Water Benchmarks of CWANA project

2

Selection and Characterization of Badia Watershed Research Sites

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ICARDA
International Center for Agricultural Research in the Dry Areas

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Contents

Summary

The steppe, known as Al Badia in Arabic, covers vast areas of land in West Asia and North Africa (WANA), and is characterized by its harsh climate. Rainfall, the most important natural resource, is generally insufficient to meet the basic needs of crop production. However, despite its scarcity, rainwater is generally poorly managed and much of it is lost through runoff and evaporation. Water harvesting could play an important role in the efficient use of rainwater.

How suitable an area is for water harvesting depends on local society, farming practices, and whether the area meets the basic technical requirements of the water-harvesting system 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).

This report describes the use of improved methodologies developed for identifying water-harvesting sites. It also provides general guidelines for determining site potential in relation to various parameters. The approach integrates multi-disciplinary knowledge, use of GIS, and verification in the field to develop and test a methodology to identify watersheds with specific characteristics – in this case, watersheds most suited to project activities within the Jordanian Badia.

The report consists of two sections: the first considers the detailed criteria and the procedure used for site selection; the second considers the biophysical and socioeconomic characterization of selected watersheds.

The whole approach demonstrates how GIS can be used at different scales, using whatever data are available, to help select fields that are suitable for implementing new land-use alternatives. The approach was also successful in integrating biophysical and socio-economic criteria in the selection process, to develop sustainable water harvesting interventions to improve water productivity in the Badia. It is expected that this approach will be applicable to areas similar to those considered by this report.

Chapter 1:
Identification and Characterization of Potential Watersheds

1.1 Introduction

Water scarcity in West Asia and North Africa (WANA) is a well-known problem that threatens the economic development and the stability of many parts of the region. Demand for water is growing rapidly, which makes it likely that in the future more and more of the water allocated to agriculture will be reallocated to other sectors.

A large proportion of WANA's agriculture is based on dryland farming systems, wherein production depends on low and extremely variable rainfall. Almost all countries in WANA now need to manage water in special ways under conditions of scarcity, in order to maximize the returns from each unit of water available for agriculture.

Technologies are available which can be used to manage scarce water resources. However, many of these technologies are not widely implemented or are not seen as feasible by farmers. This project therefore aims to ensure that communities participate in the research, development, testing, and adaptation of improved water-management options at the farm level.

The long-term development goal of the project is to improve rural livelihoods in the dry areas of WANA by enhancing the productivity of agriculture. Such enhancement would be based upon the efficient and sustainable management of the low volumes of water available from rainfall, and from groundwater and surface sources. The immediate purpose of the project is to develop and test, with the full participation of rural communities, water-management options that increase water productivity and optimize water use through economically viable, socially acceptable, and environmentally sound methods.

The Jordanian Badia is representative of the vast dry environments found in WANA. The underlying aim of the project conducted at the Badia benchmark site in Jordan (and at satellite sites in Saudi Arabia and Libya) is to ensure the widespread adoption of suitable water-harvesting techniques by people in the Badia. This will allow them to capture and efficiently use rainwater runoff in more productive and sustainable systems. This component of the project is expected to result in the following outputs:

- Improved methodologies for the identification of water-harvesting sites and for determining the best method(s) to use under different conditions.
- Techniques for providing sustainable supplies of water from rainfall runoff. These will allow the economically viable production of field crops and fruit trees in rangeland areas. Methodologies for designing and implementing such techniques at the field and watershed level will also be produced.
- Methodologies for characterizing the water-producing potential of catchments and for determining how optimal use could be made of the water harvested from these catchments.
- Analyses of potential economic and institutional constraints and of recommended policy measures designed to support the integration of water harvesting into agricultural systems.

The main activities used to produce these outputs will be:

- The development of methods that use remote sensing, GIS, and data obtained on the ground to identify possible sites and match them with suitable techniques for water harvesting.
- The development of methodologies that can be used (i) to characterize rainfall, (ii) to determine catchment potential, and (iii) to establish how optimal development of the watershed could be achieved using water harvesting, while at the same time minimizing soil losses through erosion.
- The development of guidelines that ensure that, within an integrated watershed system, runoff water is collected, allocated, and used in ways that are both socially acceptable and efficient.
- An analysis of water-harvesting costs and benefits (both direct and indirect). This will allow researchers to identify optimal production systems and so maximize benefits.
- The identification of institutional constraints which might adversely affect the management of large catchments (common property management). This will involve assessing different options for addressing these constraints, including sustainable community resource management options, legislation, and policy measures, etc.
- Analyses of the current polices governing Badia areas. Based on this, recommendations for policy measures will be developed to support the better management of such areas.

1.2 Outline of the watershed-selection process

During the early stages of the project, emphasis was placed on the fact that the approach used is multi-disciplinary, and integrates technology, management, institutions, and research. It was also agreed that the final selection of the potential watershed sites should match certain criteria. These are divided into three major groups: (i) target area criteria (ii) watershed criteria and (iii) community criteria. These criteria are listed below under the relevant group.

First group - target area criteria:

- The area must have an annual rainfall of 100-250 mm
- The area must consist of rangeland where the barley-livestock-based land-use system predominates with other land use systems
- Livestock production must be the main farming enterprise
- The land must be degraded (displaying low vegetative cover, soil erosion, and low levels of soil organic matter)
- There must be a shortage of feed
- The adoption rates for improved technologies must be low
- Levels of public and private investment must be low

Second group - watershed criteria:

- The area must be representative of the major physical and social characteristics of the Badia
- There must be communities in the upper, mid, and lower part of the watershed
- The potential for water harvesting must exist
- A rangeland-based land-use system must dominate
- The potential must exist for halting/reducing land degradation at a relatively low cost
- The area must display multiple rangeland uses
- The area must measure 30-150 km^2
- The area must encompass both private and communal natural resources
- Land ownership in the area must include both private and government land

- Rangeland use must involve open access
- The area must have been exposed to other projects
- The potential must exist for the project to have a noticeable impact in the area
- The area must be easily accessible
- Basic data and previous studies must be available for the area

Third group - community criteria:
- The community chosen must be poor
- The community must be committed to participating in the project Institutions (informal and/or formal) must exist
- A range of livestock-production systems must exist, from transhumant to sedentary systems
- Agriculture must play a significant role in household income-earning
- There must be access to government/development projects

These criteria were suggested by an inter-disciplinary team of specialists. However, while they are obviously very important for the success of the project, it must be recognized that selecting a watershed (or watersheds) which satisfies all these criteria would not be an easy task. Importantly, it was also recognized that the selection process should be made simple, so that it can be easily reproduced in other similar areas.
Accordingly, the watershed-selection process was divided into the following sub-components:

1. Scoring and weighting of the selection criteria.
2. Selection of potential watersheds (three stages).
3. Rapid rural, hydrological, and environmental appraisals of the most promising watershed(s).
4. Data management and manipulation.
5. Integration of sub-components 2 through 5 for the purposes of final selection.

An integral part of the above sub-components were continuous field visits and verification by the inter-disciplinary team. The field visits were meant to verify GIS and remote-sensing information (maps, images, and other information) and to conduct ground-truthing. Most importantly, these field visits were also meant to provide greater insight into local communities at the project sites. The technical approach applied in the site-selection process is outlined in Figure 1.

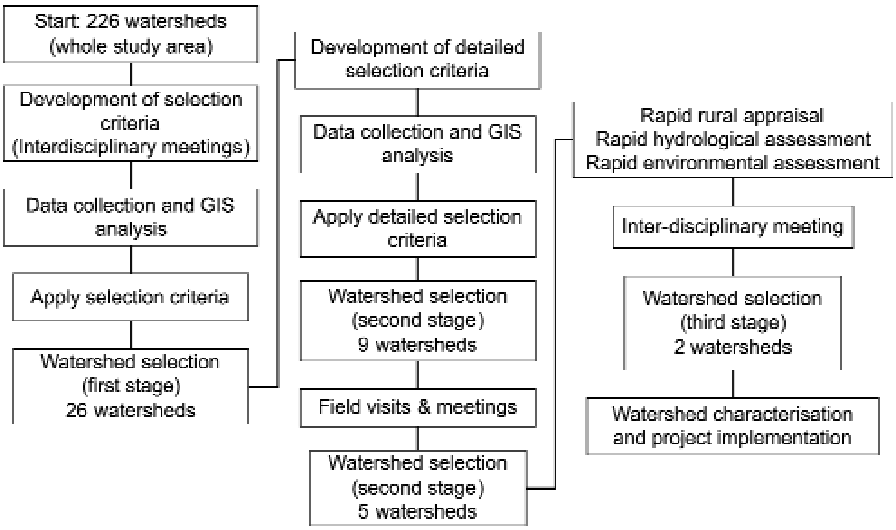


Figure 1: Flowchart of the watershed-selection process.

1.3 Description of the watershed-selection sub-components

This section describes the sub-components of the watershed-selection process, and the justification for them, as well as their objectives and the activities involved, as set out during the planning phase of the project. The interactions which occur between these sub-components are also indicated.

Sub-component 1: Scoring and weighting of selection criteria

Justification — Identifying a watershed which satisfies all the criteria defined during the opening workshop might be difficult. The relative importance of each criterion should be determined in order to undertake the selection process.

Objectives — The objective is to score and weight, according to their relative importance in the selection process, criteria agreed upon during the first workshop of the project.

Activities — Organization of a meeting between the group members, the project coordinators, and others involved in the general context of the project. This will help those involved to better under stand the criteria and to discuss the relative importance of each.

Organization of a meeting for the group members to allow them to score the criteria and to determine the relative weights.

Availability of detailed information for different watersheds will be considered during this process.

Expected outcomes — Criteria scored according to relative importance.

Sub-component 2: Watershed selection (three stages)

Justification — The selection process will be undertaken in three stages. The large number of watersheds in the study area requires the project to select and exclude watersheds at different levels of detail. The selection or exclusion of a watershed will be accom panied by justification of the decision. Excluded watersheds that are not totally outside the range of criteria will be identified as potentially useful for future investigations (if required).

Objectives — The objective of this process is to identify the most suitable water sheds, in order to select one or two water shed(s) in which to undertake project activities.

Activities

1. **First stage selection:** The output from the data review group (made available by a human and natural resources team) will be used to select the watersheds with the greatest potential. For this the following five criteria will be used: (1) rainfall, (2) presence of community, (3) soil, (4) watershed area, and (5) topography. In addition, the availability of detailed information for different watersheds will also be considered during the selection process.

2. **Second stage selection:** The revised criteria in sub-component 1 will be used to select the watersheds in the 'first stage selection' (above). A multi-disciplinary team should work together to discuss the ranking of the watersheds and add informal information to fill data gaps. If needed, the team will undertake field visits to screen the selected watersheds.
3. **Final stage selection:** The most suitable watersheds (those with the potential to satisfy all working groups) will be selected for project activities. All project components should be involved in deciding which watersheds should be selected and in justifying that selection. The criteria that will be used include the detailed criteria revised by this group (sub-component 1), the results of a rapid rural appraisal (RRA), hydrological and environmental assessments (components 3, 4, and 5), and discussion between all project members involved.

Expected outcomes	The identification of 10-20 watersheds that satisfy the above five criteria. At least 5 watersheds will be ranked based on detailed criteria and field investigation. These will then be deemed ready for further RRA, and hydrological and environmental assessment. One or two watershed(s) will be selected for project activities.

Sub-component 3 a: Rapid rural appraisal (RRA)

The details for this sub-component are given in the project's socioeconomic workplan. Mention is made of RRA here to highlight the linkages between the project's two working groups. RRA will be undertaken over each of the five or so selected watersheds, as part of the second stage selection activity of sub-component 2.

Sub-component 3 b: Rapid hydrological assessment

Justification	A hydrological assessment is required to determine how suitable the selected watershed is for water-harvesting interventions. A rapid hydrological assessment will be undertaken through out the watersheds selected as a result of activity number 2 of component 2 (at least five watersheds).
Objectives	The objective is to determine hydrological conditions within the selected watersheds and to provide a basis for selecting the final watershed(s) based on their hydrology.
Activities	Determine, based on hydrological conditions (soil, infiltration, slope, etc.), how suitable each watershed is for various water-harvesting interventions. Identify the possible negative consequences of implementing water-harvesting interventions (for example, upstream and down stream conflicts).
Expected outcomes	A foundation for the selection of potentially usable outcomes watershed(s) based on hydrological assessments. A brief hydrological characterization of the watersheds.

Sub-component 3 c: Rapid environmental assessment

Justification	An environmental assessment is required to identify the possible consequences of implementing various water-harvesting interventions. It will be undertaken in the selected watersheds from activity number 2 of component 2 (at least five).
Objectives	The objective of the rapid environmental appraisal is to identify the negative or positive environmental consequences of undertaking various activities within the selected watersheds. It is also intended to provide a foundation for the selection of the final watershed(s) based on an environmental perspective.
Activities	Identify the relevant environmental setting within the selected watersheds. Identify the possible negative consequences of implementing water-harvesting interventions.
Expected outcomes	A foundation for the selection of potential watershed(s) based on environmental assessment.

Sub-component 4: Data management and manipulation

Justification	The various activities of this group will involve the continuous delivery and collection of information. Some information will spatial and others will consist of attributes (e.g. characteristics of soil or vegetation). The integration and management of both types of information are crucial to guarantee the success of the project's activities. Linking spatial and attribute information is also important when undertaking some of the analyses required for the selection process.
Objectives	The objective is to provide information, in a suitable format, that can be used to undertake the required analysis procedures within this project.
Activities	Receive information from the data review group in various formats. Undertake the steps necessary to integrate these data into suitable digital formats. Monitor and facilitate the geo-referencing of all the data collected during the various activities and from the different sub-components. Undertake any analysis and manipulation of data needed to satisfy the various needs of the sub-components.
Expected outcomes	Maps of the selected watershed(s). A digital database containing collected data.

1.4 Development of selection criteria

The watershed-selection criteria agreed upon at an early stage of the project were revised by a multi-disciplinary team of experts. Through discussions at several meetings, each of these experts made clear his/her interests both individually and in relation to others. Accordingly, the most important criteria were selected and ranked in terms of their relative importance. In addition, some of the early criteria were amalgamated because it was decided that they belonged to one group.

The availability of detailed information covering the whole of the project area for each criterion was also considered during this process. It was felt that because a vast area is covered by the selection process, the collection of detailed information would not be justifiable. It was also decided that sufficient information was already available to apply the criteria put forward for the watershed-selection process. The reliability of this information, as compared with verification in the field, will be discussed later.

Modifying criteria for the first stage of site selection

To be selected, watersheds had to satisfy five main criteria. Table 1 gives the scores assigned to these criteria.

Rainfall was considered to be the most important factor at this stage, as it is an integral part of the definition of the study area in this project. It was therefore agreed that areas receiving either less than 100 mm of annual rainfall or more than 250 mm should be excluded, and hence were given score of zero (Table 1).

Within this range (100-250 mm) the four scores in Table 1 were used to rank the watersheds according to the amount of rainfall received. The highest score was given to areas receiving 150-199 mm, as this amount is typical for the Badia area. Higher rainfall areas (200-250 mm) were given a lower score, as they represent transitional areas that might not be considered to be typical Badia. Lower rainfall areas (100-149 mm) were given an even lower score because they might not receive enough moisture for the purposes of water harvesting.

Table 1: Scoring criteria used in the first stage of site selection.

Criterion	Score*			
	0	5	10	15
Rainfall (mm per year), obtained from isohyets	< 100 or > 250	100-149	200-250	150-199
Presence of communities (no. of villages)	None	One	Two	> Two
Soil type (dominant soil)	Lithic, Calcic, Psamment	Lithic and/ or Psamment	Calcic	Other
Watershed area (km^2)	< 30	110-150	30-70	70-110
Topography (relative relief, m)	> 200	100-200	50-100	< 50

* *If assigned a score of zero, the watershed was excluded.*

The participation of local communities is also a key aspect of this project, and the presence of communities was considered to be a very important factor at this early stage of the selection process. Watersheds without any communities would not be suitable for use in the project and were therefore given a score of zero. As the number of villages within the watershed increased the score assigned also increased.

The dominant soil type within each watershed was also considered. The level of detail given in the available soil map (scale 1:250,000) did not allow all soil properties to be investigated. Therefore, taxonomic units were used to assess the general soil characteristics that might affect the use of soil for water harvesting.

Soils displaying "Lithic" characteristics (generally shallow < 50 cm deep), "Calcic" characteristics (containing a high percentage of carbonates within 100 cm of the soil's surface) and "Psamment" characteristics (Entisols containing a high percentage of fine sand or which were coarser within the upper 100 cm) were assigned a score of zero and so excluded. The rationale behind this decision was that any soil displaying any of the above three characteristics would not be suitable for either water harvesting or cropping. Soils which displayed only "Lithic" and "Psamment" characteristics would be slightly better. Soils which displayed only "Calcic" characteristics, on the other hand, would be much more suitable and could be used, though some management might be needed. Soils free of any of these characteristics would be suited to both cultivation and water harvesting, and were therefore given the highest score.

The area of the watershed was also considered to be an important criterion for the selection process, though there was some debate regarding its use. However, most of the experts agreed that for practical reasons, and taking into account both hydrological and socioeconomic considerations, the watersheds considered for the project would have an optimum size. Very small watersheds (less than 30 km^2) would be too small for the project's purposes, especially when considering the use of water-storage structures such as earth dams. Large watersheds (100-150 km^2) would also not be suitable, as it would be difficult to build hydrological structures in such large watersheds. Furthermore, it might prove difficult to deal with the large diversity of communities that would be found within such a large watershed, especially with regard to conflicts over land tenure.

Watersheds which fell between the maximum and minimum sizes given above were subdivided into two groups. Considered best were those watersheds measuring between 70 km^2 and 110 km^2, as they represent a compromise which satisfies different aspects of the project, particularly its hydrological and socioe-conomic aspects. The second group contained watersheds with an area of between 30 km^2 and 70 km^2, which were considered to be not as good as the first group.

The general topography of the watershed was considered to be another important criterion, especially with regard to the implementation of water harvesting. The available information at this level consisted of spatial layers that enable the characterization of the relative relief of a watershed. Though relative relief is not a measurement of landscape properties that is directly relevant to water harvesting, it does indicate the general topography of a watershed. And, insofar as it is an estimation of how much elevation varies within the watershed, the information it provides is relevant. The greater the relative relief, the steeper the topography of the watershed. As a result, watersheds with a relative relief of more than 200 m were excluded. Relatively flat watersheds are also not suitable. Therefore, watersheds with slight relief (of not more than 50

m) were considered best for this project. Between the two extremes (between 50 and 200m), the watersheds were scored into two groups (Table 1).

Modifying criteria for the second stage of site selection

The second stage of site selection required researchers to apply more rigorous criteria to the watersheds selected in the first stage. Those watersheds given a score of zero for any of the five selection criteria in the first stage were excluded.

The 14 watershed-selection criteria suggested previously (see section 1.2) were at this stage revised by the project's multi-disciplinary team. The new criteria were ranked according to their relative importance to the project while bearing in mind current conditions in the Badia region, as noted by each member of the team based on their experience in the area. Some criteria were amalgamated, and the justifications for this amalgamation and ranking were recorded.

The community selection criteria were also revised and updated, as will be discussed later. This report places more emphasis on the new watershed-selection criteria, which are listed below according to their relative importance.

Watershed-selection criteria:

1. The potential for water harvesting must exist.
2. There must be communities in the upper, middle, and lower parts of the watershed.
3. Rangeland-based livelihood systems must dominate.
4. Watersheds must have an area of 30-150 km^2.
5. Watersheds must be easily accessible and the activities within them visible to farmers in the area.
6. Land ownership (land tenure), ranked in the following sequence from A (the best) to C (the worse):
   A Private and government land (best option)
   B Private land only
   C Government land only.
7. Existing land use (Range-livestock-based system is the best)
8. Basic data and previous studies must be available

The changes made to the original selection criteria (see section 1.2 above) in order to produce this modified list of selection criteria are considered below.

The first criterion in the old set ("The area must be representative of the major physical and social characteristics of the Badia") was dropped as it was an integral part of the selection process which was addressed by the other criteria. In addition, it was decided that the verification process that would follow selection and look at sites in the field would also ensure that selected watersheds conformed to this criterion.

The next three criteria were kept, though their rankings were changed. Thus the potential for water harvesting was given priority, followed by the presence of communities. The dominance of a rangeland-based system was ranked third. The team emphasized that these three criteria are essential and should determine whether or not a watershed was used by the project.

The fifth criterion ("the potential must exist for halting/reducing land degradation at a relatively low cost") and the twelfth criterion ("the potential must exist for a noticeable impact to be achieved in the area") were dropped from the list. This was done for two reasons: (i) because the two criteria would be considered anyway during the field visits which would follow the selection process (allowing for detailed judgments to be made) and (ii) because the information available was not detailed enough for accurate judgments to be made.

The sixth criterion ("the area must display multiple rangeland uses"), was considered to fall within the new criterion "type of the existing land use", which will be discussed later. The criterion dealing with the area of the watershed was retained unchanged. This is because the area of the watershed has a crucial role in determining various project's activities. to emphasize the impact that the watershed area will have on the various activities undertaken by the project.

The eighth, ninth and tenth criteria were amalgamated to form the criterion governing land tenure. The rationale for this will be discussed later. The 11th criterion ("the area have been exposed to other projects") was considered more relevant to the socioeconomic aspects of the study and hence was moved, becoming part of the new "community" criterion.
The 13th criterion ("the area must be easily accessible") and the 14th criterion ("basic data and previous studies must be available for the area") were retained and will be discussed later.

Rationale underlying the rankings used in the second stage of selection

The rankings assigned to the revised selection criteria used in the second stage are given in Table 2 and are discussed below.

Soil depth
Deeper soils were given a higher ranking than shallower soils, because the amount of water storage in the soil increases as

Table 2: Scoring of criteria for the second stage of the site selection process.

Potential for water harvesting	4th (lowest score)	3rd	2nd	1st (highest score)
Soil depth	< 50 cm	50-100 cm	100-200 cm	> 200 cm
Slope steepness	<1% or > 10%	8-10%	5-8%	1-5%
Community (location in watershed)	Upper and/ or middle	Lower and/ or middle	Upper & lower	Upper, middle & lower
Rangeland-based system	Irrigated agriculture dominates	Lack of native vegetation and barley	Native vegetation and barley dominates	Native vegetation dominates
Land use system	Field crops system	Bare livestock-based	Range-barley-stock-based	Range-live
Watershed area (km^2)		110-150	30-70	70-110
Accessibility & visibility	Not connected to roads	Connected only on one part	One road passing through watershed	Road network inside and main road passing through
Land tenure		Government	Private	Private & government
Basic data	Not available & no previous studies	Insufficient & previous studies	Available & previous studies	Available

the depth of the soil increase. The highest score was assigned to soils with a depth of 200 cm. Rainfall varies greatly in the area, and water storage in the soil profile is a factor which determines the cropping success. Soils that are less than 50 cm deep were considered to be least suitable for water harvesting. This is because below this depth the rooting zone is inadequate for most cultivated plants and water storage is limited. Between those two extremes, the soils were ranked into two groups (Table 2).

Slope steepness

Slope steepness was also used to determine whether an area displayed potential for water harvesting. Water-harvesting techniques differ depending on the slope present. Generally, on-farm water-harvesting systems are not recommended for use on slopes steeper than 5%. However, some degree of slope is necessary to encourage water to flow so that it can be harvested. The range 1-5% was therefore considered to be best for water harvesting. Slopes of 5-8% and 8-10% were considered the second and third best options, respectively. Slopes steeper than 10% and flatter than 1% were considered to be the worst options. This is because flat areas don't encourage water to flow (so runoff collection is less efficient) and steep slopes can lead to sever erosion and/or can incur additional construction costs as efforts have to be made to cope with the amounts of runoff that have to be harvested.

Community

Whether there were communities within each watershed was an issue which was evaluated in the first stage of the selection process. However, the distribution of the communities within each was also considered to be important and was evaluated in the second stage.

The best situation occurred when communities were distributed over the various parts of the watershed. Such situations were therefore ranked highest. Such a distribution makes it more likely that communities will participate in project activities throughout the whole watershed, as a result of their proximity. Furthermore, such a distribution of communities will also allow the project to investigate any upstream-downstream interactions (i.e., sharing or conflicts) between various stakeholders that might result from water-harvesting interventions. Though it might not limit the present project, this aspect must be considered because it will have an impact on future expansion efforts which aim to cover the whole Badia region. The score assigned was therefore reduced as the communities became more concentrated in one part of the watershed.

Rangeland-based system

It was decided that the target area should be characterized by the dominance of a rangeland-based system for two reasons: (i) to ensure that it was representative of the Badia, and (ii) to allow the development activities proposed by the project to be implemented. The project considered a watershed that was dominated by native vegetation to be the best area for study, because (i) this implies that land is available for development and (ii) implementing the project on such land optimizes the benefits derived from water harvesting.

The worst areas for the study were considered to be those in which irrigated agriculture dominates, because this implies that the amount of rangeland available for development is limited. It was also thought that in such areas water harvesting (which produces only limited amounts) would not be able to compete with high-investment initiatives such as irrigation. This, it was felt, might affect the willingness of farmers to adopt water-harvesting interventions.

By the same token, barley cultivation within a watershed reduced its ranking in comparison with watersheds where only native vegetation was present. This is because the project's target area was not considered to be a typical barley-growing area. The willingness of farmers to substitute barley for other rangeland plants is one of the issues that might affect the success of the proposed activities. The absence of native vegetation and barley was given a lower ranking (third place; Table 2) than their presence (second place; Table 2). However, this ranking was still higher than that assigned to irrigation (fourth place; Table 2).

Land use
The criterion concerned with land use considers both the type of land-use activities that dominate the watersheds and whether a livestock system is present. It was felt that the most suitable study area would include both rangeland conservation and complementary livestock activities. This is because the project aims to improve the productivity of degraded rangelands by making better use of the limited rainfall available. The best way to achieve these objectives is through livestock production, which directly utilizes the fodder production. Commercial production might not be expected in this case.

Again, because the area was not considered to be a typical barley-growing area, the presence of barley slightly reduced the potential of the watershed for use in the project. Land without livestock would also have very low potential with regard to project activities. The worst ranking was given to watersheds dominated by field crops (and other crops except barley) and lacking livestock. The presence of such crops implies that land use is not geared towards rangeland production, and therefore is not in harmony with the project's objectives.

Watershed area
The criterion was transferred from the first stage as is. As already mentioned, this was done to emphasize the effect that the area of a watershed has on various activities.

Accessibility and visibility
This criterion has two requirements. First, stakeholders must be able to access their lands easily and so participate in project activities during different project phases. Second, the interventions being implemented must be obvious to non-participating farmers, to ensure that the experience gained is disseminated as widely as possible. The number of roads present and their distribution were considered to be suitable for use when evaluating this criterion. The best area was felt to be one in which road networks were dense, well-distributed and covered the whole watershed; the least suitable areas were watersheds that lack roads.

Land tenure
The issue of land ownership is very important in this area, and could prove to be a factor which limits the success of the activities proposed by the project. The ownership of much of the land in the area is unclear. This poses problems with regard to the security of people's access to land, and could affect land-use patterns. Special attention was therefore paid to this issue.

The project concluded that land containing both government land (which included land that had been claimed but not registered) and privately owned land would be best for use in the project, because this situation dominates in many parts of the Badia. Areas which were heavily dominated by either government or privately owned land therefore received lower scores.

Basic data
Although the availability of basic data will be very important at later stages in the project, it should not be considered to be a limiting factor, as the collection of detailed information lies at the heart of any development project. However, it has been agreed that whenever two watersheds are nearly identical, the one for which more baseline information is available should be considered the more suitable. Thus, the rankings provided according to this criterion depended on the data collected during previous studies conducted in the area of interest.

1.5 Applying the selection criteria within a GIS environment

The criteria used in the first and the second stages of the watershed-selection process were applied using GIS overlays (maps). Each overlay was used to evaluate one or more of the first- or second-stage criteria. These maps were provided by different government institutions, mainly the Ministry of Water and Irrigation and Agriculture, the Royal Jordanian Geographic Center (RJGC), the University of Jordan (UoJ), the National Center for Agricultural Research and Technology Transfer (NCARTT), the Department of Land and Surveys (DLS) and the Department of Meteorology. All maps (digital or hardcopy) were transformed into vector format and then geo-referenced to a unified coordinate system (the Jordanian Transverse Mercator, using the WGS-84 as a working datum). ArcView GIS software was used for the analysis.

The procedures used in both the first and second stages are described in the following sections. Procedures were intended to be reproducible and to allow criteria to be easily modified (and the new, adjusted results to be presented). This is because the watersheds ultimately selected had to satisfy experts from various disciplines, a process which might require several cycles of selection.

First stage: Criteria development and initial selection

Applying the criteria used in the first stage of selection
The basic map used in various analyses showed the subdivisions of each watershed. This map was developed from the hardcopies of topographic maps (scale 1:50,000) produced during a previous project (Jordan Arid Zone Productivity Project, JAZPP) conducted by the University of Jordan. Contour lines and streams were used to define the boundaries of each main watershed and the sub-watersheds found throughout the whole of the transitional Badia (100-200 mm rainfall).

Each sub-watershed was given a serial number to identify it. This serial number also indicated which main watershed each sub-watershed belonged to. A hardcopy map showing the sub-watersheds was digitized and merged to produce a single layer for the whole area. Within this, the sub-watersheds within each main watershed were merged to produce a layer which showed the boundaries of the main watersheds (Figure 2).

The output indicated that the Badia is covered by 226 main watersheds, ranging in area from 0.3 to 266 km^2. It would be very difficult to work with such a large number of watersheds. Therefore, the criteria assigned for the first stage (Table 1), which were very general in nature, were applied to exclude watersheds that were unsuited to this project. This section explains how these criteria were applied and the main results of this process.

First criterion: rainfall

A digital map showing rainfall isohyets was available. Overlaying this onto the watersheds' boundaries indicated that the average amount of rainfall received per year varied within the boundaries of most of the watersheds (Figure 3).

Therefore, the two maps were intersected within the ArcView GIS and the average rainfall for each watershed calculated (Figure 4). The average amounts of rainfall calculated for each watershed were used to classify it according to the rainfall score given in Table 1. Figure 5 shows the scores assigned to the watersheds according to rainfall, and indicates that the scores assigned to the watersheds follow the rainfall distribution pattern indicated in Figure 3.

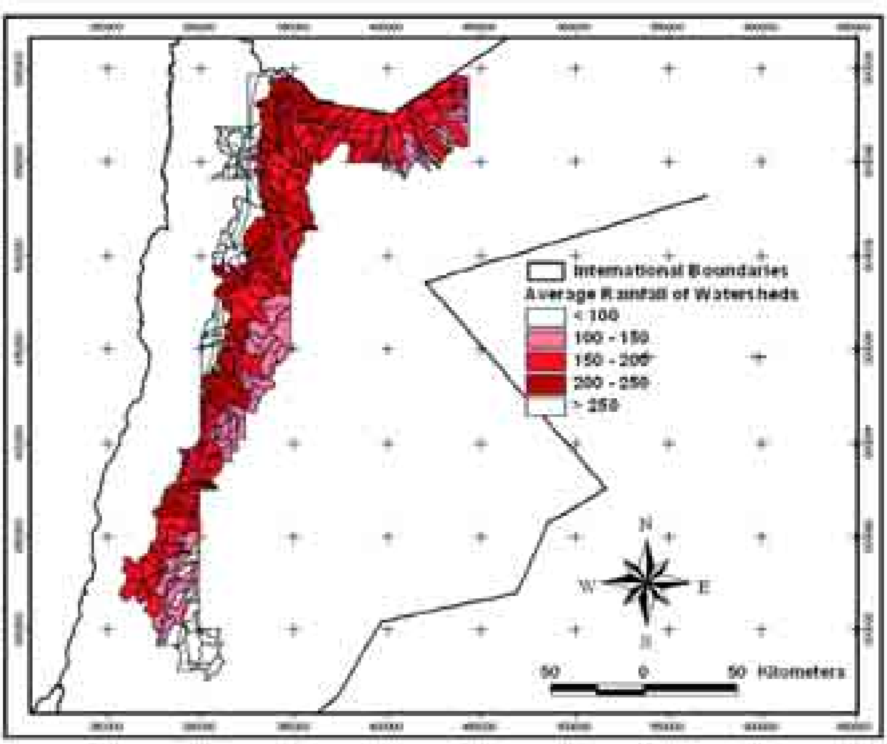


Figure 2: Main watersheds classified according to area (km²).

