Rainwater Harvesting for Dry Land Agriculture - Developing a Methodology Based on Remote Sensing and GIS

Dieter Prinz[1], Theib Oweis[2] and Annette Oberle[3]

ABSTRACT

To feed the growing population in the dry areas of the world, more irrigation is needed but the quantity of irrigation water is extremely limited. The "classical" sources of irrigation water are often at the break of overuse and therefore untapped sources of irrgation water have to be sought for.

As rainfall in dry areas is often lost in evaporation, rain water harvesting which is the collection of surface runoff mainly for agricultural and domestic purposes, might be an alternative. However, the selection of appropriate sites and the determination of suitable methods of water harvesting on a large scale present great challenges, since the necessary hydrological and soil data and the infrastructure are often lacking.

An ongoing research work at the ICARDA, Aleppo, Syria is aimed at developing a methodology for the application of remotely data and GIS for identifying appropriate sites and methods of water harvesting in dry areas in West Asia and North Africa.

A pilot project site was selected in central Syria, covered by a whole LANDSAT TM scene. The image processing software ERDAS IMAGINE and GIS software ARC/INFO were used to process the images and to establish a geo-information system comprising digital data sets of satellite imagery, topography, soil, vegetation, hydrology and meteorology. Using these tools it was posssible to identify areas generally suitable for water harvesting and to determine water harvesting techniques for those sites. The developed methodology is also applicable in other regions with similar conditions.

Keywords: Water Harvesting, Geographical Information System, Remote Sensing, Syria

INTRODUCTION

Only a small fraction of the rainfall falling in arid and semi-arid areas percolates into deeper soil or rock layers to recharge an aquifer. Another small fraction is used for transpiration of vegetation or of agricultural crops. The majority of the precipitation evaporates from the often bare soil or from surface depressions. To feed the growing population in the dry areas of the world, more irrigation is needed but the quantity of irrigation water is extremely limited. The "classical" sources of irrigation water are often at the break of overuse and therefore untapped sources of irrgation water have to be sought for. To increase agricultural production in dry areas, the necessity exist to think about the utilisation of the evaporative portion of precipitation to be used for agricultural purposes before it is released to the atmosphere (Oweis and Taimeh, 1996).

Since time immemorable, farmers in dry areas collect surface runoff of precipitation, using various types of ‘water harvesting’ (Prinz, 1995, Prinz, 1996). ‘Water harvesting’ is here defined as the collection of surface runoff mainly for agricultural and domestic purposes.

[1] Prof. of Rural Engineering, University of Karlsruhe, D-76128 Germany
[2] Water Management Specialist, ICARDA, Aleppo, Syria
[3] Research Associate, ICARDA, Aleppo, Syria

In spite of several thousand years of experience in water harvesting, a number of open questions remain, e.g. how to increase the water yield of a given catchment or how to identify areas suitable for certain techniques of water harvesting. The latter question is in the focus of a running research project carried out by ICARDA (International Center for Agricultural Research in the Dry Areas) and the University of Karlsruhe, Germany.

Some years ago, the University of Karlsruhe was already engaged in the development of a methodology to identify areas suitable for water harvesting in West Africa (Tauer and Humborg, 1992; Prinz, Tauer and Vögtle, 1994). This methodology was developed under tropical conditions in a zone with precipitation amounts of about 500 mm/annum, in a summer rainfall area and a region with a sedentary farming population. The situation in the Middle East, were the present methodology is developed, is rather different: the region in question belongs to the winter rainfall area, experiences only 100-300 mm of rainfall/annum and the rural population is nomadic or semi-nomadic. Therefore, a totally new approach has to be used and a new methodology to be developed.

In rain water harvesting three different **groups of techniques** are distinguished: (1) **flood water harvesting** from far away, large catchments, (2) **rainwater harvesting** from **macro-catchment systems** utilising the runoff from a nearby slope for agricultural purposes (with or without interim storage) and (3) **rainwater harvesting from micro-catchments**, where the water from an adjacent, small catchment is used for cropping (Fig. 5; Critchley and Siegert ,1991, Prinz, 1996, Reij et al., 1989). It is evident, that all three groups of water harvesting techniques need different geographic settings to be implemented. Besides the topography, the runoff conditions of the surface, the infiltration rates, the soil types of the run-on areas and the depth of the soil layer in the cropping areas are among the most important natural parameters for the implementation of any water harvesting system. Additionally, socio-economic factors have to be taken into due consideration.

