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Evaluation of Prevailing Irrigation Practices and Their Relation to Soil Properties - A Case Study of Hamadan-Bahar Area of Western Iran

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Abstract: A study was conducted in a semi-arid area of Iran to investigate the relation between irrigation methods and the soils, using remote sensing data and a geographic information system (GIS). Spatial distribution of soils, soil attributes and kind of land use/land cover were the main determinant factors investigated. Spatial distribution of the soils was determined at semi-detailed level. Soil attribute maps were derived from the soil map and the laboratory analyses of the samples for physical and physico-chemical characteristics such as infiltration rate, permeability, bulk density, available water content (AWC), sodicity and salinity, pH, and by using rule-based expert survey system. Digital and visual analysis of LANDSAT TM data, supported by field survey, was performed to extract the required information on land use/land cover, on the basis of which the extent of each irrigation method was estimated. Suitability of the soils for the application of various irrigation methods were mapped and compared with the soils of the area where they are practised. This was done on the basis of spatial distribution of the soils and a number of determinant soil attributes, using ILWIS (ITC, 1993) geographic information system.

Key words: Irrigation methods, land use/cover classification, semi-arid, irrigability classification, soil-water relationship.

One way to partly overcome the problem of water shortage in arid and semi-arid regions is its judicious application, based on crop water requirement. Amongst the remedies commonly suggested, one is adoption of appropriate irrigation method, taking into account the crop and in particular, type of soil. Soils manifest considerable inherent variability in their physical and chemical properties, as a result of variation in parent material and other soil forming factors. Variability in soil affects irrigation efficiency and thus needs to be well described (Israelsen and Hansen, 1962).

On the other hand, whatever may be the source of irrigation water, some soluble salts are always dissolved therein, which affect the soil properties and subsequently the plant growth (Paliwal, 1971). This suggests the necessity of assessment of cultural and irrigation practices in relation to soils, as an integral part of good agricultural management.

Performing the expensive conventional field surveys for monitoring cultural and irrigation practices in remote areas of Iran is not economically feasible. Sophisticated and new techniques such as remote sensing

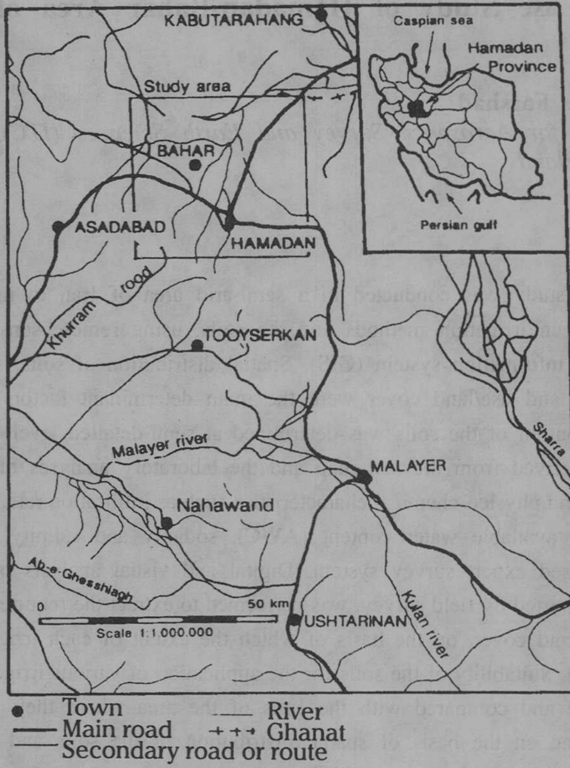

Fig. 1. Location map of the study area.

can be used to perform spatial mapping in near-real time more conveniently. Remote sensing data integrated with GIS, have proven to be capable of storing and retrieval of large volume of data for land use/land cover mapping (Nellis, 1984; Csillag, 1986; Lo *et al.*, 1986).

In the present study, attempt has been made to map the extent of various irrigation application methods in relation to crops and assess their applicability in these soils. Data collected in sample areas in conjunction with the remotely sensed data (LANDSAT TM images in different wavelength bands and aerial photographs at 1:50,000 scale), integrated with a geographic information system, have been used to assess the relationship between soils and prevailing irrigation methods in the Hamadan-Bahar area of north-western Iran.

