Integrating Expert Knowledge in GIS to Locate Biophysical Potential for Water Harvesting

Methodology and a Case Study for Syria

Eddy De Pauw
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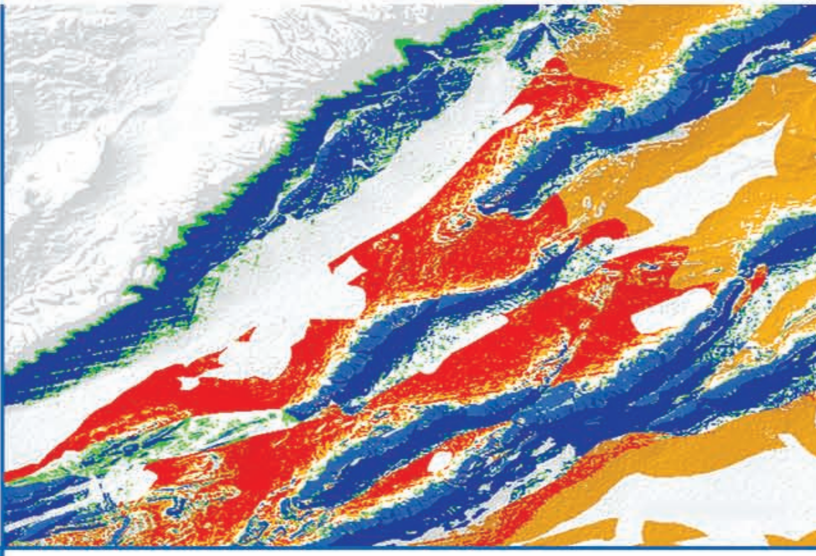

Comprehensive Assessment of water management in agriculture

ICARDA International Center for Agricultural Research in the Dry Areas

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ABSTRACT

Water harvesting covers various techniques to collect rainwater from natural terrains or modified areas and concentrating it for use on smaller sites or cultivated fields to assure economic crop yields. In micro-catchment systems, the source and target areas are essentially that close to each other that they cannot be at scales larger than the field level, and the storage facility is either the soil's root zone for immediate or a small reservoir for later use. In macro-catchment systems, run-off water is collected from a relatively large catchment outside a relatively small target area with storage provided by surface structures, such as small farm reservoirs, and subsurface structures, such as cisterns, or the soil in the target area itself.

In Syria water harvesting is not much adopted by farmers. One of the reasons is that the agricultural research and extension support services in Syria lack specific and systematic knowledge on potential areas and suitable locations for water harvesting. The objective of this study is to provide a rapid GIS-based analytical technique to assess suitability for various water harvesting systems in Syria, with the ultimate objective to adapt the technique for use at the level of the CWANA region.

The assessment was undertaken by matching in a geographical information system with simple biophysical information, systematically available at country level, to the broad requirements of the specified water harvesting systems. The systems evaluated include 13 micro-catchment systems, based on combinations of six techniques and three crop groups, and one generalized macro-catchment system. The environmental criteria for suitability were based on expert guidelines for selecting water-harvesting techniques in the drier environments. They included precipitation, slope, soil depth, texture, and salinity, as well as land use/land cover and geological substratum. The dataset included interpolated surfaces of mean annual precipitation, a high-resolution digital elevation model, a soil map of Syria, a land use/land cover map of Syria, and a geological map of Syria.

The evaluation had two stages: scoring of the land attributes according to individual criteria, followed by the combination of the individual scores in a multi-criteria evaluation. Fuzzy membership functions were used to evaluate suitability for continuous variables, such as precipitation and slope. For these, the boundary between 'suitable' and 'unsuitable' forms by nature a continuum. The functions are fully defined by their shape (either sigmoid or linear) and inflection point positions. Other relevant factors, such as soils, land use or geological materials, could at the national level only be described as qualitative constraints. In addition, for these datasets, it is quite normal that the pixels contain mixtures with different properties.

When several constraints occur, it becomes very difficult to estimate the total proportion of the pixel that is affected by one constraint or another. Monte-Carlo simulation of sub-pixel constraint overlap indicated that a reasonable approximation of total proportion of a pixel affected by one constraint or another could be obtained by taking the sum of the estimated proportions of the individual constraints. The individual factors were then scored on a common scale (0-100) and combined through the Maximum Limitation Method (MLM) as a special case of Boolean overlay.

To identify areas suitable for macro-catchment systems, two separate assessments were undertaken – the first one to evaluate suitability to serve as a catchment, and the second one to evaluate suitability as a target area, with the additional constraint that both areas should be within a certain distance of each other. The evaluation for catchment suitability included fuzzy membership function for precipitation and slope, in which the scores were adjusted by taking into consideration the soil hydrological properties.

The results of the suitability assessments are presented as a set of 14 maps and summarized at provincial and district levels in the form of tables.

1. INTRODUCTION

Water harvesting covers various techniques to collect rainwater from natural terrains or modified areas and concentrating it for use on smaller sites or cultivated fields to assure economic crop yields. Collected runoff is stored in the soil, behind dams or terraces, cisterns, gullies or used to recharge aquifers.

Water harvesting can thus be considered a spatial variant of supplemental irrigation. It is based on the dryland management principle that it is often better to deprive part of the land of its low and unproductive share of rain, in order to add it to another part of the land and obtain economic yields (Oweis et al., 2001).

Water harvesting systems come in a variety of implementations, but the common components are invariably a *catchment* or source area, a storage facility, and *target* or use area. In *micro-catchment systems* the source and target areas are essentially that close to each other that they cannot be separated at a scale beyond the field level. In a GIS context, this can be translated as source and target area being located *in the same pixel*, of relatively small size (e.g. 100-250 m). For such systems the storage facility is either the soil's root zone for immediate or a small reservoir for later use.

In *macro-catchment* systems, run-off water is collected from a relatively large catchment outside a relatively small target area with storage provided by surface structures, such as small farm reservoirs, subsurface structures, such as cisterns, or the soil in the target area itself. In a GIS context, macro-catchment systems are characterized by source and target areas being located in different pixels.

In Syria, water harvesting is not much adopted by farmers. One of the reasons is that they are not acquainted with traditional systems of water harvesting, which are widely adopted in other dryland areas of, amongst others, Egypt, Pakistan, Tunisia or Yemen. Another reason is that the agricultural research and extension support services in Syria lack specific and systematic knowledge on potential areas and suitable locations for water harvesting (Oberle, 2004).

The objective of this study is to provide a rapid GIS-based analytical technique to assess suitability for various water harvesting systems in Syria, with the ultimate objective to adapt the technique in order to allow assessment of potential at the level of the CWANA region.

The assessment of potential for different water harvesting techniques is undertaken by matching in a GIS environment simple biophysical information, systematically available at country level, to the broad requirements of the specified water harvesting systems using an expert-based empirical decision model. The systems evaluated include both micro-and macro-catchment systems. Only those systems that can be consistently evaluated at country level and do not require very site-specific data, which could be difficult or impossible to extrapolate, have been retained for evaluation.

The environmental criteria for suitability are based, with some modifications, on the guidelines for selecting water-harvesting techniques in the drier environments, developed by Oweis et al. (2001). They include precipitation, slope, soil depth, texture, and salinity, as well as land use/land cover and geological substratum.

2. EVALUATING SUITABILITY FOR ON-FARM MICRO-CATCHMENT SYSTEMS

2.1. Overview

2.1.1. General approach

As noted in the introduction, in micro-catchment systems runoff is collected from a small catchment area in the form of sheet flow over a short distance. Runoff water is usually applied to an adjacent agricultural area, where it is either stored in the root zone and used directly by plants, or stored in a small reservoir for later use. The target area may be planted with trees, bushes, or with annual crops. The size of the catchment ranges from a few square meters to around 1000 m^2. Land catchment surfaces may be natural, or cleared and treated to induce runoff, especially when soils are light. Non-land catchment surfaces include the rooftops of buildings, courtyards and similar impermeable structures (Oweis, 2004).

From a GIS-modeling perspective, the main feature on-farm micro-catchments have in common, is that surface runoff is generated and collected 'within pixel' and that the precipitation criterion can be considered as almost constant. Since appropriate micro-catchment techniques exist for almost any slope, soil or crop group, the modeling of suitability at the level of Syria can be much simplified. Once the precipitation level has been evaluated, it can be assumed that suitability will be determined by the feasibility of applying the necessary terrain modification, inherent to the particular system, using slope, soil, and land use criteria.

The methodology has the following components:

- Determining the particular biophysical factors, evaluation criteria and factor thresholds for the micro-catchment systems to be evaluated;
- Evaluating these factors individually;
- Combining them in an integrated multi-criteria analysis

2.1.2. Evaluated systems

The main land-based micro-catchment techniques for which a suitability assessment can be applied at the level of Syria are:

- Contour ridges
- Semi-circular and trapezoidal bunds
- Small pits
- Small runoff basins
- Runoff strips
- Inter-row systems
- Contour-bench terraces

For each of these techniques, relevant crop groups can be considered, resulting into specific micro-catchment systems that can be evaluated (Table 1).

Table 1. Evaluated systems

Technique	Crop groups
Contour ridges	Range, Field, Trees
Semi-circular and trapezoidal bunds	Range, Field, Trees
Small pits	Range, Field
Small runoff basins	Range, Trees
Runoff strips	Range, Field
Contour bench terraces	All

These systems are briefly described in the following paragraphs, based on Oweis et al. (2001) and Oweis (2004).

2.1.2.1. Contour ridges

These are bunds or ridges constructed along the contour lines, usually spaced between 5 and 20 m apart. The first 1–2 m upstream of the ridge is used for cultivation, whereas the rest is used as a catchment. The height of each ridge varies according to the slope's gradient and the expected depth of the runoff water retained behind it. Bunds may be reinforced by stones if necessary.

Contour ridges are one of the most important techniques for supporting the regeneration and new plantations of forages, grasses and hardy trees on gentle to steep slopes in the steppe. In the semi-arid tropics, they are used for arable crops such as sorghum, millet, cowpeas and beans.

2.1.2.2. Semi-circular and trapezoidal bunds

These are usually earthen bunds in the shape of a semi-circle, a crescent, or a trapezoid facing directly upslope. They are created at a spacing that allows sufficient catchment to provide the required runoff water, which accumulates in front of the bund, where plants are grown. Usually they are placed in staggered rows. The diameter or the distance between the two ends of each bund varies between 1 and 8 m and the bunds are 30–50 cm high.

Bunds are used mainly for the rehabilitation of rangeland or for fodder production, but may also be used for growing trees, shrubs and in some cases field crops and vegetables.

2.1.2.3. Small pits

Pitting is a very old technique used mainly in Western and Eastern Africa, but adopted in some WANA areas. It is used for rehabilitating degraded agricultural lands. The pits are 30 cm to 2 m in diameter. The most famous pitting system is the *zay* system used in Burkina Faso. This consists of digging holes with a depth of 5-15 cm. Pits are applied in combination with bunds to conserve runoff, which is slowed down by the bunds. This system allows much degraded agricultural land to be put back into use. Pitting systems are used mainly for the cultivation of annual crops, such as cereals. If the pits are dug on flat instead of sloping ground, they may be regarded more as an *in situ* moisture-conservation technique than as water harvesting one.

2.1.2.4. Small runoff basins

Sometimes called *negarim*, small runoff basins consist of small diamond- or rectangular-shaped structures surrounded by low earthen bunds. They are oriented to have the maximum land slope parallel to the long diagonal of the diamond, so that runoff flows to the lowest corner, where the plant is placed. The usual dimensions are 5-10 m in width and 10-25 m in length. Small runoff basins can be constructed on almost any gradient, including plains with 1-2% slopes. They are most suitable for trees. The soil should be deep enough to hold sufficient water for the whole dry season.

2.1.2.5. Runoff strips

In this technique, the farm is divided into strips along the contour. An upstream strip is used as a catchment, while a downstream one is cultivated. The strip with crops should not be too wide (1-3 m), while the catchment width is determined in accordance with the amount of runoff water required. This technique is highly recommended for barley cultivation and other field crops in large steppe areas of WANA, where it can reduce risk and substantially improve production. The catchment area can be used for grazing after the crop has been harvested.

2.1.2.6. Contour bench terraces

Contour-bench terraces are constructed on very steep slopes to combine soil and water conservation with water harvesting. Cropping terraces are built in level with supporting stonewalls to slow down the flow of water and control erosion. They are supplied with additional runoff water from steeper, non-cropped areas between the terraces. The terraces are usually provided with drains to release excess water safely. They are frequently used to grow trees and bushes, but rarely used for field crops in the WANA region. The historic bench terraces in Yemen are a good example of this system.

2.2. Evaluating suitability of biophysical factors relevant to the selected systems

For all micro-catchment systems precipitation, slope, soils, and geological material have been considered of major relevance to evaluate their suitability. In addition, there are other general constraints related to land use that need to be considered. All these are factors that can be evaluated at national level, using either public data that are already available, or can be converted into a spatially explicit form suitable for evaluation.

2.2.1. Datasets

The data set used in the evaluation includes:

- Interpolated surface of mean annual precipitation
- SRTM (Shuttle Radar Topographic Mission) DEM
- Soil map of Syria
- Land Use/land Cover Map of Syria
- Geological Map of Syria

All these layers were available for the same spatial extent covering all of Syria and with a spatial resolution conform to the SRTM digital elevation model (see further).

2.2.1.1. Climate surfaces

A climate 'surface' is a raster file containing estimates of a climatic variable for each grid cell. The surface of mean annual precipitation was prepared by spatial interpolation of point climatic data using the thin-plate smoothing spline method of Hutchinson (1995) and the ANUSPLIN interpolation software (Hutchinson, 2000). The resolution of the climate surface was 90 m; the same as the digital elevation model used in this study (see 2.1.3.2.). The main source of climatic data for Syria was the FAOCLIM2 database (FAO, 2001).

2.2.1.2. SRTM digital elevation model

The SRTM (Shuttle Radar Topographic Mission) is a high-resolution global digital elevation model (DEM), released in 2000. Its resolution is 3 arc-seconds (90 m), suitable for use at scale 1:100,000. From this data set, available from the Internet, the subset covering Syria was created and the slopes were derived using the *Slope* function in the Spatial Analyst module of ArcGIS.

2.2.1.3. Soil map of Syria

Soil information was obtained from the study undertaken by Van de Steeg and De Pauw (2002). The latter report was itself based on a national soil mapping project undertaken by Louis Berger et al. (1982). The 1:500,000 scale map produced as part of the study, has a legend based on soil associations composed of Soil Taxonomy classification units (Soil Survey Staff, 1975). Each association is characterized by a unique combination of soil types and relative distributions within the association. The composition of each soil mapping unit (association) is provided in Annex 1. Short descriptions of each soil unit are provided in Annex 2. The vector Soil Map of Syria was converted into raster format, for compatibility with the climate surfaces and SRTM DEM.

2.2.1.4. Land use/land cover map of Syria

This map at 1:200,000 scale is a representation of the land use/land cover status in Syria for the base year 1989/90 (De Pauw et al., 2004). It is based on a visual interpretation of satellite-derived products (Landsat 5 TM hardcopy images) and field checking. The map legend consists of two main classes: *homogeneous units*, which can be considered relatively pure (80-90%), and *mixed units*, which are complexes of homogeneous units. The map has 24 homogeneous classes were differentiated belonging to the following major categories: (i) bare areas with or without sparse cover, (ii) cultivated areas, (iii) forests and other wooded areas, (iv) rangelands, (v) urbanized areas, (vi) water bodies. In addition, 43 mixed classes have been distinguished for which the proportions of the homogeneous components have been estimated. Also this vector map was converted into raster format, for compatibility with the climate surfaces and SRTM DEM.

2.2.1.5. Geological map of Syria

The Geological Map of Syria (Technoexport, 1967) is at scale 1:500,000. The legend is based on lithological associations grouped by geological period. In terms of lithological composition, the mapping units can be pure or mixed. The map does not provide indications on the proportions of each lithological group in a mapping unit. This vector map was also converted into raster format for compatibility with the other layers.

2.2.2. Suitability evaluation procedure

Evaluating the suitability for a particular water harvesting system involves two steps:

- Scoring of the land attributes according to the relevant criteria
- Combining the individual suitability scores in a multi-criteria evaluation

The factors can be rated through either a 'fuzzy' or a 'crisp' scoring system, depending on whether they are continuous variables (e.g. precipitation, slope), or discontinuous.

This is explained in the following sections.

2.2.2.1. Evaluating continuous variables through fuzzy membership functions

The difference between a 'fuzzy' or 'crisp' assessment method is shown in Fig 1, using the example of precipitation suitability for water harvesting. Suitability of precipitation is expressed on a scale between 0 (not suitable) and 1 (suitable). The crisp membership function on the left is 'binary': the precipitation is either 'suitable' or 'unsuitable' for water harvesting. To be 'suitable' it should be in the range 150-250 mm on an

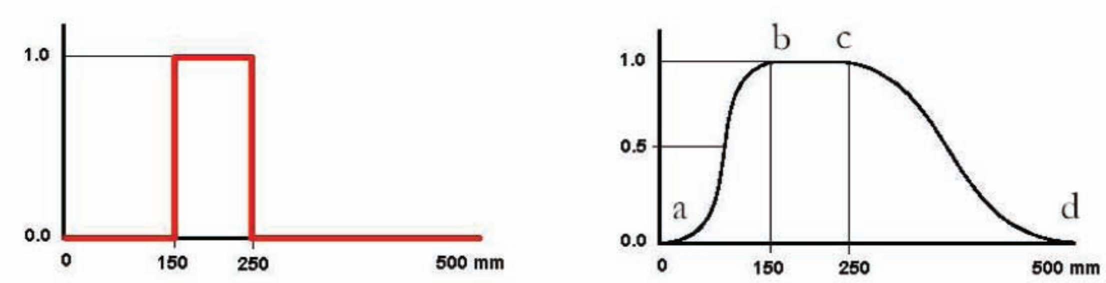

Figure 1. Example of suitability of precipitation for water harvesting, using (a) a crisp membership function (left) and (b) a fuzzy membership function

annual basis, any area with annual precipitation outside this range is considered 'unsuitable'.

The fuzzy membership function on the right is a continuous one, which in essence describes a probability that the precipitation will be 'suitable' for water harvesting. If the annual precipitation is zero, suitability for water harvesting is obviously zero (there is nothing to harvest); similarly if the annual precipitation is 500 mm or more, the suitability is also zero, but for a different reason: at this high precipitation level, it can be assumed that there is no need for water harvesting. If the annual precipitation is in the range 150-250 mm, the suitability is one, being the expert-assessed optimal range. For intermediate annual precipitation levels (<150 mm or >250 mm) the probability of belonging to the class 'suitable' is determined by the particular shape of the membership function, which is user-determined.

Fuzzy membership functions allow more subtle (and probably more realistic) assessments than crisp membership functions, since they are sufficiently flexible to adopt the shapes determined by experts as most appropriate. At the same time, they offer an excellent way to express uncertainty related to 'expert' opinion. They avoid, for example, classification traps, such as a 10% slope being 'suitable', and a 9.99% slope being 'unsuitable'.

In this analysis fuzzy membership functions are used to deal with continuous variables such as precipitation and slope, in which the boundary between 'suitable' and 'unsuitable' by nature forms a continuum.

The fuzzy membership function shown in Figure 1 is a sigmoid ("s-shaped") function, perhaps the most commonly used in Fuzzy Set theory. It is described by the position of inflection points (a, b, c, d) on the curve. Different expressions of the sigmoid membership function are shown in Figure 2. However, there are many other types of membership function, most notably J-shaped, linear functions, and functions that are entirely user-defined through control points (Eastman, 2001).

In this study, for the sigmoid type of fuzzy membership function the scores were calculated according to a cosine-type function with the following equations (Eastman, 2001):

y = 0 in the interval $x \le a$

$y = \cos\left(\frac{x-b}{b-a} * \frac{\pi}{2}\right)^2$ in the interval $a < x \le b$

y = 1 in the interval $b < x \le c$

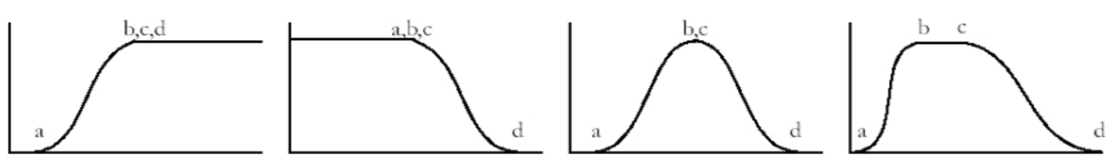

Figure 2. Variants of the sigmoid membership function (from Eastman, 2001)

y = $\cos(\frac{x-c}{d-c} * \frac{\pi}{2})^2$ in the interval c<x≤d

y = 0 in the interval x>d

2.2.2.2. Evaluating discontinuous variables through Boolean operators

The performance of the systems evaluated may, in some cases, be constrained by factors that, due to the uncertainty within the particular data set, can only be described in qualitative terms and not as a continuous function. Examples of factors that could only be described, with the available data sets, as qualitative constraints at national level are soils, land use, and geology.

In such cases the variable can for all practical purposes be considered as 'discontinuous', and a suitability score based on a 'crisp' membership function, using a Boolean operator, would be more appropriate.

An example of a rule based on a Boolean operator would be:

IF (Land Use = Forest or Land Use = Irrigated)
THEN Land Use suitability score = 0
ELSE Land Use Suitability score = 1

Soil constraints can themselves be caused by different soil characteristics that can be evaluated individually. In the case of the available soil map, it was possible to evaluate the following soil characteristics separately and consistently:

- Soil depth
- Soil salinity
- Soil texture

2.2.2.3. Combining individual scores in a multi-criteria evaluation

In conventional land evaluation the combination of individual factor scores can be done by either Boolean overlay or by a weighing mechanism based on standardizing the individual factors to a common numeric range, and then combining by means of a weighted average.

These combinations are easy to apply in most GIS software packages, on condition that the relevant raster layers have the same spatial extent and grid cell resolution.

In the Boolean overlay procedure all criteria are reduced to logical statements of suitability and then combined by means of one or more logical operators: AND (intersect) in case of a need for all factors to meet the matching criteria, or OR (union) in cases where one factor can compensate fully for another factor not meeting the criteria. In the weighting procedure, of which the Weighted Linear Combination (WLE) is the best known (Eastman, 2001), some level of compensation, determined by the weights, is possible.

In this study, the Maximum Limitation Method (MLF) is used as a special case of Boolean overlay. In this method *the most limiting factor sets the final score*, irrespective of the (better) scores on other factors.

The use of the Maximum Limitation Method is illustrated in the following example. Assume that the factors to be evaluated by fuzzy membership functions are precipitation and slope. In this case:

- the suitability score for precipitation is given by the sigmoid membership function $\mathbf{S_{precip} = \mathit{f}(precip)}$, in which the function is parameterized by user-assigned values for the inflection points;
- similarly, the suitability score for slope is given by the sigmoid membership function $\mathbf{S_{slope} = \mathit{f}(slope)}$, in which the function is parameterized by user-assigned values for the inflection points;
- the combined suitability score for precipitation and slope is then the lowest of the factor scores obtained from the two fuzzy membership functions:

$$\mathbf{S = Min\ (S_{slope};\ S_{precip})}$$

The Maximum Limitation Method is easy to implement in GIS by applying the *Minimum* function to the relevant raster layers. This function is available in most software packages.

2.2.2.4. Dealing with heterogeneous pixels

Up to now, it has been assumed that the raster layers to be combined in a multi-criteria evaluation consist of pixels that are homogeneous. That would be true for the precipitation and slope layers, but is certainly not the case for land use, soils and geology. For these themes derived from low-resolution maps at scales 1:200,000 to 1:500,000, it is simply not possible to capture, at 90 m resolution, the variability at pixel-level by a single classification unit. In such cases, it is quite normal that the pixels contain *mixtures* with different properties. In the best cases, e.g. for the land use/land cover or soil themes, this lack of homogeneity at pixel level can be somewhat alleviated if the proportions of individual components are known or can be estimated. In such cases, it also needs to be assumed that any given pixel will contain all possible states as described by these explicit statements of heterogeneity.

