ICARDA
International Center
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in the Dry Areas

Collaborative Research Projects between ARC Libya and ICARDA

Selection and Characterization of Integrated Benchmark Research Watersheds in Libya

Edited by Feras Ziadat and Theib Oweis

Research Report No. 1

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Contents

List of abbreviations

AEZ	Agro-ecological zoning
ARC	Agricultural Research Center (Libya)
ASCII	American standard code for information interchange
BMP	Best management practices
DEM	Digital elevation model
ESRI	Environmental Systems Research Institute, Inc.
ETM+	Enhanced thematic mapper
FAO	Food and Agriculture Organization of the United Nations
FAOCLIM2	World-wide agro-climatic data
GIS	Geographic information systems
GISU	Geographic Information Systems Unit (ICARDA)
GPS	Global positioning system
HRU	Hydrologic response unit
IBRW	Integrated benchmark research watersheds
ICARDA	International Center for Agricultural Research in the Dry Areas
LCCS	FAO land cover classification system
LULC	Land use/land cover
RS	Remote sensing
RWH	Rainwater harvesting
SRTM	Shuttle radar topographic mission
SWAT	Soil and water analysis tool
SWBD	SRTM water body data
UTM	Universal Transverse Mercator
WGS84 World	Geodetic System 1984
WP	Water points

Executive Summary

Selection and Characterization of Integrated Benchmark Research Watersheds in Libya

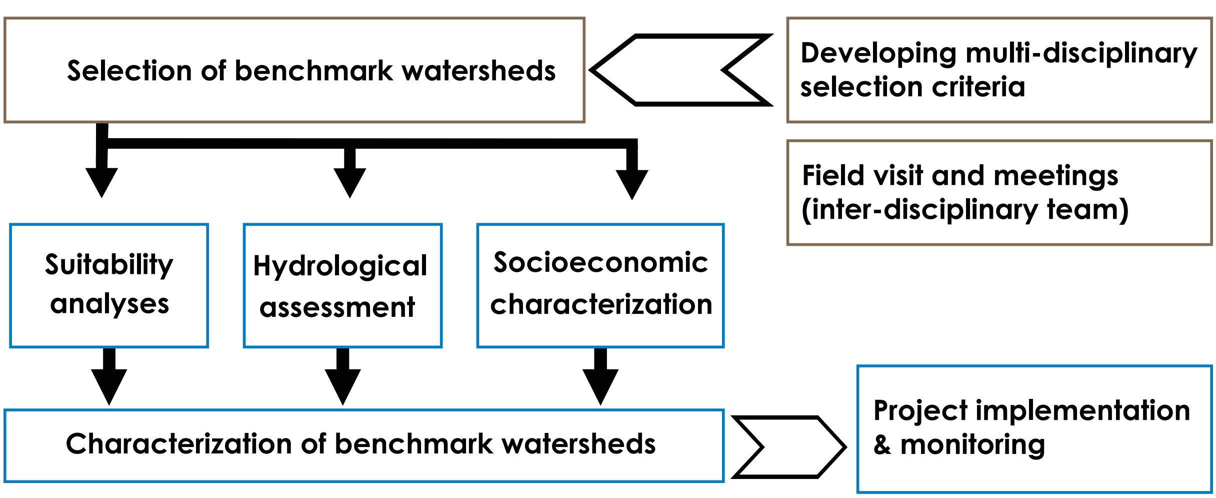
Spatial and discipline-specific isolation of biophysical and socio-economic activities is no longer acceptable in natural resources management

This report summarizes the experience of an integrated approach for the selection and characterization of watersheds for research, development, or research for development activities.

The approach was developed in Jordan then fine-tuned in Libya. It is suitable for out-scaling particularly, in the dry lands agricultural settings and other environments. Scientists can use this approach to integrate with other disciplines, planners and decision makers to view the resources in more integrated and comprehensive way. Donors will find this approach useful, in designing natural resource management program and prioritizing investments in research and development in low-income countries. A common question that is frequently asked is: "*what is the impact of the multitude of research and development projects in the arid regions*"? Part of the answer is that the haphazard implementation of research and development activities in different locations and as isolated disciplines (land, water, crop, livestock and socio-economic) is not producing the expected results.

Selecting a suitable site to integrate these different disciplines and perspectives is an opportunity to produce research that has a sharper focus on delivering positive development outcomes. The watershed is a unit that exists at every location on earth, and a place where all these disciplines are naturally integrated. Yet, watersheds are not used for the selection of sites where different factors, including the human dimension, are integrated in space and time. This report demonstrates how this perspective can work - in practice. It summarizes the experience of selecting and characterizing watersheds for research and development activities.

In conclusion, selecting an appropriate watershed, and characterizing the related natural and human resources, is an opportunity to illustrate the significance of the impact of research and development activities. The use of geographical Information systems is an indispensable tool to do this. The approach presented here is proposed for use, fine-tuning and mainstreaming by practitioners to improve the lost opportunity of implementing spatially-isolated activities for each discipline of natural resources management in the dry areas.



Foreword

Libya is a large North African country, with a total land area of 1.76 million km^2. The country has a Mediterranean coast on the northern side. While over 90% of the total area is desert, less than 2% is arable land, the rest being covered with pastures and rangelands. Traditionally, agricultural activities have been limited to a narrow strip bordering the coast, plus a number of cultivated spots in hilly areas and oases.

Libya is a typical desert country with scarce surface water resources. Except for a very limited area in the north-eastern region, rainfall is generally low and erratic, with unpredictable variation within and across years. Much of the agriculture in the coastal belt relies on supplementary irrigation, using underground water, which is more and more threatened by excessive pumping, lowering of the water table, and sea water intrusion. However, large water reserves in the central and southern desert regions enabled pivot irrigation to be launched in desert areas and the initiation of the Great Man-Made River which provides water to northern regions both for drinking and agricultural use.

Agricultural production has been traditionally located in the northern belt and the oases, but the relatively recent advent of pivot irrigation in the desert has expanded agricultural activities to cover additional areas and to increase agriculture productivity, especially for cereal and forage crops. Although production varies with commodities, the overall agricultural production covers only a modest proportion of consumption needs, the rest being met through imports.

Production of grains, essentially barley and wheat, is the most important component of agricultural production. However, local production of barley meets between 15% and 20 % of national grain needs. The low level of cereal yield results mainly from drought and heat stress, and an inadequate production technology. Animal production is the second most important agricultural activity in the country. Despite the large rangeland areas in the country, productivity is low because of unfavorable climate conditions and overgrazing. Feed needs, therefore, are met mainly through imports.

Libya faces severe water shortages and has invested heavily in developing and transferring non-renewable water resources to the coastal areas. Currently ground water is diminishing and is increasingly exposed to contamination. One renewable water resource however, is still underutilized or is mostly lost with little benefits. Rainwater on the coastal areas, particularly in Al-Jabal Al-Gharbi and Al-Jabal Al-Akhdar, and the central zone is partially used in agriculture, but, due to a lack of management, is mostly lost in evaporation or runoff to salt sinks. It is estimated that less than 10% of the precipitation falling on the three zones recharges groundwater and supports rangelands and some other crops. As a result agricultural production is low and the potential for improvement is lost. This is happening while the country is in desperate need of water to improve agricultural production.

Rainwater harvesting has been an indigenous practice in Libya for hundreds of years. It concentrates rainwater through runoff into targets so that it can be used efficiently for agricultural or other purposes. Some of the ancient techniques are still working, but maintenance and operation is very costly and some have become infeasible. Modern technologies can make water harvesting more practical and lower in cost. Many of these technologies are available now and developments in science have contributed to their success.

The problem is that farmers and communities do not have the knowledge or the means to implement suitable techniques in an appropriate way. In addition, it is necessary that some water harvesting mechanisms be tested under current conditions. The capacity of the communities and the national research program and extension services needs enhancement in the area of water harvesting. Conditions are now suitable for mobilizing human and financial resources to improve the situation under appropriate physical and socioeconomic environments. Successes achieved in implementing water harvesting in similar areas have encouraged the adoption of these approaches on a large scale in Libya.

The overall objective of the project is to improve agricultural and rainwater productivity in the costal zones by integrating appropriate water harvesting techniques into the agricultural system. The areas covered include those with isohyets above 100mm. These include Al-Jabal Al-Gharbi and Al-Jabal Al-Akhdar. The project is using an integrated watershed management approach and is community based and participatory.

This report documents two main activities within this project. The first is the selection of a number of benchmark watersheds to capture the maximum possible variability in local conditions with typical communities for testing and evaluating major water harvesting systems. The criteria and procedures for the selection of pilot watersheds were developed by all concerned stakeholders. Socioeconomic, technical, and climate data were used to evaluate and select the pilot communities and sites. Linkage with other research and development projects was also a criterion for the selection. It is of the utmost importance that the work on cereals and livestock productivity improvement projects be conducted as much as possible within the selected benchmarks. The second main activity is characterization of the selected benchmark watersheds for their biophysical and socioeconomic conditions. Field surveys and investigations were conducted and analyzed. Special attention was given to the social aspects and community involvement. The results were used as an input to identify and design appropriate water harvesting techniques suitable for various conditions within the selected benchmark watersheds.

Summary

This work develops and implements a process for the selection and characterization of integrated benchmark research watersheds (IBRWs). The benchmark watersheds are used to undertake research activities in farmers' fields under 'real life' conditions, and to develop, test, adapt, and evaluate improved agronomic, genetic, and natural resources management practices and technologies. The process is summarized in the flowchart below. Chapter 1 of this report explains the systematic process of selecting benchmark watersheds for integrated agricultural research. The process started by determining selection criteria that satisfy the long term research objectives and activities. The selection criteria were developed during a workshop involving an inter-disciplinary team of researchers and later modified and circulated to get final agreement. This was followed by a comprehensive data collection process to satisfy the data needs for all the selection criteria. The data were collected from different institutions in Libya and from the Geographic Information System Unit (GISU) at ICARDA. The study areas of the project in the eastern and western parts of Libya were determined based on 'agricultural regions' mapping results and the discussion during the workshop.

The data were extracted for the potential study areas then checked for correctness and content and re-classified to match the selection criteria. It was then analyzed to match the selection criteria with the existing biophysical and socioeconomic conditions of all the watersheds in the study areas. This included analyzing the criteria of rainfall, cropping (production) systems, communities (rural settlements), accessibility and visibility, topography, and soil. Based on the analyses, a number of watersheds (16 watersheds in the east and 18 watersheds in the west) were identified as being potentially suitable for achieving the project objectives. An inter-disciplinary team of researchers undertook several visits to all watersheds identified and discussed their potentials in the field and during dedicated meetings. The team identified 7 watersheds (3 in the west and 4 in the east) as the most suitable watersheds for the project activities. The whole approach demonstrates how geographic information systems (GIS) can be used at different scales, using available data, to help the selection of IBRWs that are suitable for implementing an integrated project. The approach was also successful in integrating biophysical and socioeconomic criteria of the selection process. The approach is applicable to areas similar to those considered by this report.

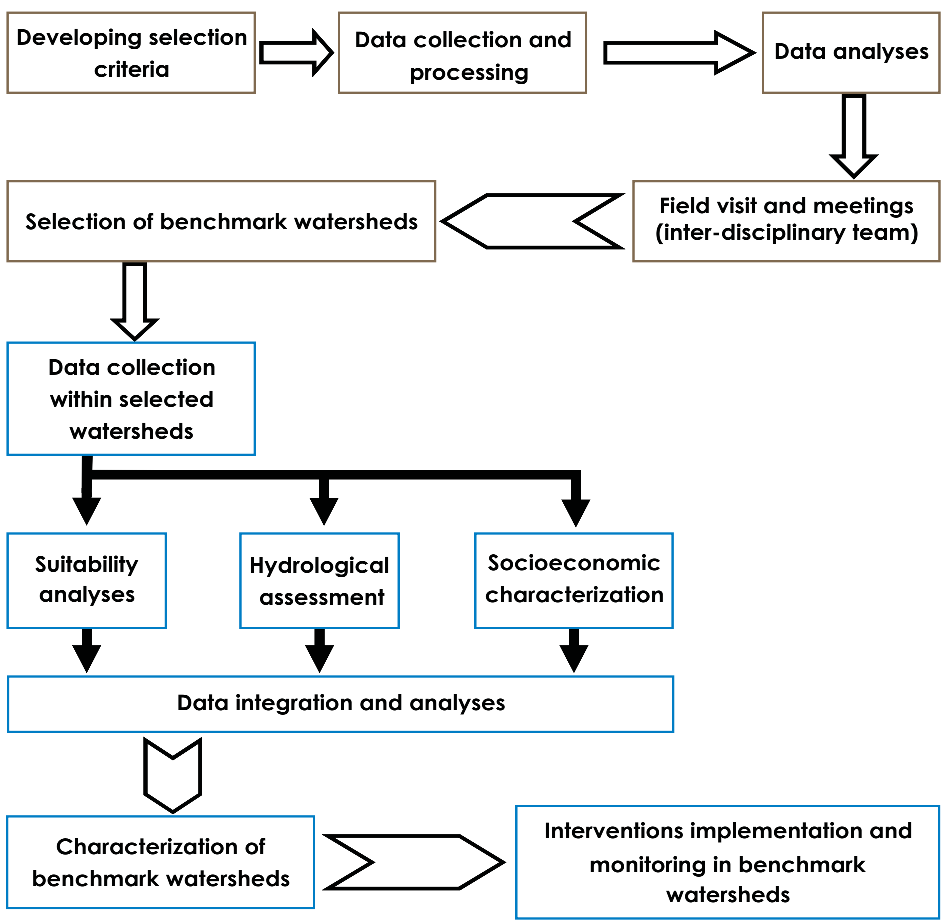
Four watersheds were selected for characterization and implementation of the project's activities. Chapter 2 of this report describes the watershed characterization process. The objective is twofold. The immediate term objective is to aid the selection of suitable sites for rainwater harvesting, supplemental irrigation interventions, and other management practices. The long-term objective is to build a database for use by scientists during the project and beyond. Suitability here includes biophysical as well as socioeconomic parameters. The process was started with the collection of available data and its integration and compilation. Field surveys were undertaken to collect missing information. This was followed by a synthesis of the maps and layers of information. The final step was to integrate all of the information into a form to serve the purposes of this project. The spatial and attributes database which was developed provides a very comprehensive and well documented tool which will be of use to future research and development activities.

The results are presented in a way suitable to serve the integrated research activities and other watershed selection processes. The approach is reproducible as needed in other areas. It is anticipated that the selected watershed will enable researchers

to undertake integrated research activities that contribute to the improvement of agriculture at national and regional levels.

The results of the watershed characterization process indicated that integration of many biophysical elements (watershed characteristics, land suitability, and hydrological characteristics) with socioeconomic characterization (community distribution and characteristics, accessibility, and willingness to cooperate) is crucial to achieve research objectives.

Without this integration, many aspects will be missing and the identified research sites may not be representative of larger study areas and hence, the out-scaling of the research findings might not be attainable. This integration significantly reduces the time needed to identify potential sites in the field. Furthermore, the results are well documented for future use beyond the project lifetime.



Chapter 1

Selection of benchmark research watersheds in Libya

F. Ziadat, A. Al-Buaishe, T. Oweis, E. De Pauw, and H. Talib

Chapter 1: Selection of benchmark research watersheds in Libya

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1.1 Introduction

Libya faces severe water shortages and has invested heavily in developing and transferring non-renewable water resources to the coastal areas. One renewable water resource, however, is still underutilized or is mostly lost with little benefits. Rainwater on the coastal areas, particularly in Al-Jabal Al-Akhdar, Al-Jabal Al-Gharbi, and the central zone, is partially used in agriculture, but, due to the lack of management, is mostly lost in evaporation or runoff. As a result agricultural production is low and the potential for improvement is lost.

Despite efforts to increase cereal production in the country, local production does not meet consumption needs. Wheat is mostly imported, while barley is largely produced locally with occasional imports for feed use. Grain yields are generally higher under research station conditions than in farmers' fields, indicating a large scope for productivity improvement if appropriate technology and policy options are adopted. Although grain yield is acceptable in certain areas, wheat productivity is frequently hindered by various factors. Crop management is generally inadequate and needs strengthening to improve cereal productivity under various cropping (production) systems.

Small ruminants are the major livestock in Libya and contribute to between 30% and 40 % of the country's meat production. Sheep and goats are raised in single or mixed flocks in arid and semi-arid pastoral areas, and also under an intensive system within cereal project areas in the southern regions. The production systems in Libya face several constraints and there is an urgent need to improve the productivity of sheep and goats under the current livestock production systems.

Rainwater harvesting has been an indigenous practice in Libya for hundreds of years. It concentrates rainwater through runoff into targets so it can be used efficiently in agricultural or other uses. Some of the ancient techniques are still working, but maintenance and operation is very costly and, in some instances, has become infeasible. Modern technologies can make rainwater harvesting more practical and lower in cost. Many of these technologies are available now and developments in science have contributed to their success. A special study is underway to review the past and existing rainwater harvesting works in Libya.

The problem is that farmers and communities do not have the knowledge or the means to implement suitable techniques in an appropriate way. In addition it is necessary that some approaches be tested under current conditions. The capacity of the communities and the national research program and extension services needs enhancement in the area of rainwater harvesting. Conditions are now suitable for mobilizing human and financial resources to improve the situation under appropriate physical and socioeconomic environments. Success achieved in implementing rainwater harvesting in similar areas encourages adoption of these approaches on a large scale in this location.

One reason for the low level of adoption of successful land and water management practices is the lack of specific and systematic knowledge on potential areas and suitable locations for these interventions. Suitable utilization of the land lies within the land use planning process, which seeks to optimize land use while sustaining its potential by avoiding the degradation of resources. These goals become more urgent within the expected scenario of climate change, where rainfall is expected to decrease and the probability of extreme events (such as severe storms) is expected to increase.

The suitability of a location for rainwater harvesting and management practices that improve productivity depends on the local society, farming practices, and whether the area meets the basic technical requirements of the management practices in question. When planning such systems, appropriate data must be available on the climate, soil, crops, topography, and socioeconomics of the project area. These data can be collected through a combination of field visits, site inspections, topographic and thematic maps, aerial photos, satellite images, and GIS.

This report describes the use of improved methodologies developed to identify suitable watersheds based on an integrated resources management concept. The approach integrates multi-disciplinary knowledge, GIS utilities, and verification in the field to develop and test a methodology to identify watersheds with specific characteristics – in this case, the watersheds most suited to the project activities.

The objective of this process is to select suitable watersheds in which to undertake research on three project components: (i) integrating rainwater harvesting in the agricultural systems for improved productivity in Libya; (ii) integrated improvement of wheat- and barley-based cropping systems in rainfed and irrigated areas of Libya; and (iii) improvement of small ruminant productivity in Libya; in addition to cross-cutting socioeconomic components.

1.2 Developing selection criteria

1.2.1 Stakeholders consultations

The benchmark watershed selection process started from the first implementation workshop of the 'Integrating rainwater harvesting in agricultural systems' held in Tripoli, Libya, February 10-17, 2009. Previous experience with a similar process of benchmark watershed selection for the *Badia* of Jordan was presented and discussed with an inter-disciplinary team of researchers. The suitability of the process to the conditions in Libya, and particularly to this project, was discussed. The participants concluded that the process is necessary before the project can proceed with activities. This is primarily because the project integrates three major components (rainwater harvesting, cereals and livestock, and cross-cutting socioeconomic components) and it would be necessary to choose watersheds that serve integrated research activities for all components. It was agreed that if one watershed is not enough to achieve all objectives, more watersheds in each area will be considered. Many participants indicated the availability of detailed data for the target area. However, upon discussion it was revealed that the data does not always cover the whole study area, but was designed to cover small areas within the whole study area, which is not suitable for the selection process. Other data that cover most of the target area are available, but are scattered. Some areas with annual rainfall below 200 mm are not covered by any of these data. This is an important consideration for the selection process, which might require the use of less detailed information.

Four groups were formed to discuss the criteria for the selection of benchmark watersheds. These groups were rainwater harvesting, crops (cereals), small ruminants, and socioeconomics. Each group reported the main criteria, which were discussed by the group as a whole. For each group, a set of criteria was determined as being the most important for site selection (Appendix A). All criteria were processed and amalgamated to produce one set of criteria which took into consideration all factors. This set of criteria was distributed to all interested participants (the inter-disciplinary team of experts) from the Agricultural Research Center, Libya (ARC) and ICARDA. This team commented on the criteria and all team members were satisfied with the criteria and their ratings.

Some criteria required detailed informa tion (for example pH, electrical conductivity (EC), and others) that might not be available from the small scale maps and available data. In this case the criteria were simplified and were considered during the field visits. The participants indicated that the incorporation of a minimum number of criteria would be better than including many. The complete process would be verified during the field visits, when any missing criteria or important aspects would be taken care of.

The process was enriched by the inter-disciplinary team of national and international scientists visiting the field. The purpose was to get a clearer view of the environmental and socioeconomic conditions of the area, which benefited the whole selection process.

1.2.2. Al-Jabal Al-Gharbi field assessment

The field assessment included a transect from the coastal area, south through the mountains, to the desert areas. Several cropping (production) systems were observed, including rangelands, crops, fruit trees, and mixed systems. Following are some remarks from the field visits:

- Many areas were identified as part of a possible benchmark research watershed. These areas, which included cereal production, livestock, olive trees, and rangeland, were suitable for rainwater harvesting. Barley is the most common cereal, while wheat is mainly grown in the irrigated projects in the south
- Barley and wheat trials from ICARDA were planted at the Sofit research station, along with the national program of breeding and agronomy trials. The station has been used for cereal breeding since the early 1990s
- An option of selecting a watershed that drains to the south might be considered as there is gradual change in slope and soil toward the south. Watersheds draining to the north (towards the sea) include the Gefara plain where irrigation is dominant. Generally as we moved south, rainfall amounts were lower and land degradation becomes very obvious (poor vegetation cover, overgrazing, and soil erosion)
- The area close to Sofit station is cultivated with fruit trees. Tabias (contour earth dikes) have been implemented in some of the orchards on sloping lands. There is great potential for implementing rainwater harvesting techniques for trees to improve productivity in this area. This might generate obvious results that would be appreciated by the inhabitants
- The land tenure regime might add some complications. In this area, land is owned by the government and is given to a certain tribe to be subdivided between the members of the tribe. Land ownership is not secure, but as far as these people are concerned there is no danger of them losing use of their land. Another important aspect in the area with low rainfall (< 200 mm) is that there are no actual farmers; there are many pastoralists who are not involved in cultivating or improving the rangeland, but simply use it. This is an important consideration for rainwater harvesting development projects.

1.2.3. Al-Jabal Al-Akhdar field assessment

- Most of the southern part of Al-Jabal Al-Akhdar is located within a low rainfall area. Barley is planted in the bottom of *wadis*, depressions, and in water collection areas, showing the great demand for feed. The area of Al Marj might be more suitable for the project purposes
- Al Marj research station is located in a typical barley and wheat growing area. Cereal yields in farmers' fields are low, around 1 t/ha. The main reason being the low adoption of fertilizer application. In contrast, the barley and wheat breeding trials in the station are all grown under optimum fertilizer application. The strategy is to identify lines that perform better under fertilizer application, and not in farmers' fields
- Most of southern part of Al-Jabal Al-Akhdar is located within a low rainfall area with little chance of growing cereal crops. It was generally concluded that watersheds that drain towards Al Marj area might be more suitable for the project purposes.

A work plan to organize the watershed selection process was prepared. Given the time limitations associated with starting other activities based on this process, it was agreed that some simplification of the process was needed (by making only one field visit to five watersheds in each of the two sites). And, assuming that data would be made available in a short period of time, a special inter-disciplinary team decided the selection of watershed(s) in the two study areas.

1.2.4. Development of watershed selection criteria and verification

A first set of criteria was developed by consulting the results from the thematic group discussions of the interdisciplinary team during the first workshop in Libya and by referring to relevant documents (Oweis et al., 2001; Ziadat et al., 2006). These criteria compromise the various requirements of the four groups (rainwater harvesting, cereals, livestock, and socioeconomic).

Therefore, all these requirements are taken into consideration, not just the requirements of one group. In addition to these criteria, the following aspects were examined during the inter-disciplinary field visits:

1. Major hydrological characteristics of the area
2. Safety for research implementation (equipment)
3. Population density
4. Willingness of the community to cooperate
5. Land tenure system (use rights and property rights)
6. Proximity to research station(s)

Any criteria for which data was not available would be looked at during the field visits using the experience of the interdisciplinary team. The figures presented for this set of criteria represent the best values, but that does not mean that the occurrence of less favorable classes would be a reason to exclude the watershed. Therefore, during the application of these criteria in the GIS, high scores were given to watersheds that included a high percentage of the criteria, but that did not mean that other values are not included within the watershed. For example, a high score is given to a watershed with a large proportion of its area receiving an annual rainfall of between 100 mm and 300 mm (preferred for rainwater harvesting and livestock), but it was still important to include areas with an annual rainfall of between 300 mm and 500 mm (more preferred for cereals). It was anticipated that this approach would satisfy all groups and help to select watersheds that suited all requirements. Field visits were also another means to ensure that the various groups were satisfied with the selected watershed(s). This will be explained later in more detail.

