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Run-off Potential Indices of Watersheds in Tilaiya Catchment, Bihar (India) through Use of Remote Sensing and Implementation of GIS

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ABSTRACT

The present study was aimed at assessing the potential of remote sensing data in providing input to the SCS model developed by USDA and exploring the possibilities of improving the model through implementation of a GIS package. Subsequently, prioritization of watersheds in Tilaiya Catchment area (Bihar, India) based on their run-off potential indices was envisaged.

The result demonstrated the capability of Landsat data in providing multithematic maps which could be used to provide input to the run-off model. Implementation of the GIS package enabled computation of run-off potential indices on pixel-by-pixel basis imparting physically distributed approach to the model.

Introduction

Flooding is one of the environmental problems which has been of global concern since the very ancient days. In the wake of recurring loss of agricultural lands and human sufferings, the problem of floods has attracted the attention of all concerned in India. Floods hit the country every year and cause damage to an average area of 6.7 million hectares resulting in an estimated annual loss of 1260 million rupees (Das, 1977). Optimal management of flood-prone areas necessitates flood control measures in recipient areas as well as the execution of integrated watershed management programmes in the catchment areas, which contribute to the problem of flooding, by generating high run-off and causing siltation in the river beds.

The large financial and manpower commitments involved in treating vast catchments indicate the need for following

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selective approach of identifying smaller hydrologic units with relatively high run-off generating potential.

Several empirical models (Ragan *et al.*, 1980; Bathurst, 1986) are in use for predicting the total quantum of run-off generated from a specific hydrologic entity. Information on the climatic parameters, terrain configuration, soils and land cover forms the basic inputs to a run-off prediction model.

Remote Sensing data acquired from space-borne platforms, owing to its wide synopticity and multispectral acquisition, offer unique opportunities for study of soils, land use/land cover and other parameters required for run-off modelling. The utility of space remote sensing data for small scale soil and land use mapping has been demonstrated by several workers (Hilwig, 1980; Dipaolo & Hall, 1982; Fredrick, 1982). The capability of these data for estimating relative values of run-off potential indices of subwatersheds within catchment areas has also been shown by Dohare *et al.* (1986) and Saini *et al.* (1986) through generation of monothematic maps using visual analysis. However, the establishment and maintenance of geographic data base in computer readable form has great potential for supplying resource management information for run-off estimation. Compatibility of the data to digital analytical techniques makes it yet a powerful tool in building a sound data base by integrating multithematic information in geographically referenced formats. These data, through the use of a suitable GIS package and an automated system, could be used for computation of run-off volumes on grid basis distributed over the entire hydrologic unit to arrive at more realistic predictions.

The present study was aimed at assessing the potential of remote sensing data products and GIS for providing input to the empirical run-off model used by USDA Soil Conservation Service for estimating total discharge from a hydrologic unit. Prioritizing the watersheds of a catchment based on their run-off generating potential using a case study in Tilaiya subcatchment, D.V.C., Bihar was the main objective of the project. An improvement in the run-off model by introducing vegetation index and slope component was also envisaged.

Study Area

Encompassing a total area of nearly 0.1 million hectares, Tilaiya Catchment is located between 24°05' - 24°28' N Lat. and 85°09' - 85°23' E Long. (Fig. 1).

Geologically, the area is quite complex, having rocks of varying composition. Archaean gneisses and micaceous schists constitute the main lithology of the region. Forming a part of the vast Chhotanagpur plateau, the area is charactérized by hills, gently undulating plateaux, intermontane valleys and alluvial landforms. Monadnocks and rocky hills provide evidence of the degradational processes active in the area whereas, sand bars and narrow alluvial plain bear testimony to the aggradational phenomenon.

Sub-humid sub-tropical monsoonic type of climate, characterized by hot summers and mild winters, is prevalent in the area. The total annual precipitation of 1157 mm is distributed mainly between June to September. The average storm intensity by considering storms of more than 30 minutes duration works out to 37 mm.

Model Used

The model for estimating quantum of run-off generated from various hydrologic units is based on the average precipitation/storm and the storage capacity of the soil (Ragan *et al.*, 1980). The empirical relationship can be expressed as:

