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Production System Planning for Natural Resource Conservation in a Micro-Watershed

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Natural resources management is crucial for sustainable development of a region. It involves the knowledge of natural resources, planning for the sustainable use, and implementation at field level. A watershed is an area within a region with natural boundaries that are most appropriate for natural resources management. This paper emphasizes the need for a watershed approach, provides a brief description of that approach taken by India, and presents an exercise in planning and aiding in decision-making for a case study watershed. Production Systems Planning (PSP) is an approach presented here that can be taken for achieving natural resource conservation for the case study watershed. The proposed conservation measures are quite useful in the harmonious development of the region for food production.

Key Words: Natural Resources Management, Sustainability, Sustainable Development, Watershed Management, Production Systems Planning (PSP)

Introduction

Man's interaction with nature is rapidly becoming more complex due to a multitude of activities that directly or indirectly cause a disturbance in the natural system. The deeper interactions between human activities and natural ecosystems call for an interdisciplinary approach to natural resources management, while the inputs from multiple disciplines need to be effectively utilized in achieving it. This prudent natural resources management will enable sustainable development of a region without losing the resource base. Sustainable development essentially aims to reconcile conflicting objectives of economic development and improvement in human welfare, and ecological sustenance and functioning of ecosystems. The term *sustainable development* is defined by the Brundtland Commission as "the development that constitutes meeting needs of the current generation without compromising the ability of meeting needs of future generations" (Brundtland, 1989). Sustainable development is now globally accepted as a supreme long-term goal of humanity (World Commission on Environment and Development, 1987). Sustainable utilization of natural resources is essential for sustainable development.

It follows that the sustainability of renewable natural resources in general and common property resources in particular assumes importance in both developed as well as developing countries because of the finite capacity of the resource base and the increasing demand for its exploitation. The technical definition of the term *sustainability* is given as, "the ability of a natural resource system to produce a socially optimum level of output that is necessary to meet the needs and aspirations of the people dependent on the system perpetually without any detrimental effects on the resource system itself and the physical environment, and with no imposition of significantly greater risks on future generations" (Colchester as quoted by Singh, 1995). This might be comprehensive and deep rooted, but in other words, sustainability implies not only conserving natural resources but also maintaining ecological functions and the supply of natural resource products, which are essential to the livelihoods of local people. Sustainability in this sense is a dynamic concept that reflects changing levels of output corresponding with changing human needs and production technologies over time.

Natural Resources Management

Natural resources discussed here are broadly covered under land, water, and biomass (or vegetation). These three resources are crucial for production under various systems namely, agriculture, horticulture, silviculture, pisciculture, and animal husbandry. Management of these three major resources is crucial for making production in these systems sustainable and enhanced. Sustainability of these systems can be threatened due to disruption in the linkages between these resources. This may assume various forms, for example, increased soil erosion resulting in nutrient loss rendering it unfit for use in the case of land; soil water deficiency or excessiveness affecting its productivity and degradation in the case of water resources; decline in vegetation density and diversity leading to reduction in soil and water conserving properties in the case of biomass or vegetation resources, and so forth. A more detailed discussion of these follows.

Soil

Soil productivity can be defined as those properties of soil (physico-chemical and biological) that influence crop production. The increased yields from better-managed soils are due to increased inputs and improved practices rather than with improvements in the basic fabric of soil (soil productivity). In recent years the sediment derived from soil erosion has been the major non-point source of pollution in surface water bodies while loss of in-situ topsoil has caused reduction in productivity. Erosion reduces long-term production potential and seldom improves the immediate capacity of eroded soil to sustain plant growth or produced crops (Pierce, Larson, Dowdy, & Graham, 1983). Results of recent studies show that soil physical and biological properties seem to be the predominant constraints to maximizing plant production on eroded soil, compared with chemical and fertilizer constraints. For example, Rosenberry, Knutson, and Harmon (1980) suggested that yields generally decline as soils shift from one erosion phase to another, even with increased fertilizer. This is attributed to surface soil physical and biological properties. However, in addition to irrigation, other water management techniques, such as surface mulching, can also be applied for amelioration of eroded soil.