This set of criteria was sent to all the scientists involved. Feedback was received and the comments from various team members were compiled and considered. The comments and suggestions were specific to each group as well as being more general with greater emphasis on the integrated nature of this project. The four groups would be working together within a watershed and therefore it was necessary that the selected watershed satisfied all needs and demands, both individually and collectively. Based on all the comments and suggestions, a revised version of the criteria was sent out for final comment by all team members. The comments from the first round indicated some contradictions between the needs of the different groups and, therefore, a compromise was made to satisfy all groups.

This second round of collecting comments and suggestions was very important. The team indicated their satisfaction with the new version and this was considered for further processing. (Table 1.1) shows these criteria and their scores. The best conditions were given a score of 10 and the worst were given a score of zero.

1.3 Data collection and processing

Based on the criteria for watershed selection that has been explained in the previous section, the required data were determined. These data were collected from various sources and are explained under two categories, data from the GIS unit at ICARDA (GISU) (global data) and data collected from Libya. The data from the GISU include the outline of the study area, climate mapping, remote sensing, digital elevation model, and other secondary data sources. The data from Libya include soil data, cropping (production) systems, community (settlements), small ruminant density, and road and track networks.

1.3.1. Outline of the study area

The 'agricultural regions' were prepared by the GISU and the methodology is explained in a separate report (De Pauw, 2009). The 'agricultural regions' were defined as integrated spatial units, in which particular water resources and climate, terrain, and soil conditions combine to create unique environments that are associated with distinct land use patterns, farming systems, and settlement patterns.

The concept of 'agricultural regions' has been developed to address the need for a single synthesis map that shows the unity between natural environments, production systems, and livelihood systems. As experience from other countries indicates, such a synthesis map characteristically contains a limited number of spatial units (e.g. 27 in the case of Syria, and 31 for a comparable map of 'régions agricoles' in Morocco). Typically, this kind of mapping accentuates individuality rather than communality. Each mapping unit has its own 'personality' that is different from any other mapping unit, and therefore requires an individual description. The characteristics of the units are not predictable ex-ante, because in one unit the key characteristic could be high aridity, in another it could be the presence of mountains, while in yet another it could be a unique agricultural system.

The concept of 'agricultural regions' as applied to Libya combines dominant biophysical criteria and major agricultural systems. In this study the identification of such 'agricultural regions' was based on remote sensing, with validation through expert knowledge and ground-truthing, supported by auxiliary analyses and data sources.

Table 1.1. Watershed selection criteria approved by the inter-disciplinary team of researchers

Criteria	Units	Score			Remarks
		0	5	10	
Rainfall (RWH)	mm	< 100 or > 500	300-500	100-300	Watershed extends over wide range of rainfall
Cropping (production) systems		Sizable area of only one system is available	Sizable areas of only two systems are available	Sizable areas of three systems are available	Diversity of cropping (production) systems is needed: rangeland, rainfed, and irrigated
Community (rural settlement)		No sizable community inside or near watersheds	Communities available, but outside the watershed	Communities available inside and around watershed	Involvement of communities in agriculture. Subject to data availability
Accessibility and visibility	Road network	No roads	Roads cover part of the watershed	Roads and tracks cover most parts of the watershed	
Topography (slope)	%	> 20	11-20	0-10	Average within watershed. Part of watershed is flat for cereals
Potential for rainwater harvesting		Low	Medium	High	Stream density (total length of streams/ total area of watershed)
Soil type	Class	Watershed includes one or two dominant soil types	Watershed includes a few dominant soil types	Watershed includes many dominant soil types	Watershed to cover most soil types that are dominant in the ecosystem

Table 1.1. Continued

Criteria	Units	Score			Remarks
		0	5	10	
Soil depth	cm	More than 50% of the watershed has < 30	More than 50% of the watershed has 30-100	More than 50% has > 100	Average for dominant soil type(s)
Soil limitations		Soils with salinity, $CaCO_3$, shallowness, rockiness are dominant	Soils with either salinity, $CaCO_3$, shallowness, or rockiness are dominant	Soils with salinity, $CaCO_3$, shallowness, rockiness are not dominant	Subject to data availability
Soil salinity	dS/m	More than 50% of the watershed has > 10	More than 50% of the watershed has 4-10	More than 50% of the watershed has < 4	Subject to data availability
pH		<7 OR >8.5	8-8.5	7-8	Subject to data availability
Small ruminant density	Number	Low	Medium	High	
Water points (WP)		No water points in the watershed	Few water points (distance between WP > 20km)	Sufficient water points (distance between WP < 15 km)	
Availability of research stations, weather stations, data, runoff records, institutes, etc					Criteria to differentiate between potential watersheds

Based on the discussion during the first workshop, it was agreed that the study area would focus on two 'agricultural regions' (Cyrenaica in the east and Tripolitania in the west) (Figure 1.1). The outline of the study areas in the east and in the west were derived from the agro-ecological zone (AEZ) map. All the data were made available to cover these two study areas.

Hutchinson (1995), as implemented in the ANUSPLIN software (Hutchinson, 2000), was used to convert the station-based climatic database into 'climate surfaces'.

The Hutchinson method is a smoothing interpolation technique in which the degree of smoothness of the fitted function is determined automatically from the data

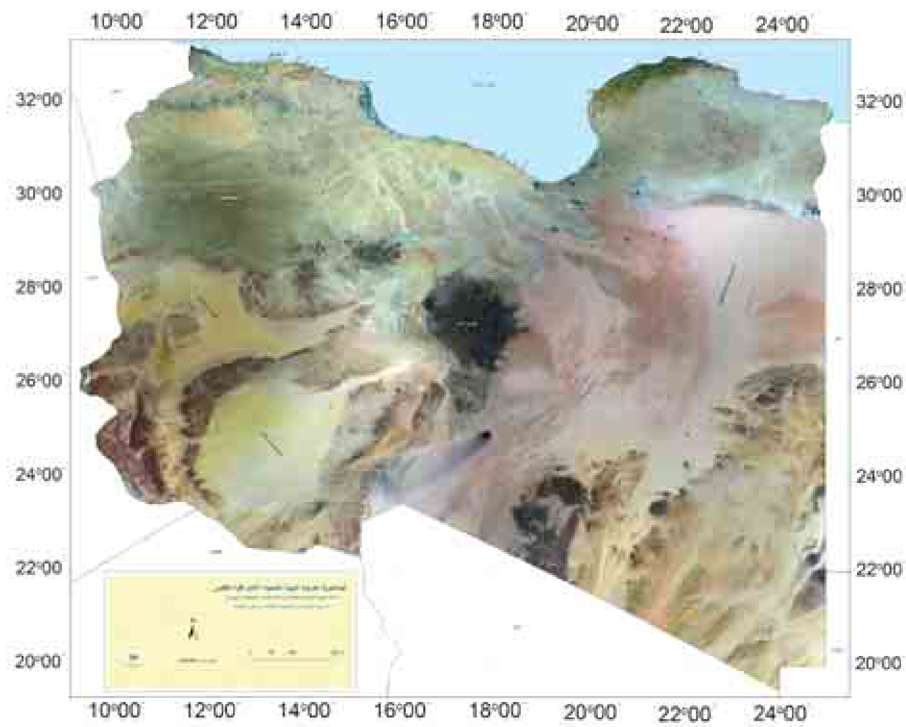

Figure1.1 Outlines of the two study areas in the east and west of Libya

by minimizing a measure of the predictive error of the fitted surface, as given by the generalized cross-validation (Hutchinson, 2000). The method uses three independent spline variables – latitude, longitude, and altitude. The latter was input into the model in the form of a digital elevation model (DEM) ASCII grid file. The DEM used to generate the climate surfaces was the SRTM30 DEM with 30 arc-second resolution. Parameter estimation was undertaken over a regular grid with the same dimensions and resolution as the user-provided DEM.

1.3.2. Climate mapping

Precipitation and temperature data from climate stations inside and outside Libya were converted into gridded maps of mean monthly and annual precipitation and minimum and maximum temperature with 30 arc-second spatial resolutions (approximately a 1 km grid cell). All data were obtained from the FAOCLIM2 database (FAO, 2001). For the spatial interpolation of precipitation, 101 stations were available – 94 inside Libya, one in Algeria, three in Tunisia, two in Egypt, and two in Chad. The 'thin-plate smoothing spline' method of

The gridded surfaces of mean monthly minimum and maximum temperatures and potential evapotranspiration were obtained by clipping using a Libya vector boundary mask from the corresponding regional surfaces for Eurasia and North Africa, developed earlier by the ICARDA GIS Unit (De Pauw, 2008). The boundary mask for Libya was derived by updating the country boundary shape file from the digital chart of the world with the vector coastline mask derived from SRTM30 –the SRTM Water Body Data (SWBD).

The annual precipitation surface was used to develop, in ArcGIS, a grid mask of the areas in Libya with annual precipitation higher than 100 mm (Figures 1.2a and 1.2b). Outside these areas precipitation is too low for agriculture, either for crops or livestock, to be feasible.

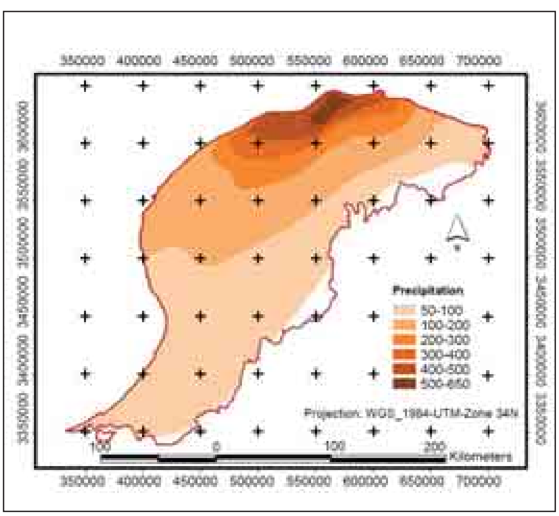

Figure 1.2a. Rainfall distribution over the eastern study area

1.3.3. Using remote sensing data

The 100 mm precipitation mask was the basis for the visual interpretation of recent satellite imagery, supported by the above mentioned secondary information, to delineate the boundaries between the

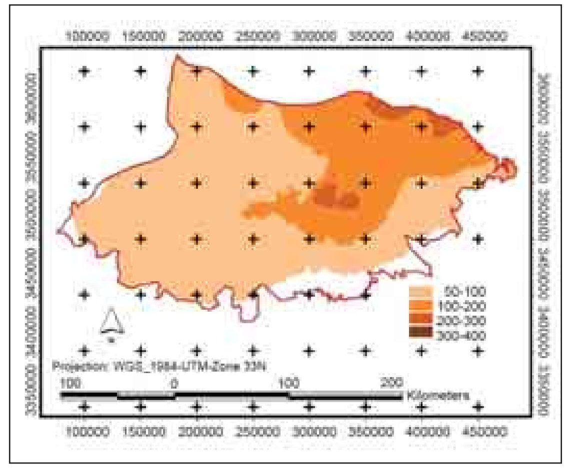

Figure 1.2b. Rainfall distribution over the western study area

regions.

The imagery used was extracted for Libya from the 2000 Geocover series of ortho-rectified Landsat 7 ETM+ mosaics. This dataset is from the Landsat 7 Enhanced Thematic Mapper (ETM+) with the 15 m panchromatic band fused with the 30 m multi-spectral bands 7-4-2. The projection is Universal Transverse Mercator (UTM)/ World Geodetic System 1984 (WGS84). Apart from ortho-rectification, these Landsat images have been tonally balanced, mosaiced, tiled, and wavelet compressed. They are of the highest quality. The spatial extent of each mosaic used is shown in (Figure 1.3). The coverage date is scene-dependent, nominally 2000 +/- 2 years. The images were clipped to include only the two study areas in the east and west (Figures 1.4a and 1.4b).

The 'professional' version of Google Earth (Google Earth Pro) was used to 'zoom' in on each of the 'agricultural regions' and view a high-resolution QuickBird image as a form of ground truthing. QuickBird is currently the highest resolution commercial optical satellite (operated by Digital Globe) and provides, through Google Earth, multi-spectral imagery at a resolution of 2.44 m, making small or narrow

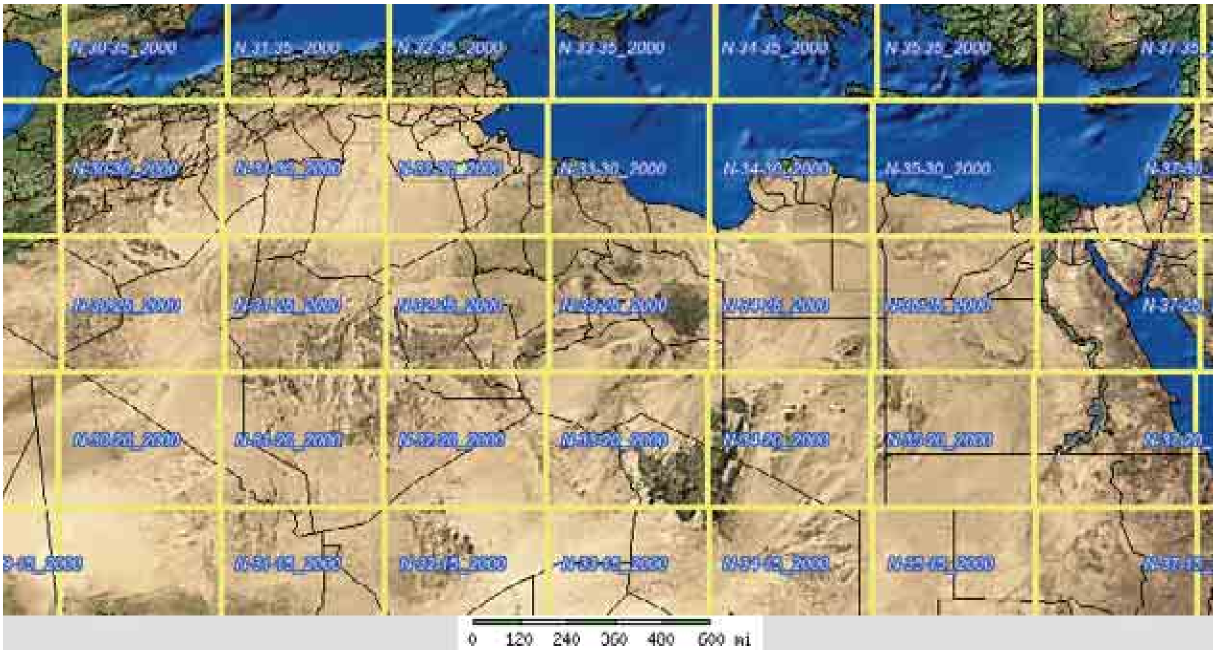

Figure 1.3. Geocover imagery covering Libya and neighboring countries

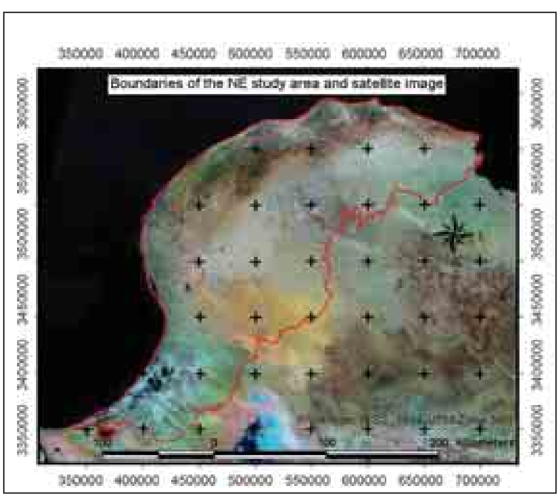

Figure 1.4a. Satellite image covering the eastern study area

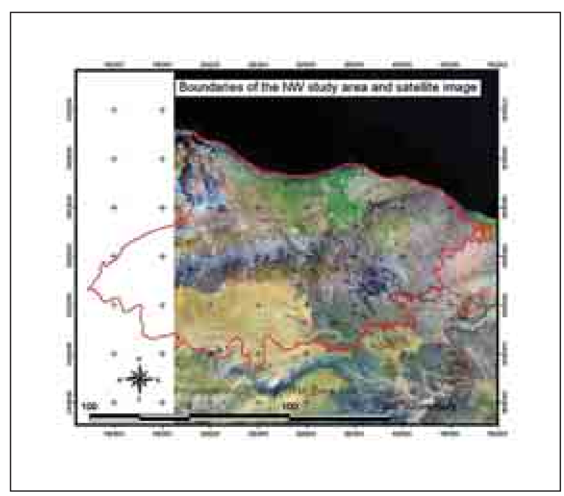

Figure 1.4b. Satellite image covering the western study area

objects, such as trees, tracks, check dams, plowing, drainage lines, and houses, visible. QuickBird imagery is available for between 60% and 70% of the 'agricultural regions' of Tripolitania and Cyrenaica. More direct ground truthing was provided by visual observations of land use/land cover (LULC) carried out during two field visits to Tripolitania and Cyrenaica (June 2008 and February 2009). These 481 point observations were recorded with a hand-held global positioning system (GPS), and overlaid onto the Google Earth and Geocover imagery.

1.3.4. Digital elevation model and other secondary data sources

In addition to the information extracted from the Geocover Landsat, and Google Earth QuickBird archives, characterization of the 'agricultural regions' was based on secondary data. The main data sources were the shuttle radar topographic mission (SRTM) DEM, the geological map of Libya, the soil map of Libya, and literature collected from the Internet.

The SRTM DEM was the source of major topography-related data, such as elevations, slopes, watersheds, and drainage lines. Slope was calculated using the slope function of the spatial analyst tools in Environmental Systems Research Institute, Inc. (ESRI) ArcGIS software (Figures 1.5a and 1.5b).

Watersheds and drainage lines were delineated using the Arc Hydro Tools utility for ArcGIS. Using the SRTM DEM as the input grid, the following steps were followed to create watersheds and drainage lines:

- Fill sinks: if a cell in the DEM is surrounded by higher elevation cells, the water is trapped in that cell and cannot flow. The Fill sinks function modifies the elevation value to eliminate these problems
- Flow direction: create a flow direction grid from a DEM grid

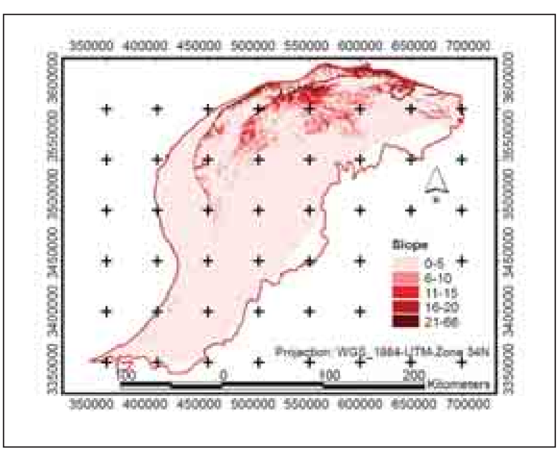

Figure 1.5a. Slope classes for the eastern area

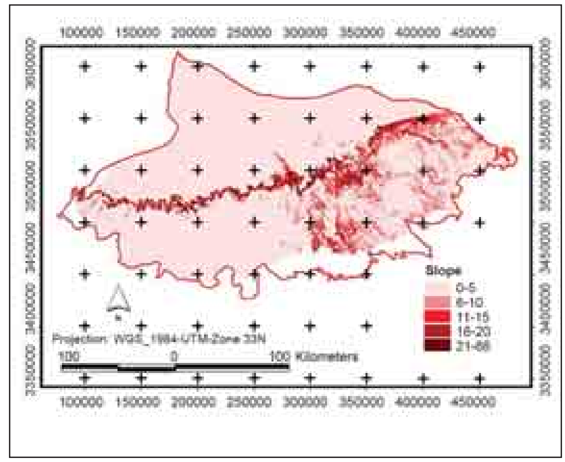

Figure 1.5b. Slope classes for the western area

- Flow accumulation: create a flow accumulation grid from a flow direction grid
- Stream definition: create a new grid (stream grid) with cells from a flow accumulation grid that exceeds a user-defined threshold
- Stream segmentation: create a stream link grid from the stream grid (every link between two stream junctions gets a unique identifier)
- Catchment grid delineation: create a catchment grid for a link grid. It identifies areas draining into each link
- Catchment polygon processing: create catchment polygons out of the catchment grid
- Drainage line processing: create streamlines out of the stream link grid.

Watersheds and drainage lines were created at three different levels, with 100,000, 50,000, and 25,000 upstream pixels as thresholds. With a 25,000 pixel threshold there are more watersheds, which are nested into a smaller number of 50,000 pixel threshold watersheds, and these in turn are nested inside fewer 100,000 pixel threshold watersheds. Watersheds and drainage lines that were created with 50,000 upstream pixels as thresholds were used in subsequent analyses (Figures 1.6a and 1.6b).

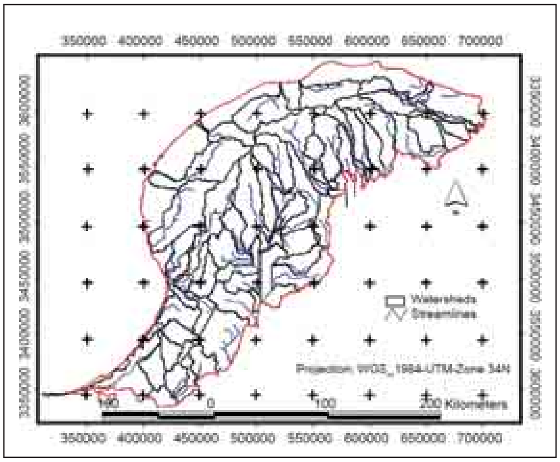

Figure1.6a. Watersheds and drainage lines for the eastern area

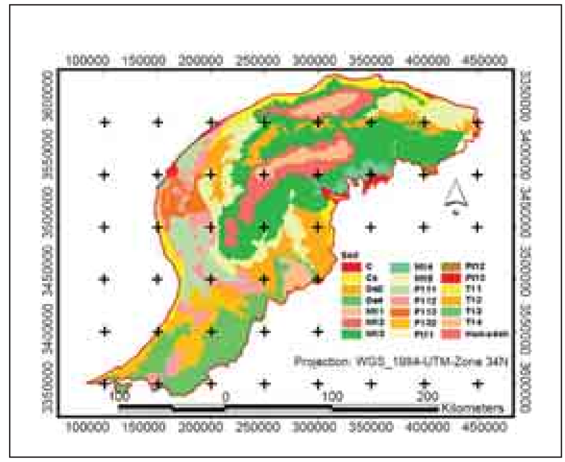

Figure 1.7a. Soil map (scale 1:2,000,000) of the eastern area

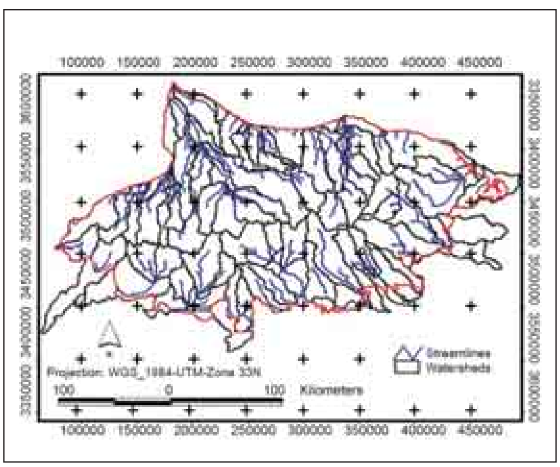

Figure 1.6b. Watersheds and drainage lines for the western area

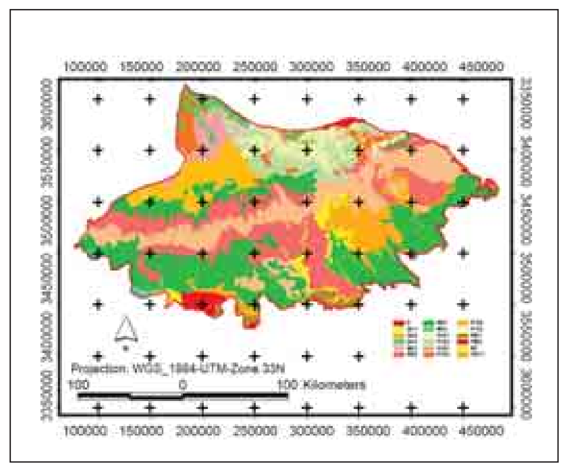

Figure 1.7b. Soil map (scale 1:2,000,000) of the western area

1.3.5. Soil data

The best available soil map was at a scale of 1:50,000. However, this map does not cover the whole study area in west and east Libya. The original survey was meant to cover areas with annual rainfall higher than 200 mm. The interest of this project extends beyond this area to cover areas with an annual rainfall higher than 100 mm. The best available soil data that covers the whole study area was at a scale of 1:2,000,000 (Figures 1.7a and 1.7b).

