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Estimation of Surface Runoff Potential of a Watershed in Semi-arid Environment - A Case Study

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ABSTRACT

An accurate assessment of run-off through aerial rainfall is a basic concept in most of the rainfall-runoff models, particularly conceptual models which emphasis a complete water balance. The run-off measurements by gauging can only be regarded as an index of rainfall and restrict our ability to successfully model the rainfall-runoff process. To overcome some of these problems, remote sensing satellite data are of immense use, particularly in mountainous and desert areas. Therefore in the present study, a typical watershed from a drought hit Banswara district of Rajasthan has been analysed using IRS-1B-LISS II satellite imagery for estimating the run-off potential under different geomorphic set-up. The run-off potential was estimated using SCS method based on the satellite data in conjunction with ground truth information collected during field visit. The results indicated that the soil and water conservation measures in the watershed would improve the existing water potential and storage capacity of the study area. Based on the study eight check dams and five lift irrigation schemes are proposed.

Introduction

Water resource development plays an important role in achieving multifaceted economic and social development of a nation. India is endowed with substantial water resources in accordance with latest estimates of Central water Commission, annual runoff of its river systems aggregates to 1800 km^3 constituting 4 % of total annual water flows of the world. As the population of India is about 16 % of world's population, there is greater pressure on use of water to meet the demands in this country. A substantial progress has been made in development and management of water resources in the last 50 years. However, the pace of development in the water resources has led to the exploitation of the water resources in leaps and bounds, resulting in overuse of surface supplies and over exploitation of ground water. Therefore, at this stage one has to realise the need and importance of conservation of water. In other words, the total quantum of the average may be enough to meet all our demands put together. But, its distribution is highly irregular. It is not available in places where it needs, at times when it requires and as per quantities it requires, hence the needs for conservation of it is essential. At the outset water resources planning is a pre-requisite for any developmental activities.

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As regards planning, watershed development program has become widely accepted concept, which is based on overall exploitation of total resources. Water resources projects in general lacks planning in most of the cases due to pressures from various sectors without taking into consideration of developmental possibilities. In view of this approach, total water resources are not being put to full use and maximum benefits are not being derived. Therefore, before taking up any water resources development project, the prime necessity is to know the probable quantity of water available from a watershed. In the present study, an attempt is made to compute and suggest the utilization of available surface runoff potential for irrigation purpose in a typical topographic situation characterized by intense rainfall during monsoon having steep slope in Banswara district of Rajasthan. In this part of the state the agricultural yields are less than 5 %. Dense forest in the past has been completely deforested. Though the average rainfall is very good (935 mm), but due to lack of management, inadequate knowledge and inadvertence of water conservation practices; this region is always under influence of drought. Hence, it is the need of the hour to access the available water potential so that it can be utilized properly for irrigation purposes and thus to enhance the productivity in the tribal areas and alleviate the migration the tribal people.

The Study Area

The study area falls in the basin of river Anas, which is a part of Mahi River in Southern Banswara district, Rajasthan. It is located between north latitude 23°10' to 23°15' and east longitudes 74°10' to 74°15' covering an area of 3840 ha (Figure 1). Physiographically the watershed can be divided into hills, pediments and alluvial plains, which have different characteristics. Elevation of watershed ranges from 440 to 500 m from mean sea level. The soils of the watershed are sandy loam to sandy clay loam. The climate is characterized by maximum and minimum temperatures of 44.2°C and 8.6°C respectively, high evaporation of 11.6 mm/day and high wind velocity of 12.4 km/h. The average annual precipitation is 935 mm. About 90% of this rainfall is received during June-September.