Location

The study site covers an area of approximately 1,150 km^2 in the Hamadan Province, about 380 km south-west of Tehran. North 34°45′ to 35°05′ and East 48°20′ to 48°40′ limit the area (Fig. 1). Elevation ranges between 1,600 m in the lowest part and over 3,500 m above m.s.l. in the mountainous areas.

Climate

Much of the rainfall occurs between October and May, with its maximum in April and minimum in June-July. The mean annual precipitation is 310 mm with uneven distribution. This amount is not enough to meet the water requirements of agricultural crops grown in the area. The mean monthly air temperature ranges from -0.6°C in December to 24°C in July. Mean annual air temperature is 10°C, while the minimum value drops far below freezing point during January.

Physiography and Soils

Mountain, hill, piedmont and valley are the main physiographic units in the study area. The Hamadan-Bahar depression forms the lowest part of the piedmont, lying at the foot of the granitic Alvand mountain. This consists of highly permeable materials derived from granite and some metamorphic rocks.

The soil types vary progressively down slope from very shallow rocky soils on the barren mountains and hills, to deeper soils on the dissected upper glacies and lower glacies. The soil texture varies with toposequence from rather coarse in the upper parts to fine in valley fills. On high glacies in the northern part of the area soils with well developed calcic horizons are being formed (Fig. 2 and Table 1).

Generally, the soils are calcareous, alkaline in reaction (pH varies from 7.5 to 8.5) and have calcium carbonate accumulation in the upper 150 cm of soil. Moderate profile development (dominantly Inceptisols), medium to fine texture, low organic matter and low biological activity are the other characteristics (Moameni, 1994).

Materials and Methods

The methodology adopted in this study consists of several main and intermediate steps which are depicted in Fig. 3.

Step 1: Preparation of a soil map for the study area on the basis of aerial photo-interpretation, followed by soil survey activities in the field. This map was later used to prepare different data layers (attribute maps) such as slope class, infiltration rate, soil permeability, etc.

Step 2: Information extraction through digital and visual interpretation of the satellite images. The objective of this step was to classify land use/land cover in general, and further discrimination of the crop types in particular. The assumption was that irrigation is crop-dependent, i.e., if crop type is determined, the irrigation method can be inferred.

Step 3: Rectification and combination of the data layers using ILWIS (ITC, 1993) software package. This step resembles the "matching" process in the procedures of land evaluation (FAO, 1976) in which the requirements of the land use types (here, irrigation methods) are compared with the qualities of each of the land units, leading to suitability classification of the land units in physical terms for specific purposes (here irrigation-method suitability classification of the land; Fig. 3).

Soil mapping

Five representative sample areas were selected from the pre-field aerial photo-interpretation map and were studied geopedologically (Zinck, 1988/89). The required detailed information on morphology, and physical and chemical characteristics were

