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OPTIMUM UTILIZATION OF WATER RESOURCES FOR EFFECTIVE IRRIGATION MANAGEMENT USING REMOTE SENSING AND GIS - A CASE STUDY

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ABSTRACT

India is primarily an agrarian nation with major portion of population depending on agriculture for their livelihood. About 83% of the total available water resources in India are utilized for agriculture. Hence, it is necessary to assess the water resources availability, progressive development and utilization for sustainable agricultural yield. This can be done both spatially and temporally using analytical procedures and models for studying the rainfall patterns, river water flow and its storage. An attempt has been made, therefore, to study the existing cropping patterns and water resources availability in drought prone area of Narsapuram watershed of Anantapur district in India.

The crop water requirements (CWR) for each of the existing cropping pattern is estimated using modified Penman method and information on existing water resources is obtained from the local government organizations. The correlation of existing ground water resources, its corresponding draft and the requirement of water for the existing cropping patterns have been studied, which revealed that the requirement of water for the existing cropping pattern is more than the water available in the Narsapur watershed of Anantapur district.

Various thematic maps, prepared from IRS IC LISS III satellite imagery and SOI toposheet, were integrated to prepare a composite map showing the status of ground water development and to identify sites for construction of artificial recharge structures. It is recommended that groundwater potential be improved through this artificial recharging of water to the aquifers so that it can meet the requirement of water for existing cropping patterns. This ultimately leads to increase in the crop yield and in turn increases per capita income of this chronically drought prone area for sustainable development. Therefore, an attempt has been made to suggest measures for increasing the groundwater potential by means of artificial recharge and to suggest suitable cropping patterns based on the type of soils and seasons.

INTRODUCTION

Andhra Pradesh in India has a heritage for cultivation and irrigation dating back to several centuries. 70% of population in India lives on agriculture for livelihood. Since, water is the prime resource for agriculture, the need for conservation of such resource is much more relevant when water is becoming a scarce material as the development progresses. Effective conservation of water can be achieved by better water management practices and by adopting suitable cropping patterns duly considering the climatic and soil conditions. It permits better utilization of the other production factors and thus leads not only to increased yields per unit of land and time but also stability in the economic conditions of farmers. Recognizing this fact, considerable efforts have been made in India to develop both surface and groundwater resources. The most important developmental activity, which can spread its benefits to our large rural population and promote all round economic growth in the countryside, is proper planning, development and management of the existing water resources for effective irrigation and sustainable production.

The main objectives of the study include to study the existing cropping patterns and the available water resources in the study area; to compute the crop water requirements by using modified Penman method; to prepare the thematic maps using satellite data and SOI toposheets by visual interpretation technique; to identify the sites for construction of artificial recharge structures which increase the ground water potential and meet the requirement of water for existing crops; and to recommend suitable cropping patterns based on seasons and soil types.

THE STUDY AREA

The study area is Narsapur watershed in Anantapur district of Andhra Pradesh State, which has been a highly drought-prone area. It lies in Pennar river basin which is fully exploited and found to be deficit in water. Geographically, Narsapur watershed lies between 13°30' and 20°30' N latitude, and 77°30' and 85°30' E longitude. The total area of Parigi mandal is 15873 hectares. The geological formation of the study area comprises of older groups of rocks of precambrian age like arches, composite geneses, granites and alluvium. In the area the agro-ecological situation is characterized by single crop systems due to predominantly rainfed cultivation with low and erratic rainfall (Census of India 2001). The terrain of the command area has a fairly good slope to facilitate natural drainage.

METHODOLOGY

Methodology adopted involves the study of existing cropping patterns and computation of crop water requirements based on evapotranspiration (Eto), crop coefficient (KC) and rainfall data. Eto is calculated using modified Penman method that makes use of climatic data, and KC is calculated by the method described by Food and Agricultural Organization (Yoo et al. 2006, Hafeez et al. 2005). The methodology also comprises of generation of thematic maps showing current land use/land cover practices, soil types, hydrogeomorphological conditions and drainage patterns on 1:50,000 scale using visual interpretation technique. Survey of India (SOI) toposheets 57 G/5 and 57 G/7, and IRS IC LISS III satellite images were used to extract the themes followed by ground survey. These derived data systems are converted into consistent map format using ARC/INFO and ARC View GIS software. Specific integration and analysis of these data can be performed to derive useful outputs in the form of maps or statistical data. This multi-thematic information is integrated using GIS techniques and a final map showing the existing status of ground water in the study area was prepared (Krishnamurthy et al. 1996, Saraf & Chaudhary l998, Khan & Mohrana 2002). Suitable sites for construction of artificial recharge structures to improve the ground water are then identified. The GIS technique helps to visualize, organize, combine, analyse, predict and query the spatial data along with non-spatial data (Burrough 1983, ESRI 1992). The methodology adopted for the study is given in Fig. 1.