For relatively small areas (in the range of several hundred hectares) a ground truth carried out by a number of experienced people will be the best technique to identify suitable areas for water harvesting. For medium range sizes of areas, the use of aeroplanes equipped with photographic equipment could be suitable and for even larger areas the application of remote sensing by using satellite images could be the most relevant means of identification of areas suitable for certain techniques of water harvesting. For any of the above mentioned techniques, the application of a suitable GIS (Geographic Information System) is indispensable.

It has to be mentioned however, that the application even of the best GIS will not guarantee the success of any water harvesting scheme, as a number of external factors such as **water and land rights**, **macro-economic conditions**, **traditional rules** and believes can hardly be incorporated into such a GIS, but might influence the development of the water harvesting scheme strongly.

OBJECTIVES

The general objective of the study is an **improved agricultural production** in the steppe zone of the Middle East which helps combating desertification by more efficient utilisation of rainfall through proper water harvesting planning. Specific objectives include:

(1) Identification of potential areas which are suitable for given methods of water harvesting in a pilot area in Central Syria,

(2) Development of a methodology through which remotely sensed data together with a minimum of field investigations and the application of a GIS can be used to assess the potential for water harvesting and advise on the appropriate water harvesting

methods in those areas.

PROJECT PILOT AREA

For this study, an area in Central Syria covering about 33,000 km^2 between latitudes 33,8° N and 35,5 °N and between longitude 36,8° E and 38,8° E was chosen. This area is covered by a scene of path 179, row 36 of the LANDSAT Thematic Mapper. The area is sparcely populated with major settlements being Salamiyeh, Palmyra and Quaryatain. Small villages and minor settlements are scattered mostly over the southern part of the project area. The infrastructure is rather poor and no detailed information on topography, soils, climatic conditions and socio-economic data is available for the area (Fig. 1).