Data Used and Methodology

The land use, soil and drainage maps were prepared using IRS-1B-LISS II imagery. Some of the required data and soil samples were collected at the selected query points in different land use/cover in the field. The soil samples were tested for the textural analysis and the infiltration tests conducted in different mapping units in the field. The land use/cover, soil map prepared by using IRS FCC as base map was transferred on the topographical map of 1:50,000 scale. The original SCS (1964) model is given by the following relationship for estimating direct runoff from ungauged areas:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (1)$$

Where,

Q = accumulated direct runoff (mm)
P = accumulated precipitation (mm)
S = potential maximum retention (mm)

Potential maximum retention S is conveniently expressed in terms of Curve Number (CN) by the relationship.

$$CN = \frac{25400}{254 + S} \quad (2)$$

The parameter S depends on a combination of hydrologic soil-vegetation-land use complex (SVL complex) and antecedent moisture condition of a watershed. The curve number is a measure of a given SVL complex and varies from 0 (no runoff) to 100 (all rainfall becomes runoff). Curve number values are given in SCS National Engineering Handbooks, section IV (NEH-4), for combination of hydrologic soil group, land use and treatment classes.

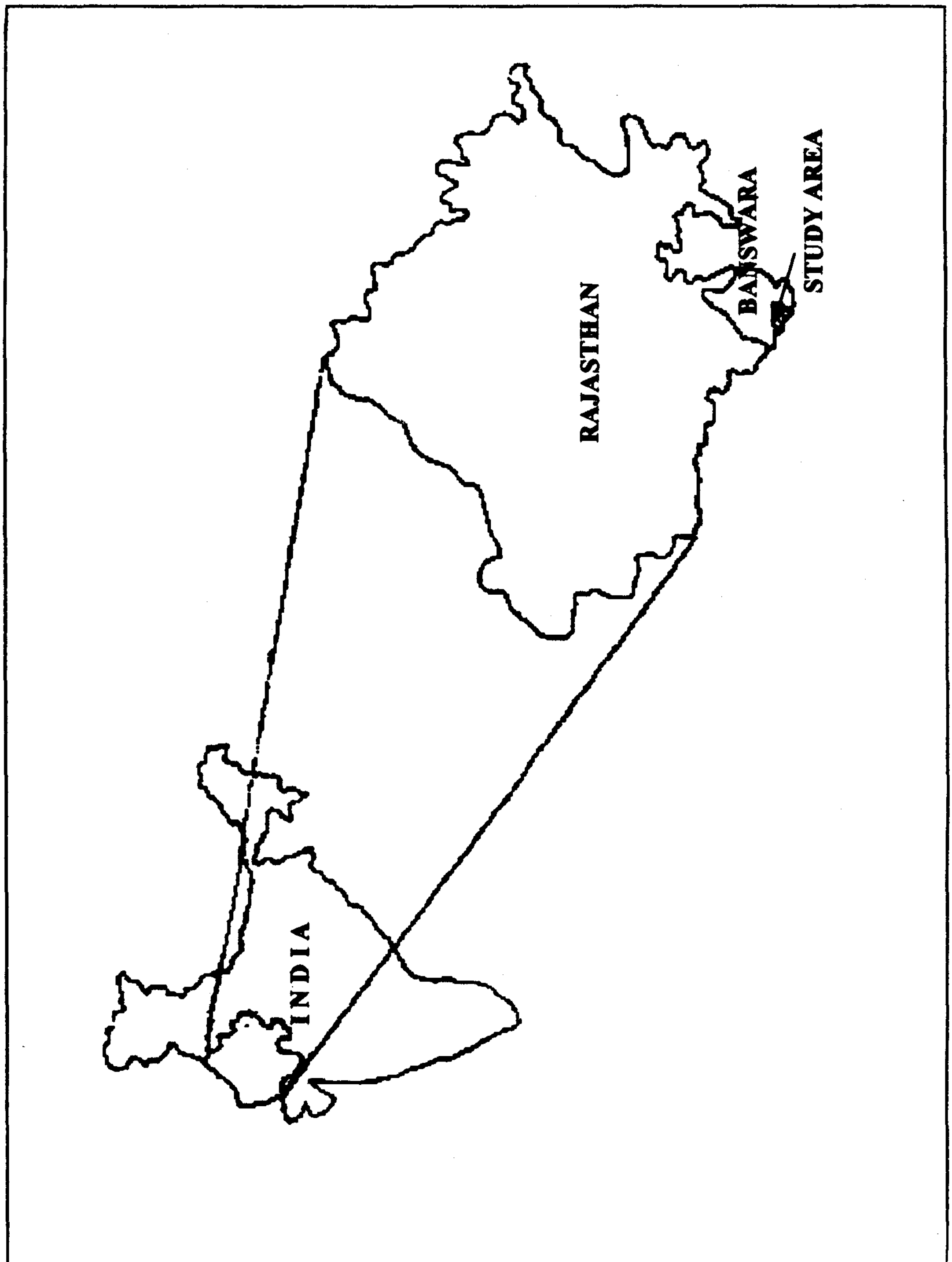

Fig. 1. Location Map

Results and Discussion

The watershed is the natural unit of land upon which water from direct precipitation, snow melt, and other storage collects in a channels and flows downhill to a common outlet at which the water enters another water body such as a stream, river, wetland, lake or the ocean. For taking up any water resources development project, the information regarding quantity of water available is very essential. The quantity of runoff from a watershed is depends on the watershed characteristics. These watershed characteristics include land use/cover, soil type, and morphometric parameters.

Spatial Distribution of Land use Pattern