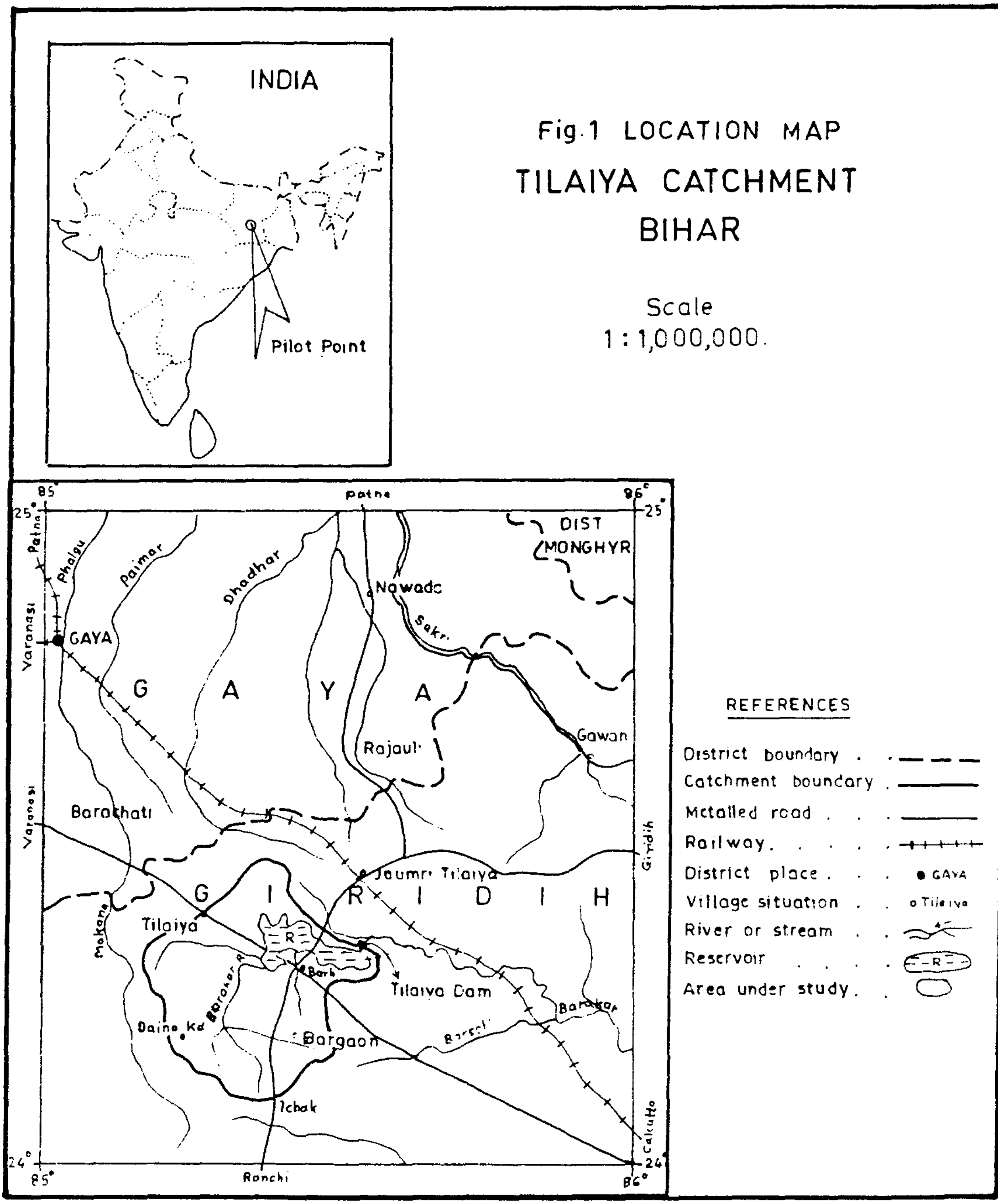

Fig.1 LOCATION MAP
TILAIYA CATCHMENT
BIHAR

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

Where Q = Run-off in inches
P = Average precipitation/storm in inches
S = Storage capacity of the soil in inches expressed as (1000/CN) - 10

The CN value (run-off curve number) is arrived at by using standard SCS look up tables of USDA which are based on hydrologic soil groups and land use/cover.

A slope factor (1 - (Av. % slope of watershed/100)) was used to modify the 'S' factor and consequently the computed 'Q' values, assuming that the impact of watershed gradient may not cause a reduction of more than 25% in the storage capacity of soils.

Materials and Methods

The following data were deployed for the study:

- Landsat MSS computer compatible tapes pertaining to path 151/row 43, May 77.
- Survey of India (SOI) topographic map Nos. 72 H/3, 72 H/7 and 72 H/11 on 1" = 1 mile scale.
- Report on priority demarcation of subwatersheds in Tilaiya subcatchment, Bihar (No. Agri-578) published by All India Soil & Land Use Survey.

A false colour composite (FCC) using Landsat bands 4, 5 and 7 was generated and enlarged to the scale of 1" = 1 mile. This FCC was used as base map for obtaining different input parameters to the model.

A data base was generated by integrating monothematic maps on soils, land use/cover within the framework of watersheds and the model was implemented by manipulating the data layers and using a GIS package developed by ERIM, deploying Vax 11/780 system. The steps involved in the preparation of data base are discussed below:

Framework of Watersheds: Delineation of watersheds within the catchment area was based on stream order using drainage network analysis of the map drawn fron SOI topomap. All the streams depicted on the map were assigned order numbers. The perimeters of third, fourth and fifth order basins were subsequently drawn on the map.

The delineated watersheds were numerically coded following the hierarchy of the stream orders.