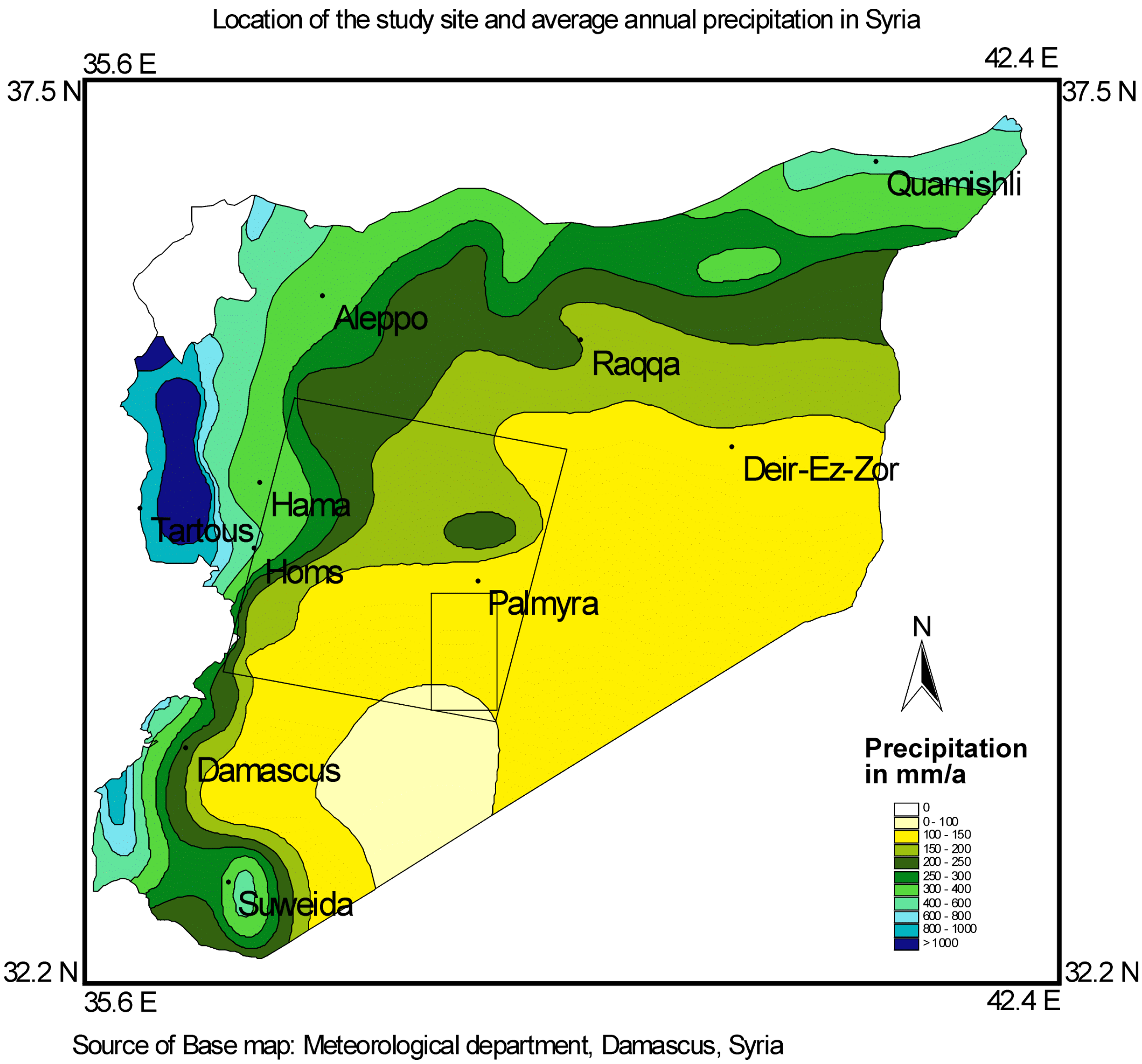


Fig.1: Location of the study region and average precipitation in Syria

The **climate** in the Syrian steppe is characterised by cold, rainy winters and dry and hot summers. Mean monthly temperatures vary from 6°C in January to about 32°C in August. Precipitation occurs during the months November to April, this means annual ranges between 250 mm in the north-west to less than 100 mm in south-east of the project area. Rainfall is highly variable in space and time and falls as storms with often high intensity causing substantial runoff. The low precipitation amount contrasts sharply with the evaporation demand of the atmosphere which is calculated to be in the range of 2200-2300 mm /annum (Soumi, 1991).

The **soils** of the area are classified as aridisoils and entisols according to the FAO classification system. The soils are weakly developed and low in organic matter (1-2%). One common feature is the presence of a surface crust, consisting of pavement of embedded pebbles the socalled 'desertic pavement' which impedes the infiltration. Some wide plains are often inundated after rainstorms in springtime and the lower slope of the mountain valleys are often covered with a thick horizon of alluvial sediments of loamy find sand. These soils are richer in organic carbon and often used for the cultivation of barley.

Shrubs and grasses dominate the **vegetation** of the area, which is associated to the Irano-Turanian zone. In earlier days *Pistacia atlantica* was widespred but can rarely be found nowadays. Bushes like *Artemisia herba-alba* and *Haloxyletum articulatum* and annual herbs such as *Astralagus sp.* can be found along wadis and in local depressions. The natural vegetation is heavily degraded due to overgrazing; especially the disappearance of legumes affects the productivity of the pastures and illustrates the degradation of the land. As a consequence of the degradation of the vegetative cover, a severe soil degradation is visible in many locations.

The land is mainly used for grazing; about 90% of the project area is rangeland. In low laying, fertile areas some barley and forages are cultivated by Beduins; in some isolated areas orchards of pommegranades, apricots and olives can be found, often irrigated with groundwater. In areas favourable in terms of infrastructure, soils and groundwater resources, vegetable cropping was started, leading to a lowering of the ground water table due to overpumping (Fig. 2).

METHODOLOGY

The core data for the determination of suitable water harvesting areas are taken from **satellite images** which were provided by the LANDSAT Thematic Mapper. For the evaluation of land vegetative cover and geological /geomorphological features the near and mid-infrared channels were used. As the spatial variability of the features in question is very low in this sparsely populated arid region, the resolution of 30 m x 30 m on ground is apparently quite sufficient. Satellite scenes, shortly taken after the rainy season (April 1994 and 1995) were selected to assess the water availability and to identify regions with sufficient runoff (Table 1).

For reasons of comparison with the dry summer period, satellite scenes of July 1994 and October 1993 were also evaluated.