Water

Crop productivity is also affected by moisture availability in soil. In the post-green revolution, particularly in the 1980s, instability in crop productivity increased on account of the rise in sensitivity of output to variations in rainfall in India (Rama Mohan Rao et al., 1999). This increasing vulnerability of agricultural output to variations in rainfall, particularly during droughts when the soil moisture is scarce, is attributed to inadequate expansion of irrigation by these same authors. It is minor irrigation, which is not given priority that can be part of the strategy under watershed development. Similarly, decline in water quality has affected crop productivity in saline and alkaline lands that were created by excessive irrigation or polluted water in northern parts of India.

Vegetation

At the same time, vegetation adds much to resource endowment and has crucial linkages with soil and water. Good vegetation cover functions as a soil and water-conserving agent, whereas, lack of vegetation will make the soil vulnerable to erosion and allow water to flush off the sediments. Biological diversity of vegetation is crucial in the survival of the vegetation itself and the sustenance of the ecosystem in that region. In fact, planning based on land use can effectively conserve soil as well as water. This is little elaborated under Production Systems Planning (PSP).

A distinction, however, needs to be made between the goals of attaining sustainability and of increasing productivity. While higher productivity may be required to achieve the sustainability goal, the requisite increase in productivity must be achieved in a manner that will not jeopardize the ability of a natural resource system to meet future needs. In other words, it is possible to achieve increases in productivity through unsustainable short-term approaches (York as cited in Singh, 1995).

Watershed Management

The term *watershed* denotes the area defined by natural boundaries characterized by terrain (slope), soils, and drainage delimitations. Watershed is an appropriate unit for environmental (or ecological) planning for sustainable management of natural resources of a region. *Watershed Management* is a practice of conserving soil, water, and biological resources using scientific principles, traditional and systems knowledge, and local resources with an objective of increasing crop productivity. It involves rational utilization of land and water resources for optimum production with minimum hazards to national resources. It essentially relates to soil and water conservation in the watershed which means land use according to land potential, protection of land against all kinds of deterioration, building and maintaining soil fertility, conserving water for farm use, proper management of water for drainage, flood protection, sediment reduction, and increasing productivity for all kinds of land uses (Tejwani, and Tideman as cited in Das, 1998).

Watershed Management in India

Watershed management has come into focus in India with the advent of productivity fluctuations with rainfall, necessitating micro-irrigation in drier parts, and also with the advent of space technology

tools, which are useful in the micro-level planning. Land water related management projects and schemes have been implemented under various programs since the beginning of the Five Year plans. In particular, the third Five Year plan introduced the watershed as the basic hydrological unit for soil conservation planning and execution (Iyengar, 1996). Increased emphasis on watershed development programs for dry land plain regions in India, *inter alia*, is a manifestation of the shifting priorities in the agricultural sector, which until recently concentrated mainly on crops and regions with assured irrigation (Shah, 1998). Successful case studies of Ralegaonsiddhi, Myrada, are well known (Singh, 1995).

An integrated watershed development approach was taken for sustainable management of natural resources with micro-level planning. The main components of watershed management programs undertaken were:

- Creation of a database for macro and micro level planning;
- Awareness programmer for policy makers, planners, soil conservationists, foresters, scientists, and farmers; and,
- People's participation.

The government had shown concerted efforts towards soil and water conservation during the third Five Year plan. Besides numerous schemes and projects undertaken in that direction, there are three major programs that were implemented on a watershed basis: (1.) soil conservation in the catchments of River Valley Projects (RVP), (2.) integrated watershed management in the catchments of Flood Prone Rivers (FPR), and (3.) National Watershed Development Projects for Rainfed Areas (NWDPPRA). For implementation of watershed projects, the government has taken an approach of identifying critical watersheds after prioritizing watersheds on the basis of criticality of natural resources (in terms of degradation indices likes sediment yield, etc.) and other socio-economic conditions prevalent at country/state/district level. Recently, Rama Mohan Rao has made an attempt, et al. (1999) to classify soil and water conservation zones in India.