This map includes associations of soils within the soil mapping units; the percent of each association is recorded. The map satisfied the needs of the project at this preliminary stage. The particular data needed about soil are available from the description of the soil association and using the keys to soil taxonomy. The main limitations of soil association were carbonate, soil depth, soil salinity, and the presence of sea shore sand.

1.3.6. Cropping systems

The available land use map was used to derive information on production systems and LULC. The scale of this map was 1:50,000 and was derived using the legend of the FAO land cover classification system (LCCS). This map was prepared previously during the mapping project of Libya. The following steps were followed in the preparation of the map; field work, interpretation of satellite images (scale 1:50,000), collection of ground truthing observations using GPS (accuracy from 5 m to 10 m), followed by office interpretation, and field checking. The original legend of these maps includes the following classes:

For the eastern area (Figure 1.8a):

- **IL** irrigated land
- **RL** rainfed land
- **NV** rangeland
- **BC** bare soil consolidated
- **BU** bare soil unconsolidated
- **NF** natural forest
- **UB** urban

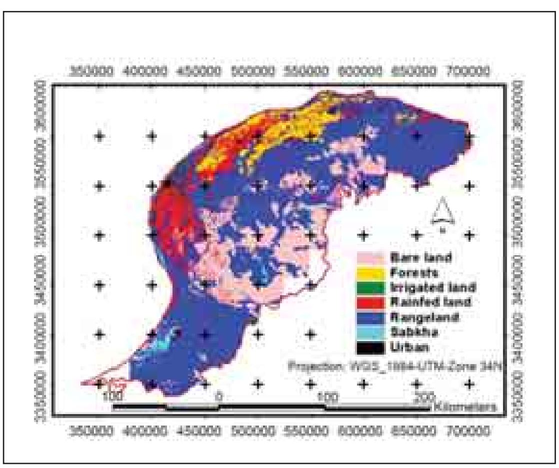

Figure 1.8a. Land use/land cover classes for the eastern area

For the western area (Figure 1.8b):

- **IL** irrigated land
- **RL** rainfed land
- **NVF** natural forest
- **BL** bare land
- **F** reforestation
- **SB** sabkha
- **UB** urban

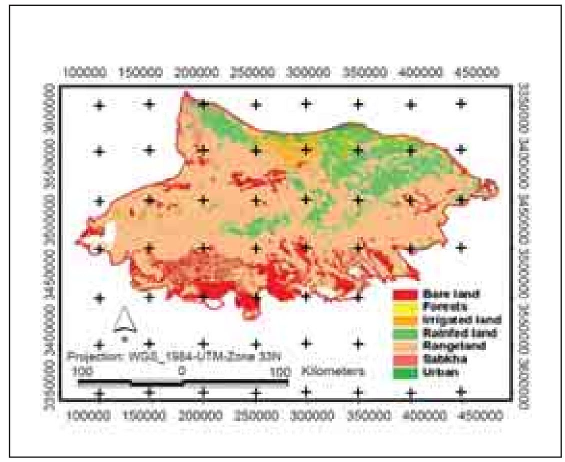

Figure 1.8 b. Land use/land cover classes for the western area

1.3.7. Road network and community (selection)

The spatial distribution of settlements (geographic location) over the watershed subdivision was mapped from various sources. The preliminary sources were topographic maps at a scale of 1:50,000. Field checks revealed that some communities do not exist on the maps. Therefore other sources of information were consulted to get a better coverage of this important information. Among these were the satellite images explained before and Google Earth. The data from these sources were compiled into one data layer (Figures 1.8a and 1.8b). The road network was derived from 1:50,000 topographic maps (Figures 1.9a and 1.9b).

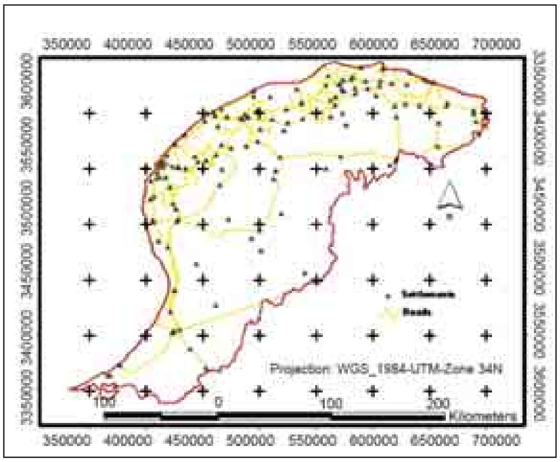

Figure 1.9a. Distribution of roads, towns, and villages for the eastern area

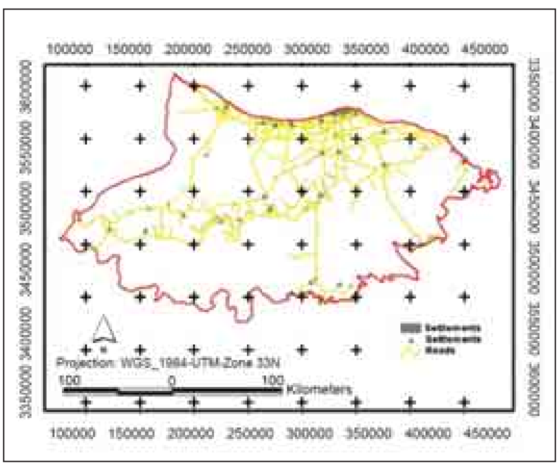

Figure 1.9b. Distribution of roads, towns, and villages for the western area

1.4. Approach for analyses

The watershed selection criteria agreed by the inter-disciplinary team were applied to the collected data and some watersheds were selected. At this stage only four criteria were used – rainfall, cropping (production) system, community, and accessibility and visibility. This was used to test the methodology, get feedback from team members, and then develop a robust approach for watershed selection. Two approaches to undertake the selection process were possible. The first was to apply the scoring reported in (Table 1.1) for each watershed and then use the summation of scores for all criteria to classify the watersheds from best to worst with respect to their satisfying the project objectives. The main advantage of this approach is its simplicity and reproducibility. However, a disadvantage is that some watersheds might be excluded because one of the criteria is not satisfied, even when all other criteria were ideal. Furthermore, the approach is not flexible enough to accommodate the diverse requirements assigned by the four project components and simply find watersheds that satisfy all. For example, the rainwater harvesting team was looking for that part of the watershed with an annual rainfall of between 100 mm and 300 mm and a slope in the range 0% to 10 %, while the crop improvement team was looking for that part of the watershed with a higher rainfall and probably less steep slopes. Simple scoring of the whole watershed would certainly use the average of these criteria to assign one score for the whole watershed, which would not accommodate the needs of the various components.

The preliminary results of applying this approach were presented and discussed with representatives from various components. The masks of cropping (production) systems (Figures 1.8a and 1.8b), rainfall (Figures 1.2a and 1.2b), watershed boundaries (Figures 6a and 6b), and distributions of communities and roads (Figures 1.9a and 1.9b) were overlaid and interactively and visually analyzed. The capabilities of the GIS to overlay different masks, zoom in and out, and make queries were implemented to enrich the live discussion about the whole process of watershed selection. The advantages and disadvantages of the selection process were discussed and suggested modifications were formulated.

Based on this meeting, an alternative approach was followed after discussion with all team members. This alternative approach was to look at the variability of various criteria within each watershed and try to characterize the watershed based on this variability and how good or bad the watershed is in terms of satisfying the various needs of all components. This is simply an elimination process of those watersheds that are obviously not close to satisfying the project objectives. The process started with the application of one criterion (rainfall for example). Each watershed where the evidence indicated that it was not suitable for the project (for example a large proportion of the watershed lies in an area with a rainfall of less than 100 mm) was then eliminated. The process is then repeated for the next criterion and so on for the rest of criteria. Finally, the watersheds which are selected after screening for all criteria are those with potential for the project. The implementation of this approach for each criterion is explained in the following sections and then the final selection of the potential watershed is explained.

1.4.1. Rainfall

The watershed map (Figures 1.6a and 1.6b) was overlaid with the rainfall isohyets map (Figures 1.2a and 1.2b). Each watershed was characterized in terms of the minimum, maximum, and average rainfall (Figures 1.10a and 1.10b).

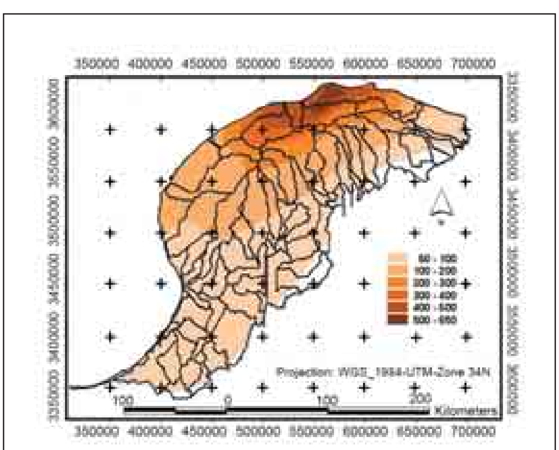

Figure 1.10a. Watershed boundaries and rainfall distribution for the eastern area

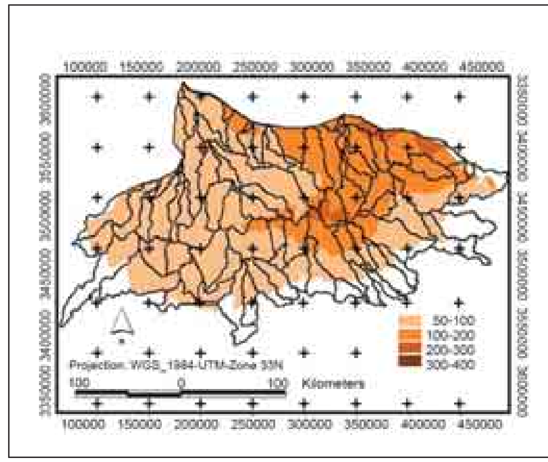

Figure 1.10b. Watershed boundaries and rainfall distribution for the western area

Watersheds which fall completely outside the range of rainfall that is suitable for this project were eliminated – for instance, watersheds with majority of their areas located in zones with less than 100 mm or more than 500 mm annual rainfall.

These were not considered for any further analyses. The rest of the watersheds were analyzed to apply the remaining criteria. During the meeting to discuss the preliminary selection of the watershed, the selection criteria were fine-tuned. It was agreed that, based on the preliminary selection, the selection of only one watershed in the east and only one watershed in the west satisfying all components might not be possible given the diversity of requirements to satisfy all components. Therefore, the analyses must consider that the project might select two or more watersheds where different components are satisfied. It was suggested that one watershed might be used for rangeland and rainwater harvesting with rainfall between 100 mm and 300 mm and another watershed for rainfed cropping and rainwater harvesting with rainfall between 300 mm and 500 mm. Based on this, the criteria limits in Table 1.1 were detailed in a more practical way (Table 1.2). This detailed criteria defined a lower limit and an upper limit for rainfall. These limits were derived from the actual requirements of each activity and were detailed for the eastern and western areas separately.

Applying the first scenario in (Table 1.2) (select only one watershed) resulted in just five watersheds in the eastern area and six watersheds in the western area that were suitable for this project from a rainfall point of view (Figures 1.11a and 1.11b).

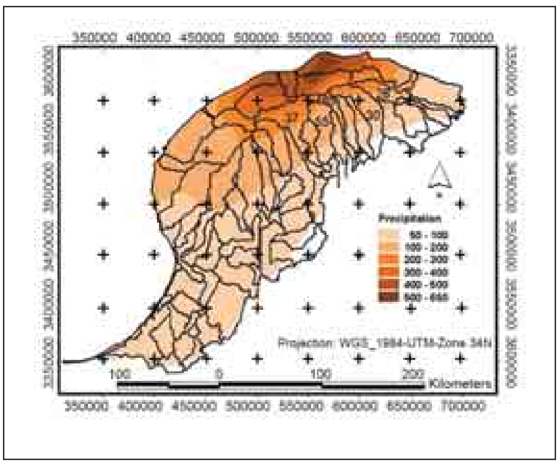

Figure 1.11a. Watersheds that have a rainfall range between 100 mm and 500 mm (suitable for all project components) in the eastern area

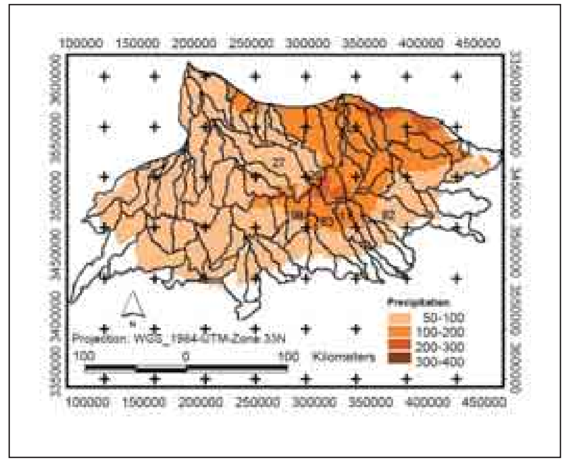

Figure 1.11b. Watersheds that have a rainfall range between 100 mm and 500 mm (suitable for all project components) in the western area

However, applying the second scenario in (Table 1.2) (allow the selection of two watersheds) resulted in 26 watersheds in the eastern area and 28 watersheds in the western area that were suitable for this project from a rainfall perspective (Figures 1.12a and 1.12b). These might be considered for rainfed cropping only, rangeland only, or for both uses in the same watershed (see the legend). These watersheds were considered for further analyses to include the rest of criteria and achieve the final selection of the watersheds.

Table 1.2. Detailed criteria limits for rainfall

One watershed			Two watersheds			
			Rangeland		Rainfed	
Area	**Lower limit (mm)**	**Upper limit (mm)**	**Lower limit (mm)**	**Upper limit (mm)**	**Lower limit (mm)**	**Upper limit (m)**
Original criteria	100	500	100	300	250	500
East	≤150[1]	≥350[2]	≤150[1]	≥250[3]	≤250[4]	≥350[2]
West	≤150[1]	≥300[2]	≤150[1]	≥250[3]	≤250[4]	≥300[2]
Actual criteria[5]						
East	97-146	363-503	98-163	245-319	200-499	349-652
West	98-152	293-402	93-197	229-281	182-268	300-404

[1] rainwater harvesting for rangeland not more than 150 mm
[2] necessary for wheat, not less than 350 mm in the eastern area and not less than 300 mm in the western area
[3] necessary to implement various types of rainwater harvesting interventions
[4] lower limit for rainfed barley
[5] actual limits that were applied based on the actual data available for the east and west

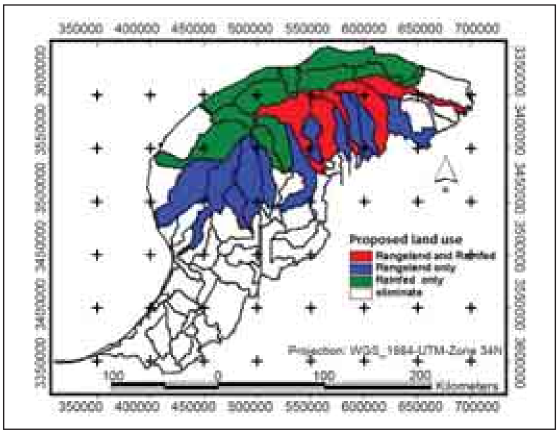

Figure 1.12a Watersheds that have a rainfall range between 100 mm and 300 mm (rangeland only), or between 300 mm and 500 mm (rainfed only), or between 100 mm and 500 mm (rangeland and rainfed) in the eastern area

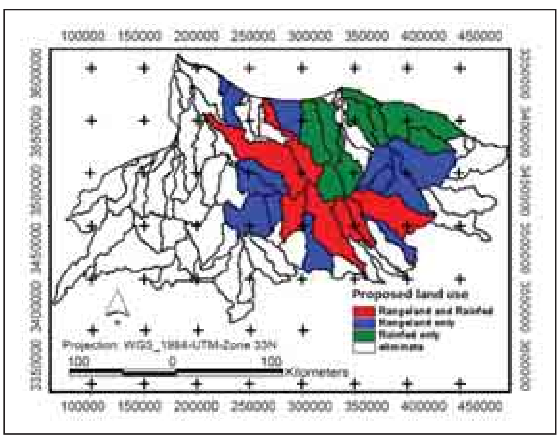

Figure 1.12b Watersheds that have a rainfall range between 100 mm and 300 mm (rangeland only), or between 300 mm and 500 mm (rainfed only), or between 100 mm and 500 mm (rangeland and rainfed) in the western area

1.4.2. Cropping systems

The area of different LULC was estimated to ensure that not only the rainfall criteria match the required cropping (production) system, but also that there is a sizable area of the intended uses within the watershed.

Considering the presence of irrigated areas within the watershed helps the selection criteria narrow down the options considerably. Therefore, we could select watersheds without irrigated areas within their boundaries. This would give more flexibility in the selection. Beside, suitable areas for irrigation might be there, but the land is not currently under irrigation, so we can relax this criteria.

Maps of the distribution of the cropping (production) systems (Figures 1.8a and 1.8b) were overlaid with the maps of the watershed boundaries (Figures 1.6a and 1.6b) and the area of each cropping (production) system within each watershed was calculated. The important classes of the LULC map for this project are rainfed and rangeland (Figures 1.8a and 1.8b). Therefore, these two classes were considered in this analysis. Based on the presence of significant areas of different cropping (production) systems within the watersheds, the intended use of some watersheds was changed. In the eastern area, four watersheds were changed from being considered for rainfed and rangeland (based on rainfall criteria) to be considered for rangeland only because the analysis indicated that the area under rainfed agriculture was not enough to support the implementation of rainfed research (Figure 1.13a). In these watersheds the *wadi* floor and flat area around the *wadi* in a very low rainfall area were

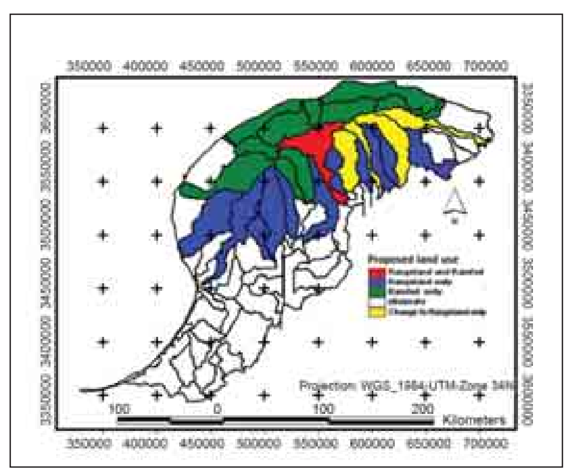

Figure 1.13a Changing a watershed's intended use based on the availability of sufficient land use (production systems) within the watershed in the eastern area

considered as rainfed in the LULC cover maps. This is not suitable as rainfed cropping systems are defined in this project and, hence, there is a limited chance that the improvement in rainfed cropping systems could be investigated in these narrow areas.

In the western area, three watersheds were changed from rangeland only to rainfed and rangeland because the cropping systems indicated a significant rainfed area within these watersheds despite low rainfall. Two watersheds were classified for rainfed cropping based on rainfall, but were eliminated when the actual cropping systems within these watersheds were considered because there was a very limited area under rainfed cropping. One watershed was changed from rainfed and rangeland to rangeland only because of the limited rainfed cropping within the watershed (Figure 1.13b). The selected watersheds, based on the rainfall and cropping systems criteria, are shown in (Figures 1.14a and 1.14b).

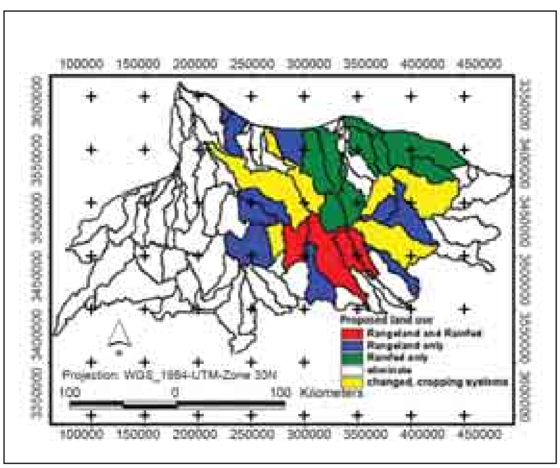

Figure 1.13b Changing a watershed's intended use based on the availability of sufficient land use (production systems) within the watershed in the western area

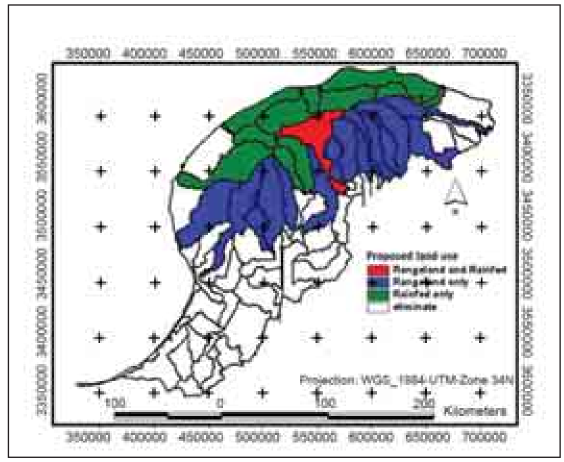

Figure 1.14a Watersheds selected after applying rainfall and cropping (production) systems criteria in the eastern area

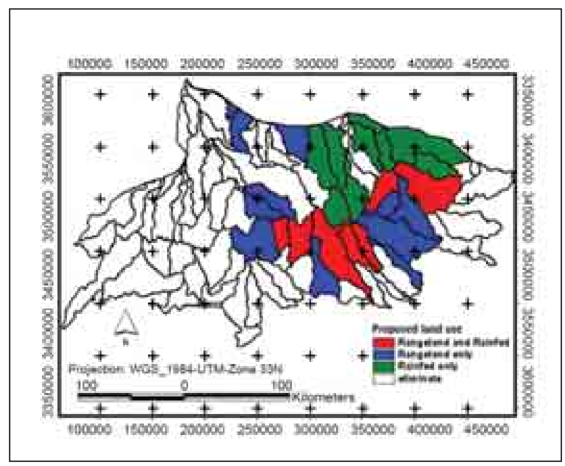

Figure 1.14b Watersheds selected after applying rainfall and cropping (production) systems criteria in the western area

1.4.3. Communities

The locations of communities (rural settlements) for the whole study area were determined from various sources:

- Topographic maps: these were derived by a previous project
- LULC maps: urban areas, only for major towns and cities, were digitized as part of this mapping
- Satellite images: any settlement that can be seen was digitized. However, this could be only an urban area not a community . A field check during the site visits was necessary
- Google Earth: any settlement that can be seen was digitized. However, this could be only an urban area not a co mmunity. A field check during the site visits was necessary.

The spatial distribution of communities derived from these sources was compiled in one layer. This layer was overlaid on the watersheds to identify the locations of the communities with respect to each of the watersheds selected after applying the rainfall and cropping (production) systems criteria (Figures 1.14a and 1.14b). A proximity analysis (buffer analysis) was applied for the community criteria. This is because the community does not necessarily have to lie within the watershed for the watershed to be considered suitable for the project.

The community can be at certain distance from the watershed and the people of the community still own some land in the watershed. It was decided that the community should be inside the watershed or close to the watershed boundaries – not more than 10 km distant from the boundary. A 10 km buffer area was drawn around each community. Furthermore, the proximity of the communities to the desired activities was also considered as an important factor for the suitability of the watershed for the project. For example, a community should be close to rangeland when rainwater harvesting is being considered. The project required a community to be present to work with – community participation in this project was an important and conceptual requirement. For rainfed areas, the presence of communities was not a limiting factor because most settlements are concentrated in high rainfall areas. However, for rangeland, there are some areas without communities. The criterion of the presence of a community within 10 km of the intended use and within the targeted watersheds was applied. The criterion applied was that communities should be within 10 km if the intended use is for both rangeland and rainfed agriculture, within 10 km if the intended use is for rangeland, and within 10 km if the intended use is for rainfed agriculture.

In the eastern area, all watersheds either included one community inside its boundaries or within 10 km from the boundaries (Figure 1.15). However, five watersheds were eliminated because there were no communities that were close to the area of intended use (Figure 1.16a). The implementation of the project would have been very difficult without the participation of a community. In the western area, three watersheds were eliminated from further consideration because no community was inside or close to the intended area of use (Figure 1.16b).