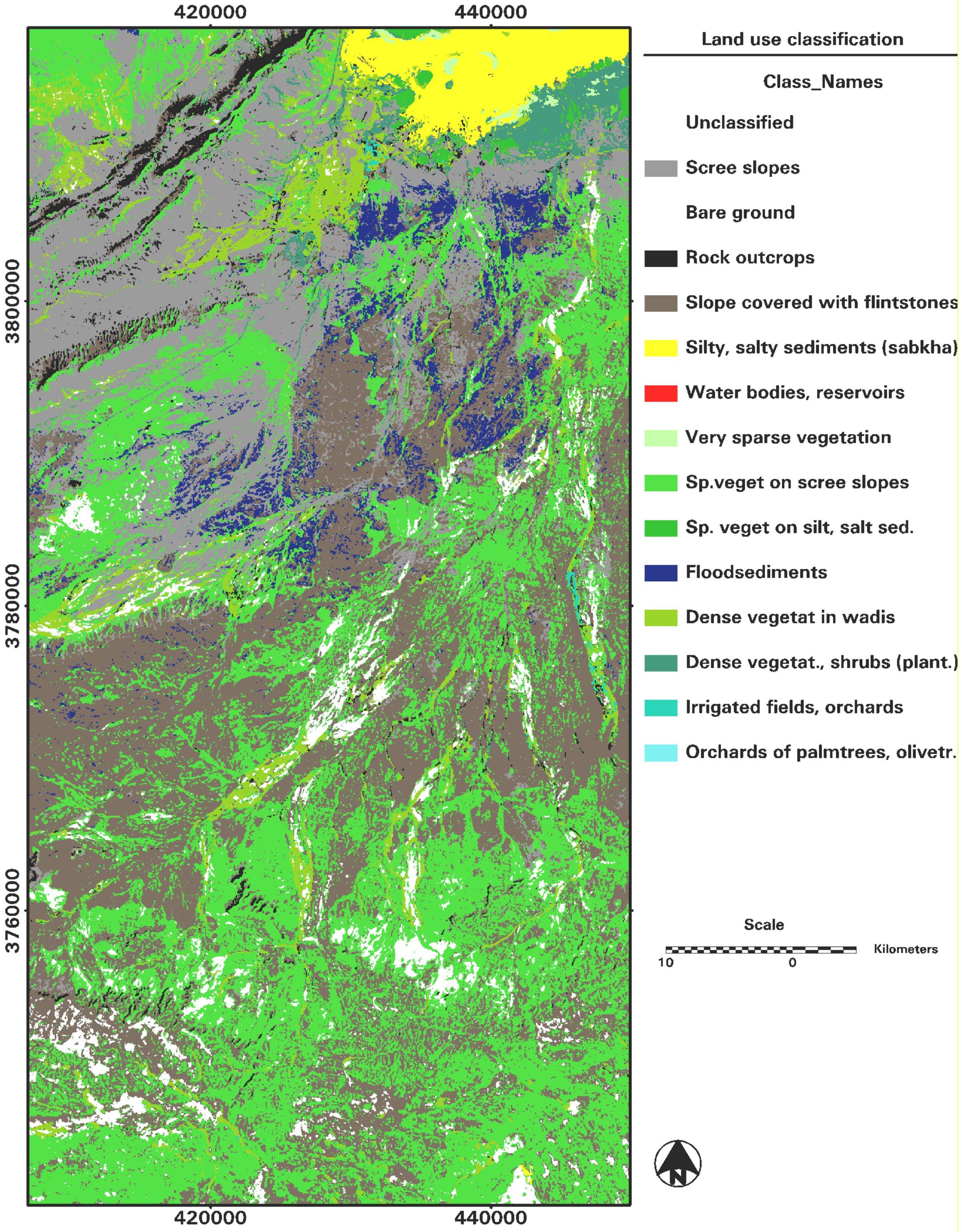
To insure the exact fitting of the pixel grid of the image to a map projection system, a **geo-information system** data base was established. The pixel grid of the satellite data is usually distorted due to instrument errors or earth rotation effects. Rectification was conducted by using roads, landmarks and the Global Positioning System (GPS). The complete satellite scene was divided into four sub-sets for easier handling of the data.

The **image** was processed on a DEC workstation, using the software **ERDAS IMAGINE.**

The classification of the images was carried out by using the **maximum likelyhood procedure**. The classification was checked by **field investigations** were the typical characteristics of each class were investigated. The separability of the various classes was checked by different statistical appproaches.

The classified image was incorporated into the Geo-Information System **ARC-INFO**. Topographic maps at a scale of 1:100.000 were digitized and a Digital Terrain Model was developed.