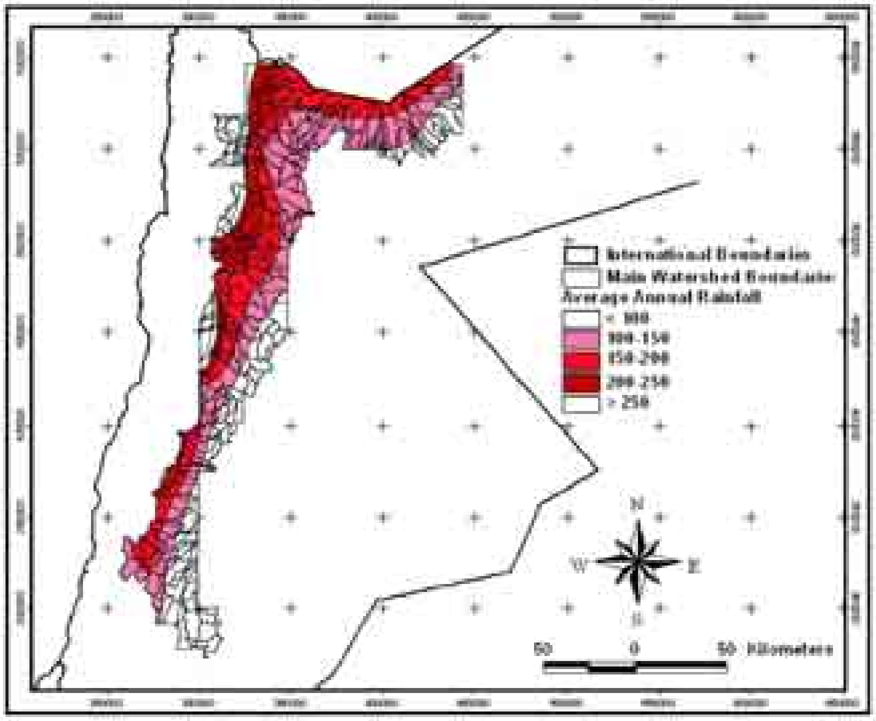


Figure 3: Rainfall distribution over the watersheds (mm).

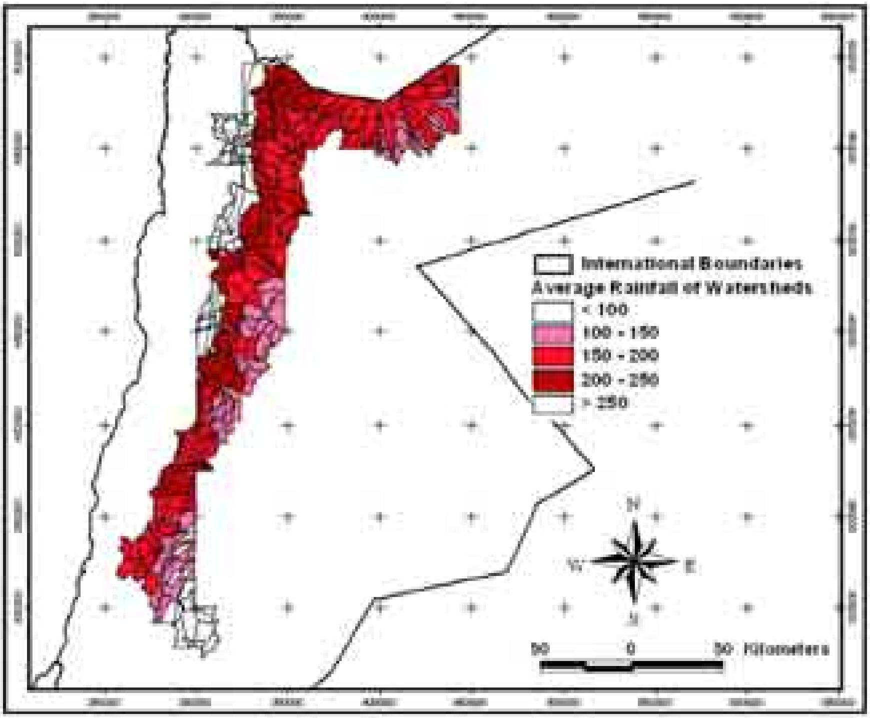


Figure 4: Average rainfall for each watershed (mm).

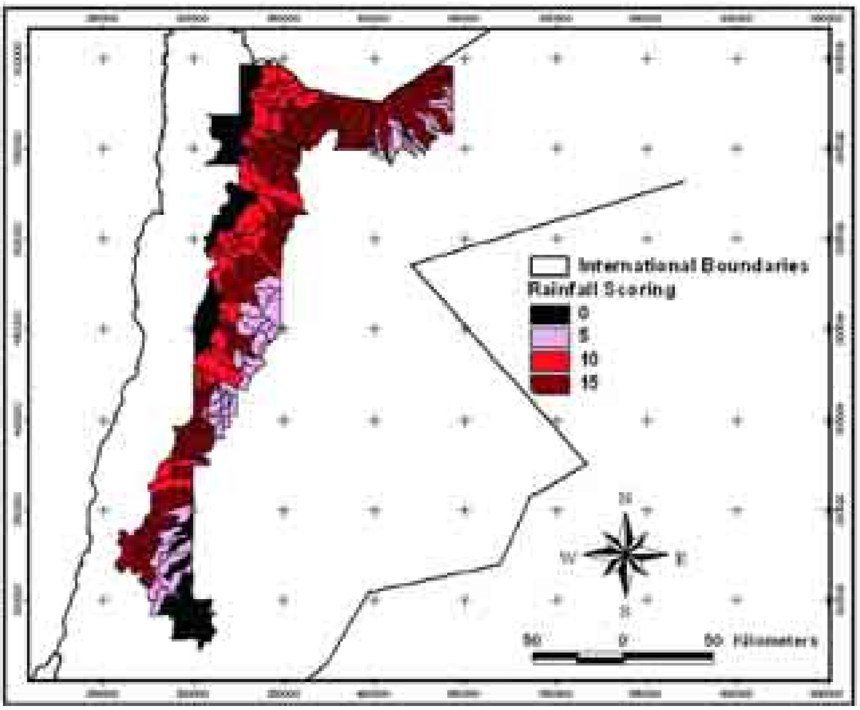


Figure 5: Watershed scoring according to average annual rainfall.

Second criterion: the presence of communities

The distribution of villages throughout the whole Badia was used to evaluate the potential of different sites. Villages, represented as a point layer, were overlaid onto the watershed layer (see Figure 6).

The number of villages within each watershed was counted, and each watershed was assigned a number, to indicate how many villages were found within it. The scores assigned to the watersheds based on this count are shown in Figure 7. The scores assigned according to community follow the same pattern of village distribution and indicates more communities toward the west and the north of the area. This also follows the pattern of increase in the amount of rainfall.

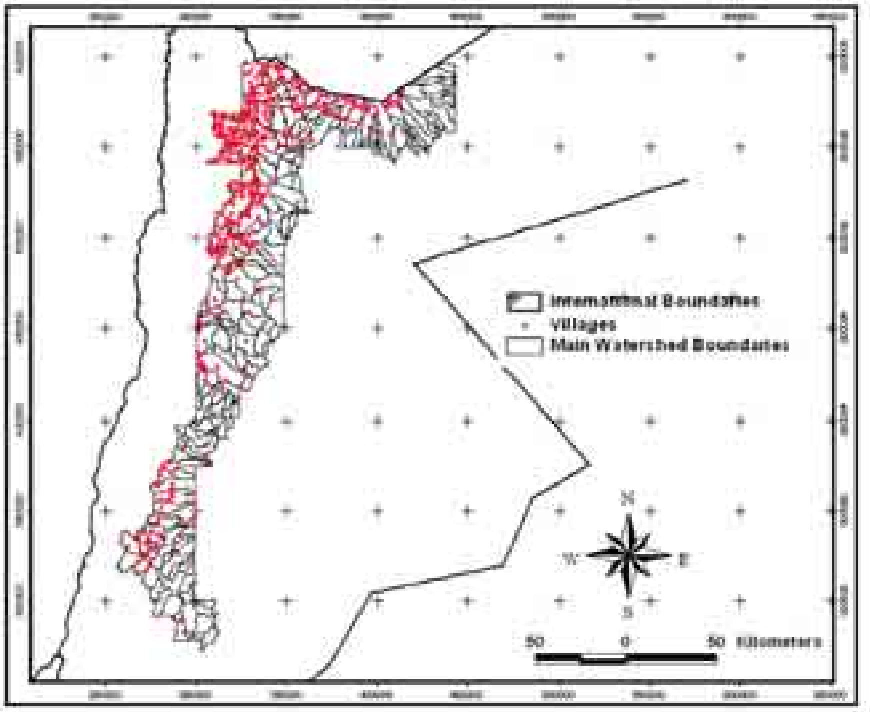


Figure 6: Distribution of villages over the watersheds.

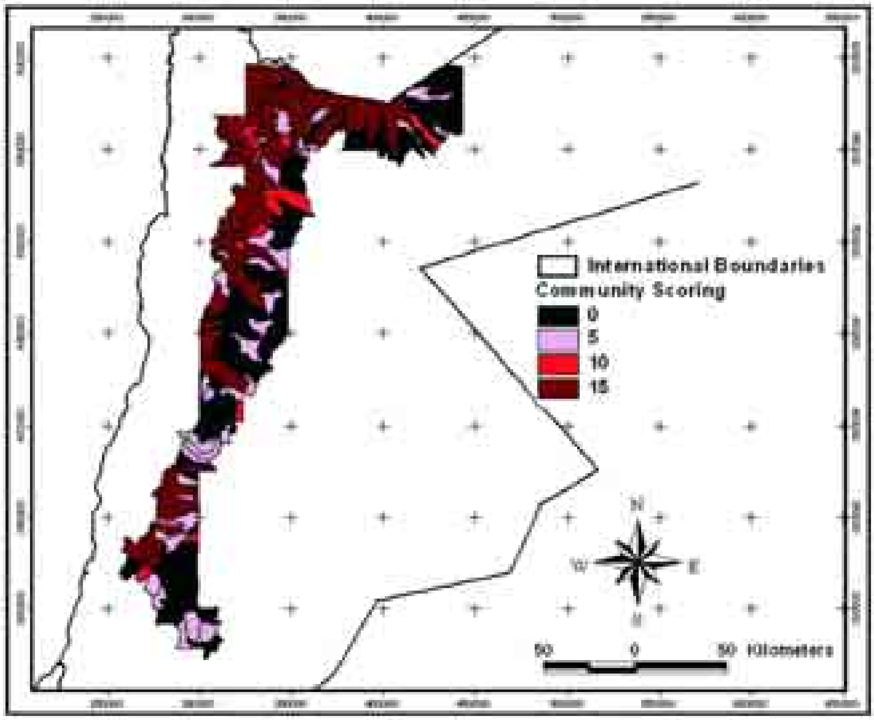


Figure 7: Watershed scoring according to community.

Third criterion: soil type
A soil map was available for the whole Badia (scale 1:250,000). This consisted of 166 soil mapping units, distributed over 369 polygons (as the same mapping units occurred in several places). The boundaries of these soil mapping units did not match the boundaries of the watersheds, and some watersheds encompassed many soil mapping units. Therefore, to characterize the soil type of each watershed, the soil map was intersected with the watershed boundaries.

This produced a map showing the area of each soil mapping unit within each watershed. This new map contained 1267 new polygons, as a result of intersecting the 369 polygons from the soil map with the 226 polygons found on the watershed boundaries map. For each watershed, more than one soil mapping unit resulted from the intersection process. Each soil mapping unit was scored based on the descriptive legend attached to it. An example of such a legend is given in Table 3.

The characteristics and percentages of soil associations within each soil mapping unit were used to apply the criteria in Table 1, and hence to assign a score for each mapping unit. An example of the scores assigned to the soil mapping units and of their relationship to the watersheds' boundaries is given in Figure 8. Each watershed was then assigned a score proper based on the dominant score(s) of the soil units within the watershed (see Figure 9).

As shown in Figure 9, very few of the watersheds received low scores. The soils in the northern and the central part of the Badia scored highest, while the soils in the eastern and the southern parts of the Badia proved to be less suitable for water harvesting. This is because Calcic and Lithic soils dominate in the eastern part of the area, while Psamment soils dominate in the south.

Table 3: An example of the soil mapping unit description used to apply the soil scoring criteria.

Soil map unit	Description	Soil association
ABY11	Gently undulating deposition plains of Quaternary alluvium and loess overlying Al Hisa Phosphorite and Muwaqqar chalk and Marl formations; weakly incised by wadis; colluvial upper slopes merge into alluvial lower slopes; occasional depositional (Qa') basins, and low rounded rocky interfluves; gradients <10%; altitude 750 to 950 m; relative relief < 10 m; steppe grassland.	70% Xerochreptic Calciorthid and Camborthid 5% Calcixerollic Xerochrept 5% Lithic (Xerochreptic) Camborthid 5% Lithic Xeric Torriorthent

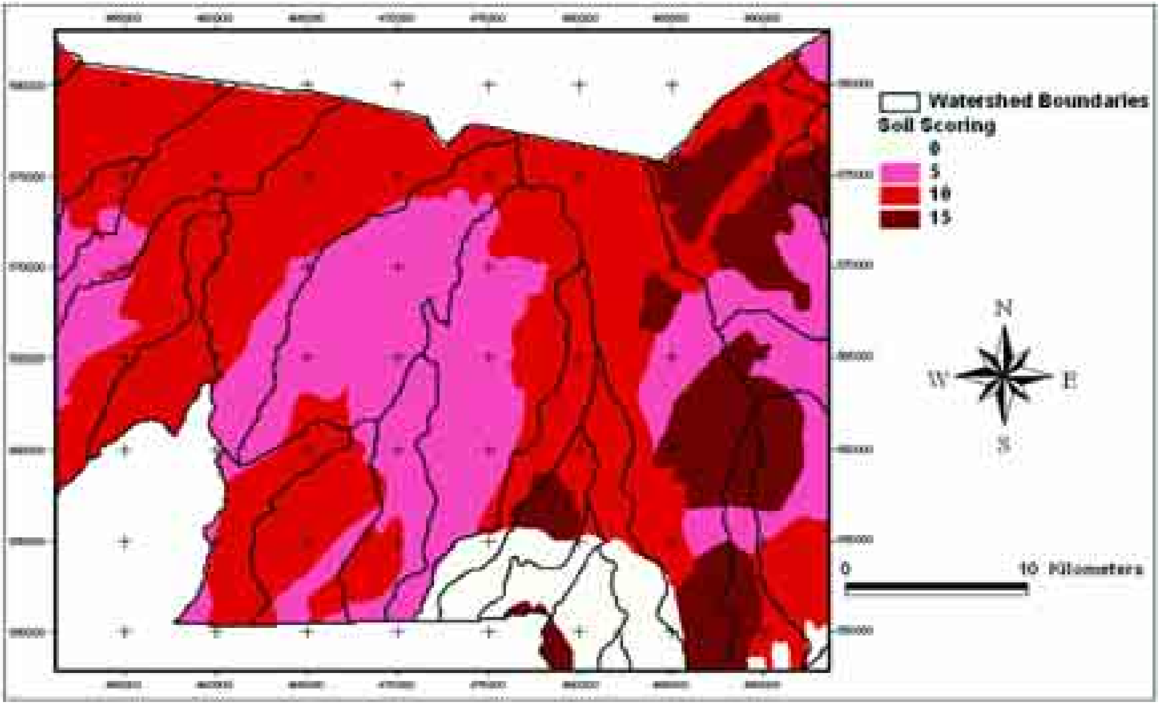


Figure 8: Relationship between the boundaries of the soil mapping units and the watershed boundaries.

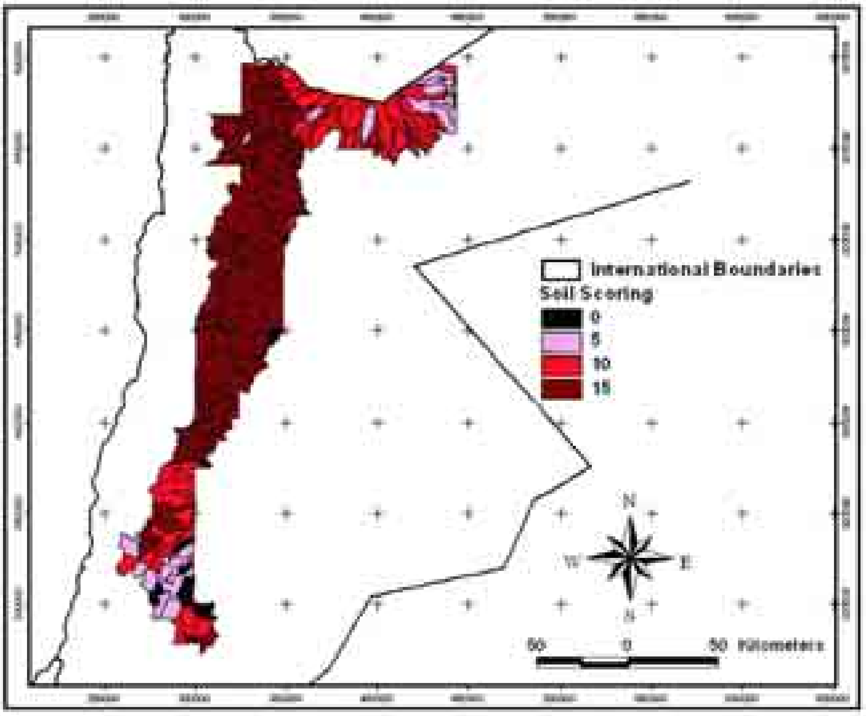


Figure 9: Watershed scoring according to soil type.

Fourth criterion: watershed area
The area of each watershed (in m^2) was easily computed using ArcView GIS software. Once these were converted to km^2 (Figure 2), the criteria given in Table 1 were applied to score each watershed according to its size. The scores obtained are shown in Figure 10.

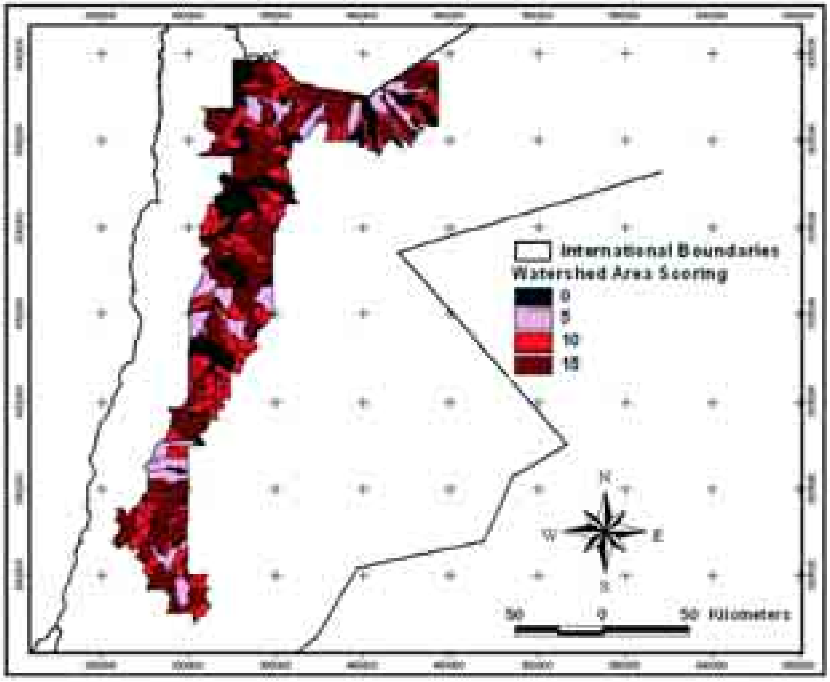


Figure 10: Watershed scoring according to area.

of a soil mapping unit description (see Table 3 for an example), only the relative relief obtained for each soil mapping unit was used. The criteria in Table 1 were then applied to score each soil mapping unit based on its relative relief value. As was the case when scoring soil type, it was found here that soil mapping units do not

Fifth criterion: topography
At this stage of the watershed-assessment process, general information about topography was considered sufficient for scoring. Therefore, each mapping unit was scored on the basis of the relative relief recorded for it. The output layer produced by intersecting watershed boundaries and soil mapping units was also used to score this criterion. Instead of using all elements coincide with watershed boundaries. The relationship between the scores obtained for each soil mapping unit according to relative relief and watershed boundaries are given in Figure 11. Each watershed was assigned a relative relief value based on the average value of the relative relief scores for all the soil mapping units within the watershed (Figure 12).

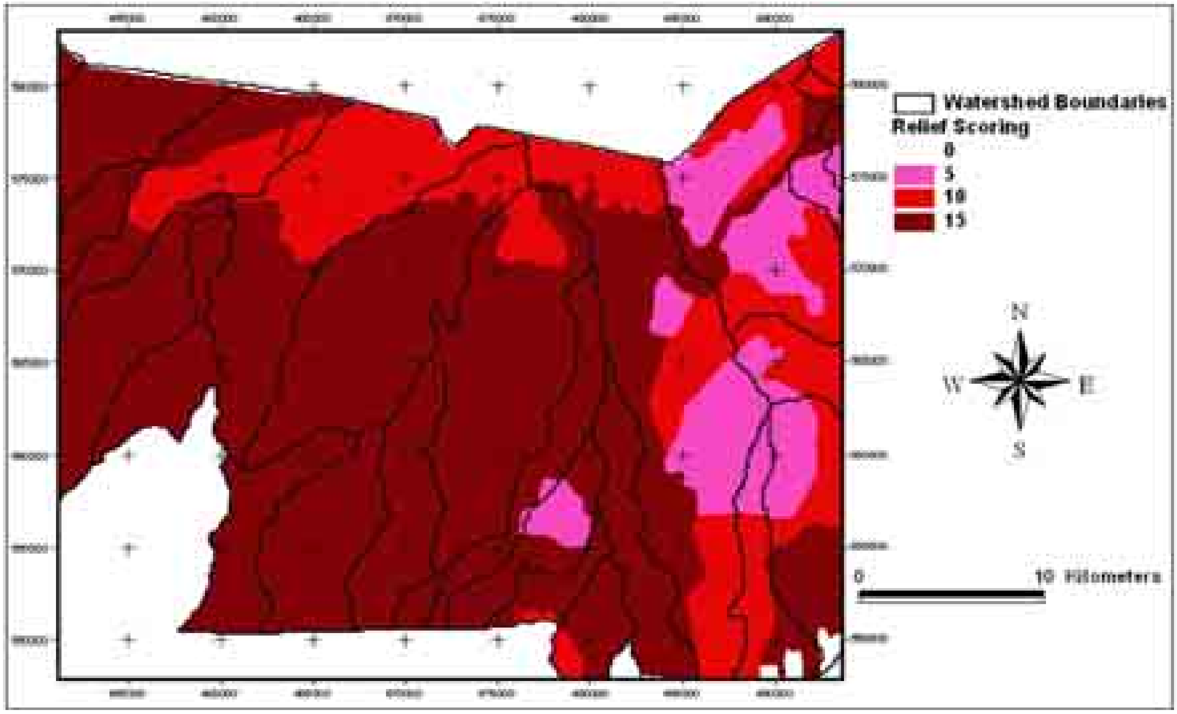


Figure 11: Relationship between soil mapping units boundaries (scored according to relative relief) and watershed boundaries.

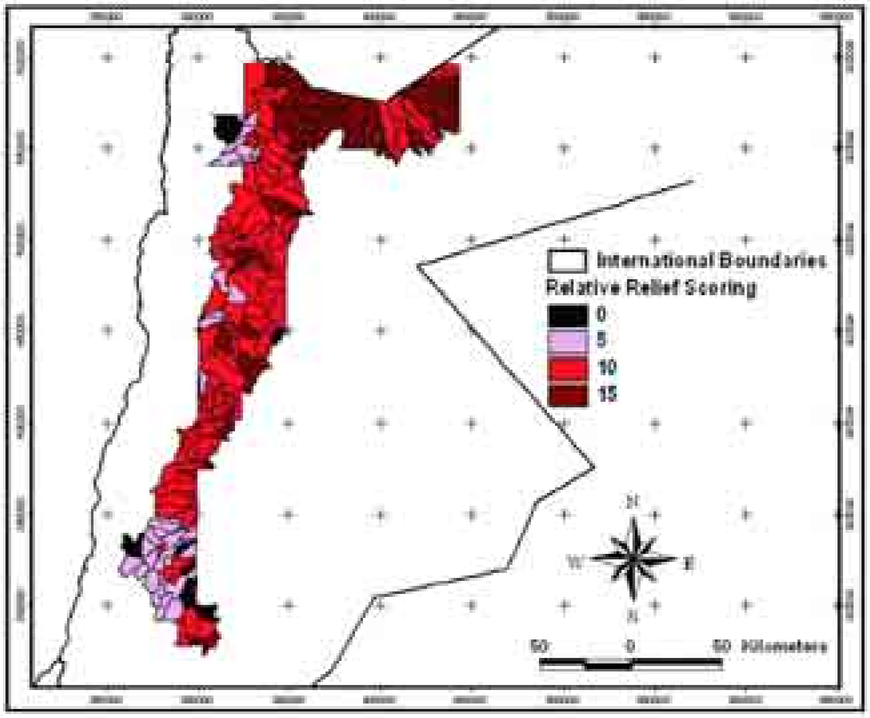


Figure 12: Watershed scoring according to topography.

Watershed selection (first stage)

The first stage of the selection process aimed to identify those watersheds which were most suitable for further investigation. Of the 226 watersheds that cover the whole of the Badia, it was felt that 25-30 could, for reasons of practicality, be investigated further. The watersheds with the most potential were those which scored highest for the five criteria mentioned in Table 1. The scores assigned based on these five criteria are given in Figures 5, 7, 9, 10 and 12. The sum of the scores for the five criteria was used to identify those watersheds with most potential. The scores for each criterion, as well as the final score for each of the 226 watersheds are presented in Appendix A. The classifications accorded to all the watersheds based on the final scores obtained are shown in Figure 13.

The final scores ranged between zero and 70 (Appendix A). The zero score assigned needs some explanation. After the scores for the five criteria had been added up, watersheds which had scored zero for any of the five criteria were given a final score of zero, regardless of the scores obtained for the other four criteria. This is because the five criteria were considered to be necessary for any watershed used in the project.

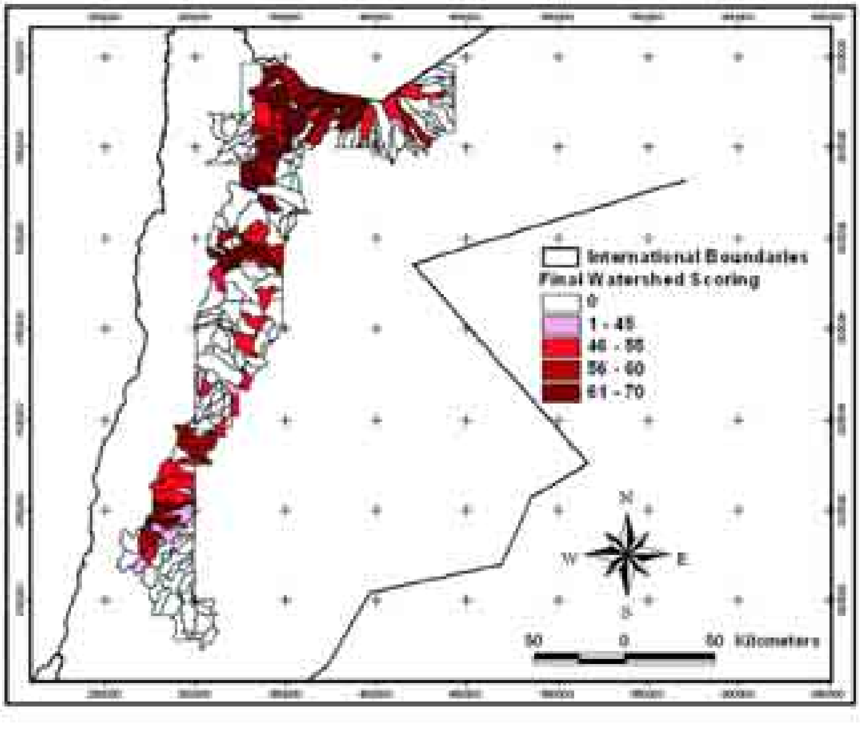


Figure 13: Classification of watersheds according to the final scoring (first stage).

A large number of watersheds received a final score of zero (Figure 13). However, these watersheds should not necessarily be considered unsuitable for other activities in the Badia, even though they were unsuited to this project. Of the 226 watersheds, 158 were excluded. This left 68 for further consideration. The scores for these 68 watersheds ranged between 40 and 70. Figure 12 shows the distribution of these watersheds: most of those with high scores are found in the northern and the central part of the Badia.

The scores obtained for these 68 watersheds are presented in Table 4. Forty of the watersheds had scores of 60, 65, or 70, the three highest scores obtained. These were considered for further investigation. Some, however, were then excluded because their boundaries extended into Syria, something which could complicate project activities (see Figure 14). Other watersheds were excluded because much of their area fell outside the Badia. This left the 26 watersheds shown in Figure 15. The scores assigned to these watersheds are given in bold in Table 4.

Table 4: Final scoring (first stage) after excluding watersheds with scores of zero.

Watershed Number	Area score	Rainfall score	Community score	Soil score	Topography score	**Final Score**	Watershed	Number Area score	Rainfall score	Community score	Soil score	Topography score	**Final Score**	Watershed	Number Area score	Rainfall score	Community score	Soil score	Topography score	**Final Score**
18	15	15	15	15	10	**70**	16	15	10	5	15	15	**60**	189	5	15	15	10	10	**55**
19	15	15	15	15	10	**70**	17	10	15	10	15	10	**60**	200	10	15	15	10	5	**55**
35	10	15	15	15	15	**70**	29	15	15	5	15	10	**60**	38	10	15	5	5	15	**50**
36	15	15	15	10	15	**70**	33	10	10	15	10	15	**60**	90	5	15	5	10	15	**50**
37	15	15	15	10	15	**70**	51	5	15	15	10	15	**60**	129	15	10	5	15	5	**50**
50	15	15	15	10	15	**70**	55	10	10	15	10	15	**60**	132	15	5	5	15	10	**50**
54	15	10	15	15	15	**70**	57	10	10	15	10	15	**60**	136	15	5	5	15	10	**50**
61	15	15	15	10	15	**70**	58	10	10	15	15	10	**60**	148	5	15	5	15	10	**50**
62	15	15	15	10	15	**70**	79	15	15	10	10	10	**60**	152	10	5	5	15	15	**50**
190	15	15	15	15	10	**70**	108	10	10	15	15	10	**60**	167	10	5	10	15	10	**50**
27	15	10	15	15	10	**65**	120	15	15	5	15	10	**60**	169	10	5	5	15	15	**50**
28	15	10	15	15	10	**65**	125	10	15	5	15	15	**60**	184	5	10	15	10	10	**50**
30	5	15	15	15	15	**65**	173	15	15	5	15	10	**60**	186	10	15	5	10	10	**50**
31	10	10	15	15	15	**65**	174	15	15	5	15	10	**60**	187	5	10	15	10	10	**50**
34	15	10	15	10	15	**65**	182	15	15	5	15	10	**60**	192	10	15	5	15	5	**50**
59	15	10	15	15	10	**65**	197	10	15	15	15	5	**60**	161	10	10	5	15	5	**45**
103	15	10	10	15	15	**65**	199	10	15	15	15	5	**60**	164	10	5	5	15	10	**45**
121	15	10	15	15	10	**65**	15	5	10	15	15	10	**55**	191	15	5	5	10	10	**45**
122	10	10	15	15	15	**65**	65	5	15	15	5	15	**55**	195	10	15	5	10	5	**45**
123	10	10	15	15	15	**65**	78	5	15	15	10	10	**55**	215	10	15	10	5	5	**45**
128	15	10	15	15	10	**65**	117	10	10	10	15	10	**55**	77	10	5	5	10	10	**40**
193	15	15	15	15	5	**65**	118	15	10	5	15	10	**55**	196	15	5	5	10	5	**40**
13	10	10	15	15	10	**60**	179	10	15	5	15	10	**55**							

Note: Bold text for each individual score per watershed signifies watersheds in Figure 15 whose boundaries did not fall outside the Badia, or outside the country.

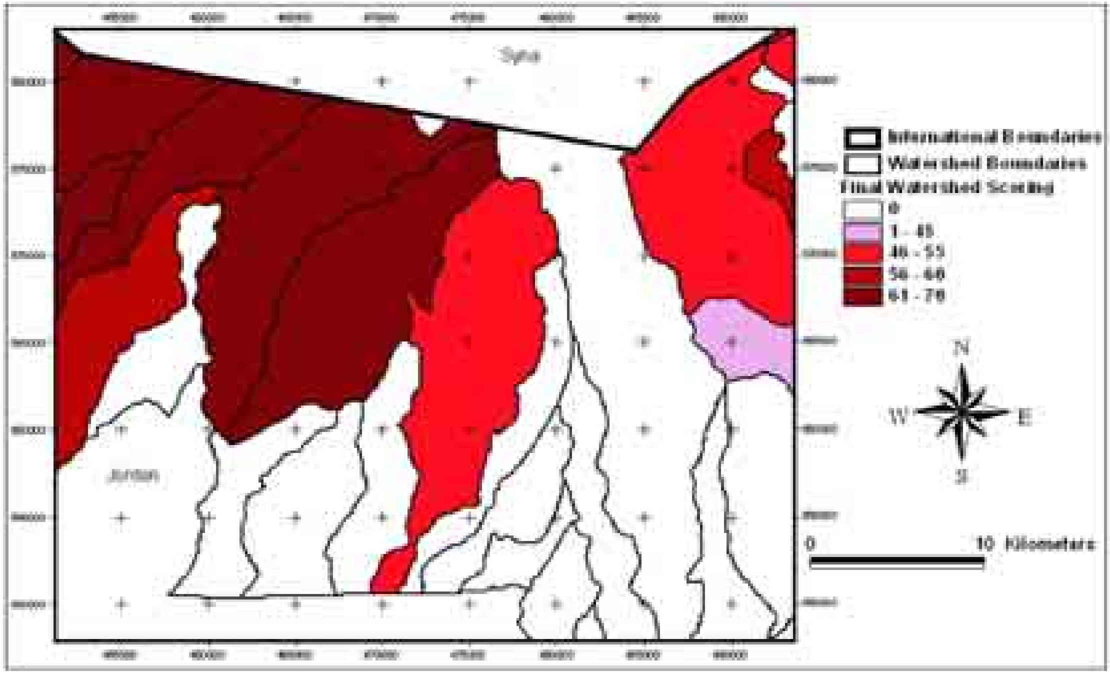


Figure 14: Examples of watersheds excluded because they crossed international boundaries.