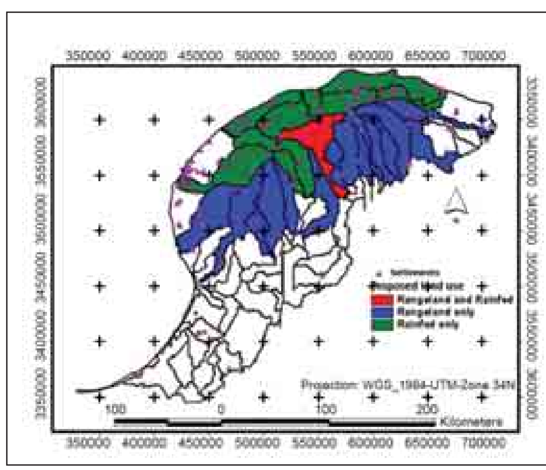

Figure 1.15 Location of communities inside or in close proximity to watersheds in the eastern area

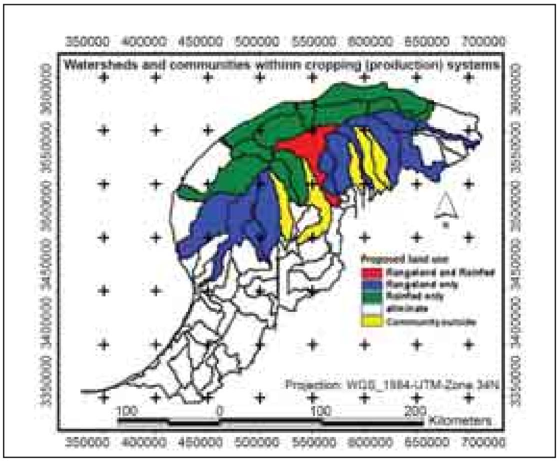

Figure 1.16a Watersheds eliminate because no community was close to the intended area of use in the eastern area

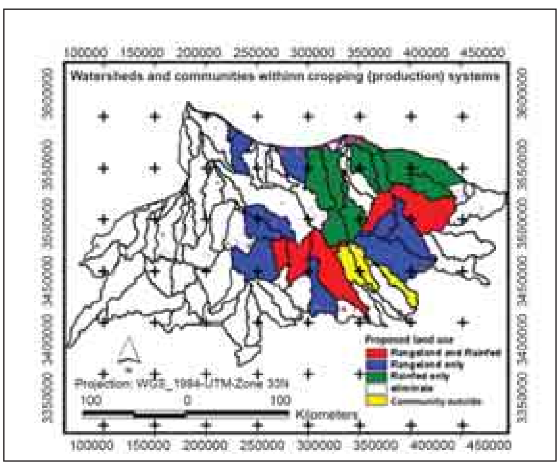

Figure 1.16b. Watersheds eliminated because no community was close to the intended area of use in the western area

1.4.4. Accessibility and visibility

The road network which was derived from topographic maps (Figures 1.9a and 1.9b) was overlaid with the watersheds selected after applying the criteria of rainfall, cropping (production) system, and communities. Any watershed which is totally disconnected from roads was eliminated because there was little chance of it being accessible and visible to the farming community. In the eastern area, all watersheds were connected to roads and therefore no watershed was eliminated (Figure 1.17a). However, in the western area, three watersheds were eliminated from further considerations because they were disconnected from the road network (Figure 1.17b). Access to these watersheds is not possible and the visibility of the project activities would be very low (may be restricted to just the local community). Furthermore, it was noted that no communities were located within these three watersheds, which makes the implementation of this project impossible in these locations.

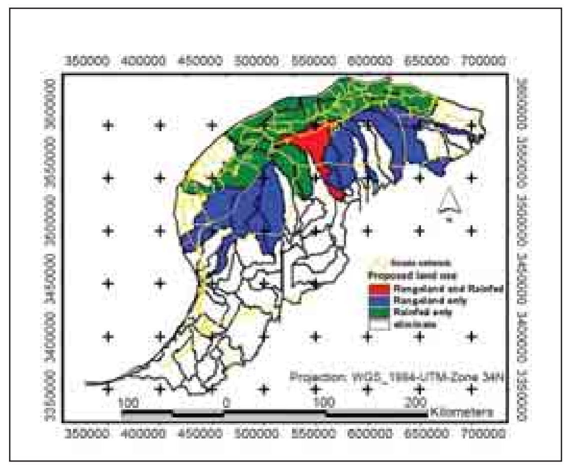

Figure 1.17a Watersheds and road network (accessibility and visibility) in the eastern area

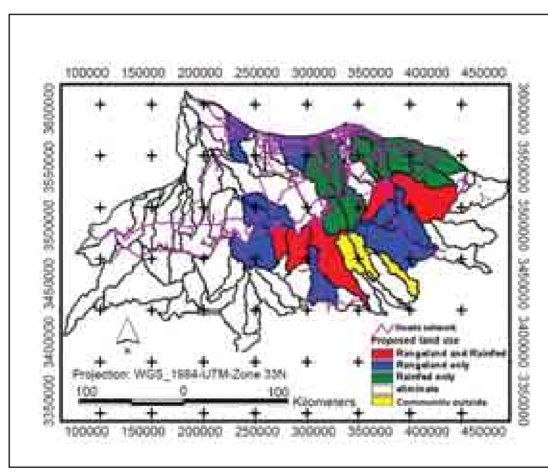

Figure 1.17b Watersheds and road network (accessibility and visibility) in the western area

1.4.5. Topography

The slope map was classified into three classes (0-10%, 11-20%, and > 20 %) and was overlaid on the watershed boundaries map. The area of each slope class was calculated for each watershed. Most watersheds included enough areas with slope 0-10 % (the best slope class for the project activities). In the eastern area, the smallest area of the class 0-10% was recorded in watershed number 267 – 225 km^2. In the western area, the smallest area of the class 0-10% was recorded in watershed number 440 – 147 km^2. Therefore, there were no limitations in finding areas of good slope for the project activities.

However, for rainwater harvesting, it is necessary that an area with good slope (less than 10 %) is associated with rangeland areas and not with other land uses. The LULC map was overlaid on the classified slope map and the areas under rangeland and for the different slope classes was calculated for each watershed. Again, most watersheds included enough area with a slope in the range of 0% to 10 % which was used as rangeland. The smallest rangeland area with slope in the class 0-10% was recorded for watershed number 267 (eastern area) – 53 km^2. Therefore, there was no limitation to finding rangeland with good slope for rainwater harvesting.

This criterion was further revised after consultation with experts, to estimate the areas with slopes between 0% and 5% and between 6% and 10 % which was, at the same time, under rangeland use. The reason for this further refinement was that some rainwater harvesting techniques are more suitable for slopes between 6% and 10 % than for flatter ones. Some watersheds in the eastern and western areas had limited areas with slopes between 6% and 10 % which were also under rangeland use. These were eliminated because the implementation of various types of rainwater harvesting systems required slopes in the range greater than 5% and less than 10%. Three watersheds were eliminated in the eastern area (Figure 1.18a), and four were eliminated in the western area (Figure 1.18b).

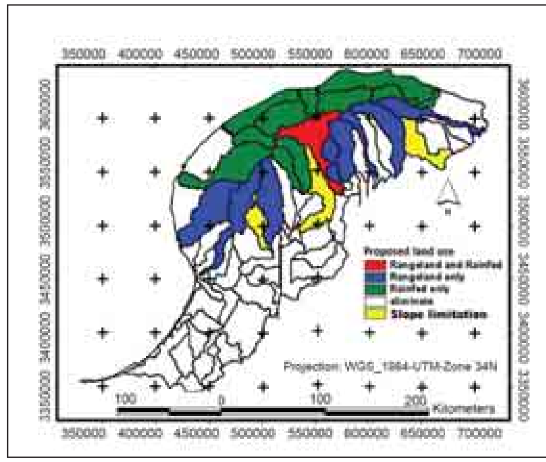

Figure 1.18a. Watersheds eliminated because of insufficient area with suitable slope for the intended land use in the eastern area

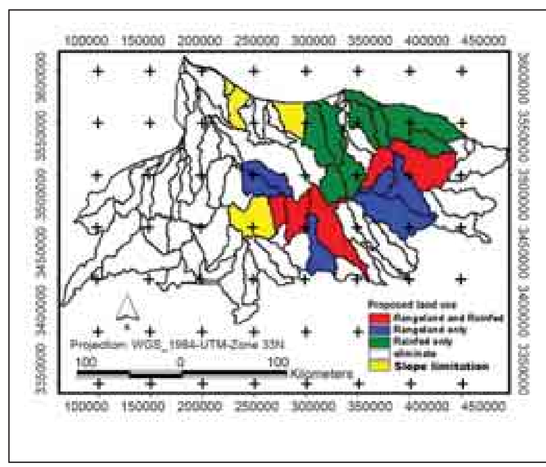

Figure 1.18b. Watersheds eliminated because of insufficient area with suitable slope for the intended land use in the western area

1.4.6. Soils

The legend of the soil map (1:2,000,000) was used with the keys to the soil taxonomy in order to find the major and secondary limitation(s) of each soil mapping unit. Each mapping unit comprised associations of many soil types. Soil associations for each mapping unit were defined and the keys for the soil taxonomy were used to identify the major limitation(s) of each association. Based on the relative area of each association, the major and second major limitation of each mapping unit were defined (Figures 1.19a and 1.19b).

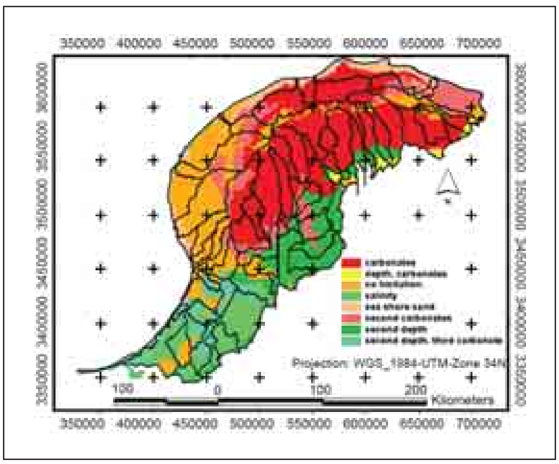

Figure 1.19a Major limitations of soil mapping units in the eastern area

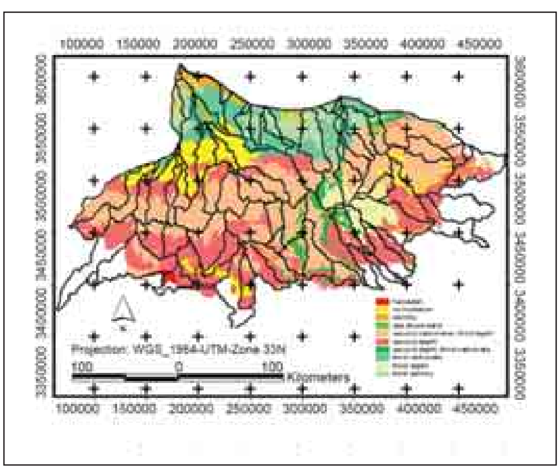

Figure 1.19b Major limitations of soil mapping units in the western area

This map was overlaid on the watersheds boundaries map and the area of each soil mapping unit, and consequently the area of limitation(s), was calculated for each watershed. Watersheds with insignificant limitation(s) area within the watershed were eliminated from further considerations. The limitations considered were carbonate concentration, depth, salinity, and sea shore sand content . These might be a major limitation when the dominant soil association is having this limitation as the first limitation or as a second or third limitation when less dominant soil associations are having this limitation. For the eastern area, the dominant limitation was sea shore sand in three watersheds (Figure 1.20a). For the western area the main limitation was salinity for one watershed and sea shore sand for one watershed (Figure 1.20b).

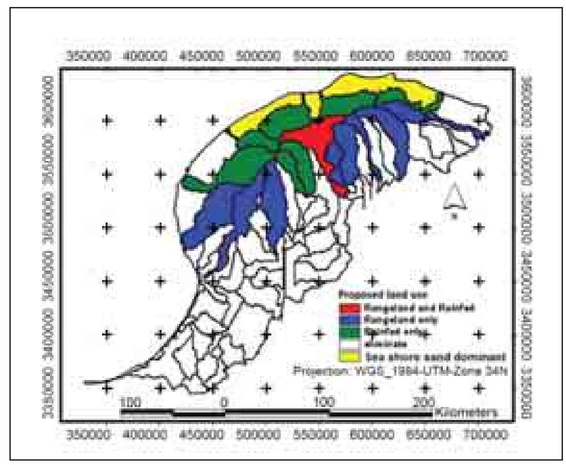

Figure 1.20a Watersheds eliminated because of limitations imposed by the dominant soil in the eastern area

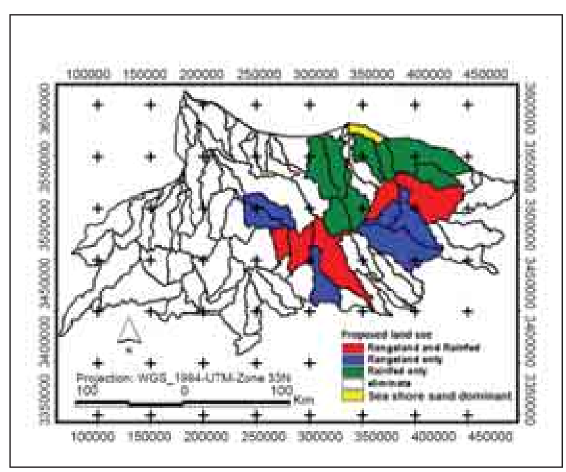

Figure 1.20b Watersheds eliminated because of limitations imposed by the dominant soil in the western area

1.4.7. Criteria not considered

The following criteria were not considered in the selection process for various reasons:

- Potential for rainwater harvesting: insufficient data was available to permit judgment of this criterion (for example the intensity of the stream network). Therefore, it was decided that it would be better to judge the potential for various rainwater harvesting intervention during the field visits.
- Soil pH: the available soil map, which covers the whole study area, did not contain data to satisfy this criterion
- Small ruminant density: data about this criterion was only available at the *Shaibiat* level (locally known administrative unit in Libya), which was very coarse with respect to the watersheds considered in the selection process. One *Shaibiah* extended over many watersheds and therefore, it was not possible to distinguish individual watersheds based on the density of small ruminants
- Water points: data about water points was available, but the projection of the data was not known. The study area extends over four geographic zones and, therefore, the conversion of this data into a useable format was not possible
- Availability of research stations: the geographic coordinates of research stations were not known and, hence, could not be overlaid with the other GIS data.

Nevertheless, these criteria were considered during the field visits. The observations of the team and the experience of members of the team in the study area were used to judge these criteria and they were incorporated in the final selection.

1.4.8. Potential watersheds determination

The above process resulted in a selection of potential watersheds that were earmarked for field visits to judge their suitability for project activities. As a result of applying the above criteria, 16 watersheds were selected in the eastern area (Figure 1.21a) and 18 watersheds were selected in the western area (Figure 1.21b). These watersheds were visited by the inter-disciplinary team of researchers (Appendix B) to select those watersheds that would be used to implement the project.

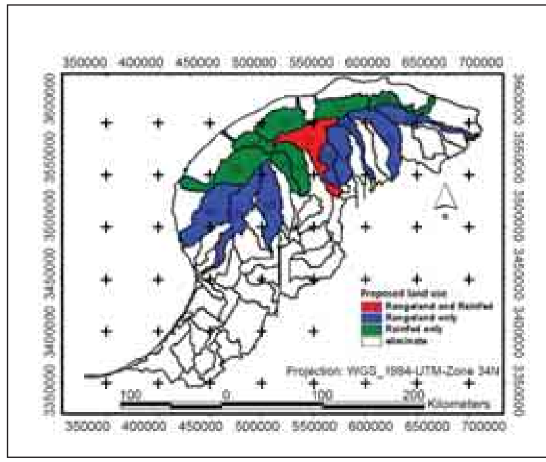

Figure 1.21a Potential watersheds for field visits after applying the selection criteria in the eastern area

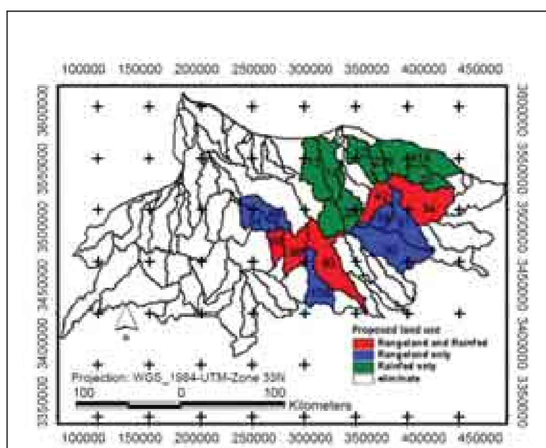

Figure 1.21b Potential watersheds for field visits after applying the selection criteria in the western area

1.5 Field assessment and final selection

1.5.1. Field visits

The inter-disciplinary team undertook a series of field visits during the period July 7-14, 2009. The main purpose was to visit the 16 potential watersheds in the eastern area and the 18 potential watersheds in the western area that had been identified (see previous sections) and to finally select the Integrated Benchmark Research Watersheds (IBRWs). These visits were followed by a report that announced the final selection as made by the researchers from ARC, ICARDA, and other national institutes in Libya.

For navigation, a map sheet was prepared for each watershed as well as an index map for all watersheds. The map layout was printed on A0 size paper and the following layers and information were displayed for each layout:

- Satellite image as background
- Watershed boundaries (based on 50,000 and 25,000 upstream pixels)
- Drainage lines (25,000 upstream pixels)
- Rainfall isohyets
- Roads
- Villages (location and names of all settlements, towns, and communities)
- Coordinates grid, scale bar, north arrow, legend, and watershed number.

The layouts were stored on CD-ROM and copies kept at ICARDA and ARC for future use. The hardcopies were kept at ARC, Libya. An example of these layouts is shown in (Figure 1.22).

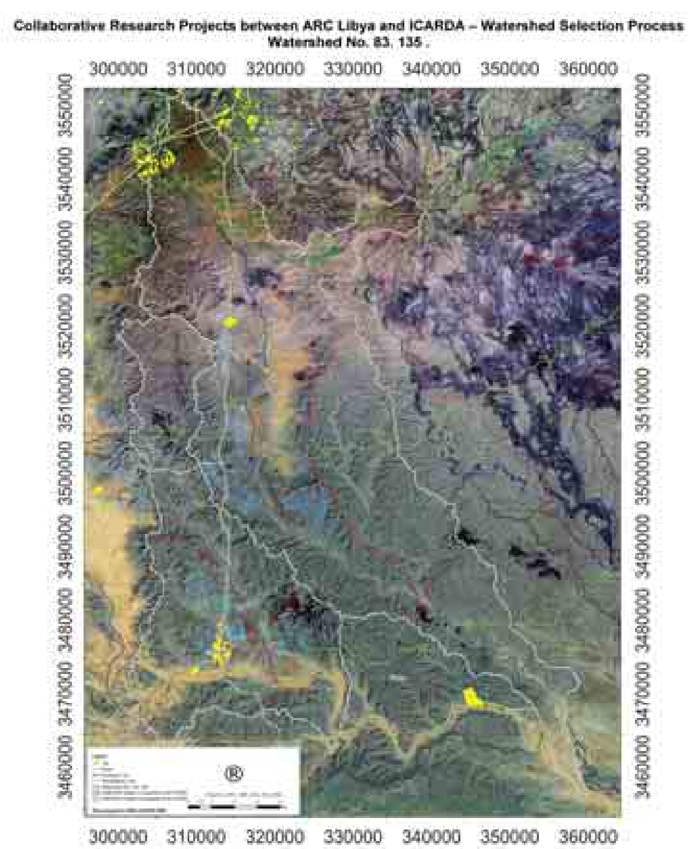

Figure 1.22 Potential watersheds for field visits after applying the selection criteria in the eastern area

Each team member was asked to fill in a form about his/her evaluation of the suitability of each watershed for project activities. The form included questions such as the suitability of the watershed for further consideration, the intended use of the watershed (rainfed agriculture, rangeland, or both) and any other helpful comments (Table 1.3). These forms were helpful during the meeting that was held after the visits to discuss the final selection.

After making many stops within the watershed, the team discussed the possibility of working in each watershed. This avoided focusing on localized spots, which might give a wrong impression about the watershed; rather it encouraged looking at the whole watershed after finishing the visit to that watershed.

During four days of field work, the team managed to visit all the potential watersheds. The routes followed during these visits are shown in (Figure 1.23a) for the eastern area and in (Figure 1.23b) for the western area.

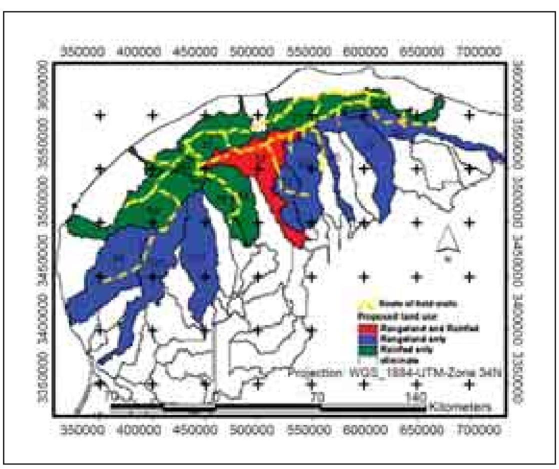

Figure 1.23a Route followed to cover potential watersheds during the two-day field visits in the eastern area

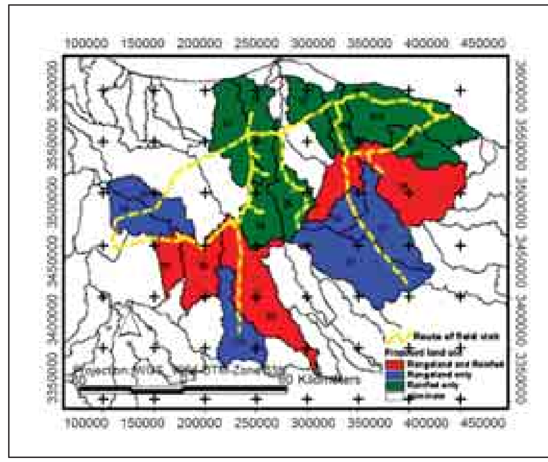

Figure 1.23b Route followed to cover potential watersheds during the two-day field visits in the western area

Many stops were made at each watershed and the following aspects were evaluated and discussed by the team after finishing their visit to each location:

- Presence of a community (population density)
- Willingness of community to cooperate (their involvement in agriculture)
- Presence of small ruminants
- Availability and proximity to water points
- Availability and proximity to research stations
- Potential for rainwater harvesting
- Hydrological characteristics of the area
- Safety for research implementation (equipment)
- Land tenure system (use rights and property rights).

Table 1.3. Field assessment form used by individual team members during the field visits

Name of Evaluator:		**Specialty:**	
Watershed number	***Consider for further analyses (Yes or No)***	***Intended use (Rainfed and rangeland Only rangeland Only rainfed)***	***Comments***

1.5.2. Post field visits meeting and final selection

Group meeting for Al-Jabal Al-Gharbi

The team met after the two-day visits to the watersheds and discussed the final ones to be considered for the project activities. In addition to the aspects that were discussed in the field for each watershed, the following issues were highlighted and discussed for the different watersheds:

a. The presence of communities and their potential willingness to participate
b. Accessibility and distance to research stations
c. The soil limitations for some watersheds

The team expressed an obvious preference for three watersheds, which were ranked in terms of their potential from the most desirable to the least desirable (Figure 1.23b):

a. First was watershed no. 83 (Al-Ghadama)
b. Second was watershed no. 99 (Saffeat)
c. Third was watershed no. 416 (Al-Nakaza)

(Table 1.4) shows brief, general features of these watersheds.

Group meeting for Al-Jabal Al-Akhdar

In this meeting it was obvious that there were many options to consider. Therefore, the team arranged their opinions in a matrix to express their preferences (Table 1.5).

Watersheds were eliminated, starting with the watersheds with the lowest number of votes. People who voted for the watershed provide their rationale for selecting it. If the characteristics of the watershed were similar to those of other watersheds with a higher number of points, it was eliminated. The final decision was to select four watersheds (table 1.6) in which to undertake the project activities. These were:

a. Watershed no. 37 (Samalos)
b. Watershed no. 58 (Al Qatara)
c. Watershed no. 28 (Al Mualaq)
d. Western part of watershed no.17 (Al Marj)

The watershed location can be seen in (Figure 1.23a). Table 1.6 shows brief, general features of these watersheds.

Table 1.4. General features of watersheds No. 83 (Al-Ghadama), 99 (Saffeat), and 416 (Al-Nakaza).

Watershed no.	Watershed name	Watershed main features
83	Al Ghadama	The watershed is dominated by the three major production systems, rainfed, irrigated, and rangelands. Fruit trees grow in the upper elevations with the higher rainfall, followed by cereal areas and rangelands in the lower elevations of the watershed. The watershed includes several communities and a research station (Gandouba) near the top of the catchment. The watershed drains to the south.
99	Saffeat	Saffeat watershed is dominated by rangelands and fruit trees with some cereals in the upper elevations of the watershed. It has in it the Saffeat research station and several communities. The watershed drains to the south.
416	Al Nakaza	Al Nakaza is a large watershed that covers all types of production systems in Al-Jabal Al-Gharbi, including rainfed fruit trees, crops, and rangelands, but it is dominated by trees. When water resources are available, summer irrigation is also practiced. Major communities are settled and many of the indigenous rainwater harvesting systems are located in the watershed. This watershed drains to the Mediterranean sea.