Land Use Map



420000
440000
3800000
3780000
3760000
420000
440000
Land use classification
Class_Names
Unclassified
Scree slopes
Bare ground
Rock outcrops
Slope covered with flintstones
Silty, salty sediments (sabkha)
Water bodies, reservoirs
Very sparse vegetation
Sp.veget on scree slopes
Sp. veget on silt, salt sed.
Floodsediments
Dense vegetat in wadis
Dense vegetat., shrubs (plant.)
Irrigated fields, orchards
Orchards of palmtrees, olivetr.
Scale
10
0
Kilometers
N

Fig. 2: Land use map of Subset of LANDSAT TM Scene Path 190/11; (main study area in Central Syria);

Table 1: Land cover units according to the classification of the satellite image. (Code 10: suitable for catchment, Code 20: suitable for cultivated area, Code 30: not suitable)

Land cover units	**Classes**	**Code**
Bare ground	Scree slopes	10
	Bare soil	10
	Rock outcrops	10
	Soil covered with flintstones	10
	Ploughed land	20
	Water bodies, natural lakes, reservoirs	30
Vegetable cover	Dense natural vegetation in the wadis	20
	Sparse, scattered vegetation on scree slopes	10
	Sparse, scattered vegetation on plain or slightly pending slopes	10
	Sparse vegetation on flood sediments	10
	Shrub plantations	20
	Irrigated fields and orchards	20
	Orchards of palmtrees, olive trees and grenadiers	20

The most important parameters were determined as follows:

Vegetative cover: The vegetative cover is determined by classifying satellite scenes taken after the end of the rainy season. 13 different landcover units were determined and grouped into 3 classes, according to their suitability for (1) catchment, (2) cultivated area or (3) not suitable. The high degree of degradation of the vegetation made it difficult to conclude from the density of the vegetation to soil features. In the study carried out in West Africa (Tauer and Humborg 1992) there a high degree of congruence between density of vegetation and suitability of the soil to be used for cropping areas was detected.

Topography: The land cover map was indexed by the digital elevation model, calculated by applying the triangulation method to digital data of the topographic maps (scale 1:100,000) by use of the TIM module of ARC INFO package (Table 2).

Table 2: Terrain classification

Land form	Slope Gradient (%)	Relief intensity	Different units of land form
Level land	0 to 8	50 m/2 km	Intermontane plains
			Flat saline plains
			Slightly undulating plains with dry wadis and desert type outliers
			Plateaux
			Depressions
			Low-gradient footslopes
			Wadi beds
Sloping land	8 to 30	> 50 m/2 km	Medium gradient mountain with undulating hilly relief
			Ridges
			Plains dissected by wadis
Steep land	> 30	>600 m/2 km	High gradient mountains
			High gradient hills (badlands)

The **geomorphological** classification involved the general classification into (1) level land (0-8% inclination), (2) sloping land (8-30% inclination) and (3) steep land (above 30% inclination). Furtheron 15 different units of land form were distinguished. The terrain analysis was done by visual analysis of the LANDSAT TM scene in combination with interpretation of the digital elevation model.

Length of slope: The terrain analysis was also used for the determination of the length of slope, a parameter regarded of very high importance for the suitability of an area for water harvesting. With a given inclination, the runoff volume increases with the length of slope, but conveyance losses have to be taken into account. The slope length was also one parameter used for differentiation between the suitability for macro-, micro- or mixed water harvesting systems.

Soil depth: Wet surfaces after several rainless days, shown by difference in colour, indicate larger soil depths. Furtheron, certain assumptions could be made on soil depth by classifying the topographic situation (foot of large slopes, depressions). The minimum requirement for soil depth was considered to be 1 m; soil depth of less than 1 m was regarded as suitable for catchments only.
Drainage system: The drainage system was classified according to the density (average channel length divided per unit area of land). According to the SOTER data base, three classes were defined: (1) slightly dissected (< $10km/km^2$), (2) dissected (10-25 km/km^2) and (3) highly dissected (more than 25 km/km^2). The drainage system was digitized on the LANDSAT TM satellite image and the areas with high drainage density were ranked higher in suitability for cropping area of a water harvesting system. By determination of the location of the farest point contributing to runoff, it was tried to define the runoff contributing areas of the various catchments.
Precipitation: Climate data were incorporated in terms of iso-hyetes, showing the average number of rainfall events exceeding 5mm /day. This quantity of rainfall has proved in several locations (Jordan, SW U.S.A.) to be the minimum amount of rainfall causing runoff.
Table 3 shows the coverage and raster units used for the setup of the GIS.
Most of the data layers were created in vector format; to analyze data within the GIS module of ERDAS IMAGE, the vector layers were converted to raster format.

