A Synergistic Approach towards Sustainable Land Resources Management Using Remote Sensing and GIS Techniques

An Indian Experience in the Semi-Arid Tropics under the National Project 'Integrated Mission for Sustainable Development'

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1. Abstract

Land is a vital resource and is the basis of the existence of mankind. Management of this resource including its conservation and utilization is of crucial importance. In many countries across the globe, land is subjected to varying degrees and forms of degradation due to the pressure of the growing population, increased demand for food, fodder and fuelwood and intensive industrial activity. Satellite remote sensing technology coupled with conventional methods have been used to generate information on the current status and utilization potential of land resources. These databases have been analyzed to identify local specific alternate landuse management practices. The resultant landuse model' was validated on the ground. These models have been found to be extremely helpful in developmental planning and implementation.

2. Introduction

The natural resources of a country are its most sacred endowment. It is a base on which all life depends and in most countries of the world it is the life support system. In the recent past, with burgeoning populations and the national goals of seeking self-sufficiency in food and fibre production, the resource base is slowly being stripped. While natural systems often adapt to stress in a remarkable fashion, some relationships -once destroyed - can never be restored (Dill, 1990).

The main result is man-induced degradation of land resources through inadvertent, inappropriate or misuse of technological innovations. When degradation becomes a continuing process, yields decline and the farmer is forced to eke a living on another piece of land, which in most instances may be a fragile ecosystem like steep lands or coastal swamps since much of the better arable land is already under cultivation. The system then becomes iterative to the detriment of all.

Out of the total geographical area of 329 million hectares of India, about 187 million hectares is under various stages of degradation (Sehgal and Abrol, 1994) due to the pressure of growing population, increased demand for food, fodder and fuelwood and intensive industrial activity. Urgent efforts are called for conserving the shrinking land resource base (from the present 145 million hectares to an expected 123 million hectares by 2030 AD) and at the same time, exploiting it to support the exploding population from the present 934 million to the expected 1400 million by 2030 AD with a foodgrain requirement of 240 million tons (Ministry of Agriculture, Government of India, 1996). This makes proper planning of development plans an imperative rather than an option for sustainable management of natural resources.

Geographical Information Systems (GIS) have proved to be immensely helpful in the organization of the huge database generated through space technology (Trotter, 1991). The utility of GIS in the analysis and modeling of integrated information is well established (Burrough, 1989). GIS has been used in the development of digital databases, assessment of status and trends of resources utilization of the areas and to support and assess various resource management alternatives (Clark, 1990). Spectacular developments in the field of GIS to synthesize various thematic information with collateral data have not only made this technology effective and economical but also a tool to arrive at development strategies for sustainable land and water resources management.

Natural resources management for sustainable development is a major study undertaken by the Department of Space, Government of India, under the project 'Integrated Mission for Sustainable Development (IMSD). The study has been taken up in 174 districts all over the country, covering nearly 45 percent of the geographic area of the country. It aims to generate spatial databases on various natural resource themes, to integrate and analyze them for arriving at sustainable agro-based landuse alternatives. These maps serve as vital inputs for policy makers in the planning and implementation of developmental activities related to watershed management.

This paper presents the methodology and results obtained in the applications of remote sensing and GIS for suggesting landuse alternatives for sustainable land management in a selected watershed in Ahmednagar district of Maharashtra state, India. The watershed has semi-arid tropical conditions. The results obtained in this case study, though location specific, are indicative of the direction of the approach and their usefulness in planning sustainable land management.

3. Methodology

The methodology comprises the establishment of a spatial resource database and its analysis to arrive at land and water resources development plans (fig. 1).

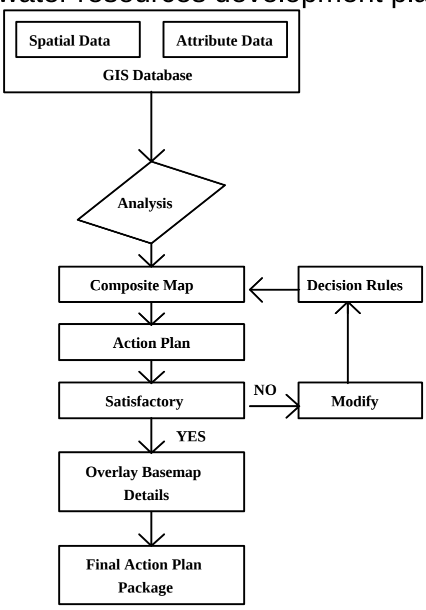

Figure 1. Flow Chart showing the Study Methodology.

4. Resources Database

High resolution (36 meters) multi-spectral data from Indian Remote Sensing Satellite (IRS) - 1A/1B of rainy, post - rainy and summer seasons are used for generating the spatial database at 1:50,000 scale. Both digital data and photographic data products are used in the analysis and mapping. Limited ground checks were carried out for improving the accuracy of thematic maps viz. Landuse / landcover, Soils and Hydro-geomorphology.

