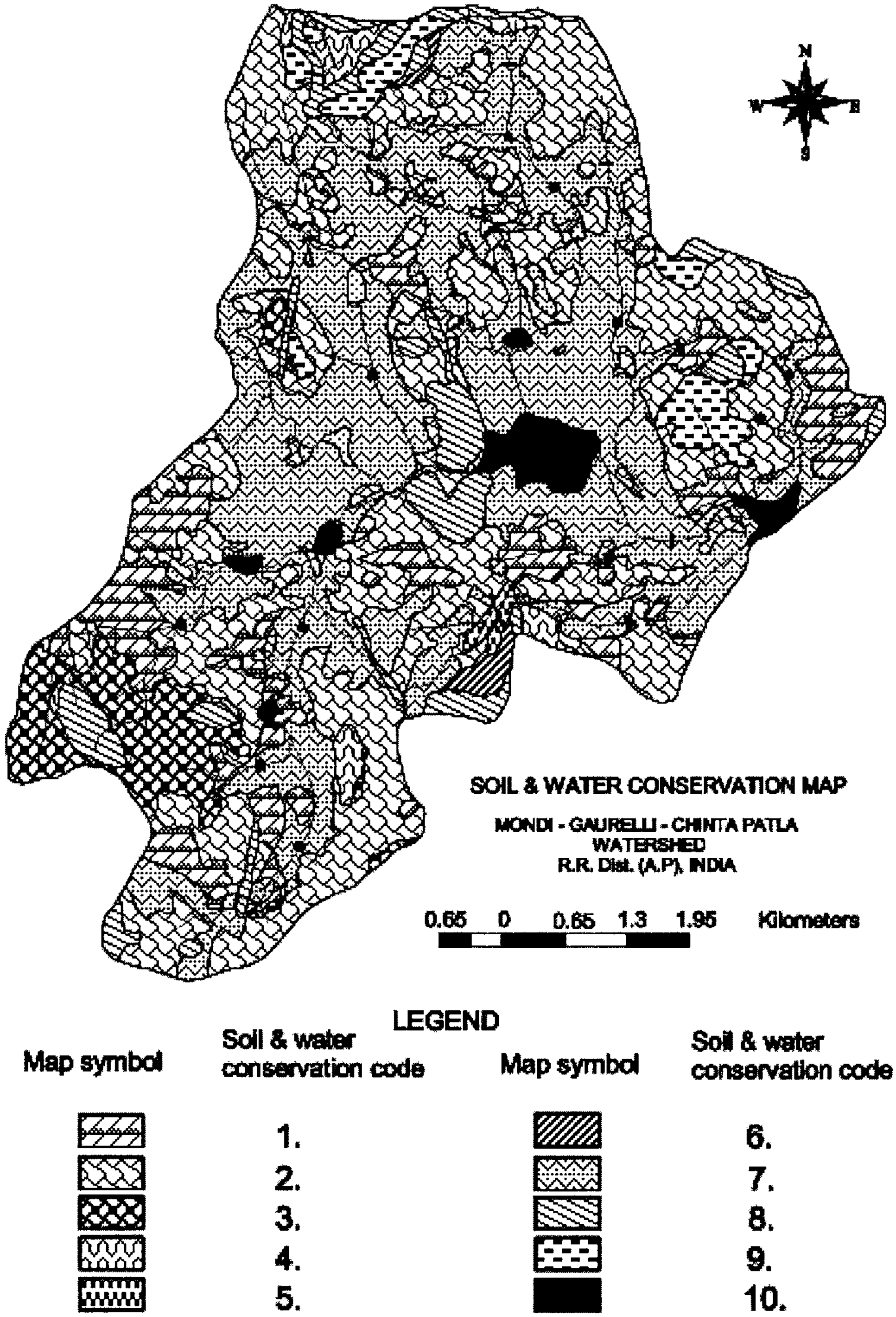


Fig. 6. Soil and water conservation map

3. Proposing soil and water conservation measures,
4. Estimating the groundwater availability by preparing groundwater prospects map, and
5. Proposing alternative land use options.

The steps followed in developing the alternative sustainable land use options were as follows:

Step 1—Soil map, present land use/land cover map, and slope map were prepared and input into GIS.

Step 2—Soil erosion was estimated using the Universal soil loss equation (USLE) (Wischemier and Smith 1978) to prepare a soil erosion and displacement map. The detailed procedure adopted, to prepare it, is explained below.