Table 3: Coverage and raster units used for the setup of the GIS

LANDSAT TM. false colour image (453)
Land cover map (classified satellite image)
Inclination of slope (DEM)
Length of slope (DEM)
Land unit map
Drainage system
Water catchment area
Isohyetes of number of rainfall events exceding 5 mm/d
Map of soil depth
Soil map according to SMSS classification
Geological map

RESULTS AND DISCUSSION

In a subset of about 50 to 60 km of the study area in a zone with about 100 mm precipitation/annum about 11% of the area were considered to be unsuitable for water harvesting systems. About more than 70 % of the area are suitable for the application of microcatchment systems e.g. like contour strips. Sites which may be utilized for macrocatchment systems are found in 6% of the area.
Flood water spreading systems can be applied in other parts of the study area but they need normally rather large constructions to guarantee the safety in case of flash floods. In a nearby project of UNDP in the Mihassa valley, (below 100 mm rain per year) dams and spillways were washed away during one big flood recently.

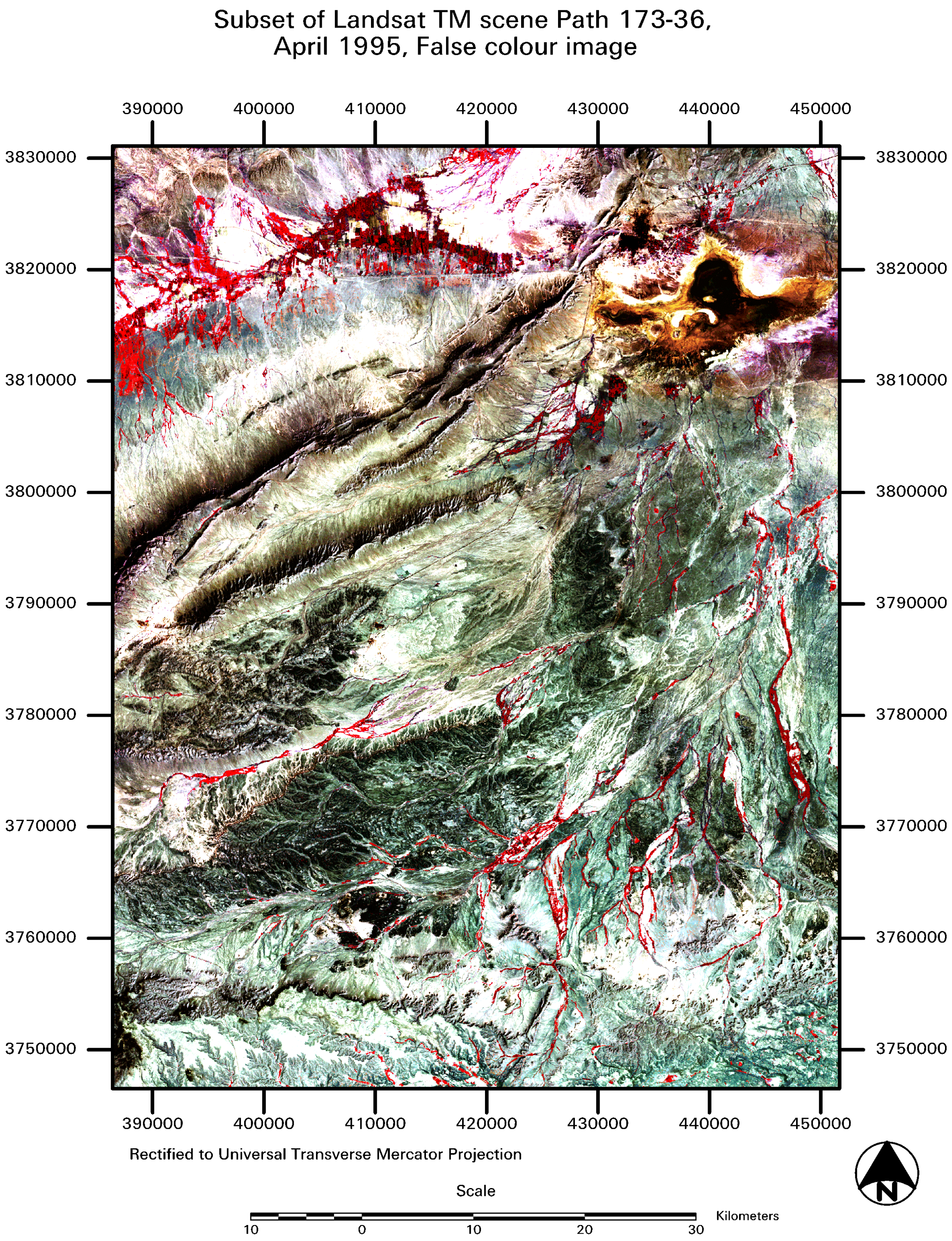


Fig. 3: Subset of LANDSAT TM scene Path 190/11, April 1995; False colour image

Fig. 4: Potential areas for water harvesting in the study area in Central Syria (Subset of LANDSAT TM scene Path 190/11)