Land and water resources are intimately interconnected and exert considerable influence in determining various hydrologic phenomena such as infiltration, overland flow, evaporation and interception. Furthermore, the land use and vegetation cover characteristics of a watershed have a significant influence on the quantity of runoff of that watershed. Details of the land use pattern are given in table 1, which is prepared by using IRS-1B-LISS II FCC and mapped as shown in figure 2.

Forest Land

This category of land use associated with rocky gravelly buried pediments and sandstone plateau appeared in light red and dull red tone on IRS-FCC. Total forest cover is only 3.14 % of the total geographical area. Khuta Galiga and Panchmaluda past have largest density of forest. The main species present in the area are *Acacia spp.* and *Zyzyphus spp.* The area as per revenue records under forest is less than mapped areas, which could be due to the facts that the small areas under this category could not be delineated and were merged with the cropland.

Shrubs

Shrubs are found on relatively shallow soil with less than 30 % gravel, along the banks of the streams. The shrubs cover near about 5.78 % of total watershed area.

Grass Land

Flat and undulating topography, gravely surfaces and gravely sand to loamy sand and water erosion characterizes the grassland, which is mostly used for grazing purpose associated with hillside rocky gravely pediments. Major plant species of such grassland are *Cynodon Dactylon, Pesmostachya Bipirata, Cinehrus spp. Sacchrum Munja and Heteropogan Contorts* etc.

Table 1: Land use/cover pattern defined in total watershed area using IRS-1B-LISS II satellite imagery.

Sub-washed No.	Total Geographical area (ha)	Cultivated land (ha)	Forest Land (ha)	Grass land (ha)	Barren land (ha)	Shrubs (ha)	Water body (ha)
1.	1235	624	57	234	228	61	32
2.	488	308	13	56	69	39	4
3.	225	13	21	33	159	--	--
4.	181	21	--	--	155	1	--
5.	293	185	23	33	14	37	--
6.	420	240	--	117	18	42	3
7.	479	371	--	83	--	22	3
8.	519	230	6	263	--	20	--