RESULTS

Studies on Existing Cropping Pattern

Based on the collateral data, a field study was conducted to know the existing cropping patterns by a detailed discussion held with the local farmers. The discussion revealed that the general crops in practice are seasonal crops having different growing periods as shown in Table 1. It was found that groundnut and millets are presently grown and suit the red soils, and have a good long-term market prospects and can feed the local industries. But there is no assured irrigation and very little area is under tank irrigation. All the crops depend on rainfall, which is scanty, erratic and uneven.

Computation of Crop Water Requirement (CWR)

The crop water requirement (CWR) for the major crops namely, groundnut, millets, pluses, sunflower and paddy, and gross irrigation requirement (GIR) are estimated to increase the irrigation potential. The crop water requirement equations are formulated by considering the factors such as the required timing and amount of applied water, which in turn is governed by the prevailing climatic conditions, crop, stage of growth and soil moisture holding capacity (Yongqiang Zhang et al. 2004, Hess 1996).

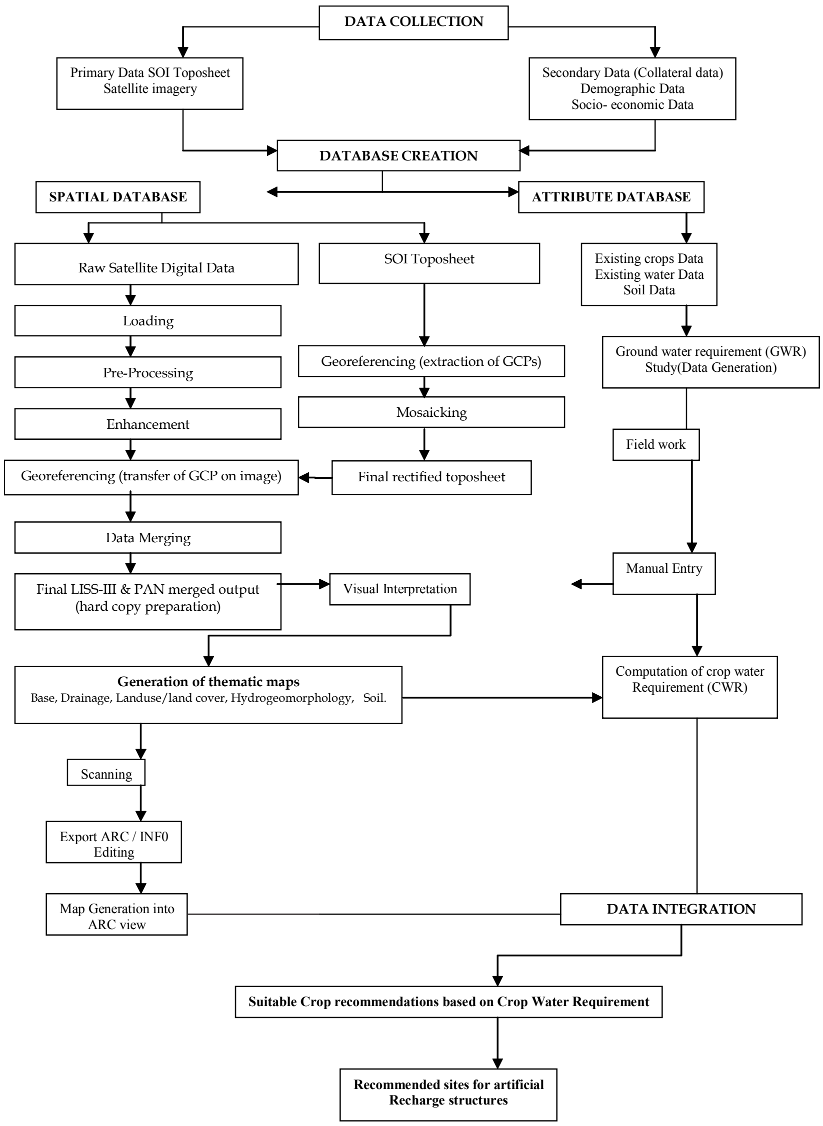

Fig. 1: Flow chart showing the methodology adopted for the present study.