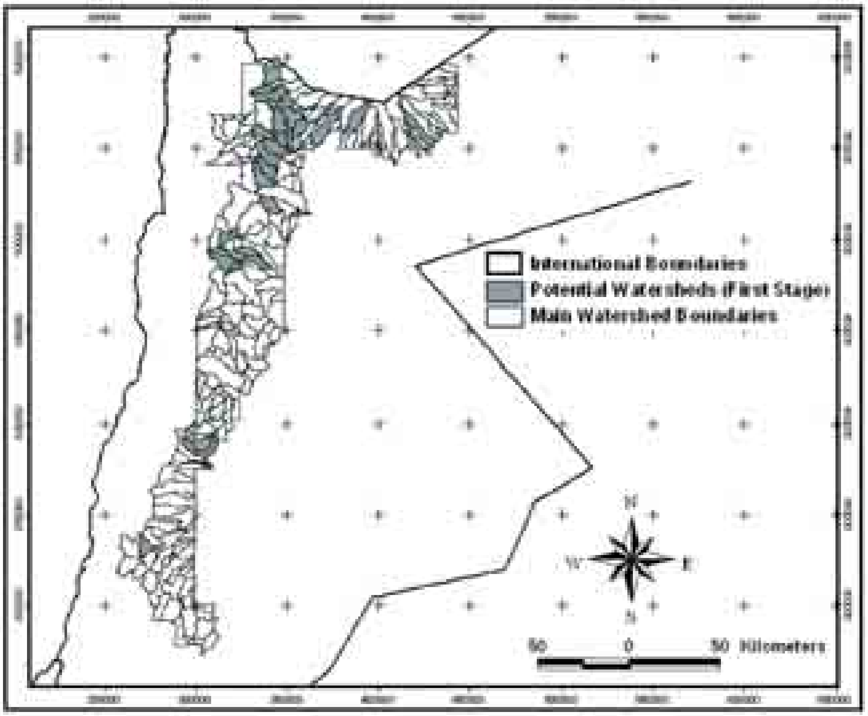


Figure 15: Final selection of potential watersheds (first stage).

Second stage: Application of criteria and intermediate selection

Applying the selection criteria for the second stage of selection

In the second stage of selection, additional criteria were applied to the 26 watersheds selected in the first stage in order to reduce their numbers. Because the criteria used at this stage were more detailed than those used in the first stage of selection, lengthy team discussions were required. The modifications and the rationale behind the choice of criteria used at this point were fully discussed previously. The application of these criteria is discussed below.

First criterion: soil depth

Information about soil depth was obtained from field observations made during the National Soil Map and Land Use Project (NSMP). This recorded 3047 observations within the 26 watersheds in question. These observations were converted into ArcView shape files with known geo-referenced data. An example of the distribution of the field observations and soil depth values obtained across a watershed is provided in Figure 16. This data was intersected spatially with the watershed boundary layer, thus enabling researchers to identify all observations fall within each watershed. ArcView functions were then used to calculate average soil depth in each watershed using all the observations made within the watershed. The table produced, which included soil depth averages, was merged with the attribute table of the watersheds to attach a soil depth value to each watershed.

The criteria given in Table 2 were used to score and rank each watershed according to average soil depth (see Table 5 and Figure 17). Table 5 and Figure 17 indicate that the scores assigned to the watersheds generally placed them in low classes (indicating shallow soils). None of the watersheds fell into either the first or the second classes. This is because soils in the Badia are generally shallow.

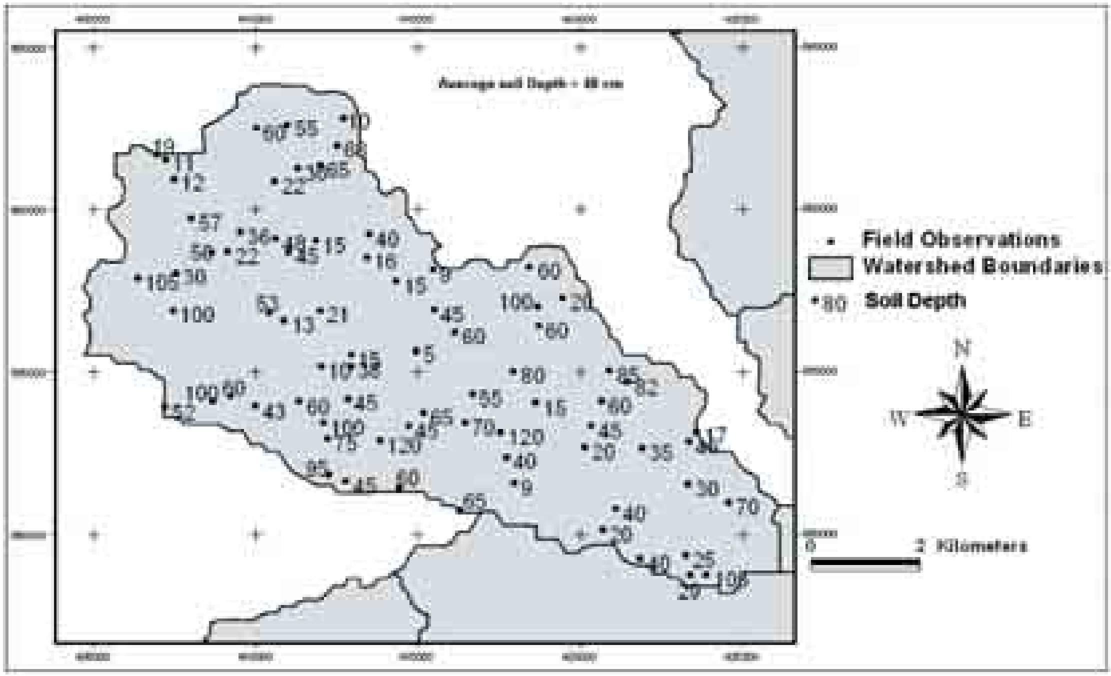


Figure 16: Soil depth values based on field observations within a watershed.

Table 5: Average soil depth and soil-depth scores for different watersheds.

Watershed no.	Average soil depth (cm)	Soil-depth score	Watershed no.	Average soil depth (cm)	Soil-depth score
173	43.2	4	16	58.5	3
103	44.1	4	28	59.3	3
174	44.3	4	17	61.4	3
62	45.0	4	36	62.2	3
58	47.0	4	108	65.6	3
13	48.2	4	18	66.8	3
79	48.3	4	30	66.9	3
199	50.3	3	59	67.3	3
54	50.6	3	122	68.9	3
19	53.0	3	123	71.9	3
51	54.8	3	128	79.4	3
29	55.6	3	125	80.6	3
35	58.3	3	31	88.5	3

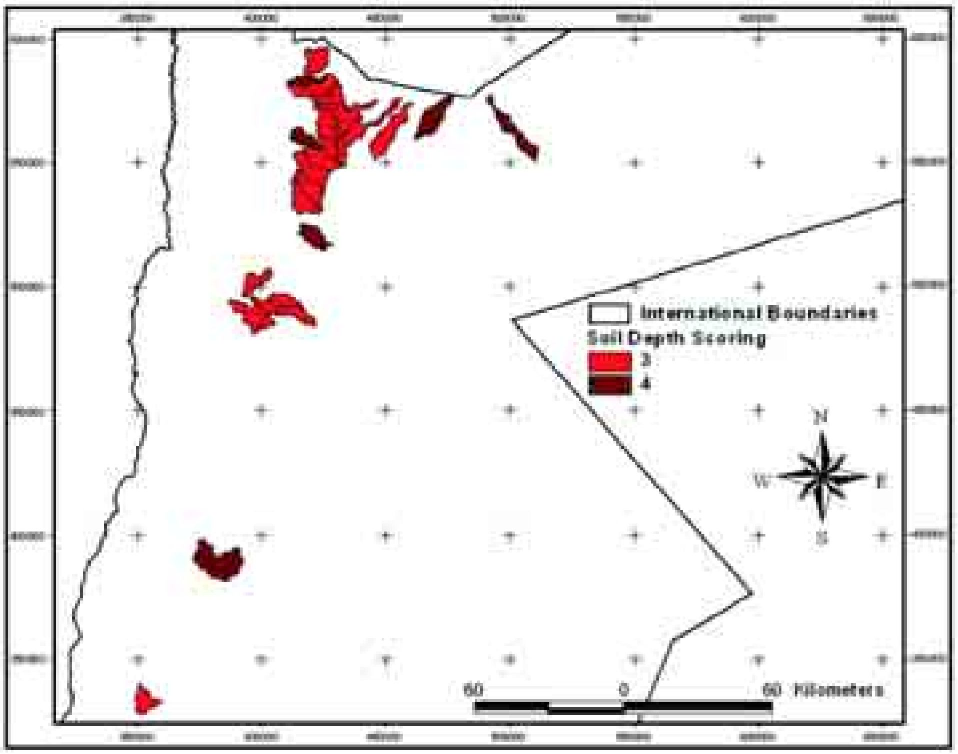


Figure 17: Watershed scoring according to soil depth.

Second criterion: slope steepness
The same field observations and procedures used to score the watersheds according to soil depth were used to score them according to slope steepness. Table 6 gives average slope values and scores for all 26 watersheds, while Figure 18 shows the distribution of watersheds with various scores.

Table 6: Average slope steepness and slope scores for different watersheds.

Watershed no.	Average slope steepness	Slope score	Watershed no.	Average slope steepness	Slope score
31	1.8	1	122	5.8	2
62	1.9	1	28	6.0	2
51	2.3	1	123	6.1	2
36	2.7	1	16	6.3	2
30	2.8	1	29	6.4	2
125	2.9	1	18	6.4	2
79	3.3	1	17	6.5	2
103	4.1	1	174	6.6	2
35	4.4	1	58	6.7	2
128	4.9	1	19	7.4	2
59	4.9	1	13	8.7	3
54	5.3	2	199	9.3	3
108	5.8	2	173	10.6	4

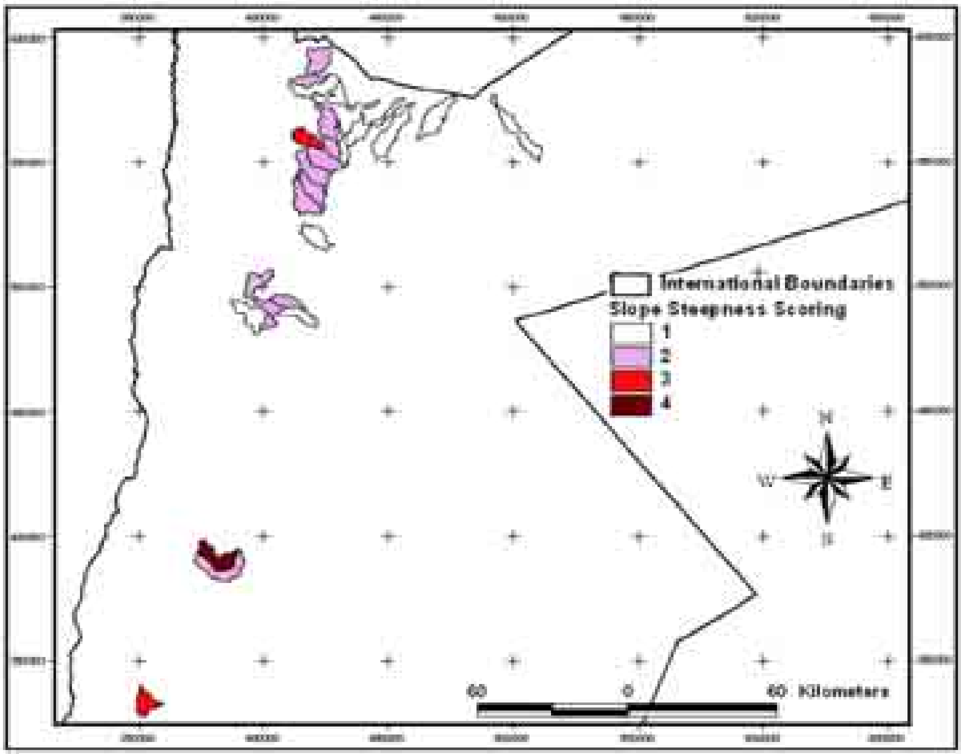


Figure 18: Watershed scoring according to slope steepness.

Third criterion: community
The method used to evaluate the community criterion at this stage was different from that used to evaluate "community" in the first stage, as at this stage researchers took into account the number and distribution of villages within a given watershed. The layer which shows how the villages were distributed was superimposed onto the layer showing watershed boundaries (see Figure 19).

Each watershed was then assessed visually and a score assigned for the community criterion. This was done according to the scoring system outlined in Table 2. See also Figure 19 which shows the community scores for the watershed and so will clarify the relationship between the scores and the way the villages are distributed. The scores assigned to all watersheds according to community distribution are shown in Figure 20.

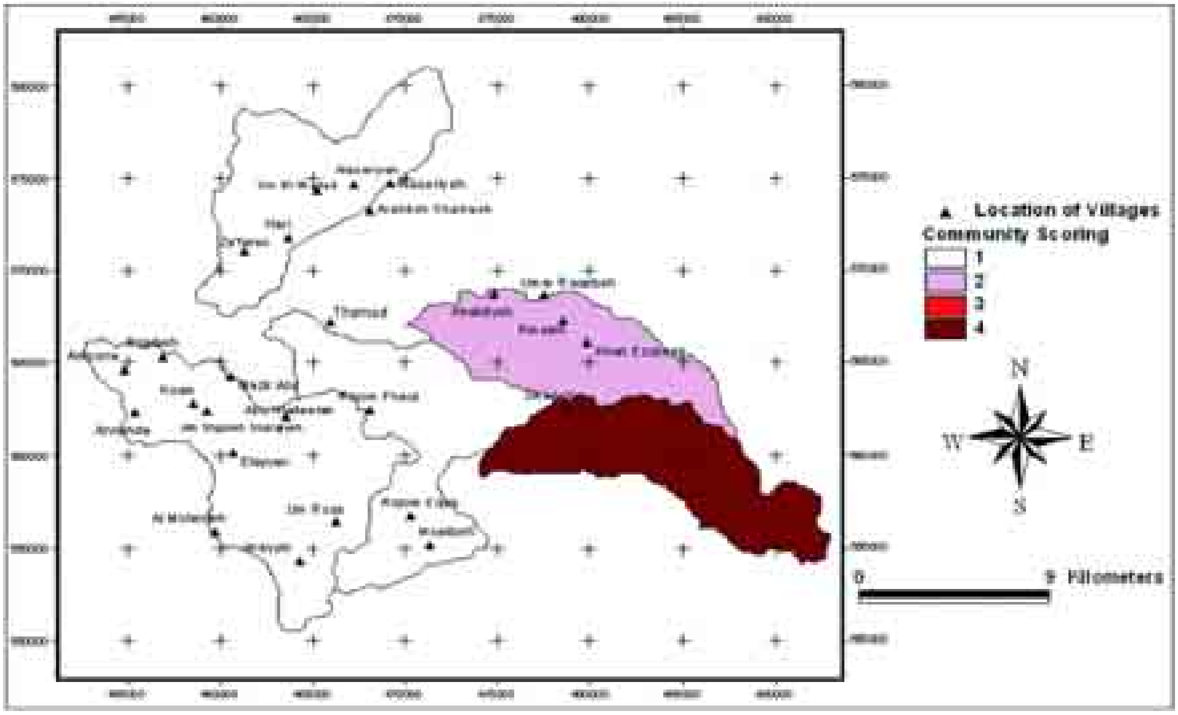


Figure 19: Distribution of villages with respect to watershed boundaries.

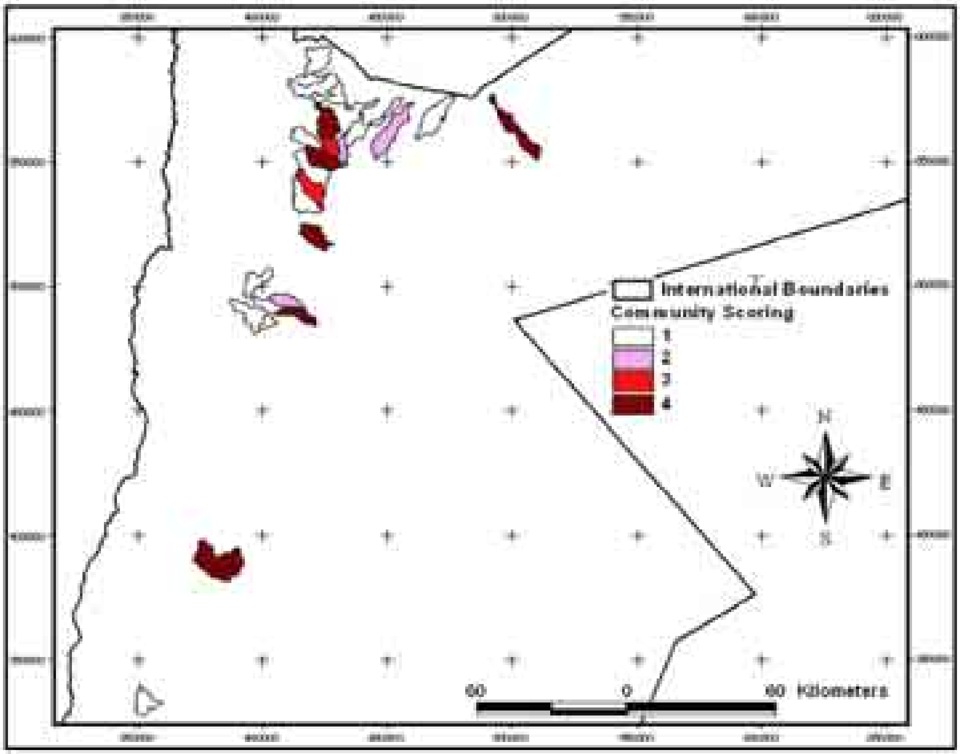


Figure 20: Watershed scoring according to community distribution.

Fourth criterion: rangeland-based system
The type of vegetation present was also recorded for the field observations made during the National Soil Map and Land Use Project (NSMP). Using ArcView, all field observations made within each watershed were placed in a database recording all existing vegetation types and occurrences in each watershed. The percentage of each vegetation type found within a watershed was then calculated by dividing the number of observations recorded for a given type of vegetation by the total number of observations within the watershed. These percentages were used to gauge the dominant type of vegetation within each watershed.

The different types of vegetation found in the watersheds were classified by the project's rangeland specialist into three classes (Table 2): (i) native, (ii) barley, and (iii) irrigated crops. This classification scheme was used to score the watersheds according to dominant vegetation type. An example of the types of vegetation within a watershed, and of the classification and scoring system used for this criterion, is given in Table 7 for watershed number 13. The scores for all watersheds are shown in Figure 21. From this it can be seen that the watersheds were scored to only the first and the second scores, with more watersheds scored as first with respect to this criterion. This indicates that the area is dominated by either native vegetation and/or barley. It should be mentioned that the field observations were made and recorded between 1990 and 1994 (over a decade ago). It is possible, therefore, that the type of vegetation present might have changed since then. That this is the best information available for the selected watersheds emphasizes the importance of the verification in the field that was undertaken by the project. This will be discussed later.

Table 7: An example of the scores assigned to a watershed according to the criteria concerned with the presence of a rangeland-based system.

Watershed number 13					
Vegetation type	**Classification**	**Count**	**Percentage**	**Summary**	
Grasses	Native	10	17	Class	Percentage
Yenton	Native	7	12	Native	73
Thistle	Native	6	10	Barley	8
Ado	Native	5	8	Irrigated	18
Barley	Barley	5	8		
Khurfaish	Native	5	8	Score	1
Olives	Irrigated	4	7		
Shia	Native	3	5		
Gaisum	Native	2	3		
Serra	Native	2	3		
Sheih	Native	2	3		
Barseem	Irrigated	1	2		
Cabbage	Irrigated	1	2		
Cauliflower	Irrigated	1	2		
Clover	Irrigated	1	2		
Flowers	Irrigated	1	2		
Jarger	Native	1	2		
Kheiss	Native	1	2		
Maize	Irrigated	1	2		
Peach	Irrigated	1	2		

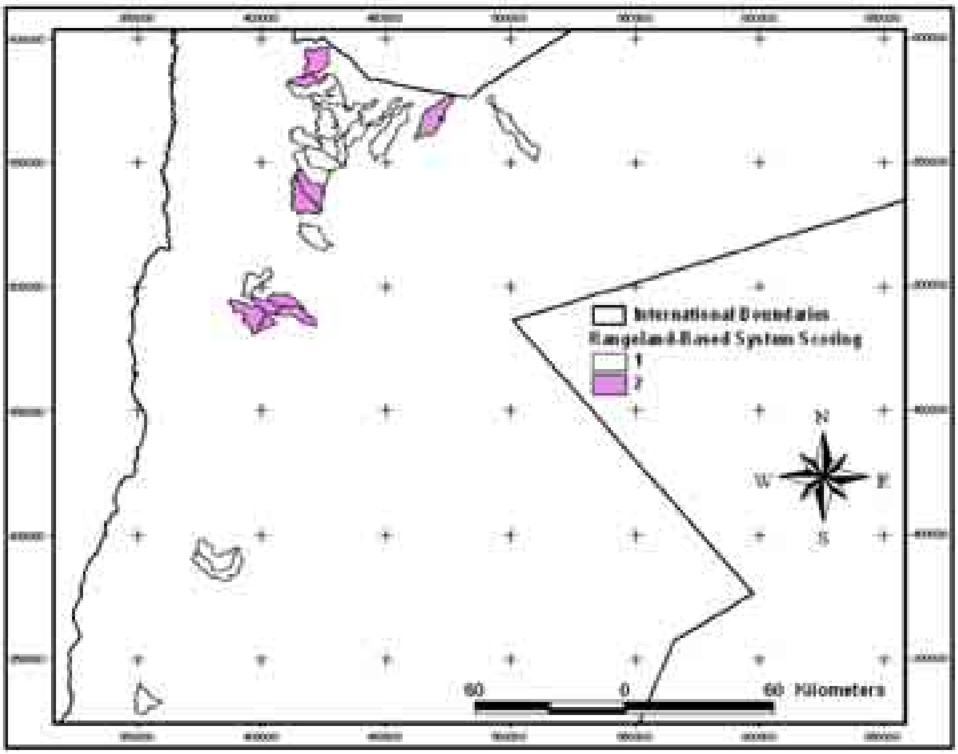


Figure 21: Watershed scoring according to rangeland-system criteria.

Fifth criterion: land use

When assessing the land-use criterion, researchers applied a procedure similar to that used when assessing the criterion concerned with the use of a rangeland-based system. In the database built using observations made in the field by NSMP, the land-use types were divided into various classes (see Table 8). It should be noted that these classes are different from the categories given in Table 2. This is because these classes were re-classified into the categories given in Table 2 in order to allow the project to score watersheds according to land-use type.

The percentage of each watershed that each land-use type accounted for was used to derive a score (see Table 9 for an example). In addition, information on livestock numbers within each watershed was also obtained from the Jordanian Department of Statistics. This was then used in combination with the land-use information to judge livestock numbers in the area. However, none of the watersheds exhibited obviously low numbers of livestock. Therefore, the scores applied mainly depended on land-use type (as illustrated in Table 9). The scores for all watersheds are shown in Figure 22.

Table 8: Land-use classes recorded for each field observation.

Land-use type	Classification	Land-use type	Classification
Cereals	Barley	Mixed tree/annuals	Field crop
Fallow	Barley	Natural browsing + grazing	Range
Forage	Range	Natural grazing	Range
Greenhouses	Field crop	Other field crops	Barley
Horticulture	Field crop	Planted forest	Range
Improved browsing + grazing	Range	Tilled	Barley
Improved grazing, pasture	Range	Tree crops, orchards	Field crop
Mix forest/grazing	Range	No vegetation, bare	Bare
Mixed cropping	Range and barley	Urban	Bare

Table 9: An example of how watersheds were scored according to land use.

Watershed number 174					
Land-use class	**Classification**	**Count**	**Percentage**	**Summary**	
Cereals	Barley	2	2	Range	36%
Fallow	Barley	25	27	Barley	62%
Natural browsing + grazing	Range	5	6	Bare	2%
Natural grazing	Range	27	30	Field crop	0%
Tilled	Barley	30	33		
No vegetation, bare	Bare	2	2	Score	2

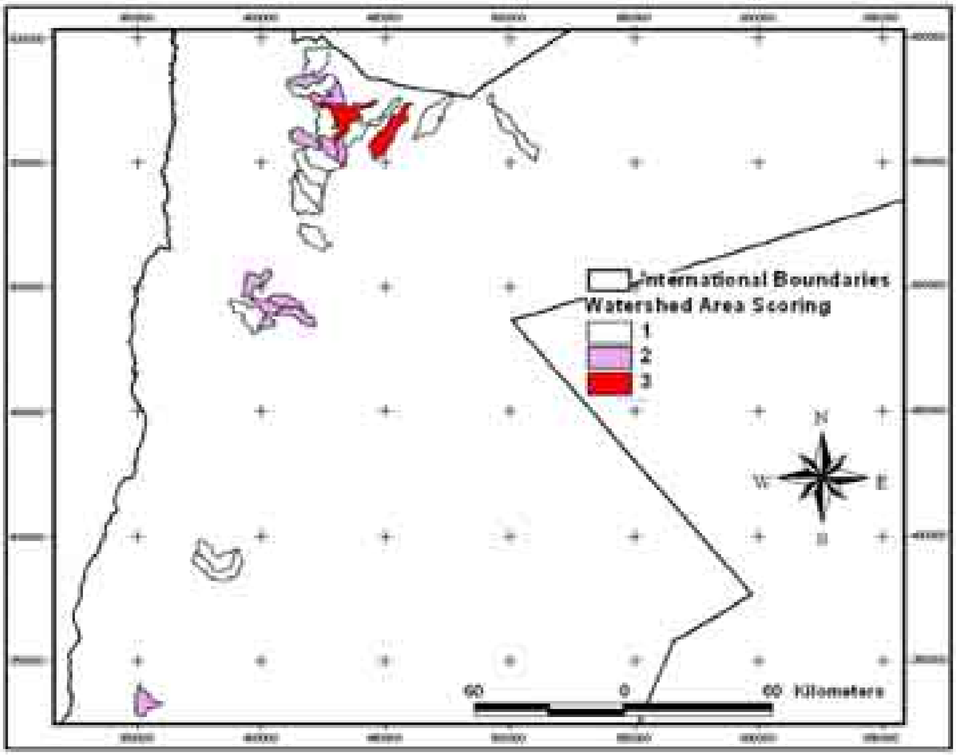


Figure 22: Watershed scoring according to land use.

Sixth criterion: watershed area
In stage 2, this criterion was scored in exactly the same way as it was in stage 1. As previously mentioned, this criterion was repeated to guarantee that the area of the selected watershed fell within the range deemed suitable for the various project activities. The scores assigned to all watersheds are shown in Figure 23.

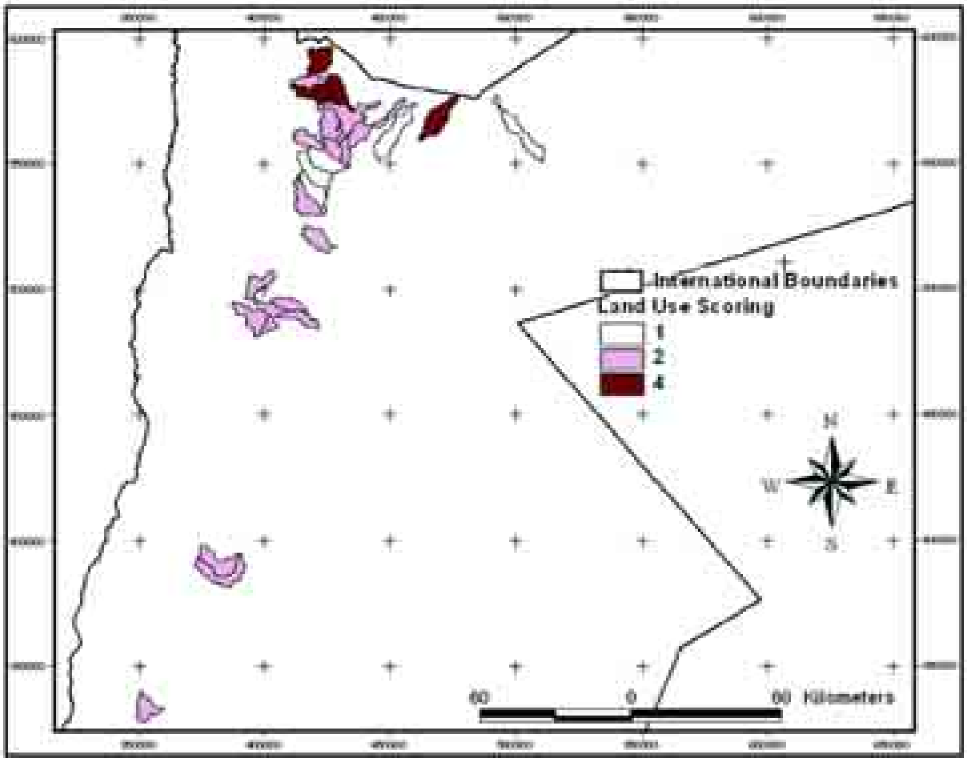


Figure 23: Watershed scoring according to watershed area.

Seventh criterion: accessibility and visibility

It has been assumed that the number of roads in a watershed dictates both the access that farmers have to their lands and how visible any interventions put in place are to the local farming community. Researchers superimposed the layer showing road networks over the watershed boundary layer to evaluate this criterion. Because the criterion being assessed is qualitative, researchers interpreted the results visually and scored the watersheds based on this. A distinction was made between main roads and secondary roads: main roads were given more weight in the selection process. Examples of how roads were distributed within watersheds, together with the scores assigned to these watersheds, are presented in Figure 24 to illustrate how this criterion was evaluated.

Figure 25 shows the scores assigned to all watersheds based on the accessibility and visibility criterion. With the exception of four of the watersheds, all were given a top score for accessibility and visibility (Figure 25). This indicates that the selection of watersheds in the study area may not be limited by accessibility or visibility.

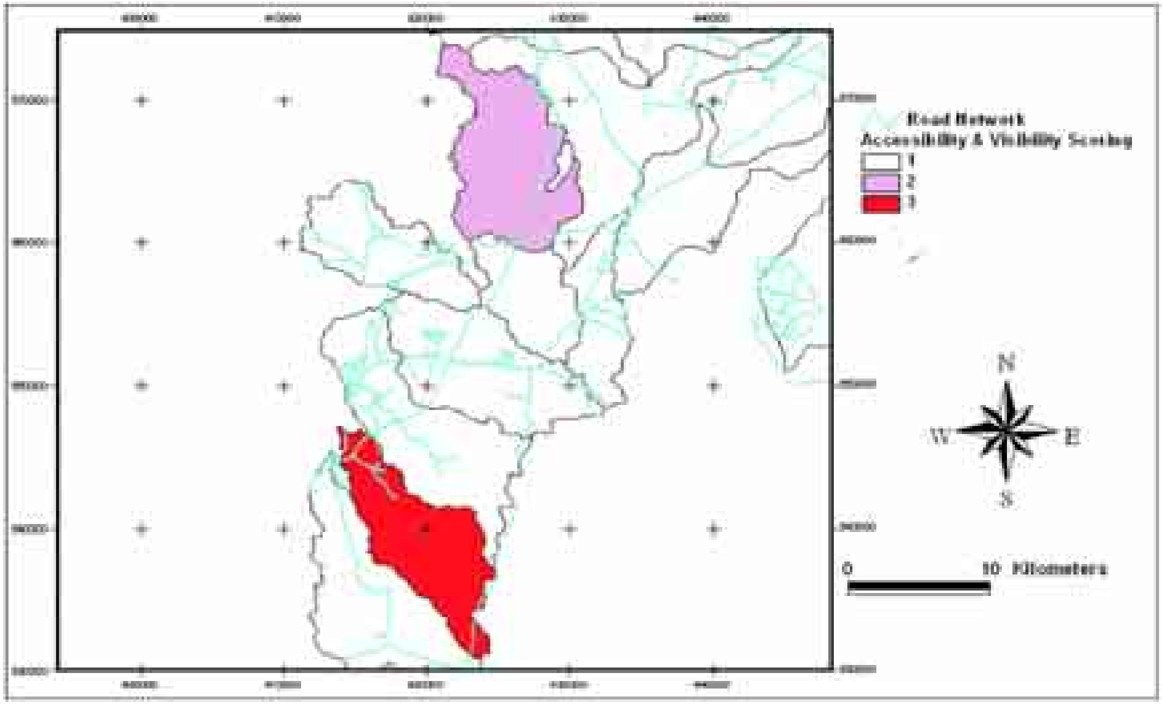


Figure 24: Distribution of roads within some watersheds and relevant scoring.