Heterogeneous pixels present special problems for multi-criteria evaluations. Whereas constraints can be handled with relative ease, if there is only one of them in a particular pixel, complex combinations can arise when several constraints occur. In such cases, it becomes very difficult to estimate the *total* proportion of the pixel that is affected by one constraint or another.

Two hypotheses are plausible:

- a minimal solution (H1): the total proportion of a pixel affected by one constraint or another is the highest of the proportions of the individual constraints

  H1 = Max (p_i) **i=1, 2,…n**

- a maximal solution (H2): the total proportion of a pixel affected by one constraint or another is the sum of the proportions of the individual constraints

  H2 = Min $(\sum_{i=1}^{n} p_i, 1)$ **i=1, 2, …n**

The hypotheses were tested by a Monte-Carlo simulation to figure out which of the two came closest to reality. A pixel was subdivided in 100 blocks and the overlap of a variable number of blocks, of which the number and position were generated by randomization, was simulated. The results, reported in Annex 3, indicate that the overlap calculated by H2 comes closer to the simulated overlap than H1, and that this agreement gets better as the number of constraints increases.

Using H2 as rule, the total proportion of a pixel affected by a prohibitive (non-suitable) *soil constraint* is the sum of *weighted* proportions in the pixel of soils that are either too shallow, or too saline, or have a severe textural constraint):

$$p_{NS,Soil} = weight_{depth} * p_{NS,Depth} + weight_{salinity} * p_{NS,Salinity} + weight_{texture} * p_{NS,Texture}$$

The proportions of soil constraints are based on the particular attribute class each soil unit of the Soil Map of Syria has been assigned (Van de Steeg and De Pauw, 2002). The weights for depth, salinity or texture are in the range 0-1. These weights are assigned, through expert judgment, *on the basis of the perceived degree of limitation of the concerned property to a particular water harvesting system*. For example, the weight for the factor 'depth' could be 1 for the system 'contour ridges, field crops' if the soil is very shallow, or 0.5 if the soil is shallow, or an intermediate value if the soil type itself can be either shallow or very shallow. The weights given to different values of the soil properties for each evaluated system are shown in Table 4.

The proportion of a pixel with a prohibitive (non-suitable) *land use constraint* is the sum of proportions of that pixel with a prohibited land use, in this case forests or irrigation (i.e. adding water where there is already enough):

$$p_{NS,Land\ use} = p_{NS,forest} + p_{NS,irrigated}$$

The proportions of land use constraints are based on the proportion a prohibited land use type (forest or irrigated land) occupies in each mapping unit of the Land Use/Land Cover Map of Syria (De Pauw et al., 2004).

The proportion of a pixel with a prohibitive geological constraint is the (tentative) proportion of occurrence of a geological parent material considered highly sensitive to erosion, if at the same time a slope criterion is met:

if slope < x% then $p_{NS,Geol} = 0$

else $p_{NS,Geol} = p_{sensitive\ pm}$

in which **x** is particular for the system considered.

The proportions of geological constraints are based on the proportion occupied by an unfavorable geological parent material. These proportions are estimated on the basis of the 1:500,000 scale geological maps of Syria, and, given the low map resolution, have to be considered very tentative (Table 2).

Table 2. Tentative probabilities of highly erodible parent materials, derived from the 1:500,000 Geological Map of Syria

Geological units	Description	Tentative proportion (%)
N2	Continental conglomerates, sandstones, limestones, clays, marls; marine clays, tuff-breccias.	40
N13	NW Syria: Gypsum, marls, limestones.	NW: 33
	Al-Furat basin: clays, sandstones, marls, siltstones, gypsum (Upper Fars formation)	Furat basin: 60
N12	Nahr El-Kabir basin: marine marls, limestones, sandstones.	33
	Anti-Lebanon-Palmyrides: continental clays, sandstones, conglomerates	
N12t	NW-Syria: limestones, marls, conglomerates, sandstones.	NW: 25
	Al-Furat basin: gypsum, limestones, marls, clays, sandstones, rock salt (Lower Fars formation)	Furat basin: 33
N12h	Organogeneous-detrital limestones (pelcypodal, gastropodal and algal varieties.	Kurd-Dagh: 25
	Eastern slope of Kurd-Dagh: conglomerates, limestones, sandstones, marls	
N11	Northwestern Syria: marine limestones, marls, clays, conglomerates, sandstones.	NW Syria: 40
	Anti-Lebanon-Palmyrides: continental quartz sands	A-Lebanon: 100
Pg23	Chalky limestones, marls	50
Pg22	Soft chalky and hard nummulitic limestones, marls	33
Pg1-Pg21	Chalky/nummulitic limestones with flint interbeds;marls, clays	50
Pg1	Limestones and marls	50
Cr2m-d	Chalky limestones, marls	50

2.2.2.5. Combining scores for homogeneous and heterogeneous pixels

To combine scores a uniform pixel size of 90 m was used for all thematic layers.

Using the H2 hypothesis, the proportion of a pixel with either a prohibitive land use, geological or soil constraint is, then, the sum of the proportions of the soil, land use and geological constraints:

$$p_{NS} = p_{NS,Soil} + p_{NS,Geol} + p_{NS,Land\ Use}$$

The final score, combining the continuous, homogeneous variables, precipitation and slopes, with the discontinuous and heterogeneous variables, soils, land use and geological parent materials can then be represented by the formula:

$$S = \text{Min}\ (S_{slope}; S_{precip}) * (1 - p_{NS})$$

The overall methodology is illustrated in Figure 3. Input layers (left hand column of Figure 3), with the same geographical scope and resolution, are converted into individual factor or constraint scores (middle column of Figure 3). The factor or constraint scores are then combined in a multi-criteria evaluation using the principles explained in this section.

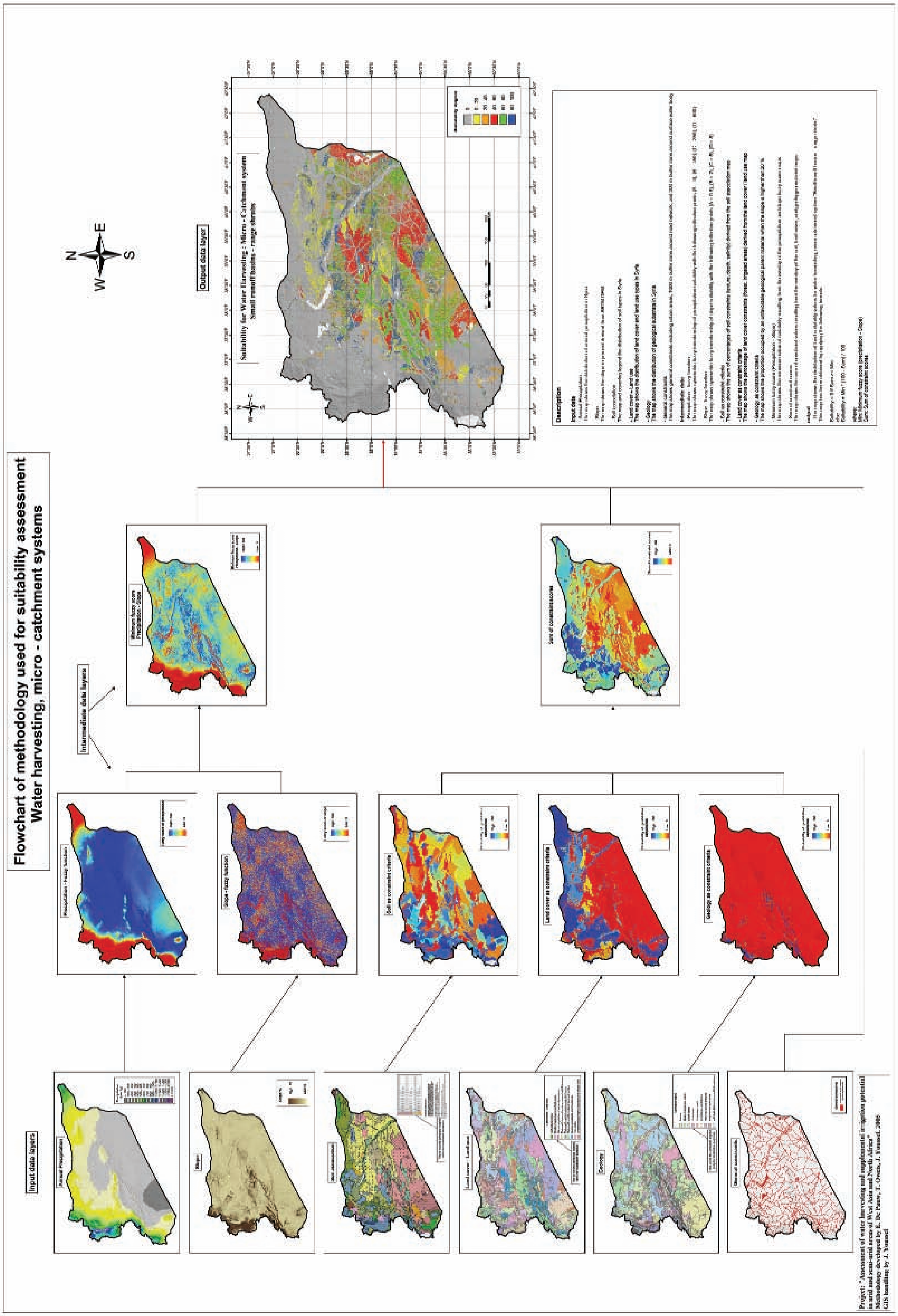

Figure 3. Processing sequence in assessing suitability for water harvesting techniques

2.2.3. Criteria and constraint values

2.2.3.1. Precipitation

For all on-farm micro-catchment systems, the precipitation criterion is taken as constant and suitability is approximated using a fuzzy symmetric sigmoid membership function with four inflection points A: 0 (0); B: 150 (1); C: 250 (1); D: 500 mm (0). The output is a 'precipitation score' layer.

2.2.3.2. Slope

To avoid sudden changes in suitability resulting from a minor change in actual slope, the slope criterion is modeled by a fuzzy symmetric sigmoid membership function with inflection points determined by the requirements of the particular system. The slope is expressed as a percentage of the ratio 'rise/run'. Thus a vertical rise of 100 m over a horizontal distance (run) of 100 m corresponds with a slope angle of 45° and with a slope percentage of 100%. For a slope angle of nearly 90° the slope percentage approaches infinity.

The following slope class terminology is used:

- Flat (slope range: 0-1%)
- Almost flat (slope range 1-2%)
- Gentle (2-5%)
- Medium (5-15%)
- Steep (15-30%)
- Very steep (30-50%)
- Precipitous (50-100%)
- Near vertical (>100%)

The output is a 'slope score' layer.

2.2.3.3. Soils

All soils are acceptable unless they are too shallow, or too saline for agriculture, or have very severe textural limitations that affect the system's feasibility. In GIS, this can be modeled using an exclusion rule, eventually in combination with other rules (e.g. texture in combination with slope). The output is a layer showing the percentage of each pixel that is excluded as being unacceptable for the particular water harvesting system. Alternatively, it can be interpreted as a 'probability' of not meeting the soil requirements. If several soil criteria apply, the highest percentage is considered.

The classes used in assessing whether soil factors are constraints were established by Van de Steeg and De Pauw (2002), and are listed in Table 3.

Referring to the formula for $P_{NS, Soil}$ on page 7, it may be possible, through expert opinion, to assign weights in accordance with the perceived strength of the particular soil constraint. The weights will depend on the importance and value of the particular soil characteristic for each evaluated system. They are listed in Table 4.

2.2.3.4. Geology

In some cases severe system problems (e.g. erosion risk on steep soils developed on marls or clayey limestones), may not be evident from the soil characteristics, in which case geological parent materials may have higher indicative value and be incorporated into the evaluation

Table 3. Soil attribute classes

Soil Factor	Class symbol	Class range
Depth	D	Deep (from 100 to 150 cm)
	M	Moderate (from 50 to 100 cm)
	S	Shallow (from 30 to 50 cm)
	V	Very shallow (less than 30 cm)
	M-D	Moderate to deep (from 50-150 cm)
Texture	Y	Very clayey
	C	Clayey
	L	Loamy
	S	Sandy
	X	Extremely sandy
	N	No soil
	S-X	Sandy and extremely sandy
	C-L	Clayey and loamy
Salinity	N	No salinity
	G	Salinity due to gypsum
	S	Salinity due to sodium

Table 4. Suggested weights for constraint strength

Constraint	Micro-catchment water harvesting system												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Depth Class:													
• D	0	0	0	0	0	0	0	0	0	0	0	0	0
• M	0	0	0.5	0	0	0.5	0.25	0.75	0.25	1	0	0.5	0.5
• S	0	0.5	1	0	0.5	1	1	1	1	1	0.5	1	0
• V	1	1	1	1	1	1	1	1	1	1	1	1	1
• M-D	0	0	0.25	0	0	0.25	0	0.5	0	0.5	0	0	0.75
Salinity Class:													
• N	0	0	0	0	0	0	0	0	0	0	0	0	0
• G	0	0	0	0	0	0	0	0	0	0	0	0	0
• S	1	1	1	1	1	1	1	1	1	1	1	1	1
Texture Class:													
• Y	0	0	0	0	0	0	0	0	0	0	0	0	0
• C	0	0	0	0	0	0	0	0	0	0	0	0	0
• L	0	0	0	0	0	0	0	0	0	0	0	0	0
• S	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0
• X	1	1	1	1	1	1	1	1	1	1	1	1	1
• N	0	0	0	0	0	0	0	0	0	0	0	0	0
• S-X	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.75	0.75	0.5
• C-L	0	0	0	0	0	0	0	0	0	0	0	0	0

Notes: Numbers in top row refer to systems as follows:
1: contour ridges, range shrubs; 2: contour ridges, field crops; 3: contour ridges, tree crops; 4: semi-circular bunds, range shrubs; 5: semi-circular bunds, field crops; 6: semi-circular bunds, tree crops; 7: small pits, range shrubs; 8: small pits, field crops; 9: small runoff basins, range shrubs; 10: small runoff basins, tree crops; 11: runoff strips, range shrubs; 12: runoff strips, field crops; 13: contour bench terraces

using exclusion rules. The output is a layer showing the percentage of each pixel that is excluded as being unacceptable for the particular water harvesting system. Alternatively, it can be interpreted as a 'probability' of not meeting the geological material requirement.

2.2.3.5. General constraints (applicable to all micro-catchment techniques)

Urban areas are automatically excluded (i.e. score = 0), as well as areas within a 1-km buffer zone around roads and within 200 m of surface water bodies.

2.2.4. Adaptation for specific micro-catchment systems

2.2.4.1. Contour ridges, range shrubs

Slopes. Any slope between 'medium' and 'steep' is optimal. At a slope range higher than 'steep', another technique, *contour-bench terracing*, may be more appropriate. Inflection points of the sigmoid function are A: 1 (0); B: 5 (1); C: 30 (1); D: 50 (0).

Soil constraints. Soils with the following classes are excluded:

- Depth class V
- Salinity class S
- Texture class X and class S-X (50%) if slope >20%

Geological constraints.Geological units N2, Pg22 and Pg23 are excluded if the slope exceeds 20%.

2.2.4.2. Contour ridges, field crops

Slopes. 'Medium' slopes (5-15%) are optimal. Inflection points of the sigmoid function are A: 2 (0); B: 5 (1); C: 15 (1); D: 30 (0).

Soil constraints. Soils with the following classes are excluded:

- Depth classes V and S
- Salinity class S
- Texture class X and class S-X (50%) if slope >20%

Geological constraints. Geological units N2, Pg22 and Pg23 are excluded if the slope exceeds 20%.

2.2.4.3. Contour ridges, tree crops
Slopes. 'Gentle' to 'medium' slopes (2-15%) are optimal. Inflection points of the sigmoid function are A: 1 (0); B: 2 (1); C: 15 (1); D: 30 (0)

Soil constraints. Soils with the following classes are excluded:
- Depth classes V, S and M, M-D (50%)
- Salinity class S
- Texture class X and class S-X (50%) if slope >20%

Geological constraints. Exclude geological units N2, Pg22 and Pg23 if slope >20%

2.2.4.4. Semi-circular bunds, range shrubs
Slopes. 'Medium' slopes (5-15%) are optimal. Inflection points of the sigmoid function are A: 1 (0); B: 5 (1); C: 10 (1); D: 15 (0)

Soil constraints. Soils are excluded with
- Salinity class S
- Texture class X and class S-X (50%)
- Depth class V

2.2.4.5. Semi-circular bunds, field crops
Slopes. 'Medium' slopes (5-15%) are optimal. Inflection points of the sigmoid function are A: 1 (0); B: 5 (1); C: 10 (1); D: 15 (0)

Soil constraints. Soils are excluded with
- Salinity class S
- Texture class X and class S-X (50%)
- Depth classes V and S

2.2.4.6. Semi-circular bunds, tree crops
Slopes. 'Medium' slopes (5-15%) are optimal. Inflection points of the sigmoid function are A: 1 (0); B: 5 (1); C: 10 (1); D: 15 (0)

Soil constraints. Soils with the following classes are excluded:
- Salinity class S
- Texture class X and class S-X (50%)
- Depth classes V, S and M, M-D (50%)

2.2.4.7. Small pits, range shrubs
Slopes. 'Gentle' to 'medium' slopes are optimal. Inflection points of the sigmoid function are A: 1 (0); B: 2 (1); C: 10 (1); D: 15 (0).

Soil constraints. Soils with the following classes are excluded:
- Salinity class S
- Texture class X and class S-X (50%)
- Depth classes V and S

2.2.4.8. Small pits, tree crops
Slopes. 'Gentle' to 'medium' slopes are optimal. Inflection points of the sigmoid function are A: 1 (0); B: 2 (1); C: 10 (1); D: 15 (0).

Soil constraints. Soils with the following classes are excluded:
- Salinity class S
- Texture class X and class S-X (50%)
- Depth classes V, S, M

2.2.4.9. Small runoff basins, range shrubs
Slopes. Almost flat to gentle slopes are optimal. Inflection points of the sigmoid function are A: 0.5 (0); B: 2 (1); C: 5 (1); D: 8 (0)

Soil constraints. Soils with the following classes are excluded:
- Salinity class S
- Texture class X and class S-X (50%)
- Depth class V and S

2.2.4.10. Small runoff basins, tree crops
Slopes. Almost flat to gentle slopes are optimal. Inflection points of the sigmoid function are A: 0.5 (0); B: 2 (1); C: 5 (1); D: 8 (0)

Soil constraints. Soils with the following classes are excluded:
- Salinity class S
- Texture class X and class S-X (50%)
- Depth classes V, S and M, M-D (50%)

2.2.4.11. Runoff strips, range shrubs
Slopes. 'Gentle' to 'medium' slopes are optimal. Inflection points of the sigmoid function are A: 1 (0); B: 2 (1); C: 10 (1); D: 15 (0)

Soil constraints. Soils with the following classes are excluded:
- Salinity class S
- Texture classes S, X and S-X
- Depth class V and S

2.2.4.12. Runoff strips, field crops
Slopes. 'Gentle' to 'medium' slopes are optimal. Inflection points of the sigmoid function are A: 1 (0); B: 2 (1); C: 10 (1); D: 15 (0)

Soil constraints. Soils with the following classes are excluded:

- Salinity class S
- Texture classes S, X and S-X
- depth class V, S and M

2.2.4.13. Contour bench terraces

Slopes. This system is suitable in areas with strongly dissected topography. Most fitting slope classes for this system, subject to appropriate wall fortification, are 'steep' to 'very steep'. Inflection points of the sigmoid function are A: 10 (0); B: 20(1); C: 50 (1); D: 100 (0)

Soil constraints. In evaluating the presence of soil constraints, one has to be aware that the cut-and-fill operations involved in the construction of contour bench terraces create such a degree of soil modification that the original depth and stoniness properties are permanently changed. Concentration of agricultural soil on the terrace flat is a common practice, whereas the terrace walls are strengthened with the coarse fragments, stones and rocks. For this reason, the presence of shallow and stony soils is considered a bonus, since it means that the necessary wall materials are already in place. At the same time, given the separation of the soil fractions involved in building the terraces, it is not possible to evaluate the soil constraints separately for tree or field crops.

Soils with the following classes are excluded:

- Depth classes V, D, M
- Salinity class S
- Texture class X and class S-X (50%)

2.2.5. Enhanced visualization

Figure 4 shows a sample area from the suitability map for the technology 'micro-catchments/ small runoff basins/ range shrubs'. For diverse purposes, such as reproduction on small-scale maps, more concise pattern delineation or simply reduction of file size using file compression, it may be useful to apply a noise-reduction procedure. To achieve this, the suitability rankings were regrouped into 6 classes as follows:

- Class 1: 0 (no suitability)
- Class 2: 0 – 20 (very low)
- Class 3: 20 – 40 (low)
- Class 4: 40 – 60 (moderate)
- Class 5: 60 – 80 (suitable)
- Class 6: 80 – 100 (high suitability)

This layer containing class values was then separated into 6 different layers, each containing either the value x (where x equals the class number) or zero (not belonging to class x). To each layer a majority filter was applied (Fig. 5). In case the majority function leads to 'no data' values (when there is no majority within the neighbors), the original pixel value was retained.

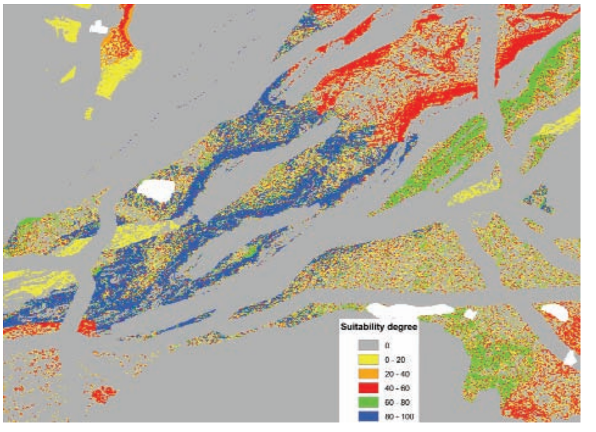

Figure 4. Sample area with unprocessed suitability rankings

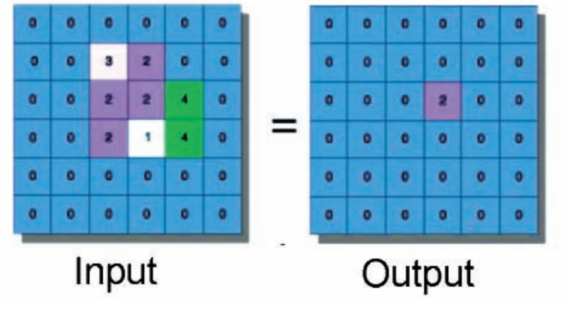

Figure 5. Focal majority filter (ESRI, 2005)

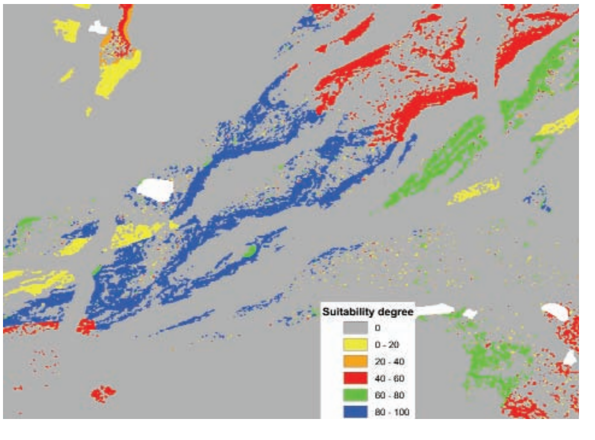

Figure 6. The same sample area with aggregated suitability rankings

Finally, the 'maximum' function was applied on the six layers for each pixel, in order to promote the higher suitability ranking. The results of this procedure are shown for the same sample area in Figure 6.