1. A soil erodibility factor "K" was assigned to each soil series in the soil map, as per characteristics of soil, such as percentage of sand, silt, organic matter content to obtain soil erodibility map, i.e., K-factor map from soil map (Singh et al. 1982).
2. A topographic factor map, i.e., LS-factor map was derived from the slope map by calculating topographic factor for percent slope and slope length for each category of slope.
3. A cropping management factor and supporting practice factor, i.e., "CP" factor map was obtained from land use/land cover map. The cropping management factor "C" and supporting practice factor "P" were arrived at by assigning ap-

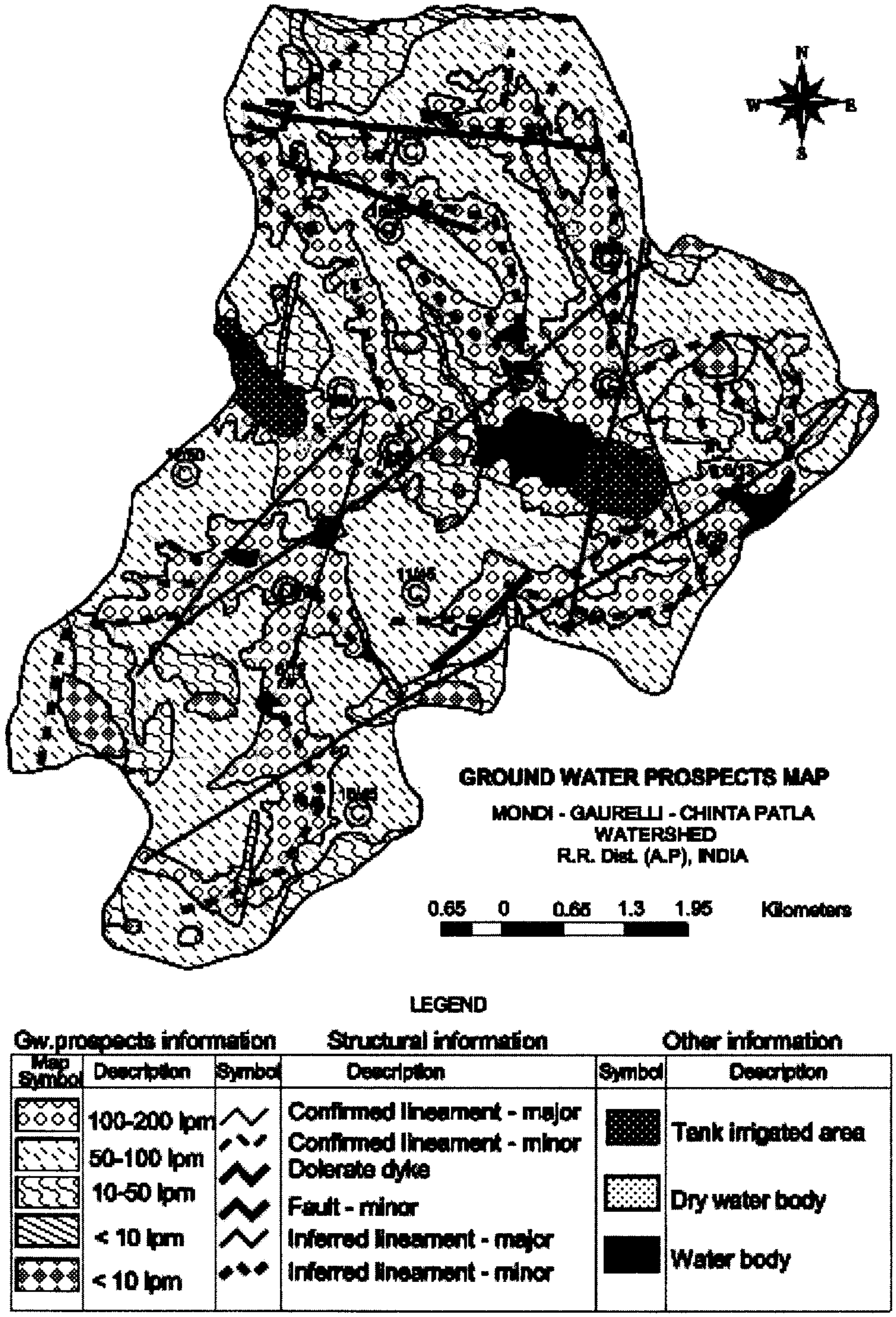


Fig. 7. Groundwater prospects map

propriate values for each land use/land cover category and the practices, such as contouring, terracing followed in the watershed.