Crop water requirement (CWR) = Kc × Eto

Where,
Kc = fortnight value of crop coefficient
Eto = evapotranspiration as per modified Penman method in mm/day.
Net Irrigation Requirement (NIR) = Crop Water Requirement (CWR) - Effective Rainfall (ER)

The net irrigation requirement worked out is at the root zone and irrigation requirement at any point in the system can be worked out by applying proper efficiency factor. Gross irrigation requirement (GIR) is calculated by considering 50% overall efficiency, crop requirement and area of extent.

GIR of each crop = (NIR of Crop/Efficiency) × Area of Extent

Correlation Study

A comparative study was conducted between the total existing water resources from both Parigi and Uttukuru tanks and tube wells in the study area. The study revealed that during kharif season the

Table 1: Cropping pattern in the study area.

Crop pattern	Growing period (days)	Seasonal months
Ground nut	105	1 August - 13 November
Pulses	70	1 August - 9 October
Finger millets	100	16 August - 23 November
Sunflower	90	1 August - 28 November
Paddy	150	1 July - 28 November

Table 2: Hydrogeomorphology of the study area .

Geomorphic Unit/land Farm	Lithostrati -ography	Structure	Description	Ground water Prospects
Shallow weathered pediplain (PPS)	Peninsular granite & gneiss’s	Fracture/ Lineament	Flat & smooth surface of weathered pediplain with 0-5m overburden generally covered with alkaline soils	Poor to moderate yields are expected along the fracture/lineament, but quality-wise not suitable for drinking & agricultural purposes.
Moderately weathered pediplain (PPM)	Peninsular granite & gneiss’s	Fracture/ Lineament	Flat & smooth surface of weathered pediplain with 5-15m weathering	Moderate to good-very good yields along fracture/lineament, yields are ranging from 2-3 lps
Moderately weathered buried pediplain (BPPM)	Peninsular granite & gneiss’s	Fracture/ Lineament	Flat & smooth surface of weathered pediplain with 0-5m thick over-burden with the black soil cover	Moderate to good moderate yields are expected along fracture/lineament, but quality-wise the water is brackish.
Alluvial plain (AP)	Constitutes gravel, sand, silt& clay of varying percentages	-	Level or gently sloping land surface produced by extensive deposition of alluvium.	Excellent
Flood plain (FP)	Primarily comprises of unconsolidated material like gravel, sand, silt	-	Flat surface, adjacent to a stream/river, composed of unconsolidated fluvial sediments	Good-very good

existing water is 109.968 M cum, whereas the requirement is 184.800 M cum, and during the rabi season the existing water resource is 36.299 M cum and the optimum requirement is 43.87 M cum. This shows that there is a necessity of increasing the water resources through some means, so that the yield increases and areas will be under sustainable development. This can be achieved by augmenting the groundwater levels through artificial recharge, and remote sensing with its unique capabilities plays an important role in identification of sites for construction of recharge structures.

Spatial Data Creation Using Remote Sensing

Remotely sensed data in the form of false colour composite of IRS-IC LISS-III imagery and SOI toposheet are used for preparing the thematic maps of the study area, which form the spatial database. The following thematic maps are prepared on 1:50,000 scale using visual interpretation technique. Based on the above maps a final action plan map was generated suggesting suitable sites for artificial recharge. Suitable cropping patterns were also suggested in the study area based on soil type and season. The preparation, interpretation, relevant observations and their significance with respect to the computation of CWR are discussed below.