5. Collateral Data

Apart from the resource information derived from satellite data, collateral information is collected from various sources. The data included Survey of India topographical maps (1:50,000 scale), information on slope, soil chemical characteristics and meteorological information. Besides, data related to demography and socio-economic framework of the region are used to ensure that the development plan arrived at is locale-specific while being socially and culturally acceptable.
Maps on the following themes were prepared at 1:50,000 scale.

- Geology, geomorphology and ground water prospects
- Current landuse /land cover
- Soils
- Slope
- Drainage, surface water bodies and watershed
- Settlement location and transport network

6. Digital Resource Database

All the thematic maps were converted into digital form, using a scanner. The dataset was converted from raster to vector from using RVCS Software. After preliminary editing, the data were imported into ARC/Info GIS (version 7.0.1 on IBM RS6000 workstation) and different thematic layers were edited to create an error free digital database.

7. Data Integration and Development Alternatives

The integration of various thematic maps and further manipulation / analysis for identifying alternatives for development were carried out using ARC /Info GIS.

The digitally classified outputs were feature coded and stored in the map information system. These individual maps were integrated to arrive at 'Composite Land Units' (CLU). A CLU is a three-dimensional landscape unit, homogenous in respect of characteristics and qualities of land, water and vegetation and separated from other dissimilar units by distinct boundaries. The CLU characteristics imply physical parameters of the component resources of a biophysical domain, whereas qualities are suggestive of their potentials for specific users under a defined set of conditions. Based on the interaction among the basic resources of land, water and vegetation, which form the major components of primary production systems, useful inferences are drawn about their behaviour in meeting various planning goals. Socio-economic, institutional and other statistical data were entered into the attribute database. The decision criteria were structured within the framework of resource potentials and other determinants to evolve a pragmatic model.

8. Development of land / water use alternatives

The development model alternatives within the framework of optimal landuse. The optimal broad landuse category is derived from the CLU. This, when matched with present landuse helps in the decision of landuse revision, matching the land capability class. The land resources development plans generated suggest suitable sites for water, harvesting structures, sites for soil conservation, sites for agroforestry, horticultural plantations, silvipasture etc.

9. Study Area

The study area is the GV130 watershed, Ahmednagar district, Maharashtra, India. The IRS FCC image of the watershed is given below. The area is about 12100 hectares and lies between North latitudes 19°04'32" and 19°15'18" and East longitudes 75°05' and 75°15'. Physiographically the area consists of hilly and undulating terrain, foothill zones and plains. It receives rainfall during the southwest monsoon and the normal annual rainfall varies from 500mm to 700mm. It is generally drought prone and agriculture is dependent on the monsoons leading to uncertain and lower crop intensity.

10. Natural resource setting

Figures in Annex 1 (and next page) show the thematic maps and action plan map. These are briefly described below.

FCC image of the study area

10.1 Geomorphology

The major geomorphic units identified were dissected plateau with varying severity of dissection and valley fills along stream courses. The plateau is of basaltic origin.

10.2 Slope

Seven categories of slopes have been identified. The general slope of the watershed is southeast to northwest.

10.3 Groundwater

The data obtained on various groundwater related parameters (Physiography, drainage, structure, geomorphology etc. analyzed in conjunction with ground based data) indicated that plateau with slight dissection and valley fill areas have good ground water potential.

10.4 Land Use / Land Cover

The spatial distribution of landuse / land cover of the watershed as interpreted from satellite imagery was presented in Table 1. As seen from the Table about 53 percent of the total area in the watershed is under cultivation. Wasteland constitutes about 36 percent of the geographic area of watershed. Forests occupy about 9 percent of the area.

10.5 Soils

In all, 11 soil categories (series and associations) were identified in the watershed.

10.6 Drainage

The drainage pattern of the project area is dendritic to sub parallel. The thematic information was organized in ARC/Info GIS and integrated to generate the CLU map. A set of decision rules (Appendix 2) already framed (based on ground observations, discussions held with experts in relevant fields and available literature) were applied on the integrated coverage, using the logical expressions in GIS. These rules consider the available resources and suggest the best alternative landuse possible for sustainable resource utilization.

Thematic Maps and derived Action Plan of GV130 Watershed.

Action Plan Map derived by integrating the four resource maps and application of 'decision rules' on the integrated map

11. Results

The 'Action Plan' map showing the spatial distribution of different agro-based alternate landuse suggestions Viz. Double crop, horticulture, agrohorticulture, silvipasture, afforestation and agroforestry were derived from the CLU map. The spatial statistics for existing land cover and suggested landuse are given in Tables 1 & 2.