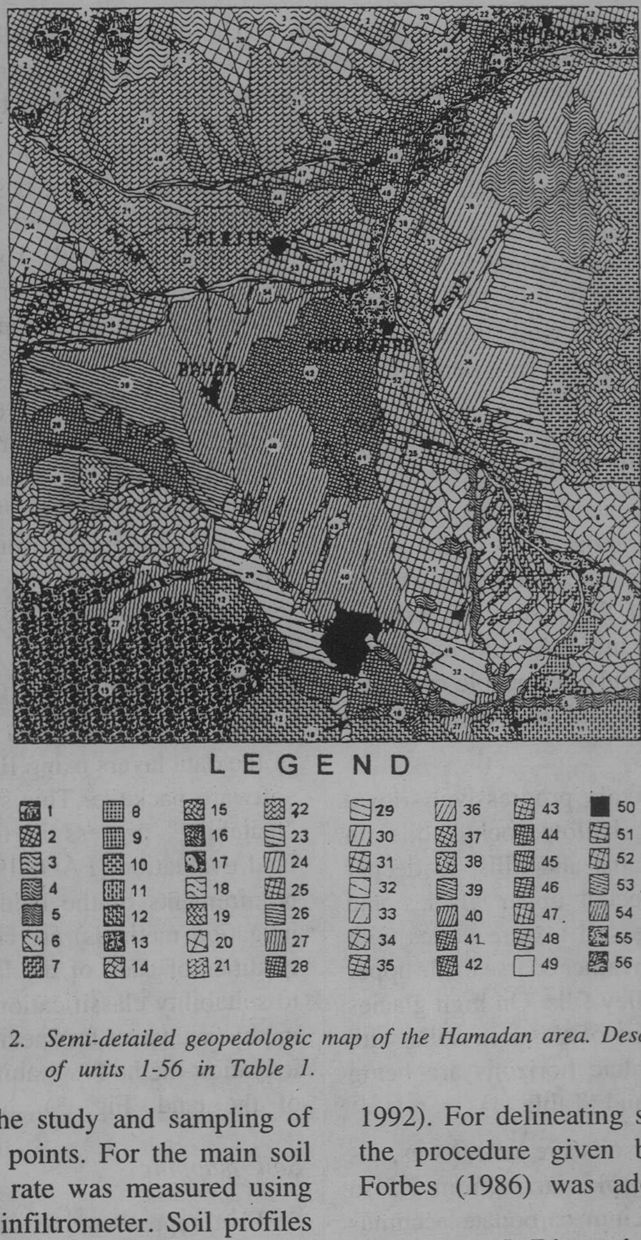

Fig. 2. Semi-detailed geopedologic map of the Hamadan area. Description of units 1-56 in Table 1.

obtained from the study and sampling of 120 observation points. For the main soil units infiltration rate was measured using double-cylinder infiltrometer. Soil profiles were described using the FAO Guidelines for Soil Profile Description (FAO, 1977). The soils were classified at family level, according to the U.S. Department of Agriculture Soil Taxonomy (Soil Survey Staff, 1992). For delineating soil mapping units, the procedure given by Wambeke and Forbes (1986) was adopted.

Results and Discussion

Land use/land cover mapping

LANDSAT TM data of September 1990 (path 157 row 041) were digitally analysed

Table 1. Physiographic soil association of Hamadan-Bahar area

No.	M. Unit/ Symbol	Soil association	No.	M. Unit/ Symbol	Soil association	No.	M. Unit/ Symbol	Soil association
1	Mo111	L. Xeror	20	Pi212	Ca. Xeroc. - T. Xeroc.	39	Pi421	Ca: Xeroc. - T. Xeroc.
2	Mo131	NS	21	Pi213	Ca. Xeroc. - T. Xeroc.	40	Pi422	Ca. Xeroc. - F. Xeroc. - T. Xeror.
3	Mo141	NS	22	Pi214	Ca. Xeroc. - F. Xeroc.	41	Pi423	T. Xeror.- F. Xeroc.- Ca. Xeror
4	Mo151	NS	23	Pi221	Ca. Xeroc. - F. Xeroc.	42	Pi424	Mollic Halaquepts
5	Mo161	NS	24	Pi222	Ca. Xeroc. - T. Xeroc.	43	Pi425	F. Xeroc. - T. Xeroc.
6	Mo211	NS	25	Pi223	Ca. Xeroc. - F. Xeroc.	44	Pi511	T. Xeroc. - Ca. Xeroc.
7	Mo311	NS	26	Pi231	Ca. Xeroc. - L. Xeroc.	45	Pi512	T. Xeroc. - F. Xeroc.
8	Mo321	NS	27	Pi241	T. Xeroc. - L. Xeroc.	46	Pi611	Ca. Xeroc. - F. Xeroc.
9	Mo331	NS	28	Pi242	Ca. Xeroc. - T. Xeroc.	47	Pi711	T. Xeroc. - F. Xeroc. - T. Xerof.
10	Hi111	L. Xeror. - Rock outcrop	29	Pi243	F. Xeroc. - T. Xeroc. - Ca. Xeroc.	48	Pi721	T. Xeroc. - T. Xeror.
11	Hi112	T. Xeroc. - Ca. Xeroc.	30	Pi251	Ca. Xeroc. - F. Xeroc. - T. Xeroc.	49	Rb	River bed
12	Hi113	Pet. Xeroc.- Ca. Xeroc. - L. Xeror	31	Pi261	T. Xeroc.- T. Xerof.	50	U	Urban area
13	Hi121	L. Xeror. - Ca. Xeroc.	32	Pi262	T. Xeroc.	51	Va121	T. Xeroc. - Ca. Xeroc.
14	Hi211	T. Xeroc. - L. Xeror - Rock outcrop	33	Pi263	T. Xeror. - T. Xeroc.	52	Va221	T. Xeroc. - T. Xerof. - T. Xeror.
15	Hi311	T. Xeroc. - F. Xeroc. - T. Xeror.	34	Pi311	Ca. Xeroc. - T. Xeroc. - F. Xeroc.	53	Va222	Aq. Xeroc. - T. Xeroc.
16	Hi312	Ca. Xeroc. - F. Xeroc.	35	Pi321	Ca. Xeroc. - F. Xeroc.	54	Va223	Ca. Xeroc.- F. Xeroc.
17	Hi313	T. Xeroc.- Ca. Xeroc.	36	Pi411	Ca. Xeroc. - F. Xeroc. - Pet. Xeroc.	55	Va321	F. Xeroc. - Aeric Endoaquepts - T. Xerof.
18	Hi321	Ca. Xeroc. - F. Xeroc.	37	Pi412	Ca. Xeroc. - F. Xeroc.	56	Va322	T. Xeroc. - Aq. Xeroc. - F. Xeroc.
19	Pi111	L. Xeror. - Rock outcrop	38	Pi413a	Ca. Xeroc.			