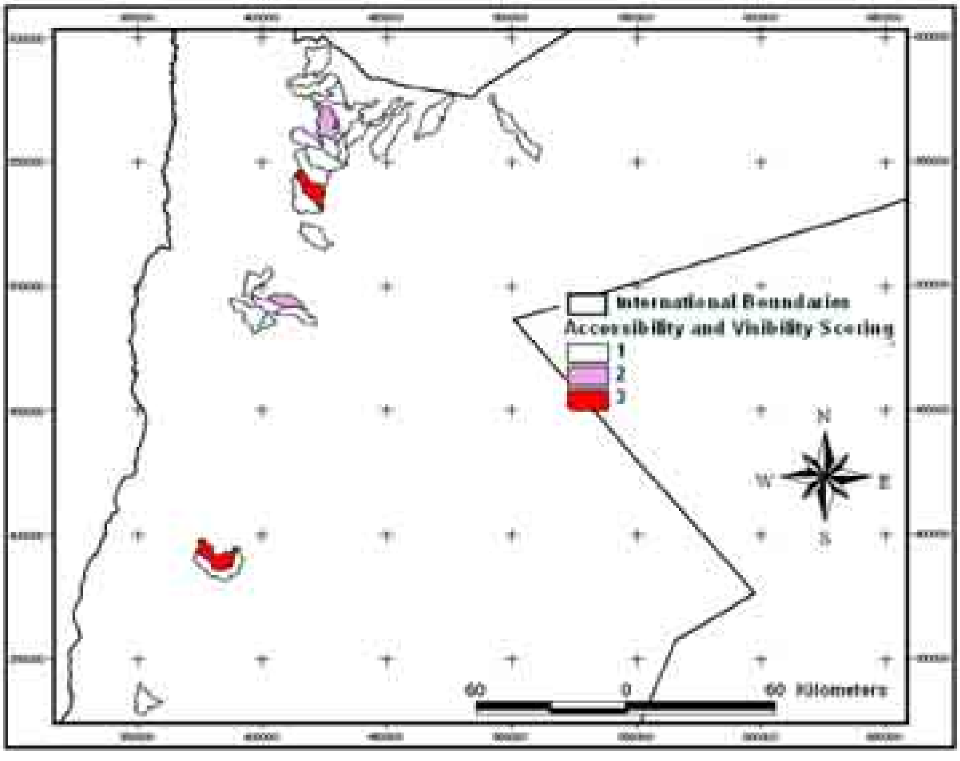


Figure 25: Watershed scoring according to accessibility and visibility.

Eighth criterion: land tenure

The Department of Land and Surveys (DLS) registers land by grouping individual parcels into blocks ("Ahuad") and blocks into villages. It was noted that the cost of creating digital layers which include detailed information about individual parcels would be very high for such a large area. In addition, it was also decided that for this level of selection such detailed information was not necessary. Instead, the DLS was asked to provide those digital layers which showed the boundaries of villages (the least detailed subdivisions), together with tabular information indicating the number of parcels and the type of ownerships associated with each village. This provided a layer which consisted of 128 polygons. Each of these represents a village boundary and contains relevant data on the type of land ownership present.

The types of ownership, as determined by the DLS, were classified into four categories: Mulk, Meri, reserved Meri, and Meri-forests. Though each of these categories is fully defined by the DLS based on a number of considerations, for the purposes of this project it was sufficient to know whether the land in question was owned by the private sector or by the government. Therefore, the four categories were amalgamated into two categories ("privately owned" or "government owned") based upon the DLS definition of each type. Data were then processed to calculate the percentages of government and private ownership found within each village. Using the system of scoring given in Table 2, each village was then assigned a score based on the percentage of the two types of ownership found there (Table 10). The relationship between the boundaries of villages and watersheds is illustrated in Figure 26.

Table 10: Scoring of villages based on the dominant type of ownership identified by the Department of Land and Surveys (DLS).

DLS village code	Privately owned (%)	Government-owned (%)	Score	DLS village code	Privately owned (%)	Government-owned (%)	Score	DLS village code	Privately owned (%)	Government-owned (%)	Score
2609	100	0	**2**	**2202**	99	1	**2**	**1142**	99	1	**2**
2618	100	0	**2**	**3102**	100	0	**2**	**1328**	100	0	**2**
5129	90	10	**2**	**3103**	96	4	**2**	**1129**	100	0	**2**
2606	100	0	**2**	**3107**	99	1	**2**	**1306**	55	45	**1**
5133	100	0	**2**	**4205**	100	0	**2**	**1327**	99	1	**2**
5139	100	0	**2**	**5207**	100	0	**2**	**1305**	97	3	**2**
2402	100	0	**2**	**3125**	100	0	**2**	**1106**	100	0	**2**
5136	100	0	**2**	**3202**	97	3	**2**	**1312**	18	82	**3**
5130	100	0	**2**	**3204**	100	0	**2**	**1329**	50	50	**1**
2506	92	8	**2**	**3206**	95	5	**2**	**1127**	96	4	**2**
2612	100	0	**2**	**4201**	90	10	**2**	**1147**	97	3	**2**
5124	95	5	**2**	**4204**	100	0	**2**	**1112**	59	41	**1**
2611	87	13	**2**	**4202**	100	0	**2**	**6203**	37	63	**1**
5112	86	14	**2**	**1130**	100	0	**2**	**6213**	54	46	**1**
5104	100	0	**2**	**1125**	100	0	**2**	**6401**	99	1	**2**
5126	92	8	**2**	**1123**	98	2	**2**	**6135**	46	54	**1**
5119	99	1	**2**	**1337**	36	64	**1**	**6111**	45	55	**1**
5113	77	23	**2**	**1145**	100	0	**2**	**6317**	91	9	**2**
5120	100	0	**2**	**1326**	61	39	**1**	**6319**	99	1	**2**
2202	99	1	**2**	**1135**	97	3	**2**	**6310**	79	21	**2**
5101	100	0	**2**	**1314**	96	4	**2**	**7108**	95	5	**2**
5123	91	9	**2**	**1326**	61	39	**1**	**7101**	75	25	**1**
2402	100	0	**2**	**1336**	61	39	**1**	**7106**	100	0	**2**
5114	91	9	**2**	**1139**	97	3	**2**	**7201**	94	6	**2**
5125	96	4	**2**	**1131**	70	30	**1**	**7202**	91	9	**2**
5147	92	8	**2**	**1146**	98	2	**2**	**7120**	96	4	**2**
5122	100	0	**2**	**1111**	98	2	**2**	**8304**	100	0	**2**
5129	90	10	**2**	**1341**	75	25	**1**	**8301**	71	29	**1**
5115	100	0	**2**	**1340**	24	76	**3**	**2202**	99	1	**2**
5134	92	8	**2**	**1149**	83	17	**2**	**8101**	100	0	**2**
5138	97	3	**2**	**1330**	54	46	**1**	**8303**	100	0	**2**
5131	90	10	**2**	**1113**	89	11	**2**	**8401**	99	1	**2**
5137	97	3	**2**	**1311**	73	27	**1**	**8302**	100	0	**2**
3119	98	2	**2**	**1324**	71	29	**1**	**8102**	100	0	**2**
5116	99	1	**2**	**1318**	57	43	**1**	**8115**	37	63	**1**
5135	52	48	**1**	**1310**	62	38	**1**	**8106**	85	15	**2**
4303	69	31	**2**	**1338**	66	34	**1**	**8404**	94	6	**2**
5111	99	1	**2**	**1102**	100	0	**2**	**8208**	100	0	**2**
3302	95	5	**2**	**1334**	92	8	**2**	**5106**	100	0	**2**
3126	91	9	**2**	**1137**	100	0	**2**	**3101**	100	0	**2**
5103	100	0	**2**	**1302**	20	80	**3**				
3128	95	5	**2**	**1316**	51	49	**1**				
3110	100	0	**2**	**1307**	74	26	**1**				
3120	70	30	**1**	**1133**	92	8	**2**				

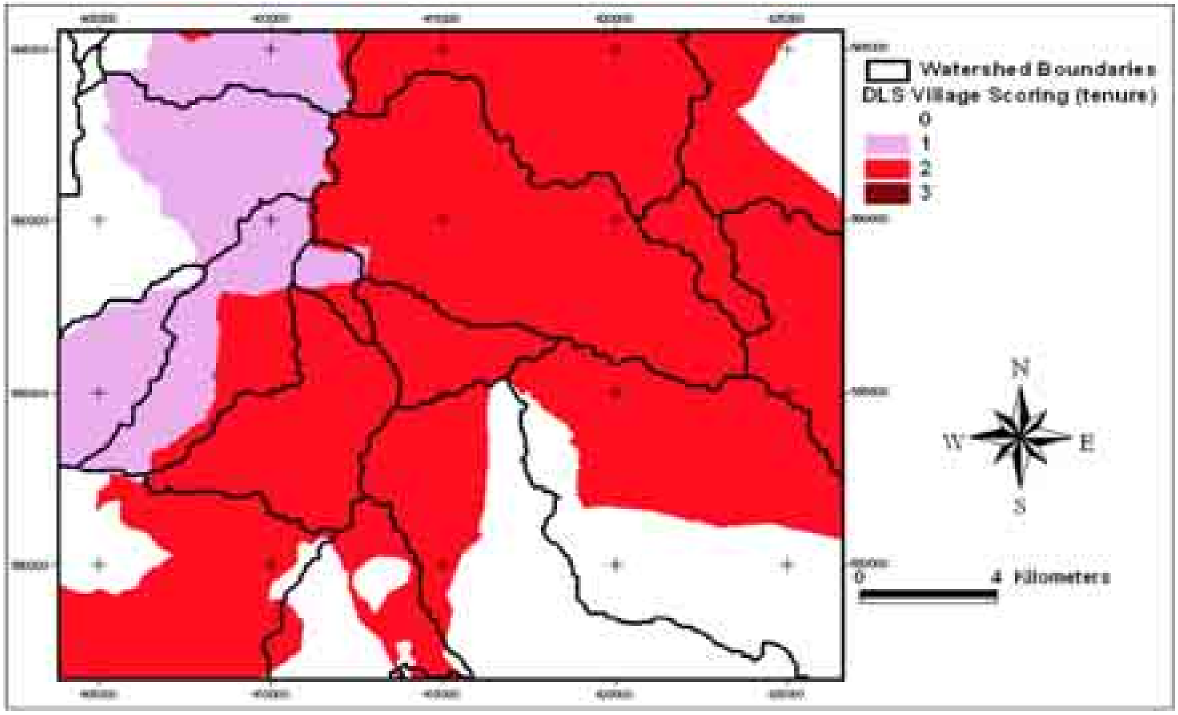


Figure 26: Example of the relationship between DLS villages classified according to land tenure and watershed boundaries.

Figure 26 illustrates that the boundaries of the DLS villages do not coincide with the watershed boundaries. Therefore, the digital layer which shows the DLS villages boundaries was intersected with the watersheds' boundaries. Using the system of classification given in Table 2, each watershed was then assigned a land tenure score based on the scores of all the villages found within it (see Figure 27). In the case of all except two of the watersheds, private ownership dominates (see Figure 27). However, it should be stressed that it is still possible to find some governmental land within these watersheds, though the percentages are very low. This is again due to the fact that the minimum amount of detailed information was used at this stage.

It is worth mentioning that information regarding ownership was not available for all villages, as indicated by those villages assigned a score of zero in Figure 26. It was decided that at this stage that sufficient information was available to verify the existence of private and government ownership. However future analyses, once a watershed had been selected, would require researchers to use all available information about land tenure, even that concerned with individual parcels.

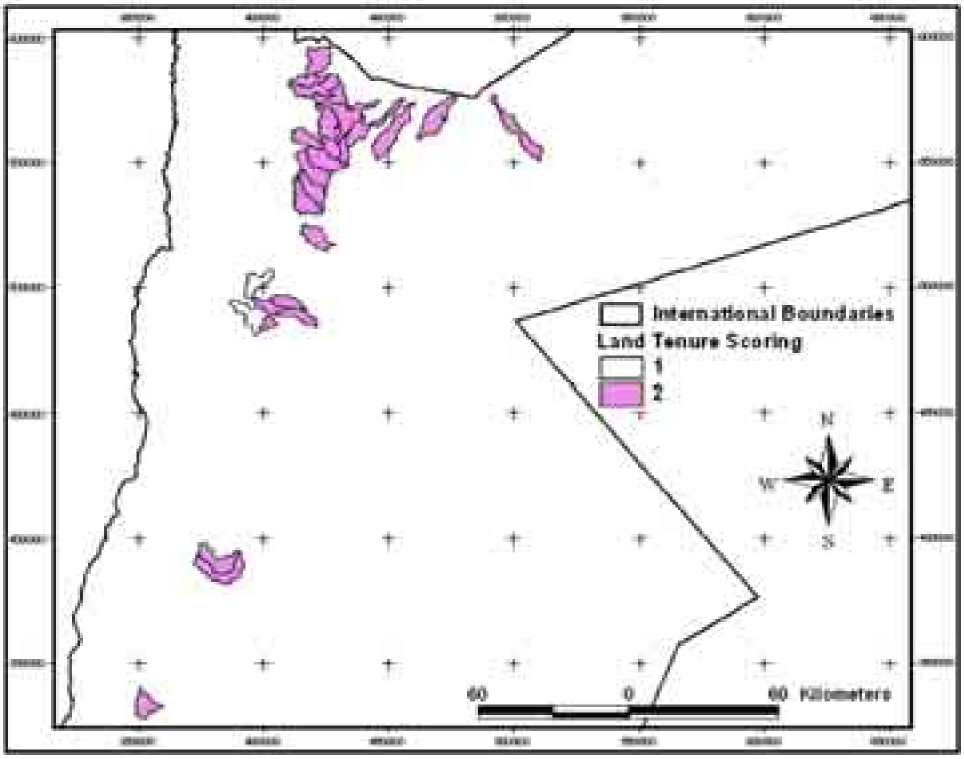


Figure 27: Watershed scoring according to land tenure.

Ninth criterion: basic data
As explained previously, the availability of basic information for a watershed should not be considered to be a selection criterion in the same way as the criteria discussed above should. In fact, the biophysical and socioeconomic criteria discussed above are more important than the availability of data. However, data availability was considered an important criterion when choosing between watersheds that have similar scores. It was therefore only considered when such cases arose.

Watershed selection (second stage)
For the final scores calculated for each of the 26 watersheds based on the eight selection criteria considered in the second stage, see Table 11.

Table 11: Final scores for the second-stage selection.

Water-shed number	Soil depth	Slope steepness	Comm-unity	Access-ibility & visibility	Water-shed area	Range-land system	Land use	Land tenure	Final* score
19	3	2	1	1	1	1	1	2	**12**
36	3	1	1	1	1	1	2	2	**12**
128	3	1	1	1	1	2	2	1	**12**
108	3	2	1	1	2	1	2	1	**13**
28	3	2	1	1	1	2	2	2	**14**
30	3	1	1	1	3	1	2	2	**14**
35	3	1	2	1	2	1	2	2	**14**
51	3	1	2	1	3	1	1	2	**14**
59	3	1	1	1	1	1	4	2	**14**
18	3	2	4	1	1	1	1	2	**15**
31	3	1	1	1	2	1	4	2	**15**
79	4	1	4	1	1	1	1	2	**15**
123	3	2	1	1	2	2	2	2	**15**
199	3	3	1	1	2	1	2	2	**15**
13	4	3	1	1	2	1	2	2	**16**
17	3	2	3	1	2	1	2	2	**16**
54	3	2	1	1	1	2	4	2	**16**
58	4	2	1	1	2	2	2	2	**16**
62	4	1	1	1	1	2	4	2	**16**
103	4	1	4	1	1	1	2	2	**16**
16	3	2	4	2	1	1	2	2	**17**
29	3	2	3	3	1	2	1	2	**17**
122	3	2	2	2	2	2	2	2	**17**
125	3	1	4	1	2	2	2	2	**17**
174	4	2	4	1	1	1	2	2	**17**
173	4	4	4	3	1	1	2	2	**21**

** Low scores indicate higher potential for water harvesting.*

The best score it was possible for a watershed to be assigned was 8 (where all criteria scored 1), while the worst was 32 (where all criteria scored 4). The results given in Table 11 indicate that the 26 watersheds tended to receive what would be considered a better score: the highest score for suitability was 12 and the lowest was 21. This indicates that the watersheds selected in the first stage all have the potential to satisfy the project's purposes. The distribution of watersheds and their final scores is illustrated in Figure 28.

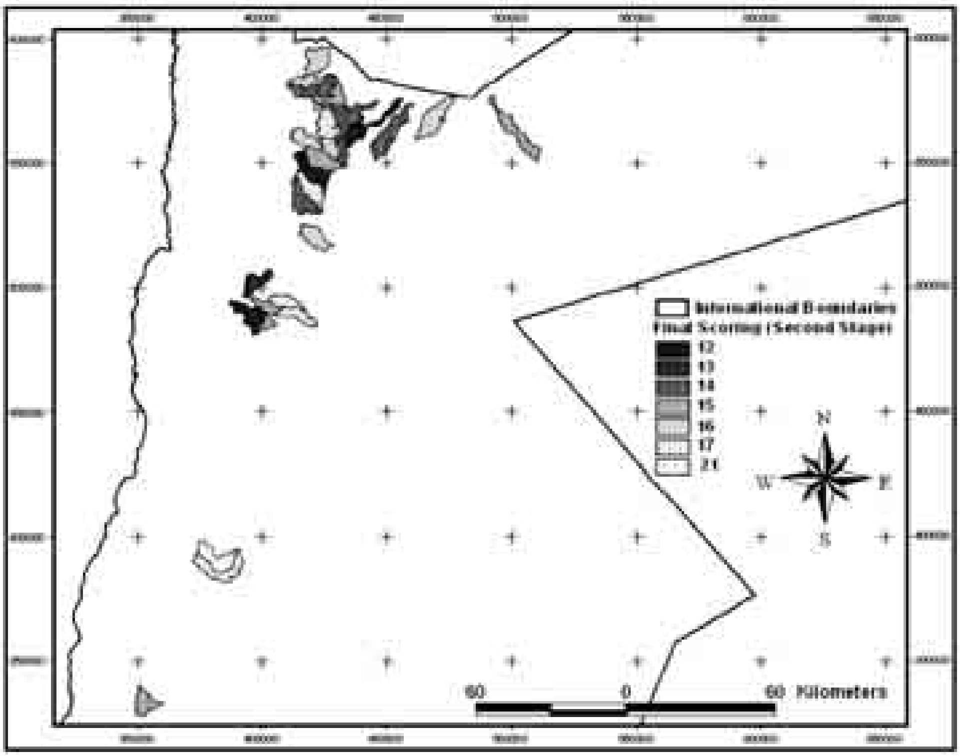


Figure 28: Distribution of watersheds with different final scores (second stage).

Nine watersheds (those with scores of 12, 13, and 14) were selected. The spatial distribution of these nine watersheds provides reasonably comprehensive of coverage of the Badia (Figure 28).

1.6 Field visits and outcomes

For the purposes of organizing the study, a detailed map was prepared for each of the nine watersheds and distributed to the whole project team. The maps show both the boundaries of each watershed as well as road networks. They also show villages and provide a coordinate grid. They helped investigators to navigate in the field and also to gather useful information about the watersheds, such as the actual distribution of communities. See Figure 29 for an example of the maps used. A copy of the map shown in Figure 28 was also sent to those involved, in order to show them how the various watersheds linked together.

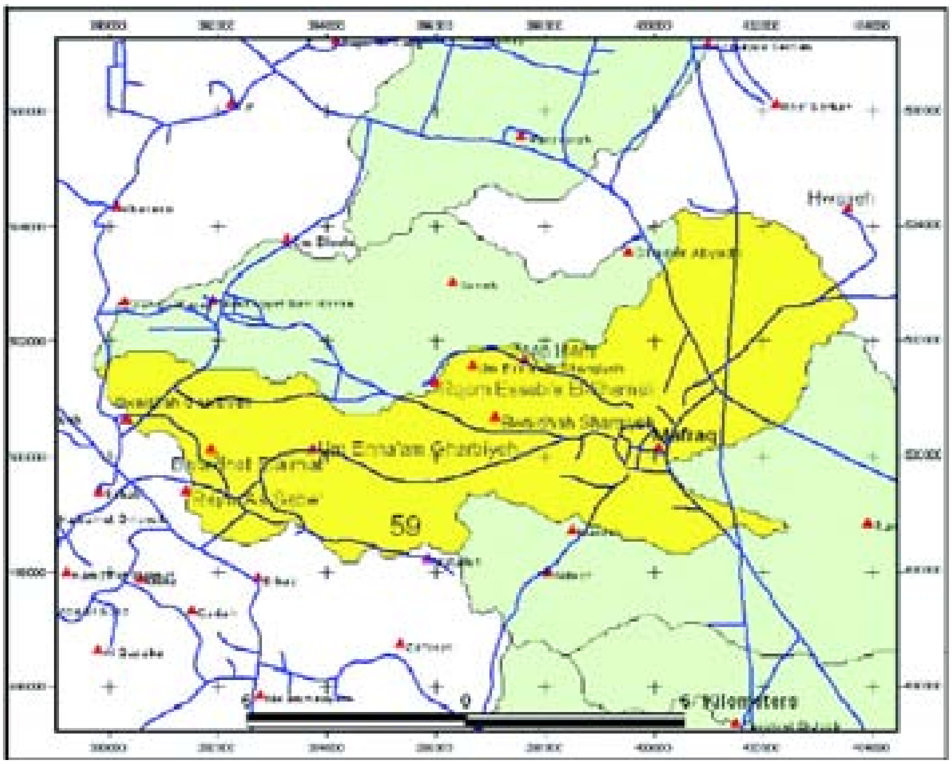


Figure 29: Watershed number 59: an example of the maps prepared for field visits.

As well as maps, a form was also prepared and distributed to team members in order to help them to document any observed advantages and disadvantages within a surveyed watershed (see Table 12). This form was designed to organize the collection of relevant information according to different disciplines, because the project team was made up of researchers from different disciplines. Team members were therefore also asked to make a final decision based on group discussions in the field. This was felt to be necessary because integrating the perspectives of the different disciplines is an important part of the selection process.

The field visits were completed in three days. During the first two days, all nine watersheds were visited and discussed by team members. Each member stated what

Table 12: Evaluation form used during field visits.

Watershed no.	
Evaluator	
Discipline/specialty	
Advantages of the watershed	
Disadvantages	
Group decision	
(choose one option)	Watershed to be included for further investigations
Any other comments	OR excluded

they felt were the advantages and disadvantages of each according to his or her point of view. Interaction between different disciplines was also discussed. The final decision regarding the selection or rejection of a watershed was made once all field visits for all the watersheds had been completed and the information gathered had been reviewed. This is because it was felt that the team would have a better overview of all the available alternatives at that point. Certain issues were highlighted by the team members during the field visits, some of which are listed below.

1. The large number of urban areas found within most of the watersheds visited was considered to be a disadvantage with regard to some project activities. This is partly because the selected watersheds were mostly within rainfall areas associated with urbanization (150-200 mm). Most villages are concentrated toward the west, where rainfall increases (Figure 6). The occurrence of dense settlements in the watersheds selected was also due to the criteria used when scoring communities in the first and the second stage, as this determined the minimum number of villages needed but not the maximum. Therefore, any watershed that included three villages or more, distributed over the whole watershed, was assigned a high score, regardless of how many villages there were. It might have been better to revise this criterion in order to set a limit beyond which the number of communities would begin to negatively affect project activities.
2. The high concentration of irrigated farms within some watersheds was considered to be a disadvantage because water harvesting would be less popular than intensive irrigated agriculture and so could not compete with it. During the second stage of the selection process, the scores assigned according to the rangeland system indicated that very few watersheds were dominated by irrigation. However, the records for this criterion were taken from field surveys undertaken in 1994. Over the last 10 years, it seems that many irrigated farms were established without being adding to the records. This highlights two issues: (i) the importance of considering the age of the data used for evaluating the selection criteria, especially those related to dynamic features such as land use and the community, and (ii) the need to verify the selection process by making field visits. The team therefore decided to evaluate the land use criterion through field visits which covered the whole watershed.
3. It has been also argued that most of the watersheds visited represent transitional Badia and are not typical of "rangeland". This is explained by the fact that the team decided to give areas that receive 150-250 mm of rainfall better scores than areas receiving less than 150 mm of rainfall. The decision is justifiable in that there is little opportunity to implement successful water harvesting techniques in areas which receive less than 150 mm of rainfall. In addition, areas that receive 150-250 mm of rainfall represent more of the Badia area. Therefore, it was decided to keep the rainfall scoring system used, and to search for watersheds with ecosystems typical of Badia receiving 150-250 mm of rainfall.

As a result of the issues discussed above, the team decided to revise the scoring system used with respect to the community criterion and to identify additional watersheds which could be added to the nine watersheds already selected. The final scores obtained for the first stage of selection (see Appendix A) were recalculated to exclude the community score (i.e. the watershed scores without taking into account the community criterion). This was done because people owning land within a watershed do not necessarily live within its boundaries, though they probably live close to their land. The new watersheds were examined in order to select those with villages close to the watershed boundaries, though not necessarily within them.

The following watersheds received high scores without including the community score (see Appendix A), and also there was a fair number of communities close to these watersheds: 100, 101, 104, 118, 119, 126, and 127. For the distribution of these watersheds, see Figure 30.

At this point it was decided to exclude watersheds 100 and 101, because they were located outside the area which receives less than 150 mm of rainfall. The watersheds that remained (Figure 30) were visited and evaluated in the field. In all, 14 watersheds were evaluated during the field visits.

Final discussion and selection

The team held a final meeting after the field visits. During this, the results of the field visits were thoroughly discussed in order to determine which watersheds should be advanced to the third stage of the selection process.

The team started the discussion (i) by considering all the watersheds and then eliminating those which they felt had any disadvantages, and (ii) by arranging the rest of the watersheds according to an agreed scaling methodology. Table 13 details the watersheds that were eliminated from further discussions due to obvious limitations. These judgments were reached by referring to the notes taken in the field by each expert (recorded on the form presented in Table 12).

The remaining watersheds were ranked according to how well they fitted certain criteria evaluated in the field. The team worked together during the meeting to agree upon a ranking for each watershed, again by referring to the form presented in Table 12 and the discussions held during

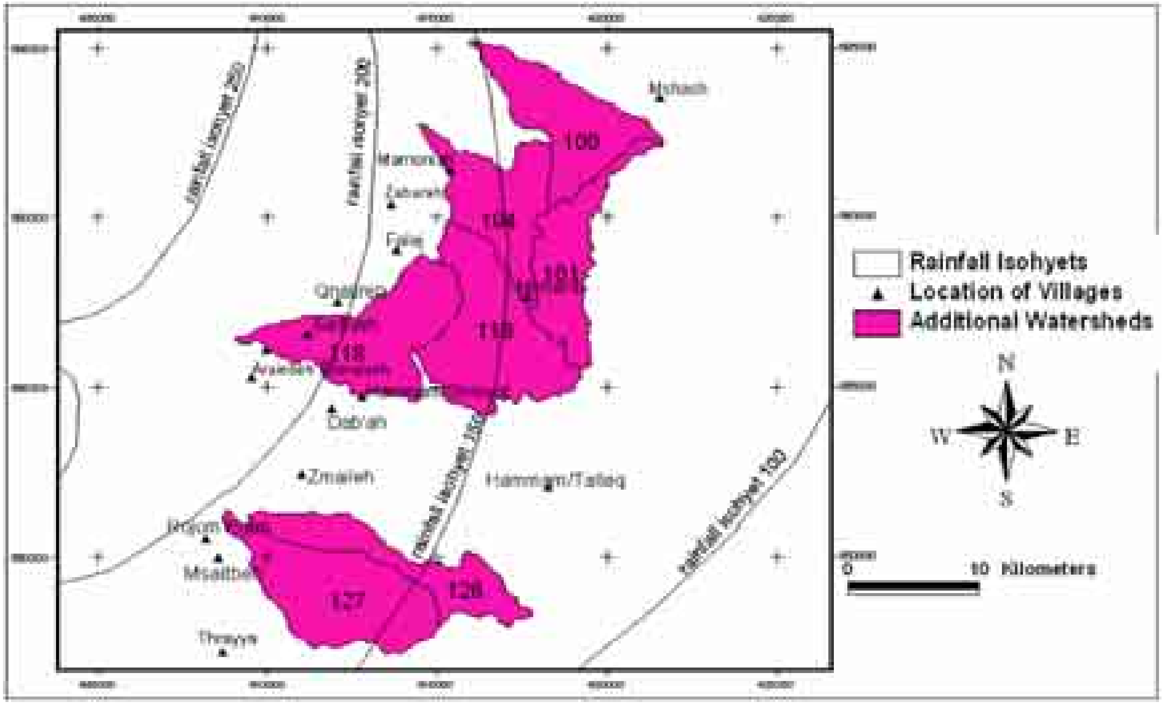


Figure 30: Watersheds selected after revising the community criterion.

the field visits. The results are summarized in Table 14.

The aim of this process was to summarize the observations made in the field into rational items relevant to the project. These items fall under three major headings: biophysical factors, water-harvesting-related factors, and socioeconomic aspects.
The production systems used were evaluated based on the dominance of the rangeland system, as assessed in the field. In addition, the community criterion was re-evaluated based on the size and distribution of communities and, most importantly, upon how willing community members were to participate in the project.
Urbanization was evaluated based on the density and distribution of urban centers.

The existence of institutions and of the past impacts of development projects needed to be thoroughly investigated. Assessment of these issues was therefore not dealt with until the third stage.

Here, "scaling out" is taken to mean the extent to which activities undertaken within the watershed can be extended and applied outside of it. "Competitiveness" is a term used to evaluate those activities already found in the watershed (e.g. industry and/or irrigation) which might compete with water harvesting and so lessen the impact of the project. All items except urbanization were scored from 1 (worst) to 3 (best). Urbanization, however, was scored in negative figures because it would have a negative impact on project activities by making land permanently unavailable for agriculture.

Watershed number 128 was excluded from further consideration (in the third stage) because of the very low scores it obtained in comparison with the other watersheds

Table 13: Excluded watersheds and the obvious limitation(s) which meant they were rejected.

Watershed number	Limitation(s)
19	- Reserved area which the public may not enter.
36	- Intensive irrigation. - Very limited community. - Dominated by flat topography.
28	- Very steep and stony watershed. - Industrial and urban activities.
35	- Intensive industrial zone.
51	- Intensive irrigation activities.
126	- Intensive irrigation activities.
127	- Dominated by flat topography. - Very limited community.
118	- Intensive irrigation activities.

Table 14: Ranking of the potential watersheds.

	Watershed number					
Criterion	**128**	**30+31**	**59**	**108**	**104**	**119**
Production system	1	2	2	2	3	3
Community	3	3	3	3	1	0
Urbanization	-3	-2	-2	-3	0	-1
Institutions	?	?	?	?	?	?
Development projects	?	?	?	?	?	?
Scaling-out potential	1	2	2	3	3	3
Competitiveness of water harvesting	1	2	2	2	3	2
Total score	**3**	**7**	**7**	**7**	**10**	**7**

considered (Table 14). In addition, watersheds 31 and 30 were combined, as they were adjacent and complemented each other in many respects. Ultimately, this stage of selection yielded a total of five watersheds (31&30, 59, 108, 104, and 119) which were forward for further detailed evaluation in the third stage of the selection process.

1.7 Stage three: Selection of the final watershed

The third stage of the site-selection process included the detailed investigation of (i) socioeconomic issues (through RRA), (ii) hydrological issues, and (iii) environmental issues (through impact assessments). All available information concerning the five watersheds was provided to the socioeconomic specialists responsible for undertaking each type of assessment. The following sections summarize the main findings of these investigations.

Rapid rural appraisal

The main results of the rapid rural appraisal are summarized in Table 15. The team scored different aspects of each watershed by assigning values that ranged from 0 (worst) to 5 (best). The sum of these scores was then used to rank the watersheds.

From a socioeconomic point of view, the most suitable watersheds were numbers 59, 104&119, and 108 (Table 15).

Rapid hydrological assessment

The selection process also considered the amount of surface runoff generated from rainfall throughout the whole watershed. Expected runoff coefficients were then calculated for the watersheds. These are summarized in Table 16. The results indicated that all watersheds were acceptable from a hydrological point of view.

Table 15: Summary of the results of the rapid rural appraisal.

Watershed	Community	Commitment to participate	Institutions	Agriculture-Livestock role	Poor community	Development projects	Total
30&31	Edon	0	-	-	-	-	0
	El-Jobb	2	5	5	1	5	18
	Abu-Hayal	0	-	-	-	-	0
	Mfradat	5	5	5	5	4	24
59	Um El-Naam	5	5	5	4	4	23
	Bayadet Al-Elemat	4	5	2	4	2	17
104&119	Majedia	5	1	5	5	5	21
	Moharib	5	1	5	5	5	21
108	Um Al-Walid	3	1	5	3	5	17
	Um Qaseer	5	3	5	4	5	22

Table 16: Summary of the hydrological assessment results.

Watershed no.	Yearly runoff (mm)	Yearly rainfall (mm)	Runoff coefficient
30	5.769	122	4.729
31	4.081	156	2.616
59	32.240	219	14.722
104	12.031	139	8.655
108	2.969	120	2.474
119	9.607	125	7.686

Rapid environmental assessment

A rapid environmental assessment was used to analyze existing land uses in relation to watershed characteristics, and to determine possible environmental constraints that might affect water-harvesting techniques in each watershed. According to the rapid environmental assessment, the most suitable watersheds were, in order of preference, 59, 108, and 104.