Table 1. Area statistics for landuse/landcover map

S.No	Action Item	Area km^2
1	Kharif	8.92
2	Rabi	12.64
3	Double crop (Kharif+Rabi)	43.17
4	Fallow	0.763
5	Degraded/under utilised forest	5.42
6	Scrub forest	2.83
7	Forest plantation	3.02
8	Land with /without scrub	42.97
9	Water body	1.31
Total 121.043		

Table 2. Area statistics for Action Plan

S.No	Action Item	Area km^2
1	Afforestation	5.84
2	Fuel and Fodder Plantation	20.274
3	Silvipasture	3.23
4	Horticulture	12.585
5	Agro-forestry	0.801
6	Agro-horticulture	16.714
7	Double Crop	12.565
8	Area not recommended for any activity	49.039
Total 121.043		

12. Feed back

The 'Action Plan' map was handed over to the implementing agencies for use in regional planning. Impressed by the results, the implementation of various suggested activities was taken up by the local administration.

13. Future Challenges

An increasingly useful application of GIS is the development of Land Information System, which provides upto date records of land tenure, land values, landuse, ownership details etc. in both textural and graphic formats. In such a system, the land parcel (survey boundary) is the principal unit around which the collection, storage and retrieval of information operate. The information contained in a cadastral system makes it possible to identify the extent and level of development and management of land (assuming the quality of information in the cadastres is adequate) to make effective plans for the future.

With the availability of high-resolution data from state - of - art satellite like IRS-1C and proposed satellites like Cartosat with 2m resolution, the satellite data with integration of cadastral boundaries help in generating information in greater details and facilitate updating of existing records. They also serve as useful inputs in prioritizing implementation of area development plans and effective monitoring.

14. Conclusion

Sustainable land management technologies require reliable and repetitive information on the current status and utilization potential of natural resources. Satellite remote sensing data in conjunction with collateral data proved to be very effective in meeting these requirements. Geographic Information system (GIS) served as a very effective tool in the storage, manipulation, analysis, integration and retrieval of information. The synergistic use of these front line technologies helped to evolve an ‘action plan’ which was quite useful in planning for sustainable management of land resources.

15. Acknowledgements

The authors thank Dr. DP Rao, Director, NRSA, for his constant encouragement during the course of this work and permission to present this paper. Thanks also to the colleagues of the Integrated Surveys Division for their useful suggestions and to the scientists of Maharashtra State Remote Sensing Centre for their valuable inputs for this study. Thanks to Mrs. Sunitha Xavier for typing assistance.

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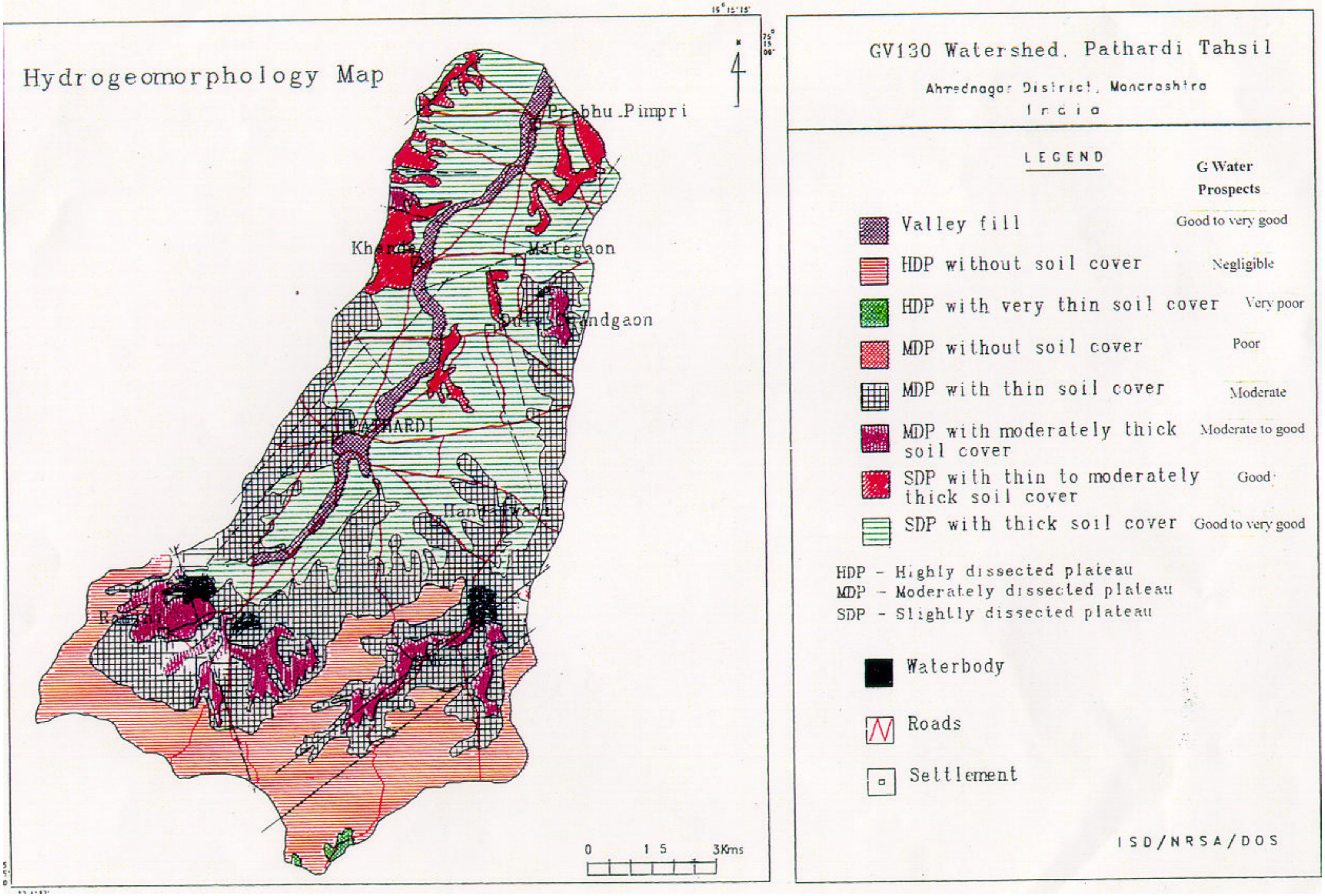