2.3. Results

The results of the analysis are summarized in Table 5 and in Annex 4. In addition, a set of maps on the CD shows the suitability domains for the different water harvesting technologies. Table 5 shows the percentages of each province with high or very high suitability scores. A similar table with a breakdown by district is provided in Annex 4.

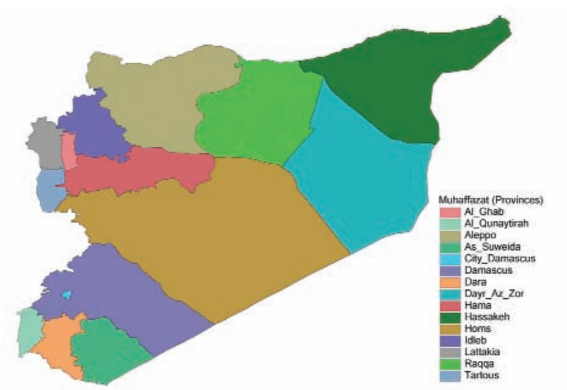

Figure 7. Provinces of Syria

Figure 7 shows the location of the provinces. Homs, Hama, Dayr Az Zor and Raqqa have the highest concentrations of areas with high suitability for various water harvesting techniques. In large parts of these provinces, the precipitation is in the optimal range for water harvesting, while at the same time soils are generally not prohibitive by depth or soil texture, although salinity is present in some areas. Although Damascus and Sweida provinces also have large areas with a suitable precipitation range and slopes, the soils are generally too shallow or stony for using the in-situ harvested water.

In these higher-potential areas for water harvesting, the highest scores for range shrubs (in terms of percentage of the province with high and very high suitability scores) are for small runoff basin systems, followed by contour ridges and small circular bunds. Small pits have the lowest scores whereas runoff strips have intermediate scores. In the case of field crops, the relative performance of the different technologies is similar, but the scores are much lower, except for the small pits, where they are the same. The results also seem to indicate that for tree crops the most suitable WH techniques are contour ridges and small runoff basins. With small runoff basins, the best performing technology for shrubs and field crops, tree crops are likely to perform less well under the particular climatic, soil and terrain conditions.

Table 5. Percentages of Syrian provinces with high suitability scores for different water harvesting techniques

WH system	**Contour ridges - Range shrubs**			**Contour ridges - Field crops**			**Contour ridges - Tree crops**			**Semicircular bunds - Range shrubs**			**Semicircular bunds - Field crops**			**Semicircular bunds - Tree crops**		
Muhafaza (Province)	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S
As_Suweida	2	1	4	0	0	1	0	1	1	2	1	3	0	0	1	0	0	1
Dara	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Al_Qunaytirah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Damascus	5	3	8	1	2	3	6	3	9	4	2	6	2	1	4	2	1	3
Tartous	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Homs	6	9	15	5	3	8	12	9	20	6	8	14	6	3	9	3	2	5
Hama	2	4	6	2	2	4	1	8	9	2	4	6	3	2	4	1	1	3
Al_Ghab	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lattakia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Idleb	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dayr_Az_Zor	3	5	8	4	1	4	12	4	16	3	4	7	4	1	5	1	0	2
Raqqa	2	4	6	2	1	3	7	7	14	2	4	6	2	1	4	1	1	2
Aleppo	2	1	3	0	1	1	2	2	4	1	1	3	1	1	1	0	1	1
Hassakeh	2	1	2	0	0	1	2	2	4	2	0	2	1	0	1	0	0	1

Notes: %S: percentage of the Province with suitability score 0.6-0.8 (or 60-80% on percentage basis)
%VS: percentage of the Province with suitability score 0.8-1 (or 80-100% on percentage basis)
%S+VS: sum of above

Table 5. Percentages of Syrian provinces with high suitability scores for different water harvesting techniques

WH system	Small pits- Range shrubs			Small pits- Field crops			Small runoff basins- Range shrubs			Small runoff basins- Tree crops			Runoff strips- Range shrubs			Runoff strips- Field crops			Contour bench terraces		
Muhafaza (Province)	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S
As Suweida	0	0	1	0	0	1	0	1	1	1	0	1	0	0	1	0	0	1	0	0	0
Dara	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0
Al Qunaytirah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Damascus	2	1	3	2	1	3	7	2	9	7	2	9	2	1	4	2	1	3	1	0	1
Tartous	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Homs	3	2	5	3	2	5	13	8	21	13	8	21	6	3	9	3	2	5	0	0	1
Hama	1	1	3	1	1	3	2	8	10	2	8	10	3	2	4	1	1	3	0	0	0
Al Ghab	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lattakia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Idleb	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dayr Az Zor	1	0	2	1	0	2	13	5	18	14	4	18	4	1	5	1	0	2	0	0	0
Raqqa	1	1	2	1	1	2	7	8	15	7	8	15	3	1	4	1	1	2	0	0	0
Aleppo	0	1	1	0	1	1	2	2	4	2	2	4	1	0	1	0	0	1	0	0	0
Hassakeh	0	0	1	0	0	1	2	2	4	2	2	4	1	0	1	0	0	1	0	0	0

%S: percentage of the Province with suitability score 0.6-0.8 (or 60-80% on percentage basis)
%VS: percentage of the Province with suitability score 0.8-1 (or 80-100% on percentage basis)
%S+VS: sum of above

3. EVALUATING SUITABILITY FOR MACRO-CATCHMENTS

3.1. Methodology

3.1.1. Overview

Macro-catchment systems are sometimes referred to as ‘water harvesting from long slopes’ or as ‘harvesting from an external catchment’ (Oweis et al., 2001). The modeling of suitability for macro-catchments is more complicated than for micro-catchments, because the run-off is generated outside the pixel to be evaluated, and is a largely unknown quantity.

Using the current simple rainfall, soil, terrain and land use criteria at country level, the evaluation of suitability for macro-catchments requires the separate evaluation of suitability for a ‘catchment’ area and for a ‘use’ area. The criteria for the ‘catchment’ and ‘use’ areas are different:

- for the catchment area, strongly sloping land with soils that are shallow, rocky, or have poor infiltration capacity is preferable;
- for the use area, level or gently undulating land with deep soils and no other limitations to agricultural use is preferable
- in addition, land suitable for use as a catchment, must be within a certain distance of land suitable for agricultural use.

The problem of identifying, in a GIS environment, land with these contrasting requirements is then reduced to a separate assessment of suitability for catchment and agricultural purposes, followed by an assessment of the constraint imposed by distance between these two different environments.

It is to be noted that in this assessment the suitability for reservoir construction has not been taken into consideration.

3.1.2. Evaluating suitability for catchment use

The following factors are considered:

- precipitation
- slope
- hydrological properties of soils
- geological materials

3.1.2.1. Precipitation

For all macro-catchment systems the precipitation criterion is the same as for the micro-catchment systems, and suitability is approximated using the same fuzzy symmetric sigmoid membership function with four inflection points A: 0 (0); B: 150 (1); C: 250 (1); D: 500 mm (0). The ‘precipitation score’ layer Sprecip = ?(precip) is therefore the same.

3.1.2.2. Slope

Any surface can act as a catchment as long as it has some slope, very limited permeability for precipitation and no obstacles. As a first approximation, one could consider the slope as non-limiting, as long as it is not near zero. This condition can be simulated by a fuzzy symmetric sigmoid membership function with two inflection points A: 0% (0); B: 5% (1) and the ‘slope score’ layer is then $S_{slope} = f$ (slope)

3.1.2.3. Soil hydrological properties

Soils have different hydrological properties and as such are a major factor in the run-off generating potential of catchments. The Soil Conservation Service of the US Department of Agriculture (1969) differentiates four major hydrological classes:

- Class A (low run-off potential): deep sandy soils;
- Class B: shallow sandy soils and medium-texture soils with above average infiltration rates;
- Class C: shallow soils of medium to heavy texture with below-average infiltration rates;
- Class D (high run-off potential): clay and shallow soils with hardpan, high groundwater table etc.

Using this framework and expert judgment, the soils of Syria have been reclassified into hydrological classes (Table 6). For a summary description of the soil types of Syria is referred to Van de Steeg and De Pauw (2002) and to Annex 2.

The interpretation of Figure 8 is that if, for example, the soil in a particular pixel belongs to hydrological class D, there will be no reduction in runoff if the slope is 3% or higher; if, on the other hand, the soil belongs to hydrological class C, a reduction factor of .5 will be applied as compared to the optimal slope range for this class (> 8%).

It is useful to use for Class D, with its very low permeability, the analogy of a plastic sheet. No water will run away from the sheet, if the slope is zero. However, the slightest slope will be cause for runoff. At the other end, one could visualize for Class A the same plastic sheet, but full of holes. Water poured over the sheet will drain through the holes. To generate runoff, the slope must be quite steep for the water to run off before it has the time to seep through the holes. Classes B and C have intermediate drainage properties.

Also in this situation, one has to consider the case of heterogeneous pixels. Since several soil types may occur in a pixel, eventually with different hydrological properties, a weighted reduction factor is calculated as follows:

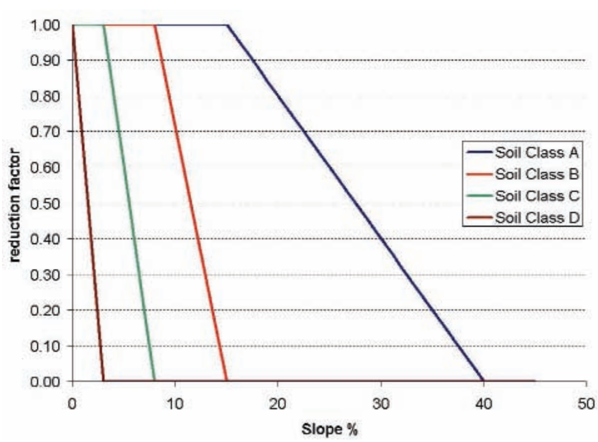

Figure 8. Reduction factors for soil hydrological classes

Referring to Table 6, the reduction factor for a particular soil hydrological class i is then:

if Slope ≥a then $RF_i = 0$
if Slope ≤b then $RF_i = 1$
if Slope between (a,b) then

$$RF_i = \frac{Slope - a_i}{b_i - a_i}$$

and

$$RF_p = \sum_{i=1}^{n} w_i RF_i$$

with RF= reduction factor for pixel p; i = class A, B, C or D; wi is weight (percentage) of hydrological class A, B, C, or D; RFi the reduction factor for hydrological class i.

The soil-corrected score for slope is, then, taken as the lowest value of either the slope score or the reduction factor as follows:

$$S_{slope,cor} = Min(S_{slope}, 100\text{-}RF_p)$$

The final score for suitability as a catchment is, then, taken as the lowest of the precipitation score and the soil-corrected slope score:

$$S = Min(S_{slope,cor}; S_{precip})$$

3.1.2.4. Geological materials

Soils on certain parent materials may have somewhat different hydrological properties than estimated in Table 4. The soils for which an adjustment of the hydrological class is considered necessary are the shallow soils and rock outcrops on limestones and dolomites with strong karstic properties. These soils are shown in **bold** in Table 4. These soils should be

Table 6. Soils of Syria: hydrological classes

Hydrological class	Soil	a	b
A	21a; 21b; 21c; 22; 23	40%	15%
B	1; 3a; 3b; 4a; 4b; 7a; 7b; 8; 9a; 9b; 10; 15b; 16; 17; 25a; 25b; 25c;30a;30b; 30c; 30d; 32; 37; 42c	15%	8%
C	7c; 12a; 12b; 12c; 15a; 19; 31a; 31b; 31c; 38; 39a; 39b; 40a; 40b; 41	8%	3%
D	2a; 2b; 2c; 5; 6a; 6b; 11; 13; 14; 18a; 18b; 18c; 18d; 18e; 20a; 20b; 20c; 20d; 20e; 24; 26a; 26b; 26c; 26d; 27; 28; 29; 33; 34; 35a; 35b; 36; 42a; 42b	3%	0%

processed as if they belong to hydrological class B if they coincide with the following parent materials, identified from the 1:200,000-scale Geological Map of Syria:

- **N1h**: Neogene, Helvetian organogenic limestones
- **Pg_2^2 :** Paleocene, middle Eocene clayey limestones, limestones and nummulithic limestones
- **Cr2cm-t**: Cretaceous, Cenomanian and Turonian undifferentiated limestones and dolomites

These parent materials were located within the areas of potential suitability by the combined use of the 1:200,000 geological maps and Landsat imagery.

The hydrological soil classes are then used to apply a reduction factor on the score for slope, as indicated in Table 6 and shown in Figure 7.

3.1.3. Evaluating suitability for agricultural use

3.1.3.1. Precipitation

The same criterion as for all WH methods and the same sigmoid membership function with four inflection points A: 0 (0); B: 150 (1); C: 250 (1); D: 500 mm (0).

3.1.3.2. Slopes

‘ Flat to gentle’ slopes are optimal. This is simulated by a monotonically decreasing sigmoid membership function, with inflection points A: 0 (1); B: 15 (0).

3.1.3.3. Soils

Soils with the following classes are excluded:

- Depth class: S,V
- Texture class: X
- Stoniness class: A,D
- Salinity class: S

3.1.3.4. Land use

Forest and irrigated areas are excluded.

3.1.3.5. Scoring for the agricultural areas

Score for agricultural area:

$$\mathbf{Min(S_{slope}, S_{precip}) - p_{NS}}$$

with $p_{NS} = p_{NS,LULC} + p_{NS,Soil}$

and $p_{NS,LULC} = p_{forest} + p_{irrigated}$

and $p_{NS,Soil} = p_{NS,Depth} + p_{NS,Salinity} + p_{NS, Texture}$ (see also sections 2.2.2.4 and 2.2.2.5)

3.1.4. Combining suitability for catchment and agricultural uses

The combined suitability for catchment and agricultural purposes is assessed by identifying those areas where suitable catchments and agricultural areas are close together. The limiting distance between the two is taken as 2 km.

3.2. Results

3.2.1. Suitability for macro-catchment use

Map 14 in Annex 5 shows the suitability scores for macro-catchment use across Syria.

3.2.2. Suitability for agricultural use

Map 15 in Annex 5 shows the suitability scores for agricultural uses.

3.2.3. Suitability for macro-catchment water harvesting systems

Map 16 in Annex 5 shows the areas that are suitable for either macro-catchment use or agricultural use, in the assumption that they are within a close distance from each other.

Figure 9 summarizes the process for identifying areas suitable for macro-catchment systems. Two small inset maps on the bottom right show target areas that meet both requirements of suitability for catchment and target use and are close to each other.

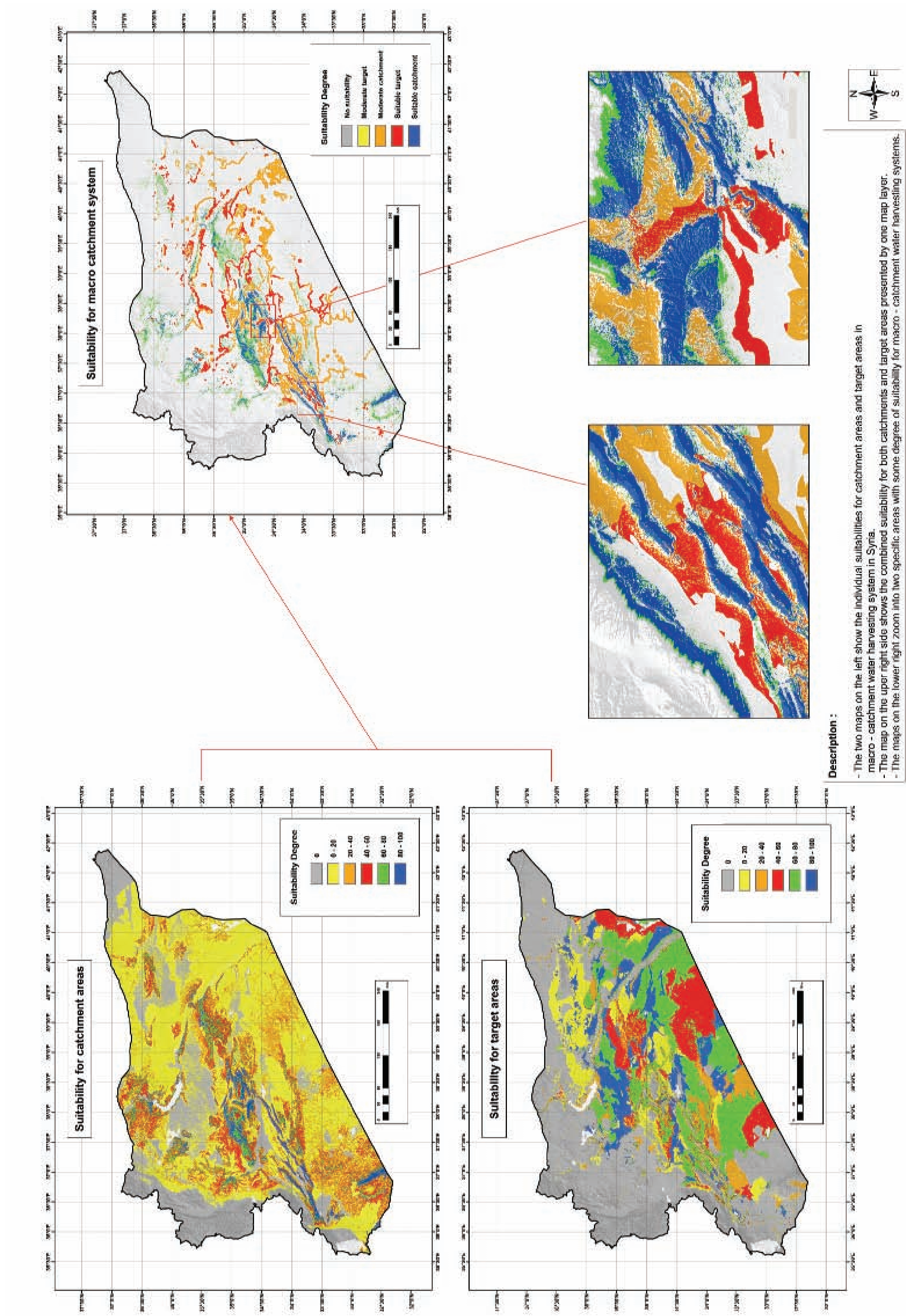

Figure 9. Sequence in assessing suitability for macro-catchment water harvesting techniques

4. CONCLUSIONS AND FOLLOW UP

A methodology has been developed for the assessment of suitability for water harvesting from a biophysical perspective. The approach is based on the pixel-level scoring of individual constraints that have been identified by technology experts, and their subsequent combination in a multi-criteria evaluation. The application of this methodology has resulted in suitability maps for 13 variants of micro-catchment systems and a single generalized macro-catchment system.

The approach can, subject to the availability of similar data, be applied without modifications to other dryland countries. In addition, it is a relatively straightforward exercise to modify the methodology to develop a regional or global map. In a follow-up study, a regional study will be presented that extends the current methodology to all dryland areas.

It needs to be remembered that the method is a kind of modeling exercise and therefore, requires validation. This validation will be taken up in the form of a targeted field survey that will compare the results predicted by the model with an assessment of actual conditions in sample locations.

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ANNEX 1. SOIL ASSOCIATION COMPOSITION

Soil association	Soil 1	% Soil 1	Soil 2	% Soil 2	Soil 3	% Soil 3	Soil 4	% Soil 4	Soil 5	% Soil 5	Soil 6	% Soil 6	Soil 7	% Soil 7
A11a	3b	70	7b	30										
A11b	3a	45	13	35	18b	10	7b	10						
A11c	3a	50	19	30	18b	10	2b	10						
A11d	3b	50	19	20	18b	15	7b	10	42b	5				
A11e	3a	50	19	20	18b	10	7b	10	2b	10				
A11f	3a	70	7a	20	2a	10								
A11g	3a	50	7b	20	13	20	18b	5	2b	5				
A11h	3a	45	2a	20	18b	10	7b	10	12c	10	42b	5		
A11i	3a	60	12c	30	9a	10								
A11j	3a	50	12c	20	11	20	18c	10						
A11k	3a	50	18b	25	2a	10	7b	10	42b	5				
A11m	3a	60	32	30	9b	10								
A12a	2c	40	3a	25	18b	20	7b	15						
A12b	2c	50	18b	30	7b	20								
A12c	2c	40	18b	30	3a	20	42b	10						
A12d	2c	50	18b	20	4b	20	42b	10						
A13a	4a	50	25b	30	3a	10	7b	10						
A13b	4a	40	3a	30	13	10	9a	10	25b	10				
A21a	7b	40	18d	20	6a	20	5	10	15b	10				
A21b	7b	80	3a	20										
A21c	7b	65	4a	20	3b	10	15b	5						
A21d	7c	40	6b	30	18e	20	42b	10						
A22a	8	70	4a	30										
A22b	8	50	6b	30	18e	15	42b	5						
A31a	12b	50	9b	30	3a	10	11	10						
A31b	12b	50	3a	30	7a	10	9b	5	10	5				
A31c	12c	40	3a	20	19	20	9a	10	4b	10				
A31d	12c	40	11	30	3a	15	9a	15						
A31e	12c	50	3a	20	9a	15	18b	10	42b	5				
A31f	12c	50	3a	20	11	20	9a	10						
A31g	12a	50	3a	30	9a	10	10	10						
A31h	12a	40	3a	20	9a	20	4b	10	11	5	13	5		
A31i	12c	70	15a	30										
A31j	12c	40	15a	30	11	20	3a	10						
A31k	12a	50	11	30	3a	20								
A32a	11	60	18a	20	12c	20								
A32b	11	40	12c	20	19	20	3a	10	22	10				
A32c	11	40	12c	20	3a	20	13	10	42b	10				
A41a	13	60	3b	40										
A51a	15a	70	14	30										
E11a	16	70	15a	15	19	10	14	5						
E21a	17	80	21a	20										
E41a	26	100												
E51a	18b	70	42b	20	2c	10								
E51b	18b	50	19	30	3b	15	42b	5						
E51c	18b	60	42b	30	19	10								
E51d	18c	50	12c	30	42b	20								
E51e	18c	50	19	20	42b	10	12c	10	3a	5	11	5		
E51f	18c	40	11	30	12b	20	42b	10						
E61a	20c	40	26c	30	42b	20	30d	10						
E61b	20c	60	35b	20	26d	15	42b	5						
E61c	20b	80	26b	10	42b	10								
E61d	20a	50	26a	20	42b	10	25a	10	28	10				
E61e	20c	45	26c	20	25a	20	42b	10	28	5				
E61f	20a	70	42b	20	26a	10								
E61g	20a	40	42b	30	26a	20	30c	10						

ANNEX 1. continued

Soil association	Soil 1	% Soil 1	Soil 2	% Soil 2	Soil 3	% Soil 3	Soil 4	% Soil 4	Soil 5	% Soil 5	Soil 6	% Soil 6	Soil 7	% Soil 7
E61h	20a	40	42b	20	26a	20	30c	10	35a	5	34	5		
E61i	20a	40	42b	30	26a	10	30c	10	34	5	36	5		
E61j	20e	50	26a	30	1	10	30a	10	42b	0				
I11a	30a	70	31a	30										
I11b	30b	40	31c	30	21c	20	40a	10						
I11c	30d	40	42c	30	20c	10	26d	10	31b	10				
I11d	30a	40	26b	30	20b	10	28	10	42b	10				
I11e	30a	60	25c	30	26c	10								
I11f	30b	60	26d	30	28	10								
I12a	25b	40	3a	30	12b	30								
I12b	25b	40	30b	30	26b	10	20b	10	31c	10				
I12c	25b	40	3a	20	7c	20	26c	10	30d	10				
I12d	25c	40	31a	30	15a	10	39a	10	40a	10				
I12e	25b	50	30b	20	4b	20	26b	10						
I12f	25b	50	30b	15	31c	10	28	10	26a	5	42b	5	20a	5
I13a	26b	50	20c	40	28	10								
I13b	26d	50	30d	20	31b	10	29	10	42b	5	20c	5		
I13c	26a	40	35b	30	20d	10	30c	10	42b	10				
I13d	26b	40	20b	20	28	20	30a	10	25b	10				
I13e	26a	50	30a	30	42b	10	28	10						
I13f	26b	40	28	30	25b	10	30d	10	31c	10				
I13g	26c	40	25a	30	3a	20	18a	5	13	5				
I13h	26b	40	25c	30	20b	10	28	10	30a	10				
I13i	26b	40	30a	20	21c	20	20b	10	42b	10				
I13j	26b	40	25b	30	20c	20	42b	10						
I14a	28	70	25c	30										
I14b	28	60	26d	20	20b	10	30a	10						
I15a	31c	40	30b	20	40a	20	37	10	41	10				
I15b	31b	50	40b	20	30d	15	26c	10	42a	5				
I15c	31b	50	30d	20	40b	10	42a	10	26c	10				
I15d	31c	50	40a	20	25b	20	30b	10						
M11a	37	40	30a	30	36	20	33	10						
M11b	37	35	30a	30	24	20	21b	10	40a	5				
M11c	37	35	30d	25	31a	20	42b	5	20e	5	23	5	26a	5
M12a	35b	40	30a	30	26c	10	36	10	38	10				
M12b	35a	30	26b	20	27	20	30a	20	20d	10				
V11a	40b	70	39b	30										
V11b	40b	40	31c	30	30a	20	26a	10	42b	-				
X11a	42a	100												
X11b	42a	100												
X11c	42a	100												
X11d	42a	100												
X12a	42b	100												