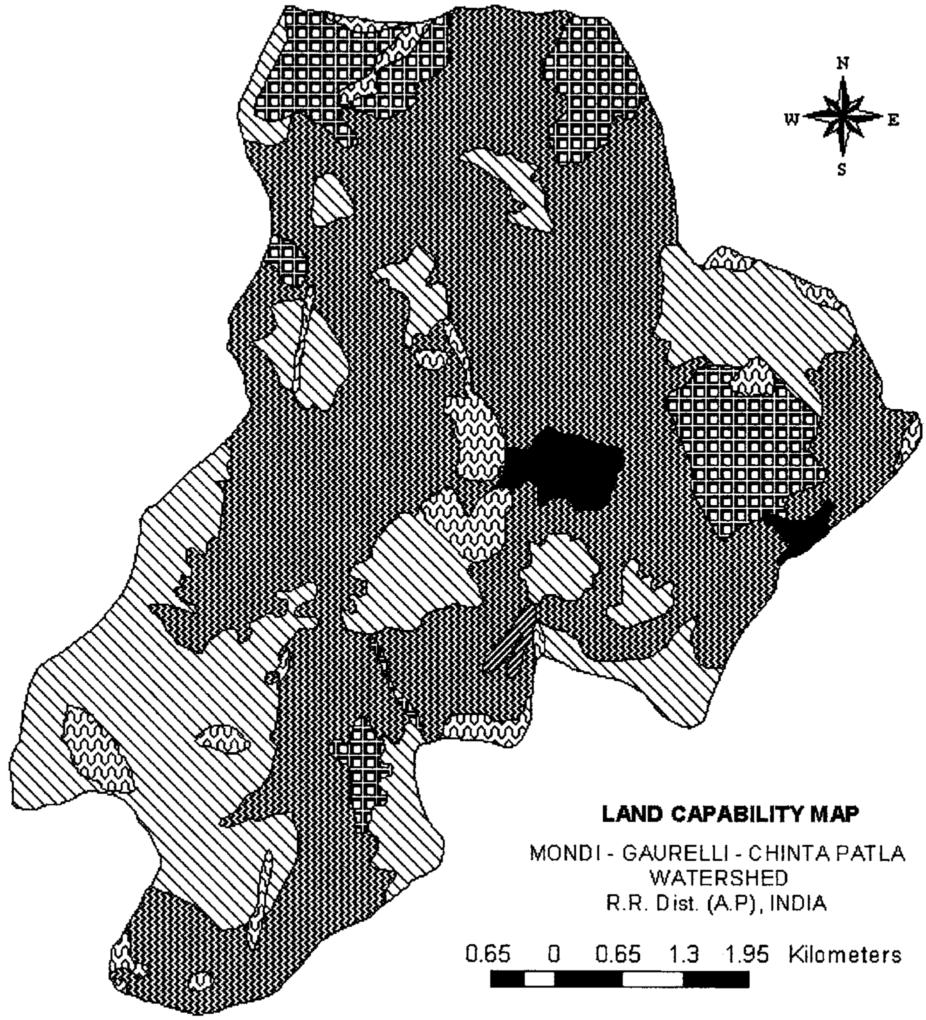
4. These three maps were integrated and an item, soil erosion = RKLSCP was introduced to estimate soil erosion at various places in the watershed. A constant value for rainfall erosivity factor "R" was assigned in the integrated map.
5. Ranges for soil erosion values were fixed and assigned to obtain soil and displacement map. Erosion values do not exceed 20 t ha^{-1} yr^{-1} in the region, therefore, values above it are taken as soil displacement and not erosion, while fixing the ranges.

Step 3—Soil erosion and displacement map, soil map, and slope map were integrated.

Step 4—Based on the allowable erosion rate, for the soil depth, in each of the soil series (Zacher 1982), actual soil erosion rate and slope value in each polygon of the integrated map decision rules for soil and water conservation were proposed, and incorporated in the integrated map to prepare a soil and water conservation map.

Step 5—Hydrology, geomorphology, geological structures, well inventory, and drainage maps were integrated to obtain a groundwater prospects map.