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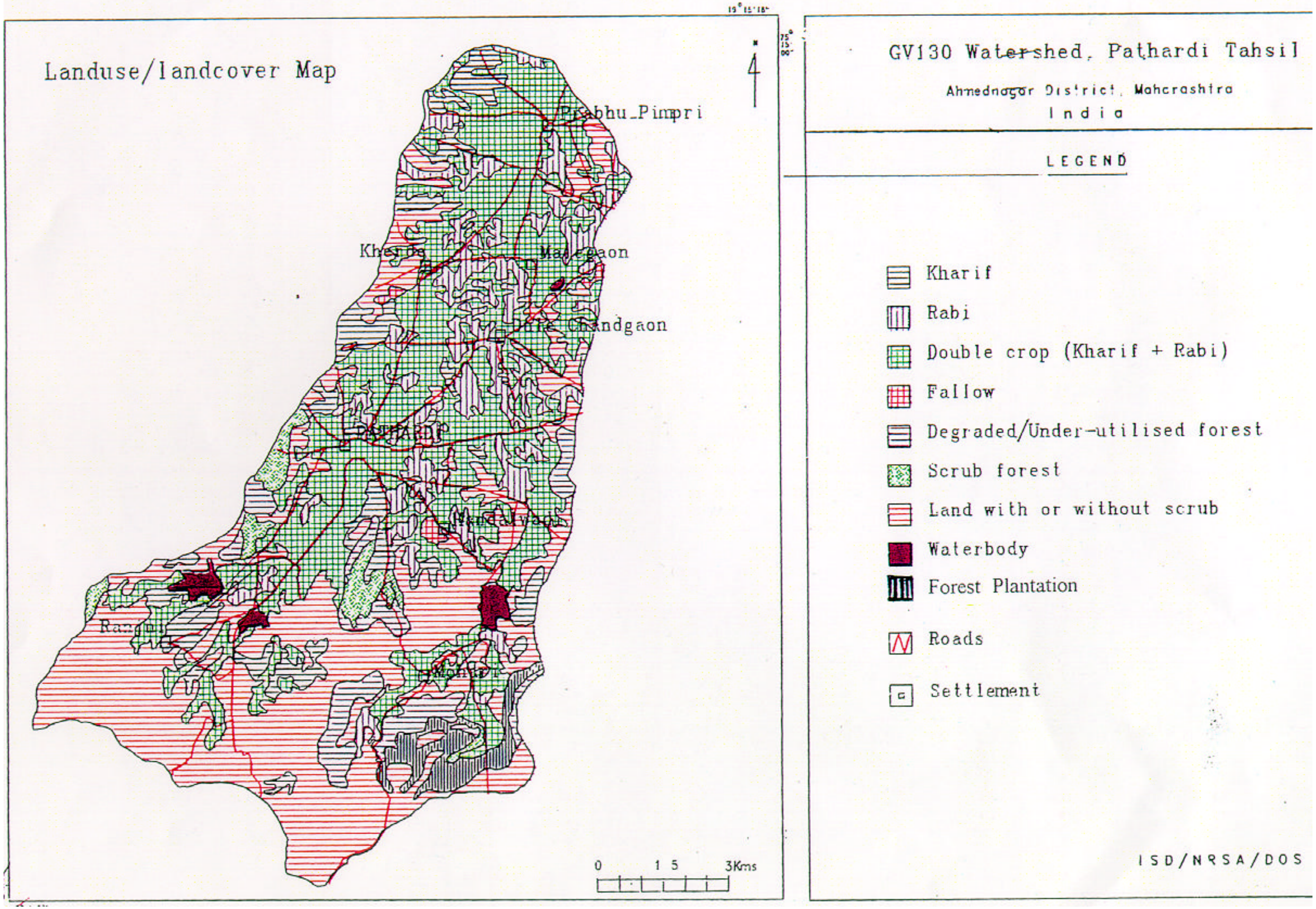