Explanatory notes:
Column 1: Soil association label
Column 2: 1st soil type of the soil association
Column 3: Estimated percentage of the 1st soil type in the soil association
Column 4: 2nd soil type of the soil association
Column 5: Estimated percentage of the 2nd soil type in the soil association
Column 6: 3rd soil type of the soil association
Column 7: Estimated percentage of the 3rd soil type in the soil association
Column 8: 4th soil type of the soil association
Column 9: Estimated percentage of the 4th soil type in the soil association
Column 10: 5th soil type of the soil association
Column 11: Estimated percentage of the 5th soil type in the soil association
Column 12: 6th soil type of the soil association
Column 13: Estimated percentage of the 6th soil type in the soil association
Column 14: 7th soil type of the soil association
Column 15: Estimated percentage of the 7th soil type in the soil association

ANNEX 2. BRIEF DESCRIPTION OF SOIL TYPES IN SYRIA

SOIL_ID[1]	Soil taxonomy label	Depth class[2]	Texture class[3]	Stoniness class[4]	Salinity class[5]	Hydrological class[6]	Description
1	Typic Haploxeralfs	M	Y	N	N	B	Well drained, moderately deep, dark brown to dark reddish brown, clayey textured soils with clay accumulation in depth. The subsoil is strongly structured. The AWC is between 100 and 150 mm. The soil moisture regime[7] is xeric.
2a	Lithic Calciorthids	S	C	A	N	D	Well drained, shallow, strong brown to reddish yellow, clayey textured soils. The subsoil is weak to moderately structured. The surface contains abundant stones. The AWC is between 20 and 60 mm/m. The soils have a horizon enriched in calcium carbonate and are developed on limestone, marl or basalt. The soil moisture regime is aridic.
2b	Lithic Calciorthids	S	C	V-F	N	D	Well drained, shallow, strong brown to reddish yellow, clayey textured soils. The subsoil is weakly structured. The AWC is between 20 and 60 mm/m. The surface contains few to very few stones. The soils have a horizon enriched in calcium carbonate and are developed on limestone, marl or basalt. The soil moisture regime is aridic.
2c	Lithic Calciorthids	S	Y	V	N	D	Well drained, shallow, strong brown, clayey textured soils. The subsoil is moderately structured. The AWC is between 20 and 60 mm/m. The surface contains very few stones. The soils have a horizon enriched in calcium carbonate and are developed on limestone or basalt. The soil moisture regime is aridic.
3a	Typic Calciorthids	D	C	F	N	B	Well drained, deep, strong brown to reddish yellow, clayey textured soils. The subsoil is weakly structured and contains between 15 and 35% gravel. The surface contains few stones. The AWC is between 100 and 150 mm/m. The soils are X-ray amorphous, and have a horizon enriched in calcium carbonate. They are developed on pyroclastic material. The soil moisture regime is aridic.

[1] *All soil types contain free $CaCO_3$. For this reason the attribute is not repeated in the descriptions.*
[2] *For explanation of depth class symbols, see Table 3 in section 2.2.3.3.*
[3] *For explanation of texture class symbols, see Table 3 in section 2.2.3.3.*
[4] *See explanatory notes at the end of this table related to stoniness classes*
[5] *For explanation of salinity class symbols, see Table 3 in section 2.2.3.3.*
[6] *For explanation of hydrological class symbols, see section 3.1.2.3.*
[7] *See explanatory notes at the end of this table related to soil moisture regimes.*

ANNEX 2. Continued

SOIL_ID[2]	Soil taxonomy label	Depth class[3]	Texture class[4]	Stoniness class[5]	Salinity class[6]	Hydrological class[7]	Description
3b	Typic Calciorthids	D	Y	V	N	B	Well drained, deep, yellow to very pale brown, clayey soils. The subsoil is weakly structured and contains between 15 and 35% gravel. The surface contains very few stones. The AWC is between 150 and 200 mm/m. The soils are developed on lacustrine or fluvial deposits. The soils have a horizon enriched in calcium carbonate. The soil moisture regime is aridic.
4a	Xerollic Calciorthids	D	L	F-C	N	B	Well drained, deep, dark brown to brown, loamy soils. The subsoil is weakly structured and contains more than 35% gravel. The surface contains few to common stones. The AWC is between 150 and 200 mm/m. The soils have vertic properties and a horizon enriched in calcium carbonate The soil moisture regime is aridic.
4b	Xerollic Calciorthids	D	L	M-A	N	B	Well drained, deep, dark brown to brown, loamy soils. The subsoil is weakly structured and contains more than 35% gravel. The surface contains many to abundant stones. The soils have vertic properties and have a horizon enriched in calcium carbonate. The AWC is between 150 and 200 mm/m. The soils are developed on limestone, marl and gypsum. The soil moisture regime is aridic.
5	Aquic Camborthids	D	Y	N	G	D	Imperfectly drained, deep, dark brown to very pale brown, clayey soils. The subsoil is moderately structured. The surface contains very few stones. The AWC is between 100 and 150 mm/m. The soils are developed on limestone or colluvial deposits. The soil moisture regime is aridic.
6a	Lithic Camborthids	S	Y	N	N	D	Well drained, shallow, dark brown to yellowish brown, clayey soils. The subsoil is moderately structured. The surface is free of stones. The AWC is between 150 and 200 mm/m. The soils have vertic properties and are developed on basalts. The soil moisture regime is aridic.
6b	Lithic Camborthids	S	Y	D	N	D	Well drained, shallow, brown to strong brown, clayey soils. The subsoil is structureless and contains more than 35% gravels. The surface predominantly contains stones and rocks. The AWC is less than 20 mm/m. The soils have vertic properties, and are developed on limestone, marl, gypsum, colluvial or marine deposits. The soil moisture regime is aridic.

ANNEX 2. Continued

SOIL_ID[2]	Soil taxonomy label	Depth class[3]	Texture class[4]	Stoniness class[5]	Salinity class[6]	Hydrolo-gical class[7]	Description
7a	Typic Camborthids	D	C	N	N	B	Well drained, deep, reddish yellow to strong brown, clayey textured soils. The Bsubsoil is moderately structured. The AWC is between 100 and 150 mm/m. The soils have vertic properties, and are developed on limestone and/or basalts. The soil moisture regime is aridic.
7b	Typic Camborthids	D	C	N-V	N	B	Well drained, deep, yellowish brown to dark brown, clayey textured soils. The subsoil is moderately structured. The surface contains no to very few stones. The AWC is between 100 and 150 mm/m. The soils have vertic properties, and are developed on colluvial deposits. The soil moisture regime is aridic.
7c	Typic Camborthids	M	C	A-D	N	C	Well drained, moderately deep, yellowish brown to yellowish red, clayey textured soils. The subsoil is moderately structured and contains more than 35% gravel. Stones and rocks dominate the surface. The AWC is between 60 and 100 mm/m. The soil moisture regime is aridic.
8	Xerollic Camborthids	D	Y	N	N	B	Well drained, deep, yellowish brown, clayey textured soils. The subsoil is weakly structured. The AWC is between 100 and 150 mm/m. The soils are developed on limestone. The soil moisture regime is aridic.
9a	Calcic Gypsiorthids	M-D	C	N	G	B	Well drained, (moderately) deep, strong brown, clayey textured soils. The subsoil is weakly structured and contains between 15 and 35% gravel. The AWC is between 60 and 100 mm/m. The soils have a horizon enriched in both gypsum and calcium carbonate The soil moisture regime is aridic.
9b	Calcic Gypsiorthids	M-D	L	N	G	B	Well drained, (moderately) deep, dark yellowish brown, loamy textured soils. The subsoil is weakly to moderately structured and contains between 15 and 35% gravel. The AWC is between 100 and 150 mm/m. The soils have a horizon enriched in both gypsum and calcium carbonate The soil moisture regime is aridic.

ANNEX 2. Continued

SOIL_ID[2]	Soil taxonomy label	Depth class[3]	Texture class[4]	Stoniness class[5]	Salinity class[6]	Hydrological class[7]	Description
10	Cambic Gypsiorthids	D	Y	N	G	B	Well drained, deep, yellowish brown, clayey textured soils. The subsoil is weakly structured. The AWC is between 100 and 150 mm/m. The soils have a horizon enriched in gypsum and are developed on limestone or basalt. The soil moisture regime is aridic.
11	Petrogypsic Gypsiorthids	S	L	N	G	D	Shallow soils, with varying degree of stoniness. The soils have a strongly cemented horizon enriched in gypsum and are developed on limestone and/or gypsum, or colluvial deposits.
12a	Typic Gypsiorthids	D	C	V-F	G	C	Well drained, deep, yellowish brown to reddish brown, clayey textured soils. The subsoil is weakly structured. The surface contains very few to few stones. The AWC is between 100 and 150 mm. The soils are saline, and have a horizon enriched in gypsum. They are developed on lacustrine or fluvial deposits. The soil moisture regime is aridic.
12b	Typic Gypsiorthids	D	L	N	G	C	Well drained, deep, dark yellowish brown to yellowish brown, loamy textured soils. The subsoil is structureless and contains between 15 and 35% gravel. The AWC is between 100 and 150 mm/m. The soils are saline, and have a horizon enriched in gypsum. They are developed on lacustrine and fluvial deposits. The soil moisture regime is aridic.
12c	Typic Gypsiorthids	D	L	N-V	G	C	Well drained, deep, brownish yellow to yellowish brown, loamy textured soils. The subsoil is structureless. The surface contains none to very few stones. The AWC is between 100 and 150 mm. The soils are saline, and have a horizon enriched in gypsum. They are developed on lacustrine or fluvial deposits. The soil moisture regime is aridic.
13	Typic Paleorthids	D	Y	N	N	D	Very shallow, well drained soils. The soils have a strongly cemented layer in depth and are developed on limestone and/or colluvial deposits.
14	Aquollic Salorthids	D	C	N	S	D	Moderately well drained, deep, dark brown to grayish brown, clayey textured soils. The subsoil is structureless. The AWC is between 100 and 150 mm/m. The soils are saline and are developed on limestone and basalt. The soil moisture regime is aridic.

ANNEX 2. Continued

SOIL_ID[2]	Soil taxonomy label	Depth class[3]	Texture class[4]	Stoniness class[5]	Salinity class[6]	Hydrological class[7]	Description
15a	Typic Salorthids	D	C	N	S	C	Moderately well drained, deep, dark brown to brown, clayey textured soils. The subsoil is structureless. The AWC is between 100 and 150 mm/m. The soils are saline and are developed on fluvial deposits. The soil moisture regime is aridic.
15b	Typic Salorthids	D	L	V	S	B	Moderate well drained, deep, light yellowish brown to pale brown, loamy textured soils. The subsoil is moderate to strong structured. The surface contains very few stones. The AWC is between 100 and 150 mm/m. The soils are saline and are developed on limestone. The soil moisture regime is aridic.
16	Typic Torrifluvents	D	C	N	N	B	Moderately well drained, deep, grayish brown, clayey soils. The subsoil is structureless. The AWC is between 100 and 150 mm/m. The soils are developed on limestone. The soil moisture regime is aridic.
17	Typic Xerofluvents	D	Y	N	N	B	Moderately well drained, deep, dark grayish brown to grayish brown, clayey soils. The subsoil is structureless. The AWC is between 100 and 150 mm/m. The soils have gleyic properties. The soils are developed on lacustrine deposits. The soil moisture regime is aridic.
18a	Lithic Torriorthents	S	C	A	N	D	Well drained, shallow, dark yellowish brown, clayey soils. The subsoil is weakly structured and contains between 15 and 35% gravel. The AWC is between 20 and 60 mm/m. The soil moisture regime is aridic.
18b	Lithic Torriorthents	S	C	A	N	D	Well drained, shallow, yellowish brown to strong brown, clayey soils. The subsoil is weakly structured, and contains between 15 and 35% gravel. The surface has abundant stones and rocks. The AWC is between 20 and 60 mm/m. The soils are developed on limestone, gypsum, and basalt. The soil moisture regime is aridic.
18c	Lithic Torriorthents	S	C	N-F	N	D	Well drained, shallow, dark yellowish brown, clayey soils. The subsoil is weakly structured, and contains between 15 and 35% gravel. The surface contains no to few stones. The AWC is between 20 and 60 mm/m. The soils are developed on gypsic rocks.

ANNEX 2. Continued

SOIL_ID[2]	Soil taxonomy label	Depth class[3]	Texture class[4]	Stoniness class[5]	Salinity class[6]	Hydrological class[7]	Description
18d	Lithic Torriorthents	V	L	A	N	D	Well drained, very shallow, dark grayish brown to gray, loamy soils. The subsoil contains between 15 and 35% gravel. The AWC is between 20 and 60 mm/m. The soils are developed on lacustrine deposits. The soil moisture regime is aridic.
18e	Lithic Torriorthents	S	Y	A	N	D	Well drained, shallow, yellowish brown, clayey soils. The subsoil contains between 15 and 35% gravel. The surface rockiness is abundant. The AWC is between 20 and 60 mm/m. The soils are developed on basalt.
19	Typic Torriorthents	D	C	A	N	C	Well drained, deep, yellowish brown to strong brown, clayey soils. The subsoil contains more than 35% gravel. The surface contains abundant stones. The AWC is between 20 and 60 mm/m. The soils are developed on lacustrine deposits. The soil moisture regime is aridic.
20a	Lithic Xerorthents	V	C	A	N	D	Well drained, very shallow, light gray to dark grayish brown, clayey soils. The subsoil contains between 15 and 35% gravel. The AWC is between 20 and 60 mm/m. The soils are developed on limestones and fluvial deposits. The soil moisture regime is xeric.
20b	Lithic Xerorthents	V	C	A	N	D	Well drained, very shallow, reddish brown, clayey soils. The subsoil is weakly structured and contains between 5 and 35% gravel. The surface contains common rocks. The AWC is between 20 and 60 mm/m. The soils are developed on limestones and marls. The soil moisture regime is xeric.
20c	Lithic Xerorthents	S	C	A	N	D	Well drained, shallow, dark brown to brown, clayey . soils. The depth is very shallow. The subsoil contains between 15 and 35% gravel. The surface contains abundant stones. The AWC is between 20 and 60 mm/m. The soils are developed on limestone and marls. The soil moisture regime is xeric.
20d	Lithic Xerorthents	S	L	C	N	D	Well drained, shallow, very dark grayish brown to grayish brown, loamy soils. The subsoil is weakly structured and contains between 15 and 35% gravel. The surface contains common stones and rocks. The depth is shallow, the soil contains common to many rocks. The AWC is lower than 20 mm/m. The soils are developed on basalt and/or limestone. The soil moisture regime is xeric.

ANNEX 2. Continued

SOIL_ID[2]	Soil taxonomy label	Depth class[3]	Texture class[4]	Stoniness class[5]	Salinity class[6]	Hydrological class[7]	Description
20e	Lithic Xerorthents	V	S	A	N	D	Well drained, very shallow, yellowish brown to dark grayish brown, sandy soils. The AWC is lower than 20 mm/m. The soils are developed on basalt. The soil moisture regime is xeric.
21a	Typic Xerorthents	D	S	N	N	A	Excessively drained, deep, sandy soils. The subsoil contains more than 35% gravel. The AWC is lower than 20 mm/m. The soil moisture regime is xeric.
21b	Typic Xerorthents	D	C	A	N	A	Excessively drained, deep, reddish brown to yellowish red, clayey textured soils. The subsoil is moderately structured and contains more than 35% gravel. The surface contains abundant stones. The AWC is lower than 20 mm/m. The soil moisture regime is xeric.
21c	Typic Xerorthents	M-D	C	A	N	A	Excessively drained, (moderate) deep, reddish brown to yellowish red, clayey textured soils. The subsoil is moderately structured and contains more than 35% gravel. The surface contains abundant stones and common rocks. The AWC is lower than 20 mm/m. The soils are developed on limestone. The soil moisture regime is xeric.
22	Typic Torripsamments	D	S	C	N	A	Excessively drained, deep, strong brown, sandy soils. The AWC is between 60 and 100mm/m. The soils are developed on limestone or basalt. The soil moisture regime is aridic.
23	Typic Xeropsamments	D	S-X	N	N	A	Excessively drained, deep, brown, sandy soils. The AWC is between 60 and 100 mm/m. The soils are developed on colluvial deposits. The soil moisture regime is xeric.
24	Aquic Xerochrepts	D	C	N	N	D	Imperfectly drained, deep, grayish brown, clayey soils. The subsoil is structureless or weakly developed. The AWC is between 100 and 150 mm/m. The soils are developed on limestone, or colluvial, fluvial or lacustrine deposits. The soil moisture regime is xeric.
25a	Calcixerollic Xerochrepts	M-D	Y	N	N	B	Well drained, (moderately) deep, dark reddish brown, clayey soils. The subsoil is strongly structured and contains 15 to 35% gravel. The AWC is between 100 and 150 mm/m. The soils are developed on limestone. The soil moisture regime is xeric.
25b	Calcixerollic Xerochrepts	D	C	F	N	B	Well drained, deep, reddish brown to strong brown, clayey soils. The subsoil is moderately structured and contains 15-35% gravel. The surface contains few stones. The AWC is between 100 and 150 mm/m. The soil moisture regime is xeric.

ANNEX 2. Continued

SOIL_ID[2]	Soil taxonomy label	Depth class[3]	Texture class[4]	Stoniness class[5]	Salinity class[6]	Hydrolo-gical class[7]	Description
25c	Calcixerollic Xerochrepts	D	Y	N	N	B	Well drained, deep, dark reddish brown to yellowish brown, clayey soils. The subsoil is weakly structured and contains 15-35% gravel. The surface is free of stones. The AWC is between 100 and 150 mm/m. The soils are developed on marine deposits. The soil moisture regime is xeric.
26a	Lithic Xerochrepts	S	Y	A	N	D	Well drained, shallow, yellowish red to reddish brown, clayey soils. The subsoil is weakly to strongly structured and contains 15 to 35% gravel. The AWC is between 20 and 60 mm/m. The soils have gleyic properties. The soils are developed on lacustrine deposits. The soil moisture regime is xeric.
26b	Lithic Xerochrepts	S	C	A	N	D	Well drained, shallow, reddish brown to dark brown, clayey soils. The subsoil is moderately structured and contains 15 to 35% gravel. The surface contains abundant stones and common to abundant rocks. The AWC is between 20 and 60 mm/m. The soils are developed on limestone and fluvial deposits. The soil moisture regime is xeric.
26c	Lithic Xerochrepts	S	C	C	N	D	Well drained, shallow, reddish brown to dark brown, clayey soils. The subsoil is weakly to moderately structured and contains 15 to 35% gravel. The surface contains common stones and common to abundant rocks. The AWC is between 20 and 60 mm/m. The soils are developed on limestone and colluvial deposits. The soil moisture regime is xeric.
26d	Lithic Xerochrepts	S	C	F-M	N	D	Well drained, shallow, very dark grayish brown to brown, clayey soils. The subsoil is weakly to moder ately structured and contains 15 to 35% gravel. The surface contains few to many stones. The AWC is between 20 and 60 mm/m. The soils are developed on limestone. The soil moisture regime is xeric.
27	Lithic-Vertic Xerochrepts	S	C	A	N	D	Well drained, shallow, dark brown to brown, clayey soils. The subsoil is strongly structured and contains 15 to 35% gravel. The surface contains abundant stones and common rocks and shows considerable shrink-swell properties. The AWC is between 20 and 60 mm/m. The soils are developed on basalt and fluvial deposits. The soil moisture regime is xeric.

ANNEX 2. Continued

SOIL_ID[2]	Soil Taxonomy label	Depth class[3]	Texture class[4]	Stoniness class[5]	Salinity class[6]	Hydrolo-gical class[7]	Description
28	Petrocalcic Xerochrepts	S	C	N	N	D	Well drained, shallow, dark brown to brown, clayey soils. The subsoil is structureless and strongly indurated with calcium carbonate. The AWC is 60 to 100 mm/m. The soils are developed on limestone and basalt. The soil moisture regime is xeric.
29	Ruptic Lithic Xerochrepts	S	C	C	N	D	Well drained, shallow, reddish brown to yellowish red, clayey soils. The subsoil is moderately structured and contains 15 to 35% gravel. The surface contains common stones. The AWC is 60 to 100 mm/m. The soils are developed on limestone and marls. The soil moisture regime is xeric.
30a	Typic Xerochrepts	D	C	N	N	B	Well or moderately well drained, deep, dark grayish brown to reddish brown, clayey soils. The subsoil is moderately to strongly structured. The AWC is between 100 and 150 mm/m. The soils are developed on basalts, limestone and marls. The soil moisture regime is xeric.
30b	Typic Xerochrepts	D	C	N-C	N	B	Well or moderately well drained, deep, yellowish red to dark red, clayey soils. The subsoil is structureless to moderately structured. The surface contains no to common rocks. The AWC is between 100 and 150 mm/m. These soils have vertic properties and are developed on basalts. The soil moisture regime is xeric.
30c	Typic Xerochrepts	D	Y	N	N	B	Well drained, deep, dark brown, clayey soils. The subsoil is weakly structured. The AWC is between 100 and 150 mm/m. The soils are developed on fluvial deposits, or on limestone or colluvial deposits. The soil moisture regime is xeric.
30d	Typic Xerochrepts	D	Y	F-A	N	B	Well drained, deep, reddish brown to yellowish red, clayey soils. The subsoil is strongly structured. The surface contains few to abundant stones. The AWC is between 100 and 150 mm/m. The soils are developed on basalts. The soil moisture regime is xeric.
31a	Vertic Xerochrepts	D	Y	N	N	C	Well drained, deep or moderately deep, dark brown to yellowish red, clayey soils. The surface shows considerable shrink-swell properties. The subsoil is moderately to strongly structured. The AWC is between 100 and 150 mm/m. The soils are developed on limestone and/or basalts, or marls. The soil moisture regime is xeric.