Note: Aq = Aquic; Ca = Calcixerollic; F = Fluventic; L = Lithic; M = Mapping; NS = Not surveyed; Pet = Petrocalcic; T = Typic; Xeroc = Xerochrepts; Xeror = Xerorthents.

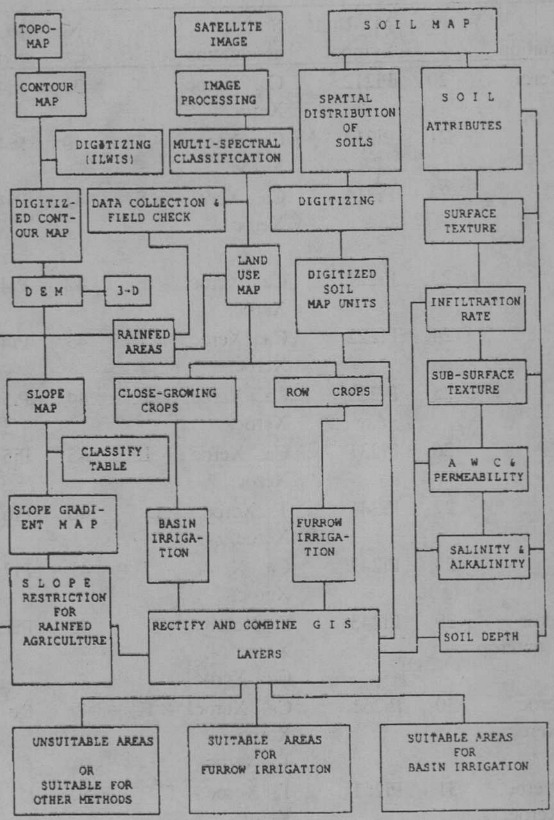

Fig. 3. Methodology for irrigation suitability.

for land use/land cover in general, and crop type in particular. Prior to image processing, corrections for atmospheric scattering, contrast stretching (Sabins, 1987) and geometric correction (bi-linear resampling method) of the images were carried out. An unsupervised classification of a false colour composite (FCC) image, prepared from 3 spectral bands (i.e., band 5: middle infrared, band 4: near infrared and band 3: red), was performed using maximum likelihood classifier. The whole image was classified. Several classes of land use/land cover were identified, but the results were not quite satisfactory regarding different crop types. This was due to the minimum contrast between the wilted natural vegetation and harvested cereals with dry stubble at the surface during data acquisition (Table 2). The irrigated crops were at different development stages on the date of imaging. In the case of alfalfa, potato and orchards, which were green, there was no serious problem concerning the classification, but the problem was encountered while discriminating crop types which were

Table 2. Crop development status at the time of image acquisition

Crop	Sowing/Planting date	Harvesting date	Field conditions duirng TM data acquisition
Alfalfa	March/April	August/October	Green; partly harvested
Garlic	October/November	July	Residues
Melons	May	August/September	Green
Peas	March/April	July	Residues
Potato	April/May	September/November	Green
Fruit trees	March/April	July/September	Green
Wheat, Barley	October/November	July/August	Residues

being harvested or were at the harvest stage. These crops included mostly wheat, barley and garlic. The spectral reflectance of wheat and barley residues were the same as those of the wilted natural vegetation (seasonal grasses). Optical and IR bands, as well as images created through image ratioing (NDVI), principal component analysis and tasselled cap procedures, were combined to produce different FCCs in order to improve the results of the unsupervised classification, but not much improvement was achieved.