Final decision

The results of the above three investigations were synthesized to allow the multi-disciplinary project team to reach a final decision. The team then met and discussed the whole site-selection process, paying particular attention to the following:

1. The project's evaluation of the communities in each watershed.
2. The biophysical conditions found within each watershed.
3. The degree to which each area was representative of the Badia.
4. Any obvious hydrological and environmental impacts.

Ultimately, it was decided that two watersheds would be necessary to undertake project activities and that these should be representative of the wide range of conditions (biophysical and socioeconomic) found in the Badia. Consequently, watershed no. 104 was selected as the main watershed for the project, and watershed no. 59 as a supplementary watershed (see Figure 31).

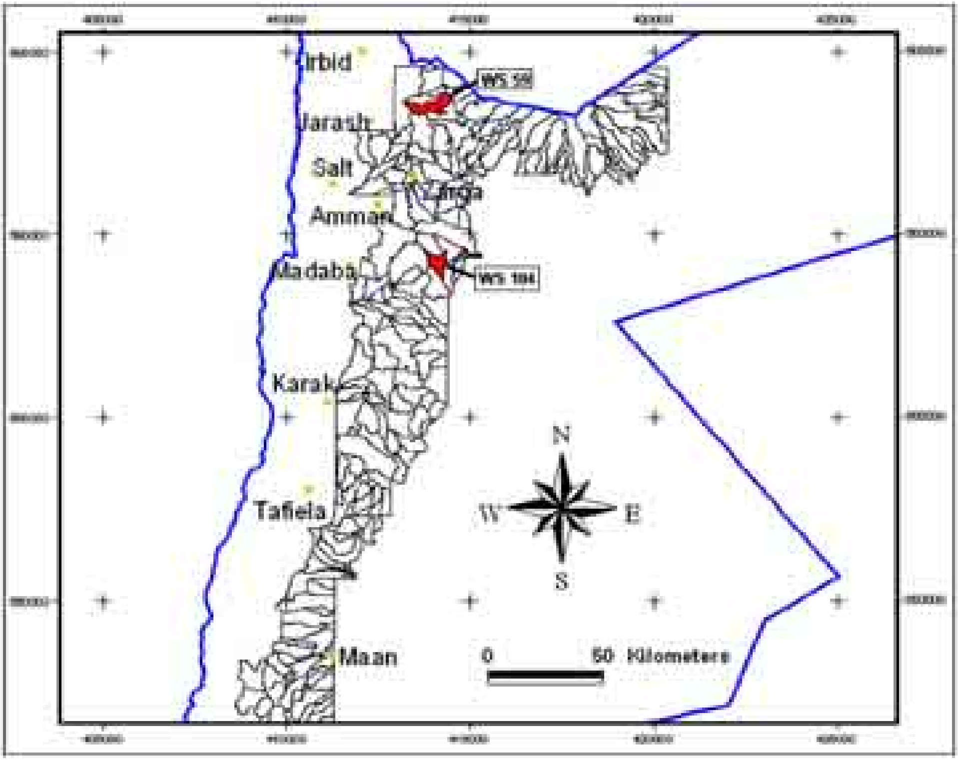


Figure 31: The locations of watershed nos. 104 and 59.

1.8 Concluding remarks

The approach followed when selecting the watershed most suited to the project's needs was multi-disciplinary, and took into account the concerns of each of the different disciplines represented. The use of GIS tools and analyses was an indispensable part of this process. The distinguishing features of the approach used are considered below.

1. The subdivision of the selection process into three stages proved to be useful because the process covered a large geographical area which encompassed a variety of conditions. The first stage eliminated a large number of watersheds on the basis of general, but critical, criteria. This reduced the number of watersheds for which detailed analysis was required from a few hundred to 26. The second more detailed and thorough analysis was used to further reduce the number of watersheds being considered to nine.
2. Field visits were very important, as they highlighted certain limitations that arose from the use of both old and new databases and coarse maps. Field visits also led to the revision of some criteria, which resulted in more watersheds being added. The final inter-disciplinary discussions relied heavily on the field visits, and thus allowed the most promising five watersheds to be selected.
3. The level of detail used in the analyses varied at different stages in the process. And, analyses were made easier by the fact that fewer watersheds were investigated during the later stages. This is one of the important features of the proposed approach highlighted in this report.
4. It is expected that this approach could be used by similar projects working in similar areas. In fact, assuming that the basic information is available, the approach could be tailored to suit any selection process involving watersheds. Furthermore, a range of different criteria could be evaluated as the approach could incorporate different data types and use whatever information is available.
5. Use of GIS allowed both numeric and qualitative measures to be integrated. Of particular importance was the use of GIS databases to integrate the biophysical and socioeconomic factors identified by the team of specialists from different disciplines. The spatial presentation of results made clear what modifications on the evaluation procedure would be needed to achieve the best results.
6. GIS also facilitated the revision of criteria and the re-scoring that was required at various stages. This provided advantages which were most noticeable during the inter-disciplinary meetings used to reach consensus.

Finally, it is also necessary to highlight some key points which must be borne in mind when using the methodology:

1. All the information used when applying GIS must be harmonized in terms of the geographic locations considered. This is important because the layers produced will be analyzed together and any discrepancy will affect the final results.
2. A minimum amount of information must be available. Of particular importance is the accurate delineation of the watersheds' boundaries, which will determine the level of accuracy available for subsequent analysis.
3. The criteria used for selection must first be checked and revised by the relevant specialists, and then re-evaluated by the whole team. This will remove any discrepancies and conflicts between the different criteria used, so allowing the inputs made by experts from various disciplines to be better integrated. Each criterion and the data used to evaluate it should be crosschecked

against other available information. This will ensure that the results of the evaluation are reliable. In this regard, particular attention should be paid to how detailed the information used to evaluate each criterion is.

How old the information used is will play an important part in determining how relevant the results obtained are. This is especially important when dynamic features, such as urbanization and land use, are being considered. Information can be updated through ground-truthing (field verification).

Chapter 2: Characterization of the Selected Watersheds

2.1 Introduction

Watershed characterization aimed to provide data for the selection of sites suited to various water-harvesting interventions. To this end, data were collected from two watersheds (59 and 104). However, only data from watershed 104, the main watershed for the project, was analyzed. This is because the project will start implementing water-harvesting interventions 2005/2006 and it is important to finalize this analysis before implementation begins.

The main purpose of the characterization was to provide a suitability map showing the distribution of areas suited, from a biophysical point of view, to the various water-harvesting techniques the project will implement within the watershed. The process emphasizes the need for each unit to be suited to more than one type of intervention, in order to leave room to include socioeconomic issues in the selection process. In each case, in fact, the intervention selected for an area must be acceptable biophysically and socially and economically.

This report describes the procedures followed to achieve this. Specifically, it first explains the procedure followed during data collection, which involved both accessing existing data and gathering data in the field. Next, it explains the procedure used for the suitability analysis. Finally, it explains the main output and the procedure used to integrate this output with future activities.

2.2 Data Collection

Available data

This section explains the procedure used to compile GIS data for the project. Data were gathered from various sources and in various formats. The first step, therefore, was to ensure that it was compatible with the data that would be used later. The next step was to construct GIS layers from the collected data.

Data from the Royal Jordanian Geographic Center (RJGC)

The following topographic information was extracted from topographic maps with a scale of 1:50,000. This was the best scale available for the study area.

1. Contour lines (as line coverage), with a height value being given for each contour. In addition to this layer, spots were also provided that showed where heights had been recorded in the field. Figure 32 shows the two layers for watershed 104; similar data is also available for watershed 59.

Source: Royal Jordanian Geographic Center (1:50,000 topographic maps)
Figure 32: Contour lines and spot heights for watershed no. 104.

Source: Royal Jordanian Geographic Center (1:50,000 topographic maps)
Figure 33: Streamlines for watershed no. 104.

2. Streamlines (Figure 33). This layer was used with the contour lines to delineate sub-watershed boundaries.
3. A digital elevation model (DEM). RJGC used the contour lines available to generate a DEM with a resolution of 20 m for both watersheds (Figure 34). For the purposes of interpolation, contour lines were used as the main layer while the above-mentioned spot heights and streamlines provided supplementary information. This improved the accuracy of the interpolation.

Data derived from topographic information

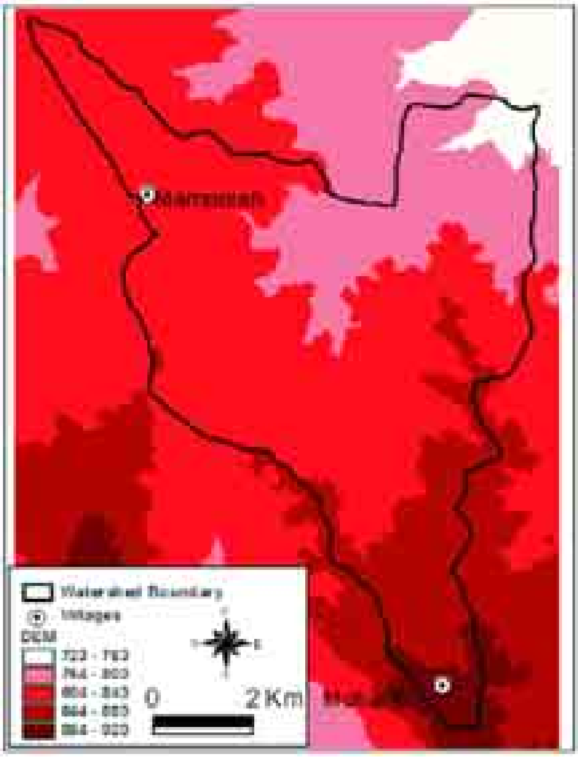
The following layers were derived from the topographic information available

1. Watershed sub-division

Each watershed was divided into sub-watersheds visually, using the contour lines (Figure 32) and streamlines (Figure 33) provided by RJGC. This was done to make it easer to select areas in which special water-harvesting interventions, such as small dams and hafair (ponds), could be implemented. Subdividing each area was also intended to facilitate the hydrological analyses that would be undertaken in each watershed. The subdivisions for watershed no. 104 are shown in Figure 35.

2. Slope map of the watersheds

For each watershed, a slope map with a resolution of 20 m was derived from the DEM provided by the RJGC. The Arc/Info standard command (SLOPE) was used to



Source: Royal Jordanian Geographic Center (1:50,000 topographic maps, with interpolation)

Figure 34: Digital elevation model (DEM) for watershed no. 104.

Figure 35: Sub-watersheds within the main watershed no. 104.

derive slope grid. A 5x5 average (smoothing) filter was applied to clean the layer of small (suspicious) units. The grid was then converted into polygons to ready it for subsequent analyses. The final output of this process is shown in Figure 36.

Slope units derived from this step were used as basic mapping units when deriving suitability units. Theoretically, soil mapping units should be used for this purpose. However, this was not possible because the information provided by the soil map available for the area was far less detailed than was required for the analyses in hand. In the study area, however, a strong relationship exists between slope steepness and the distribution of soils. In addition, slope steepness is one of the most important criteria for the selection and implementation of water-harvesting interventions. Therefore, the project decided that slope units could justifiably be used when deriving suitability units for the area.

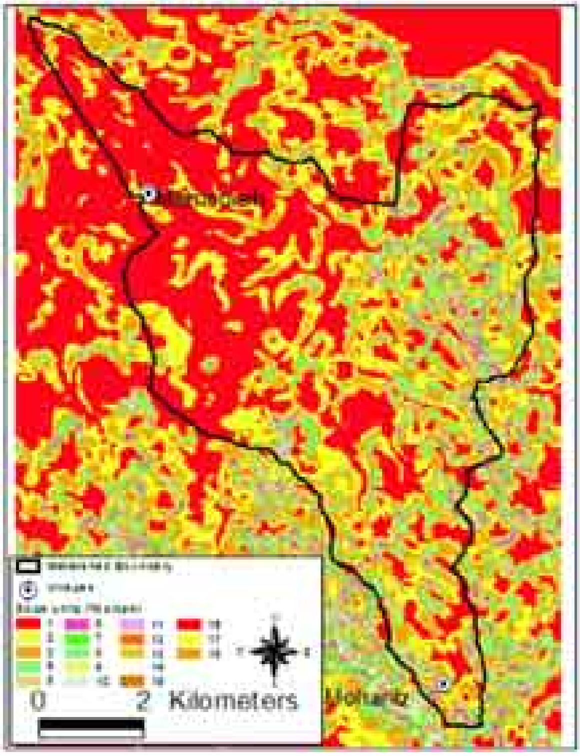


Figure 36: Slope units for watershed no. 104.

Data from the Department of Land and Surveying (DLS)

Cadastral maps

Jordan's Department of Land and Surveying (DLS) provided a dataset which included shape files suited to the Jordan Transverse Mercator (JTM) geo-referencing system. This meant that the files could be used in conjunction with the other data sets available for the project. Moreover, an additional field was added to the owners' attribute table to allow maps and attributes to be linked. The data was prepared for further analysis as follows.

1. Map sheets were joined together to generate one layer for each watershed.
2. Using the DLS-Key as a common field, each land parcel was linked to its owner name.

Figure 37 provides an example of the merged cadastral map for watershed no. 104. The data served two purposes:

1. The area of each parcel was used to identify land suited to water harvesting. Once a suitability map had been prepared, the cadastral map and the suitability map were overlaid to incorporate the area of the parcel as a criterion for selection. This was crucial for interventions that required a minimum area for implementation (see Table 18 in section 2.3 below).

2. The cadastral map created was used later in the project to identify the owner(s) of land suited to particular water-harvesting interventions. The socioeconomic team will use this information to approach the relevant owner(s) and begin negotiations concerned with implementation.

Source: Department of Land and Surveying (DLS)
Figure 37: Cadastral map for watershed no. 104.

Data collected in the field

The absence of detailed information about the soil in the area being investigated was an important limitation. The possibility of constructing a detailed soil map as a way of overcoming this was discussed. However, it was agreed that the high cost of mapping in detail was not justifiable. It was therefore decided that observations should be made in the field, at certain sampling intervals. These recorded only relevant soil and site properties.

Sampling procedure

Samples were collected using a method that constitutes a compromise between two extreme sampling methods: free sampling and grid sampling. Grids composed of uniformly sized cells were used (2000 m by 2000 m and 500 m by 500 m for watersheds no. 59 and 104, respectively). One field observation was taken from each cell. The surveyor was free to select the best site within each cell, in order to avoid an un-representative site being sampled. At the same time, this also ensured that various conditions within the watershed were sampled by distributing the sampling evenly across the grid (see Figure 38).

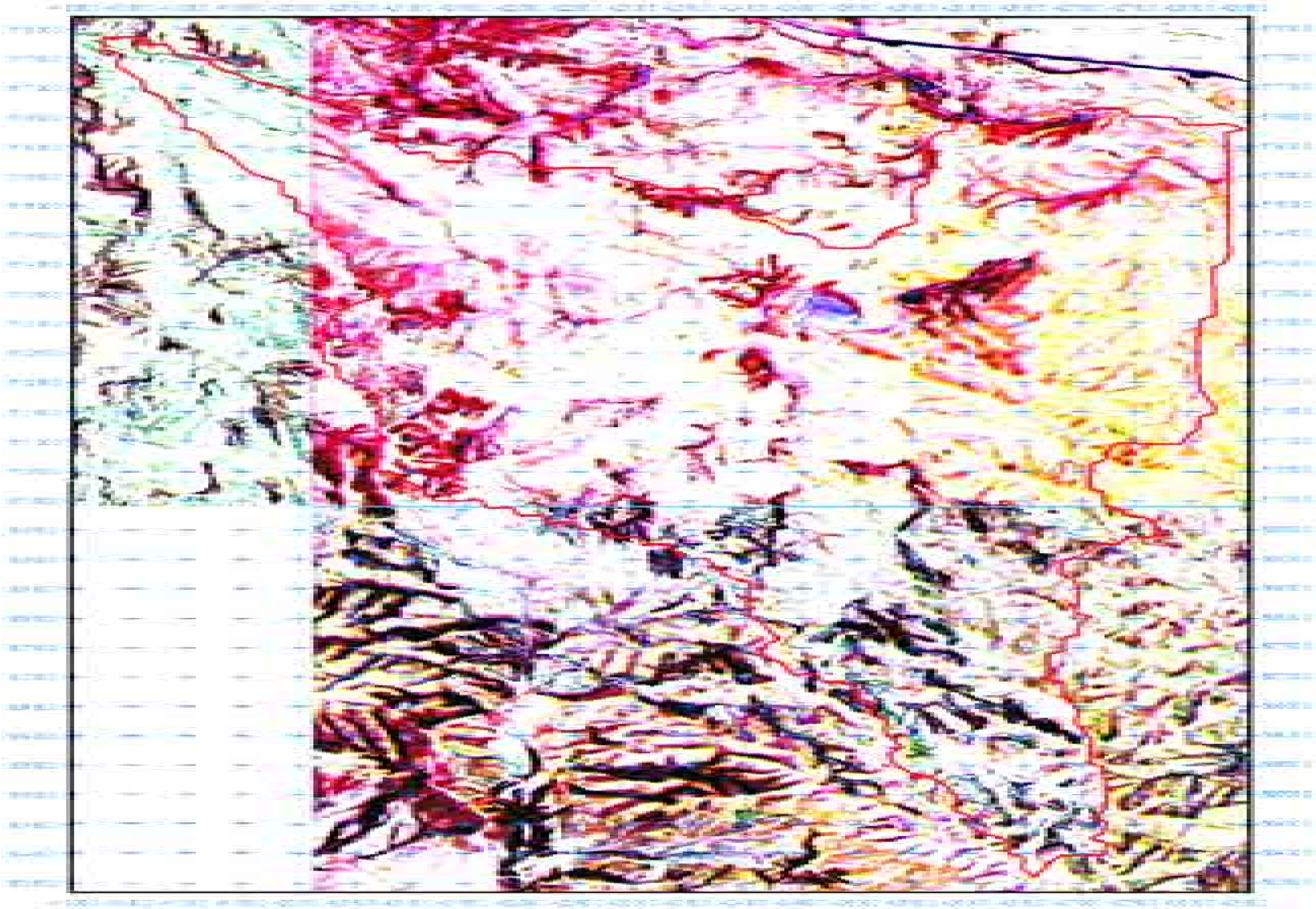


Figure 38: Sampling grid for watershed no. 104.

In total 138 sites were sampled in watershed no. 104. Nine of these were selected as representative of the dominant slope classes of that watershed, and for these sites some laboratory analyses were undertaken.

Only 27 sites were sampled in watershed no. 59, because the site had already been covered in some detail by a previous survey (Ministry of Agriculture, 1995).

Watershed no. 104, on the other hand, had received much less detailed coverage in that survey. This said, the few observations available for watershed no. 104 from the Ministry of Agriculture survey were still added to the total number of observations (increasing the total number of observations to 160). For the distribution of the observations made in the field, see Figure 39.

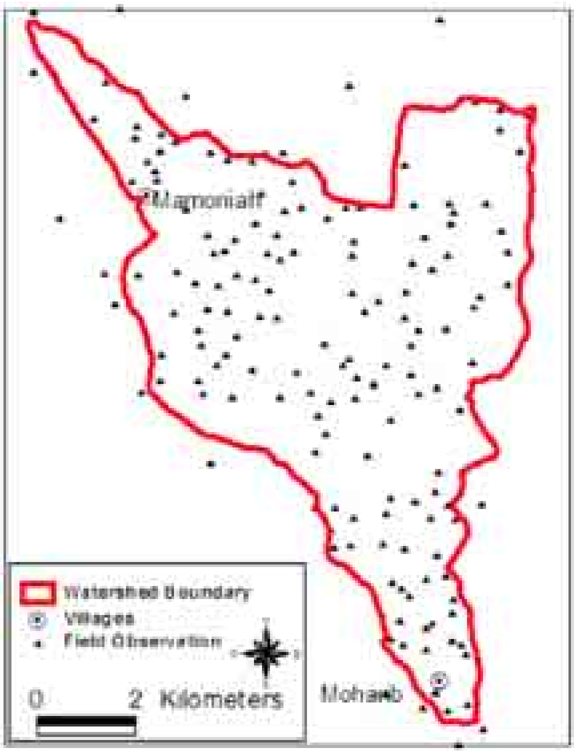


Figure 39: Distribution of field observations made in watershed no. 104.

Attributes recorded in the field

The field survey was basically designed to provide information about the biophysical factors in the watersheds. Of particular interest were those factors required to judge the suitability of an area for water-harvesting interventions (see Table 18 in section 2.3 below). Consequently, the following parameters were recorded for each set of observations made in the field:

1. Slope steepness (percentage; measured using an Abney level).
2. Surface cover of the land (percentage stoniness).
3. Vegetation type and coverage (percentage; only measured for some sites).
4. Texture of the surface horizon (estimated by touch).
5. Limiting soil depth (cm).
6. GPS coordinates (easting, northing, and elevation).

Table 17 shows the data recorded for the observations made in the field in watershed no. 104. Full details and field survey reports are included in Appendices B and C.

Geo-referencing concerns

The data mentioned in the previous sections were geo-referenced using different projection systems. These can be classified into three categories:

1. The data provided by the RJGC, which were geo-referenced using the Jordan Transverse Mercator (JTM) and unpublished datum.
2. The data from the DLS, which were geo-referenced using the JTM and unpublished datum.
3. The background image, which was geo-referenced using the JTM and NAD-1927 (North America_1927) datum.

All the data were sent to the RJGC and processed to ensure the best match between all layers. This was done using parameters set by the RJGC. One drawback exists, however, with regard to the collection of data in the field using GPS (which is a continuous process), because the RJGC considers the JTM parameters used when geo-referencing the data to be "classified information". This means that GPS readings must be collected using the Universal Ttransverse Mercator (UTM) projection, and WGS84 as a datum (defined on any GPS). It must then be sent to the RJGC so that it can convert the coordinates to JTM.

This has very important implication for the future collection of data in the field using GPS. The major limitation is that it is not possible to accurately navigate in the field, because the GPS coordinates and the map coordinates are in different projections. There is no specific way to address this without knowing the parameters used by the RJGC.

Table 17: Attributes recorded during field visits (watershed no. 104).

Site No	Altitude (m)	Slope (%)	Stones(%)	Soil depth	Site No	Altitude (m)	Slope (%)	Stones (%)	Soil depth (m)	Site No	Altitude (m)	Slope (%)	Stones (%)	Soil depth (m)	Site No	Altitude (m)	Slope (%)	Stones (%)	Soil depth (m)
1	724	5	25	65	50	772	4	15	37	97	845	10	30	30	144	860	3	15	34
3	740	9	20	28	51	770	6	15	43	98	857	15	35	25	745	925	9	30	35
4	757	12	40	24	52	760	9	35	25	99	832	4	5	65	146	905	17	60	15
5	804	18	35	47	53	764	8	30	28	100	855	8	15	48	147	819	3	5	30
6	705	6	30	43	54	752	3	5	58	101	866	12	20	32	148	822	4	30	30
7	711	7	15	49	55	771	7	15	62	102	846	8	15	35	149	765	3	10	52
8	755	2	5	40	56	784	4	5	44	103	838	9	20	30	150	835	13	15	45
9	755	1	15	58	57	726	11	35	25	104	813	4	10	55	151	875	2	10	110
10	758	3	10	73	58	799	5	15	38	105	808	5	15	60	152	880	27	45	35
12	799	7	40	29	59	847	6	10	52	106	806	6	10	55	153	855	1	5	35
13	785	6	20	45	60	816	5	15	55	107	822	7	15	45	154	812	5	10	40
14	783	9	35	48	61	825	4	10	65	108	825	6	10	35	155	810	3	10	30
15	804	7	40	44	62	804	5	5	60	109	814	4	5	55	156	814	3	1	120
16	815	3	35	58	63	824	9	15	30	110	830	5	5	65	157	805	5	5	90
17	829	10	30	42	64	830	5	5	65	111	891	15	35	20	158	840	5	10	30
18	824	2	20	63	65	790	6	5	60	112	861	12	30	35	159	810	7	20	20
19	835	3	20	55	66	762	5	15	55	113	847	4	10	60	160	850	3	25	10
20	855	5	15	45	67	772	7	20	25	114	853	7	30	25	161	862	3	3	90
21	849	2	5	50	68	757	6	35	28	115	827	4	10	55	162	676	1	2	110
22	882	5	25	38	69	730	12	20	32	116	837	5	10	65					
23	877	5	20	40	70	742	6	15	35	117	819	4	20	50					
24	876	7	25	55	71	756	9	15	45	118	815	3	10	55					
25	887	8	15	53	72	756	7	10	60	119	822	3	5	50					
26	849	9	20	28	73	751	11	5	45	120	836	4	10	45					
27	785	6	15	45	74	753	9	15	48	121	844	6	15	42					
28	798	10	10	38	75	752	6	10	55	122	855	9	35	28					
29	780	4	10	55	76	760	4	5	62	123	856	7	30	36					
30	776	5	15	42	77	765	3	5	55	124	869	10	20	40					
31	774	7	15	32	78	769	4	5	65	125	883	6	15	48					
32	765	4	5	60	79	770	3	5	60	126	904	15	45	20					
33	764	7	10	40	80	767	3	5	65	127	890	6	30	45					
34	780	9	15	35	81	768	4	5	62	128	918	20	45	20					
35	761	4	5	30	82	763	12	15	20	129	914	18	40	25					
36	759	3	3	50	83	743	7	10	58	130	905	6	15	55					
37	760	3	3	62	84	746	12	35	25	131	903	6	15	60					
38	763	2	5	65	85	737	11	25	42	132	899	5	10	65					
39	770	7	15	43	86	742	12	35	32	133	875	4	10	60					
40	765	4	10	37	87	763	10	25	35	134	893	8	15	30					
41	773	10	35	25	88	790	13	45	25	135	877	5	10	60					
42	742	6	35	40	89	765	7	20	55	136	752	2	5	90					
43	758	5	25	35	90	748	9	30	45	137	793	3	20	33					
44	744	7	20	32	91	750	6	35	35	138	795	3	0	100					
45	706	3	15	65	92	835	9	30	20	139	828	2	10	28					
46	704	4	25	70	93	847	11	15	30	140	890	15	15	70					
47	749	9	35	32	94	831	10	5	35	141	852	7	10	50					
48	759	5	20	35	95	865	4	5	65	142	862	2	20	17					
49	780	3	10	55	96	860	12	15	25	143	884	3	20	60					

2.3 Suitability for water-harvesting interventions

A suitability analysis was undertaken to determine the distribution of those areas suitable, from the biophysical point of view, for different water-harvesting techniques. The first step, therefore, was to determine the physical requirements of each water-harvesting intervention. The second step was to characterize each unit of land in terms of the physical conditions found there. The third step was to match the requirements of each water-harvesting intervention with the conditions of each area in order to identify areas suited to that water-harvesting intervention. These steps will be explained in the following sections.

Requirements for water harvesting

The criteria used to determine the requirements of each water-harvesting intervention were taken from a published source (Oweis, T., Prinz, D., Hachum, A. 2001. Water Harvesting: Indigenous Knowledge for the Future of the Drier Environments. ICARDA, Aleppo). These criteria were then modified to take into account some issues relevant to the project (see Appendix D), particularly the need to reduce the number of alternatives available in order to provide a manageable number that was still adequate for the objectives of the project.

Researchers also divided the conditions into 'best' and 'second best' conditions for an intervention. This was meant to provide more flexibility when determining the suitability of an intervention, while at the same time building in the flexibility that would be required for the final selection, which would consider socioeconomic factors. So, if the land being considered were suitable for three interventions, for example, it would be possible to select one of them based on the owner's preference. If the land were suited only to one intervention, it would be difficult to incorporate the farmer's opinion in the selection process. The final criteria used are summarized in Table 18.

Table 18: Modified guidelines for selecting water-harvesting techniques.

Technique	Crop	Soil: Depth (1) P1	Soil: Depth (1) P2	Soil: Texture P1	Soil: Texture P2	Land slope (2) P1	Land slope (2) P2	Land cover: vegetation (3) P1	Land cover: vegetation (3) P2	Land cover: Stoniness (4) P1	Land cover: Stoniness (4) P2	Soico-economics: Farm size (5) P1	Soico-economics: Farm size (5) P2
Micro-catchments On-farm systems													
Contour ridges	Range	shl	med	med	var	med	steep	poor	med	med	low	var	var
	Field	med	deep	med	var	low	med	poor	poor	low	low	sml	med
	Trees	deep	deep	heavy	med	med	low	poor	poor	low	med	sml	med
Semi-circular and triangular bunds	Range	shl	med	var	var	med	low	poor	med	med	low	var	var
	Field	med	deep	med	heavy	low	med	poor	poor	low	low	sml	med
Small basins	Trees	deep	deep	heavy	med	low	low	poor	med	low	med	sml	sml
Runoff strips	Range	med	var	med	var	med	low	poor	med	med	var	med	var
	Field	deep	med	med	med	low	med	poor	poor	low	med	sml	med
Inter-row system	Trees	deep	deep	heavy	med	low	low	poor	med	low	med	sml	med
Contour bench terraces	Trees	deep	med	heavy	heavy	steep	med	poor	med	low	med	sml	med
	Field	deep	med	heavy	var	steep	med	poor	poor	low	med	sml	med
Narrow-base contour terraces (Gradoni)	Trees	deep	deep	med	heavy	steep	med	poor	med	low	low	sml	med
	Range	deep	med	med	var	med	steep	med	dense	low	med	med	var
Macro-catchments Wadi-bed systems													
Meskat and trapezoidal	Trees	deep	med	med	heavy	low	low	poor	med	med	low	med	large
bunds (cultivated area)	Field	med	med	heavy	med	low	med	poor	poor	low	med	sml	med
Catchment area	-	shl	var	var	heavy	med	steep	poor	poor	low	med	large	med
Wadi - bed cultivation (Water spreading)	All crops	deep	med	med	heavy	low	low	dense	med	Var	var	med	sml
Jessour	Trees	med	var	heavy	med	med	steep	var	med	med	var	sml	med
Off-wadi systems													
Water spreading (diversion)	Field	med	deep	med	heavy	low	med	poor	med	low	med	med	var
	Trees	deep	med	med	heavy	low	low	poor	poor	med	low	med	sml
Large bunds	Trees	deep	deep	heavy	med	low	low	poor	var	med	low	med	large
	Field	med	var	med	var	low	low	poor	poor	low	med	med	med
	Range	med	var	var	var	med	low	var	poor	var	var	med	large
Hillside runoff systems (cultivated)	Field	med	med	med	var	low	med	poor	med	low	var	med	var
	Trees	deep	med	med	heavy	low	med	poor	med	low	var	med	med
Catchment	-	shl	var	var	heavy	steep	med	poor	poor	low	med	large	med
Tanks and hafair (ponds)	All crops	variable	med	heavy	low	var	poor	med	variable		med	var	
Cisterns	-	shl	med	variable		variable		poor	med	variable		sml	med

Notes: P1 = best conditions for this intervention (first priority), P2 = second-best conditions for this intervention (second priority)
(1) shl < 50 cm, med: 50-100 cm, deep > 100 cm; (2) low < 4%, med: 4-12%, steep > 12%; (3) poor < 15%, med: 15-30%, dense > 30%; (4) low < 10%, med: 10-25%, high > 25%; (5) sml < 5 ha, med: 5-25 ha, large > 25 ha

Physical conditions of the watershed

The data needed for the physical characterization of the watershed were obtained partly from data which was already available and partly from the field survey conducted by the project. The first step in the characterization process was to agree upon the land mapping unit used as the basis for the characterization. As has been mentioned above, because a detailed soil map is not available for the vast majority of the Badia, the project's team elected to use the slope unit (Figure 36) as the basis for this characterization.

The data recorded during each field visit was used to characterize each slope unit in terms of the physical characteristics listed in Table 18 (section 2.3 above). The observations were used to run an interpolation algorithm (inverse distance weighted [IDW] interpolator ArcView spatial analyst 3.2). This interpolator depends on the relationship between the distance between observations and their attributes, and is used to generate a continuous grid of the desired attribute. This is the best method available for generating enough attributes to cover the entire area being studied. The results of the interpolation for soil depth and stone-cover percentage are given in Figures 40 and 41, respectively. The classes in the figures represent the reclassified values of each attribute as it is shown in Table 18. The map for soil texture is not shown because the whole watershed has one class (medium). For the map for slope steepness, see Figure 36 above.

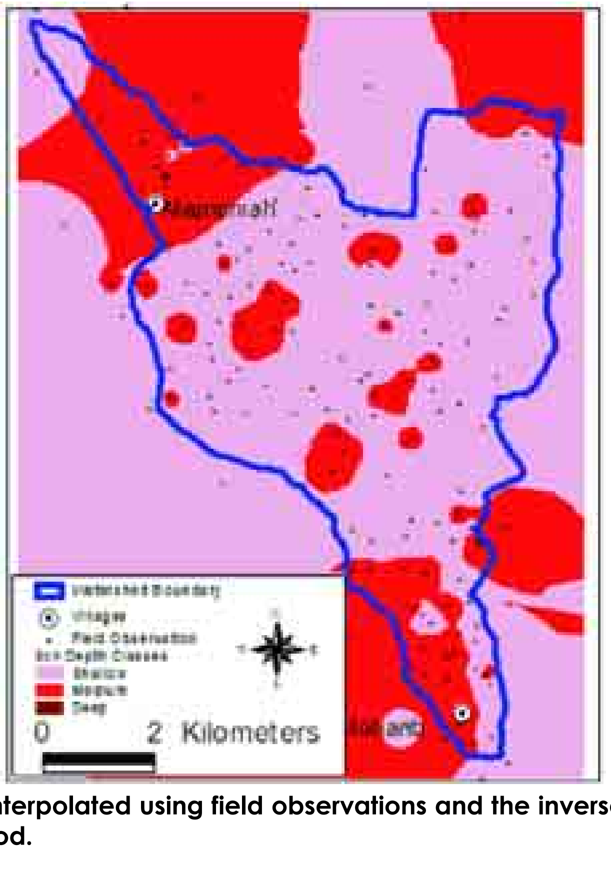


Figure 40: Soil depth interpolated using field observations and the inverse distance weighted (IDW) method.