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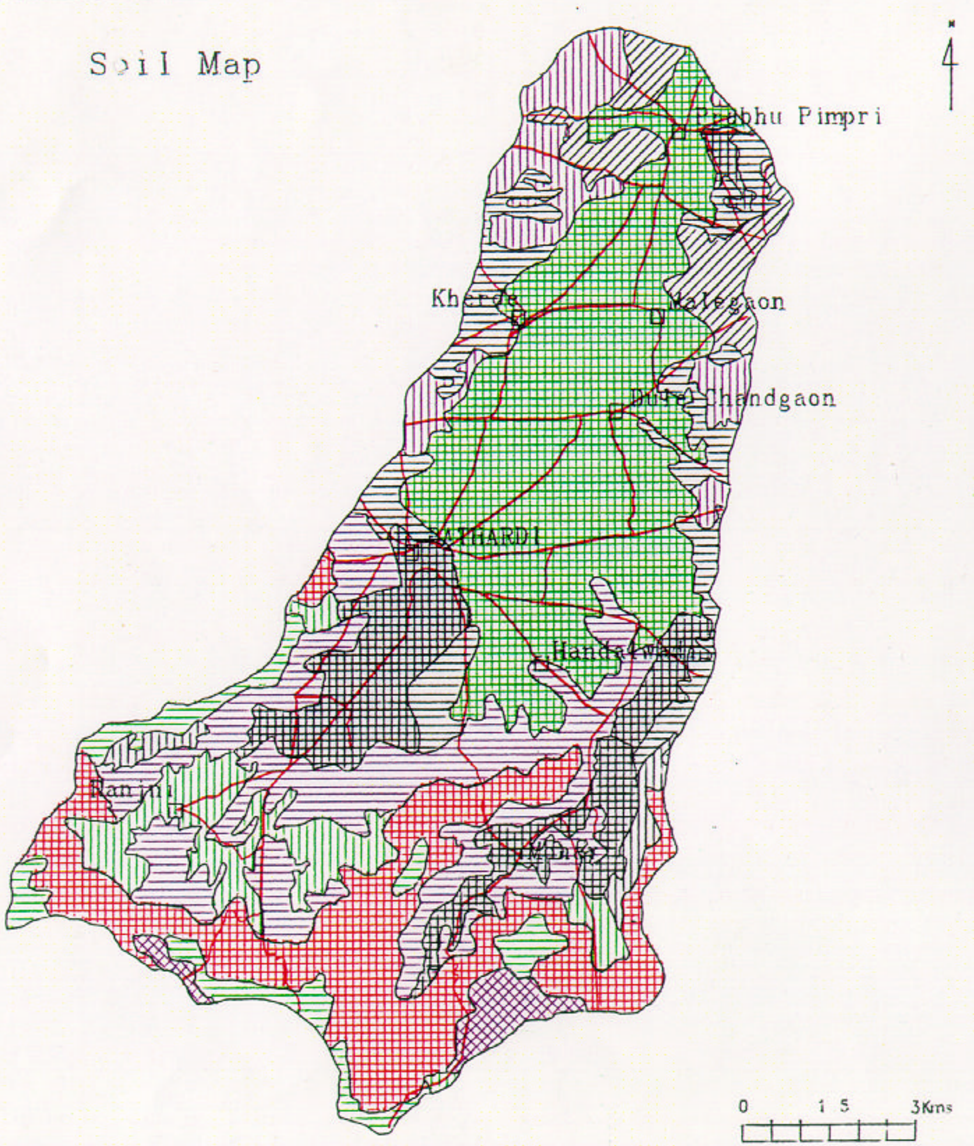