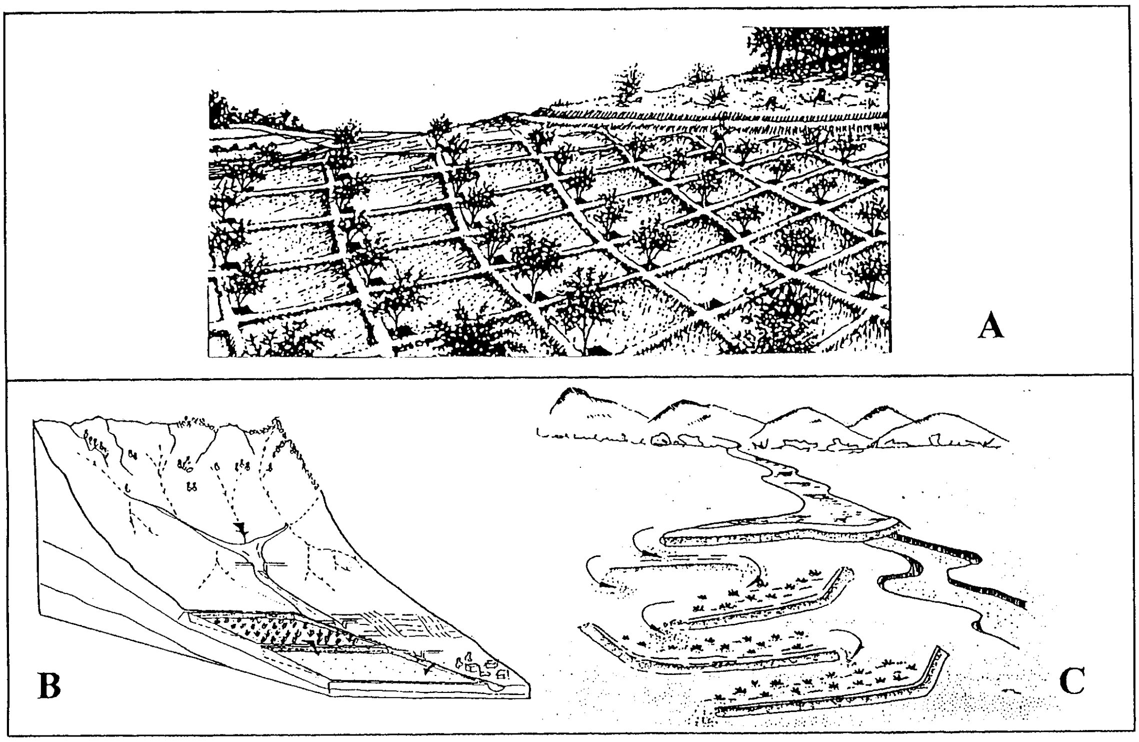


Fig. 5: Examples of Rainwater and Floodwater Harvesting. A: Microcatchment 'Negarin' Type, B: Macrocatchment 'Hillside Conduit' system,   C: Floodwater Harvesting: Floodwater diversion system
Sources: A: Rocheleau et al. 1988; B and C: Prinz 1996

In general the area can be used for tree and shrub cultivation or rangeland improvement. The decision making process concerning the best method applicable also depends on the kind of crop and on economic and social factors. Microbasins like semicircular hoops are more convenient for tree cultivation than e.g. contour strips.

Labour is often the most important economic factors if local material only is used. The construction of contour ridges of 0.2 m height with an horizontal intervall of 1.5 m needs 90 man days (MD) per ha in the first year and 50 MDin the second year (Experience from Kenya; Reij et al., 1988). The accessibility of the site has also to be considered: If a construction needs big machinery like heavy lorries, areas far from paved roads have to be excluded. There are a number of reports that water harvesting can be economically very profitable; Rodriguez (1996) e.g. showed that wheat grown under microcatchment water harvesting in highland Balochistan is more viable and profitable than any of the traditional methods.