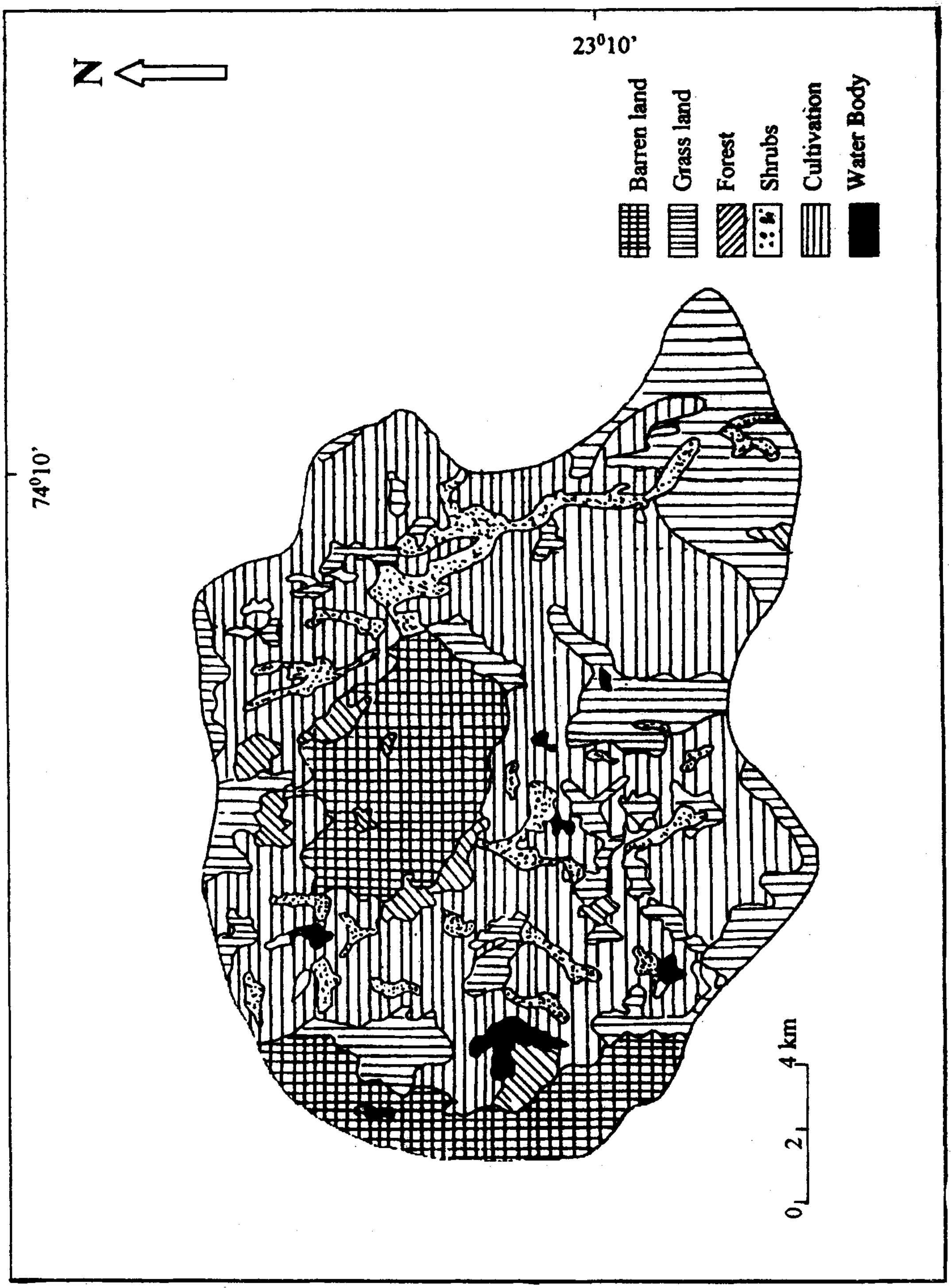

Fig. 2. Land Use/ Land Cover

Barren Land

This category of land use comprising of sandstone, granite rocks, rhyolite and sheet rocks is characterized by steep slope, presence of water erosion, boulders, cobbles and gravely sand. The total geographical area of the barren land is 17 % of the total geographical area of watershed.

Soil characteristics

The soil characteristics of watershed viz., texture, structure and infiltration characteristics plays a significant role in estimation of runoff quantity, Hydrologic soil grouping is based on soil characteristics, which have a correlation with runoff curve number. After the laboratory analysis of collected samples of soils form different land use/ cover pockets, the soils can be classified into various groups based on soil properties.