Production Systems Planning

In the sequence of evolution of natural resources management using the watershed approach for sustainability of these resources, thrust is on the productivity of natural systems. It is the productivity of natural systems that needs to be conserved through planning so that the needs of an increasing population are met and the threat to their renewability is thwarted. The watershed approach is an ideal approach to carry out a planning operation, and its planning framework shall fit well under the implementation and execution activities. Central to the success of the process is the participation of the population during the crucial implementation. Production systems planning (PSP) is a method of planning for the use of natural resources under the watershed approach with a focus on ecological characteristics. It essentially involves spatial allocation of land use for various production systems, namely, agriculture, horticulture, and animal husbandry, by which conservation goals are met through better decision-making. PSP is similar to regional land use planning, but it differs from it in that it depends on ecological characteristics at the watershed level rather than activities at the regional level. However, in both cases land use is an important element. The role of production systems in soil and water conservation is evident from the water and soil losses of catchments under such production systems such as mentioned by Mallik (as cited in Dhruv narayan, et al., 1989).

Table 1: *Soil and Water Losses Under Various Production Systems*

S. No.	Catchment Coverage	Loss of Water (cm)	Loss of Soil (kg/ha)
1.	Forest with normal cover	1	1
2.	Forest with poor ground cover	3	20

3.	Well managed pasture	3	14
4.	Agricultural crop	3	3250
5.	Grass lands (Pastures)	10	130

In most of the watershed management programs in India, emphasis is given on the operationalization of soil and water conservation program at the field level. PSP is a conservation-planning tool useful for watershed management through allocation of production systems to take care of soil and water conservation. PSP is not attempted in any of the watershed programmes in India. However, the Indian Council for Agricultural Research (1973) has proposed a three-tier production system based on the terrain characteristics alone to serve as a guide for PSP.

Table 2: *Terrain Based Production Systems Planning*

S. No.	Terrain Category (Slope)	Production System
1.	Gently sloping to flat (< 5%)	Arable crops
2.	Flat to moderate sloping (5-30%)	Horticultural crops
3.	Steep (>30%)	Forestry

In the current study, we attempt to carry out the production systems planning based on the ecological characteristics of a watershed. A micro-watershed is demarcated from a larger watershed and natural characteristics of the ecosystems are captured under thematic categories of slope, soil, drainage, and geomorphology. These along with the current land use are superimposed to prepare a production system plan. The methodology and procedure are described in the following section.

Case Study: Exercise Of Production Systems Planning In Gutturu Watershed

Introduction

We chose for our case study a micro-watershed from the watershed priority map of the study district Anantapur in Andhra Pradesh (Andhra Pradesh State Remote Sensing Applications Centre, 1995). This drought prone district has precarious natural resources and is affected by the excessive use of environmental resources resulting in a qualitative and quantitative decline leading to the prevalence of desertification conditions (Ramakrishna, 1996). This watershed falls under the Penukonda administrative block of the district and has a major village named Gutturu, by which it is named.

Data Analysis

As a first step of the exercise, thematic maps of the watershed describing the ecological characteristics were prepared. The slope [map1] and drainage maps [map2] were prepared using the topographic maps of the watershed. The maps of geomorphology [map3], soils [map4], and land use [map5] were prepared from visual interpretation of satellite imagery of IRS-1B provided by the Andhra Pradesh State Remote Sensing Applications Centre (APSRAC). The resulting classification under various themes and the maps created under each theme are presented hereunder. However, combining these themes into one single classification scheme is very difficult and often requires overlaying maps. The normal practice of analyzing overlain maps is to prepare a composite map of all

classes and then to reclassify into broad categories so that a suggestive measure is derived using the field knowledge and experience of an expert. This is verified through field level examination.