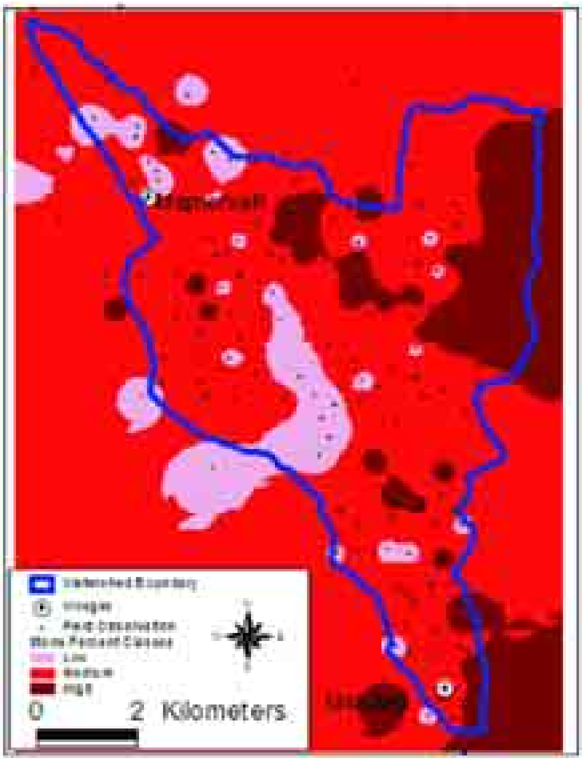


Figure 41: Percentage cover of stones on the soil surface, interpolated using field observations and the inverse distance weighted (IDW) method.

Layers overlay and suitability analysis

The interpolated grids were intersected with each other (using the INTERSECT command in ArcView 3.2) and with the slope unit map. This produced new mapping units which contained a unique combination of all variables. For each slope unit, the value of every variable was defined. This provided a physical characterization of each slope unit (Figure 42). This intersection proved useful when the slope unit was divided into more than one unit (based on variation in the other variables). This commonly happens when one land variable changes independently of the others. Figure 42 shows the subdivisions created, and should be compared with Figure 36, which only shows slope units.

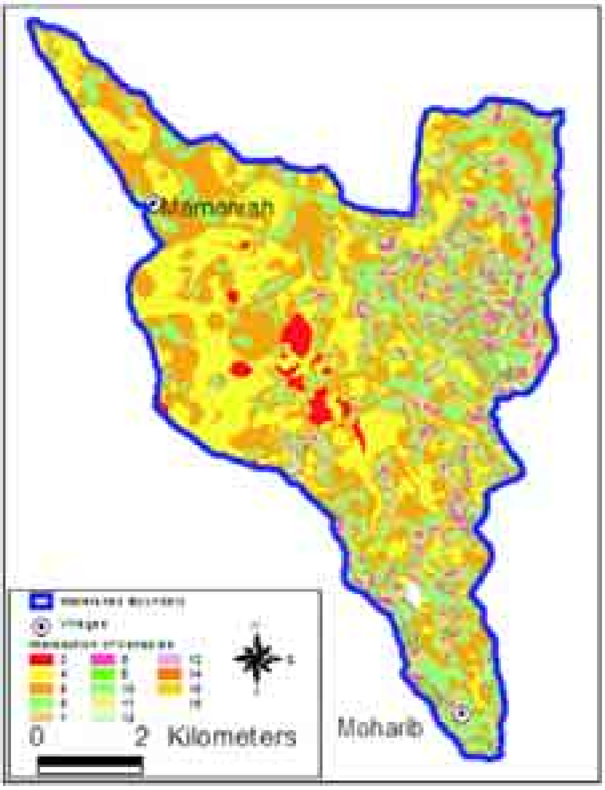


Figure 42: Classes indicating the various combinations of land variables within slope units.

After each slope unit had been characterized, the criteria listed in Table 18 were applied to each mapping unit. This resulted in a table with a row for each mapping unit and 56 columns. These columns represent the 16 different water-harvesting interventions listed in Table 18, each with different crop types (trees, field crops, and range crops). In addition, for each combination of these, two options (priorities) were considered. In each column, the mapping units suited to the relevant intervention were marked with the symbol S1 (suitable), while those not suited to a particular intervention were assigned the symbol NS (not suitable).

The table was then further manipulated to produce a list of interventions suited to each of the mapping units considered. Figure 43 shows these options for all mapping units within the watershed. The legend for this figure and the abbreviations used are explained in Table 19. The information given represents one of the final outputs of the watershed characterization process.

Before the results obtained were used, however, they had to be verified. This was done through field visits, which allowed the suitability results to be assessed and confirmed at selected sites. Field visits were also used to highlight any modifications that might be needed to improve the output.

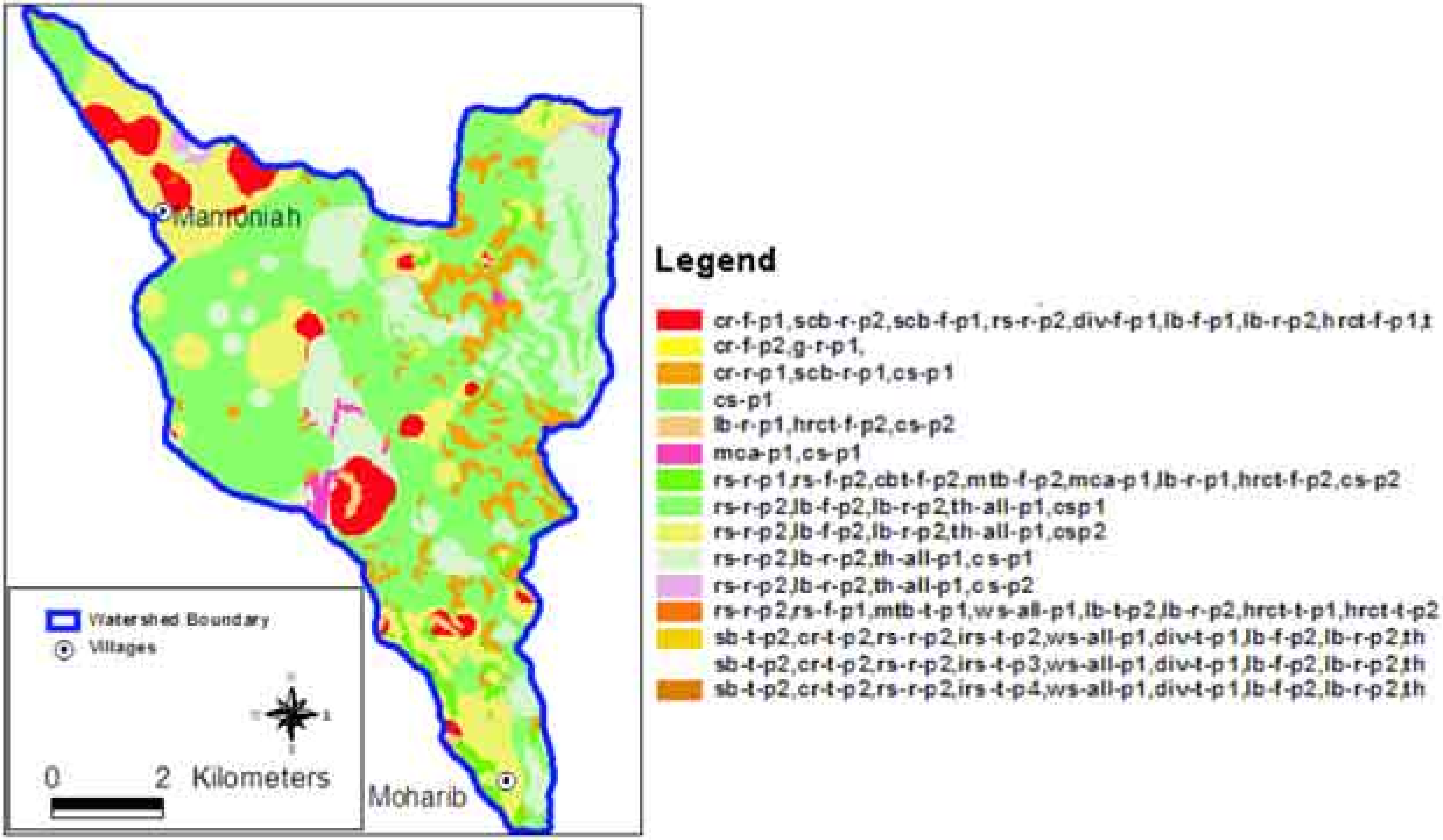


Figure 43: Possible water-harvesting option(s) suitable for each mapping unit.

Table 19: Index for water-harvesting (WH) techniques.

Code	WH technique/crop/priority
CR	Contour ridges
SCB	Semi circular bund
SB	Small basins
RS	Runoff strips
IRS	Inter row system
CBT	Contour bench terraces
G	Gradoni
MTB	Meskat trapezoidal bunds (cultivated area)
MCA	Meskat catchment area
W WS	Water spreading
J	Jessour
Di Div	Water spreading (diversion)
LB	Large bunds
HRCT	Hillside runoff systems (cultivated)
Hcat	Catchment (hillside catchment)
TH	Tanks & hafair (ponds)
CS	Cisterns
r	Range crops
f	Field crops
t	Trees
all	All crops
P1	First priority
P2	Second priority

2.4 Use of the suitability analysis results

This section explains how the suitability results discussed in the previous section could be used to accomplish a variety of tasks within the Badia Benchmark project. One fruitful way of using this output would be to ensure the efficient integration of the various project components. What has been accomplished constitutes characterization from a purely biophysical point of view. Social, economic, and hydrological aspects, as well as aspects related to plant concerns, have not been incorporated yet.

Farm size as a selection criterion

The size of a farm (parcel) could be used as a criterion to reduce the number of options available for each mapping unit (see Table 18). Judging how important this criterion is in the implementation of a water-harvesting technique will be the role of the team's socioeconomic specialist. Technically, it is fairly easy to overlay the suitability map (Figure 43) with the farm (parcels) map. Each farm (parcel) is classified according to the categories given in Table 18 (i.e. 'small', 'medium' or 'large'), and consequently, many options (especially those requiring a large farm, such as macro-catchment systems) could be dropped from the list. An example of the overlay of a suitability map and classified farm units is presented in Figure 44.

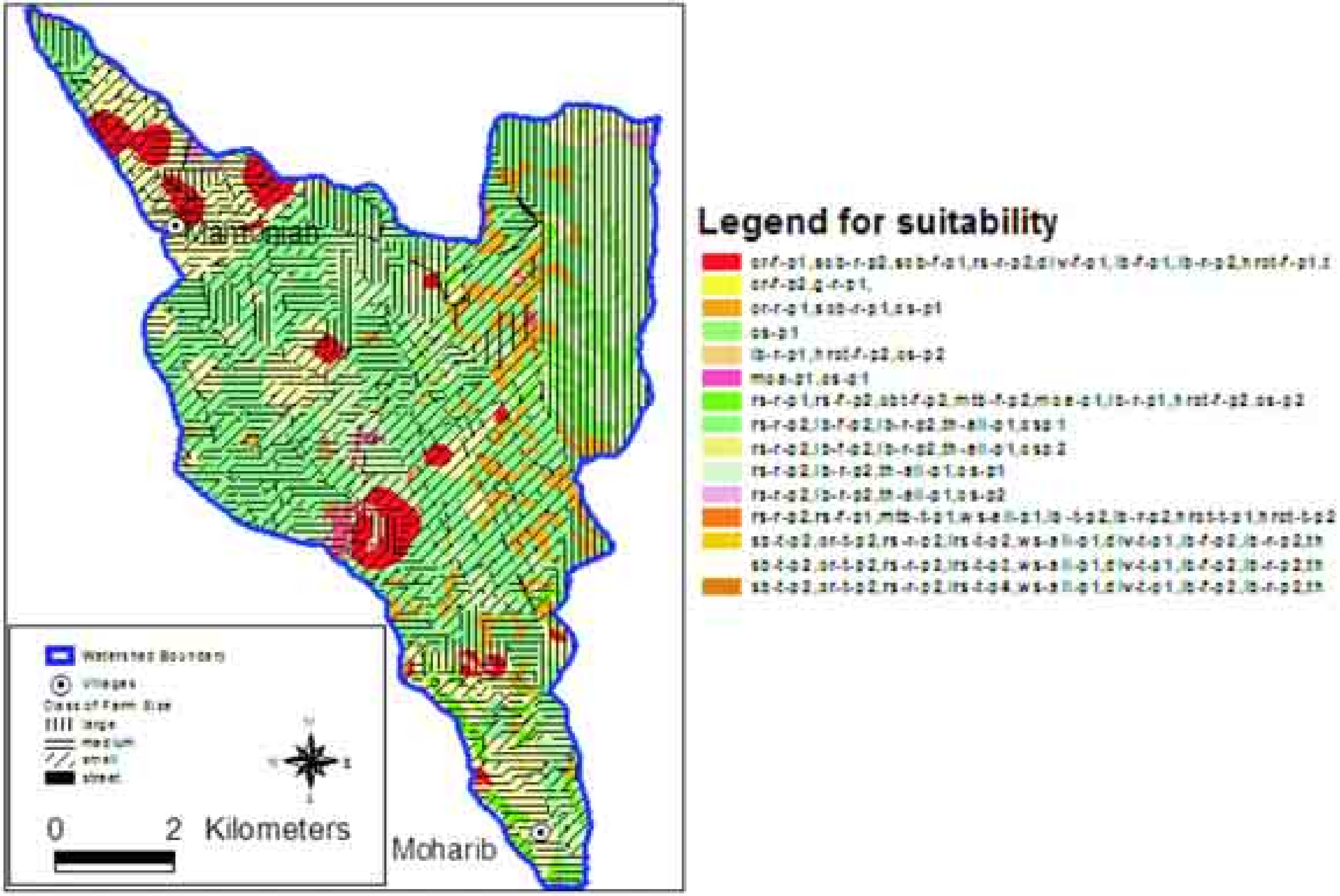


Figure 44: Suitability map overlaid with classified farming units (according to the size of the land parcel).

Suitability and watershed subdivision

It would also be possible to overlay the suitability map and the watershed subdivisions (Figure 45). It is easy to identify watershed subdivisions within which a significant area is dominated by a certain water-harvesting technique. That water-harvesting intervention can then be intensively implemented in that watershed. However, the result obtained through the use of this technique would have to be confirmed by a multi-disciplinary team. Of particular importance would be the link between this analysis and the results of the hydrological analysis, as this would provide information about the candidate locations for small dams and other storage structures. How well these candidate watersheds suit various water-harvesting interventions could be used as another criterion when selecting a watershed that could provide runoff for a storage structure. By the same token, watersheds suited to on-farm (micro-catchment) water harvesting would be used for that purpose and not as a source of runoff.

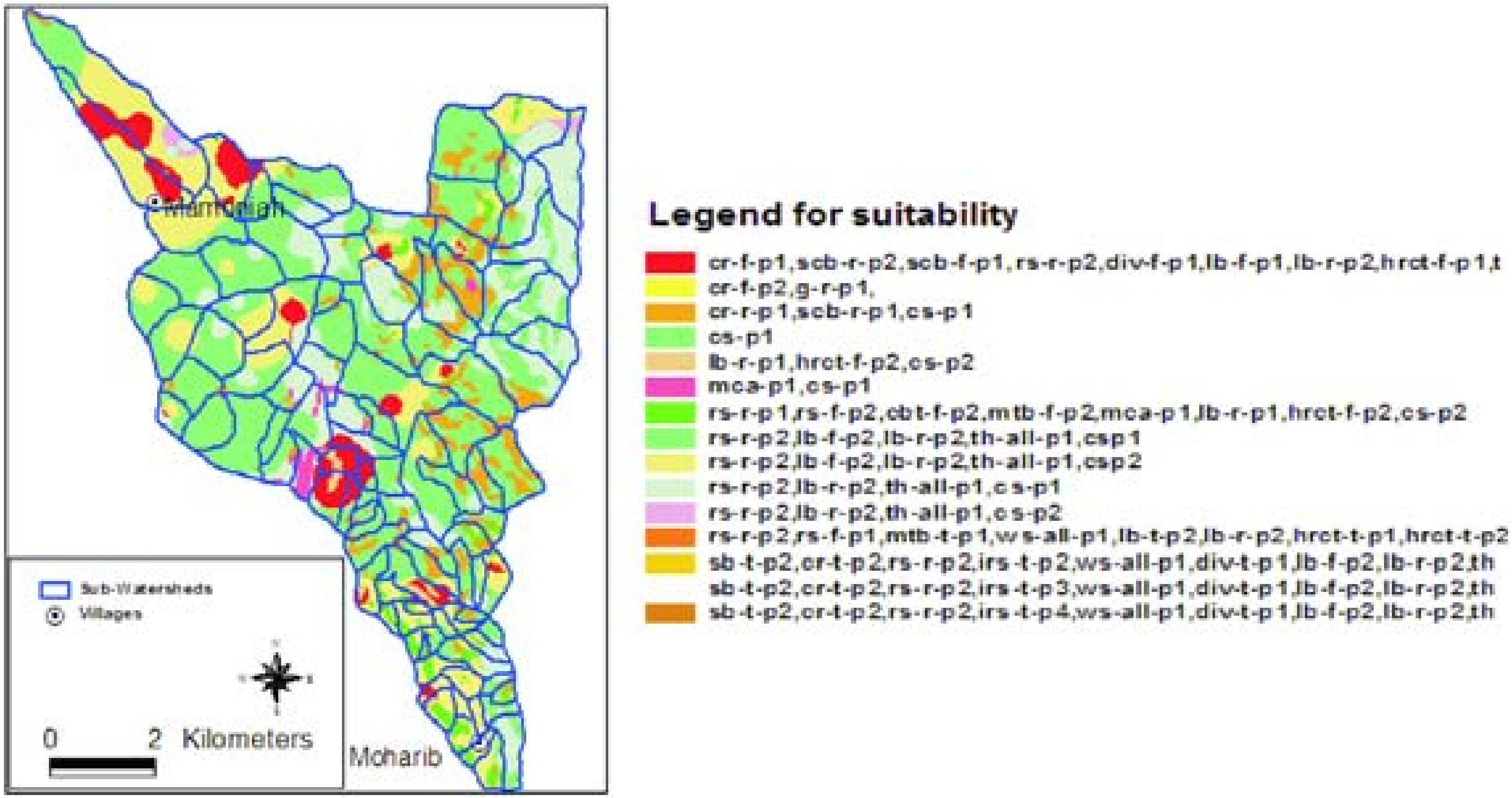


Figure 45: Suitability for water harvesting in relation to watershed subdivisions.

Suitability and land owners

To determine who owned land suitable for project activities, the suitability map and the cadastral maps were overlaid (Figure 46), as the cadastral map is linked with a database that provides information about landowners (including their names). This means that after it has been determined what sites suit particular water-harvesting efforts, the farmers (or owners) can be approached to confirm that the intervention can be implemented. Another way to do this would be to decide upon certain target groups (a certain tribe or family, for example) and then decide what interventions their land is suited to.

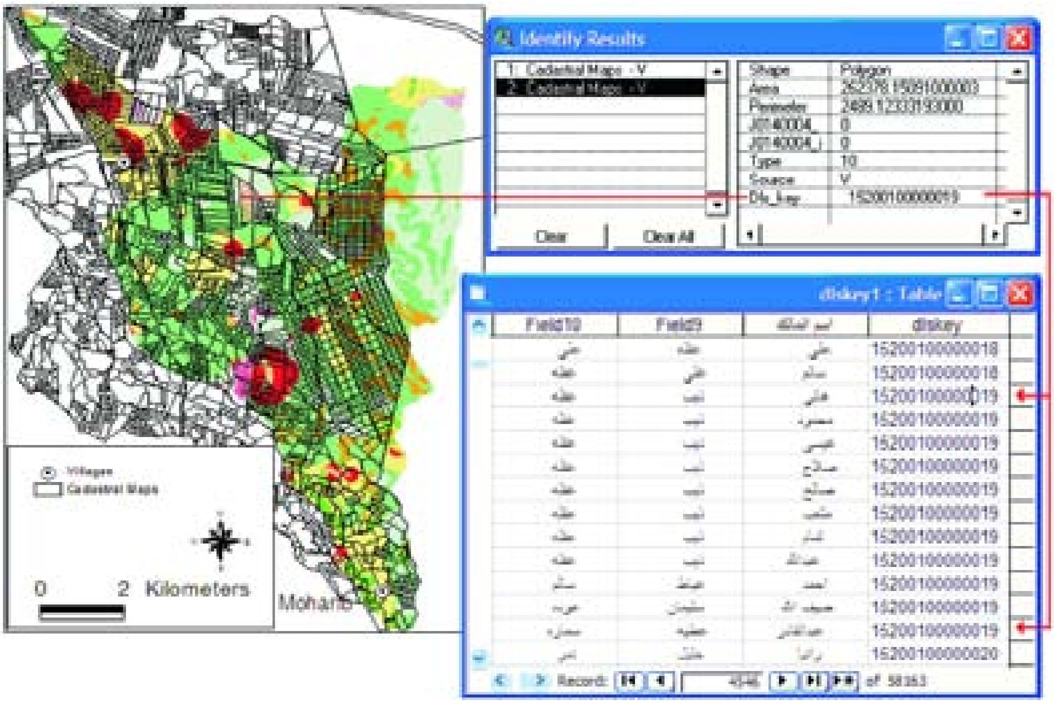


Figure 46: Suitability and cadastral maps (owner's information).

2.5 Using the results of suitability analysis to implement water-harvesting interventions

Identification of suitable locations for water-harvesting interventions

The results of the analyses considered above were used to identify locations at which various types of water-harvesting interventions could be implemented. A multi-disciplinary team then visited the study area. The following were used during the visits:

1. Information concerning the suitability of land for different water-harvesting techniques
2. Information on the locations of potential earth dams and hafair (from the hydrological analysis)
3. Satellite images and GPS (used for navigation)
4. Cadastral maps.

Visits began in the north-western part of watershed number 104. Different sites, all showing obvious potential for various water-harvesting techniques were visited in sequence. At each site the team took notes and made observations. The information was then summarized and used to make a final decision regarding what sites should be selected, what intervention should be applied at each site, and how the sites chosen should be prioritized with regard to implementing the interventions (first priority or second priority).

Nine sites were geo-referenced in the field. Other sites (intended for micro-catchment water harvesting) were also included for further considerations but were not geo-referenced. The locations of the nine sites that were geo-referenced are shown in Figure 47. For information and comments about each site, see Table 20.

Table 20: Information concerning the sites visited.

Site no.	Proposed intervention	Comments
1	- On-farm water harvesting*	- Far from the community
2	- Check dam	- Far from the community
3	- First option: Pond (hafair)	
	- Second option: Check dam	- Far from the community
4	- Pond (hafair)	- More suitable than location 3
	- Far from the community	
5	- Earth dam	- Far from the community
6	- Earth dam	- Close to the community
7	- Water spreading	- Flat area & deep soil
8	- Check dams	- Mostly broken
9	- On-farm water harvesting	- Close to the community

** On-farm water harvesting includes: contour ridges; runoff strips; narrow runoff strips; Vallerani water-harvesting structures; and micro-catchments (please refer to the final implementation workplan 2005-2006).*

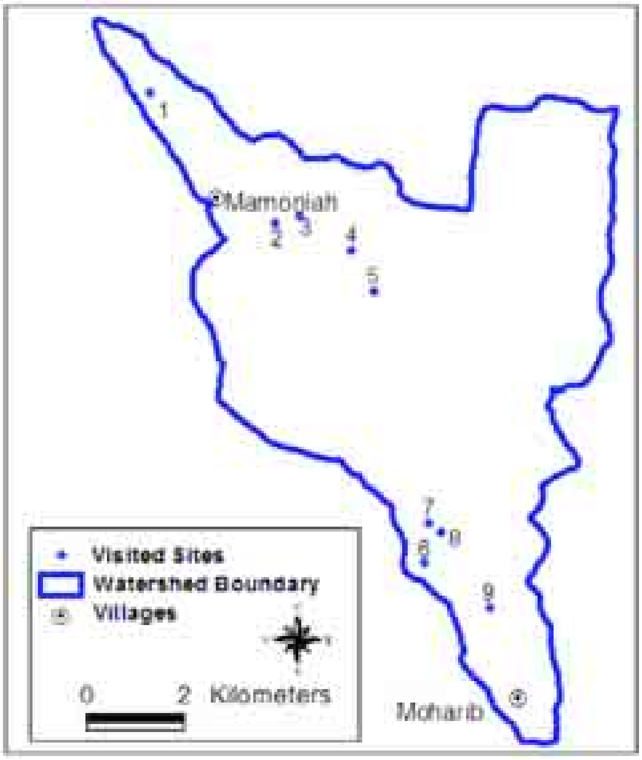


Figure 47: Locations of the sites visited by the multi-disciplinary team.

Importantly, the findings of the field visits agreed with those of the suitability analyses and hydrological assessments. This emphasizes that these methods are reliable and could be used to choose sites suited to different types of water-harvesting interventions. The analyses undertaken using GIS information narrowed down the number of sites visited by the team, guiding the team to sites which had a high potential with regard to the intended water-harvesting techniques.

The data recorded in Table 20 was discussed in detail following a field day which included a meeting between the project team and the inhabitants of two villages (Al-Majediah and Muhareb). The results of this inter-disciplinary discussion are summarized in the following two points.

1. The chances of successfully implementing interventions at sites which don't have communities nearby are limited. It was therefore concluded that such sites should be eliminated from further consideration. This decision includes the first five sites considered in Figure 47. Specifically, even though these sites were rated as being highly suitable from a biophysical point of view, the small number of people living near them would limit their use. This would mean that the structures built there would not be sustainable. The team therefore strongly expressed the need to find sites that are biophysically suitable but also located close to communities.
2. The team noted that the project needs to collect information about the owners of sites deemed to have potential. This, it was felt, should be considered the first step in the actual implementation of water-harvesting interventions. For potentially suitable sites, the owner(s) need to be approached and a discussion should be started to implement the technique. The investigations regarding

the owners are explained in the next section.

Land ownership implications

Some of the sites selected as potentially usable (see Table 20) were excluded from the study because their owners did not wish to participate in the project (for example site no. 6; Table 20). Other sites were excluded because their owners did not live in the area (for example site no. 7; Table 20). This added to the problem caused by the fact that more sites were required to implement the on-farm WH techniques being considered than had already been included in the selection process. As a result, more sites were selected and, after discussion with their owners, added to those considered in Table 20. This was done by visiting the land of people who had indicated that they were interested in participating in the project. If their land was found to be suitable, it was added to the list of potential sites. Farmers had been given the opportunity to indicate their interest in participating in the project during a field day, which was used as an effective way of involving more land owners in the project. For information on the newly selected sites, see Table 21. All potential sites are shown in Figure 48.

Table 21: Information about the additional sites added after consideration of ownership issues.

Site no.	Proposed intervention	Comments
10	- Check dam	Rehabilitation of existing structure
11	- Pond (hafair)	Or site 12
12	- Pond (hafair)	Or site 11
13	- On-farm water harvesting*	Check soil depth
14	- On-farm water harvesting	Check soil depth
15	- On-farm water harvesting	Check soil depth
16	- On-farm water harvesting	Check soil depth
17	- On-farm water harvesting	Check soil depth
18	- On-farm water harvesting	Check soil depth
19	- Water Spreading	Check soil depth
20	- On-farm water harvesting	Check soil depth
21	- Pond (hafair)	Check detailed technical aspects
22	- Pond (hafair)	Check detailed technical aspects
23	- Earth dam	Check detailed technical aspects

** On-farm water harvesting includes: contour ridges; runoff strips; narrow runoff strips; Vallerani water-harvesting structures; micro-catchments (refer to the final implementation workplan 2005-2006).*

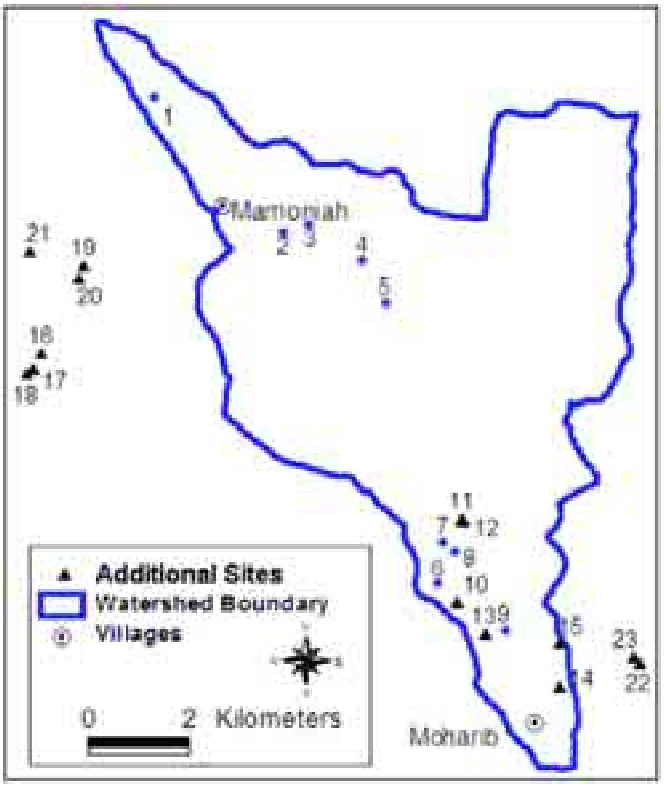


Figure 48: Locations of the sites added after consideration of ownership issues.

Final selection

Ultimately, sites 8 and 9 (Table 20) and all sites in Table 21 were judged to be both biophysically and socio-economically suited to the implementation of relevant water-harvesting techniques. The project's technical team therefore undertook data collection and detailed surveys at these sites, in order to facilitate the design and implementation of the techniques to be used. For further details, please see the project's final implementation workplan (2005-2006).

Appendix A: Scores for the five selection criteria and the final score for all watersheds.