ANNEX 2. Continued

SOIL_ID[2]	Soil Taxonomy label	Depth class[3]	Texture class[4]	Stoniness class[5]	Salinity class[6]	Hydrological class[7]	Description
31b	Vertic Xerochrepts	D	Y	A	N	C	Well drained, deep or moderately deep, yellowish red, clayey soils. The surface shows considerable shrink-swell properties. The subsoil is strongly structured. The surface contains abundant stones and some rocks. The AWC is between 100 and 150 mm/m. The soils are developed on limestone, marls or colluvial deposits. The soil moisture regime is xeric.
31c	Vertic Xerochrepts	D	Y	C	N	C	Well or moderately well drained, deep, yellowish brown to dark brown, clayey soils. The surface shows considerable shrink-swell properties. The subsoil is structureless to strongly developed. The surface contains common stones. The AWC is between 100 and 150 mm/m. The soils are developed on limestone and/or marls, or on basalts. The soil moisture regime is xeric.
32	Typic Vitrandepts	S	L	D	N	B	Somewhat excessively drained, shallow, dark grayish brown, loamy soils. The subsoil is weakly developed and contains more than 35% gravel. The surface contains dominant stones. The AWC is between 20 and 60 mm/m. The soils are developed on limestone and/or pyroclastic deposits, or on fluvial deposits.
33	Aquic Haploxerolls	D	C	N	N	D	Imperfectly drained, deep, dark brown to grayish brown, clayey soils. The subsoil is structureless to moderately structured. The AWC is between 100 and 150 mm/m. The soils are developed on limestone and/or gypsum. The soil moisture regime is xeric.
34	Entic Haploxerolls	M	C	A	N	D	Well drained, moderate deep, dark reddish brown to yellowish brown, clayey soils. The subsoil is moderately structured and contains more than 35% gravel. The surface contains common rocks and abundant stones. The AWC is between 20 and 60 mm/m. The soils are developed on gypsum, limestone, marls or fluvial deposits. The soil moisture regime is xeric.
35a	Lithic Haploxerolls	S	C-L	A	N	D	Well drained, shallow, dark (reddish) brown, clayey to loamy soils. The subsoil is usually weakly structured. The surface contains few stones. The AWC is between 60 and 100 mm/m. The soils are developed on basalts and limestone. The soil moisture regime is xeric.

ANNEX 2. Continued

SOIL_ID[2]	Soil Taxonomy label	Depth class[3]	Texture class[4]	Stoniness class[5]	Salinity class[6]	Hydrological class[7]	Description
35b	Lithic Haploxerolls	S	C-L	A	N	D	Well drained, shallow, dark brown, clayey to loamy soils. The surface contains abundant stones and few to many rocks. The AWC is between 60 and 100 mm/m. The soils have vertic properties and are developed on limestone and marls. The soil moisture regime is xeric.
36	Pachic Haploxerolls	M-D	C	A	N	D	Well drained, (moderately) deep, grayish brown to dark brown, clayey soils. The subsoil is structureless and contains more than 35% gravel. The surface contains abundant stones and moderate rocks and has a thick topsoil enriched in organic matter. The AWC is between 20 and 60 mm/m. The soils are developed on limestone and/or gypsum. The soil moisture regime is xeric.
37	Typic Haploxerolls	D	Y	C	N	B	Well drained, deep, dark reddish brown to dark grayish brown, clayey soils. The subsoil is strongly structured and contains between 15 and 35% stones. The surface contains common stones. The AWC is between 100 and 150 mm/m. The soils are developed on gypsum or fluvial deposits. The soil moisture regime is xeric.
38	Vertic Haploxerolls	D	Y	A	N	C	Vertic Haploxerolls (Haplic Kastanozems) are very limited defined. The surface contains many rocks and abundant stones and shows considerable shrink-swell properties. The soils are developed on limestone and/or gypsum, or on fluvial or colluvial deposits. The soil moisture regime is xeric.
39a	Entic Chromoxererts	D	Y	N	N	C	Moderately well drained, deep, dark yellowish brown to very dark grayish brown, clayey soils with strong shrink-swell properties. The subsoil is moderately structured. The surface is free of stones. The AWC is between 100 and 150 mm/m. The soils are developed on basalts. The soil moisture regime is xeric.
39b	Entic Chromoxererts	D	Y	N	N	C	Well drained, deep, dark brown, clayey soils with strong shrink-swell properties. The subsoil is structureless. The surface is in general free of stones, but contains common rocks. The AWC is between 100 and 150 mm/m. The soils have vertic properties. The soils are developed on limestone, marls, colluvial and fluvial deposits. The soil moisture regime is xeric.

ANNEX 2. Continued

SOIL_ID[2]	Soil Taxonomy label	Depth class[3]	Texture class[4]	Stoniness class[5]	Salinity class[6]	Hydrological class[7]	Description
40a	Typic Chromoxererts	D	Y	N-M	N	C	Moderately well drained, deep, dark yellowish brown to very dark grayish brown, clayey soils with strong shrink-swell properties. The subsoil is usually moderately to strongly structured. The subsoil contains between 15 and 35% gravel. The surface usually contains no to many stones. The AWC is between 100 and 150 mm/m. The soils are developed on basalts and limestone. The soil moisture regime is xeric.
40b	Typic Chromoxererts	D	Y	N	N	C	Moderately well drained, deep, reddish brown to dark reddish brown, clayey soils with strong shrink-swell properties. The subsoil is structureless and contains between 15 and 35% gravel. The surface is free of stones. The AWC is between 100 and 150 mm/m. The soils are developed on basalts. The soil moisture regime is xeric.
41	Typic Pelloxererts	D	Y	N	N	C	Moderately well drained, deep, very dark gray to very dark brown, clayey soils with strong shrink-swell properties. The subsoil is strong structured, and contains between 15 and 35% gravel. The AWC is between 150 and 200 mm/m. The soil moisture regime is xeric.
42a	Basalt flows	V	N	A	N	D	Self-explanatory
42b	Rock outcrops	V	N	A	N	D	Self-explanatory
42c	Rubble lands	V	N	A	N	B	Self-explanatory

Stoniness classes:
N: None (0%); V: Very few (0-2%); F: Few (2-5%); C: Common (5-15%); M: Many (15-40%); A: Abundant (40-80%); D: Dominant (>= 80%)
Note on soil moisture regimes:
In the Soil Taxonomy classification system the soil moisture regime is an inherent descriptor of the soil types.

The following soil moisture regimes are recognized in Syria:

- Aridic and torric;
- Xeric

Without going into the precision offered by Soil Taxonomy, the following conditions apply:
Aridic/torric moisture regime: the soil profile (about 1 m) is completely dry in most years for more than 6 cumulative months, and partially or completely moist for less than 3 consecutive months. This moisture regime corresponds with moisture conditions in arid zones or semi-arid zones with poor water infiltration, e.g. crusty surfaces or very shallow soils. There is little or no leaching in these moisture regimes, and, in the presence of a source, soluble salts can accumulate.
Xeric moisture regime: the soil profile is completely dry for at least 45 days in the 4 months following summer solstice, and partially or completely moist for at least 45 days following winter solstice. This moisture regime corresponds with moisture conditions in Mediterranean climates, with moist and cool winters and warm and dry summers. The moisture, coming during winter when potential evapotranspiration is at a minimum, is particularly effective for leaching.

ANNEX 3. MONTE-CARLO SIMULATION OF SUB-PIXEL LEVEL CONSTRAINTS OVERLAP

Introduction

The quantification of constraints is a particular problem for datasets in which the mapping units are not homogeneous. Even when the composition of these datasets is known, no information is available about the spatial distribution of the components at sub-pixel level. The best one can do is to assume that such constraint can occur anywhere in a pixel and that each sub-pixel has an equal probability to be covered by a constraint. This is shown in Figure 10 where a pixel is represented as a square composed of 100 blocks.

0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Figure 10. Initial probabilities of constraints at sub-pixel level

When several constraint layers are combined in GIS, each of them with several components, of which the position, spatial pattern and contiguity inside each pixel is unknown, it becomes much more difficult to apply a reduction factor that will account for these various constraints.
The two hypotheses seem particularly plausible, that the total proportion of a pixel affected by one constraint or another is either the highest of the proportions of the individual constraints (H1), or the sum, with the condition that it does not exceed 1 (H2).

H1 = Max (p_i) **i=1, 2,…n**

H2 = Min $(\sum_{i=1}^{n} p_i, 1)$

Conventional wisdom would incline towards the belief that probably H1 would be more likely to be true when the various constraints have high probabilities of occurrence. In such cases the chances of overlapping spatial patterns would increase, especially as the number of constraints increases. In the same view H2 might be more likely to be true when the various constraints have low probabilities of occurrence. In such cases the chances of overlap would be low and the total area within a pixel could be taken as the sum of the areas (proportions) within a pixel of the individual constraints.

Procedure

These two hypotheses were tested by a Monte-Carlo simulation, in which a pixel was subdivided in 100 blocks and the overlap was simulated of a variable number of blocks, of which the number and position were generated by randomization. The following conditions applied:

- in each simulation run the number of blocks to be generated could vary at random between 1 and 100
- the position of the blocks could vary at random subject to *spatial contiguity*
- the number of constraints varied between two and six

The procedure is illustrated in Figure 11 for a single run that generates at random 6 blocks. The growth of these building blocks is at random, on condition that the pixel boundaries are not exceeded and that growth occurs in a cell that is a neighbor to the growing shape.

A total of 250,000 simulation runs was executed. The number of constraints simulated varied between 2 and 6, totalling 50,000 runs for each number of constraints. For each number of constraints, the number of blocks was organized in 10 classes. In each class the number of blocks could be randomized within the class boundaries only, e.g. for the class 1-10 the number of blocks could have values between 1 and 10 only, for the class 41-50 the number of blocks varied between 41 and 50.

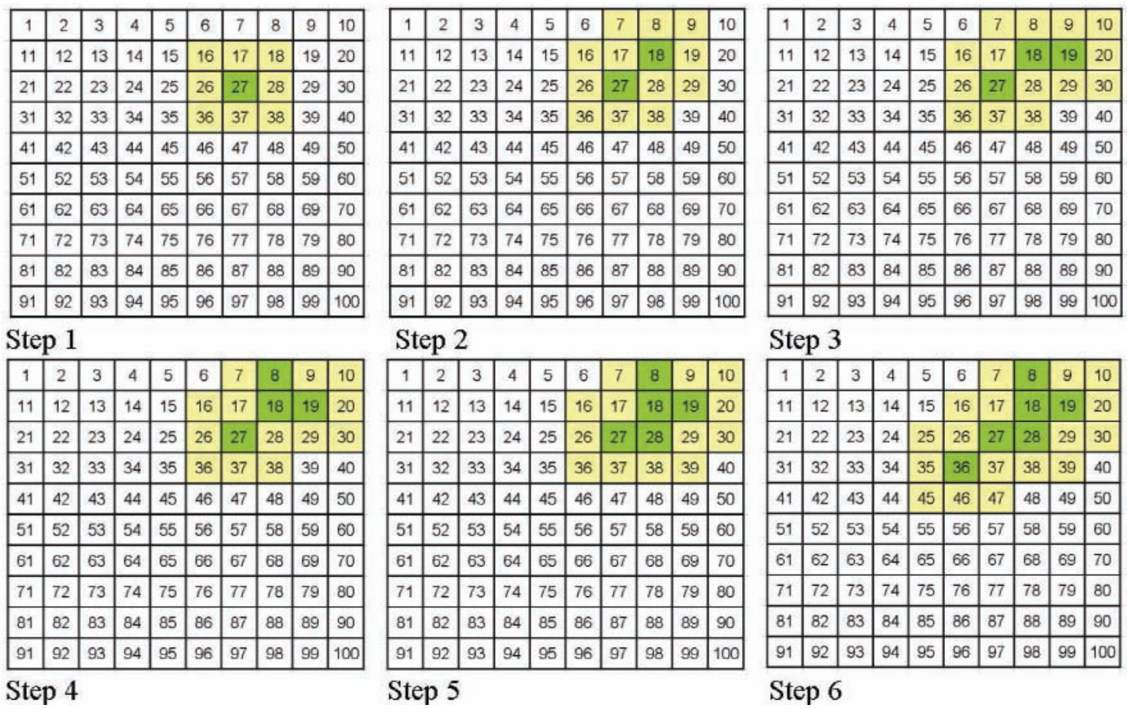


Figure 11. Simulating the generation of random polygons within pixels (6 blocks); in green the growing shape, in yellow the growing neighborhood

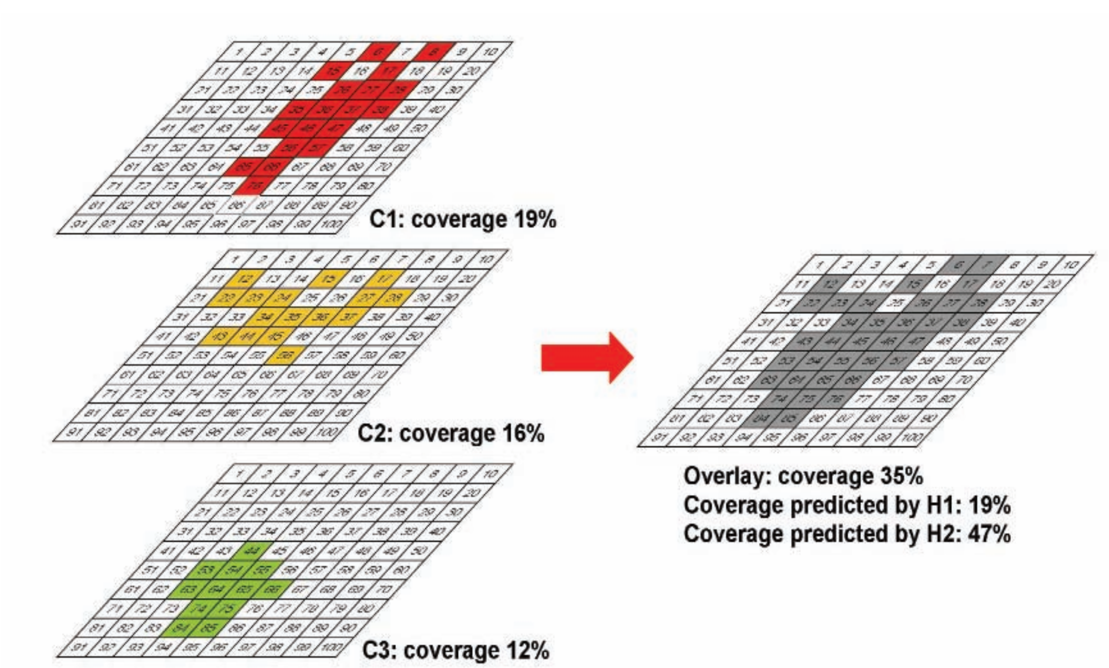


Figure 12. Example using 3 constraints for comparing simulated coverages with those predicted by H1 and H2

For each simulation run the total coverage was calculated from the individual coverages for each constraint, and compared with the coverages predicted by either H1 or H2 (Fig. 12).

The average coverage in each class was then compared with the coverage predicted by H1 and H2 and the differences between them calculated and plotted for different numbers of constraints (Figs. 13-15).

Results

Figs. 13-15 show that the H2 method of summation leads to smaller differences with the coverages generated by simulation, than the H1 method. If the results for H2 under different numbers of constraints are compared (Fig. 16), it appears that high prediction errors can be expected particularly where the total coverage for the different constraints is in the range 50-80%. Below and above this range the errors in prediction are low.

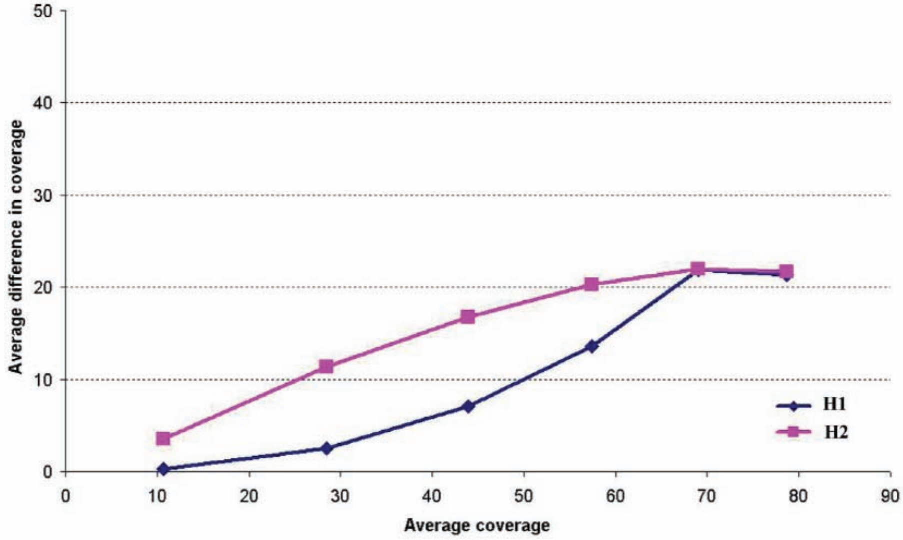


Figure 13. Absolute average difference in coverage (2 constraints)

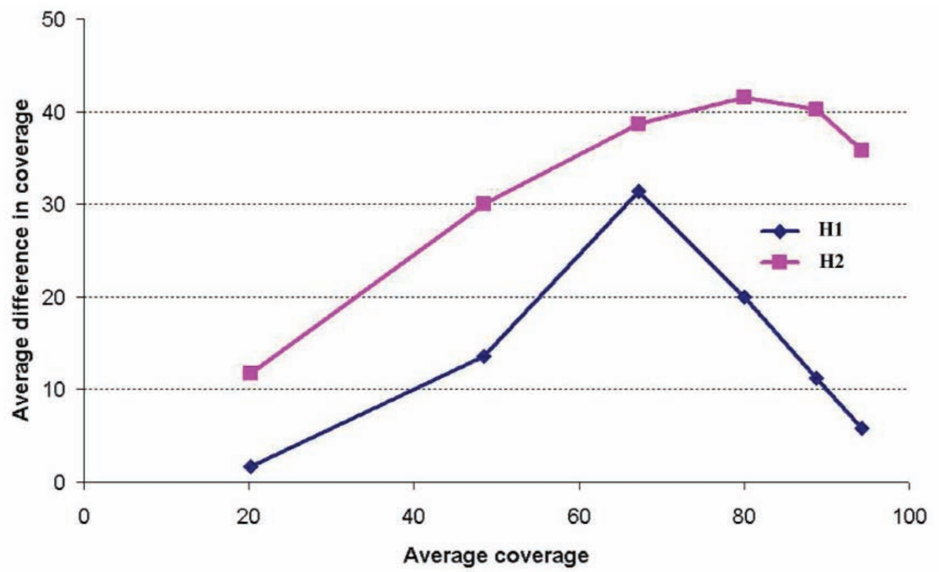


Figure 14. Absolute average difference in coverage (4 constraints)

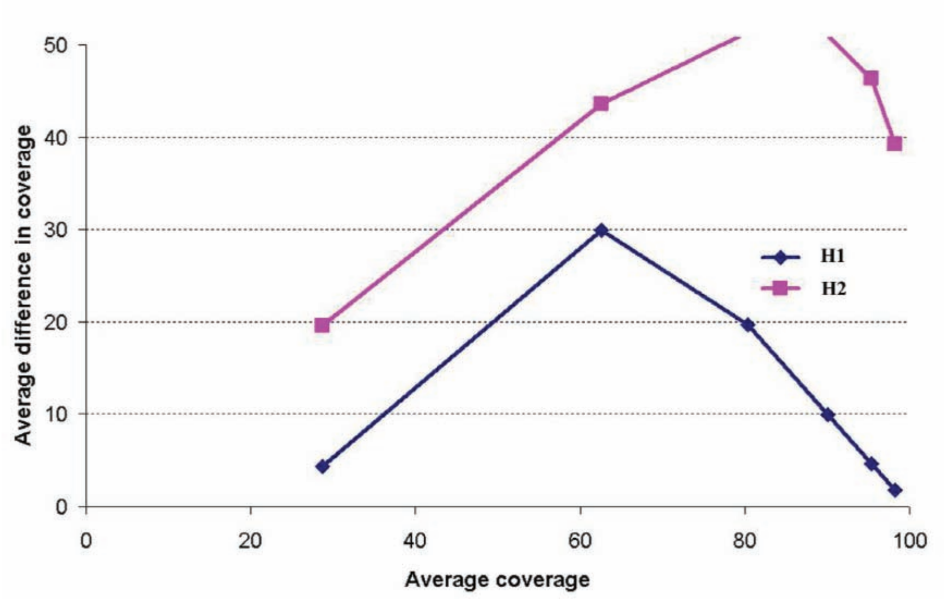


Figure 15. Absolute average difference in coverage (6 constraints)

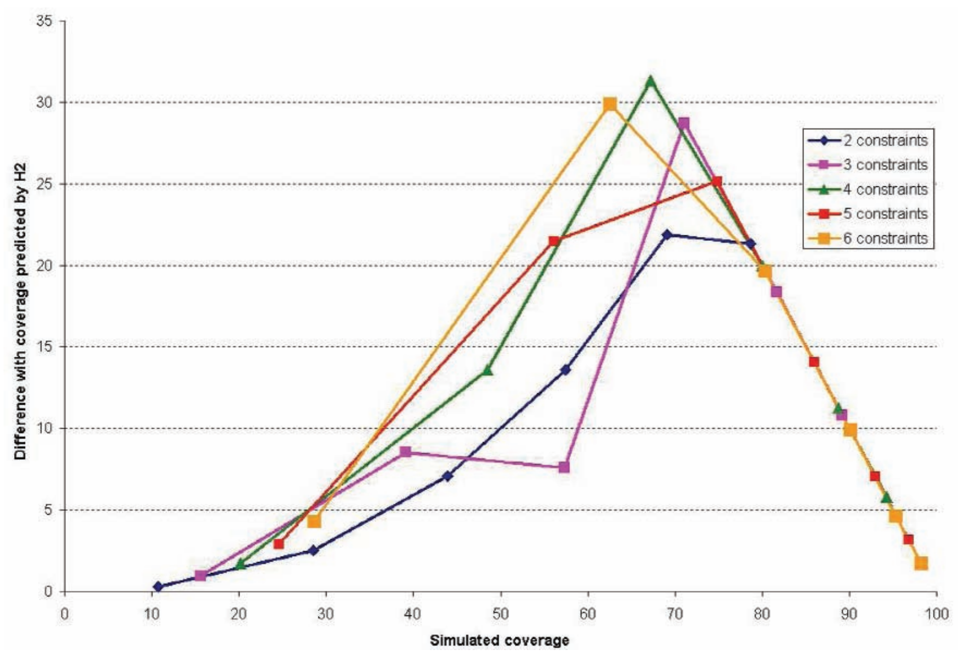


Figure 16. Difference between simulated and H1-predicted coverage
for different numbers of constraints

ANNEX 4. SUMMARY OF DISTRICT AREAS SUITABLE FOR DIFFERENT WATER HARVESTING TECHNIQUES

This annex provides a summary of areas suitable or highly suitable for different water harvesting techniques aggregated on district basis. Figure 17 shows the location of the different districts. The results, aggregated by district, are summarized in Tables 7 and 8.