Soil Texture

Soil texture refers to relation of proportion of various soil separates in a soil material and is related to soil water interrelationships. On the basis of relative proportion of these basic properties, various soil textural groups are recognized. Clay being the most active and reactive fraction is used as a single factor index in deciding hydrologic group of a series. Clay content of the surface layer and the average clay content of the whole profile are considered for this purpose and the relationship between clay content and runoff potential is given in table 2.

Soil Structure

Soil structure refers to the arrangement of soil particles in the soil profile. Soil structure governs the moisture and air regimes in the soil movement of water in the soil and soil structure and texture affect its transmission. The influence of structure on runoff potential is given in the table 3.

Infiltration

Infiltration is the term applied to the process of water entry into the soil, generally by downward flow through all parts of the soil surface. The Maximum rate at which the soil can absorb water through the soil surface is termed as infiltration capacity. This is a function of soil moisture condition. At saturation, infiltration capacity is minimum and is the characteristics of the soil i.e. texture, structure, organic matter content, type of clay mineral, antecedent soil moisture etc. The relationship between

Table 2: Relationship between clay content and runoff potential

Clay Content (%)	Textural Classes	Runoff potential
15 – 20	Sandy Loam	Low to moderately low
20 – 35	Sandy clay loam	Moderately high to high

Table 3: Relationship between soil structure and runoff potential

Soil Structure	Runoff Potential
Granular, Crumb	Moderately low to low
Sub-granular blocky Columnar	Moderately low to moderately high
Strong angular block to prismatic	Moderately high to high

infiltration classes and runoff potential is given in the table 4.

From the soil textural analysis, it is found that the dominant soil textures present in the area are sandy loam followed by sandy clay loam. The shallow soil depth with dense cover of gravels over the surface has been found in forest as well as grassland.

To assess the surface runoff potential of watershed, a drainage map of 1:50,000 scale was prepared. From this map the sub-watershed boundaries were marked according to different size and shape, which is essential for evaluating the surface runoff potential and to fix up the priorities for water harvesting structures. The size of the sub-watershed varies from 181 to 1235 ha. On the basis of land use and soil as well as the infiltration rate, the whole area of watershed is divided into four hydrologic soil groups as shown in figure 3.

Combination of hydrological soil group, land use and conservation practice, called cover complex were demarcated and used to estimate runoff curve number for prevailing antecedent moisture conditions. Antecedent moisture conditions have been fixed based on the rainfall amount for previous five days of rainfall. The individual curve number values have been averaged over the entire sub-watershed. The weighted curve number for the each sub-watershed is calculated. Mean annual runoff is found to be 362 mm, which is approximately 39 per cent of mean annual rainfall. Water yield for all eight sub-watersheds varied from 331 to 402 mm (Table 5).

By adopting proper planning for water conservation measures additional surface water resources can be developed by constructing different water harvesting structures under different land use/cover units and also by increasing the

Table 4: The relationship between infiltration rate and runoff potential

Infiltration Classes	Basic Infiltration rate (cm/h)	Runoff Potential
Very high	< 8.0	Low
High	5.01 - 8.0	Low to moderately low
Medium	3.11 - 5.0	Moderately low to moderately high
Low	1.60 - 3.1	Moderately high to high
Very low	<1.6	High

Table 5: Mean annual runoff of each sub-watershed area

Sub-watershed No.	Sub-watershed Area (ha)	Mean Annual Runoff (mm)
1.	1235	347
2.	488	362
3.	225	331
4.	181	402
5.	293	367
6.	420	357
7.	479	369
8.	519	369