Watershed number	Area score	Rainfall score	Community score	Soil score	Topography score	**Final score**	Watershed number	Area score	Rainfall score	Community score	Soil score	Topography score	**Final score**	Watershed number	Area score	Rainfall score	Community score	Soil score	Topography score	**Final score**
1	15	0	15	15	0	**0**	40	10	15	0	10	15	**0**	79	15	15	10	10	10	**60**
2	15	0	15	15	0	**0**	41	0	15	5	15	15	**0**	80	5	15	0	10	10	**0**
3	0	0	10	15	0	**0**	42	0	15	5	15	10	**0**	81	0	5	5	10	15	**0**
4	0	0	10	15	5	**0**	43	10	15	0	15	10	**0**	82	10	5	0	10	15	**0**
5	0	0	0	15	0	**0**	44	10	15	0	15	15	**0**	83	10	5	0	10	15	**0**
6	10	0	10	15	5	**0**	45	15	15	0	15	10	**0**	84	0	15	0	5	15	**0**
7	10	0	15	15	5	**0**	46	0	15	0	15	15	**0**	85	10	5	0	5	15	**0**
8	10	0	15	15	5	**0**	47	10	15	0	15	10	**0**	86	10	5	0	5	15	**0**
9	0	10	10	5	10	**0**	48	10	15	0	15	10	**0**	87	0	5	0	0	15	**0**
10	0	10	10	15	10	**0**	49	0	15	5	10	15	**0**	88	0	5	0	5	15	**0**
11	0	10	0	15	10	**0**	50	15	15	15	10	15	**70**	89	0	5	0	5	15	**0**
12	0	10	5	15	10	**0**	51	5	15	15	10	15	**60**	90	5	15	5	10	15	**50**
13	10	10	15	15	10	**60**	52	10	15	0	10	15	**0**	91	15	15	0	5	15	**0**
14	0	15	0	15	10	**0**	53	0	10	5	15	15	**0**	92	15	15	0	5	15	**0**
15	5	10	15	15	10	**55**	54	15	10	15	15	15	**70**	93	0	5	0	10	15	**0**
16	15	10	5	15	15	**60**	55	10	10	15	10	15	**60**	94	0	15	0	10	15	**0**
17	10	15	10	15	10	**60**	56	0	10	0	15	15	**0**	95	15	15	0	5	10	**0**
18	15	15	15	15	10	**70**	57	10	10	15	10	15	**60**	96	10	15	0	10	10	**0**
19	15	15	15	15	10	**70**	58	10	10	15	15	10	**60**	97	0	15	0	15	15	**0**
20	10	0	15	15	5	**0**	59	15	10	15	15	10	**65**	98	0	10	10	15	10	**0**
21	0	15	10	15	5	**0**	60	10	15	0	10	15	**0**	99	0	15	0	15	15	**0**
22	0	10	0	15	5	**0**	61	15	15	15	10	15	**70**	100	10	15	0	15	15	**0**
23	0	10	5	15	5	**0**	62	15	15	15	10	15	**70**	101	10	15	0	15	10	**0**
24	0	10	15	15	5	**0**	63	10	15	0	10	15	**0**	102	10	15	0	10	10	**0**
25	15	0	15	15	5	**0**	64	10	15	0	10	15	**0**	103	15	10	10	15	15	**65**
26	0	0	10	15	5	**0**	65	5	15	15	5	15	**55**	104	10	15	0	15	10	**0**
27	15	10	15	15	10	**65**	66	10	15	0	10	15	**0**	105	0	10	0	15	5	**0**
28	15	10	15	15	10	**65**	67	0	15	0	10	10	**0**	106	10	0	15	15	10	**0**
29	15	15	5	15	10	**60**	68	0	15	0	10	15	**0**	107	0	10	5	15	5	**0**
30	5	15	15	15	15	**65**	69	0	5	0	10	15	**0**	108	10	10	15	15	10	**60**
31	10	10	15	15	15	**65**	70	10	5	0	10	15	**0**	109	10	0	15	15	10	**0**
32	0	15	10	15	15	**0**	71	0	15	15	10	10	**0**	110	0	0	15	15	10	**0**
33	10	10	15	10	15	**60**	72	10	5	0	10	10	**0**	111	0	10	5	15	10	**0**
34	15	10	15	10	15	**65**	73	15	5	0	10	10	**0**	112	0	10	15	15	10	**0**
35	10	15	15	15	15	**70**	74	0	5	0	10	15	**0**	113	0	10	10	15	10	**0**
36	15	15	15	10	15	**70**	75	10	5	0	10	15	**0**	114	0	10	0	15	15	**0**
37	15	15	15	10	15	**70**	76	10	5	0	10	15	**0**	115	0	10	0	15	10	**0**
38	10	15	5	5	15	**50**	77	10	5	5	10	10	**40**	116	0	10	15	15	10	**0**
39	0	15	5	15	15	**0**	78	5	15	15	10	10	**55**	117	10	10	10	15	10	**55**

Appendix A: continued

Watershed number	Area score	Rainfall score	Community score	Soil score	Topography score	**Final score**	Watershed number	Area score	Rainfall score	Community score	Soil score	Topography score	**Final score**	Watershed number	Area score	Rainfall score	Community score	Soil score	Topography score	**Final score**
118	15	10	5	15	10	**55**	157	10	5	0	0	0	**0**	196	15	5	5	10	5	**40**
119	15	15	0	15	10	**0**	158	0	5	0	15	10	**0**	197	10	15	15	15	5	**60**
120	15	15	5	15	10	**60**	159	0	10	0	15	5	**0**	198	0	15	0	10	10	**0**
121	15	10	15	15	10	**65**	160	10	15	0	15	10	**0**	199	10	15	15	15	5	**60**
122	10	10	15	15	15	**65**	161	10	10	5	15	5	**45**	200	10	15	15	10	5	**55**
123	10	10	15	15	15	**65**	162	10	10	0	15	10	**0**	201	10	0	10	10	5	**0**
124	0	10	0	15	15	**0**	163	0	15	5	15	10	**0**	202	15	5	0	10	5	**0**
125	10	15	5	15	15	**60**	164	10	5	5	15	10	**45**	203	10	0	0	0	0	**0**
126	10	15	0	15	10	**0**	165	0	5	0	15	10	**0**	204	15	5	0	5	5	**0**
127	15	15	0	15	10	**0**	166	10	5	0	15	10	**0**	205	15	5	0	5	10	**0**
128	15	10	15	15	10	**65**	167	10	5	10	15	10	**50**	206	10	0	0	5	10	**0**
129	15	10	5	15	5	**50**	168	10	5	0	15	15	**0**	207	0	0	0	0	0	**0**
130	0	15	15	15	10	**0**	169	10	5	5	15	15	**50**	208	5	5	0	5	5	**0**
131	15	5	0	15	10	**0**	170	10	5	0	15	10	**0**	209	10	0	0	0	0	**0**
132	15	5	5	15	10	**50**	171	10	15	0	15	10	**0**	210	10	0	0	0	0	**0**
133	15	15	0	15	5	**0**	172	0	15	0	15	10	**0**	211	10	0	0	0	0	**0**
134	5	0	15	15	10	**0**	173	15	15	5	15	10	**60**	212	10	0	0	0	0	**0**
135	5	10	0	15	10	**0**	174	15	15	5	15	10	**60**	213	15	15	15	5	0	**0**
136	15	5	5	15	10	**50**	175	0	5	0	15	10	**0**	214	15	15	0	10	5	**0**
137	10	5	0	15	15	**0**	176	10	5	0	15	10	**0**	215	10	15	10	5	5	**45**
138	0	5	0	15	10	**0**	177	10	5	0	15	10	**0**	216	15	15	5	5	5	**0**
139	5	5	0	15	10	**0**	178	15	15	0	15	10	**0**	217	10	5	5	0	5	**0**
140	10	0	0	15	5	**0**	179	10	15	5	15	10	**55**	218	15	5	0	5	5	**0**
141	10	0	15	15	5	**0**	180	0	5	5	10	10	**0**	219	15	0	0	5	5	**0**
142	0	10	0	15	10	**0**	181	0	15	0	10	15	**0**	220	15	0	5	10	10	**0**
143	0	0	0	15	10	**0**	182	15	15	5	15	10	**60**	221	10	0	0	15	15	**0**
144	5	0	15	15	10	**0**	183	10	15	0	15	10	**0**	222	5	0	5	10	10	**0**
145	15	10	0	15	15	**0**	184	5	10	15	10	10	**50**	223	15	0	5	10	10	**0**
146	10	15	0	15	10	**0**	185	10	15	0	10	15	**0**	224	10	0	0	15	15	**0**
147	10	15	0	15	10	**0**	186	10	15	5	10	10	**50**	225	15	5	0	15	10	**0**
148	5	15	5	15	10	**50**	187	5	10	15	10	10	**50**	226	0	15	0	15	15	**0**
149	10	5	0	15	15	**0**	188	0	15	5	10	10	**0**							
150	10	5	0	15	15	**0**	189	5	15	15	10	10	**55**							
151	10	5	0	15	15	**0**	190	15	15	15	15	10	**70**							
152	10	5	5	15	15	**50**	191	15	5	5	10	10	**45**							
153	15	10	0	15	10	**0**	192	10	15	5	15	5	**50**							
154	0	10	15	15	10	**0**	193	15	15	15	15	5	**65**							
155	10	5	0	15	10	**0**	194	0	0	0	10	5	**0**							
156	15	5	0	15	10	**0**	195	10	15	5	10	5	**45**							

Appendix B: Methods for characterizing the selected watersheds (104 and 59)

Note: In this Appendix, the characterization methodologies initially proposed for the project are described. These were subsequently used in the field (see Appendix C for the results of the biophysical characterization), although minor changes were later made to the guidelines used to select suitable water-harvesting techniques (see Appendix D).

Biophysical Characterization

The purpose of the biophysical characterization is to provide data that will help researchers to select sites that are suitable for various water-harvesting interventions. The following criteria will be considered and characterized:

- Slope steepness
- Surface cover of the land
- Vegetation type and coverage
- Texture of the surface and subsurface horizons (selected sites)
- Limiting soil depth
- Size of land holdings.

It is vitally important that water-harvesting specialist, either from the Jordanian team or ICARDA, agree upon these criteria. If necessary, they may agree to add other criteria, for which data will be collected in the field. The water-harvesting specialists should also determine threshold values for these variables-which will be used to decide whether conditions suit a particular water-harvesting intervention. To start with, Table B1 will be considered for the selection of suitable sites for WH interventions. This table is taken from the following: Oweis, T., Prinz, D., Hachum, A. 2001, Water Harvesting: Indigenous Knowledge for the Future of the Drier Environments, ICARDA, Aleppo. The criteria in this table will be applied unless there are modifications that are agreed upon and forwarded to the watershed characterization team.

The procedures and timetable for collecting this information are explained below and in Tables B2 and B3.

1. Watershed sub-division
Each watershed will be subdivided into sub-watersheds. This subdivision will be undertaken visually using the contour lines and streamlines received from the Royal Jordanian Geographic Center (RJGC). The NCARTT team will be trained so that they can undertake this subdivision. The size of the sub-watersheds will range between 3 and 15 km^2.

2. Preparation and validation of the slope map of the watersheds
A slope map was derived for each watershed from the DEM received from the RJGC at the University of Jordan. However, the slope values derived will be validated using field observations.

3. Field observations
A sampling grid has been drawn over each watershed, using variable spacing. Watershed number 59 has already been covered by a large number of field observations, made during a previous soil survey (National Soil Map and Land Use Project, Ministry of Agriculture). Therefore, 2 km between field observations should be adequate to characterize the watershed. Because the previous survey made few observations in watershed number 104, a spacing of 500 m between observations was used in that watershed.
The sampling procedure will be a compromise between free sampling and grid sampling. One sample will be taken within each square of the sampling grid; the exact location of the sample will be determined in the field based on the variability of the soil and how representative the

location is of the whole grid-square. The locations of the field observations made in watershed number 59 and watershed number 104 are shown in Figure B1 and Figure B2, respectively.

A. For each of these observations, the following variables need to be recorded (see Table B3):
   1. Slope steepness (percent; using an Abney level).
   2. Surface cover of the land: by estimation; recording percentage of dominant cover (stoniness or rockiness).
   3. Vegetation type and coverage Natural vegetation (percentage cover)
      Cultivated (type of crop).
   4. Texture of the surface and subsurface horizons (take sample from selected sites for mechanical analysis in the lab). See Figure B2 to locate the suggested grids from which samples should be taken so that they represent each slope class.
   5. Limiting soil depth - through use of an auger.
   6. GPS coordinates - easting, northing and elevation.

B. Location of streams and watershed boundaries - a GPS reading is required at certain locations to verify the DEM derivatives. Select two points that represent the beginning and the end of stream or gully and take GPS measurement at those two points (take several measurements as you walk through the stream or gully). Select a line which also represents clearly a watershed boundary (not necessarily the whole boundary) and take measurements similar to those outlined above for streams.

Use of Cadastral Maps

Cadastral maps will be received from Department of Land and Surveys (DLS). The maps will be converted by the DLS to fit the coordinate system used in the project (JTM). A separate table, containing information about the owners, will also be delivered by DLS. To use these maps, the following steps will be undertaken:

1. Attributes attached to maps using the combination of fields in the table and the DLS-Key in the maps.
2. All map sheets joined to generate one layer for each watershed.
3. This map overlaid with the other layers generated above.

Procedures for Characterizing the Watersheds

1. Two techniques may be used to characterize the watersheds, as outlined below:
   I. Slope units can be used as base mapping units and each mapping unit characterized using the data collected from the field. This will produce a map with slope polygons that can be used to select suitable sites for water harvesting.
   II. Between field observations can be interpolated to generate a map for each attribute (including slope). These maps can then be overlaid to generate a map of suitability for various water-harvesting interventions. This map differs from the map generated in the first option because it follows the variability of each factor, and thus reflects these variabilities. However, the map might contain a large number of polygons, which might complicate the selection process.
2. Use the map generated from either of the techniques above to apply the criteria for the selection of suitable water-harvesting interventions. Generate a map of land suitability for different water-harvesting interventions.
3. Overlay the map generated in 2 above with the cadastral maps for the following two purposes:

a. To identify, based on the size of the holding, areas where water harvesting is or is not possible.
b. To identify the owners of every piece of land on which the project is considering implementing a certain water-harvesting intervention. This information will be used by the socioeconomic team to approach the owners, to find out whether they would agree to the implementation of the suggested interventions.

Table B1: Criteria for the selection of suitable sites for water-harvesting interventions.

Technique	Crop	Soil		Land	Land Cover			Socio-economics			Storage type
		Depth (1)	Texture	Slope (2)	Vegetation (3)	Stoniness (4)	Farm size (5)	Capital (6)	Labor (7)	Skill	
Micro-catchments On-farm systems Contour ridges	range field trees vegetable	variable med.-deep deep med.-deep	variable " med.-heavy "	med.-steep medium low-med. "	poor-med. poor poor-med. "	low-med. low " "	variable small-med. " small	low " " "	medium " " "	local/ training " "	soil profile " " "
Semi-circular bunds (trapezoidal triangular)	range field trees vegetable	" " deep "	variable med.-heavy " "	" " " "	poor " poor-med. "	low-med. " low "	variable small-med. " small	" " " "	high " " "	local/no training " "	" " " "
Small pits	field range	" shallow-med.	" "	" "	poor poor-med.	" low-med.	variable "	" "	medium "	" "	" "
Small basins (Negarim)	range trees	med.-deep deep	" "	" low	poor poor-med.	" "	small small-med.	" "	high "	" "	" "
Runoff strips	range field	variable med.-deep	" "	low-med. "	poor poor-med.	" "	" "	" "	low "	" "	" "
Inter- row system (roaded catchment)	trees vegetable field	deep medium "	" variable "	Low " "	poor " "	low " "	large " med.-large	high " "	medium " "	local/training " "	" " "
Meskat (Khushkaba)	trees field	deep medium	med.- heavy	low-med. "	poor-med. poor "	" "	variable small-med.	low "	" low	local/no training	" " "
Contour bench terraces	trees field	deep medium	" "	Steep "	" "	" "	" "	high "	medium "	external skill "	" "
Rooftops	drinking vegetable	na variable	na variable	na "	na "	na "	small "	" "	medium "	local/training "	surface/ subsurface "
Macro-catchments Wadi-bed systems Small farm reservoirs	all crops	variable	"	low-med.	variable	variable	med.-large	high	high	external skill	surface/ subsurface
Wadi-bed cultivation	trees/ vegetable	med.-deep	med.- heavy	"	poor	Low	small-med.	medium	med.-high	local	surface/soil profile
Jessour	trees	"	"	med.-steep	variable	variable	small	"	high	local/training	"
Off-wadi systems Water spreading	field/trees	"	"	low-med.	poor	low-med.	variable	"	medium	external skill	soil profile
Large bunds	trees field range	deep medium shallow-med.	" " variable	" " "	poor-med. poor med.-dense	" low variable	med.-large medium med.-large	" " "	" " "	local/training " "	" " "
Tanks and hafair	all crops	variable	med.- heavy	low	variable	"	"	med.-high	"	external skill	surface/ subsurface
Cisterns	drinking/ trees/vegetable	deep	rock	all slopes	poor-med.	variable	small-med.	medium	high	local/training	subsurface
Hillside runoff	field/trees	med.-deep	med.-heavy	low-med.	poor-med.	low	small-med.	"	high	local/training	soil profile

(1) shallow < 50 cm, medium: 50-100 cm, deep> 100 cm; (2) low < 4%, medium: 4-12%, steep > 12%; (3) poor < 15%, medium: 15-30%, dense > 30%; (4) low < 10%, medium: 10-25%, high> 25%; (5) small<5 ha, medium:5-25 ha, large> 25 ha; (6) low < $ 25/ ha, medium: $ 25-100/ ha, high > $ 100/ ha; (7)low < 5 man-day/ ha, medium: 5-20 man-day/ ha, high > 20 man-day/ ha; na : not applicable.

Table B2: Steps and timetable to characterize the selected watersheds.

Step	Days	Deadline
Watershed subdivision	5	10/10/2004
Data collection from the field	10	15/10/2004
Processing of cadastral maps	5	15/10/2004
Data processing and suitability maps	5	22/10/2004
Overlay cadastral maps and generate final maps	5	30/10/2004

Table B3: Physical characterization of field observations.

Observation number	GPS Easting	GPS Northing (JTM)	GPS Elevation (JTM)	Slope % type (m)	Stoni-ness(%)	Rocki-ness (%)	Veget-ation type	Veget-ation cover (%)	Sample for texture	Limiting soil depth (cm)

The variables in Table B3 are defined as follows:

Stoniness:	Percentage of land surface covered by stones, gravels, or boulders
Rockiness:	Percentage of land surface covered by a rock outcrop
Vegetation type:	Type of natural vegetation or name of crop if cultivated
Vegetation cover percent:	Density of coverage - poor, medium or dense
Sample for texture:	'Yes' recorded if a sample was taken; 'No' recorded if no sample was taken
Limiting soil depth:	Depth to limiting feature - rock, stones, etc.

Figure B1

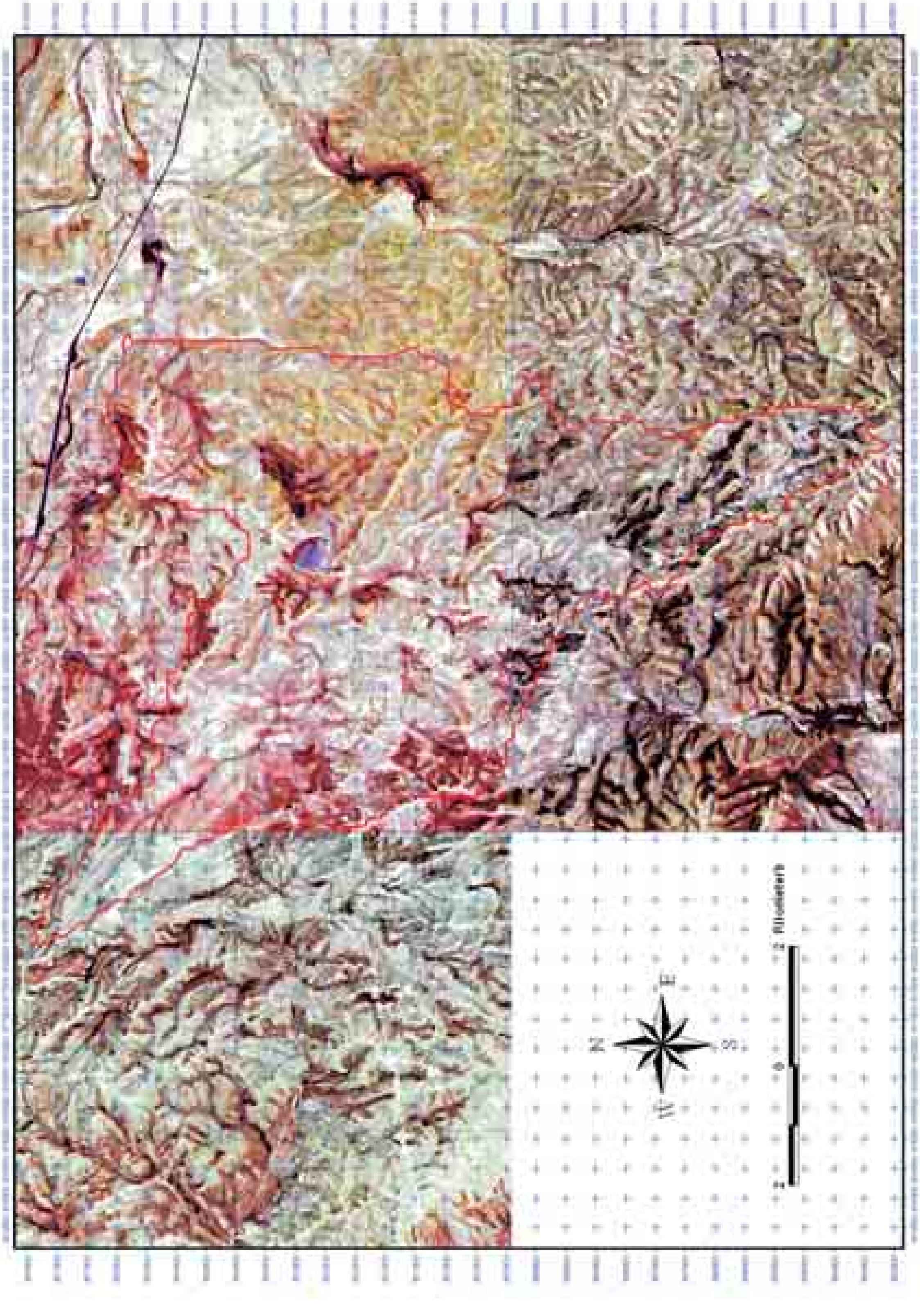


Figure B2

Appendix C: Biophysical characterization of watersheds

Biophysical characterization of watershed 104

ACTIVITY

A study was conducted to characterize the biophysical aspects of watershed 104. This was done to provide data that could be used when deciding which sites would be suited to different water-harvesting interventions. The following criteria were considered:

- Slope steepness.
- Surface cover (vegetation type and density of cover).
- Texture of the surface and subsurface horizons.
- Limitation of soil depth.
- Size of land holdings.

Location

Watershed no. 104 lies about 25 km to the northeast of Queen Alia Airport. Its area is around 100 km^2.

Physiography

Very finely dissected limestone and chert plateau on Umm Rijam Chert and Muwaqqar Chert and Marl Formations. The area forms the watershed for drainage water flowing northeast to the Azraq Depression and southwest to Wadi Walla. The pilot study area consists of rounded hills and crests, steep upper slopes, and alluvial and colluvial fans, merging downslope into alluvial fans infilling valleys. The active wadis in the area have gravelly channels

Land use and vegetation

The area lies wholly within the xeric-aridic transitional moisture regime. Precipitation in the area ranges between 100 and 150 mm. The selected watershed lies within the grassland steppe vegetation zone.

In this area, barley is grown in the valley bottom alluvium, where the moisture from the limited rainfall received is augmented by runoff from the hillsides. The dominant species in the area are those of the Anabasis and Poa genera. The steppe grassland produces a tough turf, which protects the soil surface from wind and water erosion. Frequent grazing keeps vegetation growth close to the soil surface.

METHODOLOGY

Office work

A sampling grid was drawn over the map of watershed no. 104, providing a spacing of 500 m between field observations. Using this spacing, a sampling procedure was applied that constituted a compromise between free sampling and grid sampling. During the field work, one sample was taken within each square of the grid; the exact location of the sample was decided on the basis of soil variability and how representative the location was of the whole grid-square.

For each observation, the following variables were recorded and modified according to the Soil Profile Description sheet used in the 1995 Soils of Jordan National Soil Map and Land Use Project.

- Slope steepness ('low', 'medium', 'steep').
- Surface cover of the soil ('stone', 'gravel', 'boulders' or 'rock outcrops').
- Vegetation type and coverage ('poor', 'medium', 'dense').
- Texture of the surface and subsurface horizons ('variable', 'medium', 'heavy')
- Limitation of soil depth ('shallow', 'medium', 'deep').
- Size of land holdings (ha).

Fieldwork

Dr. Weal Sartawi (MOA) and Dr. Maha Al Syouf (NCARTT) began the fieldwork, including the soil and vegetative characterization, in the villages of Muhareb and Majediah.

Vegetative characterization

Quadrats were used to assess percentage cover, herbage productivity and species composition. To study species composition and productivity, quadrats (50×50 cm) were randomly thrown ten times per site. Vegetation measurements were then recorded for each population. Vegetation cover percentage was estimated visually as the percentage of the ground covered by the foliage of each plant species. In addition, the total number of individuals for each species was counted in each quadrat. Data are presented in Table C1 (vegetative characterization). A summary of the project's biophysical characterization of the area (vegetation and soils) is given in Tables C2, C3, and C4.

The longitude, latitude and elevation of each site (29 in all) were recorded. Specifically, a geographic positioning system (GPS model Garmin 12) was used to determine the longitude of the sites, based on the information received from 12 satellites. The altitude of the sites was determined, based on atmospheric pressure and temperature, using a digital barometer-altimeter (Model Air-HB-IL). Plant taxa were identified fully to the species level according to Naomi (1986) and Bor (1968). Species frequency, abundance, density and relative density were calculated following the method described by Ambshat (1982).

Based on visual estimates, the percentage cover of vegetation was very low during November. The dominant genera were *Anabasis* and *Poa*. Other genera (such as *Achillea, Colchicum* and *Salsola*) could only be found in the areas around Muhareb.

Soil characterization

An existing satellite image (1:50,000) was used as a basic map for the fieldwork undertaken. Observations were made using an auger bore and soil pits. Soil descriptions, and all information on geology, topography, location, vegetation, etc., were recorded on computer-compatible cards so that they could easily be entered into a computer. The locations of all sites were recorded on the 1:50,000-scale satellite image. In all, soil samples for soil analyses (texture and $CaCO_3$) were taken from 8 of the 29 sites. Samples were taken from both the surface and subsurface horizon. Tables C2, C3 and C4 show the biophysical characterization (vegetation and soils) of the selected profiles and sites.

The soils were described according the guidelines for soil profile descriptions provided by the FAO and were classified according to the criteria and definitions provided in the USDA Key to Soil Taxonomy (1990) (Reference: U.S. Dept. of Agriculture (USDA), Soil Conservation Service, Soil Survey Staff. 1990. Keys to soil taxonomy. 4th ed. Virginia Polytechnic Institute and State Univ., Blacksburg, VA.

The dominant soil types in the area (at the family level) were:

- Xerochreptic Calciorthids (on colluvial and alluvial fans).
- Xerochreptic Camborthids (on alluvial and colluvial fans).
- Lithic Xeric Torriorthents (on steep upper slopes and rounded hills and crests).
- Lithic (Xerochreptic) Camborthids (on steep upper slopes and rounded hills).
- Lithic Torriorthents (on steep upper slopes and rounded hills and crests on chert).

Further details are given below.

General descriptions of soils found in the study area

Loamy, carbonatic, thermic, deep families of Xerochreptic Calciorthids

Strong brown (7.5YR 5/6 - 10YR 5/6), deep (> 80 cm), silty clay loam, with a weak to strong medium subangular blocky structure, and a compact subsoil in valley alluvium: very highly calcareous; soft calcareous concretions and weakly to moderately saline, occurs on alluvial and colluvial fans, and slopes < 10%. Representative profile: PW9; full description in section "Soil and site characterization results" (this Appendix, below).

The physiochemical properties are as follows: throughout - moderately saline with ECe about 8 mS/cm, whilst reaction is slightly to moderately alkaline (pH 7.6-7.9); fertility potential is medium (CEC 12-16 meq/100 g); and inherent fertility is considered to be low, with organic matter content 1.4%, total-N about 0.1%, and available-P 16 ppm; CaCO3 levels are 18% in the topsoil and 20% in the subsoil.

Loamy, carbonatic, thermic, deep families of Xerochreptic Camborthids
Strong brown (7.5R 5/6), deep (> 80 cm) clay loam and silty clay loam, moderate to strong medium subangular blocky structure, coarser structure and compact subsoil in valley alluvium: very highly calcareous and weakly to moderately saline; occurs on alluvial and colluvial fans, and slopes < 10%. Representative profile: PW10; full description in section "Soil and site characterization results" (this Appendix, below).

The physiochemical properties are: non-saline, non-sodic, with ECe about 1 mS/cm and ESP (1.0-2.5%); reaction is moderately alkaline (pH 8.2). Fertility potential is medium with CEC of about 12 me/100 g; inherent fertility is low to very low, with nutrient and moisture reserves 'diluted' by the gravel content; $CaCO_3$ are levels are 18% in the topsoil and 20% in the subsoil; and moisture reserves are relatively low due to gravel content (the available water capacity, AWC, ranges from 40 to 50 mm/m).

Loamy, carbonatic, thermic very shallow families of Lithic (Xeric) Torriorthents
Strong brown (7.5R 5/6-7.5R 4/6) very shallow (< 25 cm) stony silty clay loam; moderate fine subangular blocky and crumb; very highly calcareous and weakly saline; occurs on rounded hills and crests with occasional sharp ridges, and steep upper slopes (2-20%). Representative profile: PW3; full description in section "Soil and site characterization results" (this Appendix, below).

The physiochemical properties are: non to slightly saline with ECe 1-3 mS/cm, and generally non-sodic with ESP < 5%; reaction is slightly to moderately alkaline (pH about 7.5); fertility potential considered to be very low due to shallowness, despite CEC of around 18 me/100 g. Inherent fertility is also very low, as are moisture reserves of about 30 mm/m for the average profile. $CaCO_3$ levels of 32-38% are high and hazardous, with nutrient imbalance likely. The surface is slightly hard with a root mat of 3-5 cm, and when tilled the surface is slightly to moderately hard, often with slight gully erosion, and usually gravel-covered.

Loamy, mixed, thermic, shallow family of Lithic Xerochreptic Camborthids
Strong brown (7.5YR 4/6) shallow (25-50 cm) silty clay loam; moderate fine subangular blocky structure; very highly calcareous and weakly saline; occurs on steep upper slopes and rounded hills and crests with occasional sharp ridges and on slopes of 2-20%. Representative profile: PW5; full description below.

The physiochemical properties are: slightly saline, non-sodic and slightly alkaline with ECe about 3 mS/cm, and pH about 7.7. Fertility potential is medium, with CEC of abut 13 me/100 g; inherent fertility is medium to very low with 1.5% organic matter, total-N about 0.1% and available-P < 20 ppm; $CaCO_3$ levels of 33-37% are moderately high and considered hazardous with a risk of nutrient imbalance, especially for P; moisture reserves are slightly inadequate with an estimated 50 mm of moisture available.

When untilled, the surface is moderately hard with a root mat of 5-8 cm and when tilled the surface is slightly to moderately hard and capped with associated runoff, exhibits slight rill erosion, and is usually covered with a moderate amount of gravel.

Loamy-skeletal, mixed, thermic, very shallow family of Lithic Torriorthents
Strong brown (7.5YR 5/6) very shallow (< 25 cm) very stony silty clay loam; moderate fine subangular blocky and crumb structure; very highly calcareous and moderately saline; occurs on steep upper slopes and rounded hills and crests on chert subject to rapid runoff; slopes of 5-20%. Representative profile: PW4; full description below.

The physiochemical properties are: non-saline, non-sodic, slightly alkaline reaction, with ECe < 1mS/cm, ESP < 2% and pH of about 7.6. The fertility potential of this shallow soil is low to very low despite the CEC of 26 me/100 g. Inherent fertility also is very low due to shallowness; $CaCO_3$ levels are 32-33%, while the moisture reserves of this shallow soil are about 25-30 mm, i.e. rather low.

Notes
Most of the data on physiochemical properties came from the previous study by the National Soil Maps and Land Use Project - Soils of Jordan (1995). Assessment in the field indicated that the dominant soil texture types were silty clay and silty clay loam; neither auger nor soil-pit sampling yielded samples dominated by sandy texture. However, later mechanical analyses indicated that the dominant soil texture types were sandy loam and sandy clay loam.

Vegetation characterization results

The vegetation data collected at each sampling site are presented in Table C1.

Table C1: Sampling site locations, vegetative cover, height and weight†, and different abundance measures‡ for the species found.