In order to classify only the irrigated parts rather than the whole image, non-irrigated areas were masked on the satellite image. Then supervised classification was performed on the basis of ground truth data collected in the sample areas. Pixels of known crop types were selected on the masked image, and the computer was trained to classify the image on the basis of introduced known spectral reflectance concerning each crop type. The Box classifier gave the best results. The overall classification accuracy was 74%. Classes of alfalfa, wheat and barley, wilted garlic, potato and tree plantation were identified.

By combining the extent of each irrigated crop discriminated on the image, along with slope and existing irrigation method (Table 3), the extent of each irrigation method

Table 3. Methods of irrigation practised for main crops

Crops	Topography	Irrigation method used
Wheat and barley	Level and nearly level	Border, corrugation
Alfalfa	Level and nearly level	Border
	Undulating	Basin
Potato	Level and nearly level	Basin, furrow
	Undulating and rolling	Small basin
Garlic	Level and nearly level	Basin
	Undulating and rolling	Small basin
Sugar beet	Level and nearly level	Basin
Tree plantation	Level and nearly level	Basin
	Undulating and rolling	Small basin
	Sloping, moderately steep	Terrace making, small basin

(applied to each crop) was determined indirectly. The newly formed analogue map, instead of the crop type, represents the extent of irrigation methods.

Mapping of irrigation suitability

The second main objective of this research was to determine suitable irrigation methods for different areas. Topsoil texture, infiltration rate, permeability, available water content and alkalinity were considered as the most important soil properties, employed to reach the above goal.

Apart from this, soil stoniness, depth to water table, soil depth and salinity are important factors for irrigability evaluation, but these are not limiting in the study area, and were not considered. The presence of calcium carbonate in the soil profile and soil structure, however, were indirectly taken into account while rating the soil characteristics. Also, soil alkalinity was taken into account, which was evident in the lowest part of the piedmont, i.e., the depression to the north of Bahar city.

Generation of attribute maps from soil information

Soil attribute maps were prepared using the ILWIS table calculator, which allows to link attribute data with the spatial data. The created attribute maps were used as data layers from which the desired information is extracted using rule-based expert system, through execution of the logical, conditional and arithmetic operators and functions.

The soil map of the study area was reclassified with the table containing infiltration data to transfer it to an interpretative map. In this map, all the soil mapping units are assigned a value between 1 and 4 with respect to their texture. The value 4 is assigned to the mountain and hilly landscape units, which are almost entirely unsuitable for surface irrigation practices due to their topographic and surface conditions.

In the next step, the topsoil texture map was integrated with the slope map, using a 2-dimensional table to model the suitability of soils for the application of certain irrigation methods.

To generate the slope map, contour lines (with intervals of 20 m), extracted from topographic maps (1:50,000 scale), were digitized to create a digital elevation model (DTM). Seven slope classes (i.e., 0-1, 2-3, 4-5, 6-8, 9-15, 16-24 and > 24%) were considered, adapting from Soil and Water Research Institute of Iran (Mahler, 1970). The slope classes were provided for recognition of either single or complex slopes. Class 6 and 7 were upgraded according to the topographical condition of the study area. A similar procedure was then followed to create permeability and AWC maps.

A value between 1 and 5 was assigned to each mapping unit of the permeability map taking into account water percolation rate of the soils. Value 5 was assigned to the mountain and hilly landscape units.

In order to determine the values of the AWC, undisturbed soil samples were collected from fields representing the most extensive soils (Calcixerollic Xerochrepts and Typic Xerochrepts). By determining moisture content (Table 4) at different metric potentials (pF), water retention curves were plotted. Values of available water con-

Table 4. Bulk density, texture and AWC (at various pF values) of Calcixerollic Xerochrepts (C.X.) and Typic Xerochrepts (T.X.)