Table 1.5. Inter-disciplinary team watershed preferences

Name	37	17	21	58	63	79	239	240	28	30	55	65	73	94	101	103
Saad	1			1												
Hussein	1			1							1					
Farouq	1							1	1		1					
Karrou	1							1	1							
Nowri	1			1				1	1		1					
Aden	1			1				1								
Ali	1	1							1							
Saeed	1	1		1				1	1							
Fawzi	1	1		1				1	1							
Jumah	1	1						1	1							
Youniss	1	1		1				1	1							
Adriana		1		1												
Feras	1	X														
Ahmed	1	1						1	1							
Theib	1	1						1	1							
Total	14	7	0	8	0	0	0	11	11	0	3	0	0	0	0	0

1 – select, X – do not agree Red –select, Blue – eliminate

Table 1.6. General features of watersheds No.37 (Samalos), 58 (Al Qatara), 28 (Al Mualak) and 17 (Al Marj).

Watershed no.	Watershed name	Watershed main features
37	Samalos	Marawah watershed extends over the annual rainfall range from over 500 mm to below 100 mm. To a large extent it has the three major production systems, rainfed, irrigated, and rangelands. Fruit trees grow in the upper elevations with the higher rainfall, followed by cereal areas and rangelands at the lower elevations of the watershed. The watershed includes several communities. The watershed drains to the south.
58	Al Qatara	Al Abyar watershed is dominated by the cereal cropping system, but also has some fruit trees at higher elevations, and rangelands. Communities are cooperative and practice all the production systems. The watershed drains to the Mediterranean.
28	Al Mualaq	Al Timimi watershed is dominated by rangelands, but has cereals at higher elevations. There are few communities in the watershed. This watershed drains to the Mediterranean.
17	Al Marj	Al Marj watershed is not a typical one as half of it drains to a depression in the western part while the eastern part drains to the Mediterranean. The group decided to use only the western part where Al Marj station is located so that this production system is investigated. It is a typical rainfed system and suitable for the supplemental irrigation of cereals and other crops.

1.6 Concluding remarks

The whole process of selecting the IBRWs faced many challenges at the beginning. Some of these might be considered as weaknesses, while others are strengths and opportunities that lead to a successful selection process. It was a big challenge to satisfy the diversity of research activities that will be undertaken in one watershed. While the water management group is looking for areas suitable for rainwater harvesting and supplemental irrigation with specific biophysical characteristics, the cereal group is looking for areas with a dominant land use for cereals, and the livestock group is seeking communities with a sufficient number of livestock. Each of these different land uses occur in a unique ecosystem that differ from the others, and the selected watershed is supposed to encompass all of them.

From a biophysical point of view, what also complicates the process is the demand by all groups for certain socioeconomic settings within which these different land uses operate. The project obviously demands a competent community with interest in the research activity under question and with a representative setting that is out-scalable for the whole Libya. Finding a suitable area from the biophysical and socioeconomic points of view was a challenging task. Furthermore, the project components mentioned above are not supposed to work separately, they should work in a fully interactive and integrated mode, with the socioeconomic component as a cross-cutting issue among all other components.

At the beginning of this process and during the first implementation workshop there was a general consensus that the national working groups needed some motivation and awareness raising about two main issues – integrated research sites for different components and the concept of the watershed as a working unit for research activities. Generally, the experience of the national team, although very diverse, long, and rich has been concentrated on individual research sites in terms of location and themes. Therefore, the concept of integrating diverse research activities, such as water management, cereals, livestock, and socioeconomic studies, is a relatively new one. The workshop was successful in highlighting all these deficiencies and helped a lot in formulating the whole selection process. Another new concept that needed introduction and discussion was that of integrating the above components within one watershed and the merit of this approach as compared with selecting many research sites without natural correlation and bindings. However, both parties that advocated the watershed concept and those who were against it were not sure at that stage that they would manage to find watersheds that would satisfy the needs of all components and research groups.

A promising feature that supported the implementation of the selection process is the consensus of all national and international researchers about the challenges that face the agricultural sector in Libya. This highlighted a strong will to change the way agricultural research has been tackled and it was very obvious that business as usual was not an option if a sustainable research strategy is to be formulated for integrated work.

Previous experience demonstrated many research activities, but, in most cases, this was scattered among various themes and locations. This was highlighted as a reason for the poor integration of research efforts in the agricultural sector, which provided support for this selection process.

Another source of support for the selection process was the availability of data about most biophysical features in the study area, especially in areas where the annual rainfall exceed 200 mm. The 'agricultural regions' study, which was finished just before the start of the selection process, provided a lot of support in the selection of promising study areas where the project would be successful. The experience of the national team and their knowledge about available relevant data was indispensable to the success of this process. One important feature of the selection process is the integration of various disciplines through the interactive participation of an inter-disciplinary team of researchers throughout the various stages of this process, from defining selection criteria, through data collection, analyses, field visits and final selection. This was supported by full utilization of GIS and remote sensing capabilities to undertake the compilation, harmonization, integration, and analysis of spatial and non-spatial data. An important feature of this is the flexibility of the approach to include data from various sources, as well as the possibility of including local experience and knowledge whenever possible and relevant. The iterative nature of the process enables the adjustment of different criteria and their application to reach acceptable results that match the ground.

The sequence of analyses followed during the selection proved successful. It started by defining the selection criteria, applying the criteria, analyzing the data, presenting the results to the team, and appropriately manipulating the criteria. This process was repeated through various iterations and finally confirmed by the results by field visits. A final selection was then agreed. The approach seems very flexible, but it sticks to fixed criteria and rules that were agreed by the whole team.

The success of the approach followed was judged using different aspects. The final voting pattern of the team indicated the agreement between the results achieved after applying the criteria and the characteristics of the watersheds as assessed during the field visits. In particular, the allocation of the different watersheds to the categories of 'rainfed only', 'range only', or 'both rainfed and range', following the field visits, shows good agreement. The experience of the national team indicated that the watersheds selected after applying the criteria were areas of good potential in which to implement the project. Judgments, based on their experience, indicated that the process guided them to the areas that best represent the rainfed, range and livestock activities. They expressed their satisfaction at finding these areas located within one watershed. They were able to determine the boundaries between watersheds based on their knowledge on the ground.

Another encouraging result that indicates the success of the approach is the clear agreement among the team members in reaching the final selection of the watersheds. The task was very easy and straight forward in the western area given the clear subdivision of rainfed and range areas. In the eastern area, the task was more difficult because of the high diversity among cropping (production) systems. However, a clear consensus was reached among the team members on a limited number of watersheds. Through the discussion, the team very easily arrived at agreement about the final selection of watersheds. It was very encouraging to find one watershed in the eastern area (Samalous watershed) and one watershed in the western area (Ghadama watershed) where both rainfed and rangeland are abundant and located within one watershed. This was a basic requirement for the project implementation. Except for one team member, the whole team voted for these two watersheds as the best ones in which to achieve the project's goals.

These achievements are very important for the project at this early stage where the integration of various components is very important. Beyond this, the process managed to present results in a way that will be useful in the future for any integrated research activities and wherever watershed selection is needed. The approach is reproducible whenever the process is needed for different research activities; the criteria can be modified and the whole process repeated to reach an acceptable result. The capacity building component was very important and the team was trained to undertake the process. Thus, the benefits of the selection process presented go beyond the immediate achievement of selecting watersheds that were confirmed by the majority of the team members. It is anticipated that the selected watersheds will enable researchers to undertake integrated research activities that contribute to the improvement of agriculture at both national and regional levels.

1.7 References

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Chapter 2

Characterization of selected watersheds for integrated research in Libya

F. Ziadat, A. Al-Buaishe, T. Oweis, M. Elkhboli, Y. Awami, E. De Pauw, A. Al Wadaey, M. Saleh, and H. Talib

Chapter 2: Characterization of selected watersheds for integrated research in Libya

F. Ziadat, A. Al-Buaishe, T. Oweis, M. Elkhboli, Y. Awami, E. De Pauw, A. Al Wadaey, M. Saleh, and H. Talib

2.1 Introduction

Libya faces severe water shortages and has invested heavily in developing and transferring non-renewable water resources to the coastal areas. One renewable water resource, however, is still underutilized or is mostly lost with little benefits. Rainwater on the coastal areas, particularly in Al-Jabal Al-Akhdar, Al-Jabal Al-Gharbi, and the central zone, is partially used in agriculture, but, due to lack of management, is mostly lost in evaporation or runoff. As a result, agricultural production is low and the potential for improvement is lost.

Rainwater harvesting (RWH) has been an indigenous practice in Libya for hundreds of years. It concentrates rainwater through runoff into targets so it can be used efficiently in agriculture or for other purposes. Some of the ancient techniques are still working, but maintenance and operation is very costly and for some systems has become infeasible. Modern technologies can make rainwater harvesting more practical and lower in cost. Many of these technologies are available now and developments in science have contributed to their success.

Rainwater harvesting can improve the productivity of rainwater and maintain productive and sustainable agro-pastoral systems in marginal environments (Abu-Awwad and Shatanawi, 1997; van Wesemael et al., 1998; Prinz, et al., 1998). It could also control soil erosion and reduce the impact of drought (Oweis and Hachum, 2006). The potential of RWH to mitigate the spatial and temporal variability of rainfall has brought about its revival during the last two decades (Mwenge Kahinda et al., 2008).

Supplemental irrigation – applying limited amounts of water to field crops and fruit trees during dry spells to improve fields and water productivity – is another option to improve the productivity of rainfed systems (Oweis, 1999). The practice can also be associated with RWH, as runoff water may be used for supplemental irrigation. Other available water resources, such as ground water and water from man-made rivers, can better be used for supplemental irrigation than in other practices. There is a great potential for the use of supplemental irrigation in both the western and eastern regions.

However, farmers and communities do not have the knowledge or the means to implement suitable techniques in an appropriate way. In addition it is necessary for some of the techniques to be tested under current conditions. The capacity of the communities and the national research program and extension services needs enhancement in the area of RWH. Conditions are now suitable for mobilizing human and financial resources for improving the situation under appropriate physical and socioeconomic environments. Success achieved in implementing RWH in similar areas encourages adoption of these approaches on a large scale in this area.

One reason for the low adoption of successful land and water management practices is the lack of specific and systematic knowledge of potential areas and suitable locations for these interventions. Suitable utilization of the land lies within the land use planning process, which seeks to optimize this while sustaining its potential by avoiding resource degradation. These goals become more urgent within the expected scenario of climate change, where rainfall is expected to decrease and the probability of extreme events (such as severe storms) is expected to increase.

A major reason for the failure of RWH projects and the slow adoption of RWH techniques is the poor selection of suitable sites and the matching of the practice with its technical and socioeconomic requirements (Oweis et al., 1998). A major knowledge gap exists concerning the identification of those parts of the drylands in which the chances for the impact and adoption of RWH techniques are high and to which further studies could be targeted (De Pauw et al., 2006). Specifically, for planning and implementation purposes, it is critical to be able to identify areas suitable for RWH (Mwenge Kahinda et al., 2008). Therefore, there is a need for a generic and flexible methodology which allows planners and users (from the national to local level) to assess the potential for RWH and to identify areas that are suitable for this technique (Patrick, 1997).

How suitable an area is for RWH, supplemental irrigation, and management practices that seek to improve productivity depends on the local society, farming practices, and whether the area meets the basic technical requirements of the management practices in question. When planning such systems, appropriate data must be available on the climate, soil, crops, topography, and socioeconomics of the project area. These data can be collected through a combination of field visits, site inspections, topographic and thematic maps, aerial photos, satellite images, and geographic information systems (GIS).

The selection of appropriate sites and the determination of suitable methods for RWH are very important for ensuring sustainable implementation of RWH systems. For relatively small areas, a field survey carried out by experienced people will be the best technique. For larger areas the application of remote sensing and GIS could be the most relevant means (Holme and Tagg, 1996; Prinz et al., 1998; De Pauw et al., 2007). However, planning for large scale implementation requires quantitative information and the spatial distribution of land characteristics, which are often unavailable for arid environments (Prinz, et al., 1998). Because of the large extent of these environments and the relatively low population density, it is very expensive to inventory them using traditional survey methods (Patrick, 2002). Therefore, the use of available data should be optimized to serve these purposes and to provide a solid basis for site selection.

Prior to this work, the project developed an integrated approach for benchmark watersheds selection (Chapter 1). The approach was started by determining the most important selection criteria. These were developed by an inter-disciplinary team of researchers. Data were then analyzed to match the selection criteria with the existing biophysical and socioeconomic conditions of all watersheds in the study areas. This includes analyzing the criteria of rainfall, cropping (production) systems, communities (rural settlements), accessibility and visibility, topography, and soil. Based on these analyses a number of watersheds were identified as being potentially suitable. An inter-disciplinary team of researchers undertook several visits to all potential watersheds and identified seven watersheds (three in the west and four in the east) as the most suitable watersheds in which to undertake the project activities. Four watersheds were then selected to start the characterization and implementation of the project's activities.

This part of the report describes the watershed characterization process for the selected watersheds. The purpose of watershed characterization is to build a rigorous biophysical database which can be used by interested scientists and facilitate the selection of suitable integrated research sites for RWH, supplemental irrigation, and other practices . The process started with the collection of available data and its integration and compilation. Field surveys were undertaken to collect missing information. Maps and layers of information were synthesized and integrated, using all the information collected, to serve the purposes of this project. The spatial and attributes database generated from this information is very comprehensive and well documented and will serve future research and development activities.

2.2 Description of the data

The objectives of watershed characterization are twofold. The long-term objective is to build a database for use by scientists during the project and beyond. The immediate objective is to aid the selection of suitable sites for RWH and supplemental irrigation interventions. Suitability here includes biophysical as well as socioeconomic aspects. Therefore, the collected information and layers were designed to satisfy these objectives. A detailed watershed selection process was undertaken prior to this analysis. The output of this process is the selection of seven watersheds, four in the eastern area and three in the western area (Chapter 1). Four of these watersheds were selected in which to start watershed characterization (Figures 2.1 and 2.2). The following data were collected; climatic data, cropping (production) system (land cover and protected areas), topography and slope, communities, water resources (RWH and soil conservation structures), and soil data. The following sections explain these data.

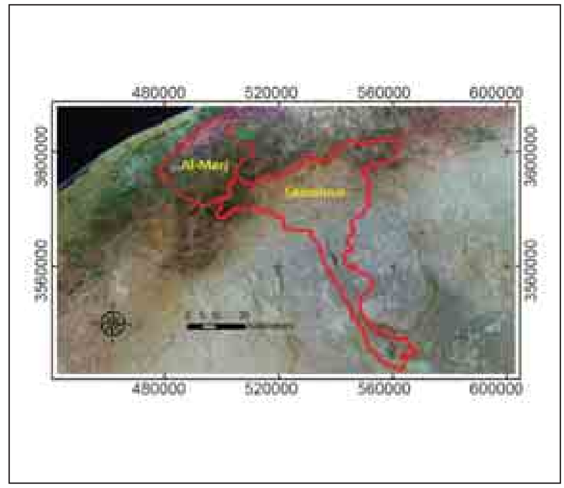

Figure 2.1. The selected watersheds in the eastern area (watersheds 17 and 37)

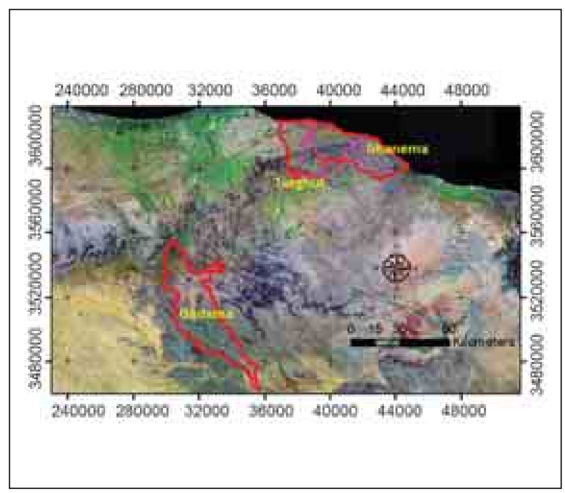

Figure 2.2. The selected watersheds in the western area (watersheds 83 and 416)

2.2.1. Climatic data

The coordinates of the weather stations in and around the targeted watersheds of the study area were derived from various sources and were used to create a map to show the distribution of these stations (Figures 2.3 and 2.4).

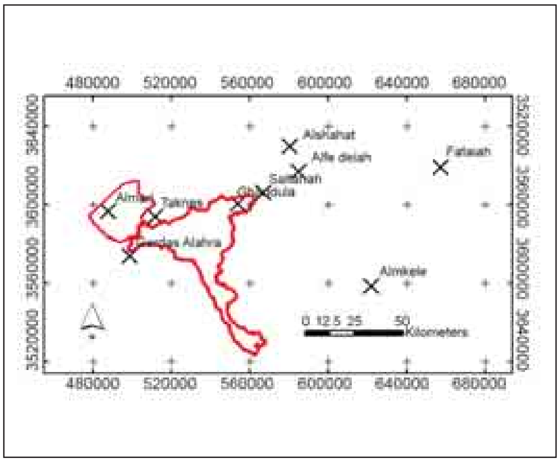

Figure 2.3 Distribution of weather stations over the eastern area (watersheds 17 and 37)

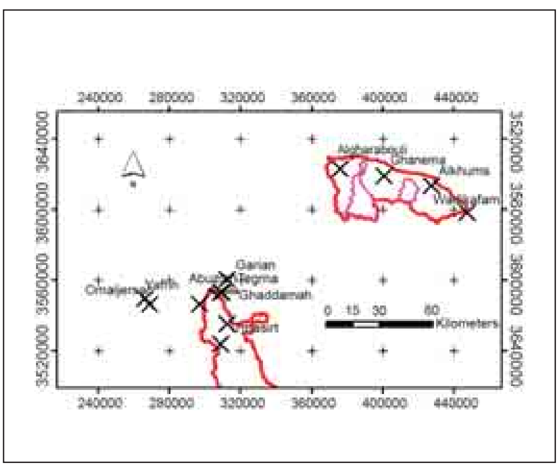

Figure 2.4 Distribution of weather stations over the western area (watersheds 83 and 416)

The following climatic parameters are available for some stations and for various years (some stations record only rainfall amounts):

- Rainfall (monthly average)
- Number of rainy days (monthly average)
- Maximum rainfall in one day (monthly average)
- Minimum and maximum temperature (monthly average)
- Wind speed (monthly average)
- Relative humidity (monthly average)
- Daily evaporation (monthly average).

A map of rainfall isohyets based on long-term average rainfall (more than 30 years) was received from the department of meteorology (Figures 2.5 and 2.6). In addition to these, many files in portable document format and images scanned from hard copy documents are available for interested researchers. These include:

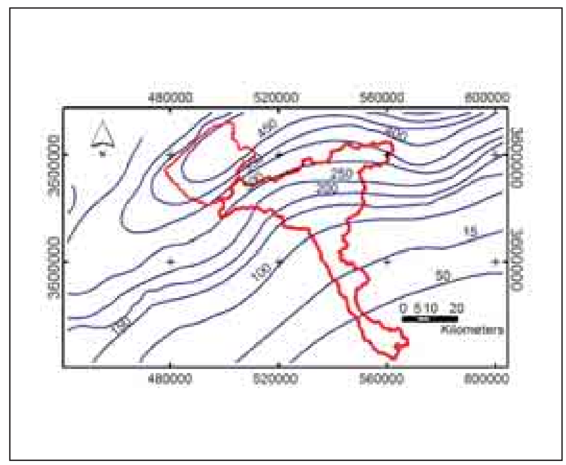

Figure 2.5 Isohyets based on long-term average rainfall for the eastern area (watersheds 17 and 37)

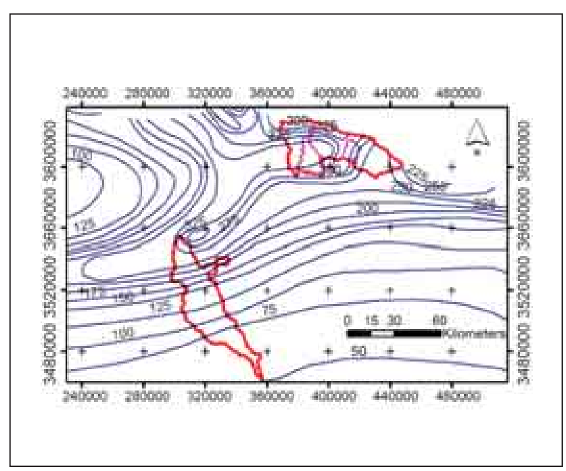

Figure 2.6 Isohyets based on long-term average rainfall for the western area (watersheds 83 and 416)

For Al Marj watershed (No. 17):

- Daily rainfall amounts (2001-2009)
- Monthly rainfall amounts (1919-2009)
- Monthly minimum and maximum temperature (1989-2002)
- Relative humidity (1989-1996)
- Two technical reports for Al Marj watershed include hydrological information (estimated runoff and runoff coefficients)
- Report on the geology of Al Marj watershed
- Surface water study for Al Marj watershed (hydrological information)
- Hard copy maps (scanned) for the location of RWH in Al Marj watershed.

For Samalous watershed (No. 37):

- Daily maximum and minimum climate record for some stations around Samalous (Mkhaili, Kharoubah, Msoos, Eizyat) including temperature, relative humidity, evaporation, precipitation, solar radiation, and wind speed and direction for the period 1979 to 1984
- Runoff, runoff coefficient, discharge, and sediment yield for the period 1980 to 1984, wadi Samalous
- Runoff, runoff coefficient, discharge, and sediment yield for the period 1980 to 1984, wadi Kharoubah
- Precipitation records for some stations (Labyar, Sllooq , Al Maqroon, Marawah, Qasr Libya, Taknes, Slinteh, Al Byathah, Al Faidyah and Darnah) for various years
- Summary of the surface water resources study for the area south of Al-Jabal Al-Akhdar (FranLab) for the period 1974 to 1976
- Technical report for the eastern area covering information about hydrology, runoff, sediment yield, and climate.

2.2.2. Cropping systems

The available land use map was used to derive this information. The scale of this map was 1:50,000 and was derived using the legend of the FAO land cover classification system (LCCS). This map was prepared during a previous mapping project in Libya (mapping the natural resources for agriculture use and planning). The following steps were followed in the preparation of the map; field work, interpretation of satellite images (scale 1:50,000), collection of ground truthing observations using GPS (accuracy between 5 m and 10 m), followed by office interpretation and field checking. The original legends of these maps include the following classes:
For the eastern area (Figure 2.7):

- Irrigated land
- Rainfed land
- Rangeland
- Bare land
- Natural forest
- Sabkha
- Urban

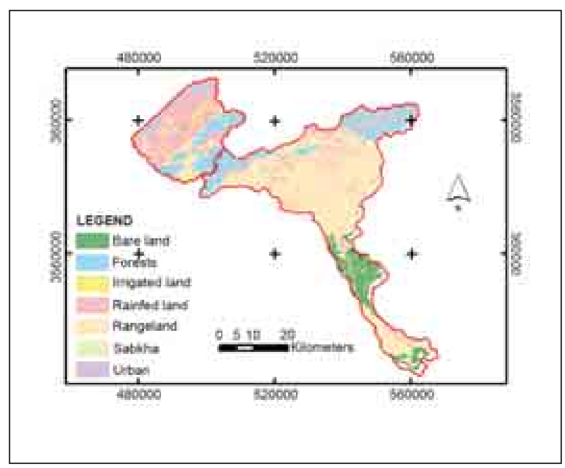

Figure 2.7. Land cover/land use map of the eastern areas (watersheds 17 and 37)

For the western area (Figure 2.8):
- Irrigated land
- Rainfed land
- Bare land
- Rangeland

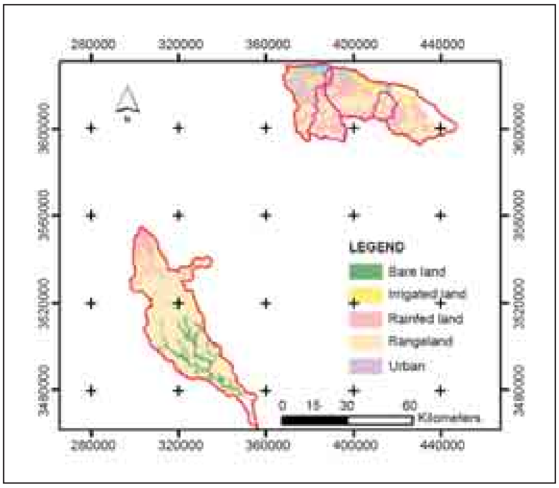

Figure 2.8 Land cover/land use map of the western area (watersheds 83 and 416)

The location and some characteristics of the protected areas in Samalous watershed were recorded by field surveys (Figure 2.9). The characteristics that were recorded for each of the 183 protected areas were:

- Area (closest town)
- Location
- Type of seedlings or crop
- Present situation
- Year of establishment
- Number of seedlings
- Presence of rainwater harvesting structures

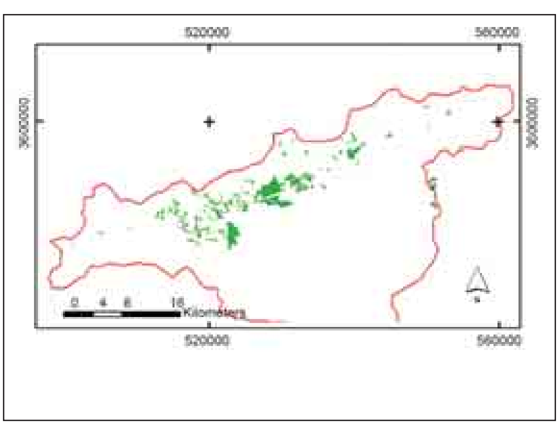

Figure 2.9 Extent and location of the protected areas within Samalous watershed (eastern area)

2.2.3. Topography and slope

These data were derived from digital topographic layers prepared previously for part of Libya (mapping the natural resources for agriculture use and planning). These topographic maps (scale 1:50,000) provided the contour lines (at 20 m vertical intervals and in some cases at 10 m vertical intervals). This detailed information was not available for parts of the selected watersheds with annual rainfall less than 100 mm. This is because the previous surveys for Libya concentrated more on areas with high rainfall and potential for development. However, in this project, areas with annual rainfall less than 100 mm are not suitable for implementing sustainable RWH and/or supplemental irrigation systems. Therefore these areas were ignored. (Figures 2.10 and 2.11) show the contour lines and drainage systems for the eastern and western watersheds.