Step 6—The next step was to integrate the soil and water



LEGEND

Map Symbol	Land Capability	Special needs and Procedures
	II e	Graded bunds, fertilizers off season till age.
	III es	Suitable crops as per the root zone limitation, vegetal cover, graded bunds to arrest erosion, fertilizers, removal of gravel.
	IIw	Off season tillage, weed control, drainage, fertilizers.
	IV es	Erosion control by provision of vegetal cover of shallow root plants, irrign. methods (sprinkler, drip irrign.), use of fertilizers.
	VI es	Control of erosion by contour trenches. Gully plugging growing grass for soil and moisture conservation.
	Water	Not applicable

Fig. 8. Land capability map (Courtesy National Remote Sensing Agency, Dept. of Space, Government of India)

conservation map, groundwater prospects map, land capability map, and present land use/land cover map.

Step 7—Decision rules were proposed for alternate sustainable land use options to prepare an action plan map based on the soil and water conservation measures, groundwater availability, land capability, and present land use/land cover in each polygon of the integrated map.

All the thematic maps were first drawn on paper. Next, they were scanned, digitized, edited, labeled, cleaned, built, and integrated in a GIS environment. GIS was also used for incorporating decision rules in the integrated map and presentation of maps.

Materials Used

1. Satellite Imagery: IRS–1C LISS III FCC 03–03–1998 and IRS–1C LISS III FCC 27–11–1996 for land use/land cover and groundwater prospects map,
2. Survey of India Toposheets No. 56 K/12, L/9 for slope map and base map preparation,
3. PC Arc Info 3.5.1 GIS software for preparation of maps, integration, attribute data storage, etc., and
4. Arc view 3.0a GIS software for analysis of data and maps.

Table 1. Soil and Water Conservation Recommendations

Soil and water conservation code	Recommendations
1	Contour cultivation, live beds on contour, mulching, conservation furrows, vegetative barriers, strengthening of boundary bunds
2	Contour cultivation, contour bund of 0.3 m^2 cross section, mulching, pasture on fallow and scrubland, vegetative barriers
3	Contour cultivation, contour bunds of 0.3 m^2 c/s with waste weirs, mulching, strengthening of existing bunds with vegetation
4	Contour cultivation, contour bunds of 0.5 m^2 c/s, gully plugging, dead furrows, pasture on fallow and scrub land, green capping of bunds
5	Provision of diversion drains, contour cultivation
6	Contour cultivation, horticulture with microcatchments, contour bunds of 0.5 m^2 c/s strengthening of bunds with vegetation
7	Strengthening of boundary bunds, contour cultivation
8	Continuous staggered contour trenches, silvipasture, forestry, gully plugging, grass waterways, stone enclosures
9	Rehabilitation of mine spoils
10	Water bodies

Thematic Maps

The detailed description of the maps is given below.

Soil Map. The soil map was adopted from the published report "Integrated mission for sustainable development: Development of action plan for land and water resources" (APSRAC 1994), prepared by Andhra Pradesh State Remote Sensing Application Center (APSRAC) for the Ranga Reddy District of Andhra Pradesh in India (Fig. 2).

Slope Map. The watershed is divided into six slope categories. The slopes in the watershed range from first to sixth category (Fig. 3). A continuous range of steep slopes curvilinear in shape, marks the northern side of the watershed.

Present Land Use/Land Cover Map. The resource map of land use/land cover was prepared by visual interpretation of satellite imagery of the area (Fig. 4). Categories of the type of land use/land cover available in the watershed are agricultural land (*Kharif* crop land, double crop land, fallow land), waste land (land with/without scrub, barren stony waste land), mining area for granite rock, and water bodies such as lakes.

Soil Erosion and Displacement Map. Soil erosion was estimated by the Universal Soil Loss Equation (USLE) developed by Wischemier and Smith (1978). The equation was incorporated in a Geographic Information System. Soil erodibility factor (K-Map) topographic factor (LS-Map), and crop management (CP-Map), and supporting practice factor map were derived from the soil map, slope map, and land use/land cover map, respectively, by assigning suitable values for each polygon in the respective maps. The values were adopted from bulletin "Soil research in India" (Singh et al. 1982). These maps were integrated, and an item soil loss = RKLSCP was created in the integrated map. The rainfall erodibility factor (R) was taken as constant, as the amount of rainfall is uniform over the watershed. The soil erosion and displacement map is depicted in Fig. 5.