Drainage Pattern: Surface water bodies like tanks and rivers along with minor streams are mapped utilizing the remote sensing images and SOI toposheet. Surface water body mapping is carried out for two seasons, i.e. both kharif and rabi. A tank can have good water storage depending upon the rainfall in that season which is again dependent upon the infiltration, slope and soil permeability of the local area. Hence, the drainage network within a particular area is of prime importance. The surface water category includes two major rivers in the study area, Pennar and Jayarnangala, and the major tanks Parigi and Uttukuru tank. The tanks are divided in 3 classes depending upon their storage capacity. They are: (1) Deep water category, with a kharif water spread of 128.328 km^2 and rabi water spread of 94.589 km^2 and with kharif storage of 1016.939 M cum and a rabi storage of 712.784 M cum. (2) Moderately deep water tanks with an average depth of 3-5 m which have a total kharif water spread of 80.69 km^2 and with kharif storage of 734.06 M cum and rabi storage of 18.46 M cum. (3) The shallow water tanks which have a total kharif water spread of 72.37 km^2 and the storage capacity of 167.80 Mcum. The rabi water spread is 38.80 km^2 and the storage capacity is 93.36 M cum.

Land Use/Land Cover: Land use/land cover inventories are assuming increasing importance in various resource sectors like agriculture planning, settlement and cadastral surveys, environmental studies and operational planning based on agro-climatic zones. Information on land use/land cover permits a better understanding of land utilization aspects on cropping pattern, fallow land, forest grazing land and waste land etc. which is vital for developmental planning (Thomas & Ralph 2000). The land use/land cover map of the study area was prepared by visual interpretation of IRS-IC LISS-III FCC satellite data and SOI toposheet (Fig. 2). The land use/land cover classification system developed by USGS and modified by National Remote Sensing Agency (NRSA) for Indian conditions has been followed in the preparation of land use/land cover map. After preliminary mapping, field check is carried out in doubtful areas and necessary modifications are done for generation of a final land use/land cover map. The major classes identified in the study area are fallow lands, land with scrub, land without scrub, plantations, kharif irrigated and kharif unirrigated areas, salt affected lands and double crop (IMSD 1995).

Hydrogeomorphology: Hydrogeomorphological studies were carried out to examine the influence of morphological characteristics on the occurrence and movement of ground water. Different

Table 3: Soil characteristics of the study area.

Mapping Symbol	Name of the soil series	Slope description of mapping units	Depth	Color	Surface	Subsurface	Drainage	Erosion	Land Class	Capacity Subclass	Soil Taxonomy
PDM	Pedamanutur	Nearly level	Deep to very deep	Dark grayish brown	Sandy loam	Clay to sandy loam	Imperfectly to poorly drained	Nil to slight sheet	II	SW	Flurentic ustochrepts
ITG	Itigi	Very gently sloping	Moderate	Shades of gray	Clay loam	Clay	Moderately well drained	Severe sheet	III	C	Lithic vertic ustocherpts
JMG	Jayamangali	Very gently Sloping	Very deep	Brown to yellow brown	Loamy sand	Loamy sand, sandy clay Loam, coarse sand	Well drained	Slight sheet	IV	W	Typic ustifluvents
KRK	Karlakunta	Very gently sloping	Deep	Dark reddish to dark red	Coarse sandy loam	Sandy clay to gravelly Clay	Well drained to moderately well drained	Slight to moderate sheet	IV	E	Udic ustochrepts
KDN	Kondenahalli	Gently sloping to undulating	Moderately deep to deep	Dark red	Gravelly sandy loam	Gravelly clay to gritty clay	Well drained to moderately well drained	Moderate to severe sheet	IV	ES	Kondic rodustrlts
MSD	Manesam-udram	Nearly level	Very deep	Dark grayish brown	Sandy loam	Clay loam to clay	Moderately well drained to imperfectly drained	Nil to slight sheet	II	WS	Typic ustifluvents
PRP	Patarlapalle	Gently sloping	Deep	Yellowish red to dark yellowish brown	Sandy loam	Sandy clay loam & Gravelly clay	Well drained	Slight to moderate sheet	III	ES	Udic pellusterts
PRG	Pairig	Very gently sloping	Moderately deep	Very dark grayish brown	Clay	Clay & Gravelly Clay	Moderately well drained	Nil to slight sheet	II	SW	Typic ustochrepts
PNR	Pennar	Nearly level to very gently sloping	Very deep	Grayish brown & light yellowish brown	Sandy loam	Fine sandy loam, fine sand clay loam, clay loam medium sandy loam	Moderately well drained	Nil to slight sheet	II	S	Typic ustifluvents

Table cont...