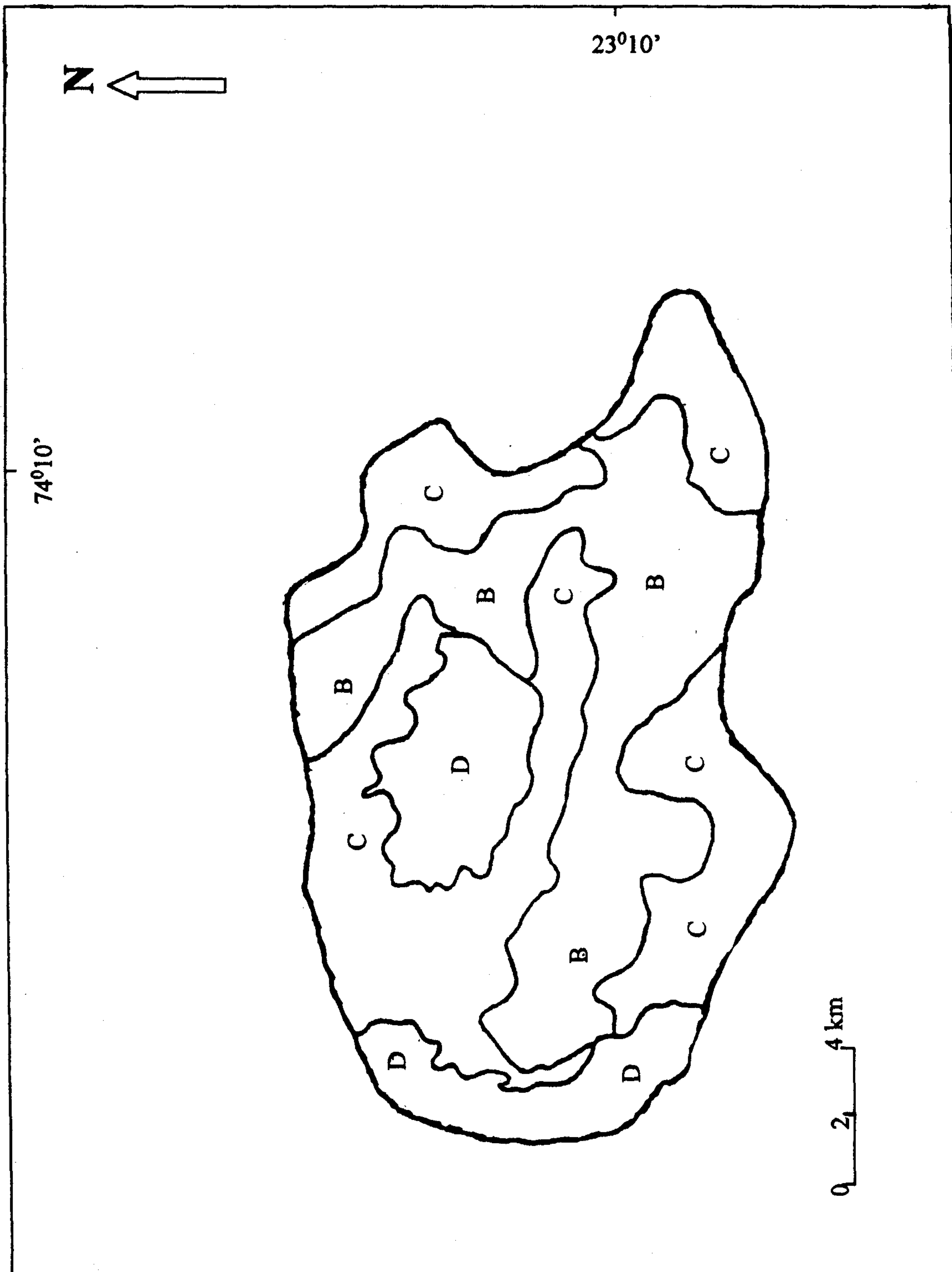

Fig. 3. Hydrological Soil Groups

storage capacity of existing major tanks within the watershed area. After the analysis of satellite imagery topographical maps and ground truth data verification the different water harvesting as well as storage structures are proposed (Figure 4) and the future scope for irrigation on full water harvesting are calculated as per the following criterion.

i) The check dams are proposed at an interval of 2 km at down-stream of storage tank as well as 4th and 5th order streams, which can irrigate 20 ha of land in its command area.

ii) The lift irrigation schemes can irrigate 50 ha of land within its command area and are proposed on check dams, which are on the 5th or higher order streams, as well as on existing tanks.

iii) The storage tank is proposed on the 3rd order streams.