Methodology

In the current study a little deviation is made such that the composite map is drawn from thematic maps after assigning weights to themes. The criterion for judgment of production system is based on the weighted thematic map of the watershed. The weights are given on the basis of importance of the theme's ecological function in the whole watershed and ranking of the themes based on importance. The weights assigned are subjective, but derived after consulting with experts in watershed management. Objective methods of weight assignment also exist in the literature (Ramanathan, 1994) but they are seldom applied in such problems. However, such methods, when applied, produce ideal results and help in finding near perfect solutions. Another approach to ranking themes is to conduct a Delphi survey of experts and then combine the opinions using numerical techniques. However, the method applied here is a beginning and it can be extended to make use of the techniques mentioned above as well as other advanced techniques in forming criterion for judgment. Further, the scope of systems planning can be extended when it is done at an even larger scale and incorporating socio-economic data on the watershed. The thematic maps of various classes for the chosen watershed are shown subsequent to the tables.

Table 3: *Classification of Slope Theme*

S. No.	Gradient (%)	Slope Class	Score	Weighted Score
1.	0-1	1	5	25
2.	1-3	2	5	25
3.	3-5	3	4	20
4.	5-8	4	4	20
5.	8-15	5	3	15
6.	15-35	6	3	15
7.	> 35	7	1	5

Table 4: *Classification of Land Use Theme*

S. No.	Land Use	Score	Weighted Score
1.	Double Cropped	5	20
2.	Kharif Rainfed	3	12
3.	Scrub Land	4	16

4.	Scrub Hill	4	16
5.	Barren Hill	1	4
6.	Fallow Land	2	8
7.	Saline Land	1	4
8.	Eroded Land	1	4

Table 5: *Classification of Geomorphology Theme*

S. No.	Map Unit	Geomorphic Unit	Groundwater Potential	Score	Weighted Score
1.	PPS	Shallow Weathered Pediplain	Poor to Moderate	2	6
2.	PPM	Moderately Weathered Pediplain	Moderate to Good	4	12
3.	PPMA	Moderately Weathered Pediplain Covered with Saline Soils	Moderate to Good	3	9
4.	P	Pediment	Poor	1	3
5.	DH	Denudational Hill	Poor	1	3
6.	RH	Residual Hill	Poor	1	3

Table 6: *Classification of Drainage Theme*

S. No.	Drainage Unit	Score	Weighted Score
1.	Dendritic	2	2
2.	Linear	1	1

Table 7: *Classification of Soils Theme*

S. No.	Soil Erosion Class	Score	Weighted Score
1.	Nil to Slight Erosion	2	4

2.	Slight to Moderate Erosion	1	2
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Results

The aggregated scores are classified into 11 classes of various ranges mentioned in Table 8. For each category of the weighted score class, a suitable production system is allocated in consultation with a remote sensing and watershed expert. The production system plan for the watershed is prepared using this allocation method. The production system plan is shown for the watershed in the map following the table.

Table 8: *Production System Allocation*

S. No.	Weighted Aggregate Score	Planned Production System
1.	10-14	Forestry
2.	15-19	Forestry
3.	20-24	Silvipasture
4.	25-29	Fuel wood Plantation
5.	30-34	Social Forestry
6.	35-39	Conservation Agriculture
7.	40-44	Dryland Horticulture
8.	45-49	Dryland Agriculture
9.	50-54	Alley/Relay Cropping
10.	55-59	Intercropping
11.	>60	No intervention

The production systems plan [map 6] thus prepared based on the thematic maps and theme weights presents a methodologically different way of preparing watershed plan. The results can be directly translated into implementation with the help of wide range of stakeholders i.e., public officials, non-governmental governments and people who are the landowners or managers in the watershed area with the agricultural farmers, horticulture farmers, or forestry personnel.