Profile	Depth (cm)	pF 2.0	2.5	2.7	3.0	3.5	3.7	4.2	Bulk density ($g\ cm^{-3}$)	Texture
C.X.	0-20	50.7	29.1	22.0	20.0	18.8	17.5	14.8	1.45	CL
	20-35	46.0	30.1	23.0	21.0	19.9	19.0	15.8	1.44	CL
	35-100	46.2	31.7	24.3	22.2	21.1	19.8	16.7	1.49	CL
T.X.	0-20	36.8	35.6	31.5	26.5	22.6	19.6	17.8	1.37	CL
	20-32	37.3	36.8	31.7	27.6	20.8	19.5	19.5	1.50	CL
	32-52	49.7	37.6	31.4	30.0	24.8	22.2	21.6	1.44	CL
	52-105	51.9	38.6	35.6	32.8	26.6	25.0	25.0	1.30	SICL

CL = Clay loam, SICL = Silty clay loam.

tent were both inferred from subsoil texture and determined on the basis of soil water retention curves of the main soils (Fig. 4). In case of AWC, all soil mapping units were rated by assigning each a value between 1 and 4, corresponding to their potential for irrigation, i.e., high, moderate, low and no assessment, respectively.

The soil map was reclassified with attribute data (rated soil properties) stored in classified tables. As a result of these operations, soil mapping units were assigned values corresponding to the values stored in rating tables. Figure 5 shows a schematic representation of these operations.

Overlay operations

In order to determine the suitability of soils for the application of irrigation methods, a number of data layers were created and integrated. Using ILWIS (version 1.4), integration of raster maps becomes possible through 2-dimensional tables. The 2-dimensional tables were created, taking into account the following data and assumptions:

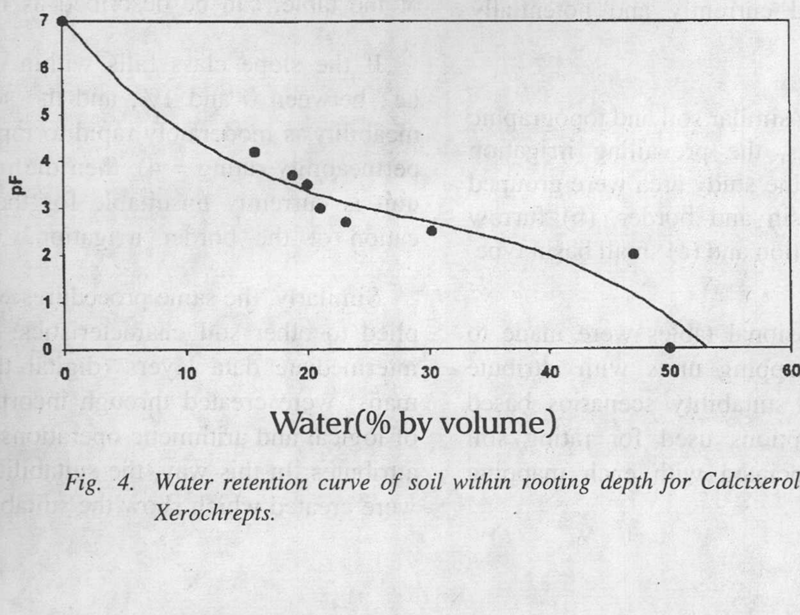

Fig. 4. Water retention curve of soil within rooting depth for Calcixerollic Xerochrepts.