Table 2. Land Capability Classification of the Watershed

Soil map unit	Land capability unit	Area km^2
1	VIes	2.56
3,11	IVes	4.72
5	IIIes	12.88
6,7,8	IIe	26.84
9	IIw	0.17
	Grand total	48.03

Soil and Water Conservation Map. The soil erosion and displacement map, soils map, and slope maps were integrated. Based on the allowable erosion rate (Zacher 1982) for the corresponding soil depth in each polygon, decision rules for soil and water conservation measures were incorporated in the integrated map (Fig. 6). In the present study, soil and water conservation measures suggested taking into account allowable soil erosion rate for the corresponding soil depth besides soil and slope characteristics. Therefore, the measures are less intensive, as the allowable rate is considered, as a threshold, for taking up conservation measures. Presently, the intensity of measures is solely dependent on the erosion rate; hence, they are intensive and consequently costly. Therefore, in absence of the detailed estimation, it can also be inferred that the measures are cost effective and not cost intensive, as a limited area needing conservation will be treated.

Hydrology Map. This map shows the distribution of areas irrigated by surface and groundwater. These are the areas, on the downstream of lakes, that get surface water for irrigation.

Geomorphology Map. This map shows the geomorphic units available in the watershed. They are: (a) pediplain (pediplain moderately weathered and pediplain shallow weathered), (b) pediment, (c) residual hill, and (d) dyke and curvilinear ridge.

Well Inventory Map. Types of wells in the area are: Dug wells, dug cum bore wells, and bore wells. Depth of bore wells, in pediplain moderately weathered geomorphic unit is ~40–60 m, and depth to water table is 3–8 m. Depth of open wells varies between 9 and 13 m. In the pediplain shallow weathered geomorphic unit, depth of wells is 40–60 m having moderate yield. Depth to water table is 8–12 m. The number of wells present is about 93. Wells in the pediment zone do not exist.

Geological Structures Map. The confirmed and inferred lineaments and few faults present in the area are depicted in this map.

Drainage Map. Streams up to third order are present in the watershed. There are two major surface water bodies covering an area of 0.856 km^2. The watershed forms the part of Musi river, in the Krishna river basin.

Groundwater Prospects Map. This map is prepared, as per the technical guidelines, for preparation of groundwater prospects maps framed for Rajiv Gandhi National Drinking Water Mission