Gradient of Watersheds: The overlay depicting watershed framework was used in combination with the SOI topomaps for computing the average gradients of watersheds. Each of the watersheds was divided into 3-5 polygons depending upon the closeness of contours and the slopes of individual watersheds were arrived at by computing the weighted arithmetic mean of the slopes of polygons over the watershed area.

Soil Map: A reconnaissance level soil map was generated from the priority delineation map provided in report No. Agri-578 published by All India Soil and Land Use Survey. This was further modified through visual interpretation of Landsat MSS FCC of the area following physiographic cum pattern recognition technique. Spectral colour tones, textures, patterns etc. were the image elements used for interpretation.

Land Use/Cover Map: Land use/cover map was generated through visual interpretation of FCC using the scheme developed by Anderson *et al.* (1976). The first level stratum of broad land categories was based on the appreciable variations in tonal contrasts and pattern whereas textures and tones were used for further classification. Ground truth support was obtained from the priority delineation map contained in AISLUS report. The different classes of cultivated lands based on the conservation practices adopted, were not discernible on the Landsat data owing to the coarse resolution. These classes were segregated based on the information provided in the priority delineation map of report No. 578 published by AISLUS.

Digitization of Data Layers: The watershed frame, soil map and land cover map were digitized using 30" x 40" Calcomp digitizing table and the digitized polygons were converted into raster format. The control points for georeferencing the data were taken from the Survey of India topomaps.

Vegetation Index: The Landsat data were processed to generate a digital file based on the vegetation index (MSS band 7/band 5). A threshold value for separating vegetated and non-vegetated areas was determined. The vegetated areas were further classified through level slicing technique into 4 classes including one class representing barren lands.

Computation of Run-off Curve Numbers (CN Numbers): The soil classes were arranged into four hydrologic soil groups and these classes together with the land cover types were used to derive CN numbers using SCS look up tables.

Computation of 'Q' Values: The pixel by pixel computation of 'Q' values was accomplished by programming the equation given by Ragan *et al.* (1980) and the run-off volumes for various watersheds were obtained by aggregating the values of all the pixels over a watershed. The 'Q' values were further modified by slope factor for arriving at the run-off potential of the watersheds.

A flow chart outlining the methodology is illustrated in Fig. 2.

Results and Discussion

The framework of watersheds in Tilaiya Catchment is depicted in Fig. 3. In all, 36 polygons were demarcated following the stream orders. The interbasinal areas of lower order streams were grouped with the basins of the next higher order for demarcating the watersheds. The watershed symbolized by code '1' represents fifth order basin, those bearing codes from 2 to 9, the fourth order basins whereas the remaining watersheds represent the third order basins. The method adopted for delineation, which is different from normal method of going downstream upwards, was thought to be more appropriate for segregating hydrologic units because it is based on delineations which follow meaningful stream orders. It was also felt that such delineation could help the segregation of flood donor areas and flood recipient areas.

The soil and land cover maps are depicted in Fig. 4 and 5, respectively, and the detailed soil mapping legend is furnished in Appendix-I. The distribution of soils follows a specific pattern from shallow, loamy skeletal Lithic and Typic Ustorthents occupying hill slopes and monadnocks; through moderately deep, coarse loamy Typic Haplustalfs on foot slopes and convex plateau slopes; to deep, fine loamy hydromorphic soils (Aeric Ochraqualfs) on the toe slopes and deep, coarse loamy Fluventic soils associated with flood plain. Major land uses of the area are low to medium density forests, grazing lands, cultivated lands and barren areas. The hydrologic soil groups and CN numbers for 11 soil classes are summarized in Table 1. A generalized value of antecedent moisture level (0.25) was assumed for all the soils under different land use categories for arriving at CN values considering the dominant effect of prolonged period of dryness notwithstanding the textural variation amongst different soils.