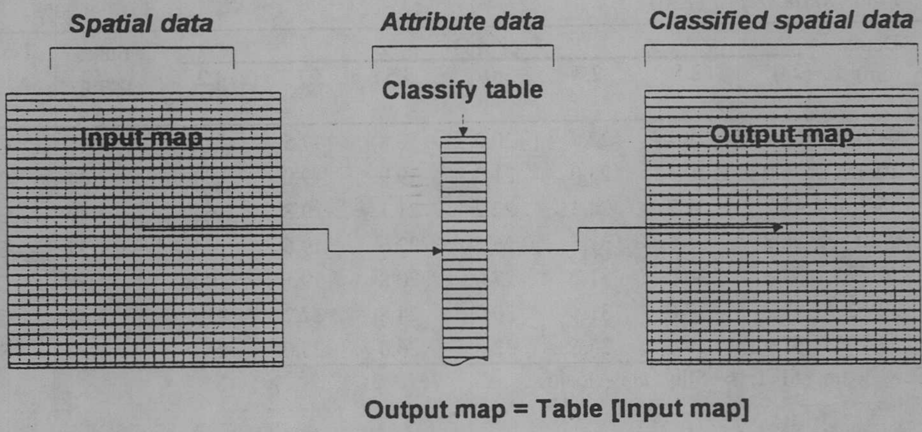

Fig. 5. Schematic of raster-based operations for reclassifying spatial data with attribute data stored in classified tables.

- The irrigation methods applied in the study area include: 1. basin, 2. border, 3. furrow, 4. corrugation, and 5. small basins.

- The classes of suitability for sustained application of the irrigation methods in the study area were designated by a value between 1 and 5, corresponding to highly, moderately and marginally suitable and currently and potentially unsuitable.

- Considering similar soil and topographic requirements, the prevailing irrigation methods in the study area were grouped into (a) basin and border, (b) furrow and corrugation and (c) small basin type.

Two dimensional tables were made to link terrain mapping units with attribute data to create suitability scenarios based on the assumptions used for rating soil properties associated with each mapping unit (Fig. 6).

In total, nine 2-dimensional tables were created to integrate all the created data layers, including soil, slope, infiltration, permeability and AWC map. As an example the 2-dimensional table created to integrate the permeability and the slope steepness is given in Table 5.

For example, the first interpretational value (suitability 4) given in the first row of the table, can be described as follows:

If the slope class falls within class 1, i.e., between 0 and 1%, and the soil permeability is moderately rapid to rapid (soil permeability rating = 4), then the mapping unit is currently unsuitable for the application of the border irrigation.

Similarly, the same procedures were applied to other soil characteristics. Several intermediate data layers (digital thematic maps) were created through incorporation of logical and arithmetic operations on soil attributes. In this way, the suitability maps were created which show the suitable areas

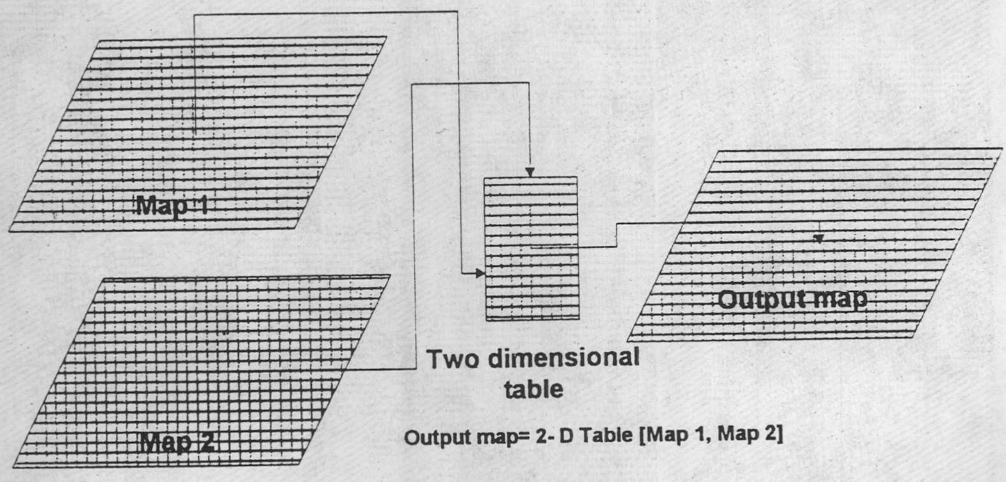

Fig. 6. Reclassification of the thematic maps with two dimensional table.

for application of the basin and border irrigation methods with respect to soil permeability, infiltration rate, AWC and slope of the terrain (Fig. 7).