These layers were used to derive a digital elevation model (DEM) using standard commands in ArcGIS. From this DEM, slope grids were derived to cover the four watersheds (Figures 2.12 and 2.13).

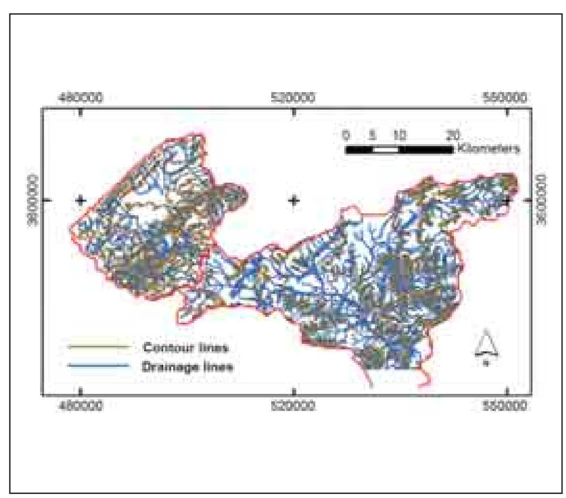

Figure 2.10 Contour lines and drainage systems for the eastern area (watersheds 17 and 37)

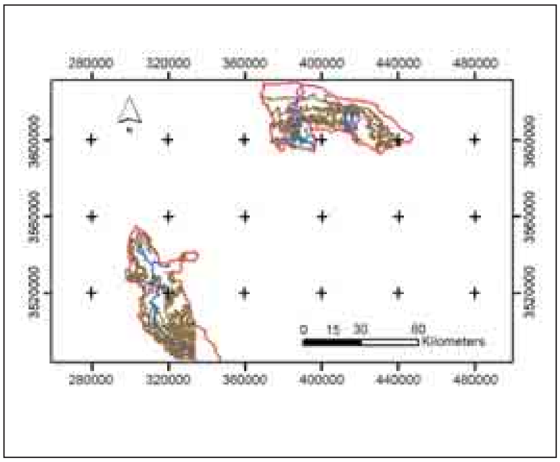

Figure 2.11 Contour lines and drainage systems for the western area (watersheds 83 and 416)

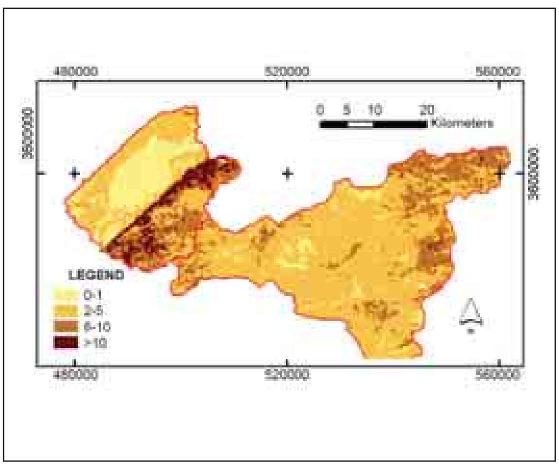

Figure 2.12 Slope grids for the eastern area (watersheds 17 and 37)

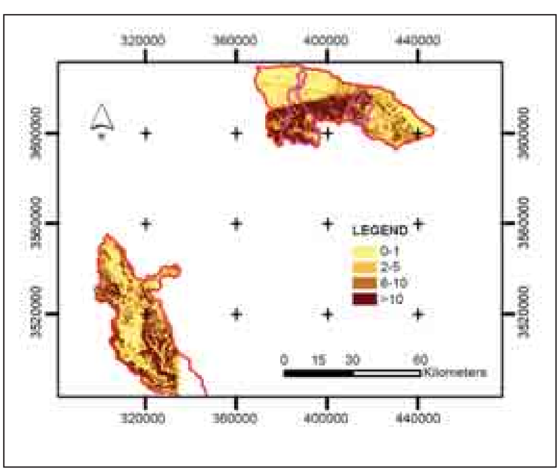

Figure 2.13 Slope grids for the western area (watersheds 83 and 416)

2.2.4. Water resources and rainwater harvesting structures

These include any structure that is implemented to store water or conserve soil and water. Some data about the locations and characteristics of these structures were available from various sources. These were compiled and converted to electronic (digital) form as GIS layers. The team recognized that many structures were not recorded and these would be important for the project. Therefore, field surveys for the eastern and western regions were planned and executed. Many structures were visited and their location (using GPS) and their characteristics were recorded in the field. These were then converted to electronic format (as GIS layers) that could be overlaid and used with other layers of information. Special processing was undertaken to read the Arabic terms in these shape files within the ArcGIS software using OpenOffice V3.1 software.

The dominant structures for the eastern area were different from those in the western area. For the eastern area, the following structures and characteristics of each structure were recorded (Figure 2.14):

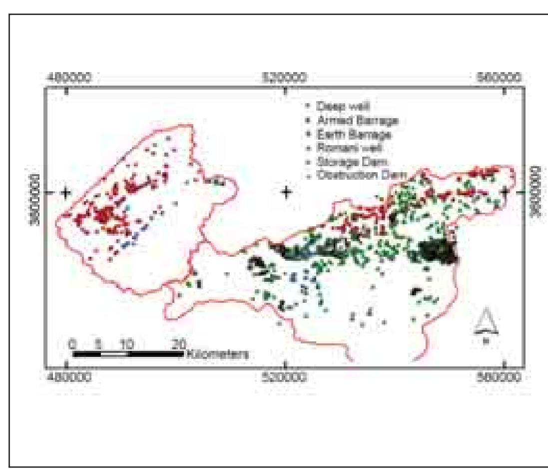

Figure 2.14 Water resources (structures) in the eastern area (watersheds 17 and 37)

Structure	Number	Characteristics
Deep wells	583	Place, location, depth, productivity, salinity, soluble salts, present situation, name of user, type of use
Check dams (loose and gabion)	1258	Place, location, volume, area, present situation, types of use, name of user
Roman wells (cisterns)	758	Place, location, volume, area, present situation, type of use
Earth fill dams	13	Place, location and locality, volume, area, precipitation, present situation
Concrete reservoirs (cisterns)	15	Place, location, present situation, number of consecutive dams, length

For the western area, the following structures and characteristics of each structure were recorded (Figure 2.15):

- Cisterns
- Contour ridges
- Deep wells (location and depth)

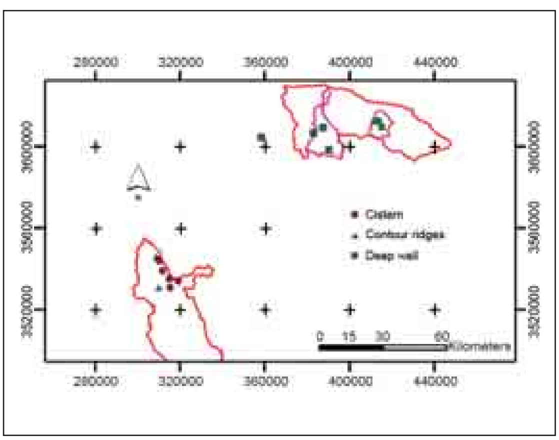

Figure 2.15 Water resources (structures) in the western area (watersheds 83 and 416)

2.2.5 Soils

The soil data were derived from a Russian study that was conducted in 1984. The scale of the map is 1: 50,000 and the soil mapping units recorded many soil characteristics. The most important characteristics for this project were:

- Soil depth
- Soil salinity
- Soil pH
- Calcium carbonates
- Soil texture

These characteristics were extracted for each soil mapping unit. Examples of soil depth maps are shown for the eastern area and western area (Figures 2.16 and 2.17).

The southern part of watershed no. 83 (Ghadama) in the western area was not covered by the soil map (scale 1:50,000).

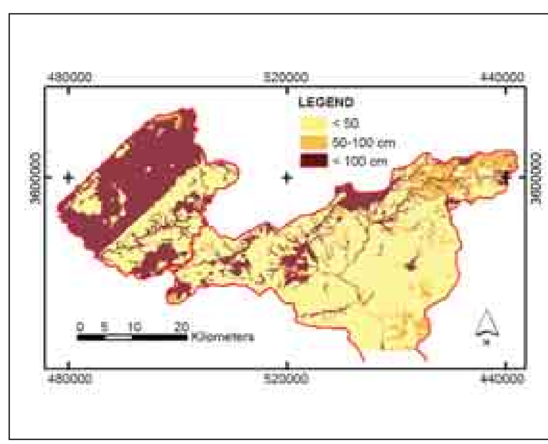

Figure 2.16 Soil depth map for the eastern area (watersheds 17 and 37) extracted from a 1:50,000 soil map

Therefore, a field survey was designed and executed to collect field observations. The survey was based on the FAO procedure. The area was divided into a 500 m by 500 m squared grid (Ziadat et al., 2006). Sixty three soil samples were collected from representative grid cells using soil augers. The samples were analyzed in the ARC soil laboratory. The following soil characteristics were recorded:

- Soil depth
- Soil salinity
- Soil pH
- Calcium carbonates
- GPS coordinates
- Soil texture

These data were used to interpolate soil characteristics and these were attached to the soil map of the watershed (Figure 2.17).

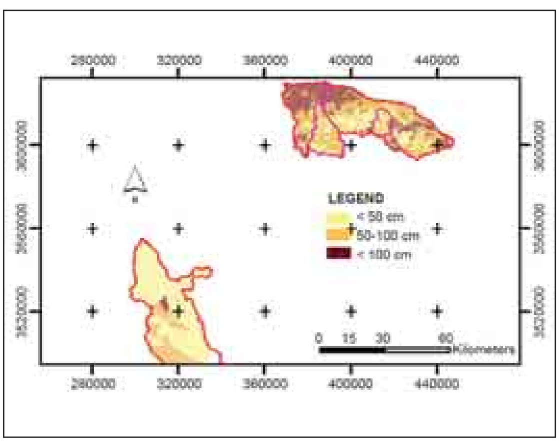

Figure 2.17 Soil depth map for the western area (watersheds 83 and 416) extracted from a 1:50,000 soil map

2.3 Suitability maps

The details of the land suitability mapping are provided in a separate report. The brief here explains the analyses and the outputs to facilitate an understanding of the role of these maps in watershed characterization and the selection of suitable sites for RWH and supplemental irrigation.

The methodology is an adaptation of the Syrian method to the datasets available in Libya and to local conditions. There are two major differences:

- The soil data are digital versions of the Russian paper maps. These are excellent maps
- The Syrian methodology applies fuzzy suitability scores for precipitation and slopes.

For the slopes there is no change (except for a regrouping of the micro-harvesting systems).

For precipitation, the scoring of suitability is NOT based on the mean annual precipitation, as in Syria, but on the 80% minimum annual precipitation. This is the annual precipitation that can be expected to be exceeded in at least 4 years out of 5. This has two advantages:

- A safety factor to account for high precipitation variability in Libya is considered;
- The area where rainwater harvesting can be useful is more realistically approximated.

The 80% minimum probability annual precipitation is derived from the mean annual precipitation using a regression equation between the two from the data of 12 stations in Libya (Figure 2.18).

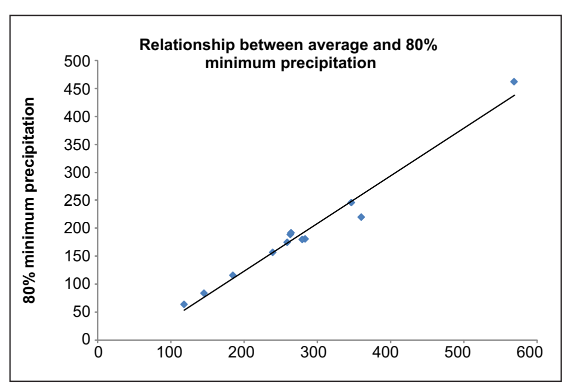

Figure 2.18 Relationship between mean annual and 80% minimum annual precipitation

Prec80%min = 0.8524 mm * Precmean = 46.536 mm

Factor scoring: scores for suitability can have a value between 0 (minimum) and 100 (maximum).

80% minimum annual precipitation: linear interpolation between cardinal points as follows:
A: 0 mm (score 0)
B: 150 mm (score 100)
C: 250 mm (score 100)
D: 500 mm (score 0)

For all RWH systems the same scoring system for precipitation applies.

For Slopes: linear interpolation between cardinal points. The cardinal points are different between the RWH systems considered.
System 1: small pits, runoff strips, small runoff basins, semi-circular bunds
A: 0% slope (score 0)
B: 2% slope (score 100)
C: 10% slope (score 100)
D: 15% slope (score 0)

System 2: contour ridges
A: 1% slope (score 0)
B: 5% slope (score 100)
C: 15% slope (score 100)
D: 30% slope (score 0)

System 3: contour bench terraces
A: 10% slope (score 0)
B: 20% slope (score 100)
C: 50% slope (score 100)
D: 100% slope (score 0)

Combination of scores for precipitation and slopes per RWH system:

Combined score = minimum $(Score_{precipitation}, Score_{slope})$

(Figure 2.19) shows that the suitability for RWH system 1 (small pits, runoff strips, small runoff basins, semi-circular bunds) is much

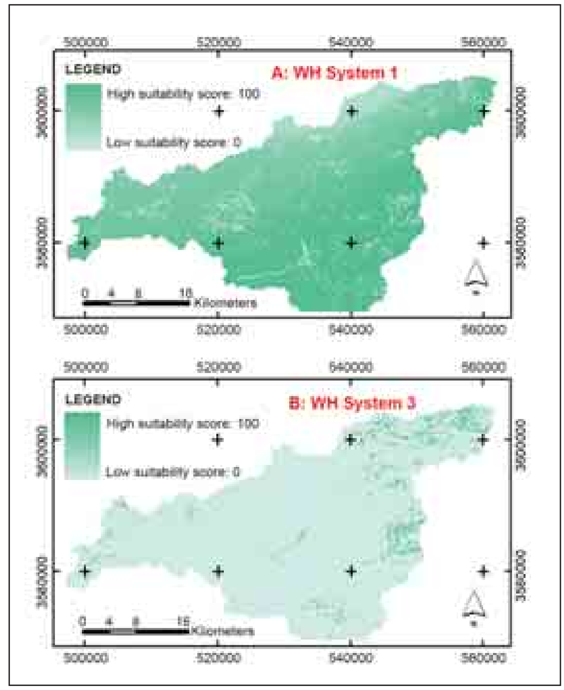

Figure 2.19 Suitability scores for A: RWH system 1 (small pits, runoff strips, small runoff basins, semi-circular bunds) and B: RWH system 3 (contour bench terraces) within watershed 37 (Samalous) in the eastern area

higher than the suitability for RWH system 3 (contour bench terraces) within watershed 37 (Samalous) in the eastern area.

2.3.1 Soil constraints

- A re-interpretation of the digital version of the Russian soil maps
- Soil constraints are shown with 3 different patterns overlaid on the maps with potential for RWH systems under 3 general categories (Figure 2.20)
  - Category 1: good agricultural soils
  - Category 2: soils with moderate limitations
  - Category 3: soils with severe limitations
- The nature of the soil constraints is shown in more detailed classes in the maps ‘Soil constraints’ for each watershed.

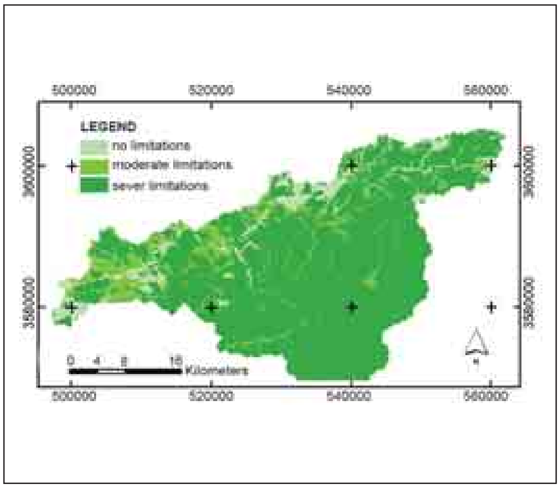

Figure 2.20 Major soil constraints for RWH for watershed 37 (Samalous)

2.3.2 Land use constraints

- The new land use overlay separates the following classes: bare land, forests, irrigated crops, rainfed crops, rangelands, sabkha, and urbanized land
- The following land uses can be considered as severely constraining for micro-catchment systems: bare land, forests, and sabkha and are mapped as a separate overlay of 'land use constraint' with each type of constraint indicated by a letter symbol
- The 'urbanized land' class is merged with the existing urban layer.

These layers were overlaid together and used with other layers to produce map layouts for field navigation and during the selection of suitable sites for RWH and supplemental irrigation. An example of these overlays is shown in (Figure 2.21). The following overlays were derived:

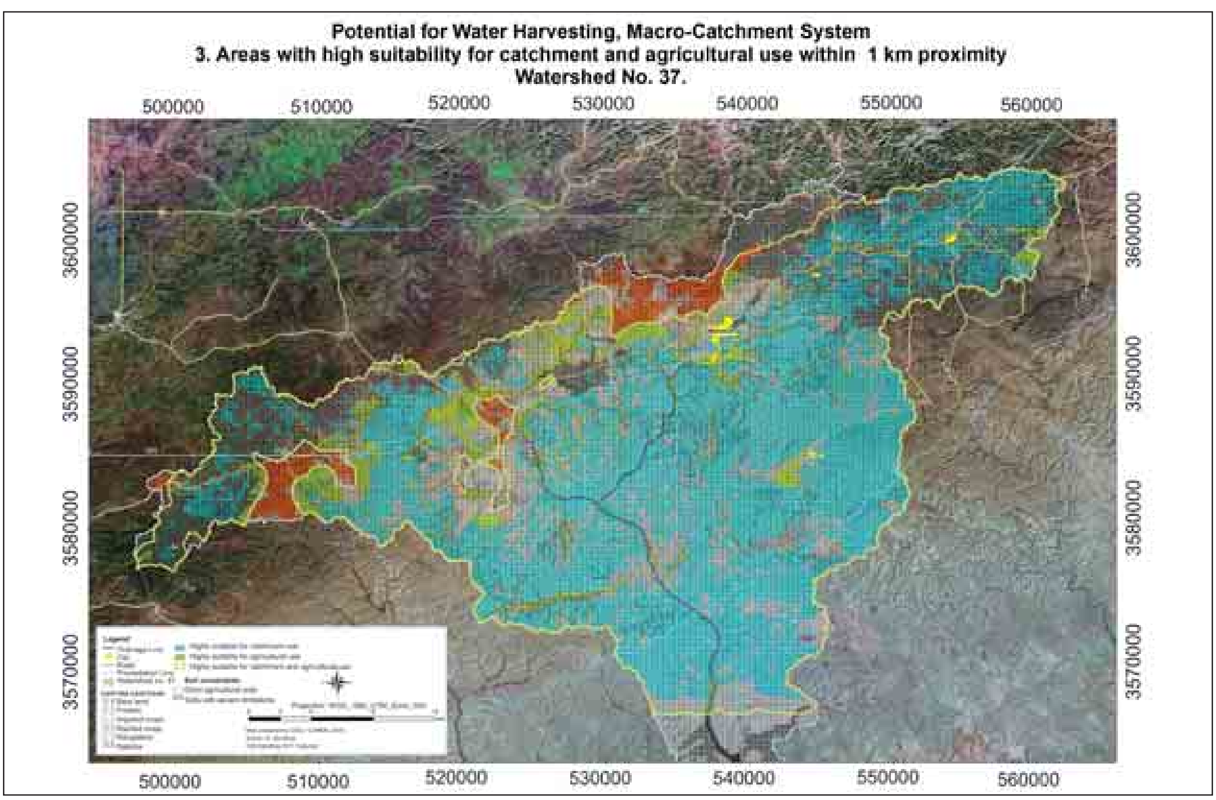

Figure 2.21 Overlays of suitability map, soil constraints, and land use constraints for watershed 37 (Samalous)

1. Overview map: four watersheds (17, 37, 83 and 416) delineated on top of Landsat imagery mosaic
2. Maps for each watershed:

   a. One map for orientation: satellite image, roads, settlements, mean annual precipitation isohyets, watershed boundary

   b. Three maps for potential for RWH: suitability scores with overlay of general soil constraints (three classes) for three micro-catchment RWH systems (groups)
      i. System 1: small pits, runoff strips, small runoff basins, small bunds, semi-circular bunds
      ii. System 2: contour ridges
      iii. System 3: contour bench terraces

   c. One map showing the soil constraints in more detail

2.4. Hydrological assessment

Hydrologic response varies within a watershed as a function of topography, soil, land cover, and climatic conditions. Spatial and temporal data from experimental watersheds may provide information on where, when, how, and why the response varies. A soil water assessment tool (SWAT) has been used for hydrological analysis in four watersheds in Libya (Arnold et al., 1998). A runoff coefficient for sub-watersheds at hydrologic response units (HRUs) and at the outlet of sub-watersheds within the selected watersheds has been simulated. In this report, the purpose of the hydrological analysis, the justification for using SWAT, an overview of the SWAT model, and the hydrological outputs of the simulation are presented.

Variations in spatial and temporal efficiencies of watershed-scale rainfall-to-runoff conversion have led to stream flow generation concepts, such as variable-source-area (Hewlett, 1961) and partial-source-area (Dunne and Black, 1970). Modeling is one among many assessment tools used in watershed planning and management. The model has three main purposes, which should help to:

- Understand when and how modeling can contribute to watershed assessment
- Learn approaches and tools that are useful for watershed modeling
- Understand the considerations in choosing models for watershed assessments.

The SWAT is one of the most widely used watershed-scale water quality models in the world. Nearly 600 peer-reviewed SWAT-related journal articles have been published and hundreds more have been published in conference proceedings and other formats. The SWAT model has proven to be a very flexible tool for investigating a range of hydrologic and water quality problems at different watershed scales, as well as being very adaptable for applications requiring improved hydrologic and other enhanced simulation needs. The use of the SWAT has expanded dramatically, not only in North America and Europe, but also in Africa, Southeast Asia, and countries such as China, India, and Iran. Several important trends have also emerged regarding improved hydrologic, best management practice (BMP), and pollutant transport methods. Therefore, modeling can answer such questions as:

- What BMP is likely to be the most effective or most cost-effective in controlling runoff and sediment loads?
- Would resource management measures, like flow controls (dams, reservoirs, etc.), be effective?
- What combinations of management/conservation practice options are likely to be most effective?
- What hydrological parameters are most important for identifying appropriate RWH techniques?

Table 2.1 Selected watershed sites and the hydrological outputs of SWAT model

Watershed site no	Water-shed area (km²)	Numberof sub basins	Average precipitation (mm)	Average surface Q (mm)	Average runoff co-efficient	Maximum runoff co-efficient
37	896	23	286	24.3	0.08	0.12
83	986	29	269	4.6	0.02	0.15
416 Ghaneamah	87	41	363	40.9	0.11	0.23
416 Turghut	239	42	374	35.5	0.09	0.14

2.4.1. Study area

Four watersheds in the eastern and western parts of Libya were selected for model simulation (Figures 2.1 and 2.2). The watershed sizes varied from 87 km^2 to 986 km^2 (Table 2.1). The average annual precipitation is less than 400 mm. The watershed benchmarks were selected in Al-Jabal Al-Gharbi and Al-Jabal Al-Akhdar with characterization and baseline information. The future study of the watersheds will involve designing and starting the execution of RWH structures. The irrigation research also will involve establishing supplemental irrigation trials to optimize and transfer the technique and assess fully irrigated agricultural systems in the targeted areas.

2.4.2. Watershed modeling with SWAT

Intensive work on the GIS data format was done to organize the data from different sources into one format and to run the model. The model was successfully setup and a simulation was run for the watersheds. Five major steps need to be conducted for model simulation.