The check dam is a structure, which intercepts the water from local catchment, and stores it for optimum utilization. A big earthen dam or a bund is constructed across gentle slope of the farmland in the valley portion to facilitate spreading and standing of collected water on the farm soil. With the above criteria and the information regarding existing area under irrigation from Irrigation Department, the approximate runoff potential (Table 6) and future scope for water harvesting were worked out (Table 7).

Based on the percentage of cultivated area and drainage density of each sub-watershed, the rating of watershed has been done into four categories (Table 8). The watershed having highest percentage cultivated area and drainage density fall under category, 'A' followed by watershed of 'B', 'C' and 'D' categories in the decreasing order as shown in table 9. It may be seen from the table that sub-watershed no. 7, which has high percentage of cultivated area and drainage density falls under category 'A' need immediate attention for soil and water conservation measures.

Conclusions

The study leads to the following conclusions:

1. It is observed that SCS method, which is based on empirical relationships, is an efficient tool for estimating the direct run-off of small-ungauged watershed.
2. For better surface water management, adopting appropriate planning measures, the additional surface water resources can be developed by

Table 6: Approximate runoff potential in the tribal region in the watershed of Banswara District with other relevant data worked out.

Sr. No.	Geographical area (ha)	Rainfall Amount (ha.m)	Runoff water potential (ha.m)	Runoff percent to rainfall (%)	Runoff water already exploited (ha.m)	Existing area under irrigation (ha)	Further water harvesting potential (ha.m)	Future scope for irrigation on full Water harvesting (ha)
1	1235	1186	371	31	111	121	260	337
2	488	468	195	42	59	60	137	166
3	225	216	68	31	20	3	47	7
4	181	174	73	42	227	4	51	12
5	293	282	118	42	35	36	82	100
6	420	403	168	42	50	46	117	130
7	479	460	192	43	57	73	134	199
8	519	498	208	42	62	44	145	124