Site 1 (PW6)					
Latitude	Longitude	Elevation(m)	Vegetative cover (%)	Height(cm)	Weight(g)
427496	514379	705	20.7	13.5	43.8
Species	Frequency(%)	Abundance	Density	Relativedensity(%)	*Colchicum*
tunicatum	20	2	0.4	44.4	
Anabasis syriaca	20	1	0.2	22.2	
Achillea fragrantissima	20	1	0.2	22.2	
Hammada eigii	10	1	0.1	11.1	
Site 2					
Latitude	Longitude	Elevation(m)	Vegetative cover (%)	Height(cm)	Weight(g)
426871	514379	734.4	4.5	9.5	12.3
Species	Frequency(%)	Abundance	Density	Relativedensity(%)	
Poa bulbosa	40	1	0.4	57.1	
Anabasis syriaca	30	1	0.3	42.9	
Site 3 (PW7)					
Latitude	Longitude	Elevation(m)	Vegetative cover (%)	Height(cm)	Weight(g)
514156	426467	711.5	5	6.2	16.4
Species	Frequency(%)	Abundance	Density	Relativedensity(%)	
Anabasis syriaca	20	1	0.2	25	
Achillea fragrantissima	10	1	0.1	12.5	
Poa bulbosa	20	2.5	0.5	62.5	
Site 4 (PW5)					
Latitude	Longitude	Elevation(m)	Vegetative cover (%)	Height(cm)	Weight(g)
511610	4264051	804	5	6.4	3.6
Species	Frequency(%)	Abundance	Density	Relativedensity(%)	
Poa bulbosa	1	1	0.1	20	
Hammada eigii	4	1	0.4	80	
Site 5 (PW4)					
Latitude	Longitude	Elevation(m)	Vegetative cover (%)	Height(cm)	Weight(g)
513207	426373	757	12	6.1	6
Species	Frequency(%)	Abundance	Density	Relativedensity(%)	
Trigonella sp.	20	1	0.2	15.4	
Poa bulbosa	80	1	0.8	61.5	
Hammada eigii	30	1	0.3	23.1	
Site 6 (PW1)					
Latitude	Longitude	Elevation(m)	Vegetative cover (%)	Height(cm)	Weight(g)
514160	426501	724	4.6	5.4	10.8
Species	Frequency(%)	Abundance	Density	Relativedensity(%)	
Schizmus sp.	20	1	0.2	22.2	
Anabasis syriaca	40	1	0.4	44.4	
Poa bulbosa	30	1	0.3	33.3	

Site 7 (PW3)					
Latitude	Longitude	Elevation(m)	Vegetative cover (%)	Height(cm)	Weight(g)
513892	426470	740.1	6.4	4.8	4.8
Species	Frequency(%)	Abundance	Density	Relativedensity(%)	
Poa bulbosa	60	1	0.6	66.7	
Anabasis syriaca	30	1	0.3	33.3	
Site 8 (PW8)					
Latitude	Longitude	Elevation(m)	Vegetative cover (%)	Height(cm)	Weight(g)
512039	423085	755	39	16	79
Species	Frequency(%)	Abundance	Density	Relativedensity(%)	
Poa bulbosa	20	8	0.2	80	
Anabasis syriaca	40	1	0.4	20	
Site 9					
Latitude	Longitude	Elevation(m)	Vegetative cover (%)	Height(cm)	Weight(g)
506156	426331	889	21.8	9.5	20
Species	Frequency(%)	Abundance	Density	Relativedensity(%)	
Noaea mucronata	20	1	0.2	1.16	
Anabasis syriaca	20	1	0.2	1.16	
Poa bulbosa	50	33.2	16.6	96.5	
Hammada eigii	20	1	0.2	1.16	
Site 10					
Latitude	Longitude	Elevation(m)	Vegetative cover (%)	Height(cm)	Weight(g)
507805	426566	863	5.5	3.1	5.3
Species	Frequency(%)	Abundance	Density	Relativedensity(%)	
Anabasis syriaca	40	1	0.4	1	
Site 11					
Latitude	Longitude	Elevation(m)	Vegetative cover (%)	Height(cm)	Weight(g)
505741	427510	877	29	10.9	66.1
Species	Frequency(%)	Abundance	Density	Relativedensity(%)	
Poa bulbosa	30	6.33	1.9	70.4	
Noaea ventricosa	20	1	0.2	7.41	
Anabasis syriaca	50	1	0.5	18.5	
Hammada eigii	10	1	0.1	3.7	

† Area harvested: 1 m^2 ‡After Ambshat (1982). Abundance scale: 1-8

Soil and site characterization results

Site number PW3

Information on site
Profile number: PW3
Soil classification: fragmental, mixed, carbonatic, thermic families of Lithic Xeric Torriorthents
Author: Weal Sartawi
Date of examination: 11/10/2004
Location: watershed no. 104
Coordinates: JTM - E 426470/ 513392 N
Elevation: 740 m a.s.l.
Position: middle slope
Slope: sloping (8%) convex to SE
Land use: natural vegetation
Climate:

- Precipitation - 100-150 mm
- Soil moisture regime - transition aridic-xeric
- Soil moisture regime - nearest rain gauge is Muwqqar

General information
Geology: sedimentary chemical origin: limestone, fluvial deposits.
Parent material: colluvium
Drainage: surface runoff - medium
Soil drainage class: well
Surface cover: gravel (20%)
Soil surface conditions: dry, very hard
Erosion: slight gully erosion
Soil depth: deep soils

Profile description
0-7 cm Reddish yellow (7.5YR 7/6) dry and strong brown (7.5YR 5/8) moist; sandy loam; weak fine platy; dry, slightly hard; moist, very friable; non-sticky; non-plastic; common very fine tabular pores; common very fine fibrous roots: 5% irregular chert coarse gravel (5-20 mm); strong reaction to HCl; clear smooth boundary to:
7-28 cm Reddish yellow (7.5YR 6/6) dry and strong brown (7.5YR 5/6) moist; very gravelly fine sandy clay loam; moderate medium subangular blocky; dry slightly hard; very friable; moderately sticky; moderately plastic; common very fine tabular pores; 45% irregular hard limestone coarse gravel (20-75 mm); strong thick CaCO3 coating of gravel; strong reaction to HCl; clear smooth boundary to (next layer):
28+ cm Lithic contact to hard limestone
Note: Analytical analyses are available for horizon 1/2

Site number PW4

Information on site
Profile number: PW4
Soil classification: loamy-skeletal, mixed, thermic, very shallow family of Lithic Torriorthents
Author: Weal Sartawi
Date of examination: 10/10/2004
Location: watershed no. 104
Coordinates: JTM - E 426373 / 513207 N
Elevation: 757 m a.s.l.
Position: middle slope
Slope: gently sloping (12%) convex to SE
Land use: natural grazing
Climate:

- Precipitation - 100-150 mm
- Soil moisture regime - transition aridic-xeric
- Soil moisture regime - nearest rain gauge is Muwqqar.

General information
Geology: sedimentary chemical organ - limestone, Chert beds
Parent material: bedrock - weathered.
Drainage: surface runoff - medium
Soil drainage class: excessive
Surface cover: stone (40%)
Soil surface conditions: dry/hard
Erosion: slight sheet erosion
Soil depth: 25 cm Lithic contact hard limestone
Diagnostic horizon: Cambic at 5 cm

Profile description
0-9 cm Pink (7.5YR 7/4) dry and strong brown (7.5YR 4/6) moist; silty loam; moderate fine subangular blocky; dry slightly hard; moist very friable; slightly sticky; moderately plastic; many fine tubular

pores; many very fine fibrous roots; 5% subrounded chert gravel (5-20 mm); strong reaction to HCl; clear smooth boundary to:

9-25 cm strong brown (7.5YR 5/6) moist; gravely silty clay loam; moderate fine subangular blocky dry slightly hard; moist very friable; moderately sticky; moderately plastic; common fine tubular pores; few fine fibrous and woody roots; 15% irregular hard limestone gravel (5-20 mm); strong reaction to HCl; clear smooth boundary to:
25+ cm Lithic contact to hard limestone
Note: Analytical analyses are available for horizon 1/2.

Site number PW5

Information on site
Profile number: PW5
Soil classification: Loamy, mixed, calcareous, thermic families of Lithic Xerochreptic Camborthids
Author: Weal Sartawi
Date of examination: 10/10/2004
Location: watershed no. 104
Coordinates: JTM - E 426405 / 512310 W
Elevation: 804 m a.s.l.
Position: steep upper slope.
Slope: sloping (18%) convex to S
Land use: unvegetated, bare
Climate:

- Precipitation: 100-150 mm
- Soil moisture regime - transition aridic-xeric

General information
Geology: sedimentary chemical origin - limestone, fluvial deposits.
Parent material: bedrock-weathered
Drainage: surface runoff - rapid
Soil drainage class: well
Surface cover: stone (35%)
Soil surface conditions: moist, soft
Erosion: slight rill erosion
Soil depth: 47 cm Paralithic contact limestone
Diagnostic horizon: Cambic at 7 cm

Profile description
0-7 cm Pink Brown (7.5YR 7/4) dry and Reddish Brown (5YR 5/4) moist; silty clay loam; weak medium platy breaking to fine subangular blocky; dry slightly hard; very friable; moderately sticky; slightly plastic; many fine irregular pores; many fine fibrous roots 15% tabular hard limestone coarse gravels (20-75 mm); strong reaction to HCl; gradual smooth boundary to:
7-47 cm Strong brown (7.5YR 5/5) moist clay loam; weak medium subangular blocky; moist very friable; moderately sticky; moderately plastic; few fine tabular pores; few very fine fibrous roots; 20% tabular hard limestone coarse gravels (20-75 mm); strong reaction to HCl; clear wavy boundary to:
47+ Paralithic contact soft limestone.
Note: Analytical analyses are available for horizon 1/2

Site number PW9

Information on site
Profile number: PW9
Soil classification: loamy mixed calcareous, thermic, deep families of Xerochreptic Calciorthids
Author: Weal Sartawi
Date of examination: 11/10/2004
Location: watershed no. 104
Coordinates: JTM - E 422479 / 512156 N
Elevation: 755 m a.s.l.
Position: lower slope
Slope: gently sloping (1%) irregular to W
Land use: natural grazing
Climate:

- Precipitation - 100-150 mm
- Soil moisture regime - transition aridic-xeric

General information
Geology: sedimentary chemical origin: limestone, fluvial deposits.
Parent material: alluvium
Drainage: surface runoff - medium
Soil drainage class: well
Surface cover: stone (15%)
Soil surface conditions: dry, slightly hard

Erosion: moderate gully erosion
Soil depth: 58+ deep soils
Diagnostic horizon: Cambic at 9 cm and Calcic at 15 cm

Profile description
0-9 cm Reddish (7.5R 5/6) dry and strong brown (7.5R 5/7) moist; silty clay loam; moderate medium breaking subangular blocky breaking to fine angular blocky; dry, hard; moist, friable; very sticky; moderately plastic; common very fine tubular pores; moderate reaction to HCl; clear smooth boundary to
9-40 cm Brownish yellow (10YR 6/6) dry; silty clay loam; weak coarse angular blocky breaking to fine subangular blocky; dry, hard; moist, friable; few very fine fibrous roots; 2% small soft calcareous concretions; strong thin $CaCO_3$ of peds; violent reaction to HCl; clear smooth boundary to:
40-58 cm Brownish yellow (10YR 6/6) dry; silty clay loam; weak coarse angular blocky breaking to fine subangular blocky; dry, hard; moist, friable; very sticky; moderately plastic; common very fine tabular pores; common very fine fibrous roots; 5% small soft calcareous concretions, weak thin $CaCO_3$ coating on peds; strong thin CaCO3 of peds; violent reaction to HCl; clear smooth boundary to:
58+ cm deep soil; up to 85 cm as measured using an auger.
Note: Analytical analyses are available for horizon 1/2.

Site number PW10

Information on site
Profile number: PW10
Soil classification: Loamy, carbonatic, thermic, deep families of Xerochreptic Camborthids
Author: Weal Sartawi
Date of examination: 11/10/2004
Location: watershed no. 104
Coordinates: JTM - E 421782 / 511835 N
Elevation: 758 m a.s.l.
Position: middle slope
Slope: gently sloping (3%) convex, concave to E
Land use: natural grazing
Climate:

- Precipitation - 100-150 mm
- Soil moisture regime - Transition aridic-xeric
- Soil moisture regime - Nearest rain gauge is Muwqqar

General information
Geology: sedimentary chemical origin: limestone, chert beds
Parent material: colluvium/bedrock.
Drainage: surface runoff slow
Soil drainage class: well
Surface cover: gravel (10%)
Soil surface conditions: dry/moderately hard
Erosion: slight sheet erosion
Soil depth: 73 cm (use of auger) (Paralithic contact soft limestone)
Diagnostic horizon: Cambic at 5 cm

Profile description
0-5 cm Pink (7.5YR 7/4) dry and strong brown (7.5YR 4/6) moist; silty loam; moderate fine subangular blocky; dry, slightly hard; moist, very friable; slightly sticky; moderately plastic; many fine tubular pores; many very fine fibrous roots; 5% subrounded chert gravel (5-20 mm); strong reaction to HCl; clear smooth boundary to:
5-32 cm strong brown (7.5YR 5/6) moist; gravely silty clay loam; moderate fine subangular blocky; dry, slightly hard; moist, very friable; moderately sticky; moderately plastic; common fine tubular pores; few fine fibrous and woody roots; 15% irregular hard limestone gravel (5-20 mm); strong reaction to HCl; clear smooth boundary to depth beyond 32cm.
Note: Analytical analyses are available for horizon 1/2.

Table C2: Detailed soil-layer and vegetation characteristics at 10 locations within watershed no. 104.

Site number	Coordinates (GPS)		Elevation (GPS, in m)	Slope (%)	Stone & gravel cover(%)	Rock cover	Vegetative cover type	Vegetative cover(%)	Soil texture*	Soil $CaCO_3$ content (%)	Limiting soil depth (cm)
	Easting (JTM)	Northing (JTM)									
PY1 0-8cm	426501	514160	724	5	25	-	*Schizmus, Anabasis*	4.6	Sandy loam	37.7	65+
PY1 8-65 cm							*Poa bulbosa*		Sandy loam	38.9	
PY3 0-7 cm	426470	513892	740	9	20	5	*Poa bulbosa*	6.4	Sandy loam	32.8	28+
PY3 7-28 cm							*Anabasis syriaca*		Sandy clay loam	38.5	
PY4 0-9 cm	426373	513207	757	12	40	10	*Poa bulbosa*	12	Loamy sand	32.1	24+
PY4 9-25 cm							*Hammada eigii*		Sandy loam	33.9	
PY5 0-7 cm	426405	511610	804	18	35	-	*Hammada eigii*	5	Sandy loam	33.9	47+
PY5 7-47 cm							*Poa bulbosa*		Sandy clay loam	37.7	
PY6 0-6 cm	427496	514379	705	6	30	-	*Colchicum, Anabasis*	20.7	Sandy loam	32.1	43+
PY6 6-43 cm							*Hammada eigii*		Sandy clay loam	26.4	
PY7 0-8 cm	426467	514156	711	7	15	-	*Anabasis, Achillea*	5	Sandy loam	22.6	49+
PY7 8-49 cm							*Poa bulbosa*		Sandy loam	18.8	
PY8 0-5 cm	423085	512039	755	2		-	*Poa bulbosa*	39	Sandy clay loam	20.0	40+
PY8 5-40 cm							*Anabasis syriaca*		Sandy clay loam	20.7	
PY9 0-9 cm	422879	512156	755	1	15	-	Not assessed	Cultiv.	Sandy loam	16.9	58+
PY9 9-58 cm									Sandy clay loam	18.1	
PY10 0-5 cm	421782	511835	758	3	10	-	*Anabasis* sp.	30	Sandy clay loam	18.8	73+
PY10 5-32 cm							-		Sandy clay loam	20.7	

Table C3: Soil and vegetation characteristics of 17 randomly-characterized sites within watershed no. 104.

Site no. (randomly charac-terized)	Coordinates (GPS) Easting (JTM)	Northing (JTM)	Elevation (GPS, in m)	Dominant species/ land-cover type/location	Veg. cover (%)	Soil texture*	Slope (%)	Stone & gravel cover (%)	Limiting soil depth (cm)
12	425325	514100	799	*Anabasis syriaca*	10	Silty loam	7	40	29
13	423788	514261	785	Rangeland	30	Silty clay loam	6	20	45
14	424205	513761	783	Barley	(plowed)	Silty clay loam	9	35	48
15	423248	514391	804	*Anabasis syriaca*	30	Silty clay	7	40	44
16	421225	515615	815	Rangeland, Cultivated	10	Silty loam	3	35	58
17	420825	515246	829	Cultivated	-	Silty clay loam	10	30	42
18	420339	514672	824	Cultivated	-	Silty loam	2	20	63
19	419798	516671	835	*Anabasis syriaca*	40	Silty loam	3	20	55
20	418710	516866	855	Top of the catchment	-	Silty clay loam	5	15	45
21	419243	515753	849	Cultivated, Rangeland	20	Silty loam	2	5	50
22	426330	506142	882	Cultivated, Barley	-	Silty clay loam	5	25	38
23	425811	505432	877	Rangeland	-	Silty loam	5	20	40
24	424897	507824	876	Cultivated, Barley	-	Silty clay loam	7	25	55
25	424390	507434	887	*Anabasis*	-	Silty loam	8	15	53
26	425733	505703	849	*Anabasis, Poa*	40	Silty loam	9	20	28
27	422381	510839	785	Rangeland, Cultivated		Silty clay loam	6	15	45
28	423226	510386	798	Rangeland	30	Silty loam	10	10	38

**Texture as described in the field*

Table C4: Soil characteristics of 60 randomly-characterized sites within watershed no. 104.

Site no. (randomly characterized)	Coordinates (GPS) Easting (JTM)	Coordinates (GPS) Northing (JTM)	Elevation (GPS, in m)	Soil texture*	Slope (%)	Stone & gravel cover (%)	Limiting soil depth (cm)
29	421436	510640	780	Silty clay loam	4	10 (rock outcrop 2%)	55
30	421760	510674	776	Silty clay loam	5	15	42
31	422040	510442	774	Silty loam	7	15 (rock outcrop 5%)	32
32	422725	510214	765	Silty clay loam	4	5	60
33	422936	510491	764	Silty clay loam	7	10	40
34	422345	510485	780	Silty loam	9	15	35
35	423518	510731	761	Silty clay loam	4	5	30
36	423938	510807	759	Silty loam	3	3	50
37	424270	510262	760	Silty loam	3	3	62
38	424745	510640	763	Silty clay loam	2	5	65
39	424680	511140	770	Silty loam	7	15 (rock outcrop 2%)	43
40	424751	511914	765	Silty clay loam	4	10 (rock outcrop 2%)	37
41	425093	512432	773	Silty loam	10	35	25
42	424986	513147	742	Silty loam	6	37 (rock outcrop 1%)	40
43	425740	514221	758	Silty clay loam	5	25	35
44	425532	515348	744	Silty loam	7	20	32
45	428290	516657	706	Silty clay loam	3	15	65
46	428366	516035	704	Silty clay loam	4	25	70
47	425668	514478	749	Silty loam	9	35	32
48	424384	514345	759	Silty clay loam	5	20	35
49	422738	515003	780	Silty clay loam	3	10	55
50	422564	514276	772	Silty clay loam	4	15	37

**Texture as described in the field*

Table C4 Continued: Soil characteristics of 60 randomly-characterized sites within watershed no. 104.

Site no. (randomly characterized)	Coordinates (GPS)		Elevation (GPS, in m)	Soil texture*	Slope (%)	Stone & gravel cover (%)	Limiting soil depth (cm)
	Easting (JTM)	Northing (JTM)					
51	422943	513910	770	Silty loam	6	15	43
52	423454	513680	760	Silty loam	9	35 (rock outcrop 5%)	25
53	423626	513184	764	Silty loam	8	30	28
54	423338	512713	752	Silty clay loam	3	5	58
55	422844	512758	771	Silty clay loam	7	15	62
56	422128	512700	784	Silty clay loam	4	5	44
57	421420	512204	726	Silty loam	11	35 (rock outcrop 2%)	25
58	420961	511254	799	Silty loam	5	15	38
59	426513	505542	847	Silty clay loam	6	10	52
60	425060	506778	816	Silty clay loam	5	15	55
61	425626	506123	825	Silty loam	4	10	65
62	424777	507522	804	Silty clay loam	5	5 (plowed)	60
63	425226	507534	824	Silty loam	9	15	30
64	426036	507534	830	Silty loam	5	5 (plowed)	65
65	425260	507545	790	Silty clay loam	6	5 (plowed)	60
66	420580	512552	762	Silty loam	5	15	55
67	420926	512666	772	Silty clay loam	7	20	25
68	421319	512522	757	Silty clay loam	6	35	28
69	422465	512997	730	Silty loam	12	20	32
70	423150	513152	742	Silty clay loam	6	15	35
71	422539	513362	756	Silty loam	9	15	45

**Texture as described in the field*

Table C4 Continued: Soil characteristics of 60 randomly-characterized sites within watershed no. 104.

Site no. (randomly characterized)	Coordinates (GPS) Easting (JTM)	Coordinates (GPS) Northing (JTM)	Elevation (GPS, in m)	Soil texture*	Slope (%)	Stone & gravel cover (%)	Limiting soil depth (cm)
72	421857	512988	756	Silty clay loam	7	10	60
73	421732	513340	751	Silty loam	11	5	45
74	421864	513665	753	Silty loam	9	15	48
75	421450	514119	752	Silty clay loam	6	10 (plowed)	55
76	420397	514446	760	Silty clay loam	4	5 (plowed)	62
77	4220545	514812	765	Silty clay loam	3	5 (plowed)	55
78	4220237	516422	769	Silty loam	4	5 (plowed)	65
79	420428	515771	770	Silty loam	3	5 (plowed)	60
80	421602	515288	767	Silty clay loam	3	5 (plowed)	65
81	422278	515283	768	Silty clay loam	4	5 (plowed)	62
82	423607	517485	763	Silty clay loam	12	15	20
83	423778	515293	743	Silty loam	7	10	58
84	428191	513213	746	Silty loam	12	35	25
85	427844	512974	737	Silty loam	11	25	42
86	427634	512502	742	Silty loam	12	35	32
87	427424	512106	763	Silty loam	10	25	35
88	427067	511862	790	Silty loam	13	45	

*Texture as described in the field

Biophysical Characterization of Watershed no. 59

Watershed no. 59 was also characterized in order to collect data that could be used to select sites that would be suitable for various water-harvesting interventions.

The following variables were assessed:
- Slope steepness
- Surface cover of the land
  - Percentage of stones, gravel and/or boulders
  - Percentage of rock
- Vegetation type and coverage
  - Natural vegetation (percentage cover)
  - Cultivated (type of crop)
- Texture of the surface horizon.

The variables selected, and the limits at which these variables were considered either suitable or not suitable for each water-harvesting intervention was determined by reference to the following work: Oweis, T., Prinz, D., Hachum, A. 2001. Water Harvesting: Indigenous Knowledge for the Future of the Drier Environments. ICARDA, Aleppo.

Field observations

A sampling grid was drawn over the watershed. A spacing of 2 km between field observations was recommended, as watershed no. 59 had already been covered by a large number of field observations made during a previous soil survey project (National Soil Map and Land Use Project, Ministry of Agriculture, Jordan).

The locations of the field observations used to characterize watershed 59 are shown in Figure B1 (Appendix B). The sampling procedure involved a combination of free sampling and grid sampling.

Twenty-seven observations were made to cover the watershed. One sample was taken within each square of the sampling grid; the exact location of the sample within the grid-square was decided in the field, based on the variability of the soil and how representative the location was of the whole grid-square.

For each of these observations, the following variables were recorded:
1. GPS coordinates (easting, northing and elevation).
2. Slope steepness (percent; using an Abney level) and slope shape (visually).
3. Surface cover of the land (see list above).
4. Vegetation type and coverage (see list above).

Main findings

General watershed characterization results

The borders of the watershed are 50 km north of Amman and 10 km east of Jerash. Most of the areas considered within the watershed contained communities and were urbanized.

Two agro-climatic zones were found in the watershed:

- A semi-arid upstream area, characterized by fertile red soils, well-developed vegetation cover, and highly developed agricultural practices and soil-conservation measures. These areas included olive and fruit-tree plots, and even some forests.
- An arid downstream area, characterized by yellowish, less fertile, and crusted soil. Vegetation cover is sparse and the main crop grown is barley.

Soil depth, land form and stoniness

Most of the sample sites were located on land with a gentle to moderate slope. One steeply sloping site was found; a dam was also found at that location. Generally, soils became shallower as slopes became steeper (Table C5).

Almost all of the area was found to have a low surface cover of stone, rock or gravel; in addition, most of the area was characterized by medium to deep soils. Few sites had a stony or rocky surface.

Vegetation

Barley was cultivated in 20 of the 27 sample sites in the watershed. Irrigated olive and tree plantations were the second most frequent vegetation type.

Grazing mainly occurs on the fringes of cultivated lands. Natural vegetation occurs in scattered spots between cultivated fields, or in stony or very steep areas. The surveys of natural vegetation were conducted mainly in such areas, and also in two or three "marabs" ("flat area around wadis") (Table C5).

The natural vegetation surveys showed that Anabasis spp. are dominant (indicating rangeland deterioration), and that palatable species are rare (Table C6).

Table C5: Biophysical characterization of watershed no. 59.

Obs no.	GPS (JTM)	North (JTM)	Elev (m)	Limiting soil depth (cm)	Limiting soil depth Des.	Slope %	Slope Des.	Slope Shape	Stoniness %	Stoniness Des.	Rockiness %	Rockiness Des.	Land use	Vegetation cover %	Vegetation cover Des.	Most dominant natural vegetation species	Nat. veg. cover (%)	Notes
1	577660	413548	865	> 100	Deep	0-2	Low	L	0-2	Low	0	low	Barley	0	Tilled	*Avena* spp. *Poa* spp. *Bromus* spp.	30	-
2	579419	412794	868	> 100	Deep	3-7	Med	Ccv	0-10	Low	2-5	Low	Barley Olive	0 50	Tilled	*Anabasis* spp. *Noeae* spp. *Poa* spp.	20	-
3	581259	414184	834	30 - 100	Shallow - med	8	Med	Ccv	0-10	Low	0	Low	Barley Olive	0 50	Tilled	*Anabasis* spp. *Poa* spp. *Bromus* spp.	40	Poultry farm
4	579766	416712	831	30 - 100	Shallow – med	10	Med	Irr	30 - 50	High	0	Low	Barley Olive	0 50	Tilled	*Poa* spp. *Noeae* spp. *Anabasis* spp.	20	-
5	579282	415701	830	50 - 100	Med	6	Med	L – irr	0-10	Low	0-2	Low	Barley Olive	0 50	Tilled	*Poa* spp. *Bromus* spp. *Phallaris* spp.	30	-
6	578230	416283	826	< 50	Shallow	14	Steep	Ccv - cvx	30	High	5-10	Low	Barley Olive	0 50	Tilled	*Poa* spp. *Fellage* spp. *Trigonella* spp.	10	Stone wall, soil conservation
7	577866	417127	816	< 50	Shallow	5-10	Med	L - Ccv	20	Med	0-5	Low	Olive, vines, fig Barley	70 0	Tilled	*Poa* spp. *Bromus* spp. *Carex* spp.	10	Stone wall, soil conservation
8	577728	419461	789	< 50	Shallow	10 - 15	Med	L - Ccv	20	Med	0-5	Low	Olive, vines, fig Barley	70 0	Tilled	*Anabasis* spp. *Noea* spp. *Poa* spp.	5	Stone wall, soil conservation
9	579398	423003	759	-	-	-	-	-	-	-	-	-	-	-	-	*Anabasis* spp. *Poa* spp. *Avena* spp.	5	Mining area + dump

Soil Depth: shallow < 50 cm, medium 50-100 cm, deep > 100 cm; Land Slope: low < 4%, med. 4-12%, Steep > 12%; Slope Shape: Linear = L, Concave = ccv, Convex = cvx, irregular = irr.; Stoniness & Rockiness: low < 10%, medium 10-25%, high > 25%, Vegetation cover: poor < 15%, medium 15-30%, dense > 30%.

Table C5 (continued): Biophysical characterization of watershed no. 59.

Obs.	GPS			Limiting soil depth		Slope		Slope shape	Stoniness		Rockiness		Land use	Vegetation cover		Most dominant natural vegetation species	Nat. veg. cover %	Notes
	East (JTM)	North (JTM)	Elev (m)	(cm)	Des.	%	Des.		%	Des.	%	Des.		%	Des.			
10	578598	421722	744	50 - 100	Med.	<4	Low	Cvx	0-2	Low	0-5	Low	Barley Olive	0 50	Tilled	*Anabasis* spp. *Salsola* spp. *Carex* spp.	10	Poultry farm
11	578474	419775	764	50 - 100	Med.	8	Med.	Cvx	0-5	Low	0	Low	Olive, cactus Barley	50 0	Tilled	*Anabasis* spp. *Carex* spp. *Koleria* spp.	10	Poultry farm
12	580140	420298	783	50 - 100	Med.	10	Med.	Cvx	25	High	5	Low	Barley	0	Tilled	*Avena* spp. *Anabasis* spp. *Estoria* spp.	10	
13	580847	421764	757	50 - 100	Med.	>12	Steep	Cvx	5-10	Low	5-10	Low	Barley	0	Tilled	*Poa* spp. *Anabasis* spp. *Carex* spp.	10	
14	581388	419626	787	50 - 100	Med.	10	Med.	Cvx	25	High	20	Med.	Barley Olive	0 50	Tilled	*Anabasis* spp.	10	Stone wall, soil conservation surrounded by houses
15	579726	419027	813	30 - 50	Shallow	15	Steep	Cvx	5-10	Low	70	High	Barley Olive	0 50	Tilled	*Anabasis* spp. *Bromus* spp. *Plantago* spp.	10	High potential for water harvesting
16	580351	415704	827	> 100	Deep	5	Med.	Cvx	20	Med.	0-3	Low	Barley Olive	0 50	Tilled			High potential for water harvesting
17	579470	413855	857	> 100	Deep	4	Med.	Flat	5	Low	0	Low	Olive, Vegetables Barley	80 0	Tilled	*Anabasis* spp.	5	Poultry farms
18	580649	411548	905	> 100	Deep	3	Low	L	2	Low	0	Low	Barley Olive	0 50	Tilled	*Anabasis* spp.	5	

Soil Depth: shallow < 50 cm, medium 50-100 cm, deep > 100 cm; Land Slope: low < 4%, med. 4-12%, Steep > 12%; Slope Shape: Linear =L, Concave = ccv, Convex = cvx, irregular = irr.; Stoniness & Rockiness: low < 10%, medium 10-25%, high > 25%, Vegetation cover: poor < 15%, medium 15-30%, dense > 30%.

Table C5 (continued): Biophysical characterization of watershed no. 59.

Obs.	GPS East (JTM)	GPS North (JTM)	Elev (m)	Limiting soil depth (cm)	Limiting soil depth Des.	Slope %	Slope Des.	Slope shape	Stoniness %	Stoniness Des.	Rockiness %	Rockiness Des.	Land use	Vegetation cover %	Vegetation cover Des.	Most dominant natural vegetation species	Nat. veg. cover %	Notes
19	581232	427694	684	> 100	Deep	0 2	Low	Flat	0	Low	0	Low				*Anabasis* spp. *Poa* spp. *Plantago* spp.	5	Airport border Crust
20	582726	430067	691	> 100	Deep	0 2	Low	Flat	0 2	Low	0	Low				*Anabasis* spp. *Salsola* spp. *Artemisia* spp.	5	Airport border Crust Marab (wadi)
21	583482	429623	690	50 100	Med.	0 2	Low	Flat	0 2	Low	0	Low				*Anabasis* spp. *Salsola* spp. *Artemisia* spp.	5	Crust Marab
22	584548	428218	675	50 100	Med.	0 3	Low	Flat	0	Low	0	Low	Barley Olive,	50	Tilled	*Poa* spp. *Artemisia* spp *Herchevilia* spp	40	Valley & Marab Crust
23	584858	427164	673	50 100	Med.	0 5	Low	Flat	20	Med.	0	Low				*Anabasis* spp.	15	Valley & Marab Crust
24	585377	425814	665	50 100	Med.	0 30	Low steep	Valley bottom	20	Med.	60	High				*Poa* spp. *Artemisia* spp *Herchevilia* spp	25	Dam and valley Water channel
25	583716	426465	680	> 100	Deep	0 2	Low	Cvx	0	Low	0	Low	Barley	0	Tilled	*Anabasis* spp.	10	Deep valley in the border Gully 4-m wide
26	583403	425422	688	> 100	Deep	0 2	Low	Flat	0 2	Low	0	Low	Barley Olive	0 0	Tilled	*Anabasis* spp. *Felago* spp. *Plantago* spp.	10	Crust
27	581657	424444	720	50 100	Med.	0 5	Low	Cvx	5 10	Low	5 10	Low				*Anabasis* spp. *Poa* spp. *Carex* spp.	10	Dump and mining area

Soil Depth: shallow < 50 cm, medium 50-100 cm, deep > 100 cm; Land Slope: low < 4%, med. 4-12%, Steep > 12%; Slope Shape: Linear =L, Concave = ccv, Convex = cvx, irregular = irr.; Stoniness & Rockiness: low < 10%, medium 10-25%, high > 25%, Vegetation cover: poor < 15%, medium 15-30%, dense > 30%.

Appendix D: Modified guidlines for selecting water-harvesting techniques, Badia Benchmark Site-Jordan

Reference: Oweis, T., Prinz, D., Hachum, A. 2001. Water Harvesting: Indigenous Knowledge for the Future of the Drier Environments. ICARDA, Aleppo.

Assumptions and Justifications Reference is made to the minutes of the biophysical team meeting held at the University of Jordan (UOJ) on March 2, 2005.

When preparing the technical plan for the project's interventions, a suitability study had to be conducted for the project sites using the GIS tool. This study was intended to determine which interventions were best suited, biophysically, to each part of the project sites. To perform the study, the guidelines for the different water-harvesting techniques had to be appropriately defined. Therefore, the set of guidelines used to select water-harvesting techniques in the drier environments was reviewed and modified in order to reflect the actual conditions of the Badia in the region and to help differentiate between the different water-harvesting techniques.

Certain assumptions and actions were considered during the review process as described below:

- Vegetables are grown as irrigated crops in the Badia region and never in micro-catchment water-harvesting techniques.
- The rooftop water-harvesting technique will not be considered in the suitability study.
- The small pits water-harvesting technique has very poor acceptability in the Badia.
- Meskat and Hillside runoff systems should be linked to catchment areas with certain characteristics.
- Trapezoidal bunds and Meskat systems are considered macro-catchment systems.
- Narrow-based contour terraces were added to the list of techniques.
- Selection guidelines were modified in a match-exclusive manner to provide more than one option for each land unit; this will provide the capacity for selection based on socioeconomics.
- The suitability study considers two priority levels (P1 and P2) during the selection process, as the third option was not suitable.
- The outcome of the suitability study, at the final step, will be verified by field visits.
- Macro-catchment wadi-bed systems require a hydrological analysis; furthermore, a wadi with a reasonable flow is required for all these systems.

The final version of the revised guidelines can be found in the main text of this report, in section 2.3 ("Suitability for Water-Harvesting Interventions").

Appendix D: Modified guidlines for selecting water-harvesting techniques, Badia Benchmark Site-Jordan

Reference: Oweis, T., Prinz, D., Hachum, A. 2001. Water Harvesting: Indigenous Knowledge for the Future of the Drier Environments. ICARDA, Aleppo.

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- The rooftop water-harvesting technique will not be considered in the suitability study.
- The small pits water-harvesting technique has very poor acceptability in the Badia.
- Meskat and Hillside runoff systems should be linked to catchment areas with certain characteristics.
- Trapezoidal bunds and Meskat systems are considered macro-catchment systems.
- Narrow-based contour terraces were added to the list of techniques.
- Selection guidelines were modified in a match-exclusive manner to provide more than one option for each land unit; this will provide the capacity for selection based on socioeconomics.
- The suitability study considers two priority levels (P1 and P2) during the selection process, as the third option was not suitable.
- The outcome of the suitability study, at the final step, will be verified by field visits.
- Macro-catchment wadi-bed systems require a hydrological analysis; furthermore, a wadi with a reasonable flow is required for all these systems.

The final version of the revised guidelines can be found in the main text of this report, in section 2.3 ("Suitability for Water-Harvesting Interventions").