- Watershed delineation. This consists of five sections, DEM setup, stream delineation, outlet and inlet definition, and watershed outlet(s) selection and definition. This tool is used to create watershed boundary delineation by a combination of DEM, digitized network, and other user inputs.
  - LULC map as a grid or shape file
  - Soil data
  - Weather data – by inserting the location coordinates of the nearest weather stations (11 weather stations were used for model simulation).
- Creating hydrologic response units (HRUs)
- The output if the model is given the amount of rainfall and surface runoff (Q)
- Run the model individually for each watershed (37, 17, 83 and 416)
- Relate the amount of runoff at each HRU to the average amount of rainfall to estimate the runoff coefficient and runoff volume for each sub-watershed within the selected watersheds (Figure 2.22).

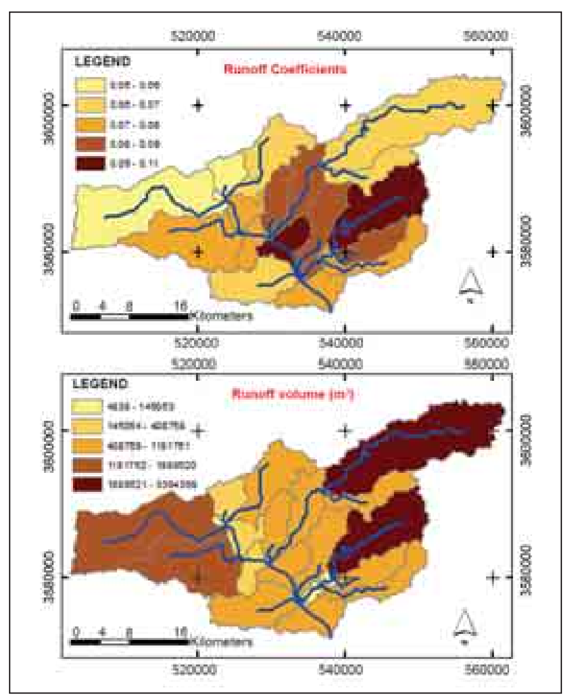

Figure 2.22 Predicted runoff coefficient and runoff volume for sub-watersheds within watershed 37 (Samalous)

(Figures 2.23 and 2.24) illustrate the overlays of the GIS layers (DEM, soil data, land use, and sub basins) during watershed delineation. Sub basin 1 represents the high elevation area while the last sub basin number (for example sub basin 33 in watershed 37) represents the outlet of the watershed. (Table 2.2)shows the weather stations used to run the simulation model.

(Figure 2.25) shows the model outputs for 11 years (2000 to 2010). Average rainfall and runoff coefficient were plotted for each watershed and the graphs show which sub basin has a high runoff coefficient. The red dots in each graph indicate those sub basins where RWH and supplemental irrigation techniques should be implemented.

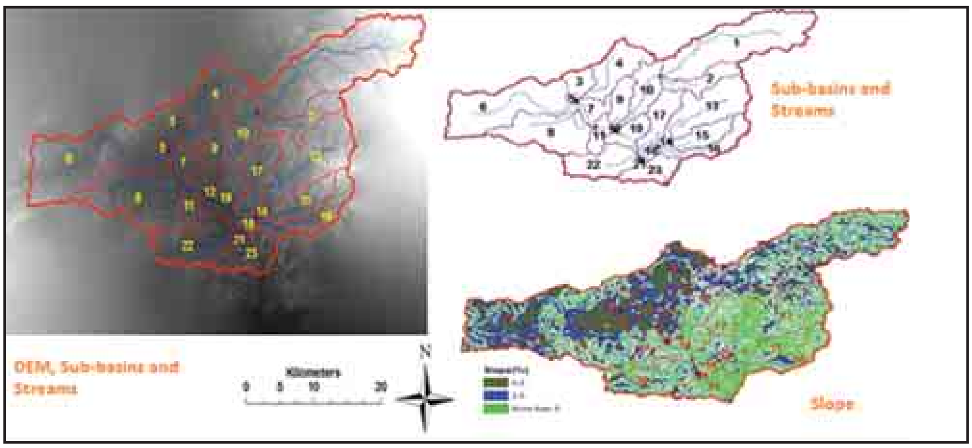

Figure 2.23. GIS layers (DEM, slope, sub basins) for watershed 37

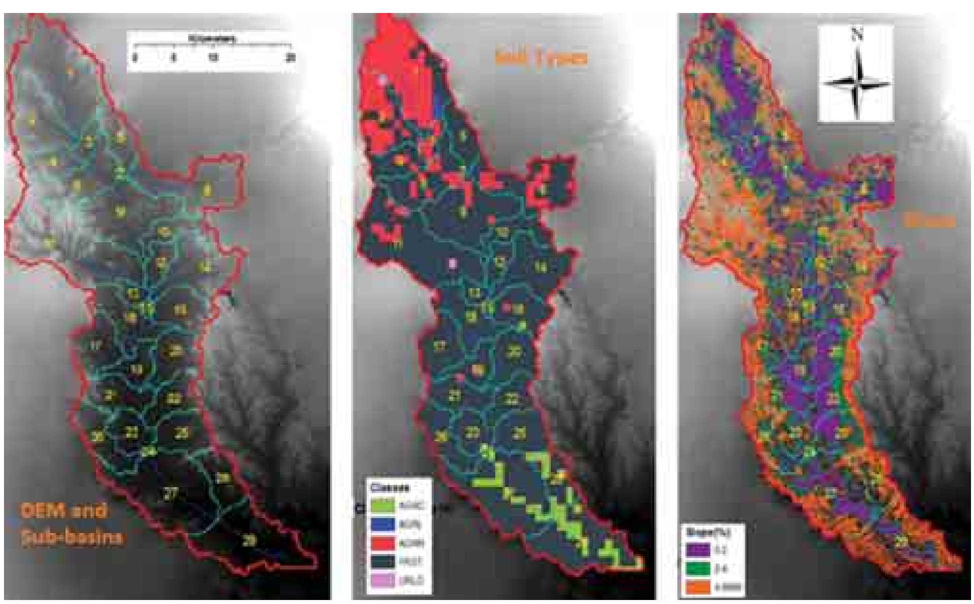

Figure 2.24. GIS layers (DEM, slope, sub basins and soil) for watershed 83

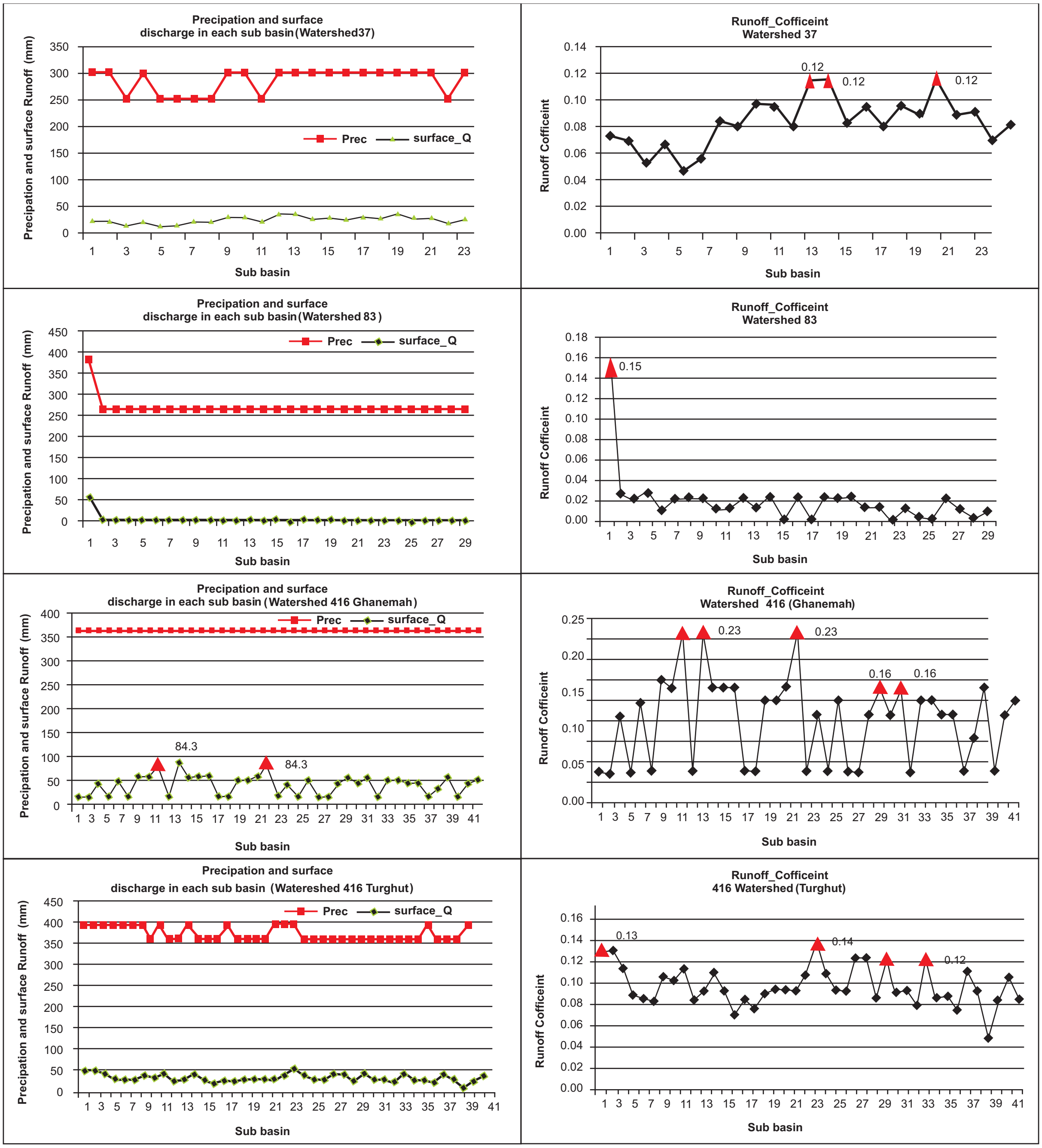

Figure 2.25. Precipitation, surface discharge, and runoff coefficient in each sub basin for the four watersheds (red triangles indicate sub basins with a high runoff coefficient)

Table 2.2. Rain gauge stations that were used for modeling with the SWAT

ID	Name	Longitude (° east)	Latitude (° north)	Elevation (m)
1	Tegrna	12.99	32.1	786
2	Mizdah	12.99	31.84	711
3	Yafrin	12.53	32.06	657
4	Garian	13.02	32.17	705
5	Abuzian	12.98	32.1	818
6	Al Aasaba	12.85	32.04	827
7	Omaljersan	12.56	32.03	715
8	Al Khums	14.23	32.66	54
9	Al Gharabouli	13.68	32.74	41
10	Wadikafam	14.45	32.52	4
11	Ghanema	13.95	32.7	75
12	Ghaddamah	13.02	31.94	713
13	Al Marj	20.87	32.51	283
14	Al Faidyah	21.91	32.69	762
15	Saltanah	21.71	32.59	754
16	Ghandula	21.57	32.54	622
17	Taknes	21.13	32.48	432
18	Gerdas Al Ahrar	20.99	32.3	632
19	Al Mkele	22.29	32.16	194
20	Al Shahat	21.86	32.8	633
21	Fataiah	22.68	32.7	251

(Table 2.3) shows the SWAT parameters that resulted during each run. Two important components of the output – hydrology and nutrients – are illustrated in the table. Hydrology parameters, such as rainfall, surface runoff, recharge, ground water, percolation, snowmelt, lateral soil discharge, and evaporation, can be estimated by the model. The nutrient parameters, such as sediment, phosphorus, nitrogen, etc., also are taken into consideration for each HRU. Other management practices, such as tillage, fertilization, buffer, constructing dams or reservoirs, etc., are parameters that can be used to evaluate different management scenarios.

The analyses indicated that less than 10% of a watershed directly participates in storm flow generation. Even in hydrologically active areas, rainfall-to-runoff conversion rates vary with the type of runoff generation processes – infiltration excess or saturation excess. Results of the model simulation indicated the runoff coefficient at the sub-catchment level varied from 0 to 0.23. Areas with high runoff coefficients should be targeted with appropriate RWH techniques to reduce runoff and erosion at the field level – the HRU. Large hydrological structures, such as dams, can be more effective practices at the sub-catchment level, especially for a stream network where high runoff is expected.

Table 2.3. Example of SWAT outputs and the hydrology and nutrient parameters that the SWAT considers for simulation

SWAT April '6 VER 2 010/Rev. 433	
General Input/output section (file.cio):	
5/31/2010 0:00 M ARCGIS-SWAT interface AV	General input/output section (file.cio):
AVE ANNUAL BASIN N VALUES	AVE ANNUAL BASIN VALUES
HYDROLOGY OUTPUTS	NUTRIENTS outputs
PRECIP = 282.7 mm	ORGANIC N = 6.613 kg/ha
SNOW FALL = 0.00 mm	ORGANIC P = 0.828 kg/ha
SNOW MELT = 0.00 mm	NO3 YIELD (SQ) = 0.015 kg/ha
SUBLIMATION = 0.00 mm	NO3 YIELD (SSQ) = 0.010 kg/ha
SURFACE RUNOFF Q = 24.22 mm	SOL P YIELD = 0.008 kg/ha
LATERAL SOIL Q = 3.02 mm	NO3 LEACHED = 0.437 kg/ha
TILE Q = 0.00 mm	P LEACHED = 0.151 kg/ha
GROUNDWATER (SHAL AQ) Q = 4.8 8 mm	N UPTAKE = 34.439 kg/ha
REVAP (SHAL AQ => SOIL/PLANTS) = 0.66 mm	P UPTAKE = 5.908 kg/ha
DEEP AQ RECHARGE = 0.29 mm	NO3 YIELD (GWQ) = 0.239 kg/ha
TOTAL AQ RECHARGE = 5.83 mm	ACTIVE TO SOLUTION P FLOW = -1.46 5 kg/ha
TOTAL WATER YLD = 31.90 mm	ACTIVE TO STABLE P FLOW = -0.115 kg/ha
PERCOLATION OUT OF SOIL = 5.88 mm	N FERTILIZER APPLIED = 29. 375 kg/ha
ET = 23 1.9 mm	P FERTILIZER APPLIED = 0. 000 kg/ha
PET = 11 41.8mm	N FIXATION = 0.000 kg/ha
TRANSMISSION LOSSES = 0.21 mm	DENITRIFICATION = 0.000 kg/ha
TOTAL SEDIMENT LOADING = 15.43 9 t/ha	HUMUS MIN ON ACTIVE ORG N = 8.85 5 kg/ha
POND BUDGET	ACTIVE TO STABLE ORG N = -3.413 kg/ha
EVAPORATION = 0.000 mm	HUMUS MIN ON ACTIVE ORG P = 1.521 kg/ha
SEEPAGE = 0.000 mm	MIN FROM FRESH ORG N = 13. 649 kg/ha
RAINFALL ON POOL = 0.000 mm	MIN FROM FRESH ORG P = 2. 469 kg/ha
INFLOW	NO3 IN RAINFALL = ******** kg/ha
WATER = 0.000 mm	INITIAL NO3 IN SOIL = 5 1.212 kg/ha

2.5. Socioeconomic characterization

The distribution and names of large and small communities within the selected watersheds was derived and compiled from various sources. Among these were the available Landsat images (30m resolution), Google Earth images (whenever of good quality), the GPS coordinates of some cities and towns, and LULC maps (urban class for large cities and towns). These layers where overlaid and a team, who knew the area very well, gathered to verify the locations and names of these communities and generate a single layer that included all communities within the selected watersheds (Figures 2.26 and 2.27). This layer of information is crucial to the project because all activities and intervention will be implemented with the communities. Therefore the presence of the communities is very important.

Since the project is seeking cooperation from the community, the socioeconomic team designed and executed a detailed survey of the existing communities within the selected watersheds. The detailed results of this survey are documented in a separate report. However, the results of this survey, which is related to this characterization, were summarized and attached to the location of each community.

Figure 2.26. Distribution of communities and the road network for the eastern area (watersheds 17 and 37)

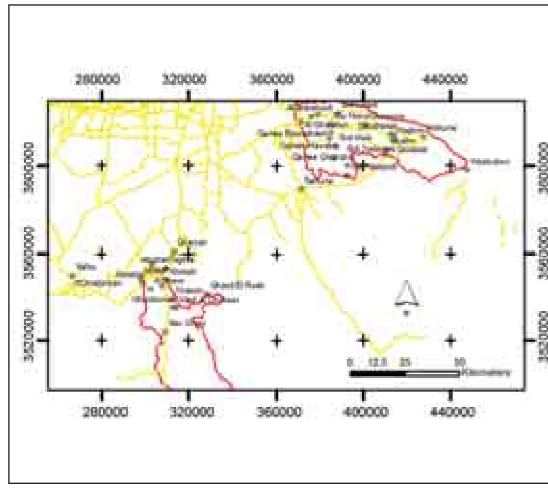

Figure 2.27. Distribution of communities and the road network for the western area (watersheds 83 and 416)

Hence, users can explore the locations of the communities with respect to other biophysical features and, at the same time, get information about the community characterization that is relevant to the activity under question (Figure 2.28). This will be discussed in a following section. The following characteristics of the community were attached to the geographic location:

- Number of inhabitants (population)
- Proposed area for implementation around the community (based on preliminary assessment)
- Land tenure regime
- Willingness of the community to cooperate with the project
- Main crops and livestock system.

2.6. Data integration and utilization

The collection and organization of the layers and information detailed in the previous sections formed a very comprehensive database for the selected watersheds. This

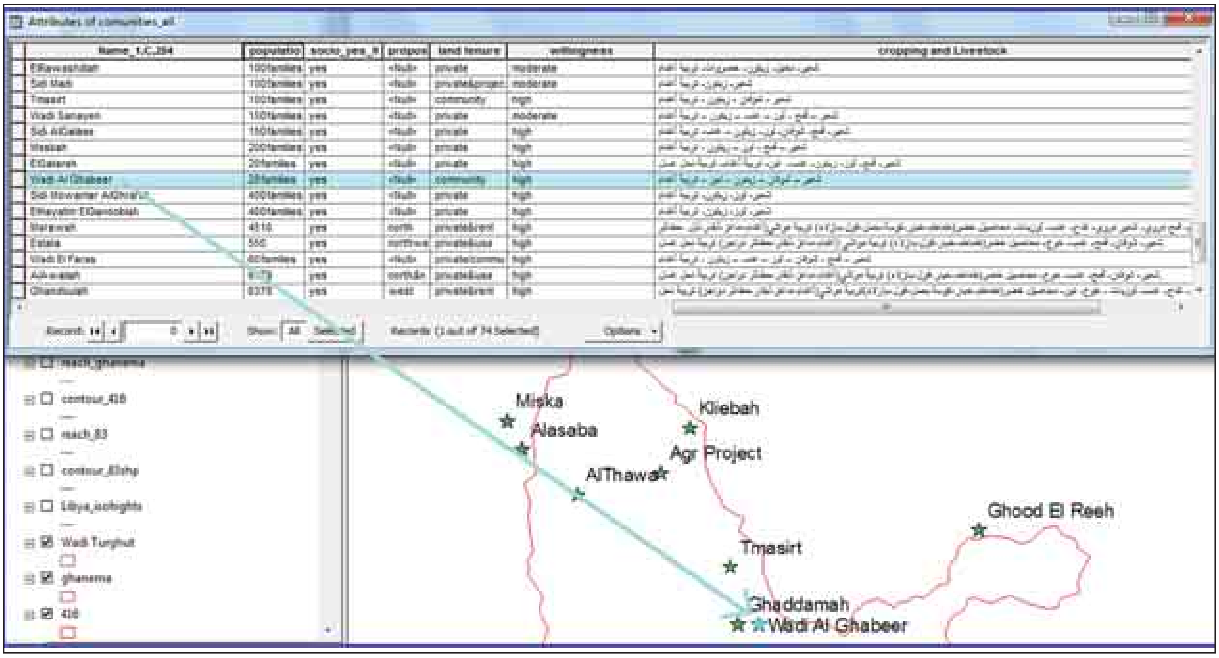

Figure 2.28. Example of the link between the geographic location of the community and the socioeconomic characterization of that community (Wadi Al Ghabeer)

database is useful for any future activities to develop the area and sustain agricultural productivity. As mentioned previously, the purpose of watershed characterization is to build a rigorous biophysical database which can be used by interested scientists and serve for the selection of suitable sites for RWH and other practices of integrated research sites. The collected layers and information were integrated and analyzed by a multi-disciplinary team of experts to identify potential sites for implementation.

The team discussed and suggested criteria to identify potential sites. These integrated many biophysical as well as socioeconomic aspects. The criteria for selecting sites for RWH were different from those used to select potential sites for supplemental irrigation.

For rainwater harvesting interventions, the following criteria were considered:

- Land should be suitable for the RWH system(s) and the soil should have minimum constraints to its use. However, land suitability analyses considered only rainfall and slope from a 90 m resolution DEM. Soil depth is an important criterion for RWH systems. This criterion was considered separately by overlaying the soil depth map (derived from the 1:50,000 soil map) with the suitability map and the soil constraints map. Also a slope map, derived from detailed topographic maps, was overlaid to get a better idea about slope classes in this area. (Figures 2.29-2.30, and 2.31) show how these layers were overlaid to explore areas that satisfy these criteria collectively
- The sites should be close enough to the community because the project will adopt a participatory approach in selecting, implementing, and monitoring the RWH system. The layer that shows the distribution of communities and their attributes, determined during the socioeconomic characterization, were overlaid with the other layers to explore this criterion (Figure 2.32). The experience of the national team in this regard was indispensible

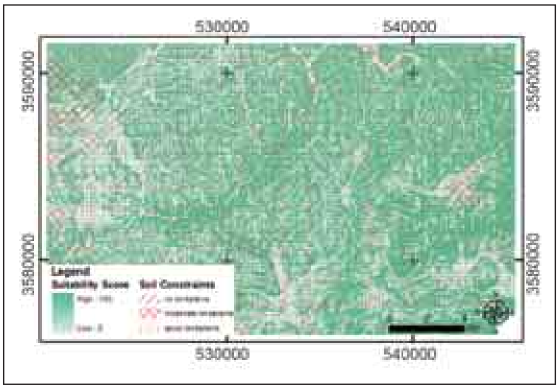

Figure 2.29. Suitability score for the RWH system overlaid with soil constraints for part of watershed 37 (Samalous)

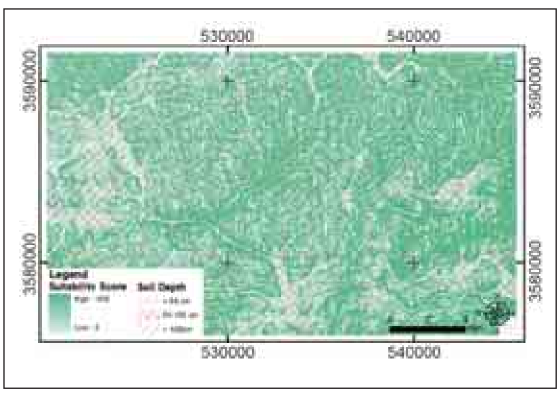

Figure 2.30. Suitability score for the RWH system overlaid with soil depth for part of watershed 37 (Samalous)

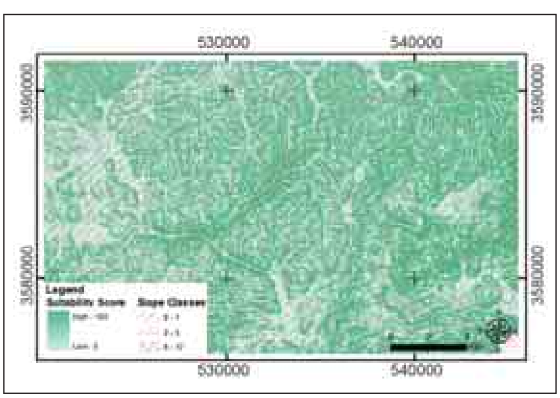

Figure 2.31. Suitability score for the RWH system overlaid with slope derived from a 1:50,000 topography map for part of watershed 37 (Samalous)

- Preferably, the site would be close to a research station. This would facilitate access to the research and the site will be used for demonstration purposes by the research station. Also, the availability of data would be an additional benefit
- The site should also be close to a farming community, preferably with livestock, existing in the vicinity. This will present the typical conditions where RWH is necessary and sustainable
- Accessibility to the site was considered as an important criterion. This was explored by overlaying the road network and by also referring to the local experts. For example, (Figure 2.32) shows that there are vast areas suitable for RWH in the southern part of watershed 37 (Samalous). However, in that part, the road network is very limited and, therefore, accessibility is a problem. Also, there are very few communities in that part, which is an important requirement for the project implementation. Therefore, biophysical suitability is not the only criteria that determined the final suitability; other factors were taken into considerations in the identification of the final potential sites.