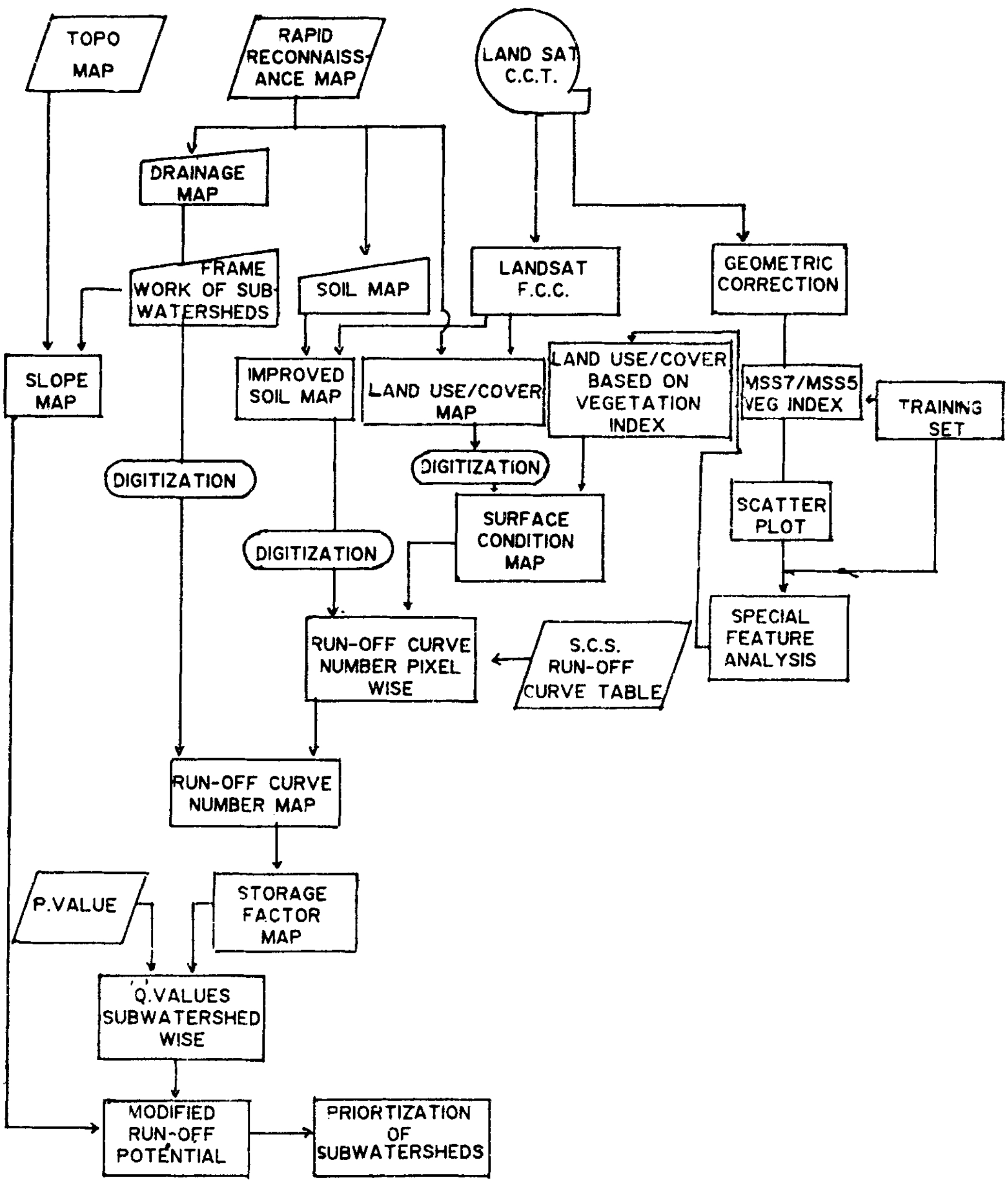

Fig. 2 : OUTLINE OF THE PROCEDURE FOR RUN-OFF MODELLING

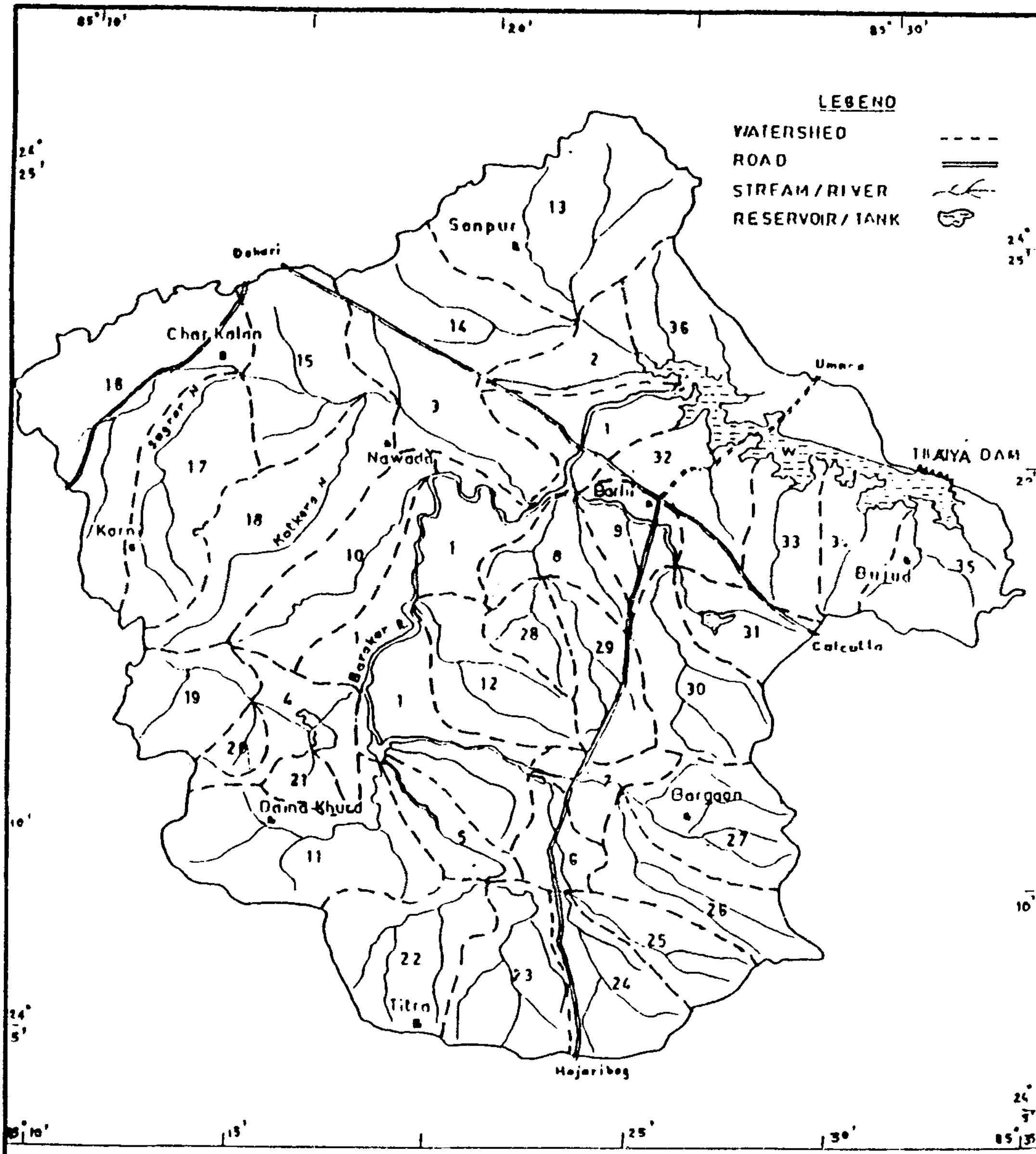

FIG. 3 : MAP SHOWING FRAMEWORK OF WATERSHEDS IN TILAIYA CATCHMENT BIHAR (INDIA)

SCALE : 1" = 4 MILES

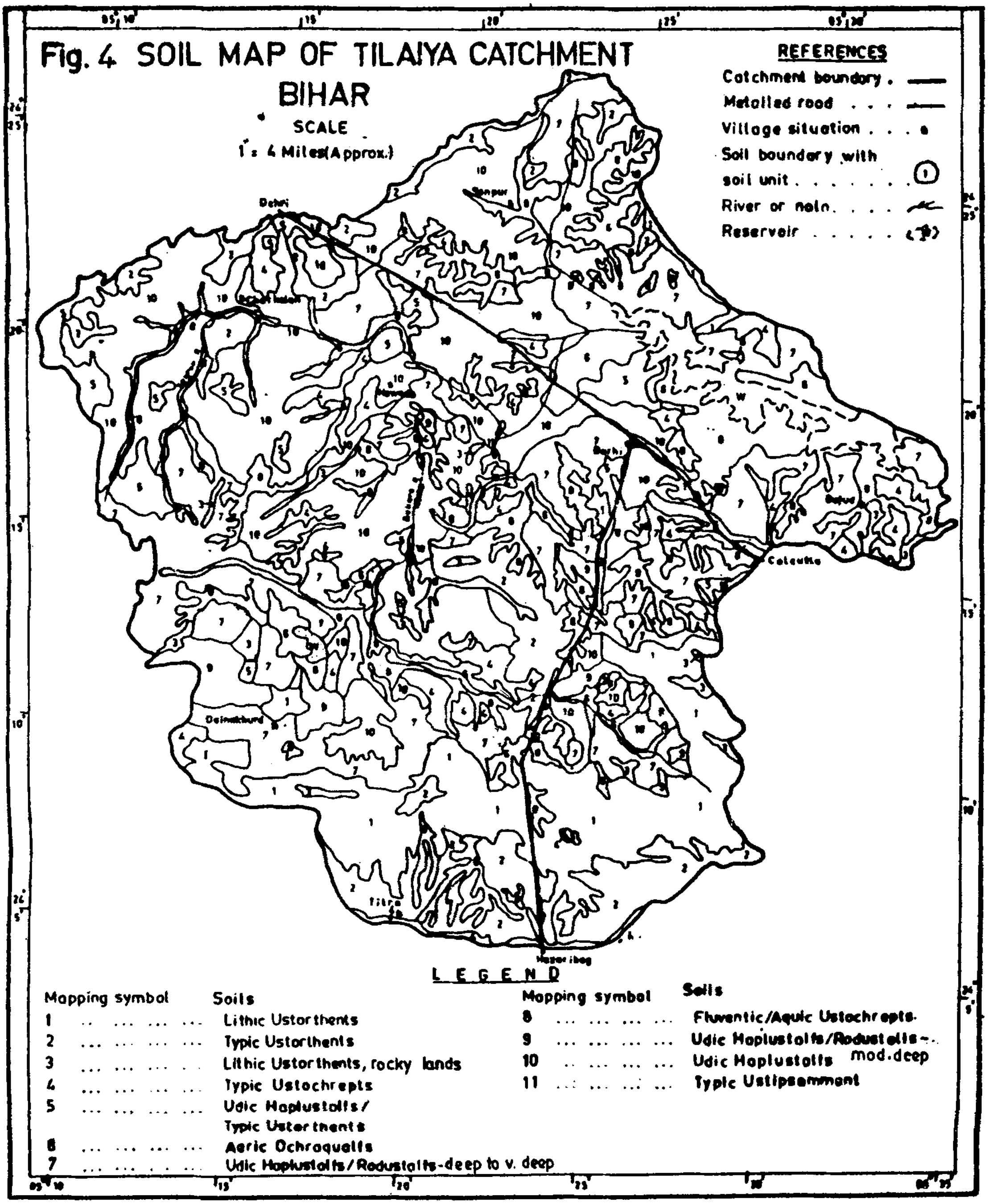
Fig. 4 SOIL MAP OF TILAIYA CATCHMENT
BIHAR
SCALE
1" = 4 Miles(Approx.)
REFERENCES
Catchment boundary
Metalled road
Village situation
Soil boundary with soil unit
River or nala
Reservoir
LEGEND
Mapping symbol Soils
1 ... Lithic Ustorthents
2 ... Typic Ustorthents
3 ... Lithic Ustorthents, rocky lands
4 ... Typic Ustochrepts
5 ... Udic Haplustolls/ Typic Ustorthents
6 ... Aeric Ochraqualfs
7 ... Udic Haplustolfs/Rodustolfs-deep to v. deep
8 ... Fluventic/Aquic Ustochrepts
9 ... Udic Haplustolfs/Rodustolfs-mod.deep
10 ... Udic Haplustolls
11 ... Typic Ustipsamment