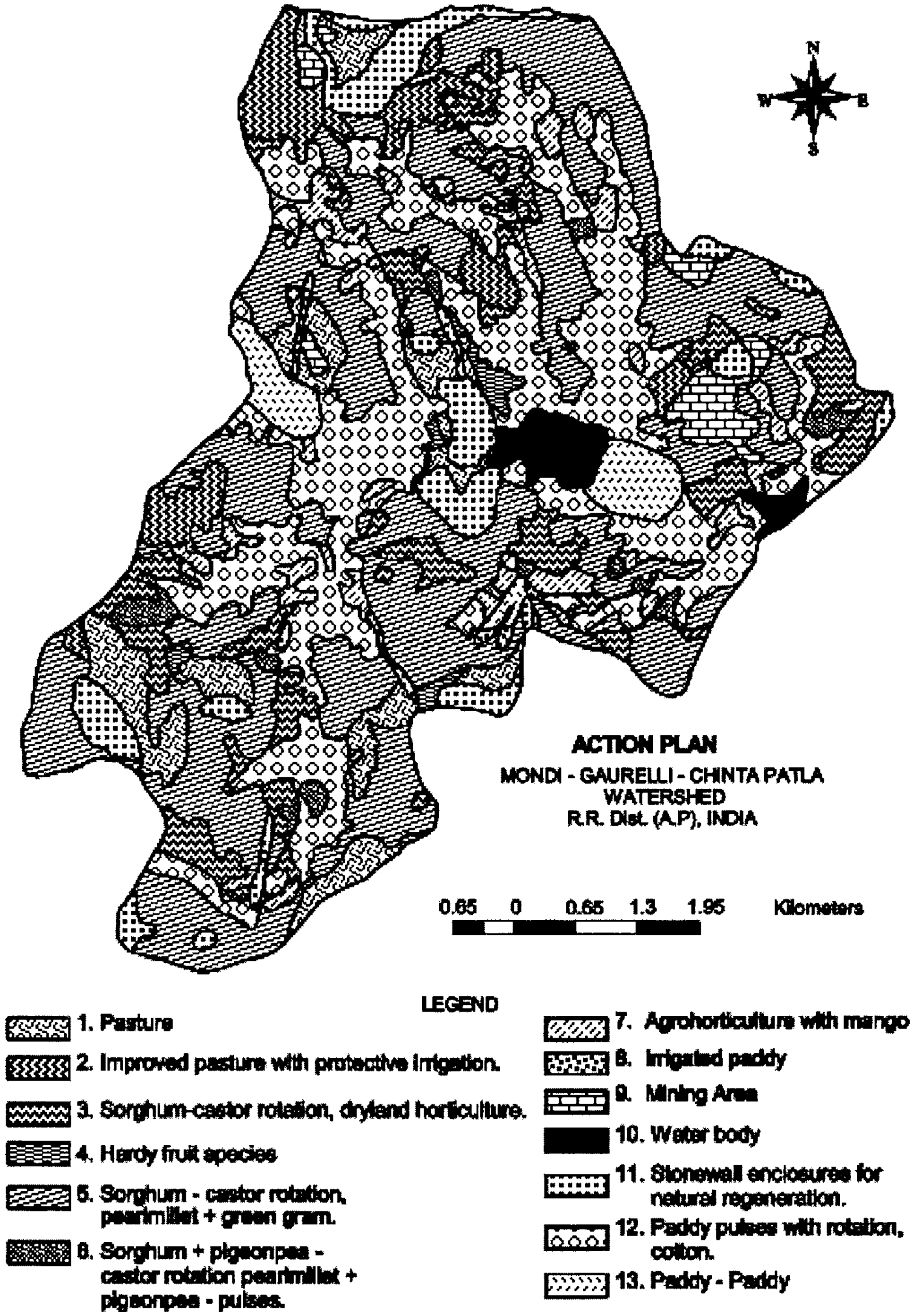


Fig. 9. Action plan map—alternate sustainable land use

by National Remote Sensing Agency (NRSA 2000), Hyderabad, in the year 2000. The following maps were integrated in GIS to obtain the groundwater prospects map: (1) hydrology, (2) geomorphology, (3) geological structures, (4) well inventory, and (5) drainage. All these maps are together shown in the groundwater prospects map. This map is presented in Fig. 7.

Land Capability Map. A land capability map was adopted from the published report "Integrated mission for sustainable development: Development of the action plan for land and water resources" (APSRAC 1994) prepared by APSRAC, for the Ranga Reddy District, India.

In all, eight land capability classes have been recognized (Soil Survey Manual 1970). Soils in Classes I to IV are considered suitable for agriculture, whereas those in Classes V to VII are not suitable for cultivation, and are recommended for silvipasture and other uses. Soils of Class VIII are not suitable for any cultural use. Land capability classes are further subdivided as per the predominant hazard and limitation of ground, such as

1. Erosion and run-off—e,
2. Excess of water—w,
3. Root zone limitations—s, and
4. Climate limitations—c.

Table 3. Proposed Decision Rules for Alternative Sustainable Land Use/Land Cover

Sl. No.	Soil and water conservation unit	Groundwater prospects liters per minute	Land capability	Present land use/ land cover	Recommended alternate land use/land cover code
1	1	10–50	IVes	LWS	1
2		50–100	IVes	LWS F	2
3		100–200	IVes	DC, KU, F	3
4		10–50	IIIes	LWS	4
5		50–100	IIIes	KU	5
6		100–200	IIIes	KU	6
7	2	10–50	IIIes	KU, LWS	1
8		50–100	IIIes	KU	2
9		50–100	IIe	KU, F	5
10		100–200	IIe	DC, KU	7
11		100–200	IIIes	KU	5
12		50–100	IIIes	KU	5
13	3	10–50	IIIes	F, LWS	1
14		50–100	IIIes	KU	5
15		100–200	IIIes	DC, KU	7
16		50–100	IIes	KU, F	5
17		100–200	IIe	KU, DC	7
18		10–50	IIIes	F, LWS	1
19		50–100	IIIes	KU, F	5
20		100–200	IIIes	KU	7
21		50–100	IVes	F, KU	2
22	4	<10	IVes	BSW, LWS	11
23		10–50	IVes	LWS	1
24		50–100	IVes	LWS	1
25		50–100	IVes	KU	5
26		100–200	IIIes	KU, DC	7
27		50–100	IIe	KU	5
28	5	50–100	IIw	DC	8
29		100–200	IIw	DC	13
30	6	10–50	IIe	F, LWS	1
31		50–100	IIe	KU	5
32		100–200	IIe	DL, KU	7
33	7	10–50	IIe	F, LWS	4
34		50–100	IIe	KU	5
35		100–200	IIe	DC, KU	12
36	8	Irrespective	Irrespective	Irrespective	11
37	9				9
38	10				10