GV130 Watershed, Pathardi Tahsil

Ahmednagar District, Maharashtra
India

LEGEND

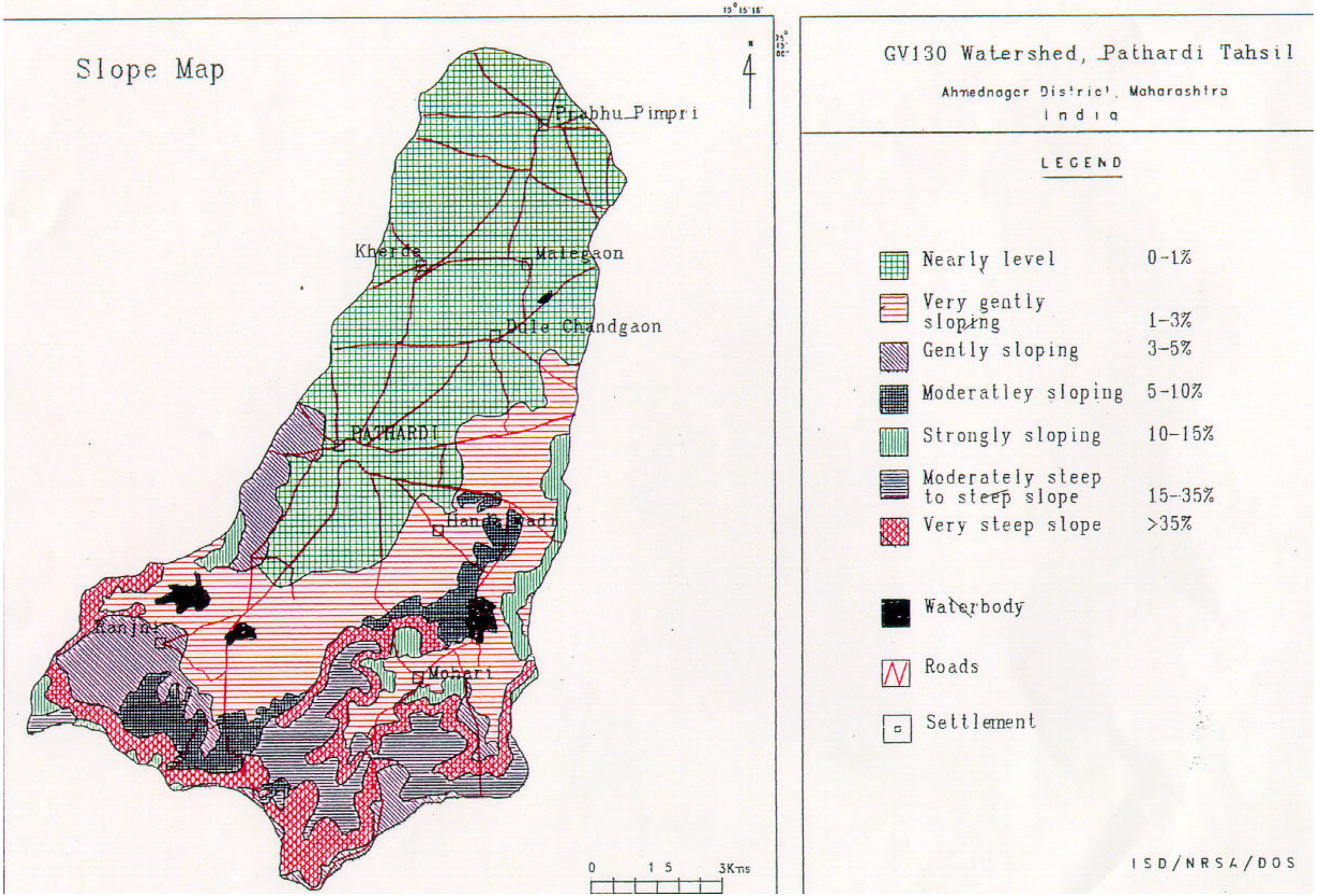
Series/ Association	Description
Sibneri Sindodi	FL mixed i h t L u thents LS mixed i h t L u thents
Sindodi Sibneri Khanapur	LS mixed i h t L u thents FL mixed i h t L u thents LS mixed i h t calc L u thents
Pargaon Wadgaon Khanapur	LS mixed i h t calc L u thents FMM i h t V u pepts LS mixed i h t L calc u thents
Pargaon Tarkewadi Sindudi	LS mixed i h t calc L u thents CS mixed i h t V u pepts LS mixed i h t L u thents
Pargaon Wadgaon Sindodi	LS mixed i h t calc L u thents FMM i h y V u pepts LS mixed i h t L u thents
Wadgaon Sawargaon Pargaon	FMM i h t V u pepts FMM i h t V u pepts LS mixed i h t calc L u thents
Pargaon Tarkewadi	LS mixed i h t calc L u thents CS mixed i h t V u pepts
Pargaon Tarkewadi Wadgaon	LS mixed i h t calc L u thents CS mixed i h t V u pepts FMM i h y V u pepts
Pargaon Wadgaon Sawargaon	LS mixed i h t calc L u thents FMM i h y V u pepts FMM i h t V u pepts
Sawargaon Nimone Otur	FMM i h t V u pepts FMM i h t U c sterts FMM i h t T c sterts
Sawargaon Otur Wadgaon Umraj	FMM i h t V u pepts FMM i h t T c sterts FMM i h y V u pepts FMM i h t U c sterts