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PDM	Peddamanulur	Nearly level	Deep to very deep	Dark grayish brown	Sandy loam	Clay to sandy clay loam	Imperfect to poorly drained	Nil to slight sheet	II	SW	Fluventic ustochrepts
RDM	Roddam	Nearly level	Very deep	Very dark gray to black	Clay	Clay	Moderately well drained to imperfectly drained	Slight to moderate sheet	III	ES	Typic pellusterts
M	Area moderately affected by salt & alkaline	Appreciable quantities of exchangeable sodium & present					Drained		III	S	
S	Area slightly affected by salt & alkaline						Little quantities of nearly natural salts in pockets, moderately well drained		II	S	

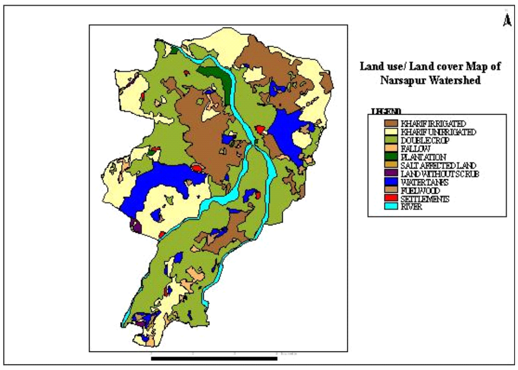

Fig. 2: Land use/land cover map of the study area.

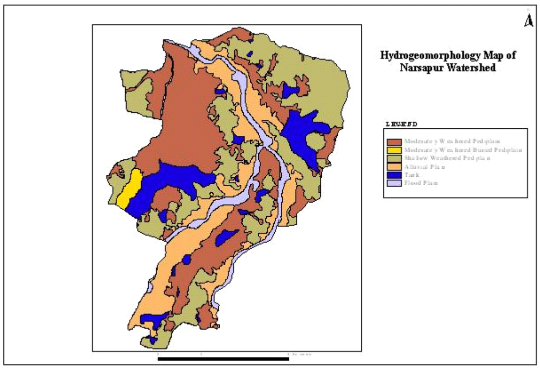

Fig. 3: Hydrogeomorphology map of the study area.

landforms were identified in the study area with the aid of satellite imagery and a hydrogeomorphological map was prepared (Fig. 3). This map helps in identification of areas where ground water prospects are low and identifies sites for construction of percolation tanks and other ground water recharge structures to increase the water levels in these areas (NRSA 2000). The details of hydrogeomorphological characteristics are given in Table 2.

Soil: The parameters taken into consideration for soil mapping are soil depth, texture, slope, elevation, drainage and present land use. The soil map is prepared by visual interpretation of IRS-IC LISS-III FCC satellite data. After preliminary mapping, field check is carried out in doubtful areas and necessary modifications are done for generation of a final soil map. The details of types of soils found in the study area are shown in Table 3 and the map is shown in Fig. 4.

CONCLUSION AND RECOMMENDATIONS

Identification of Sites for Artificial Recharge

Thematic layers of the watershed namely, drainage pattern, land use/land cover, hydrogeomorphology, soil and groundwater prospects are all derived from IRS-IC, LISS-III satellite imagery and Survey of India (SOI) toposheets. All the above thematic layers are integrated for the generation of an action plan, which is optimally suitable to the terrain and to the development of local resources so that the level of production is sustained without decline over time. Various water resources development and management techniques, soil and water conservation measures and optimal cropping patterns are suggested for the overall sustainable economic development of the watershed. Based on the integration of all the thematic layers an action plan map for water resources development showing suitable sites for construction of recharge structures like check dams and percolation tanks is generated (Fig. 5). Selection of sites and designs for artificial recharge structures depends upon the configuration of confined aquifers, hydraulic gradient and location of sources of excess surface water. From hydrogeomorphology, structural information and the well inventory data, various landforms are identified based on the ground water prospects for tapping ground water potential zones. The predominant ground water irrigated areas along lineaments, faults and fracture systems, brought out by satellite data are of immense use for taking up artificial recharge structures. The construction of water harvesting structures like percolation tanks or check dams is recommended on upstream of the drinking water sources. The sites for mini percolation tanks are identified upstream of the ground