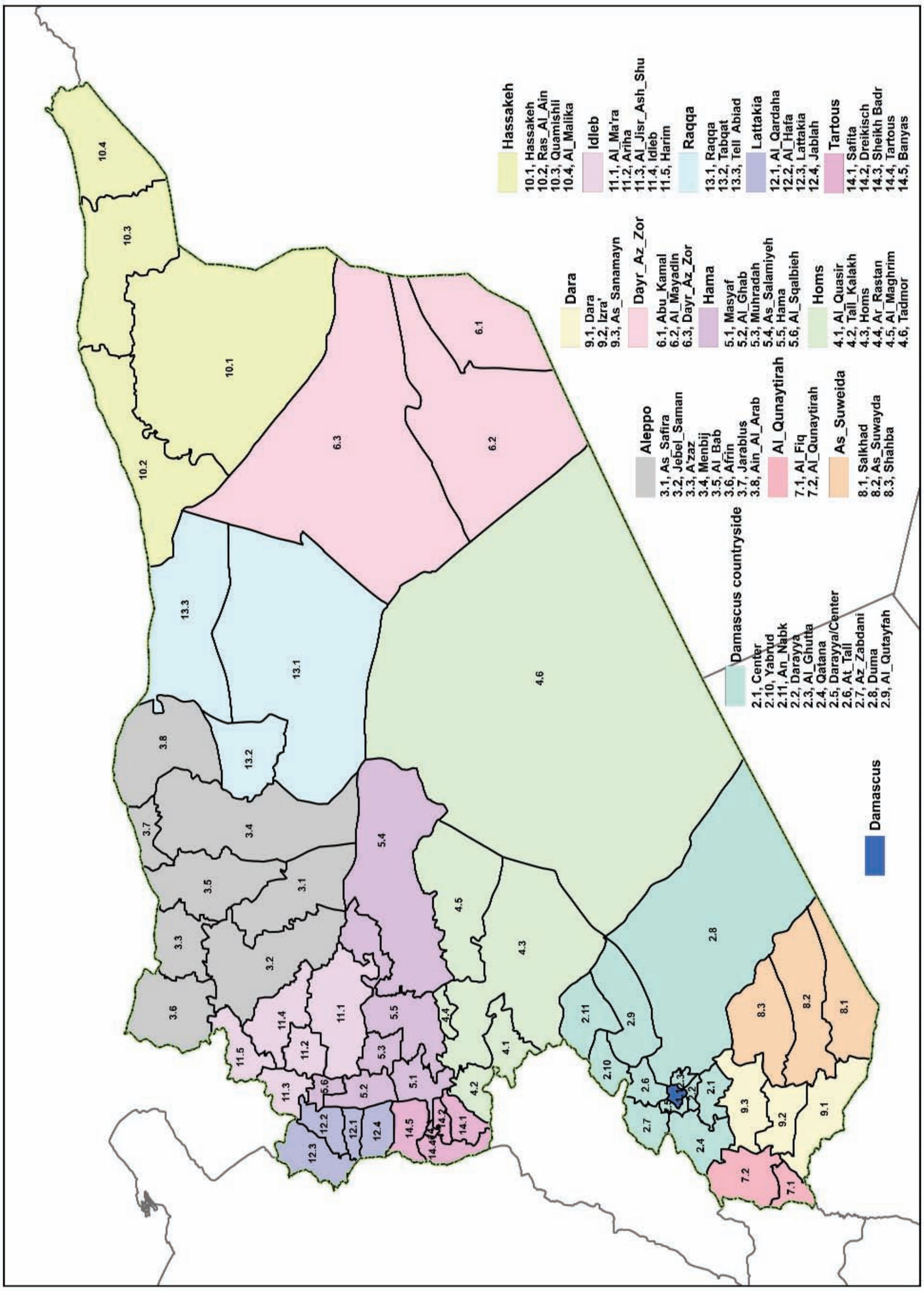


Figure 17. Districts of Syria

Table 7. Percentages of Syrian districts with high suitability scores for water harvesting techniques (group 1)

WH system	Contour ridges- Range shrubs			Contour ridges- Field crops			Contour ridges- Tree crops			Semi-circular bunds- Range shrubs			Semi-circular bunds - Field crops			Semi-circular bunds - Tree crops		
Montika	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S
Abu_Kamal	2	3	5	2	1	3	21	3	24	2	3	5	4	1	4	3	0	3
Afrin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ain_Al_Arab	4	3	7	1	0	2	0	0	0	3	2	5	1	0	1	0	0	0
Al_Bab	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Al_Fiq	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Ghab	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Ghutta	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0
Al_Hafa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Jisr_Ash_Shu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Maghrim	3	8	11	5	2	7	2	8	10	3	7	11	6	2	8	2	2	4
Al_Malika	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Ma'ra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Mayadin	2	2	3	1	1	2	14	2	16	2	2	3	2	1	2	1	0	2
Al_Qardaha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Quasir	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Qunaytirah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Qutayfah	13	19	32	4	15	19	3	29	32	8	14	22	5	13	17	5	11	16
Al_Sqalbieh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
An_Nabk	9	1	10	2	0	3	3	2	5	7	1	8	3	1	3	2	0	2
Ar_Rastan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ariha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
As_Safira	5	5	11	1	3	3	5	7	12	4	3	7	1	2	3	1	2	3
As_Salamiyeh	3	7	9	4	3	6	2	12	14	3	6	9	4	3	7	2	2	4
As_Sanamayn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
As_Suwayda	1	0	1	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0
At_Tall	2	5	8	1	3	5	3	3	6	2	4	6	1	3	4	2	2	4
Az_Zabdani	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A'zaz	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Banyas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center	7	4	10	0	1	1	1	1	2	3	2	5	1	0	1	0	0	1
City_Damascus	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Dara	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0
Darayya	4	1	5	0	1	1	1	5	6	2	1	3	0	1	1	0	1	1
Darayya/Center	11	14	25	0	0	0	0	2	2	8	12	20	0	0	0	0	0	0
Dayr_Az_Zor	4	7	11	5	1	6	9	5	14	4	7	10	6	1	7	1	1	2
Dreikisch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Duma	4	1	5	1	0	2	8	0	9	4	1	5	2	0	2	2	0	2
Hama	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Harim	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 8. Percentages of Syrian districts with high suitability scores for water harvesting techniques (group 1)

WH system	Contour ridges- Range shrubs			Contour ridges- Field crops			Contour ridges- Tree crops			Semi-circular bunds- Range shrubs			Semi-circular bunds - Field crops			Semi-circular bunds - Tree crops		
Montika	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S
Hassakeh	3	1	4	1	0	1	4	3	7	3	1	4	1	1	1	1	0	1
Homs	5	8	13	3	5	7	7	14	21	5	7	12	4	5	9	4	3	7
Idleb	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Izra'	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Jablah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jarablus	2	1	3	2	1	3	2	2	4	2	1	3	2	1	3	2	1	3
Jebel_Saman	2	1	3	0	0	1	0	2	2	2	1	3	0	0	1	0	0	1
Lattakia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Masyaf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Menbij	0	1	2	0	1	1	3	3	7	0	1	1	0	1	1	0	1	1
Mesiaf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Muhradah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Qatana	1	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
Quamishli	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Raqqa	3	5	8	3	2	5	10	11	21	3	5	8	4	2	6	2	2	3
Ras_Al_Ain	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Safita	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salkhad	4	1	5	0	0	0	0	0	0	4	1	5	0	0	0	0	0	0
Shahba	3	3	6	0	1	2	0	3	3	3	3	5	1	1	2	1	1	2
Sheikh Badr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tabqat	2	5	7	0	0	0	0	1	1	2	4	6	0	0	1	0	0	1
Tadmor	7	10	17	6	3	9	14	8	22	6	9	15	7	3	10	4	2	5
Tall_Kalakh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tartous	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tell_Abiad	0	1	1	0	0	0	1	2	2	0	1	1	0	0	0	0	0	0
Yabrud	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

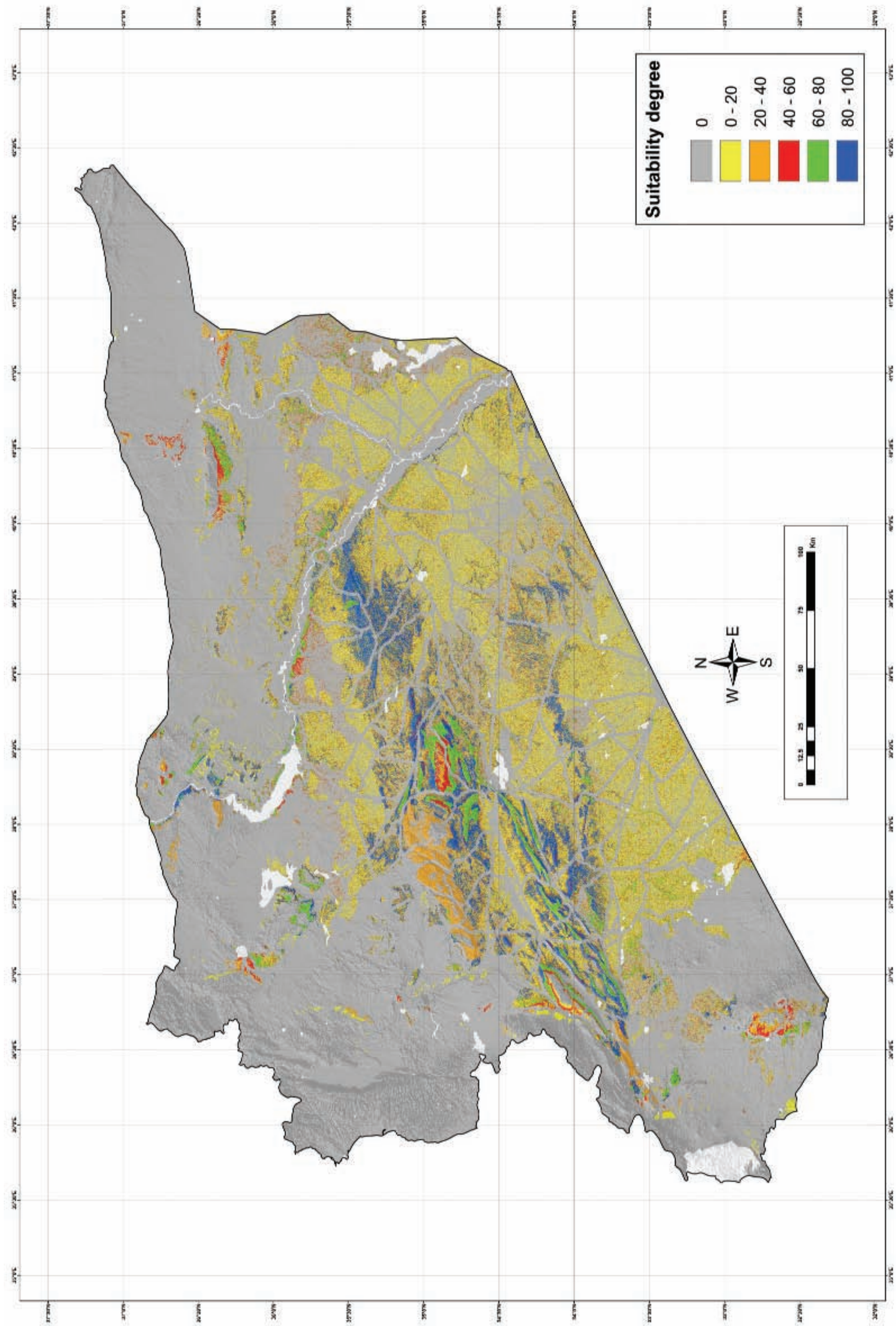
Table 9. Percentages of Syrian provinces with high suitability scores for different water harvesting techniques

WH system	Small pits- Range shrubs			Small pits- Field crops			Small runoff basins- Range shrubs			Small runoff basins- Tree crops			Runoff strips- Range shrubs			Runoff strips- Field crops			Contour bench terraces		
Montika	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S
Abu_Kamal	3	0	3	3	0	3	21	6	27	25	1	26	4	1	4	3	0	3	0	0	
Afrin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ain_Al_Arab	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1
Al_Bab	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0
Al_Fiq	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Ghab	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Ghutta	0	0	0	0	0	0	0	2	2	0	2	2	0	0	0	0	0	0	0	0	0
Al_Hafa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Jisr_Ash_Shu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Maghrim	2	2	4	2	2	4	2	7	9	2	7	9	6	2	8	2	2	4	0	0	0
Al_Malika	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Ma'ra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Mayadin	1	0	2	1	0	2	16	3	19	16	3	18	2	1	2	1	0	2	0	0	0
Al_Qardaha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Quasir	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Qunaytirah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_Qutayfah	5	11	16	5	11	16	4	19	23	4	19	23	5	13	17	5	11	16	4	3	7
Al_Sqalbieh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
An_Nabk	2	0	2	2	0	2	3	1	4	3	1	4	3	1	3	2	0	2	2	0	2
Ar_Rastan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ariha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
As_Safira	1	2	3	1	2	3	6	6	12	6	6	12	1	2	3	1	2	3	1	1	2
As_Salamiyeh	2	2	4	2	2	4	3	12	15	3	12	15	4	3	7	2	2	4	0	0	0
As_Sanamayn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
As_Suwayda	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0
At_Tall	2	2	4	2	2	4	2	1	3	2	1	3	1	3	4	2	2	4	1	0	1
Az_Zabdani	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A'zaz	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Banyas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center	0	0	1	0	0	1	1	1	1	1	1	1	1	0	1	0	0	1	3	1	4
City_Damascus	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0
Dara	0	0	0	0	0	0	1	2	2	1	2	2	0	0	0	0	0	0	0	0	0
Darayya	0	1	1	0	1	1	1	6	7	1	6	7	0	1	1	0	1	1	1	0	1
Darayya/Center	0	0	0	0	0	0	0	2	3	0	2	3	0	0	0	0	0	0	1	0	2
Dayr_Az_Zor	1	1	2	1	1	2	10	6	16	10	5	15	6	1	7	1	1	2	0	0	0
Dreikisch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Duma	2	0	2	2	0	2	9	0	10	9	0	10	2	0	2	2	0	2	0	0	0

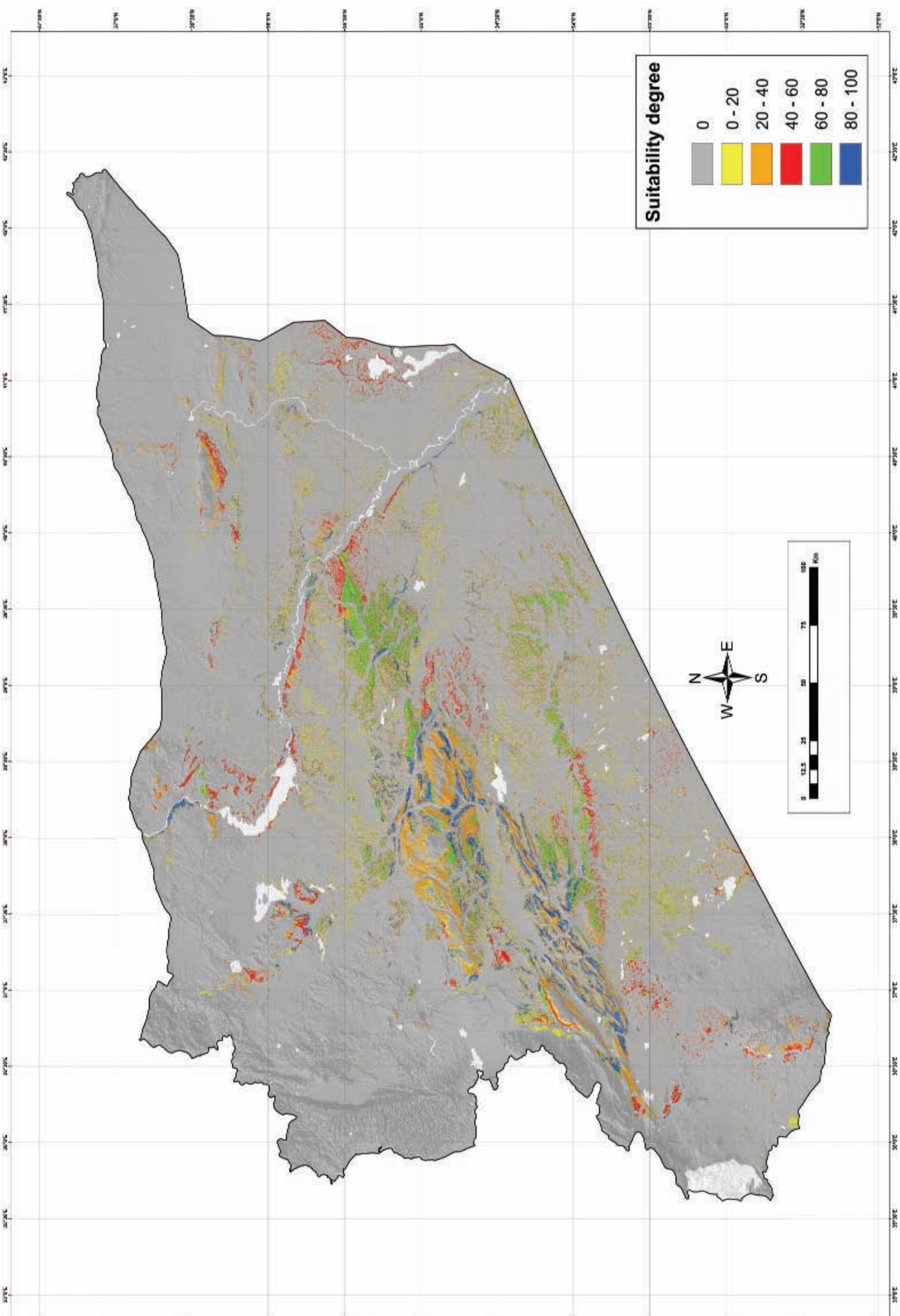
Table 9. Continued

WH system	Small pits- Range shrubs			Small pits- Field crops			Small runoff basins- Range shrubs			Small runoff basins- Tree crops			Runoff strips- Range shrubs			Runoff strips- Field crops			Contour bench terraces		
Montika	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S	% S	% VS	% VS+S
Hama	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0
Harim	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hassakeh	1	0	1	1	0	1	4	4	7	4	3	7	1	1	1	1	0	1	0	0	0
Homs	4	3	7	4	3	7	8	12	20	8	12	20	4	5	9	4	3	7	0	0	1
Idleb	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Izra'	0	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0
Jablah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jarablus	2	1	3	2	1	3	2	1	3	2	1	3	3	0	3	3	0	3	0	0	0
Jebel_Saman	0	0	1	0	0	1	0	2	2	0	2	2	0	0	1	0	0	1	0	0	0
Lattakia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Masyaf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Menbij	0	1	1	0	1	1	4	3	7	4	3	7	1	0	1	1	0	1	0	0	0
Mesiaf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Muhradah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Qatana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Quamishli	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Raqqa	2	2	3	2	2	3	11	12	23	11	12	22	4	2	6	1	2	3	0	0	0
Ras_Al_Ain	0	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0
Safita	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salkhad	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shahba	1	1	2	1	1	2	0	3	3	3	0	3	1	1	2	1	1	2	0	0	0
Sheikh Badr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tabqat	0	0	1	0	0	1	0	1	1	0	1	1	0	0	1	0	0	1	0	0	0
Tadmor	4	2	5	4	2	5	15	7	23	16	7	23	7	3	10	4	2	5	1	0	1
Tall_Kalakh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tartous	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tell_Abiad	0	0	0	0	0	0	1	2	3	2	1	3	0	0	0	0	0	0	0	0	0
Yabrud	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

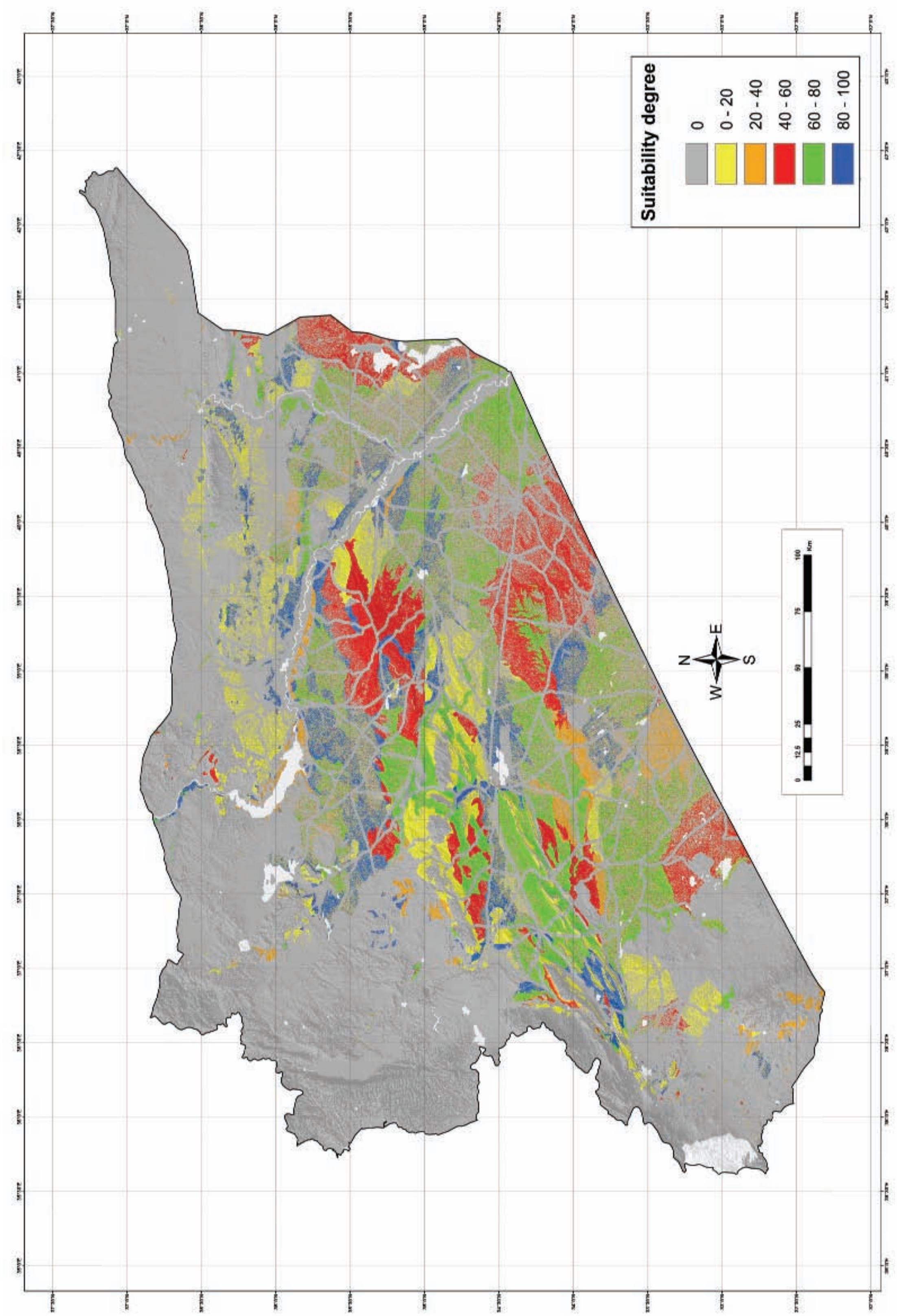
ANNEX 5. MAPS OF SUITABILITY FOR VARIOUS MICRO-CATCHMENT AND MACRO-CATCHMENT SYSTEMS



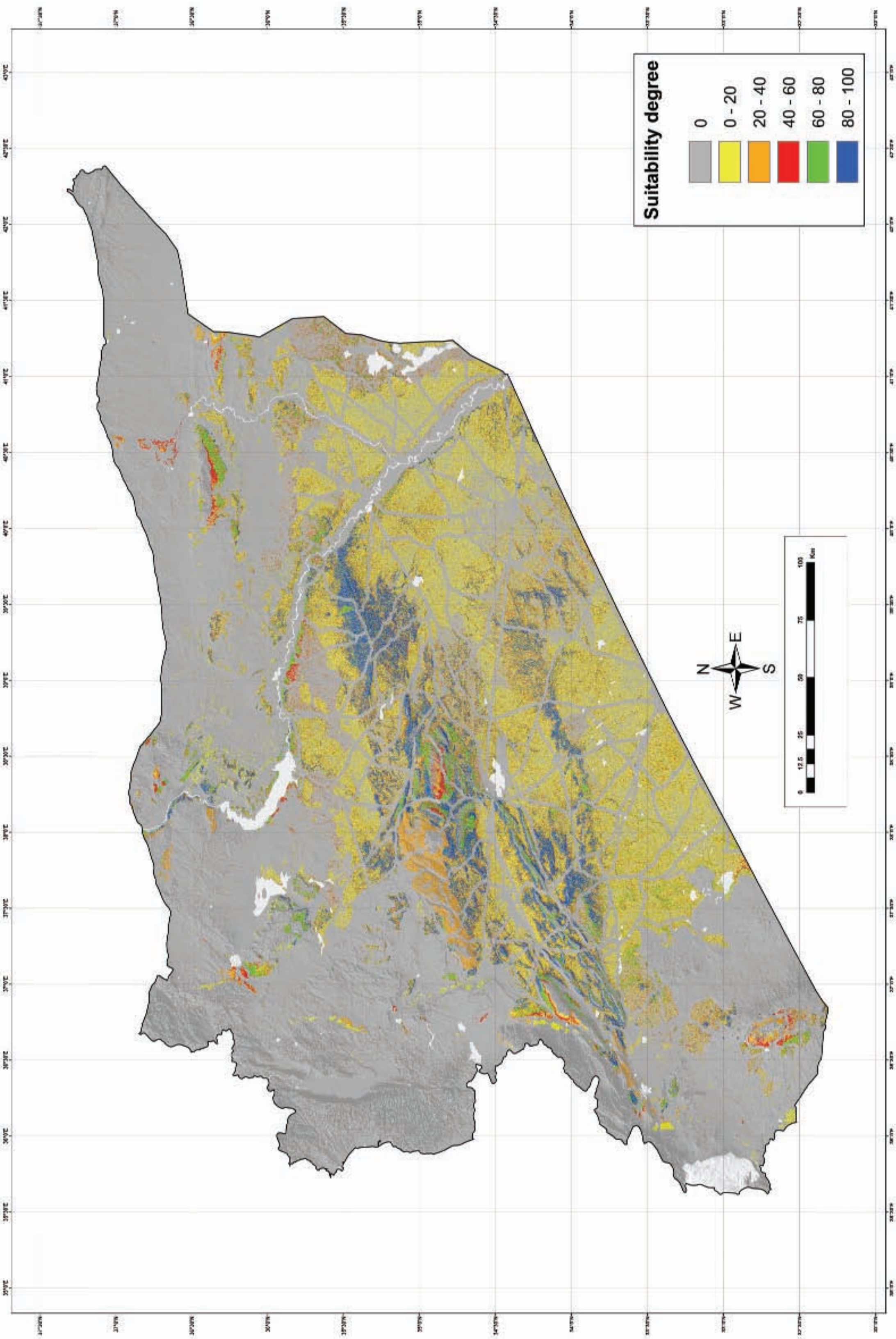
Map 1. Suitability for the micro-catchment system 'Contour ridges, range shrubs'