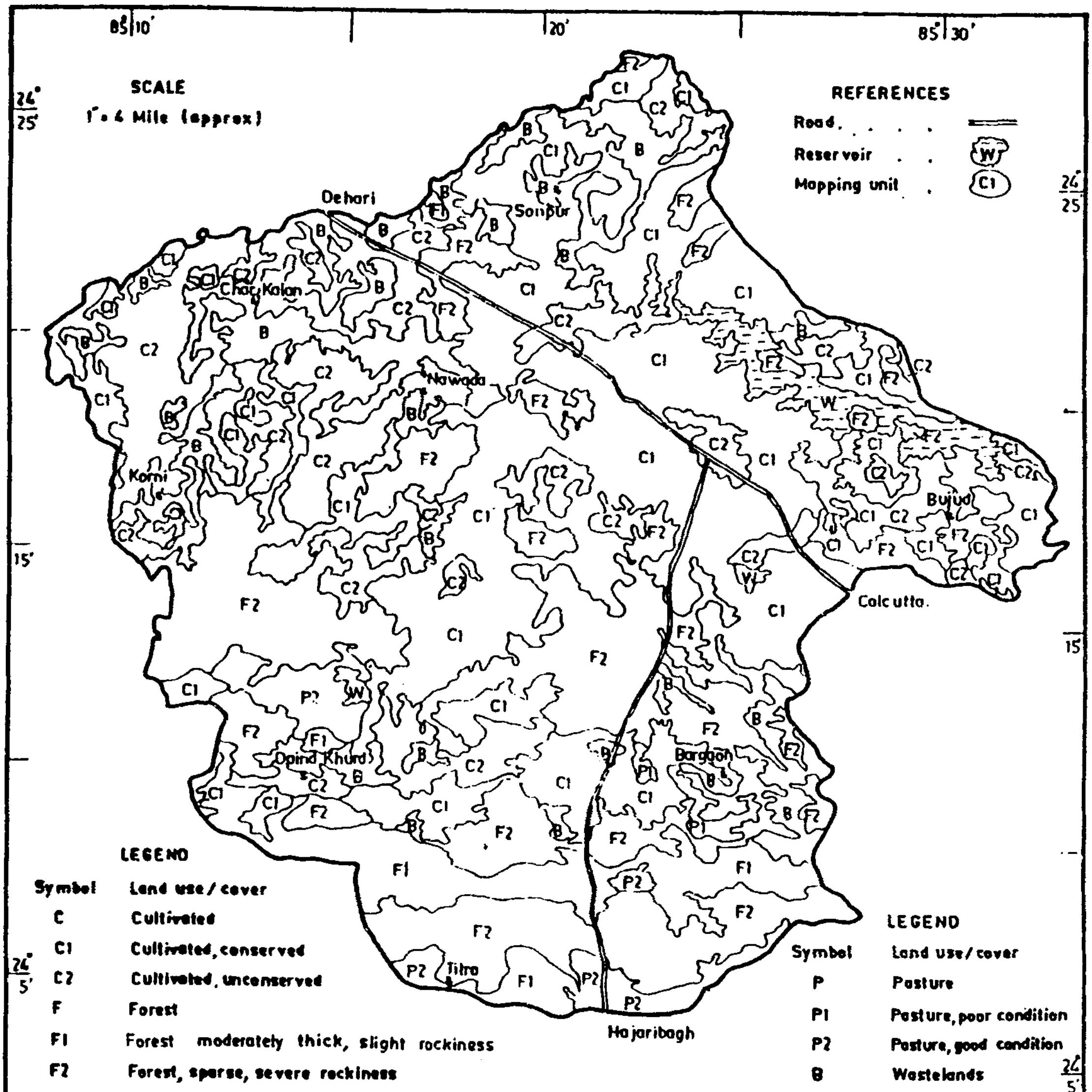

Fig. 5 : LAND USE / COVER MAP OF TILAIYA CATCHMENT BIHAR

Table 1. Hydrologic soil groups and curve numbers (CN) for various soil classes and land use categories in Tilaiya Catchment, Bihar, India.

	Hydrologic Units			
	D	B	A	C
		Soil Classes		
Land Use*	**11	4, 5, 7, 8	1, 2, 3, 6	9, 10
Cultivated land				
C1	72	88	91	81
C2	62	78	81	71
Forest land				
High	68	84	89	79
Medium	53	79	84	70
Low	39	74	80	61
Pasture land				
High	31	73	80	61
Medium	38	75	81	63
Low	45	77	83	66
Barren land	72	91	93	88
Clouds	0	0	0	0
Water	-	-	-	-

Antecedent moisture condition I_1 and $I_2 = 0.25$.
The figures in the table indicate CN values.
* Modified land use categories based on vegetation index.
** Figures are indicative of soil classes.

The predicted values of run-off for 36 watersheds computed through the model are presented in Appendix-II and summarized in Table 2 alongwith the rankings of the watersheds. To assess the validity of using vegetation index component in the model, the computations were done both with and without the vegetation index. The higher 'Q' values obtained with the use of vegetation index implied that actual surface condition has an effective intercepting capacity that is lower than the one that could be assumed on the basis of land cover classes alone.

To study the effect of slope component, the 'Q' values were compared with modified values using the watershed gradients. The range of 'Q' values for the 36 watersheds increased substantially when the slope component was incorporated into the model implying that the watershed gradients have significant effect on the run-off.

Table 2. Run-off indices of various watersheds of Tilaiya Catchment, Bihar (India) alongwith their rankings

Ranking	Watershed Code	Run-cff index	Ranking	Watershed Code	Run-off index
1	30	6.12	16	13	5.51
2	5	6.11	17	22,24	5.47
3	31	6.01	18	7	5.43
4	21	5.96	19	14	5.41
5	36	5.89	20	32	5.38
6	28	5.86	21	17	5.35
7	9	5.84	22	2,11	5.34
8	33	5.69	23	16,26	5.33
9	34	5.66	24	4,1	5.28
10	8	5.62	25	18	5.20
11	19	5.61	26	3	5.16
12	29	5.60	27	10	5.11
13	27	5.58	28	6	5.09
14	35	5.57	29	15	5.06
15	12,23	5.53	30	25	5.05
			31	20	4.72

Though the validity of the model could not be properly assessed due to lack of field data on quantum of run-off generated, the study demonstrated the potential of RS data and GIS in improving the model. The incorporation of vegetation index adds new dimension to the model that provides spatial information relevant to actual ground conditions. Implementation of a digital GIS provides basis for computations of pixel-wise run-off thus imparting physically distributed approach to the model.