The land capability map is a derived map, prepared from the soil map, based on the above criteria (Fig. 8). Accordingly, the soils in the watershed are classified into five categories (Table 2).

Alternate Sustainable Land Use Options Map. The following four maps are integrated for generating alternate sustainable land use options map (Fig. 9.)
1. Soil and water conservation,
2. Groundwater prospects,
3. Land capability, and
4. Present land use/land cover.

Proposed Decision Rules

Based on the above-mentioned four themes, alternate sustainable land use options were decided and are presented in Table 3. Detailed description of the alternate land use recommendations are provided in Table 4.

Results and Discussion

There are eight soil series in the watershed under study (Fig. 2). Soils are red in color (Alfisols), and depths vary from less than 0.25 m to more than 1.00 m. The total area covered by soils having depths more than 0.50 m is 27 km^2 and the geographical extent of soils having depths between 0.25 and 0.50 m is 12.88 km^2. Nearly level slopes ranging between 0 and 1% covers 13.4 km^2 area. Slopes in the range of 1–3% predominate the watershed with 27.75 km^2 area covered by it and 58% of the land has 1–3% slope. From the land use/land cover map, it is observed that fallow land is spread over 22.74 km^2 of the watershed. More and

Table 4. Recommended Alternate Land Use/Land Cover

Recommendation code	Description	Area covered statistics in km^2
1	Pasture	3.039
2	Improved pasture with protective irrigation	2.458
3	Sorghum−castor rotation, dry land horticulture	3.936
4	Hardy fruit species	0.408
5	Sorghum−castor rotation, Pear l millet+green gram	17.165
6	Sorghum+pigeon pea−castor rotation	0.763
7	Agrohorticulture with mango	1.990
8	Irrigated paddy	0.051
9	Mining area	1.005
10	Water body	0.854
11	Stone wall enclosures for natural regeneration	3.325
12	Paddy pulses with rotation, cotton	11.724
13	Paddy–Paddy	1.306

more area is coming under wasteland, i.e., scrub category. Presently, scrublands cover 10.727 km^2 of the watershed. Double cropping is practiced in 11.807 km^2 of the watershed, i.e., 27% of the watershed area.

From soil erosion estimates, it is found that in 41% of the area, soil erosion is above the tolerance limit. Almost 23% of the area has soil erosion between 7.5 and 20.0 t ha^{-1} $year^{-1}$. From these figures, it is quite evident that soil erosion control measures are absolutely necessary in the watershed area.

The soil and water conservation map for the watershed is presented in Fig. 6, and the details regarding the proposed soil and water conservation recommendations are coded in Table 1. As a way of farming, contour cultivation has been suggested everywhere as a basic treatment in all conservation measures. *Bunds* of size 0.3 m^2, contour cultivation, and vegetative barriers are suggested in areas where soils are moderately deep, slopes are gentle, and the erosion rate is more than the allowable limit. This treatment covers an area of 15.36 km^2, i.e., 32.24%. *Bund* is a raised embankment of the given cross section provided along the boundary of the fields. *Bunds* of 0.3 m^2 cross section, with surplus weirs and mulching of field, is suggested for areas having deep soils with an erosion rate more than the allowable limit and slope less than or equal to 5%. This treatment covers 2.42 km^2 of the watershed area, i.e., 5.08%. Nominal measures for soil conservation, as strengthening of boundary bunds, are suggested in areas having deep soils, gentle slopes having an erosion rate less than the allowable limit. These areas cover 18.67 km^2, i.e., 38.9%. For areas with a slope more than 10%, cultivation is difficult. The soils in these areas are hard, depth is less than 0.25 m. Therefore, silvipasture is recommended with gully plugging, trenches. The area covered under this treatment is 3.00 km^2, i.e., 6.24% of watershed area.