Conclusion

Information on land use was a key component in this research. However, using TM digital images (except for band 6), it is possible to map areas as small as about 0.1 ha. On the other hand, in the area studied, farms consist of many small parcels devoted to different types of land use. Small land holding was one of the factors strongly affecting the land use/land cover classification. In spite of these difficulties, technically the study was a success. Although image classification, from which information on land use has been derived, was low (55-82% depending on the land use classes), the extent of each irrigation

Table 5. Example of the 2-dimensional table used for integrating soil permeability and slope steepness maps

Slope clases	Soil permeability rating				
	1	2	3	4	5
1	4	2	1	2	5
2	4	3	2	2	5
3	4	4	4	4	5
4	4	4	4	4	5
5	4	4	4	4	5
6	4	4	4	4	5
7	4	4	4	4	5

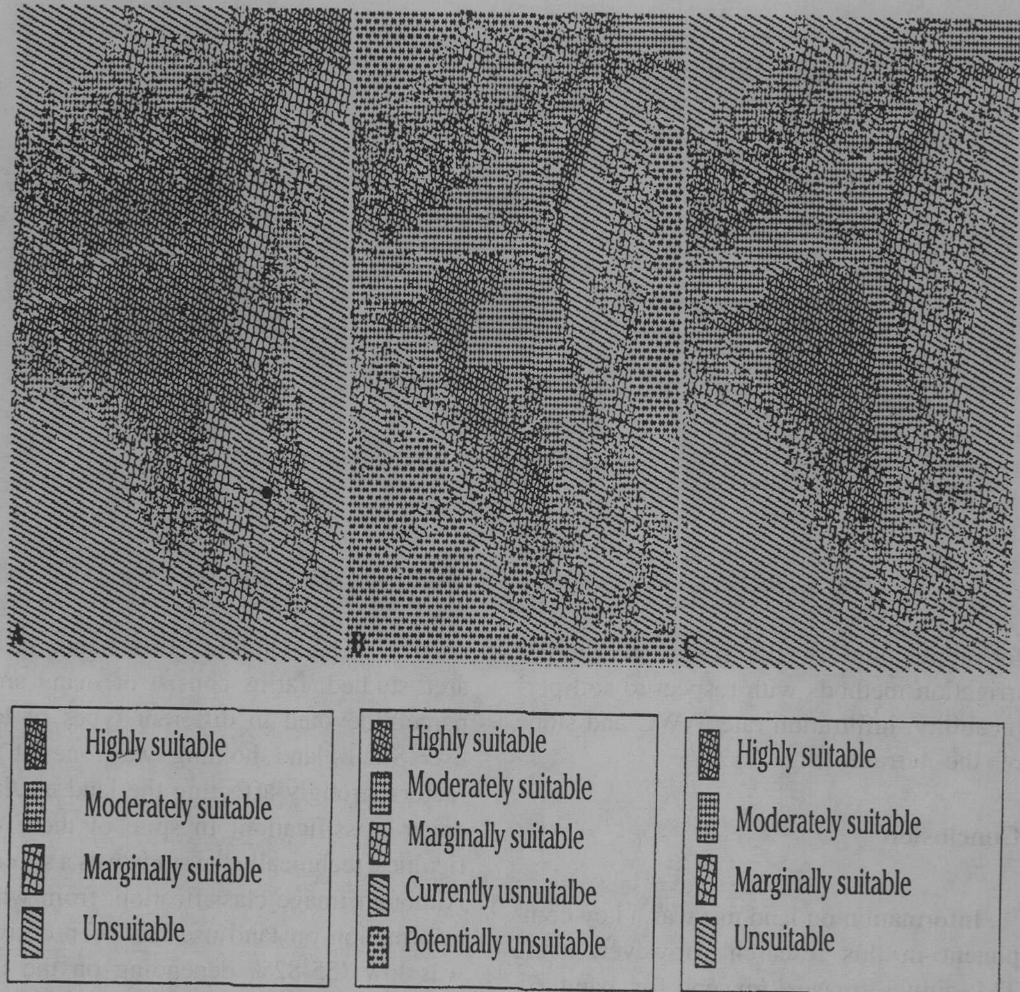

Fig. 7. Suitability maps for the application of basin and border irrigation methods based on infiltration (A), premeability (B) and available water content (C).

method was indirectly mapped. The soil attribute assignment algorithms used to assess the suitability of the soils for the application of various irrigation methods, performed properly for most areas. The approach may serve as a useful method in conducting raster-based land suitability mapping at regional and local levels.

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