Roads

Settlement

ISD/NRSA/DOS

INTEGRATED MISSION FOR SUSTAINABLE DEVELOPMENT



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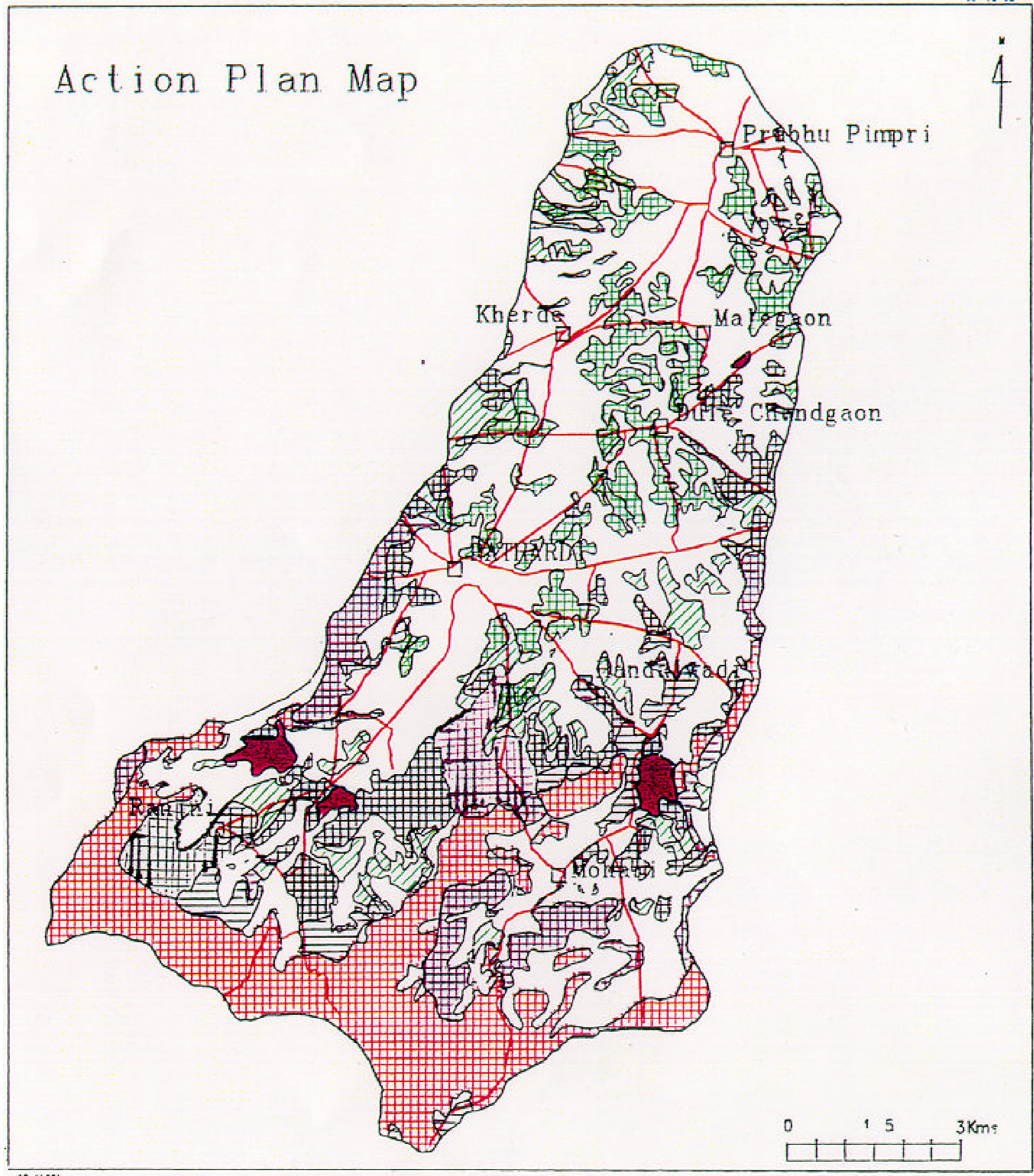

GV130 Watershed, Pathardi Tahsil

Ahmednagar District, Maharashtra

India

LEGEND

- Afforestation
- Fuel and Fodder plantation
- Silvipasture
- Horticulture
- Agro-forestry
- Agro-horticulture
- Double crop
- No recommendation
- Waterbody

- Roads
- Settlement

ISD/NRSA/DOS

Annex 2. Characteristics of Composite Land Unit and Suggested Landuse for GV 130 Watershed