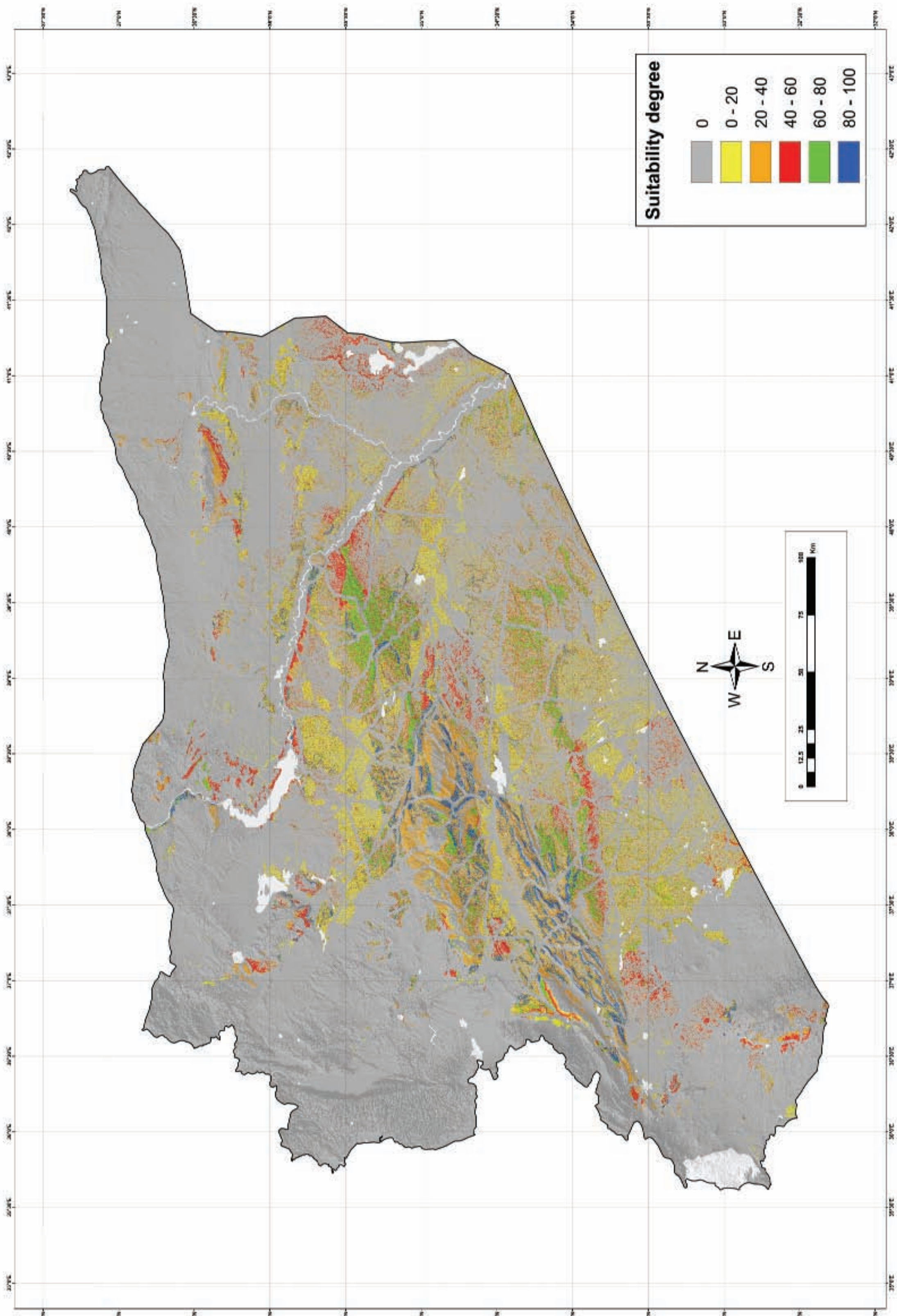
Map 2. Suitability for the micro-catchment system 'Contour ridges, field crops'



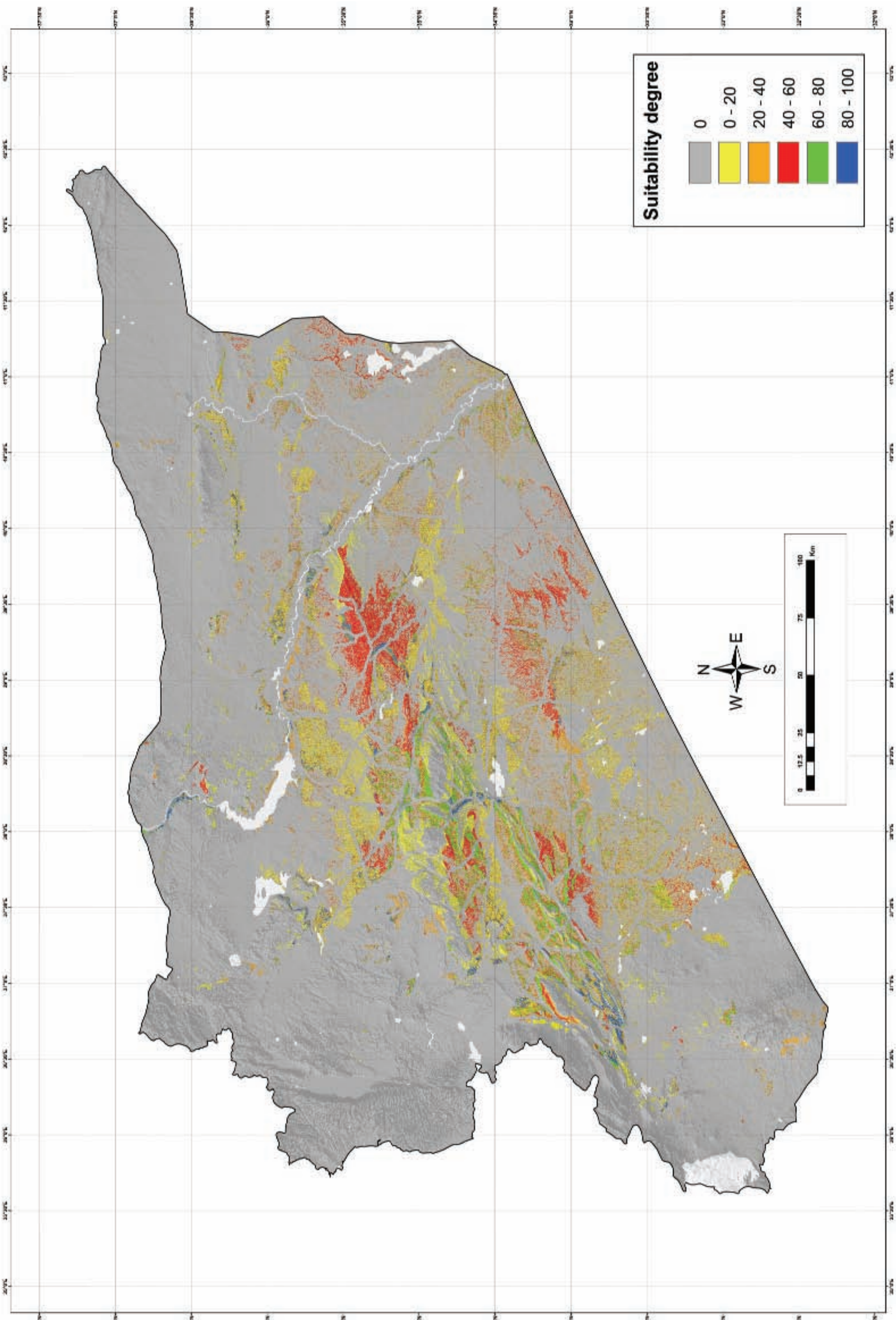
Map 3. Suitability for the micro-catchment system 'Contour ridges, tree crops'



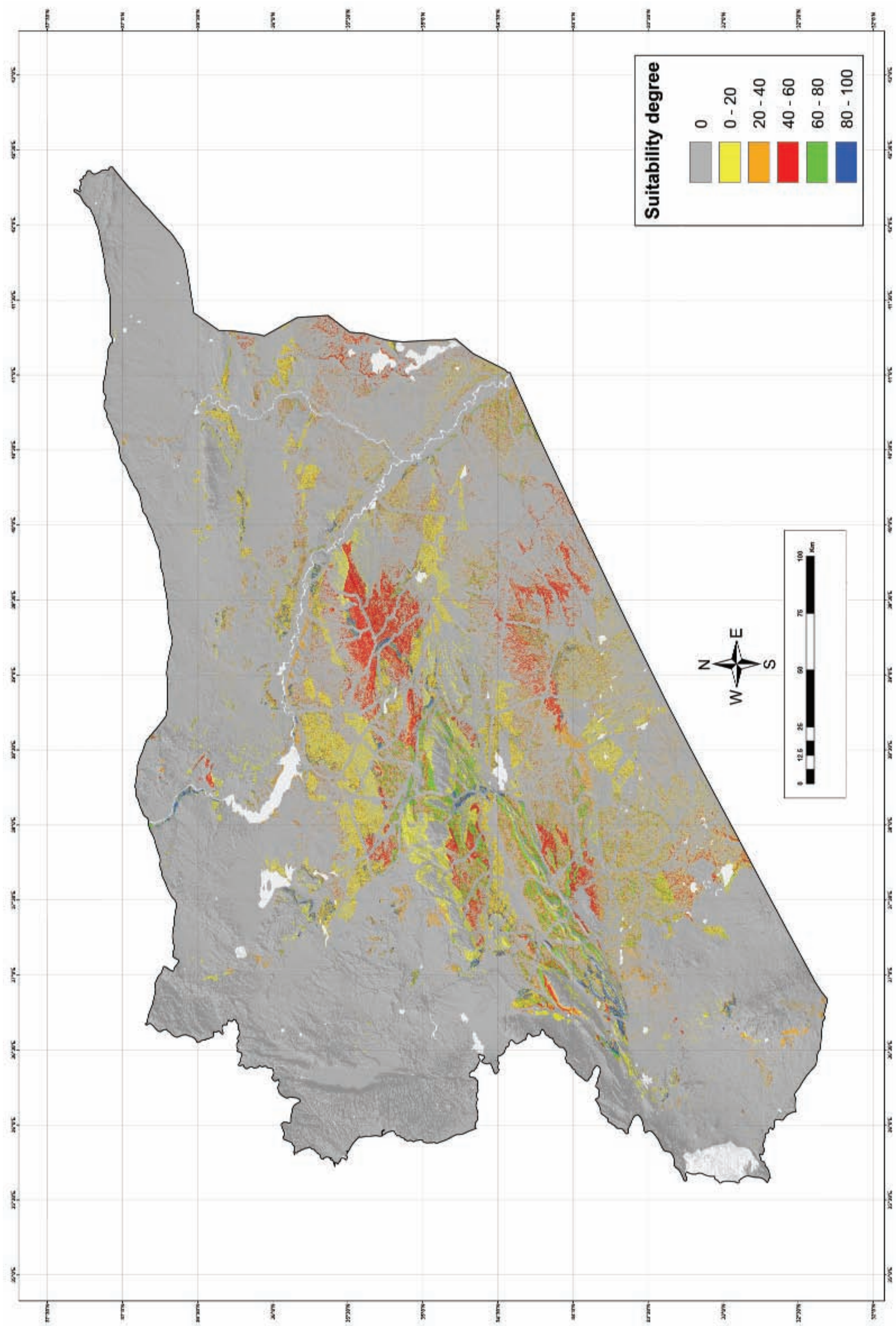
Map 4. Suitability for the micro-catchment system 'Semi-circular bunds, range shrubs'



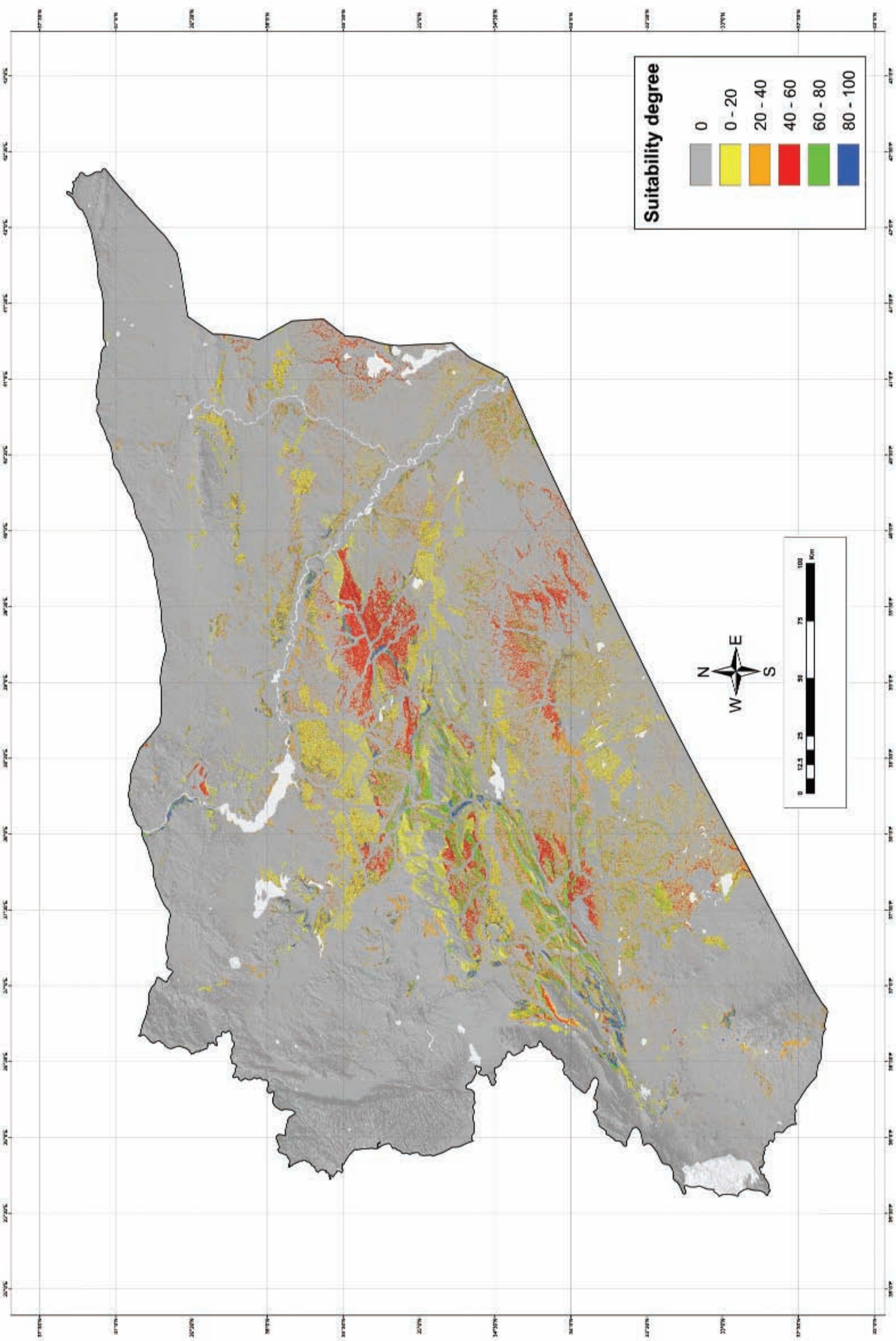
Map 5. Suitability for the micro-catchment system 'Semi-circular bunds, field crops'



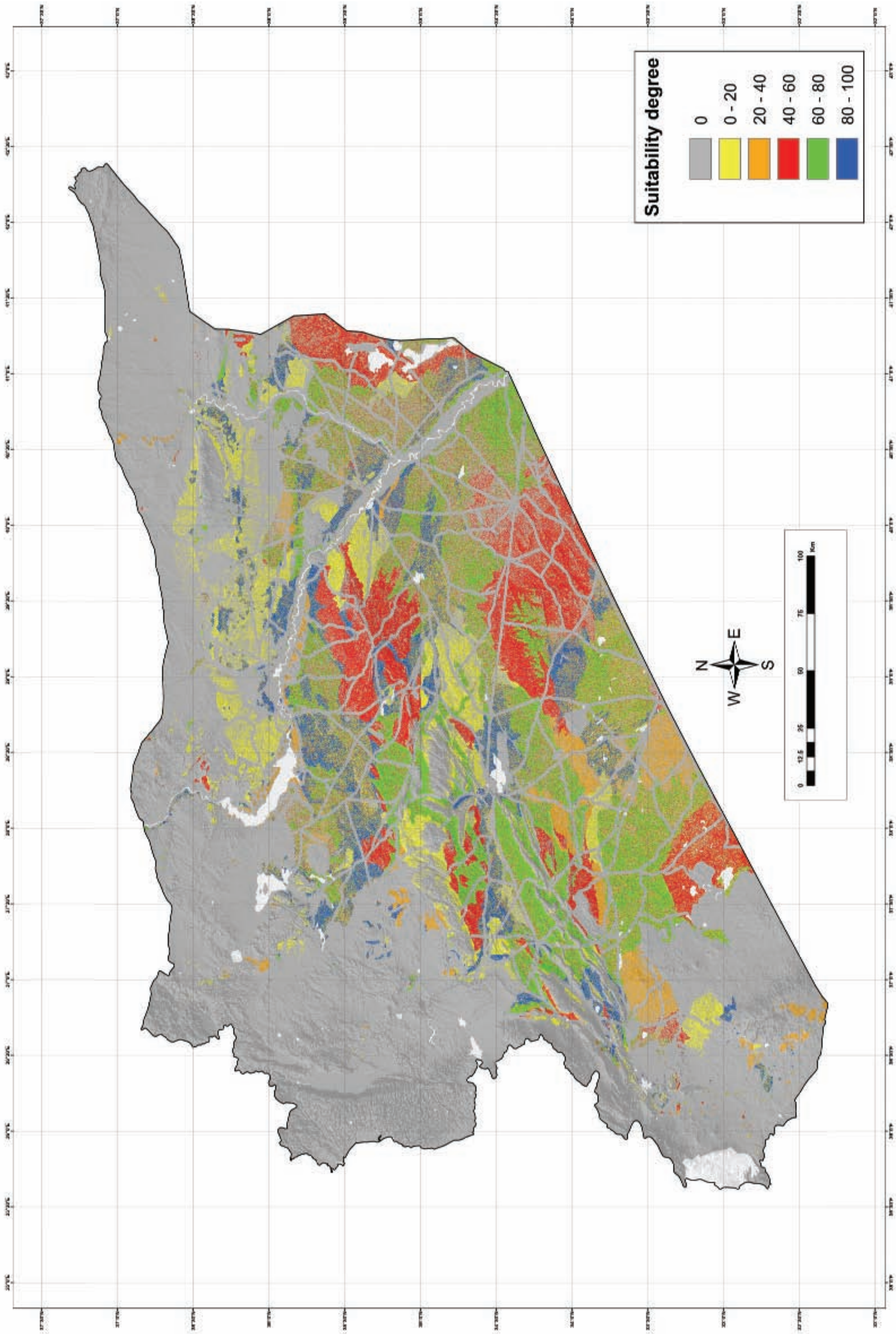
Map 6. Suitability for the micro-catchment system 'Semi-circular bunds, tree crops'



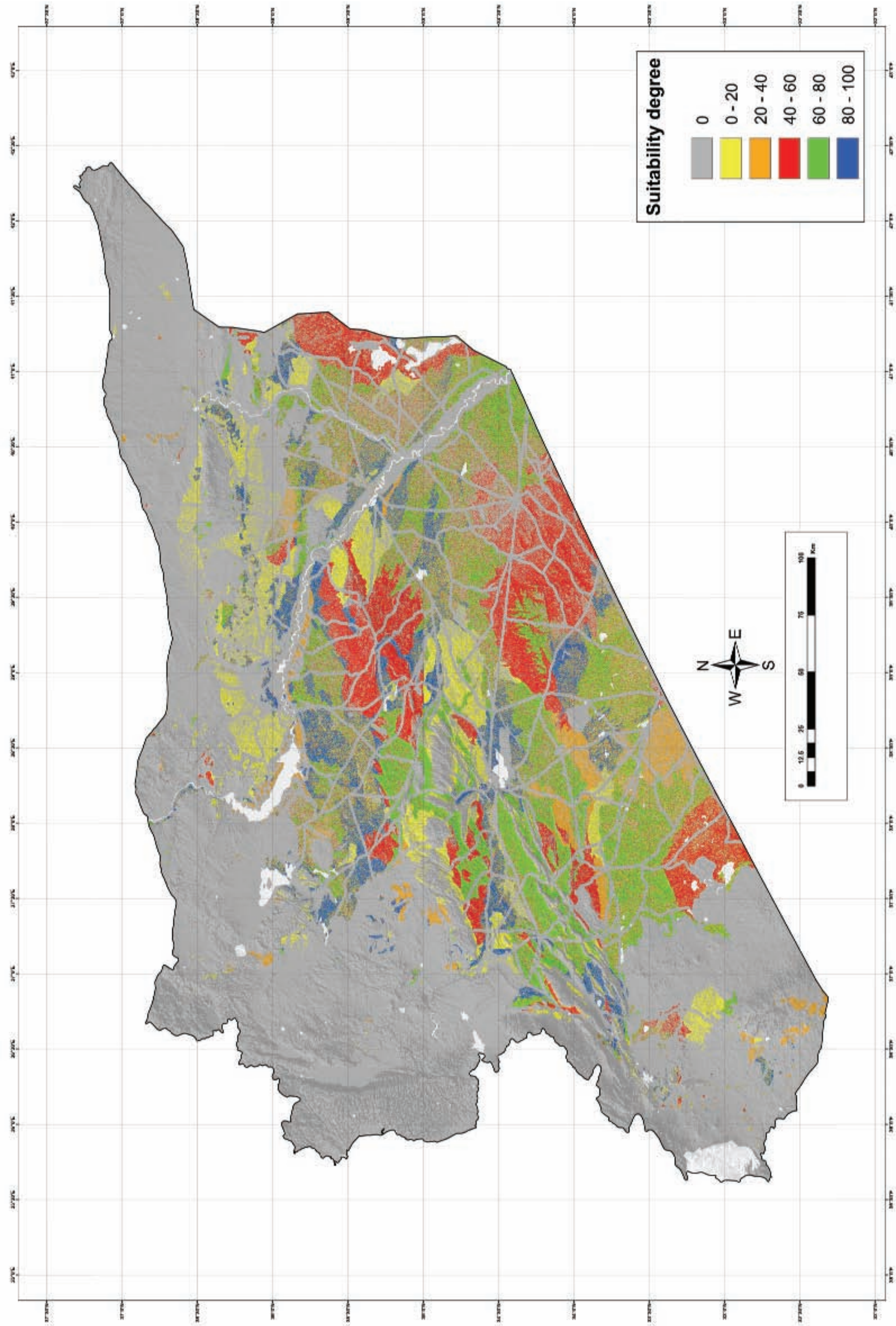
Map 7. Suitability for the micro-catchment system 'Small pits, range shrubs'