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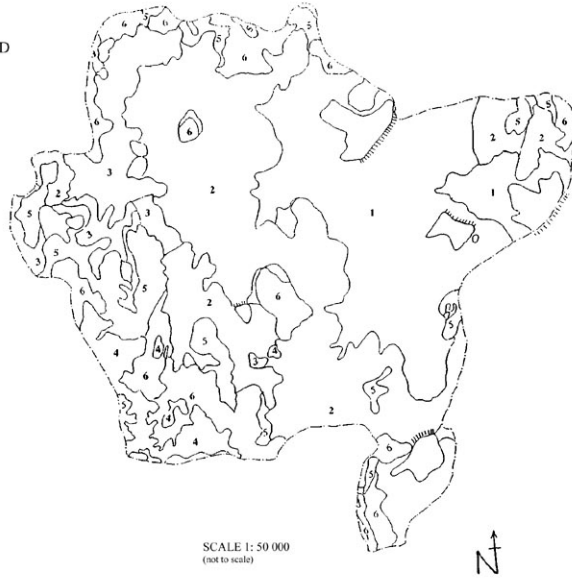
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GUTTURU MICRO-WATERSHED
SLOPE MAP

Slope Class	Gradient (%)
1	<1
2	1-3
3	3-5
4	5-8
5	8-15
6	15-35
7	>35

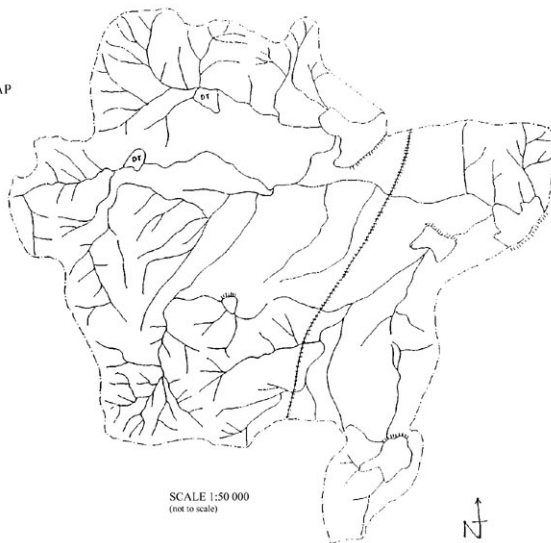


map1

GUTTURU MICRO-WATERSHED
DRAINAGE & SURFACE WATER BODIES MAP

LEGEND

	Drainage
	Dry Tank
	Tank



map2

GUTTURU MICRO-WATERSHED

HYDROGEOMORPHOLOGY MAP

LEGEND

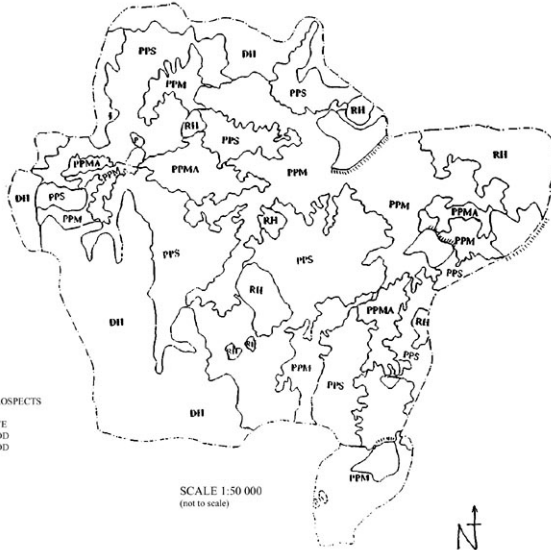
- PPS Shallow Weathered Pediplain
- PPM Moderately Weathered Pediplain
- PPMA -do- covered with Saline Soils
- P Pediment
- DH Denudational Hill
- RH Residual Hill