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APPENDIX-I

Soil Mapping Legend - Tilaiya Catchment, Bihar (India)

1. Very shallow to shallow (<25 cm) gravelly sandy loam followed by hard granite gneiss rocks (lithic contact) of the strongly to very steep sloping (15-50%) hills and escarpments, excessive drainage (Lithic Ustorthents).
2. Very shallow to shallow (<25 cm), gravelly sandy loam followed by weathered gneiss material (Paralithic contact) of the moderately to strongly sloping (5-15%) foot slopes, excessive drainage (Typic Ustorthents).
3. Mostly rock outcrops (>80%) with very little, very shallow (<10 cm), gravelly sandy loam soils at places followed by hard granitic rock (lithic contact) of moderately to strongly sloping inselbergs, excessive drainage (Rocky lands Lithic Ustorthents).
4. Shallow to moderately deep (10-50 cm), gravelly sandy loam to gravelly sandy clay loam soils (followed by weathered granite gneisses) of the nearly level to very gently sloping (0-3%) uplands, moderately well drainage (Typic Ustochrepts).
5. Shallow to moderately deep (10-50 cm), sandy loam to sandy clay loam (followed by weathered granitic gneiss) of the gently sloping (3-5%) convex uplands, well drained (Udic Haplustalfs/Typic Ustorthents).
6. Deep to very deep (>50 cm), sandy clay loam to clay, poorly drained, hydromorphic soils of very gently sloping to gently sloping areas and toe slopes (1-5%) (Aeric Ochraqualfs).
7. Deep to very deep (>50 cm), sandy clay loam to clay loam to clay, moderately well drained soils of the very gently to gently sloping (1-5%) foot hill slopes (Udic Haplustalfs/Rhodustalfs - deep to very deep).
8. Deep to very deep (>50 cm), clay loam to clay, imperfectly drained, fluventic soils of the gently to moderately sloping (3-10%) stream banks and low lying areas (Fluventic/Aquic Ustochrepts).
9. Moderately deep (25-50 cm) sandy loam to sandy clay loam to clay, soils of the gently to moderately sloping (3-10%) foot slopes (Udic Haplustalfs/Rhodustalfs - moderately deep).
10. Deep to very deep (>50 cm deep) sandy clay loam to clay loam to clay, moderately well drained soils of upland slopes (Udic Haplustalfs).
11. Sand Bars (Typic Ustipsamments).