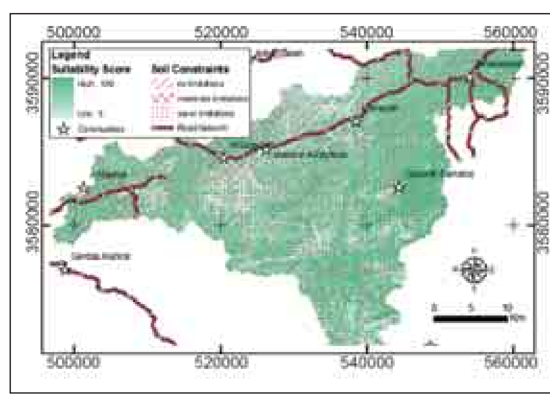

Figure 2.32. Proximity of potential sites to communities (location and characteristics) and accessibility of the site to the main road network

For supplemental irrigation, the following criteria were considered:

- The most important criterion is the availability of sufficient water for irrigation, mainly from runoff, that is to be harvested and stored in dams for later use. This criterion was explored using the layer that shows the predicted runoff coefficient and runoff volume for each sub-watershed within the selected watersheds. This provided an idea of the expected amounts of runoff to be harvested at the outlets of these sub-watersheds. In some cases the runoff was too small to ensure that a sufficient amount of water could be harvested and in other cases, the cumulative amount of runoff for successive sub-watersheds indicated very large amounts of water that would need a very large structure. This latter is beyond the scope of this project. However, in each watershed there were a number of possible sites with reasonable runoff volumes. Supplemental irrigation, however, can be practiced using groundwater resources which will be addressed in another document. The conjunctive use of harvested and groundwater resources is another option
- The other important criterion is the availability of suitable land in the vicinity of the proposed dam or water collection structure where the harvested water can be used. The availability of suitable land at an elevation below that of the proposed dam would be an advantage to save pumping energy. The layer which shows the runoff volume was overlaid with the LULC map to identify areas where both criteria are satisfied
- In addition to these two criteria, the presence of a community close to the proposed site is necessary to ensure full involvement of the farmers in the project activities. Furthermore, the willingness of the community to participate in a supplemental irrigation program is another important criterion. This was partially judged from the results of the socioeconomic characterization obtained by superimposing the layer that shows the distribution and characteristics of the community. However, this issue needs some thorough discussion with the targeted community before a decision is taken regarding implementation of the dam to insure its viability, utilization, and sustainability
- Three masks of information were overlaid and examined – runoff amount from each sub-watershed, LULC maps, and the distribution of communities. (Figure 2.33) shows that, although many sub-watersheds might generate reasonable amounts of runoff at their outlets, only two of these are potential sites for supplemental irrigation. This is because only those two sites (indicated by the arrows) satisfy the above criteria; the outlets of these sub-watersheds indicate reasonable amounts of predicted annual runoff, they are close to a collaborative community, and are surrounded by irrigated and rainfed lands, where harvested water could be distributed by gravity.

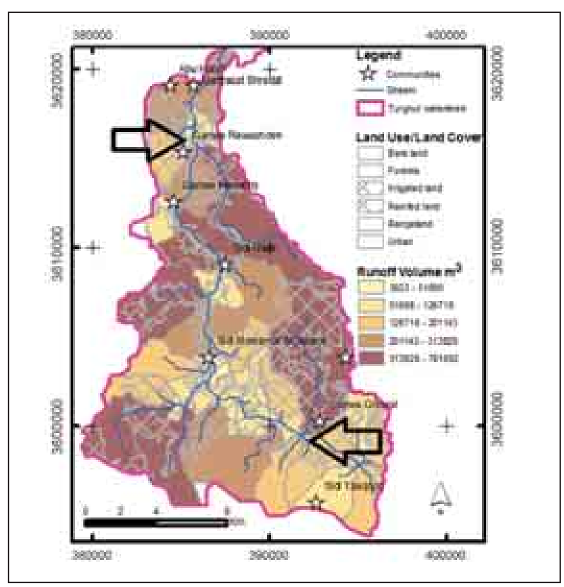

Figure 2.33. Potential sites for supplemental irrigation; an overlay of runoff volume for sub-watersheds, rainfed and irrigated lands, and distribution of communities for the Turghut watershed

Having these criteria in mind, the team explored the available data for each watershed and started to identify potential sites for various activities. They used the full capacity of GIS to zoom in and out, superimpose many layers at the same time, explore geographic features together with their attributes, and many other functions.

The identification ranges between two extremes. At the watershed level, certain RWH and/or supplemental irrigation interventions were suggested for implementation within the whole watershed. At a more specific level (field level), the possible location(s) for specific intervention were suggested and identified.

At the watershed level, the following inventory of interventions was suggested: The implementation of these interventions requires a minimum stoniness of the surface land. In addition to these, two other interventions were suggested, wherever their implementation was possible. The first was soil moisture conservation measures and the second was cisterns or hafeir for livestock or drinking water.

Watershed No. 416 (Nagazah)
In this watershed the potential for a micro-catchment RWH system is very low given the soil and land use characteristics. However, there is more potential for macro-catchment RWH systems, such as small dams for supplemental irrigation or any other similar structure and for bench terraces in steep and deep soils.

Watersheds No. 37 (Samalous) and 83 (Ghadama)

Fruit trees*	Crops**	Range**
Semicircular bunds	Small dams for supplemental irrigation	Valerrani (slope 2%)
Terraces	Water spreading	Contour ridges (slope 1%)
Tabia	Contour ridges	
Negarim (old and new)		

*Requires deep soils (greater than 100cm)
**Requires moderately deep soils (greater than 60cm)

Watershed No. 17 (Al Marj)
This watershed is dominated by cropping (both rainfed and irrigated). Therefore, there was little chance for RWH. The suggestion is to look at the existing runoff system and the structures used to reduce the velocity and amount of runoff, to explore their functionality, and to suggest improvements to the system or the need for replication. Also, other aspects could be explored to improve the water use in this watershed, such as water use (efficiency, scheduling, crops), conjunctive use with groundwater, and the link with the research station (Al Marj). In steep areas with some deep soils (as were identified on the map), bench terraces could be implemented.

At the field level, many locations were identified as potential sites for implementing one or more RWH or supplemental irrigation interventions. Examples of these sites are indicated by arrows in (Figure 2.34).

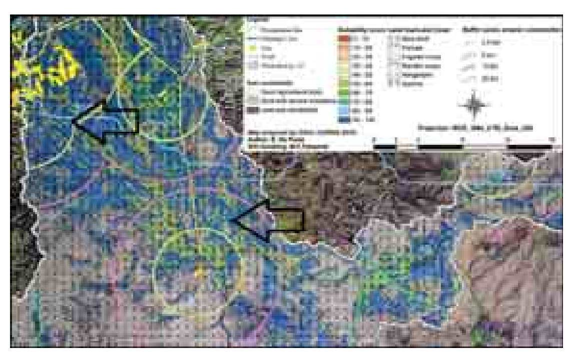

Figure 2.34. Potential sites for RWH implementation within watershed 83 (Ghadama)

2.6.1. Outcome and decision of interventions

The results of these analyses were forwarded to a team of experts who worked in the field to identify and design RWH interventions that would increase crop productivity and improve rangeland in the rainfed areas in Al-Jabal Al-Gharbi and Al-Jabal Al-Akhdar. Hardcopy maps, electronic maps, layouts derived specially for this purpose, GPS, Google Earth, and many other forms of information were used during the field mission. An example of these sites is shown in (Figure 2.35). According to the ground truthing work conducted by the team, the information provided seem to reflect the actual situation in most of the selected watersheds. A large number of suitable sites were identified in the eastern and western areas in which to apply different RWH techniques based on the watershed characterization data provided.

Figure 2.35. Sites identified for potential RWH implementation

The outcome of this (one month) field mission is detailed in a separate report (Prinz, 2010), which explains how the above analyses and watershed characterization exercise were used to find potential sites. The report provides, as well, recommendations for the location and design of various RWH and supplemental irrigation interventions. This report was used to carry out the implementation of these interventions.
The results of this extensive field survey were compared with those of the characterization activities and information to assess the whole process. Coordinates of the visited sites were used to overlay these sites on the suitability maps for various RWH systems (Figure 2.36). The suitability of each site, judged in the field by a team of experts, was compared with measures of suitability derived from the characterization process (Table 2.4). Given the scale of the available maps, these results indicated highly acceptable results and agreement between the suitability for RWH as derived from the characterization process and as judged in the field.

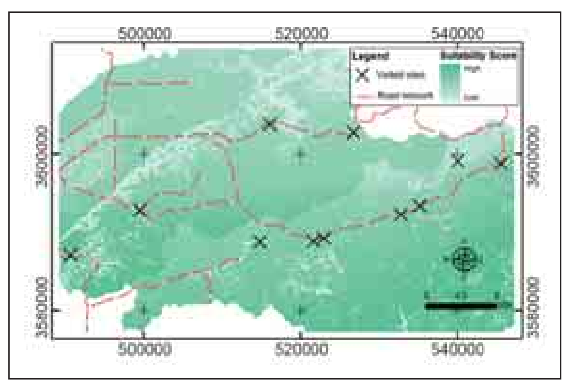

Figure 2.36. Visited sites (recommended for implementation of various RWH systems) and their suitability derived from the characterization process for Samalous and Al-Marj

Table 2.4. Suitability of visited sites as judged in the field compared with suitability derived from the characterization process.

Site	Easting	Northing	Suitability from the field			Suitability from the maps		
			System 1	System 2	System 3	System 1	System 2	System 3
1	522924	3589067	Yes	No	No	high	mod	low
2	545591	3598651	No	No	Yes	low	low	low
3	532832	3592135	Yes	Yes	No	high	high	low
4	514778	3588598	Yes	Yes	Yes	high	high	mod
5	540066	3598981	Yes	Yes	No	mod	mod	mod
6	535211	3593206	Yes	Yes	No	high	mod	low
7	521651	3588733	Yes	Yes	No	high	mod	low
8	490620	3586925	Yes	Yes	No	high	high	mod
9	499509	3592697	Yes	No	Yes	high	mod	low
10	526740	3602665	Yes	Yes	No	high	high	low
11	516058	3603675	Yes	Yes	No	high	high	low

System 1: small pits, runoff strips, small runoff basins, semi-circular bunds
System 2: contour ridges
System 3: contour bench terraces

2.7. Concluding remarks

- Data integrity is a prerequisite for the successful use of data to identify potential sites for RWH and supplemental irrigation. Two issues are important: the accuracy and reliability of individual layers of information and the compatibility of all layers of information together. This is especially true when layers are used individually, as they were, or when they are used to derive secondary layers, such as the suitability maps, hydrological analyses, and socioeconomic characterization. Any error could be easily propagated and lead to erroneous conclusions. To avoid this, ground truthing is needed to check the accuracy and relevance of the geographic and attributes information of each layer before its use in such an integrated exercise

- Although huge amounts of information were available in various formats, its full use to benefit this exercise was only realized when a multi-disciplinary team of scientists and field experts gathered to display and explore the information. Many ideas were discussed and used to explore the information and generate useful outputs. GIS and remote sensing played a crucial role in facilitating this exercise and lead to reasonable and timely outputs. The time needed to explore all the watersheds in the field and to come up with reasonable potential sites would have been enormous and might not have been achievable, given the sizes of the watersheds, without this information and functionality
- Caution should be exercised when visiting the field because there might be some cases where the results are not perfectly representative of the field. This is because some information is available only at low resolution or in small scale mapping. For example, the best available soil-mapping scale was 1:50,000. At this level, the soil depth could not be mapped with a high degree of accuracy. Therefore, large areas are mapped as one unit, but within that unit there might be high variability in soil depth. It is very costly and time consuming to produce a more detailed soil map.

Therefore, such data would be useful to guide the team to potential sites, but within that site further sampling and field investigation are needed to select the site. Another example is the outcome of the hydrological analyses. The analyses indicate the predicted amounts of annual runoff for each sub-watershed within the larger watershed. The information used to derive these estimates was not very detailed and, therefore, the predictions would not be enough to design a dam or spillway, which requires more detailed information. However, for selecting the potential site for a dam, these predictions are sufficient

- The results from the field indicated that integration of many biophysical elements (watershed characteristics, land suitability, and hydrological characteristics) with socioeconomic characterization (community distribution and characteristics, accessibility, and willingness to cooperate) is crucial to achieve reasonable results. Without this integration, many aspects are missing and the identified potential sites could be far from being suitable sites for implementation when visited in the field. This integration significantly reduces the time needed to identify potential sites in the field. Furthermore, the results are well documented for future use beyond the project lifetime
- Although most of the rainwater is being lost in runoff or evaporation and RWH can help to recover and use a good proportion of it, the agricultural development potential will still be limited and requires a great deal of investment and integration to realize.

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Appendices

Appendices Chapter 1

Appendix A. Criteria for selection of benchmark watersheds by disciplinary groups

Rainwater harvesting group

Biophysical criteria (1)

- Rain (long-term average data available):
  - Al-Jabal Al-Akhdar: 100-500 mm
  - Al-Jabal Al-Gharbi: 100-300 mm
  - Central: 100-150 mm

  Topography, slopes and relief (Digital Elevation Model available)
  - Al-Jabal Al-Akhdar: various relief, fissures, cracks: related to density of vegetative cover
  - Slopes: 2-10% maximum (including steep slope)
  - Al-Jabal Al-Gharbi: 5%
  - Central: topography not a major factor
- Soils (texture, depth, salinity) – soil maps + studies for production soils
  - Al-Jabal Al-Akhdar: calcareous, silty clay – clay, most limiting factors: salinity, CaCo3, shallowness, rocky, crusting = good
  - Al-Jabal Al-Gharbi: sandy loam dominant
  - Central: sandy
  - Biophysical criteria (2)
  - Vegetation cover > 200 mm 1:50,000 from remote sensing
  - Al-Jabal Al-Akhdar: erodibility (slope, organic matter , cover)
  - Al-Jabal Al-Gharbi:
  - Central:

  Agricultural production system
  - Al-Jabal Al-Akhdar: rangeland, rain-fed agriculture (cereals, fruit trees) [consider also importance of tillage]
  - Al-Jabal Al-Gharbi: same
  - Central: rangeland

  Existing rainwater-harvesting systems (dams, terraces etc)

  Hydrologic characteristics (daily rain, runoff)
  - most wadi studies available - Omar
- Research issues
  - 100-500 km^2 - work at different scales
  - Accessible
  - Visible
  - Safe research environment (equipment)
  - Cooperative communities
  - Good potential for success (impact)
  - Data available
  - Logistics
  - Communication
  - Land tenure system (use rights and property rights)

Socioeconomics group

The socioeconomic group agreed on the criteria to be used for benchmark sites selection from a socioeconomic perspective. These criteria included the following:

1. The site has to include the three activities of the project (water, livestock, crops)
2. There are local communities
3. The communities are accessible
4. The communities are willing to collaborate with the project
5. It is better that the site has more than one type of farming system
6. It is better that the site has more than one type of land tenure
7. Fully irrigated areas are to be avoided.

The discussion with the Libyan national team related to economic research focused on the socioeconomic criteria for sites selection. Other research issues included production systems of crops, livestock and water and their integration, agricultural policy and markets, rural institutions, gender roles, development of baseline data, data collection and analysis methods, availability of secondary data, and previous studies on the project areas.

The secondary data are generally available in Libya; many statistical abstracts are published by the relevant offices. There is also published data on the agricultural sector based on the census carried out in Libya in 2007. Previous socioeconomic studies available in the ARC in Tripoli included reports on the socioeconomic component of the Mashreq-Maghrib Project in Libya, a study on field crops, a study on livestock, a report on the economics of supplemental irrigation, and the role of women in agriculture. There are also many M.Sc. theses prepared by students and registered with the Agricultural Economic Departments in Omar El-Mukhtar and El-Fateh Universities.

Cereals group

Criteria	Score		
	0	5	10
Cereals dominance	No barley	Barley + other crops	Barley + forage/ range
Rainfall (mm)	< 150	> 250	150-250
Soil type	Too fine	Sandy loam	Sandy
Soil depth (mm)	< 30	30-50	> 50
Topography/slope	> 6%	3-6%	0-3%
Salinity	EC > 4	EC = 2-4	EC < 2
pH	>8.5	8-8.5	7-8
Al-Jabal Al-Akhdar			
Cereals dominance	No cereals	Cereals + forage/ range	Cereals +other crops
Rainfall (mm)	< 150	> 300	150-300
Soil type			
south	Sandy	Clay loam	Sandy loam
north	Sandy	Sandy loam	Clay loam
Soil depth (mm)	< 30	30-50	> 50
south	< 10	> 25	10-25
north	< 10	10-50	> 50
Topography/slope	> 6%	3-6%	0-3%
Salinity	EC > 4	EC = 2-4	EC < 2
pH	< 7.0	7-7.5	7.5-8.5
Commitment/acceptability by landowners/locals	None	Medium	High
Accessibility	Difficult	Medium	Easy

Small ruminants group

Criteria	Score		
	0 (low)	**5 (medium)**	**10 (high)**
Rainfall	50	50-150	> 150
Topography (slope)	> 20 %	10-20	> 10
Production systems (pastoral, agro-pastoral, intensive/rainfed vs. irrigated)	Irrigated	Pastoral	Agro-pastoral
Range condition (level of degradation, rangeland type)	Highly degraded	Not degraded	Medium degradation
Population density, settlements	Absence of settlements (flocks' owners living in cities)	Scattered settlements	Highly populated
Small ruminant density	Low density	Medium density	High density
Water points	Absence of water points	Few water points (distance between water points more than 20 km)	Sufficient water points (distance between water points less than 15 km)
Willingness of communities to cooperate	Community reluctant about the project	Community neutral vis-à-vis the project	Community enthusiast about the project
Proximity of research station	ARC experimental station far from the benchmark (more than 100 km)	ARC experimental station close to the benchmark (less than 50 km)	ARC experimental station within the benchmark
Accessibility and visibility	Rural track in bad conditions and far from cities	Easy access to benchmark and far from other communities (cities)	Easy access to benchmark close to other communities (cities)

Appendix B. inter-disciplinary team members

Name	Specialty
Aden Aw Hassan	Economist
Adnan Sbeita	Range
Adriana Bruggeman	Hydrologist
Ahmed Al Buaishe	GIS
Ahmed Zintani	Crops
Ali Nefzaui	Livestock production
Farouq Shomo	Economist
Fawzi Al Doumi	Soil science
Feras Ziadat	Land resource management
Hussein Talib	Water
Jum'ah Fhima	Agricultural economist
Mohamed Karrou	Agronomist
Nuri Mo'man	Soil physics
Saeed Al Sayeh	Soil
Salih Slabi	Soil and GIS
Saad Al Ghariani	Water
Sedeeq Mlatim	Range
Theib Oweis	Water and irrigation
Younes Awami	Ground/surface water

Appendices Chapter 2

Appendix A. Soil observations collected for Al-Ghadama watershed

Sample no.	Northing	Easting	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texture	$CaCO_3$ (%)	EC (dS/m)	pH	Stone (%)
100	31.67529	12.97033	0-30	16.6	14.1	69.2	Sandy loam	31.5	0.4	8.2	14.5
			30-60	22.	15.0	63.0	Sandy clay loam	36.9	1.7	7.9	17.2
			60-90	26.5	17.0	56.5	Sandy clay loam	36.9	4.8	7.9	
101	31.63416	12.98471	0-30	171	1.1	68.7	Sandy loam	45.3	0.3	8.4	28
			30-50	17.6	13.6	68.7	Sandy loam	49.0	0.2	8.3	24.9
102	31.72551	12.98547	0-30	12.1	30.1	57.7	Sandy loam	31.5	2.9	7.9	
			30-60	3.5	45.0	51.5	Sandy loam	31.5	5.3	7.5	
			60-90	10.1	26.6	3.2	Sandy loam	22.0	5.4	7.7	
103	31.77166	12.98166	0-20	14.6	21.6	63.7	Sandy loam	36.9	0.6	8.2	39
104	31.82233	12.98058	0-30	15.6	22.6	64.7	Sandy loam	37.9	1.6	9.2	40
			30-50	2.6	38.6	58.7	Sandy loam	56.5	2.6	7.7	17.3
200	31.63359	12.99879	0-30	17.	24.3	58.7	Loam	51.7	2.6	7.8	28
			30-60	145	49.8	35.7	Silt loam	76.0	4.6	7.7	
			60-80	2.5	52.8	44.7	Sandy loam	79.0	4.7	7.7	
201	31.63744	13.01876	0-30	17.6	18.1	64.2	Sandy loam	21.2	3.1	7.8	11.3
			30-60	25	37.8	59.7	Sandy loam	31.5	5.1	7.9	
			60-70	2.0	45.3	52.7	Sandy loam	20.5	4.1	7.9	
202	31.63334	13.01844	0-30	14.0	18.0	68.0	Sandy loam	21.3	0.5	7.9	
			30-60	29.5	13.0	57.5	Sandy loam	26.0	0.9	7.6	
203	31.70958	12.99308	0-30	13.5	18.0	68.5	Sandy loam	33.0	0.3	8.0	
			30-60	13.5	20.0	66.5	Sandy loam	31.5	0.9	7.7	
205	31.82018	13.03735	0-30	7.6	22.6	69.	Sandy loam	15.5	0.2	8.2	

Sample no.	Northing	Easting	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texture	$CaCO_3$ (%)	EC (dS/m)	pH	Stone (%)
			30-60	9.5	26.8	63.7	Sandy loam	19.3	0.2	8.3	
			60-90	10.5	24.0	65.5	Sandy loam	18.6	0.2	7.8	
			90-120	8.5	22.0	69.5	Sandy loam	16.0	0.2	7.9	
206	31.82803	13.06169	0-20	17.1	17.1	65.7	Sandy loam	28.8	0.2	8.1	
207	31.83721	13.09545	0-30	10.0	37.3	52.7	Sandy loam	56.4	11.8	7.7	
			30-40	5.6	43.6	50.7	Loam	56.2	12.3	7.6	
208	31.80899	13.08344	0-10	15.6	13.6	70.7	Sandy loam	36.2	0.3	8.1	32.6
209	31.79641	13.08568	0-30	9.	10.5	80.0	Sandy loam	18.2	0.2	7.7	
			30-45	16.	17.3	66.2	Sandy loam	45.3	0.4	8.2	
210	31.78061	13.07252	0-30	7.5	7.8	84.7	Sandy loam	18.6	0.3	8.1	
			30-60	10.0	12.5	77.5	Sandy loam	43.6	0.2	7.6	
211	31.77223	13.06377	0-30	2.5	35.8	61.7	Sandy loam	12.6	2.3	8.0	
			30-50	2.0	38.8	59.2	Sandy loam	17.0	2.1	8.0	
212	31.76324	13.06210	0-30	5.5	5.8	88.7	Sandy	18.5	0.4	7.7	
			30-60	17.5	11.3	71.2	Sandy loam	28.8	0.3	7.6	
			60-75	2.0	34.8	63.2	Sandy loam	31.5	2.3	7.5	
213	31.75259	13.53190	0-30	30.5	29.5	40.0	Clay loam	35.5	0.4	7.8	
			30-60	28.9	24.6	46.4	Sandy clay loam	38.2	1.3	7.9	
			60-90	27.5	27.8	44.7	Sandy clay loam	52.4	3.0	7.5	

Sample no.	Northing	Easting	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texture	$CaCO_3$ (%)	EC (dS/m)	pH	Stone (%)
214	31.70462	13.05304	0-15	11.5	10.3	78.2	Sandy loam	34.0	0.3	8.3	
215	31.68834	13.03006	0-30	14.5	9.8	75.7	Sandy loam	42.3	0.2	8.1	24.9
			30-70	18.0	12.5	69.5	Sandy loam	45.3	0.1	7.9	20.9
216	31.66164	13.02167	0-30	17.5	18.8	63.7	Sandy loam	45.8	0.2	8.2	21.4
			30-40	18.0	5.3	56.7	Sandy loam	31.5	0.3	8.3	
217	31.79775	13.05038	0-30	14.5	18.8	68.7	Sandy loam	22.0	3.7	8.2	
			30-60	21.5	17.0	61.5	Sandy loam	29.5	5.0	7.5	35.2
			60-90	20.5	23.3	56.2	Sandy loam	51.0	6.4	8.0	
218	31.81.76	13.07380	0-30	9.5	13.8	76.7	Sandy loam	52.0	0.2	8.0	
			30-60	15.6	20.1	64.2	Sandy loam	50.3	0.3	7.9	
219	31.79686	13.06201	0-30	12.5	13.0	745	Sandy loam	16.0	0.2	7.9	
			30-60	20.5	15.0	64.5	Sandy clay loam	35.0	02	7.6	
			60-70	20.0	18.5	61.5	Sandy clay loam	43.6	0.3	7.6	
220	31.78396	13.04652	0-30	15.5	15.8	68.7	Sandy loam	25.4	0.2		
			30-60	18.5	14.0	76.5	Sandy loam	26.8	0.3		
			60-90	15.5	15.5	69.0	Sandy loam	22.7	2.9		
			90-120	16.6	14.6	68.7	Sandy loam	24.0	3.3		
221	31.80219	13.01222	0-30	0.5	25.8	73.7	Sandy loam	22.0	0.3		
			30-60	0.5	35.8	63.7	Sandy loam	47.0	0.5		