Characteristics					Composite land unit	Suggested landuse
Landform	Soil	GW Prospects	Slope	Present landuse		
HDP-A	Lithic Ustorthents	Negligible	15-35%	Degraded forest & Scrub forest	**1**	***Afforestation***
MDP-B	Lithic Ustorthents	Moderate good along fractures	15-35%	Degraded forest & Scrub forest		
MDP-B	Lithic Ustorthents	Moderate good along fractures	10-15%	Degraded forest & forest		
MDP-B	Lithic Ustorthents	Moderate good along fractures	5-10%	Degraded forest & Scrub forest		
MDP-B	Lithic Ustorthents	Moderate good along fractures	3-5%	Degraded forest & Scrub forest		
MDP-B	Lithic Ustorthents	Moderate good along fractures	1-3%	Degraded forest & Scrub forest		
HDP-A	Lithic Ustorthents	Negligible	>35%	Land with / without scrub	**2**	***Fuel & Fodder plantation***
HDP-A	Lithic Ustorthents	Negligible	15-35%	Land with / without scrub		
HDP-A	Lithic Ustorthents	Negligible	10-15%	Land with / without scrub		
HDP-A	Lithic Ustorthents	Negligible	5-10%	Land with / without scrub		
HDP-A	Lithic Ustorthents	Negligible	3-5%	Land with / without scrub		
HDP-B	Lithic Ustorthents	Poor	15-35%	Land with / without scrub		
MDP-B	Lithic Ustorthents	Moderate good along fractures	15-35%	Land with / without scrub		
MDP-B	Lithic Ustorthents	Moderate good along fractures	10-15%	Land with / without scrub		
HDP-A	Lithic Ustorthents	Negligible	1-3%	Land with / without scrub	**3**	***Silvipasture***
HDP-B	Lithic Ustorthents	Very poor	3-5%	Land with / without scrub		
HDP-C	Lithic Ustorthents	Poor	3-5%	Land with / without scrub		
MDP-B	Lithic Ustorthents Vertic Ustropepts	Moderate good along fractures	5-10%	Land with / without scrub		
MDP-C	Lithic Ustorthents Vertic Ustorpepts	Moderate to good, very good along fractures	5-10%	Land with / without scrub		
MDP-A	Lithic Ustorthents Vertic Ustropepts	Poor	1-3%	Patches of single crop	**4**	***Horticulture***
MDP-B	Lithic Ustorthents Vertic Ustropepts	Moderate, good along fractures	3-5%	Land with / without scrub		
MDP-B	Lithic Ustorthents Vertic Ustropepts	Moderate good along fractures	1-3%	Land with / without scrub		
MDP-B	Lithic Ustorthents Vertic Ustropepts	Moderate, good along fractures	0-1%	Land with / without scrub		
MDP-C	Lithic Ustorthents Vertic Ustropepts	Moderate to good,very good along fractures	3-5%	Land with / without scrub		
MDP-C	Lithic Ustorthents Vertic Ustropepts	Moderate to good, very good along fractures	1-3%	Land with / without scrub		
MDP-C	Lithic Ustorthents Vertic Ustropepts	Moderate to good, very good along fractures	0-1%	Land with / without scrub		

Characteristics					Composite land unit	Suggested landuse
Landform	Soil	GW Prospects	Slope	Present landuse		
SDP-B	Lithic Ustorthents Vertic Ustropepts Udic Chromusterts Typic Chromusterts	Good, very good along fractures	0-1%	Land with / without scrub		
SDP-C	Vertic Ustropepts Udic Chromusterts Typic Chromusterts	Good to very good, more promising along fractures	0-1%	Land with / without scrub		
MDP-B	Lithic Ustorthents Vertic Ustropepts	Moderate, good along fractures	10-15%	Single crop	**5**	***Agro-forestry***
MDP-B	Lithic Ustorthents Vertic Ustropepts	Moderate, good along fractures	5-10%	Single crop		
MDP-B	Lithic Ustorthents Vertic Ustropepts	Moderate, good along fractures	3-5%	Single crop		
MDP-B	Lithic Ustorthents Vertic Ustropepts	Moderate, good along fractures	1-3%	Fallow		
MDP-C	Lithic Ustorthents Vertic Ustropepts	Moderate to good, very good along fractures	5-10%	Single crop		
SDP-B	Lithic Ustorthents Vertic Ustropepts Udic Chromusterts Typic Chromusterts	Good, very good along fractures	0-1%	Fallow		
MDP-B	Lithic Ustorthents Vertic Ustropepts	Moderate, good along fractures	1-3%	Single crop	**6**	***Agro-horticulure***
MDP-B	Lithic Ustorthents Vertic Ustropepts	Moderate, good along fractures	0-1%	Single crop		
MDP-C	Lithic Ustrothents Vertic Ustropepts	Moderate to good, very good along fractures	3-5%	Single crop		
MDP-C	Lithic Ustrothents Vertic Ustropepts	Moderate to good, very good along fractures	1-3%	Single crop		
SDP-B	Lithic Ustorthents Vertic Ustropepts Udic Chromusterts Typic Chromusterts	Good, very good along fractures	0-1%	Single crop		
SDP-C	Vertic Ustropepts Udic Chromusterts Typic Chromusterts	Good to very good, more promising along fractures	1-3%	Single crop		
SDP-C	Vertic Ustropepts Udic Chromusterts Typic Chromusterts	Good to very good, more promising along fractures	0-1%	Fallow		
SDP-C	Vertic Ustropepts Udic Chromusterts Typic Chromusterts	Good to very good more promising along fractures	0-1%	Single crop	**7**	***Double crop***

HDP - Highly dissected plateau
MDP - Moderately dissected plateau
SDP - Slightly dissected plateau