APPENDIX-II

Computed values of Average storage factor and run-off indices for various watersheds of Tilaiya Catchment, Bihar (India)

Polygon	*A*	S_{VI}	Q_{VI}	*Ranking*	*B*	Q_{BVI}	*Ranking*	*S*	*Q*	Q_B
1	21153	1.12	5.33	12	0.99	5.28	24	2.06	4.55	4.50
2	3901	1.10	5.34	11	1.00	5.34	22	2.48	4.25	4.25
3	8517	1.18	5.27	16	0.98	5.16	26	2.5	4.24	4.16
4	4266	1.45	5.03	22	1.05	5.28	24	3.3	3.73	3.92
5	3409	1.18	5.27	16	1.16	6.11	2	2.2	4.45	5.16
6	2946	1.02	4.59	29	1.11	5.09	28	1.46	5.03	5.58
7	3231	1.24	5.22	18	1.04	5.43	18	2.16	4.48	4.66
8	3095	1.04	5.40	7	1.04	5.62	10	1.98	4.61	4.79
9	6428	1.08	5.36	8	1.09	5.84	7	1.98	4.61	5.02
10	7733	1.31	5.16	20	0.99	5.11	27	3.13	3.83	3.79
11	12306	1.56	4.94	24	1.08	5.34	22	2.46	4.26	4.60
12	6756	1.07	5.37	9	1.03	5.53	15	1.84	4.72	4.86
13	15007	1.04	5.40	7	1.02	5.51	16	1.52	4.98	5.08
14	7469	1.15	5.30	13	1.02	5.41	19	2.05	4.55	4.64
15	8613	1.11	5.33	12	0.95	5.06	29	2.42	4.29	4.08
16	16391	1.11	5.33	12	1.00	5.33	23	2.75	4.07	4.07
17	8625	1.09	5.35	10	1.00	5.35	21	2.42	4.29	4.29
18	10512	1.26	5.20	19	1.00	5.20	25	2.93	3.95	3.95
19	5378	1.16	5.29	14	1.06	5.61	11	2.71	4.10	4.35
20	1085	1.84	4.72	27	1.00	4.72	31	4.01	3.34	3.34
21	1400	1.33	5.14	21	1.16	5.96	4	3.50	3.62	4.20
22	8576	1.99	4.60	28	1.19	5.47	17	2.35	4.34	5.16

Contd.

APPENDIX-II (Contd.)

Polygon	*A*	S_{VI}	Q_{VI}	*Ranking*	*B*	Q_{BVI}	*Ranking*	*S*	*Q*	Q_B
23	7066	1.52	4.98	23	1.11	5.53	15	2.20	4.45	4.94
24	5157	1.57	4.93	25	1.11	5.47	17	2.28	4.39	4.87
25	4173	1.83	4.72	27	1.07	5.05	30	2.32	4.36	4.67
26	6034	1.79	4.76	26	1.12	5.33	23	2.07	4.54	5.08
27	6995	1.51	4.98	23	1.12	5.58	13	1.79	4.76	5.33
28	2415	0.90	5.53	1	1.06	5.86	6	1.84	4.72	5.00
29	4244	1.23	5.23	17	1.07	5.60	12	2.40	4.30	4.60
30	6846	1.17	5.28	15	1.16	6.12	1	1.90	4.67	5.42
31	4112	0.92	5.51	2	1.09	6.01	3	1.39	5.09	5.55
32	4037	1.11	5.33	12	1.01	5.38	20	1.94	4.64	4.69
33	4548	1.02	5.42	5	1.05	5.69	8	2.10	4.52	4.75
34	3937	1.00	5.44	4	1.04	5.66	9	2.32	4.36	4.53
35	6651	1.03	5.41	6	1.03	5.57	14	1.97	4.62	4.76
36	8591	0.93	5.50	3	1.07	5.89	5	1.57	4.93	5.28

A = Area in Acres

S_{VI} = Average storage factors/polygon with vegetation index

Q_{VI} = Average runoff/polygon with vegetation index

B = Slope factor

Q_{BVI} = Slope modified runoff

S = As for S_{VI} but without vegetation index

Q = As for Q_{VI} but without vegetation index

Q_B = As for Q_{BVI} but without vegetation index