In the case of moderately weathered pediplain, the depth of weathering is 10−20 m. Yield range of wells is 100−200 L/min. Near the fractures, yield of wells is about 200–400 L/min. In the case of shallow weathered pediplain, weathering is 0−10 m. Groundwater prospects are moderate. The yield of well ranges between 50 and 100 liters per minute.

The watershed under this study has several confirmed and inferred lineaments and few faults trending mainly in the N–S, NNW–SSE directions. These are zones of groundwater recharge. Yield of wells in the pediplain moderately weathered is 100−200 L/min; near the fractures, it is 200−400 L/min. Yield of wells in the pediplain shallow weathered zone is 50−100 L/min. The quality of water is potable.

It was observed that 16.72 km^2 areas have good water potential wells, yielding 100−200 L/min. A geographical area of 23.08 km^2 has wells yielding 50−100 liters per minute of water, and 5.43 km^2 area has water potential of 10−50 L/min, and the remaining area of 1.937 km^2 is the run-off zone.

Soil Series 6, 7, and 8 have land capability class IIe and cover that is 26.83 km^2 area of the watershed, i.e., 55% of the total. Soil Series "9" has land capability class as IIw due its depth, which is more than 1 m, gentle slopes but poor drainage. It is available in only the 0.17 km^2 area. Land capability class IIIes is assigned to soil series "5," as its depth range is 0.25−0.50 m, erosion is severe. This series covers 12.88 km^2, i.e., 26.8%, approximately. Soils with severe limitations having class IVes, namely, soil series "3" and "11", are spread over 4.72 km^2. These soils are shallow with erosion problem. Soil series "1" have very little depth, steep slopes, and low water holding capacity. These soils have land capability class of VIes. They are categorized as unsuitable for agriculture. Area coverage of these soils is 2.56 km^2.

From the analysis of the action plan for alternative sustainable land use map (Fig. 9), it is evident that due to scarcity of water and less soil depth, 3.09 km^2 of the watershed has to be used for pasture only. Sorghum castor rotation can be implemented in places where water availability is 50−100 L/min; slopes are up to 10%, land capability IIe or IIIes; 17.16 km^2 of the watershed can have this land use. Sorghum-pigeon pea−castor rotation may be provided if water availability is 100–200 liters per minute, soils have moderate depths, i.e., between 0.25 and 0.50 m, and land capability class is IIe or IIIes. This is suggested for 0.763 km^2 of the area. Protective irrigation with pasture is suggested for places wherever water availability is moderate, i.e., 50−100 liters per minute; land capability class is IVes or IIIes. It covers an area of 2.46 km^2. Irrigated paddy is suggested for soils having drainage problems, depth of more than 100 m, land capability class IIw, water potential between 50 and 100 liters per minute: 0.0512 km^2 is suitable for irrigated paddy. Agrohorticulture with mango is recommended wherever water potential is between 100−200 liters per minute, land capability IIe and soil erosion is within limits. An area of 2.0 km^2 is suitable for agrohorticulture with mango. Only 1.306 km^2 of the area is suitable for paddy in both seasons, as this land is characterized by good groundwater potential (100 and 200) liters per minute) having IIw land capability class. Paddy and pulses are suggested in 11.0 km^2 where the water availability is between 100 and 200 liters per minute and the land capability class is IIe.

Conclusions

The new approach is found to be very useful, as it takes into consideration basic factors necessary for the overall development and management of watershed. The suggested approach is useful because

- It takes into account the present condition of resources, such as soil and groundwater,

- It caters to the needs of the local people by considering the present land use options, which may improve their livelihood (Example: pasture for cattle grazing),
- The entire watershed area can be put to use profitably, hence, optimum utilization of land is ensured,
- This method ensures stoppage of further degradation of the resources through appropriate soil conservation measures and land uses,
- Resurrection of the watershed shall result in rising water levels, due to the implementation of soil and water conservation measures, and growing of low water consuming crops/irrigated dry crops, and
- The soil conservation measures suggested are not cost intensive, and can be done by the farming community themselves,

There is enough scope available for upscaling this process in the present national watershed program' in the semiarid areas, for fulfilling the component of alternate land use systems in the watershed in a more scientific way.

Notation

The following symbols are used in the paper:

BSW = barren stony waste;
DC = double crop;
F = fallow land;
ha = hectare;
KU = *Kharif* unirrigated (rainfed);
LWS = land with/without scrub;
T = tons.
yr = year.

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