GEOMORPHIC UNIT

- SHALLOW WEATHERED PEDIPLAIN
- MODERATELY WEATHERED PEDIPLAIN
- MODERATELY WEATHERED PEDIPLAIN WITH SALINE SOILS
- PEDIMENT
- DENUDATIONAL HILL
- RESIDUAL HILL

GROUNDWATER PROSPECTS

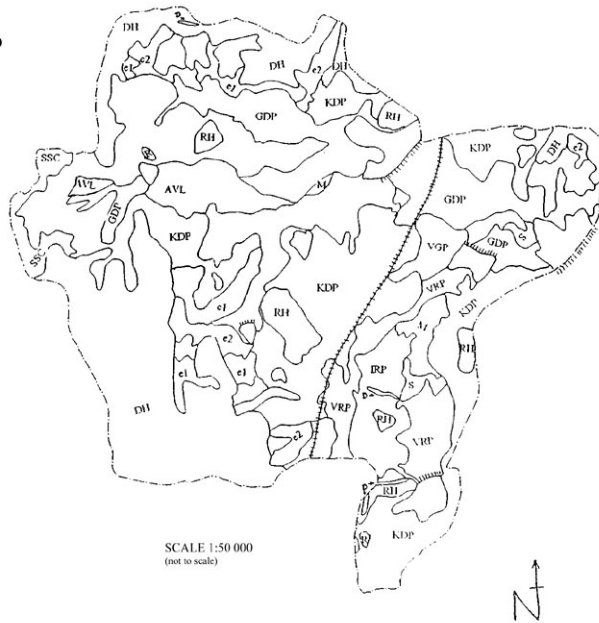
- POOR TO MODERATE
- MODERATE TO GOOD
- MODERATE TO GOOD
- POOR
- POOR
- POOR



map3

GUTTURU MICRO-WATERSHED

SOILS MAP

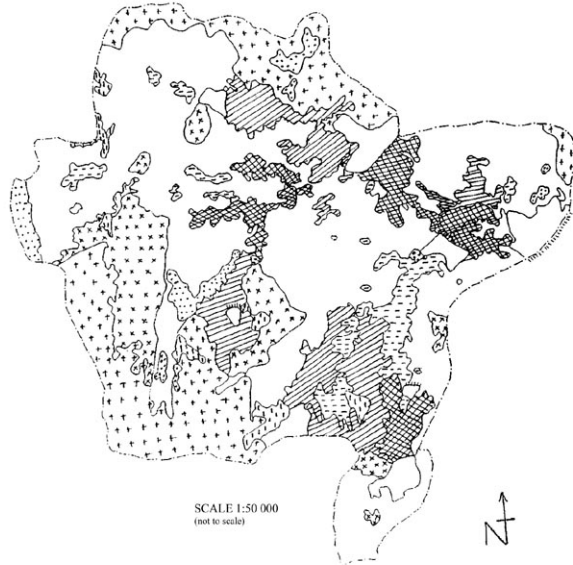


map4

GUTTURU MICRO-WATERSHED

LANDUSE MAP

- LEGEND**
- ▨ DOUBLE CROPPED
 - ▧ KHARIF-RAINED
 - FALLOW LAND
 - ▩ SCRUB LAND
 - ▤ SCRUB VEGETATED HILLS
 - ▦ BARREN ROCKY HILLS
 - ▧ SALINE LAND
 - ▨ ALKALINE LAND



map5

GUTTURU MICRO-WATERSHED
PRODUCTION SYSTEMS PLAN

- LEGEND**
- ▨ Forestry
 - ▧ Silvopasture
 - ▩ Fuel wood Plantation
 - ▤ Social Forestry
 - ▦ Conservation Agriculture
 - ▧ Dryland Agriculture
 - ▨ Dryland Horticulture
 - ▩ Alley / Relay Cropping
 - ▤ Intercropping
 - ▦ No Intervention in Crops / Pisciculture in tanks



map6