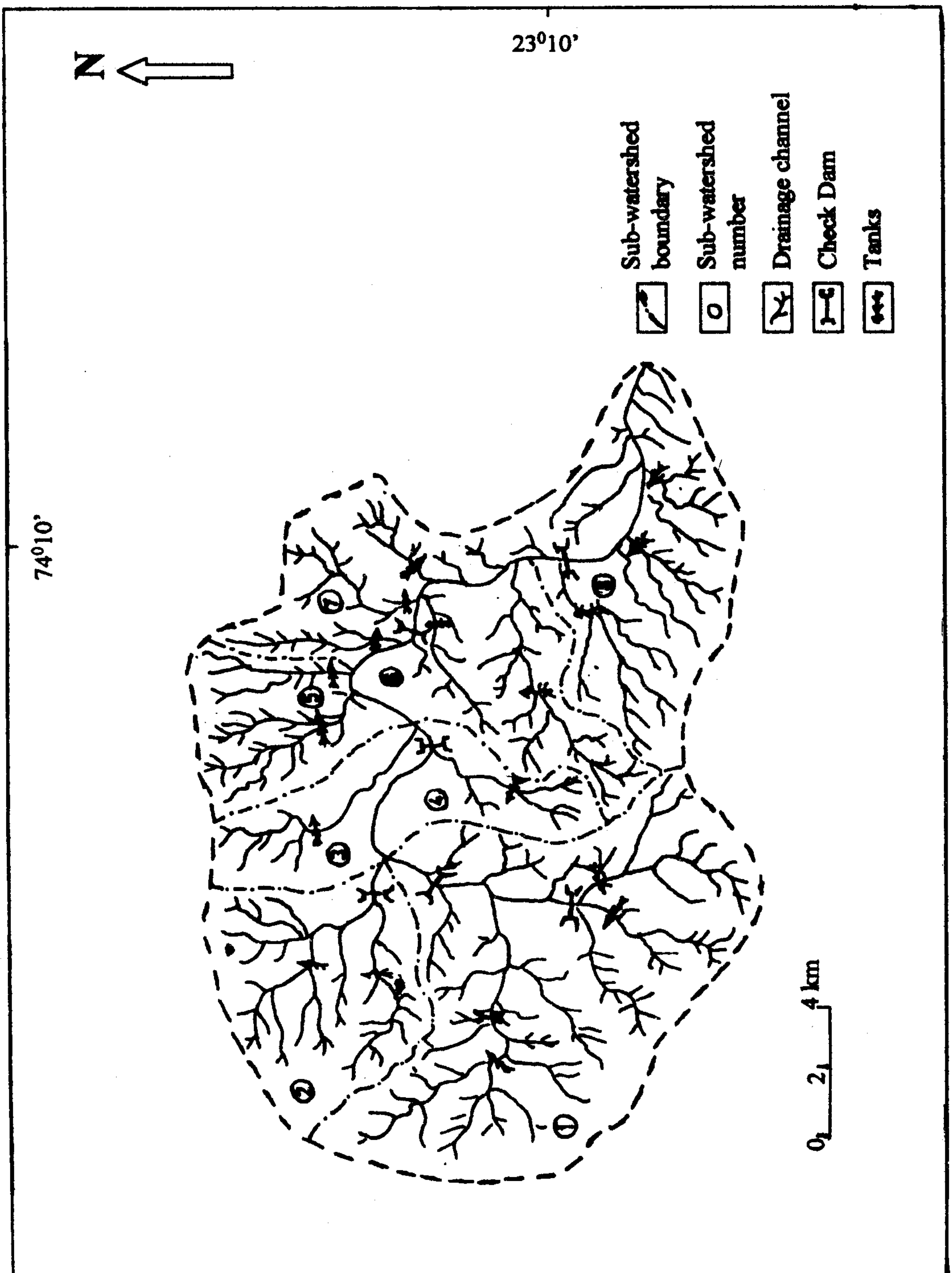

Fig. 4. Drainage Network and Location of Water Harvesting Structures in Sub-watershed

Table 7: Future scope for irrigation on full water harvesting

Sub-watershed no.	Nos. of proposed structures/ schemes		Future scope for irrigation from (ha)	
	Check Dam	Lift Irrigation	Check Dam	Lift Irrigation
1	3	1	100	150
2	1	0	-	-
3	0	0	-	-
4	1	1	0	150
5	0	0	-	-
6	1	1	0	150
7	1	1	0	150
8	1	1	-	150

Table 8: Percentage of cultivated area and drainage density of the watershed

Sub-watershed no.	Cultivated Area (ha)	Total area of Sub-watershed (ha)	Percentage cultivated Area (%)	Drainage Density (km/sq. km)
1.	624	1235	51	3.77
2.	308	488	63	3.46
3.	13	225	6	2.13
4.	21	181	12	2.71
5.	185	293	63	5.04
6.	240	420	57	4.95
7.	370	479	77	3.68
8.	230	519	44	5.10

Table 9: Categories of priority watershed

Sub-watershed no.	Percentage- cultivated area	Drainage density	Category
1	M	H	B
2	M	M	B
3	L	L	D
4	L	M	D
5	M	H	B
6	M	H	B
7	H	H	A
8	L	H	D

constructing water storage structures like small check dams and tanks.

3. Based on drainage density and percentage-cultivated area, the priority watershed is demarcated for soil and a water conservation planning. It is found that the sub-watershed number 7 falls under category 'A' needs immediate attention for soil and water conservation measures.

References

Diego, S. and Wilson, T. V. (1973). Estimation of Maximum Runoff Volumes for small piedmont Watershed. Transaction of the American Society of Agricultural Engineers, 16(4): 793-796.

Kumar, A. and Patra, S. K. (1988). Watershed Characteristics of ONG Sub-basin. Technical Report 51, National Institute of Hydrology, Roorkee.

Shrivastava, N. C. and Bhatia, D. P. (1992). Applicability of SCS runoff model for Indore Region.

Indian Journal of Agricultural Engineering, 2(2): 121-124.

Soil Conservation Service, (1964). National Engineering Hand Book, Section-4, Hydrology, USDA.