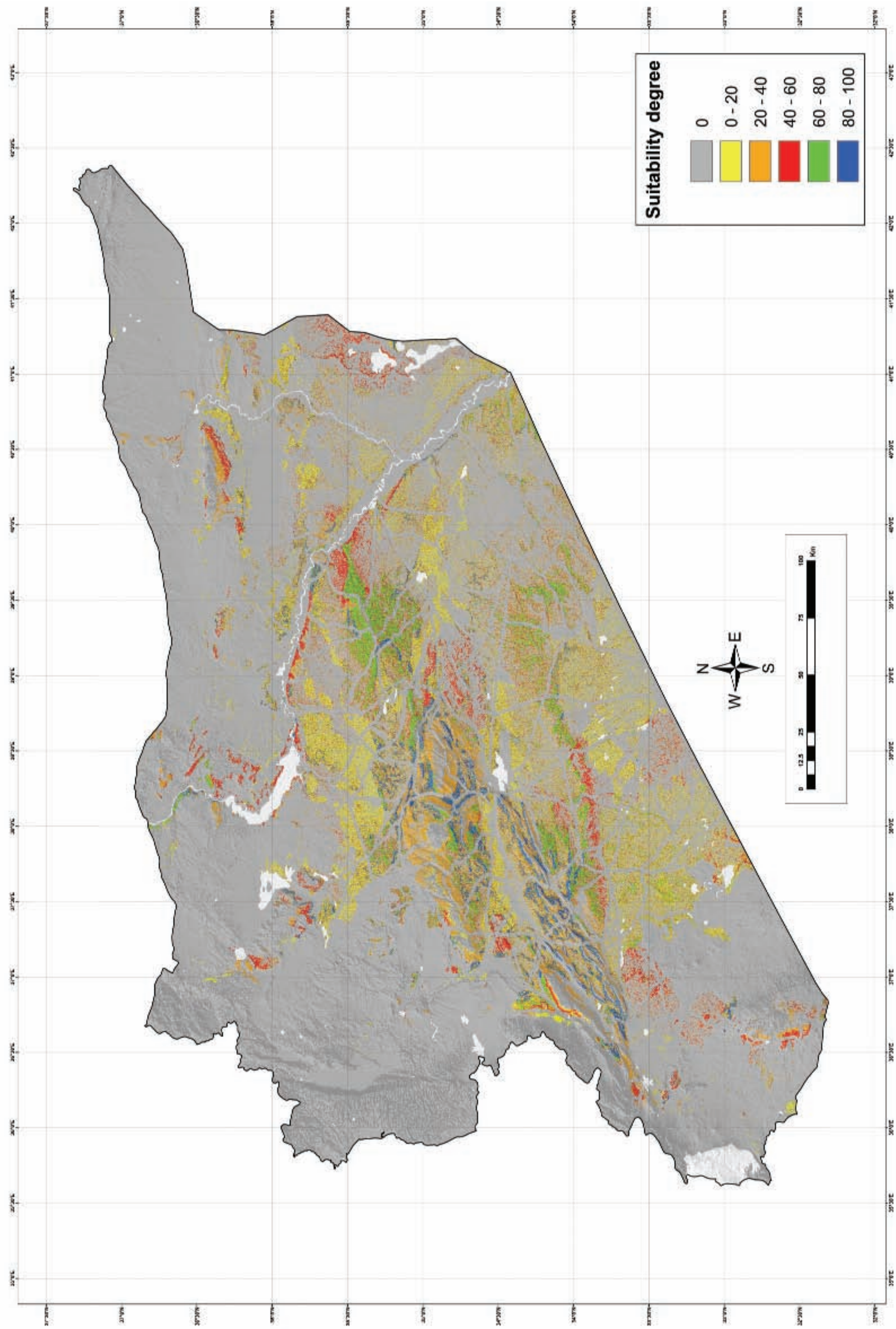
Map 8. Suitability for the micro-catchment system 'Small pits, field crops'



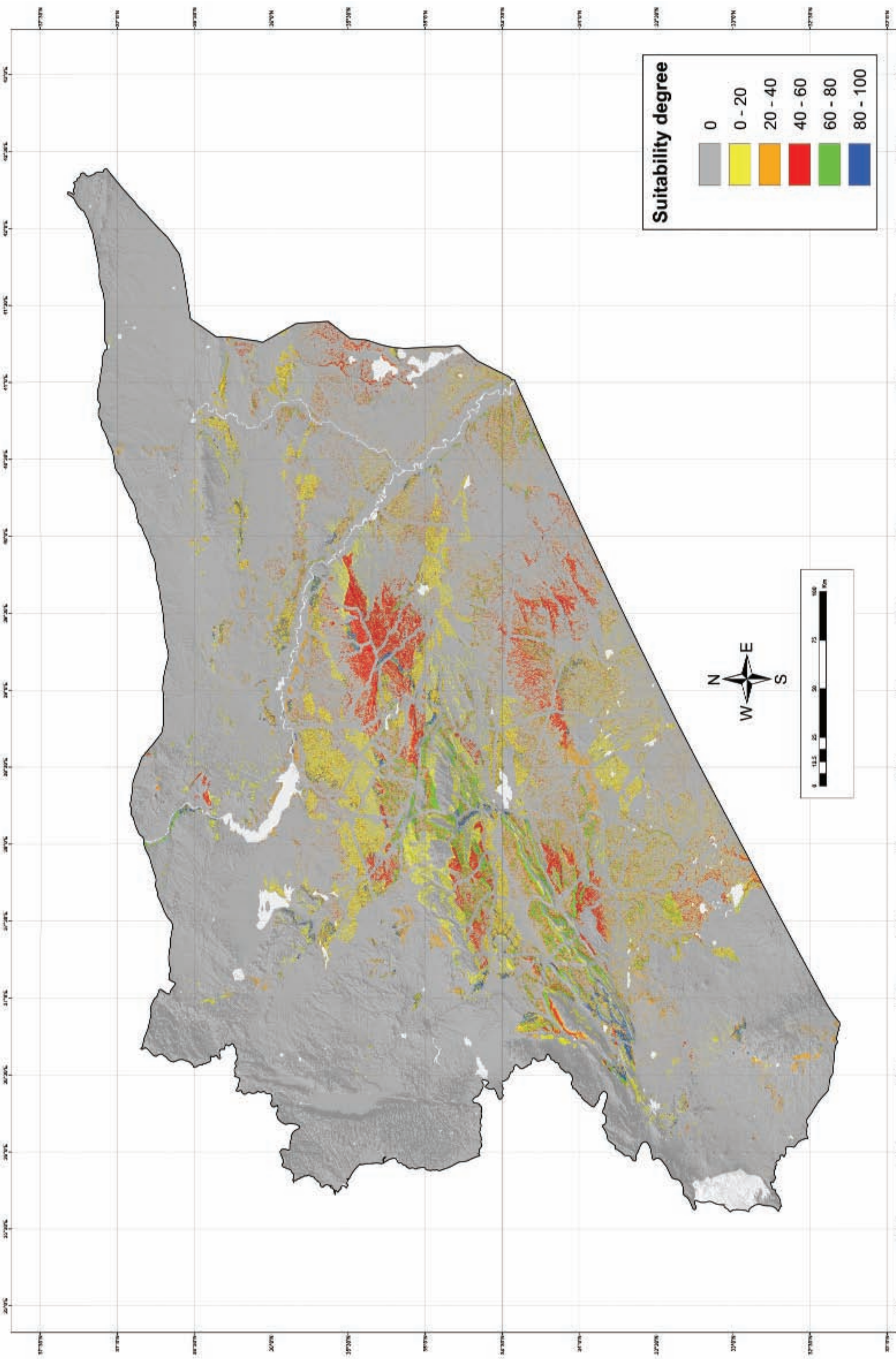
Map 9. Suitability for the micro-catchment system 'Small runoff basins, range shrubs'



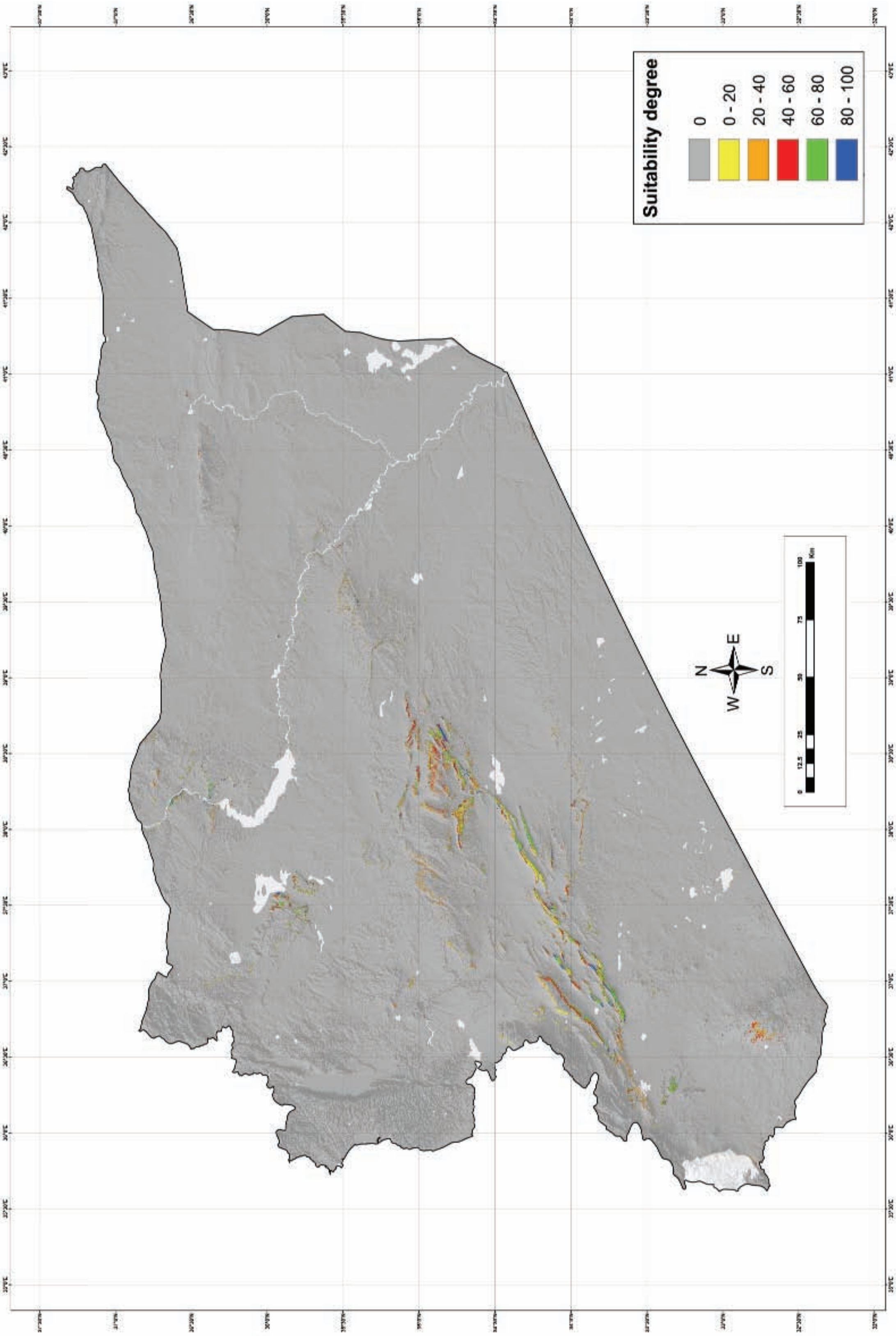
Map 10. Suitability for the micro-catchment system 'Small runoff basins, tree crops'



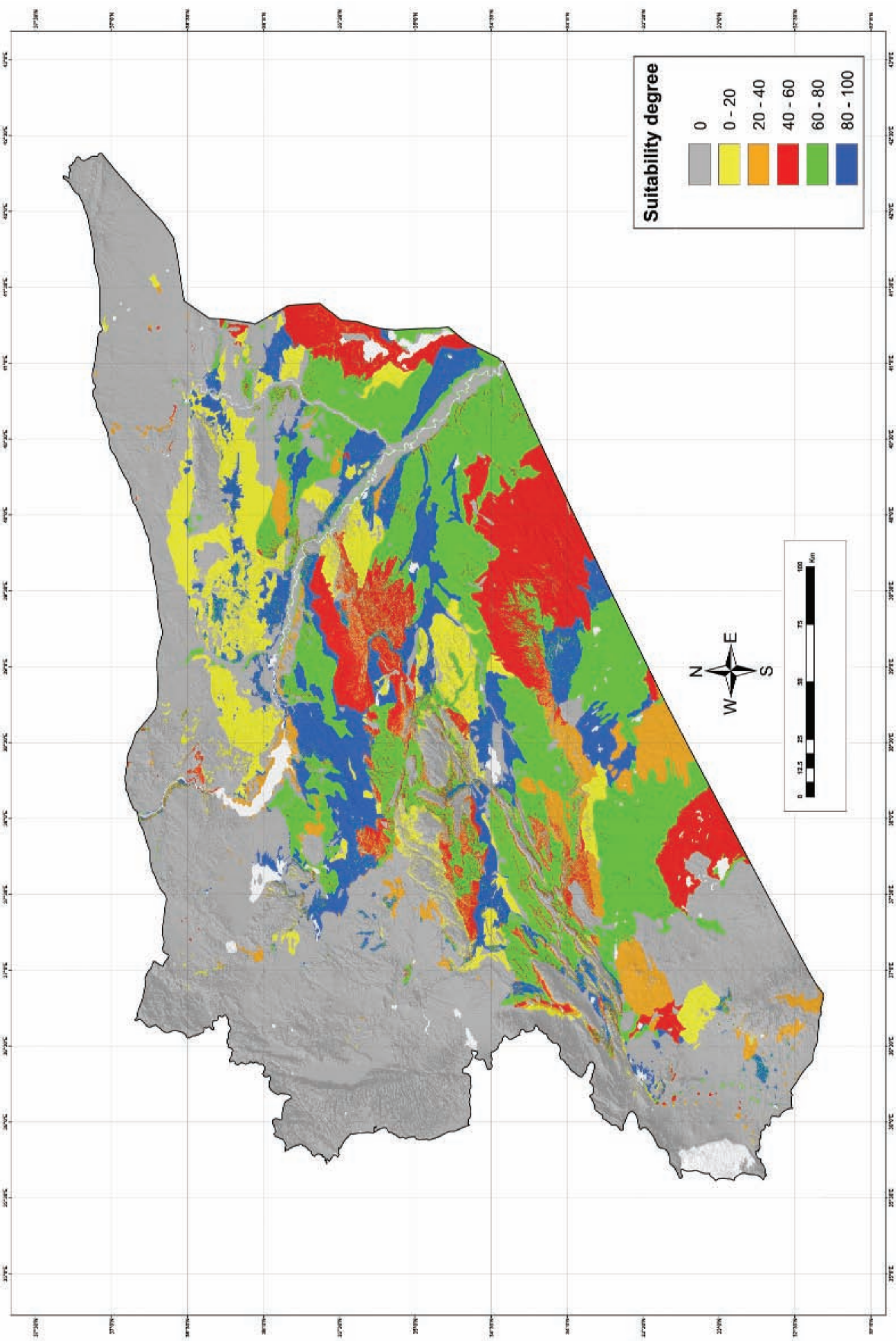
Map 11. Suitability for the micro-catchment system 'Runoff strips, range shrubs'



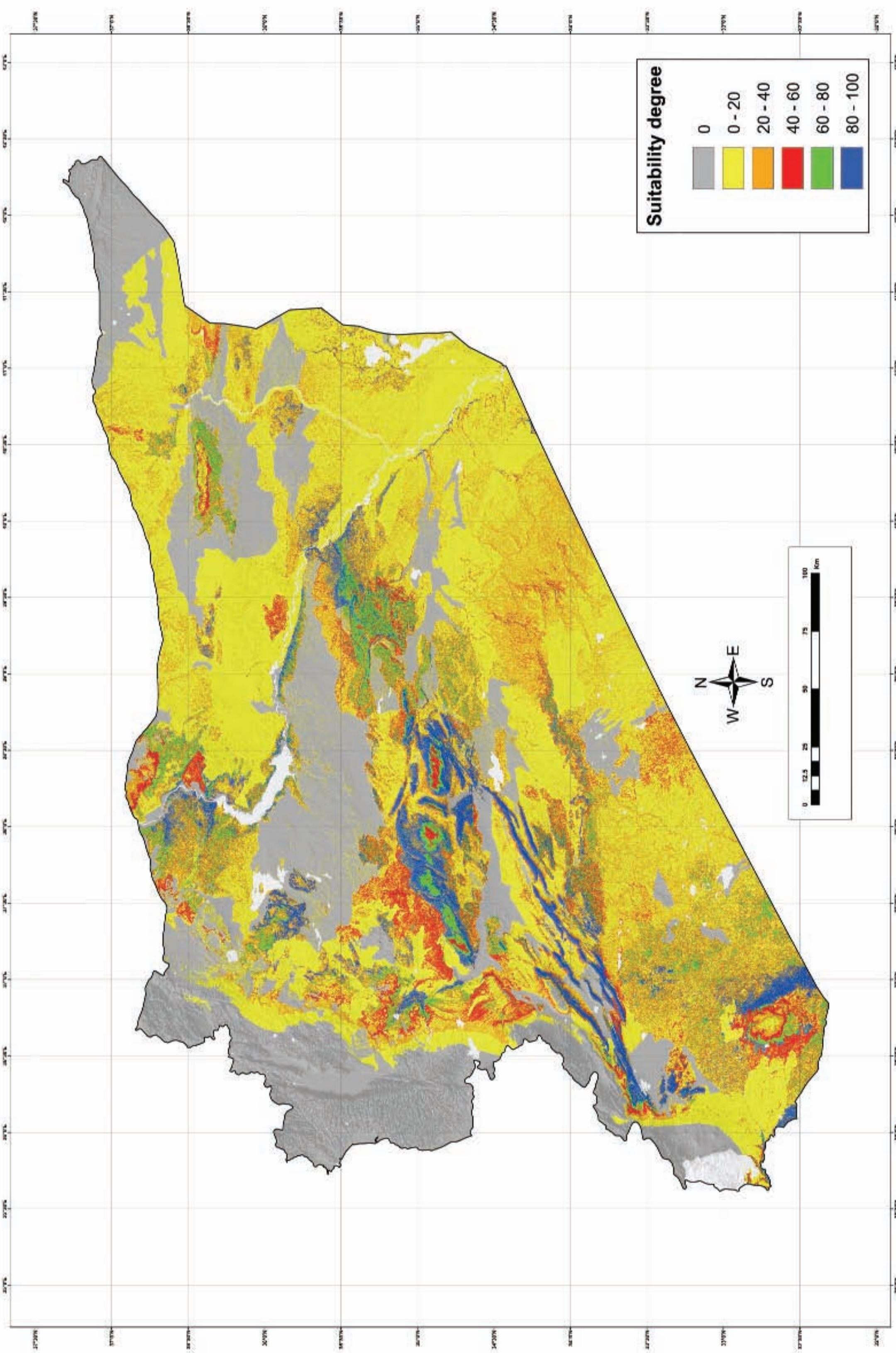
Map 12. Suitability for the micro-catchment system 'Runoff strips, field crops'



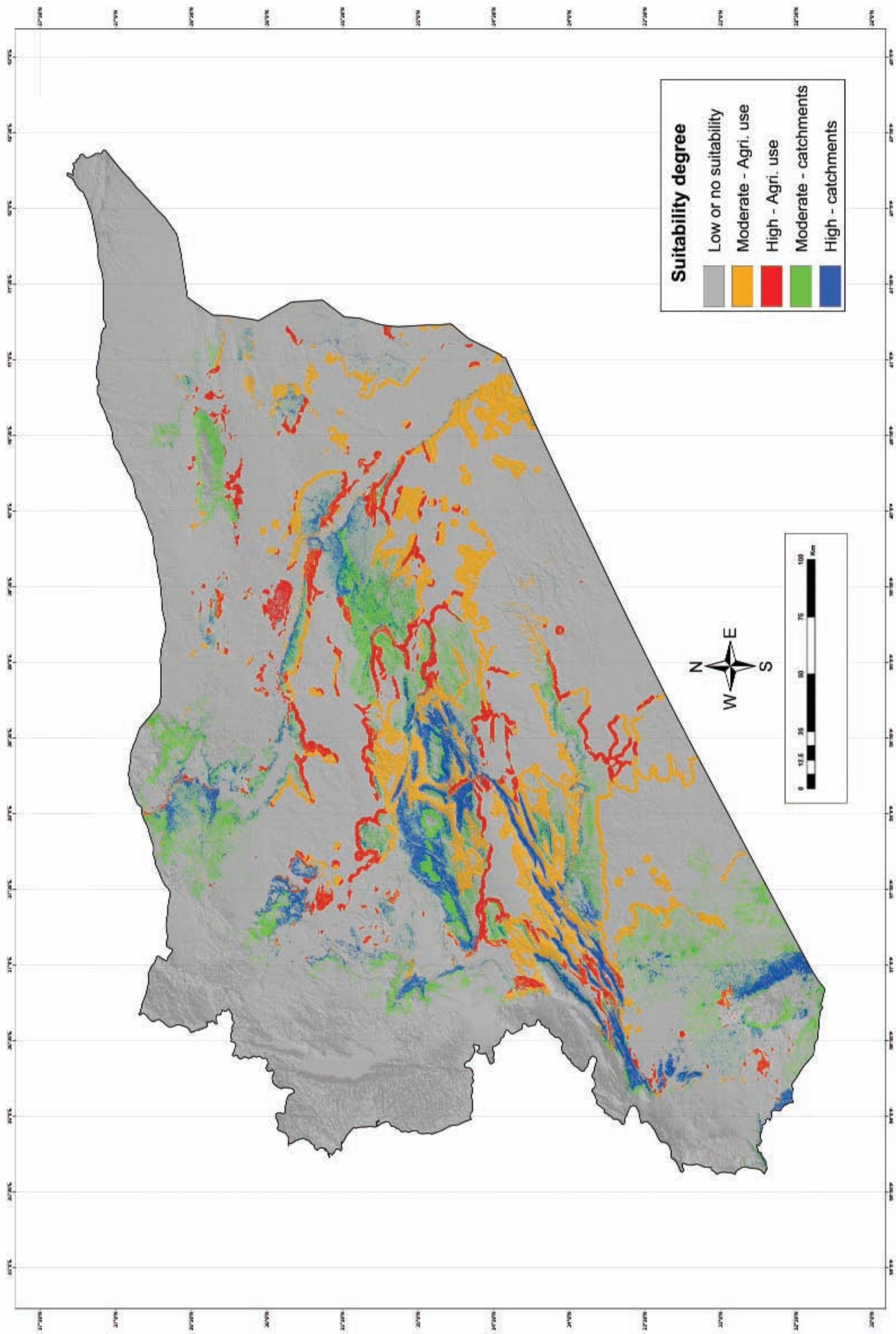
Map 13. Suitability for the micro-catchment system 'Contour bench terraces'



Map 14. Macro-catchment systems: suitability for macro-catchment use



Map 15. Macro-catchment systems: suitability for agricultural use



Map 16. Macro-catchment systems: suitability for macro-catchment or agricultural use within a distance from each other

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