One of the crucial social aspects for the success is the **participation of the beneficiaries** . The Syrian steppe is mainly used for livestock production: groups of Bedouin families, sedentary or migratory, with herds of small ruminants are users of the rangeland, which is regarded as an open access system. Data layers showing accessibility to the land and migratory pathways in the area can be included in future in the geographical information system and they will alleviate the decision making process.

The study in question has proved that satellite images can be a valuable tool in assessing the water harvesting potential of a region with low infrastructure.

- As a first step a qualitative approach is practiced , which excludes the quantification of runoff volumes.
- To quantify runoff volumes, more field data like measurements of the permeability of the

soil and determination of runoff coefficients are needed.

- Additionally, a rainfall-runoff model will be introduced, simulating the different runoff volumes according to the precipitation amount.

The methodology developed gives the opportunity to assess most of the parameters important for water harvesting systems. It should be kept in mind that the setup of the GIS is sometimes limited by low quality, unreliability or unavailability of data.
The presented methodology can be easily applied and adapted to other regions with similar climatological (and socio-economic) conditions. Although the current study was carried out with rather expensive equipment (workstation under UNIX), the same procedure can be done with a PC workstation under Windows NT, too.

ACKNOWLEDGEMENT
The project is funded by BMZ (Ministry for Economic Cooperation and Development), Federal Republic of Germany.

REFERENCES

1. Boers, Th.M., 1994. Rainwater Harvesting in Arid and Semi-arid Zones. Doctoral Thesis, Wageningen Agricultural University, Wageningen, The Netherlands.
2. Critchley, W. and C. Siegert, 1991. Water Harvesting Manual. FAO Paper AGL/MISC/17/91, FAO, Rome
3. Oweis, T. and A. Taimeh, 1996. Evaluation of a Small Basin Water Harvesting System in the Arid Region of Jordan. Water Resources Management, 10, 21-34
4. Prinz, D., 1995. Water Harvesting in the Mediterranean Environment - Its Past Role and Future Prospects. In: Tsiourtis, N.X. (ed.) Water Resources Management under Drought or Water Shortage Conditions. Proceedings, EWRA 1995 Symposium 14-18 March 1995, Nicosia, Cyprus, pp. 135-144. Balkema, Rotterdam
5. Prinz, D., W. Tauer, and Th. Vögtle, 1994. Application of remote sensing and geographic information systems for determining potential sites for Water Harvesting. Proceedings, FAO Expert Consultation on Water Harvesting for Improved Agricultural Production. Cairo, 21 - 25 Nov. 1993. FAO, Rome, 135-144
6. Prinz D., 1996: Water Harvesting - History, Techniques and Trends, Z. f. Bewässerungs wirtschaft 31, 1, pp. 64 - 105.
7. Rocheleau, D., Weber, F. & Field-Juma, A. 1988. Agroforestry in Dryland Africa. International Council for Research in Agroforestry (ICRAF), Nairobi. Kenya.
8. Reij C., P. Mulder and L. Begemann, 1988. Water Harvesting for Plant Production. World Techn. Paper 91, World Bank, Washington D.C.
9. Rodrigues, A., 1996. Sustainability and Economic Viability of Cereals Grown Under Alternative Treatments of Water Harvesting in Highland Balochistan, Pakistan. J. of Sustainable Agriculture 3: 305-315
10. Soumi, G., 1991. Supplemental Irrigation Systems of the Syrian Arabic Republic (SAR),. In: Perrier, E. R. and A.B. Salkini (ed.). Supplemental Irrigation in the Near East and North Africa. Proceedings, Workshop on Regional Consultation on Supplemental Irrigation, ICARDA and FAO, 7-9 December 1987, Rabat, Morocco, pp. 497-511. Kluwer Academic Publ., Dordrecht, NL
11. Tauer, W. and G. Humborg, 1992. Runoff Irrigation in the Sahel Zone. CTA (Technical Centre for Agricultural and Rural Cooperation), Ede/Wageningen, NL

Source:
Prinz, D., T. Oweis and A. Oberle (1998). Rainwater Harvesting for Dry Land Agriculture - Developing a Methodology Based on Remote Sensing and GIS. Proceedings,
XIII. International Congress Agricultural Engineering, 02.-06. 02.1998, ANAFID, Rabat, Morocco