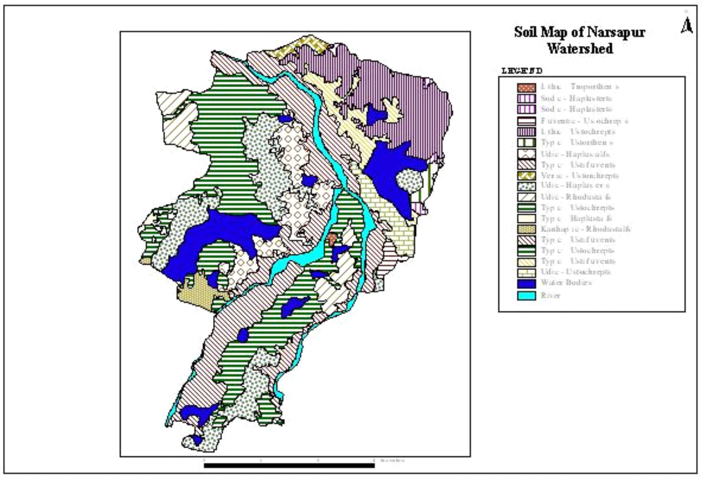

Fig. 4: Soil map of the study area.

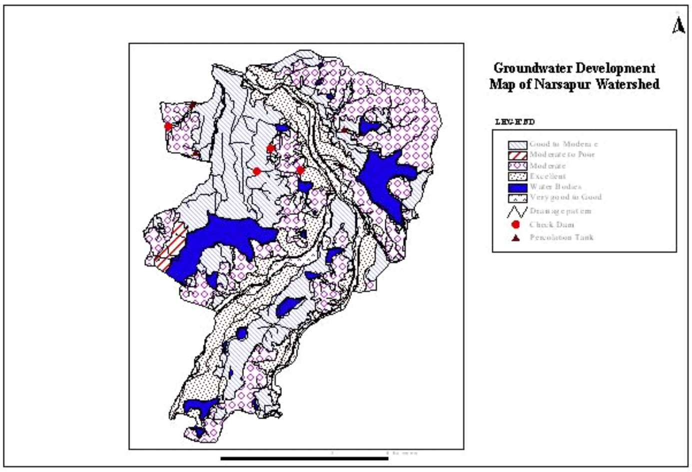

Fig. 5: Groundwater development map of the study area.

Table 4: Crop recommendations for red soils.

Early rainfall in Kharif	Late rains in Kharif	Very late rains in September	Contingent crop plan in August/September	Contingent plan
Jowar or Bajra + Green gram/Gingelly Bunch groundnut + Red gram/Jowar Groundnut (Spreading) + Castor	Bunch Ground or Korra or Horse gram/Gingelly sown in August	Horse gram in September	Korra + Red gram/ Bunch Groundnut/ Castor depending on the rainfall	Mungari cotton pure in August Korra + Sunflower in September Advanced Rabi Rains safflower or Bengal gram

water irrigated areas with considerable catchment area, on second, third and higher ordered streams while, sites for check dams are given upstream of ground water irrigated areas on lower ordered streams. This provides augmented recharge for water supply during the drought periods.

Table 5: Crop recommendations for other soils.

Kharif	Rabi
Paddy or Ragi	I.D. Ground, Black or Green gram
Cotton or I.D. groundnut	Hybrid maize or Bengal gram
Onion or vegetables	Vegetables/leafy vegetable
Jowar or Bajra	Sugarcane
Mulberry	Sunflower

Crop Recommendations

Based on the above study, it is recommended to select crops with different maturity to utilize the available water, as the CWR demand depends on the growing stages of crops. Different types of crops recommended for red soils and other soils based on seasons are given in Table 4 and Table 5. Horticulture plantations recommended in suitable areas are given below.

1. In areas with assured irrigation, the main bunds may be planted with fruit plants for reinforcing the bunds in addition to receive revenue from these plants.
2. In areas with slopes ranging from 3-15 %, horticulture plants may be planted along the contour and the interspaces are over seeded with grasses.
3. The land capability Unit- IV lands, with slopes less than 8% may be taken up with horticulture plantations. The interspaces can be grown with crops like groundnut and jowar etc. to improve the economy of the farmer.
4. The hill slopes in lower regions may also be used for horticultural plantations.

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